Composites and Materials Mechanics - DTU Orbit (15/02/2018)

Composites and Materials Mechanics
Department of Wind Energy
Short name: Composites and Materials Mechanics

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Organisation profile
The research of Composites and Materials Mechanics is particularly relevant for the development of blades for very large offshore wind turbines where weight savings are of great importance.
The section focuses on development of new fiber composite materials and on increasing the knowledge and description of existing composite materials, particularly with respect to strength, fatigue, durability and damage tolerant behavior. The field includes manufacturing and processing, characterisation of microstructures, modelling of materials, and characterisation of mechanical properties, non-destructive evaluation and structural health monitoring.
Key research areas are new composite materials (e.g. biomass-based composites and hybrid composites), process technology, compression, fatigue and fracture, adhesive joints, micromechanical testing with in-situ observations (utilising the electron microscope expertise of the Materials Science and Characterisation Section), micromechanical modelling as well as the development of new advanced mechanical testing methods and structural health monitoring.
The research is applicable for the lifetime of a wind turbine rotor blade, from development of concept, design, manufacturing, quality control, operation and maintenance to decommission.
The section has a laboratory for the manufacturing of fibre composites (materials, test specimens, prototypes) and a DANAK accredited laboratory for mechanical characterisation. The reorganisation is expected to lead to new research projects in the area of connecting macroscale and structural scale modelling and testing. Another new possible area for expansion is the manufacturing of prototype wind turbine blades (e.g. smart blades incorporating shapechanging composite structures and embedded sensors) in close collaboration with the sections Wind Turbines and Aeroelastic Design.
Thus, the section contributes to the focus area “Light and Strong Materials” and provides knowhow to other focus areas such as structural design and safety and aeroelastic design.
Organisational unit: Section

Publications:

Determination of the fibre orientation distribution of a mineral wool network and prediction of its transverse stiffness using X-ray tomography
A method to determine the orientation and diameter distributions of mineral wool fibre networks using X-ray tomography and image analysis is presented. The method is applied to two different types of mineral wool: glass wool and stone wool. The orientation information is obtained from the computation of the structure tensor, and the diameter is estimated by applying a greyscale granulometry. The results of the image analysis indicate the two types of fibres are distributed in a 2D planar arrangement with the glass wool fibres showing a higher degree of planarity than the stone wool fibres. The orientation information is included in an analytical model based on a Euler–Bernoulli beam approximation. The model enables prediction of the transverse stiffness. It is indicated that the glass wool transverse stiffness is lower than the stone wool transverse stiffness. Comparison with experimental results confirms the assumption that the underlying deformation mechanism of mineral wool is the bending of fibre segments between bonds.
Hybrid metallic nanocomposites for extra wear-resistant diamond machining tools

The applicability of metallic nanocomposites as binder for diamond machining tools is demonstrated. The various nanoreinforcements (carbon nanotubes, boron nitride hBN, nanoparticles of tungsten carbide/WC) and their combinations are embedded into metallic matrices and their mechanical properties are determined in experiments. The wear resistance of diamond tools with metallic binders modified by various nanoreinforcements was estimated. 3D hierarchical computational finite element model of the tool binder with hybrid nanoscale reinforcements is developed, and applied for the structure-properties analysis of the binder. It is shown that the metallic nanocomposites with hybrid reinforcements ensure the highest mechanical properties and also the highest wear-resistance of the machining tools, with the nanocomposites used as binder.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, National University of Science and Technology MISIS
Authors: Loginov, P. (Ekstern), Sidorenko, D. (Ekstern), Levashov, E. (Ekstern), Petzhik, M. (Ekstern), Bychkova, M. (Ekstern), Mishnaevsky, L. (Intern)
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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.296 SNIP 2.008
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.221 SNIP 2.157
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.082 SNIP 2.194
ISI indexed (2013): ISI indexed no
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.341 SNIP 2.284
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.157 SNIP 2.133
A strain gauge

The invention relates to a strain gauge of a carrier layer and a meandering measurement grid (101) positioned on the carrier layer, wherein the measurement grid comprises a number of measurement grid sections placed side by side with gaps in between, and a number of end loops (106) interconnecting the measurement grid sections at their ends. The end loops at both ends of the measurement grid extend a length (L, 500) in the axial direction in millimetres of a factor times a ratio between a width of a grid section and the gap distance, wherein the factor is larger or equal to 1.5. The invention further relates to a method for manufacturing a strain gauge as mentioned above.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern), Gili, J. (Ekstern)
Publication date: 19 Jan 2017

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Date: 19/01/2017
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Source: espacenet
Source-ID: WO2017009365
Publication: Research › Patent – Annual report year: 2017

3d Finite Element Modelling of Non-Crmp Fabric Based Fibre Composite Based on X-Ray Ct Data

Due to the high number of fatigue load cycles during the life of a wind turbine blade, fatigue is one of the main design concerns. However, it is still not possible to realistically predict the fatigue life of the non-crimp fabric based fibre composites commonly used for the main load carrying parts of wind turbine blades. Existing modelling attempts generally consider the fibre bundle structure as a perfect pattern, however recent experimental X-ray CT studies [1,2] have shown that the local variations in the fibre bundle structure have a large influence on the observed fatigue damage initiation and progression in the material. In the current study, the real bundle structure inside a non-crimp fabric based fibre composite is extracted from 3D X-ray CT images and imported into ABAQUS for numerical modelling. The local stress concentrations when loaded in tension caused by the fibre bundle structure are examined and compared to experimental observations of the fatigue damage. In the current study the bundle structure is manually segmented, however the possibility of automatic segmentation in the future is also discussed. The study shows the potential of X-ray CT based modelling for increased...
understanding of the fatigue damage mechanisms, but also sets the stage for modelling across scales including the variations caused by manufacturing process.

**General information**

**State:** Published  
**Organisations:** Department of Wind Energy, Composites and Materials Mechanics, Department of Applied Mathematics and Computer Science, Chalmers University of Technology  
**Authors:** Jespersen, K. M. (Intern), Asp, L. (Ekstern), Mikkelsen, L. P. (Intern)  
**Number of pages:** 1  
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**BFI conference series:** Nordic Seminar on Computational Mechanics (5010906)  
**Main Research Area:** Technical/natural sciences  
**Conference:** 30th Nordic Seminar on Computational Mechanics (NSCM-30), Copenhagen, 25/10/2017 - 25/10/2017  
**Non-crimp fabric based composite, X-ray CT based modelling, Finite element modelling, Fatigue damage**  
**Electronic versions:**  
**3D_FINITE_ELEMENT_MODELLING.pdf**

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**A method to investigate the biomechanical alterations in Perthes’ disease by hip joint contact modeling**

Perthes’ disease is a destructive hip joint disorder characterized by malformation of the femoral head in young children. While the morphological changes have been widely studied, the biomechanical effects of these changes still need to be further elucidated. The objective of this study was to develop a method to investigate the biomechanical alterations in Perthes’ disease by finite element (FE) contact modeling using MRI. The MRI data of a unilateral Perthes’ case was obtained to develop the three-dimensional FE model of the hip joint. The stress and contact pressure patterns in the unaffected hip were well distributed. Elevated concentrations of stress and contact pressure were found in the Perthes’ hip. The highest femoral cartilage on Mises stress 3.9 MPa and contact pressure 5.3 MPa were found in the Perthes’ hip, whereas 2.4 MPa and 4.9 MPa in the healthy hip, respectively. The healthy bone in the femoral head of the Perthes’ hip carries additional loads as indicated by the increase of stress levels around the necrotic-healthy bone interface. Identifying the biomechanical changes, such as the location of stress and contact pressure concentrations, is a prerequisite for the preoperative planning to obtain stress relief for the highly stressed areas in the malformed hip. This single-patient study demonstrated that the biomechanical alterations in Perthes’ disease can be evaluated individually by patient-specific finite element contact modeling using MRI. A multi-patient study is required to test the strength of the proposed method as a pre-surgery planning tool.

**General information**

**State:** Published  
**Organisations:** Department of Electrical Engineering, Biomedical Engineering, Department of Wind Energy, Composites and Materials Mechanics, Hvidovre University Hospital  
**Authors:** Salmingo, R. A. (Intern), Skytte, T. L. (Ekstern), Traberg, M. S. (Intern), Mikkelsen, L. P. (Intern), Henneberg, K. (Intern), Wong, C. (Ekstern)  
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Scopus rating (2015): CiteScore 0.99 SJR 0.334 SNIP 0.754  
Scopus rating (2014): CiteScore 0.94 SJR 0.284 SNIP 0.486  
Scopus rating (2013): CiteScore 0.98 SJR 0.349 SNIP 0.55  
Scopus rating (2012): CiteScore 1.4 SJR 0.434 SNIP 0.73  
Scopus rating (2011): CiteScore 1.31 SJR 0.424 SNIP 0.584
Analysis of bearing steel exposed to rolling contact fatigue

The objective of this work is to characterize fatigue damage in roller bearings under conditions of high load and slippage. A test rig constructed for rolling contact fatigue tests of rings is described, and test results are presented for rings taken from two spherical roller bearings. The preparation of the rings and the load situation are explained. Test conditions are chosen with the aim of achieving pitting formation at the contacting surfaces. During testing the contact pressure, torque and the rotational speed are monitored and recorded. After testing the tested rings have been characterized using X-ray tomography and scanning electron microscopy. The observations confirm that rolling contact fatigue testing at high loads leads to pitting failure at the contacting surfaces. The pitting mostly appears on one side of the contact, attributed to a non-uniform contact pressure in the axial direction.

General information

State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Materials science and characterization, Wind Turbine Structures and Component Design, Department of Mechanical Engineering, Solid Mechanics, Technical University of Denmark
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Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 0.172 SNIP 0.281 CiteScore 0.22
Scopus rating (2014): SJR 0.186 SNIP 0.306 CiteScore 0.18
Scopus rating (2013): SJR 0.183 SNIP 0.256 CiteScore 0.16
ISI indexed (2013): ISI indexed no
Scopus rating (2012): SJR 0.161 SNIP 0.203 CiteScore 0.14
Challenges in experimental fatigue testing of glassfibre reinforced polymer matrix composites for wind turbine industry

The wind turbine industry always strives to increase the performance of wind turbines. To design longer and lighter wind turbine blades, one of the key factors is the fatigue design limit of the composite materials used in the load carrying structures. The fatigue design limits are based on the variance of the fatigue test results on composite materials specimens. Options to improve the design limits of the composite materials are either to improve the material quality, or to decrease the variance of the fatigue test results by improving the fatigue test methods. In recent years, extensive work has been done to improve the quality of the composite materials used in wind turbine blades. This improvement has been achieved by incorporating high performance glass fibres with improved sizing and exploring new resin formulations. However, the current standardised fatigue test methods still show low reproducibility and high scatter (high variance). Therefore, in order to improve the design limits and to reflect the high performance of the composite materials, it is critical to develop improved fatigue test methods. There are three types of uniaxial fatigue test methods, tension-tension, compression-compression and tension-compression. Specific challenges exist for each test type regarding the experimental set-up and specimen geometry. Issues for the experimental setup include alignment and load introduction into the specimen. Issues for the test specimen include an specimen geometry that leads to failure in the gauge section. An example of a geometry issue is the length of the specimen. For tension-tension testing, it is beneficial if the gauge length of the specimen is as long as possible to obtain a homogeneous stress state in the test area and to have a long gripping area to be able to introduce the load through shear stresses without getting high shear stress concentrations causing shear failure in the gripping region. In compression-compression testing, the load introduction also has to be considered to avoid failure in the gripping region e.g. by transferring part of the load through the specimen’s ends and partly through shear stresses. The gauge length of the specimen is limited by the Euler buckling limit. Work on optimizing the specimen geometry and the experimental setup has been done on tension-tension fatigue by Korkiakosky et al. (2016) and on compression-compression fatigue by Fraisse and Brandsted (2017) resulting in lower scatter. However, limited work has been done on uniaxial tension-compression fatigue test methods although recent demands for wind turbine-material qualification require mainly tension-compression fatigue testing.

The current work presents the challenges in development of experimental tests, which give reproducible results in tension-compression fatigue. Considerations from the developed methods for tension-tension and compression-compression fatigue have been included, and it is found that compromises have to be made in order to be able to successfully test uniaxial composites in both tension-compression fatigue. Based on experiments and finite element simulations, the shape/geometry of test specimen as well as optimization of gripping and geometry of tabs are discussed. A presentation of the state of the art experimental methods and current test challenges will be given.

Characterization of voids in shock-loaded Al single crystal by combining X-ray tomography and electron microscopy

A combination of X-ray tomography and electron backscatter diffraction (EBSD) was applied to investigate both the shape of voids and the plastic deformation around voids in an Al single crystal shock-loaded in the direction. The combination of these two techniques allows the addition of crystallographic information to X-ray tomography and allows the addition of
three-dimensional information to EBSD data. It is found that the voids are octahedral with {1 1 1} faces and that regular patterns of lattice reorientation exist around individual voids. The results provide new insights to the process of void growth during shock loading, which is important for both civil and military applications.

**General information**
State: Published
Organisations: Department of Wind Energy, Materials science and characterization, Composites and Materials Mechanics, Oak Ridge National Laboratory
Authors: Hong, C. (Intern), Faester, S. (Intern), Hansen, N. (Intern), Huang, X. (Intern), Barabash, R. I. (Ekstern)
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BFI (2015): BFI-level 1
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Scopus rating (2013): SJR 0.183 SNIP 0.256 CiteScore 0.16
ISI indexed (2013): ISI indexed no
Scopus rating (2012): SJR 0.161 SNIP 0.203 CiteScore 0.14
ISI indexed (2012): ISI indexed no
Scopus rating (2011): SJR 0.155 SNIP 0.149 CiteScore 0.1
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**Cohesive zone modelling of nucleation, growth and coalesce of cavities**
The stress-deformation relation i.e. cohesive law representing the fracture process in an almost incompressible adhesive tape is measured using the double cantilever beam specimen. As in many ductile materials, the fracture process of the tape involves nucleation, growth and coalesce of cavities. This process is studied carefully by exploiting the transparency of the used materials and the inherent stability of the specimen configuration. Utilising the path independence of the J-integral, the cohesive law is measured. The law is compared to the results of butt-joint tests. The law contains two stress peaks-the first is associated with nucleation of cavities at a stress level conforming to predictions of void nucleation in rubber elasticity. The second stress peak is associated with fracture of stretched walls between fully-grown cavities. After this second peak, a macroscopic crack is formed. The tape suffers at this stage an engineering strain of about 800%. A numerical analysis with the determined cohesive law recreates the global specimen behaviour.

**General information**
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Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Skovde
Authors: Biel, A. (Intern), Stigh, U. (Ekstern)
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Comparison of fracture properties of cellulose nanopaper, printing paper and buckypaper

Cellulose nanopaper consists of a dense fibrous self-binding network composed of cellulose nanofibres connected by physical entanglements, hydrogen bonding, etc. Compared with conventional printing paper, cellulose nanopaper has higher strength and modulus because of stronger fibres and inter-fibre bonding. The aim of this paper is to investigate the fracture properties of cellulose nanopaper using double edge notch tensile tests on samples with different notch lengths. It was found that strength is insensitive to notch length. A cohesive zone model was used to describe the fracture behaviour of notched cellulose nanopaper. Fracture energy was extracted from the cohesive zone model and divided into an energy component consumed by damage in the material and a component related to pull-out or bridging of nanofibres between crack surfaces which was not facilitated due to the limited fibre lengths for the case of nanopapers. For comparison, printing paper which has longer fibres than nanopaper was tested and modelled to demonstrate the importance of fibre length. Buckypaper, a fibrous network made of carbon nanotubes connected through van der Waals forces and physical entanglements, was also investigated to elaborate on the influence of inter-fibre connections.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics, Queen Mary University of London, Huazhong University of Science and Technology, Royal Institute of Technology
Authors: Mao, R. (Ekstern), Goutianos, S. (Intern), Tu, W. (Ekstern), Meng, N. (Ekstern), Yang, G. Y. (Ekstern), Berglund, L. A. (Ekstern), Peijs, T. (Ekstern)
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BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.49 SJR 0.762 SNIP 1.064
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.811 SNIP 1.081 CiteScore 2.36
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.985 SNIP 1.431 CiteScore 2.54
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.933 SNIP 1.472 CiteScore 2.36
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.991 SNIP 1.407 CiteScore 2.2
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.941 SNIP 1.393 CiteScore 2.05
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Compression fatigue of Wind Turbine Blade composites materials and damage mechanisms

According to the new IEC 61400-5-rev0 recommendation, which is under preparation it will be required to qualify wind turbine blade (WTB) composite materials in fatigue at R=0.1, R=-1, and R=10. As a minimum fatigue at R=-1 is required. This is a consequence of the ever-growing blades, where gravity driven edgewise bending introduces significant fully reversed cycling at the leading and trailing edges. Therefore, material manufacturer and WTB manufacturer demand test results of highest reliability and reproducibility. However, these requirements for compression-compression and tension-compression fatigue properties are a big challenge for the test institutes to meet. Tests are very difficult to perform, as it is nearly impossible to design an optimal test setup. This study shows a newly developed sample geometry and test method in order to obtain representative and reliable results. Two different laminate architectures have been tested in order to validate the test method. Damage mechanisms and damage progression in compression fatigue have been investigated using 3D X-Ray Tomography and a qualitative explanation of the damage mechanisms is presented.

General information

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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Fraisse, A. (Intern), Brøndsted, P. (Intern)
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Main Research Area: Technical/natural sciences
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Source: PublicationPreSubmission
Source-ID: 134900563
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Computational Modelling of Materials for Wind Turbine Blades: Selected DTUWind Energy Activities

Computational and analytical studies of degradation of wind turbine blade materials at the macro-, micro-, and nanoscale carried out by the modelling team of the Section Composites and Materials Mechanics, Department of Wind Energy, DTU, are reviewed. Examples of the analysis of the microstructural effects on the strength and fatigue life of composites are shown. Computational studies of degradation mechanisms of wind blade composites under tensile and compressive loading are presented. The effect of hybrid and nanoengineered structures on the performance of the composite was studied in computational experiments as well.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern), Mishnaevsky, L. (Intern)
Number of pages: 15
Publication date: 2017
Main Research Area: Technical/natural sciences

Deformation analysis of polymers composites: rheological model involving time-based fractional derivative

A modeling approach to time-dependent property of Glass Fiber Reinforced Polymers (GFRP) composites is of special interest for quantitative description of long-term behavior. An electronic creep machine is employed to investigate the time-dependent deformation of four specimens of dog-bond-shaped GFRP composites at various stress level. A negative exponent function based on structural changes is introduced to describe the damage evolution of material properties in the process of creep test. Accordingly, a new creep constitutive equation, referred to fractional derivative Maxwell model, is suggested to characterize the time-dependent behavior of GFRP composites by replacing Newtonian dashpot with the Abel dashpot in the classical Maxwell model. The analytic solution for the fractional derivative Maxwell model is given and the relative parameters are determined. The results estimated by the fractional derivative Maxwell model proposed in the paper are in a good agreement with the experimental data. It is shown that the new creep constitutive model proposed in the paper needs few parameters to represent various time-dependent behaviors.

General information
State: Published
Dielectric barrier discharge plasma treatment of cellulose nanofibre surfaces

Dielectric barrier discharge plasma treatment was applied to modify cellulose nanofibre (CNF) surfaces with and without ultrasonic irradiation. The plasma treatment improved the wetting by deionised water and glycerol, and increased the contents of oxygen, carbonyl group, and carboxyl group on the nanofibre surface. Ultrasonic irradiation further enhanced the wetting and oxidation of the nanofibre coating. Scanning electron microscopic observations showed skeleton-like features on the plasma-treated surface, indicating preferential etching of weaker domains, such as low-molecular weight domains and amorphous phases. Ultrasonic irradiation also improved the uniformity of the treatment. Altogether, it is demonstrated that atmospheric pressure plasma treatment is a promising technique to modify the CNF surface before composite processing.
Effect of inter-fibre bonding on the fracture of fibrous networks with strong interactions

Abstract The mechanical response of cellulose nanopaper composites is investigated using a three-dimensional (3D) finite element fibrous network model with focus on the effect of inter-fibre bonds. It is found that the Young’s modulus and strength, for fixed fibre properties, are mainly controlled by the density and strength of the inter-fibre bonds. An increase of the inter-fibre bond density and inter-fibre bond strength results in an increase of both the Young’s modulus and strength of the fibrous network materials. The fracture energy of the inter-fibre bonds has a minor effect on the mechanical properties of the cellulose nanopapers. The inter-fibre bond properties and density have a minor effect on the strain to failure of the cellulose nanopaper. The effect of the fibre properties, through the ratio of fibre tensile strength to fibre Young’s modulus, has also a significant impact on mechanical response of the network including the strain to failure.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, Queen Mary University of London
Authors: Goutianos, S. (Intern), Mao, R. (Ekstern), Peijs, T. (Ekstern)
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.8 SJR 1.501 SNIP 1.713
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.502 SNIP 1.917 CiteScore 2.66
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.643 SNIP 2.048 CiteScore 2.72
Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 1.587 SNIP 2.148 CiteScore 2.6
ISI indexed (2013): ISI indexed yes
Effect of shot peening on the residual stress and mechanical behaviour of low-temperature and high-temperature annealed martensitic gear steel 18CrNiMo7-6

A martensitic gear steel (18CrNiMo7-6) was annealed at 180 degrees C for 2h and at similar to 750 degrees C for 1h to design two different starting microstructures for shot peening. One maintains the original as-transformed martensite while the other contains irregular-shaped sorbite together with ferrite. These two materials were shot peened using two different peening conditions. The softer sorbite + ferrite microstructure was shot peened using 0.6 mm conditioned cut steel shots at an average speed of 25 m/s in a conventional shot peening machine, while the harder tempered martensite steel was shot peened using 1.5 mm steel shots at a speed of 50 m/s in an in-house developed shot peening machine. The shot speeds in the conventional shot peening machine were measured using an in-house lidar set-up. The microstructure of each sample was characterized by optical and scanning electron microscopy, and the mechanical properties examined by microhardness and tensile testing. The residual stresses were measured using an Xstress 3000 G2R diffractometer equipped with a Cr K alpha x-ray source. The correspondence between the residual stress profile and the gradient structure produced by shot peening, and the relationship between the microstructure and strength, are analyzed and discussed.
Enhancement of Fracture Resistance by Multiple Cracks in Layered Structures under Mode I and Mix Mode Loading

Layered structures are susceptible to delamination because they often exhibit low interlaminar fracture resistance. Through-thickness stresses e.g. due to manufacturing defects or geometric discontinuities, can result in growing interlaminar cracks which may lead to loss of structural integrity [1]. As a result, a number of techniques have been developed to improve the through-thickness fracture resistance of layered structures e.g. fibre reinforced composites. In the field of composite materials, two directions to develop damage tolerant composites can be identified: a) material improvements (e.g. tougher matrices and interleaves) and b) modifications of the fibre architecture (e.g. stitching, z-pinning, knitting and braiding). These techniques aim to increase the fracture resistance by making the damage prone areas stronger.

In the present work, a third approach is explored. It is shown, through cohesive zone modelling, that the fracture resistance can be improved by introducing weak layers that result in multiple delaminations next to the damage prone areas. Our model is motivated by the experimental results of Rask and Sørensen [2] who observed that by changing the ply thicknesses of composite beams bonded together with a thermoset adhesive, more delamination cracks could be developed next to the main/primary adhesive/laminate crack. An analytical model, based on the J integral, was developed for multiple delaminations [3]. It is shown that the maximum possible increase (upper limit) of the steady-state fracture resistance, \( J_{R,ss} \), scales linearly with the number of delaminations in agreement with the observations of Rask and Sørensen.
Ex-situ X-ray computed tomography data for a non-crimp fabric based glass fibre composite under fatigue loading
The data published with this article are high resolution X-ray computed tomography (CT) data obtained during an ex-situ fatigue test of a coupon test specimen made from a non-crimp fabric based glass fibre composite similar to those used for wind turbine blades. The fatigue test was interrupted four times for X-ray CT examination during the fatigue life of the considered specimen. All the X-ray CT experiments were performed in the region where unidirectional fibre fractures first became visible, and thereby include the damage progression in 3D in this specific region during fatigue loading of the specimen.

Fatigue crack growth in mode II of adhesively joined composites
The structure of a wind turbine is exposed to a complex multi-axial cyclic loading. The blades are commonly manufactured of adhesively joined composites. Adhesive joints are usually strongest if loaded in shear and accordingly fatigue properties in shear are important. In the current paper, experiments are performed to derive material data for a crack propagation in shear i.e. in mode II. The shear loading of the crack is achieved by use of double cantilever beam specimens loaded with uneven bending moments. The experiments are performed under a constant cyclic displacement. An initial mode I loading is used to make the crack start in the adhesive. The crack length is measured using a load synchronized camera. Due to the shear loading the crack deviates from the adhesive layer into the laminate. A stable crack propagation is detected in the laminate. No influence have been detected due to an increasing crack length. It is also observed that the crack is trapped in the laminate; if the loading is changed to mode I the crack continues to propagate in the laminate.
Fatigue Damage Evolution in Fibre Composites for Wind Turbine Blades

One of the largest challenges in wind turbine design, is realistically predicting the lifetime of the blades. Wind turbine blades experience a high number of fatigue load cycles during their life-time, and the fatigue damage mechanisms of the non-crimp fabric based glass fibre composites used for the load carrying parts of wind turbine blades are not well understood. This PhD project establishes experimental methods making it possible to monitor the damage initiation and progression of fibre composites in 3D using X-ray CT. To overcome the resolution challenges of X-ray CT, a tension clamp solution that applies load to the specimen during X-ray CT examination is presented, and the advantage of combining X-ray CT with other techniques such as transilluminated white light imaging is demonstrated. The established methods are used to monitor the damage initiation and progression of fatigue damage on the micro-scale in the non-crimp fabric based composites used for wind turbine blades.

The results show that fibre fractures in the unidirectional (UD) load carrying fibre bundles initiate from off-axis cracks in the thin supporting backing fibre bundles. With an increasing number of fatigue load cycles, the UD fibre fractures progress gradually into the thickness direction of the UD fibre bundles, which eventually results in final fracture of the fibre composite. It is also found that the UD fibre fracture regions generally grow larger and initiate earlier at cross-over regions of the backing fibre bundles than at single backing fibre bundle regions. Furthermore, UD Fibre fractures are only observed to initiate at locations where the backing fibre bundles are 'in contact' with a UD fibre bundle. By observing the damage progression in 3D, it is also clear that the UD fibre fractures initiated and progressed as local 3D phenomena rather than being homogeneously distributed within the UD fibre bundles. Hence, the results show the importance of considering the problem in 3D.

The knowledge obtained on the fatigue damage mechanisms during the project can not only be used to improve the materials, but also sets the stage for X-ray CT based modelling. This is a step towards more realistic fatigue life-time modelling of fibre composites used for wind turbine blades, which will make it possible to push the design limits of wind turbine blades and thereby decrease the cost of energy for the wind energy production. In addition, the methods established during the PhD project can be applied to other problems, material systems, and load conditions in the future, which opens up for many new opportunities.
Fatigue Reliability Analysis of Wind Turbine Cast Components

The fatigue life of wind turbine cast components, such as the main shaft in a drivetrain, is generally determined by defects from the casting process. These defects may reduce the fatigue life and they are generally distributed randomly in components. The foundries, cutting facilities and test facilities can affect the verification of properties by testing. Hence, it is important to have a tool to identify which foundry, cutting and/or test facility produces components which, based on the relevant uncertainties, have the largest expected fatigue life or, alternatively, have the largest reliability to be used for decision-making if additional cost considerations are added. In this paper, a statistical approach is presented based on statistical hypothesis testing and analysis of covariance (ANCOVA) which can be applied to compare different groups (manufacturers, suppliers, test facilities, etc.) and to quantify the relevant uncertainties using available fatigue tests. Illustrative results are presented as obtained by statistical analysis of a large set of fatigue data for casted test components typically used for wind turbines. Furthermore, the SN curves (fatigue life curves based on applied stress) for fatigue assessment are estimated based on the statistical analyses and by introduction of physical, model and statistical uncertainties used for the illustration of reliability assessment.

General information
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Fluoropolymer coated alanine films treated by atmospheric pressure plasmas – In comparison with gamma irradiation

Fluoropolymer coated alanine films are treated by a dielectric barrier discharge and a gliding arc at atmospheric pressure as well as with gamma irradiation. The film surfaces and the underlying bulk materials are characterized before and after each treatment. The fluoride content decreases and the oxygen content increases at the fluoropolymer surfaces, while deposition of specific plasma energies in the alanine films is detected by electron paramagnetic resonance spectroscopy, indicating that not only the fluoropolymer surfaces but also the bulk alanine materials are modified. Differences of surface and bulk modification effects between the two plasma treatments are discussed in detail.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, Danish Technological Institute, University of Southern Denmark
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Imaging of Composites by Helical X-Ray Computed Tomography
Understanding the fatigue damage mechanisms of composite materials used in wind turbine rotor blades could potentially enhance the reliability and energy efficiency of wind turbines by improving the structure design. In this paper, the fatigue damage propagating mechanisms of unidirectional glass fibre composites was characterised by helical X-ray CT. The staining approach was used and it was effective to enhance the visibility of thin matrix cracks and partly closed fibre breaks instead of widely opened cracks. Fibre breaks in the centre UD bundle were found to occur locally, instead of being evenly distributed along the 0° fibre direction after 500,000 cycles. The locations of these damage sites were found to be correlated with intersecting points of +/-80° backing bundles. At higher number of cycles, edge effect becomes dominant with extensive fibre breaks in the edge UD bundles and matrix cracks in the resin-rich region.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, FEI Czech Republic s.r.o., University of Manchester
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Individual fibre segmentation from 3D X-ray computed tomography for characterising the fibre orientation in unidirectional composite materials
The aim of this paper is to characterise the fibre orientation in unidirectional fibre reinforced polymers, namely glass and carbon fibre composites. The compression strength of the composite is related to the orientation of the fibres. Thus the
orientation is essential when designing materials for wind turbine blades. The calculation of the fibre orientation distribution is based on segmenting the individual fibres from volumes that have been acquired through X-ray tomography. The segmentation method presented in this study can accurately extract individual fibres from low contrast X-ray scans of composites with high fibre volume fraction. From the individual fibre orientations, it is possible to obtain results which are independent of the scanning quality. The compression strength for both composites is estimated from the average fibre orientations and is found to be of the same order of magnitude as the measured values.
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Influence of curing profile and fibre architecture on the fatigue resistance of composite materials for wind turbine blades
The fatigue performance of unidirectional glass fibre reinforced epoxy is found to be highly dependent on the manufacturing conditions, where a low manufacturing temperature, for the investigated wind turbine relevant composite material system, is found to improve the tension/tension fatigue life-time with a factor of 10 if compared with a corresponding laminate manufactured at a high manufacturing temperature. It should be noted that a low manufacturing temperature will increase the required mould time significantly and thereby influence the cost of the manufactured wind turbine blade. In addition, the thick laminates typically used in the root section of the wind turbine blades will experience significant exothermically generated temperature raise during the curing process increasing the local manufacturing temperature. The tension/tension fatigue life-time has been investigated using 3D x-ray computer tomography. Thereby, it has been found during ex-situ fatigue studies, that the fatigue failure mechanism is highly influenced by transverse cracking in the so-called backing bundles which is present in order to ease the handling during the dry fabric layup during wind turbine blade manufacturing. It is a failure mechanism which is judged to be highly influenced by the magnitude of the residual stresses exhibit in the matrix material and therefore also in the secondary oriented backing bundles. Using fibre Bragg gratted optical fibres, the build-up of the cure-induced strains in the fibre-reinforcement has been investigated during a variety of curing profiles of the used epoxy material system. Thereby, it is possible to observe that even though the overall chemical shrinkage of the epoxy material system is independent on the chosen curing profile, the location of the gel-point and thereby the amount of shrinkage occurring in the solid state is highly influenced. During the study, it is therefore documented that even though a short mould time may be beneficial lowering the manufacturing cost, it has a drawback on the fatigue life time. In addition, it can be expected that the internal part of the thick laminates used in the root sections of a wind turbine blade has a lower fatigue resistance compared with the composite materials used elsewhere.

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Interfaces between a fibre and its matrix
The interface between a fibre and its matrix represents an important element in the characterization and exploitation of composite materials. Both theoretical models and analyses of experimental data have been presented in the literature since modern composite were developed and many experiments have been performed. A large volume of results for a wide range of composite systems exists, but rather little comparison and potential consistency have been reached for fibres and/or for matrices. Recently a materials mechanics approach has been presented to describe the interface by three parameters, the interfacial energy [J/m²], the interfacial frictional shear stress [MPa] and the mismatch strain [-] between fibre and matrix. The model has been used for the different modes of fibre pull-out and fibre fragmentation. In this paper it
is demonstrated that the governing equations for the experimental parameters (applied load, debond length and relative fibre/matrix displacement) are rather similar for these test modes. A simplified analysis allows the direct determination of the three interface parameters from two plots for the experimental data. The complete analysis is demonstrated for steel fibres in polyester matrix. The analysis of existing experimental literature data is demonstrated for steel fibres in epoxy matrix and for tungsten wires in copper matrix. These latter incomplete analyses show that some results can be obtained even if all three experimental parameters are not recorded.

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ISI indexed (2013): ISI indexed no
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ISI indexed (2012): ISI indexed no
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**Investigation of sizing - from glass fibre surface to composite interface**
Composites are far from a new invention, and have through time taken many shapes. From a simple hay clay house to advanced nano particle containing composites for advanced material applications. Since the industrialisation in the late 1800’s the use of fibre reinforced composites have increased significantly. The usage span wide, from furniture and car components to construction materials. Even though, the concept of composites is well known and widely applied, the fundamental principles of the interaction of the constituents, in the composites are still not fully understood. This thesis is a part of Danish Center for Composite Structures and Materials for wind turbine blades who work towards improving composites. Since wind turbine blades are the basis of the DCCSM it is the materials used here that are the focus, explicitly glass fibres and epoxy matrix. Glass fibre composites greatly dominate the fibre reinforced composite industry due to the combination of their relatively high stiffness and low production cost. During manufacturing the glass fibres are applied a coating, called sizing, for protection of the fibres and for compatibility with the polymer matrix. The sizing is located at the interface between glass fibre and polymer matrix. Despite the importance of this interface, in regards to the stress transfer, which is responsible for the reinforcing effect of fibres, very little research address how the interface is
affected and how it can be controlled. This thesis covers an analysis of the sizing from the glass fibre surface to the interface in composites.

Through soxhlet extraction with acetone it was possible to remove a part of the sizing from the glass fibres for analysis. By burning off the sizing at 565 °C a higher mass loss was obtained than from the extraction, indicating that a part of the sizing might be covalently bonded to the glass fibre surface. The investigation of the sizing extract by ATR-FTIR and TGA-MS revealed the presence of a DGEBA film former as one of the components of the sizing. Glass plates were successfully coated with the organosilanes APTMS and GPTMS in order to mimic the surface of the glass fibres. The non-planar surface of glass fibres yields difficulties in some analysis e.g. determination of contact angle. The plates displayed a clear difference in contact angle after being coated towards a more polar surface.

An investigation of the adhesion between fibre and matrix analysed by microbond testing and the determination of the IFSS was conducted varying the amine:epoxide group ratio in the matrix and the testing temperature. IFSS was found to be affected by both parameters. A maximum IFSS was observed around the stoichiometric ratio of amine:epoxide group (1:1). The presence of amine or epoxide groups in the sizing will affect the ratio at the interface and in all probability also the IFSS with a decrease in IFSS as the result. Furthermore, the testing temperature influenced the IFSS. The highest values were obtained at room temperature. Above the glass transition temperature the dependency of the amine:epoxide group ratio changed to become linear. Two different microbond setups were used for the determination of the IFSS and a difference was detected. It was explained by the difference in loading procedure; one had constant strain rate and the other constant load rate. Additionally the duration of the microbond test might also influence the determination of the IFSS. The influence on the mechanical properties stiffness, strength and J-integral by changes in the chemistry of the interface was investigated. The stiffness of single glass fibres increased after the removal of sizing by extraction but also when the sizing was removed by burning. This could partly be explained by the sizing being less dense than the glass fibres. For the burned glass fibres compactness of the glass structure also yields an increase in stiffness. The fibre strength was less affected by the extraction of sizing but burning drastically decreased the strength. The enlargement of surface flaws after the removal of the protective sizing is given as the cause of the decrease in strength. Coating of fibres after extraction of the original sizing by the organosilane GPTMS resulted only in insignificant changes of stiffness and strength of single glass fibres. However the effect on the adhesion measured by the J-integral was remarkable. Small scale specimens were successfully used for the DCB testing and the determination of the J-integral. The GPTMS modified fibres displayed significant higher interface adhesion in comparison to the fibres with the original sizing. From this it had been proved that the original sizing is far from the optimal when it comes to facilitating a strong adhesion between glass fibre and matrix.

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Materials for Wind Turbine Blades: An Overview
A short overview of composite materials for wind turbine applications is presented here. Requirements toward the wind turbine materials, loads, as well as available materials are reviewed. Apart from the traditional composites for wind turbine blades (glass fibers/epoxy matrix composites), natural composites, hybrid and nanoengineered composites are discussed. Manufacturing technologies for wind turbine composites, as well their testing and modelling approaches are reviewed.

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Authors: Mishnaevsky, L. (Intern), Branner, K. (Intern), Petersen, H. N. (Intern), Beauson, J. (Intern), McGugan, M. (Intern), Sørensen, B. F. (Intern)
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Mechanical properties of biaxially strained poly(L-lactide) tubes: Strain rate and temperature dependence

Poly(l-lactide) (PLLA) is a bioabsorbable polymer with high stiffness and strength compared to the other commercially available bioabsorbable polymers. The properties of PLLA can be improved by straining, causing deformation-mediated molecular orientation. PLLA tubes were biaxially strained above their $T_g$ for improvement of their strength, in a two-step process (sequential straining). Mechanical properties and crystal morphology were investigated as a function of processing strain rate and temperature. DSC revealed that a low processing strain rate allows molecular chain relaxation in the direction of strain and the crystallization is suppressed. Faster strain rates on the other hand suppress chain relaxation, and results in crystalline tubes. The mechanical properties are influenced by both processing strain rate and temperature. Low strain rates allow chain relaxation resulting in the lowest strength and stiffness, whereas a larger stiffness and strength is achieved by increasing strain rate and temperature. Isotropic mechanical properties are only observed at high processing strain rates.
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Scopus rating (2014): SJR 0.658 SNIP 0.964 CiteScore 1.76
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Scopus rating (2013): SJR 0.628 SNIP 1.085 CiteScore 1.71
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Scopus rating (2011): SJR 0.601 SNIP 0.965 CiteScore 1.45
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Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.679 SNIP 0.909
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.697 SNIP 0.825
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
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Web of Science (2007): Indexed yes
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Web of Science (2006): Indexed yes
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Scopus rating (2004): SJR 0.774 SNIP 0.962
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.816 SNIP 1.067
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.866 SNIP 1.084
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Web of Science (2001): Indexed yes
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Micromechanical model of the single fiber fragmentation test

A shear-lag model is developed for the analysis of single fiber fragmentation tests for the characterization of the mechanical properties of the fiber/matrix interface in composite materials. The model utilizes the relation for the loss in potential energy of Budiansky, Hutchinson and Evans. The model characterizes the interface in terms of an interfacial fracture energy and a frictional sliding shear stress. Results are obtained in closed analytical form. An experimental approach is proposed for the determination of the interfacial fracture energy and the frictional shear stress from simultaneously obtained data for the applied strain, the opening of a broken fiber and the associated debond length. The residual stresses are obtained as a part of the approach and enables the determination of in-situ fiber strength.

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Scopus rating (2011): SJR 1.488 SNIP 1.915 CiteScore 2.22
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Scopus rating (2010): SJR 1.413 SNIP 1.846
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.905 SNIP 2.067
Web of Science (2009): Indexed yes
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Modelling the elastic properties of cellulose nanopaper
The elastic modulus of cellulose nanopaper was predicted using a two-dimensional (2D) micromechanical fibrous network model. The elastic modulus predicted by the network model was 12 GPa, which is well within the range of experimental data for cellulose nanopapers. The stress state in the network revealed both tensile and compressive stresses during elastic deformation of the model. The length, diameter, waviness and elastic modulus of the cellulose nanofibres were varied in the model and their effect on the elastic modulus of fibrous networks was studied. It was found that high values of elastic moduli of cellulose networks could be obtained for long, thin and straight nanofibres of high stiffness. The effect of inter-fibre bonding and network density was also investigated. Increasing fibre-fibre interactions facilitated stress transfer in cellulose networks and led to a higher elastic modulus of the nanopaper. Denser networks also resulted in a higher elastic modulus due to an increasing number of nanofibres and inter-fibre bonds.

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Nanocomposites for Machining Tools

Machining tools are used in many areas of production. To a considerable extent, the performance characteristics of the tools determine the quality and cost of obtained products. The main materials used for producing machining tools are steel, cemented carbides, ceramics and superhard materials. A promising way to improve the performance characteristics of these materials is to design new nanocomposites based on them. The application of micromechanical modeling during the elaboration of composite materials for machining tools can reduce the financial and time costs for development of new tools, with enhanced performance. This article reviews the main groups of nanocomposites for machining tools and their performance.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics, National University of Science and Technology MISIS
Authors: Sidorenko, D. (Ekstern), Loginov, P. (Ekstern), Mishnaevsky, L. (Intern), Levashov, E. (Ekstern)
Publication date: 2017
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ISSN (Print): 1996-1944
Ratings:
Web of Science (2018): Indexed yes
New approach for validating the segmentation of 3D data applied to individual fibre extraction

We present two approaches for validating the segmentation of 3D data. The first approach consists on comparing the amount of estimated material to a value provided by the manufacturer. The second approach consists on comparing the segmented results to those obtained from imaging modalities that provide a better resolution and therefore a more accurate segmentation. The imaging modalities used for comparison are scanning electron microscopy, optical microscopy and synchrotron CT. The validation methods are applied to assess the segmentation of individual fibres from X-ray microtomograms.

General information

State: Published
Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Statistics and Data Analysis, Department of Wind Energy, Composites and Materials Mechanics
Authors: Emerson, M. J. (Intern), Dahl, A. B. (Intern), Dahl, V. A. (Intern), Conradsen, K. (Intern), Mikkelsen, L. P. (Intern)
Number of pages: 2
Publication date: 2017

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Main Research Area: Technical/natural sciences
Conference: 3rd International Conference on Tomography of 3D Materials and Structures, Lund, Sweden, 26/06/2017 - 26/06/2017
Segmentation, Composite characterisation, Validation, Fibre analysis

Relations

Activities:

Numerical modelling of micro-plasto-hydrodynamic lubrication in plane strip drawing

This paper presents a new finite element model capable of predicting the onset of micro-plasto-hydrodynamic (MPH) lubrication and the amount of lubricant escaping from surface pockets in metal forming. The present approach is divided in two steps. First, a simulation at the macroscopic level is conducted. Then, a second simulation highlighting microscopic liquid lubrication mechanisms is achieved using boundary conditions provided by the first model. These fluid-structure interaction computations are made possible through the use of the Arbitrary Lagrangian Eulerian (ALE) formalism. The developed methodology is validated by comparison to experimental measurements conducted in plane strip drawing. The effect of physical parameters like the drawing speed, the die angle and the strip thickness reduction is investigated. The numerical results show good agreement with experiments.
Numerical modelling of microscopic lubricant flow in sheet metal forming. Application to plane strip drawing

This paper presents a numerical investigation of microscopic lubricant flows from the cavities to the plateaus of the surface roughness of metal sheets during forming processes. This phenomenon, called micro-plasto-hydrodynamic (MPH) lubrication, was observed experimentally in various situations such as compression sliding tests, strip drawing and cold rolling. It leads to local friction drop and wear reduction. It is therefore critical to achieve a good understanding of this phenomenon.

To move towards that goal, a multiscale fluid-structure interaction (FSI) model is developed to model lubricant flows at the microscopic scale. These simulations are made possible through the use of the Arbitrary Lagrangian Eulerian (ALE) formalism.

In this paper, this methodology is used to study plane strip drawing. The numerical model is able to predict the onset of lubricant escape and the amount of lubricant flowing on the plateaus. Numerical results exhibit good agreement with experimental measurements.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Liege, ArcelorMittal Global R&D
Authors: Carretta, Y. (Ekstern), Boman, R. (Ekstern), Bech, J. I. (Intern), Legrand, N. (Ekstern), Laugier, M. (Ekstern), Ponthot, J. (Ekstern)
Pages: 203-237
Publication date: 2017
Main Research Area: Technical/natural sciences

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BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.64 SJR 1.743 SNIP 1.566
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.912 SNIP 1.689 CiteScore 2.67
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.935 SNIP 1.927 CiteScore 2.73
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.415 SNIP 1.894 CiteScore 2.8
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 2.47 SNIP 2.103 CiteScore 2.7
Optimized process for recovery of glass- and carbon fibers with retained mechanical properties by means of near- and supercritical fluids

Degradation of hybrid fiber composites using near-critical water or supercritical acetone has been investigated in this study. Process parameters such as temperature (T= 260-300 °C), pressure (p = 60-300 bar) and composite/solvent (c/s = 0.29-2.1 g/mL) ratio were varied to determine the effect on the resin degradation efficiency and the quality of the recovered glass and carbon fibers. Supercritical acetone at 260 °C, 60 bar and a c/s ratio up to 2.1 g/mL could achieve nearly complete degradation of the resin. The glass fibers were recovered with up to 89% retained tensile strength compared to the virgin glass fibers. The use of near-critical water reduced the tensile strength of the glass fibers by up to 65%, whereas the carbon fibers were recovered with retained tensile strength compared to the virgin carbon fibers using water or acetone.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Aalborg University
Authors: Sokoli, H. U. (Ekstern), Beauson, J. (Intern), Simonsen, M. E. (Ekstern), Fraisse, A. (Intern), Brøndsted, P. (Intern), Sogaard, E. G. (Ekstern)
Pages: 80-89
Publication date: 2017
Main Research Area: Technical/natural sciences

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Journal: Journal of Supercritical Fluids
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Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.01 SJR 0.976 SNIP 1.266
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.921 SNIP 1.216 CiteScore 2.71
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.139 SNIP 1.461 CiteScore 2.89
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.097 SNIP 1.503 CiteScore 3.18
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.329 SNIP 1.669 CiteScore 3.38
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.055 SNIP 1.483 CiteScore 3.03
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.337 SNIP 1.571
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.288 SNIP 1.431
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.231 SNIP 1.496
Scopus rating (2007): SJR 1.197 SNIP 1.576
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.902 SNIP 1.383
Scopus rating (2005): SJR 1.412 SNIP 1.612
Scopus rating (2004): SJR 1.065 SNIP 1.531
Scopus rating (2003): SJR 1.235 SNIP 1.34
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 1.124 SNIP 1.321
Scopus rating (2001): SJR 0.963 SNIP 1.361
Scopus rating (2000): SJR 0.934 SNIP 1.494
Scopus rating (1999): SJR 0.99 SNIP 1.361
Original language: English
Hybrid composite, Recycling, Fiber recovery, Mechanical properties, Sustainability
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Source-ID: 2352298525
Potential solution for rain erosion of wind turbine blades

General information
State: Published
Organisations: Department of Wind Energy, Meteorology & Remote Sensing, Composites and Materials Mechanics, Aerodynamic design, Danish Meteorological Institute, Vestas Technology R&D, E.ON, Vattenfall, Vestas
Number of pages: 22
Publication date: 2017

Revelling fatigue damage evolution in unidirectional composites for wind turbine blades using x-ray computed tomography

Understanding fatigue damage evolution in the load carrying laminates of wind turbine blade play an important role designing longer and lighter turbine blades. Turbine blades which will make it possible to increase the size of wind turbines or to upgrade existing turbines for lower wind classes. Thereby, it will be possible to lower the cost of energy for wind energy based electricity. In the presented work, a lab-source x-ray computed tomography equipment (Zeiss Xradia 520 Versa) has been used in connection with ex-situ fatigue testing of uni-directional composites in order to identify fibre failure during the fatigue loading. The load carrying laminates in wind turbine blades is typically based on a number of non-crimp fabrics in where the load carrying fibres are oriented in the axial direction of the blades. In order to ease the handling of the fabric during the dry fabric layup and to ensure a good alignment of the final laminates, approximately 10% of the fibres are oriented in secondary directions as so-called backing bundles and stitched to the uni-directionally oriented bundles. Due to the coarse structure of the non-crimp fabric, test samples with a larger cross-section (compared to other comparable x-ray studies) have been used in order to ensure a representative test volume during the ex-situ fatigue testing. Using the ability of the x-ray computed tomography to zoom into regions of interest, non-destructive, the fatigue damage evolution in a repeating ex-situ fatigue loaded test sample has be explored. Thereby, the fatigue failure mechanism has been uncovered showing fibre breakage regions growing from cross-over regions of the backing bundles. Based on those observations, more realistic micromechanical based fatigue damage models as well as suggestions on bundle arrangement improving the fatigue resistance of non-crimp fabric used in the wind turbine industry can be made.
Selective Laser Melting of Hot Gas Turbine Components: Materials, Design and Manufacturing Aspects

Selective Laser Melting (SLM) allows the design and manufacturing of novel parts and structures with improved performance e.g. by incorporating complex and more efficient cooling schemes in hot gas turbine parts. In contrast to conventional manufacturing of removing material, with SLM parts are built additively to nearly net shape. This allows the fabrication of arbitrary complex geometries that cannot be made by conventional manufacturing techniques. However, despite the powerful capabilities of SLM, a number of issues (e.g. part orientation, support structures, internal stresses), have to be considered in order to manufacture cost-effective and high quality parts at an industrial scale. These issues are discussed in the present work from an engineering point of view with the aim to provide simple guidelines to produce high quality SLM parts.

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State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern)
Publication date: 2017
Main Research Area: Technical/natural sciences
Self-Reinforced PLA Composites: Bio-based and Biodegradable Polymer Materials for Industrial Applications

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Technical University of Denmark
Authors: Schilliani, G. (Ekstern), Madsen, B. (Intern), Beauson, J. (Intern)
Number of pages: 1
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Publisher: Technical University of Denmark (DTU)
Article number: M-22
Main Research Area: Technical/natural sciences
Conference: Sustain 2017, Kgs. Lyngby, Denmark, 06/12/2017 - 06/12/2017
Electronic versions:
SustainAbstracts2017c.compressed_132.pdf

Shot peening speed measurements using lidar technology
The shot peening technique is used for the surface modification of metallic components that are part of wind turbines, such as gears, bolts and blade coatings to prevent erosion. An important parameter of this technique is the dynamic energy of emitted shots. In this context the objective of this project is to present a proof of concept measurement method for the evaluation of the speed of the shots. A remote sensing laser anemometer was selected as a probing instrument of the peening shots' speed since it avoids any disturbances to the flow from the presence of an in-situ instrument. Furthermore, the risk of damaging the peening machine by installing an instrument inside the chamber during operation is eliminated by this approach. Laser anemometers are being researched and developed in the department of Wind Energy, mainly in the framework of the WindScanner.dk infrastructure project [1], but also validated and used in monitoring the wind conditions around wind turbines (wake and inflow), over complex terrain as well as offshore.

General information
State: Published
Organisations: Department of Wind Energy, Meteorology & Remote Sensing, Department of Mechanical Engineering, Manufacturing Engineering, Materials science and characterization, Composites and Materials Mechanics, Materials and Surface Engineering
Authors: Angelou, N. (Intern), Zhang, X. (Intern), Sjöholm, M. (Intern), Lorentzen, L. (Intern), Huang, X. (Intern)
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Volume: 151
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E_0151.pdf

Spatiotemporally resolved characteristics of a gliding arc discharge in a turbulent air flow at atmospheric pressure
A gliding arc discharge was generated in a turbulent air flow at atmospheric pressure driven by a 35kHz alternating current (AC) electric power. The spatiotemporally resolved characteristics of the gliding arc discharge, including glow-type discharges, spark-type discharges, short-cutting events and transitions among the different types of discharges, were investigated using simultaneously optical and electrical diagnostics. The glow-type discharge shows sinusoidal-like voltage and current waveforms with a peak current of hundreds of milliamperes. The frequency of the emission intensity variation of the glow-type discharge is the same as that of the electronic power dissipated in the plasma column. The glow-type...
discharge can transfer into a spark discharge characterized by a sharp peak current of several amperes and a sudden increase of the brightness in the plasma column. Transitions can also be found to take place from spark-type discharges to glow-type discharges. Short-cutting events were often observed as the intermediate states formed during the spark-glow transition. Three different types of short-cutting events have been observed to generate new current paths between two plasma channel segments, and between two electrodes, as well as between the channel segment and the electrodes, respectively. The short-cut upper part of the plasma column that was found to have no current passing through can be detected several hundreds of microseconds after the short-cutting event. The voltage recovery rate, the period of AC voltage-driving signal, the flow rates and the rated input powers were found to play an important role in affecting the transitions among the different types of discharges.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Lund University, Swedish Defence Research Agency
Authors: Zhu, J. (Ekstern), Gao, J. (Ekstern), Ehn, A. (Ekstern), Aldén, M. (Ekstern), Larsson, A. (Ekstern), Kusano, Y. (Intern), Li, Z. (Ekstern)
Number of pages: 11
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Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.08 SJR 0.702 SNIP 0.685
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.599 SNIP 0.671 CiteScore 1.02
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.126 SNIP 1.154 CiteScore 1.69
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.109 SNIP 1.256 CiteScore 1.7
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.463 SNIP 1.267 CiteScore 1.83
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.224 SNIP 1.282 CiteScore 2.09
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.471 SNIP 1.309
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.602 SNIP 1.332
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Specimen design and instrumentation for monitoring fatigue crack growth initiating at ply drops

Unpredictable and excessive loads, for example caused by aerodynamic interaction between different turbines, can accelerate fatigue damage in wind turbine blades (Ghosal et al. (2000)). Fatigue damage can also initiate in the early service life of a wind turbine blade in regions of stress concentration, such as those caused by ply drops (Cairns et al. (1999)). Due to these issues, the design philosophy is based on conservative analysis methods and inspections at certain time intervals are required to assess the damage in the wind blades.

An alternative approach is to use damage tolerant materials and a structural health monitoring system (McGugan et al. (2015)). In this approach, a distribution of damage types within the blades is accepted as long as they can be detected by structural health monitoring techniques and their severity evaluated by material damage models. The present work aims to demonstrate this design philosophy at the laboratory level. A test specimen, which includes ply drops at different distances from each other, is tested under static and fatigue loads. The aim is to investigate if cracks starting from these locations are stable (damage tolerant) and if the cracks and their location can be detected by non-destructive methods (detection of damage initiation and evolution).

The focus of the paper is on the experimental details and set-up: a) Design of the specimen based on a finite element model. b) Manufacturing of the ply drop specimens including manufacturing issues when embedding fibre Bragg grating sensors. c) Instrumentation of the test specimen e.g. strain gauges, acoustic emission sensors, fibre Bragg grating sensors.

Selected static and cyclic results will be presented showing that certain damage types (cracks at ply drops) are stable and thus not critical for the integrity of a structure (wind turbine blade) and that structural health monitoring techniques (acoustic emission and fibre Bragg grating sensors) can detect damage initiation and monitor the damage evolution.
Studying fatigue damage evolution in uni-directional composites using x-ray computed tomography

Understanding fatigue damage evolution in the load carrying laminates of wind turbine blade plays an important role for designing longer and lighter turbine blades which will make it possible to increase the size of wind turbines or to upgrade existing turbines for lower wind classes. Thereby, it will be possible to lower the costs of energy for wind energy based electricity. In the present work, a lab-source x-ray computed tomography equipment (Zeiss Xradia 520 Versa) has been used in connection with ex-situ fatigue testing of uni-directional composites in order to identify fibre failure during the fatigue loading. The load carrying laminates in wind turbine blades is typically based on a number of non-crimp fabrics in which the load carrying fibres are oriented in the axial direction of the blades. In order to ease the handling of the fabric during the dry fabric layup and to ensure a good alignment of the final laminates, approximately 10% of the fibres are oriented in secondary directions as so-called backing bundles and stitched to the uni-directionally oriented bundles. Due to the coarse structure of the non-crimp fabric, test samples with a larger cross-section (compared to other comparable x-ray studies) have been used in order to ensure a representative test volume during the ex-situ fatigue testing. Using the ability of the x-ray computed tomography to zoom into regions of interest, non-destructive, the fatigue damage evolution in a repeating ex-situ fatigue loaded test sample has been explored. Thereby, the fatigue failure mechanism has been uncovered showing fibre breakage regions growing from cross-over regions of the backing bundles. Based on those observations, more realistic micromechanically based fatigue damage models as well as suggestions on bundle arrangement improving the fatigue resistance of non-crimp fabric used in the wind turbine industry can be made.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern)
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Mikkelsen_GRK2078_Seminar_20170523.pdf
Publication: Research › Conference abstract for conference – Annual report year: 2017

Synchrotron measurements of local microstructure and residual strains in ductile cast iron

The local microstructure and distribution of thermally induced residual strains in ferrite matrix grains around an individual spherical graphite nodule in ductile cast iron (DCI) were measured using a synchrotron X-ray micro-diffraction technique. It is found that the matrix grains are deformed, containing dislocations and dislocation boundaries. Each of the residual strain components in the matrix grains exhibits a complex pattern along the circumferential direction of the nodule. Along the radial direction of the nodule, strain gradients from the interface to the grain interior are seen for some strain components, but only in some matrix grains. The observed residual strain patterns have been analysed by finite element modelling, and a comparison between the simulation and experiments is given. The present study of local residual stress by both experimental characterization and simulation provide much needed information for understanding the mechanical properties of DCI, and represent an important contribution for the microstructural design of new DCI materials.

General information
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Organisations: Department of Wind Energy, Materials science and characterization, Department of Mechanical Engineering, Manufacturing Engineering, Composites and Materials Mechanics, Argonne National Laboratory, VESTAS Wind Systems A/S, Oak Ridge National Laboratory
Authors: Zhang, Y. (Intern), Andriollo, T. (Intern), Faaster, S. (Intern), Liu, W. (Ekstern), Sturlason, A. (Ekstern), Barabash, R. (Ekstern)
Number of pages: 7
Publication date: 2017
Conference: 38th Risø International Symposium on Materials Science, Roskilde, Denmark, 04/09/2017 - 04/09/2017
Main Research Area: Technical/natural sciences

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BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 0.39 SJR 0.187 SNIP 0.499
Web of Science (2016): Indexed yes
Three dimensional fatigue damage evolution in non-crimp glass fibre fabric based composites used for wind turbine blades

This work studies the tension fatigue damage progression of a uni-directional glass fibre composite made from a non-crimp fabric similar to those used for the main load carrying parts of a wind turbine blade. The spatial damage progression in a chosen region of a test specimen is monitored on a micro-structural scale by ex-situ X-ray computed tomography. The centimetre sized specimen remains uncut during the ex-situ experiment. The experimental results indicate that uni-directional fibre fractures initiate from matrix cracks related to the structure of the fabric: first in the thin off-axis backing bundles at triple cross-over regions where the ±45° and 90° backing bundles intersect each other and lie close to a uni-directional bundle, and later followed by damage initiation in the other cross-over regions. Uni-directional fibre fractures were seen to increase in number with increasing number of cycles, and mainly progress in the thickness direction of uni-directional bundles (away from the backing bundles). Furthermore, the crack face separation of individual broken uni-directional fibres was observed to gradually increase with an increasing number of cycles. The progression path of the uni-directional fibre fractures was seen to be very dependent on the local backing bundle arrangement.
Translational, rotational, vibrational and electron temperatures of a gliding arc discharge

Translational, rotational, vibrational and electron temperatures of a gliding arc discharge in atmospheric pressure air were experimentally investigated using in situ, non-intrusive optical diagnostic techniques. The gliding arc discharge was driven by a 35 kHz alternating current (AC) power source and operated in a glow-type regime. The two-dimensional distribution of the translational temperature (T_t) of the gliding arc discharge was determined using planar laser-induced Rayleigh scattering. The rotational and vibrational temperatures were obtained by simulating the experimental spectra. The OH A–X (0, 0) band was used to simulate the rotational temperature (T_r) of the gliding arc discharge whereas the NO A–X (1, 0) and (0, 1) bands were used to determine its vibrational temperature (T_v). The instantaneous reduced electric field strength E/N was obtained by simultaneously measuring the instantaneous length of the plasma column, the discharge voltage and the translational temperature, from which the electron temperature (T_e) of the gliding arc discharge was estimated. The uncertainties of the translational, rotational, vibrational and electron temperatures were analyzed. The relations of these four different temperatures (T_e>T_v>T_r>T_t) suggest a high-degree non-equilibrium state of the gliding arc discharge.
Tunneling cracks in full scale wind turbine blade joints

A novel approach is presented and used in a generic tunneling crack tool for the prediction of crack growth rates for tunneling cracks propagating across a bond-line in a wind turbine blade under high cyclic loadings. In order to test and demonstrate the applicability of the tool, model predictions are compared with measured crack growth rates from a full scale blade fatigue test. The crack growth rates, measured for a several metre long section along the blade trailing-edge joint during the fatigue test, are found to be in-between the upper- and lower-bound predictions.

General information

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, LM Wind Power
Authors: Jørgensen, J. B. (Intern), Sørensen, B. F. (Intern), Kildegaard, C. (Ekstern)
Publication date: 2017
Main Research Area: Technical/natural sciences

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ISSN (Print): 0013-7944
Ratings:
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BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.39 SJR 1.247 SNIP 1.676
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.362 SNIP 1.945 CiteScore 2.44
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.619 SNIP 2.214 CiteScore 2.28
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.483 SNIP 2.047 CiteScore 2.25
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
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Scopus rating (2012): SJR 1.367 SNIP 2.112 CiteScore 1.82
Uncovering fatigue damage development in unidirectional composites using x-ray computed tomography

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern)
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Abstract

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Unidirectional Fibre Composite Characterisation from X-ray Tomography

General Information
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Number of pages: 1
Publication date: 2017
Event: Poster session presented at TMS 2017, San Diego, United States.
Main Research Area: Technical/natural sciences
Electronic versions:
posterTMSconference_monj_final.pdf
Source: PublicationPreSubmission
Source-ID: 130858539
Publication: Research › Poster – Annual report year: 2017

Using a finite element pediatric hip model in clinical 2 evaluation - a feasibility study
The paper describe a method to construct a finite element model of the hip joint of a child based on clinical recorded CT data. A model which can be used for diagnostic aid and pre-operative surgical evaluation. First part of this development is a feasibility study of this method. A scan of the asymptomatic left hip of a 10-year-old girl with a dysplastic right hip was used. Cartilage was not visible why it was modeled as an interaction with constant thickness between two surfaces. For every point on the acetabular and femoral bone surfaces, the shortest distance to the other surface was used to calculate the resulting stress in the normal direction. At a load of 233% BW the model predicted peak pressures in the hip joint of 9.7-13.8 MPa and an area in contact of 351-405 mm2. Experimental validation using the hip joint of a child was not ethical viable. Instead, our results were compared to previous published experimental studies and computational models investigating the adult hip joint. Good correlation between the current model and previous models were found. The current case specific modeling technique may be a useful complement to the previously developed hip models.

General Information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Department of Wind Energy, Composites and Materials Mechanics, Copenhagen University Hospital
Authors: Skytte, T. L. (Ekstern), Mikkelsen, L. P. (Intern), Sonne-Holm, S. (Forskerdatabase), Wong, C. (Ekstern)
Number of pages: 7
Publication date: 2017
Main Research Area: Technical/natural sciences

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Electronic versions:
using_a_finite_element_pediatric_hip_model_in_clinical_evaluation_afeasibility_study_2155_9538_1000241.pdf
DOIs: 0.4172/2155-9538.1000241

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Publication: Research - peer-review › Journal article – Annual report year: 2018

A strain gauge
The invention relates to a strain gauge of a carrier layer and a meandering measurement grid positioned on the carrier layer, wherein the strain gauge comprises two reinforcement members positioned on the carrier layer at opposite ends of the measurement grid in the axial direction. The reinforcement members are each placed within a certain axial distance to the measurement grid with the axial distance being equal to or smaller than a factor times the grid spacing. The invention further relates to a multi-axial strain gauge such as a bi-axial strain gauge or a strain gauge rosette where each of the strain gauges comprises reinforcement members. The invention further relates to a method for manufacturing a strain

A strain gauge
gauge as mentioned above.

**General information**

State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern), Zike, S. (Intern)
Publication date: 11 Feb 2016

**Publication information**

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Main Research Area: Technical/natural sciences
Source: espacenet
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**3D X-ray CT of fatigue damage in fibre composites**

**General information**

State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Manchester, LM Wind Power
Authors: Jespersen, K. M. (Intern), Zangenberg Hansen, J. (Ekstern), Lowe, T. (Ekstern), Withers, P. J. (Ekstern), Mikkelsen, L. P. (Intern)
Number of pages: 1
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Main Research Area: Technical/natural sciences
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**An exponential chemorheological model for viscosity dependence on degree-of-cure of a polyfurfuryl alcohol resin during the post-gel curing stage**

In the present study, the chemorheological behavior of a bio-based polyfurfuryl alcohol (PFA) resin has been determined by rheological isothermal tests at different curing temperatures for the post-gel curing stage of the resin, using three different amounts of catalyst (2, 4 and 6 wt %). Instead of modeling the evolution of the complex viscosity using a widely used chemorheological model such as the Arrhenius model for each tested temperature, the change of the complex viscosity as a function of the degree-of-cure was predicted using a new exponential type model. In this model, the logarithm of the normalized degree-of-cure is used to predict the behavior of the logarithm of the normalized complex viscosity. The model shows good quality of fitting with the experimental data for 4 and 6 wt % amounts of catalyst. For the 2 wt % amount of catalyst, scattered data leads to a slightly lower quality of fitting. Altogether, it is demonstrated that the new exponential model is a good alternative to conventional chemorheological models due to its simplicity and suitability

**General information**

State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Complutense University
Authors: Dominguez, J. (Ekstern), Oliet, M. (Ekstern), Alonso, M. V. (Ekstern), Rodriguez, L. F. (Ekstern), Madsen, B. (Intern)
Number of pages: 7
Publication date: 2016
Main Research Area: Technical/natural sciences

**Publication information**

Journal: I O P Conference Series: Materials Science and Engineering
The paper deals with an indirect industry-friendly method for identification of the interfacial shear strength (IFSS) in a fully bio-based composite. The IFSS of flax fiber/starch acetate is evaluated by a modified Bowyer and Bader method based on an analysis of the stress-strain curve of a short-fiber-reinforced composite in tension. A shear lag model is developed for the tensile stress-strain response of short-fiber-reinforced composites allowing for an elastic-perfectly plastic stress transfer. Composites with different fiber volume fractions and a variable content of plasticizer have been analyzed. The apparent IFSS of flax/starch acetate is within the range of 5.5-20.5 MPa, depending on composition of the material. The IFSS is found to be greater for composites with a higher fiber loading and to decrease with increasing content of plasticizer. The IFSS is equal or greater than the yield strength of the neat polymer, suggesting good adhesion, as expected for the chemically compatible constituents.
Approach for investigations of progressive fatigue damage in 3D in fibre composites using X-ray tomography

Understanding fatigue damage initiation and evolution in the load carrying laminates inside wind turbine blade plays a key factor designing longer and lighter turbine blades. Thereby, it is possible to lower the Cost of Energy for the wind energy based electricity production either by simply building larger wind turbines or by upgrading existing turbines for lower wind classes. In the presented work, a Zeiss Xradia Versa 520 scanner has been used in connection with ex-situ fatigue testing with the purpose of identifying fibre failure during the fatigue loading. The load carrying laminates is typically based on stacking of a number of non-crimp fabrics in where the load carrying fibres are oriented in the axial direction of the wind turbine blade. In order to ease the handling of the fabric during the dry fabric layup and ensure a good alignment of the final laminates, approximately 10% of the fibres are oriented in secondary directions. Thereby, the non-crimp fabric is given some shear stiffness. The figures below show the results from a scanning of a fatigue damaged material. The width of the full scanned cross section is 15 mm, while the size of the zoomed scan is approximately 2.5 mm. The small black
points visible in the two lower slices taken from the zoomed scan indicate fibre failure. From the red slice, the fibre failure is seen to be located in regions with the backing bundles are located. The backing bundles in the red slice are pointing out of the figure plan. In the green slice, it can be seen that the fibre failure in the load carrying fibres, are following the 45 degree orientation of the backing bundles where the 45 degree backing bundle can be seen at the left side of the green slice figure. In addition, to the scan case shown here, an ex-situ study of the fibre progression (Jespersen & Mikkelsen, 2016) has been performed. An ex-situ study where it has been important to design a good gripping strategy inside the scanning machine. Doing this, it has been possible to scan the same region multiple times. Thereby, a progressive fatigue damage evolution has been observed.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern), Jespersen, K. M. (Intern)
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A simplified model predicting the weight of the load carrying beam in a wind turbine blade
Based on a simplified beam model, the loads, stresses and deflections experienced by a wind turbine blade of a given length is estimated. Due to the simplicity of the model used, the model is well suited for work investigating scaling effects of wind turbine blades. Presently, the model is used to predict the weight of the load carrying beam when using glassfibre reinforced polymers, carbon fibre reinforced polymers or an aluminium alloy as the construction material. Thereby, it is found that the weight of a glass fibre wind turbine blade is increased from 0.5 to 33 tons when the blade length grows from 20 to 90 m. In addition, it can be seen that for a blade using glass fibre reinforced polymers, the design is controlled by the deflection and thereby the material stiffness in order to avoid the blade to hit the tower. On the other hand if using aluminium, the design will be controlled by the fatigue resistance in order to making the material survive the 100 to 500 million load cycles experience of the wind turbine blade throughout the lifetime. The aluminium blade is also found to be considerably heavier compared with the composite blades.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern)
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Main Research Area: Technical/natural sciences

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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
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Scopus rating (2014): SJR 0.186 SNIP 0.306 CiteScore 0.18
Scopus rating (2013): SJR 0.183 SNIP 0.256 CiteScore 0.16
Carbon fiber/carbon nanotube reinforced hierarchical composites: Effect of CNT distribution on shearing strength

The strength and fracture behavior of carbon fiber reinforced polymer composites with carbon nanotube (CNT) secondary reinforcement are investigated experimentally and numerically. Short Beam Shearing tests have been carried out, with SEM observations of the damage evolution in the composites. 3D multiscale computational (FE) models of the carbon/polymer composite with varied CNT distributions have been developed and employed to study the effect of the secondary CNT reinforcement, its distribution and content on the strength and fracture behavior of the composites. It is shown that adding secondary CNT nanoreinforcement into the matrix and/or the sizing of carbon fiber/reinforced composites ensures strong increase of the composite strength. The effect of secondary CNTs reinforcement is strongest when some small addition of CNTs in the polymer matrix is complemented by the fiber sizing with high content of CNTs.

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Characterization and modelling of the mechanical properties of mineral wool

Mineral wool designates a highly porous network of fibres drawn by spinning molten minerals. Traditionally, mineral wool products have found application as thermal and acoustic insulation of buildings. Recent concepts where mineral wool products are subjected to higher structural loads have emerged and as a consequence focus on the mechanical properties of mineral wool has intensified. Also understanding the deformation mechanisms during compression of low density mineral wool is crucial since better thickness recovery after compression will result in significant savings on transport costs. The mechanical properties of mineral wool relate closely to the arrangement and characteristics of the fibres inside the material. Because of the complex architecture of mineral wool, the characterization and the understanding of the mechanism of deformations require a new methodology.

In this PhD thesis, a methodology based on image analysis to characterize the 3D structure of mineral wool materials in terms of fibre orientation, fibre diameter, contacts and pore size is proposed. The method uses 3D data obtained by X-ray tomography. The measured data are fitted to probability distributions in order to facilitate the comparison of individual characteristics of different mineral wool materials and provide simple descriptors of the 3D structure. All the methods described here are applied to glass wool and stone wool.

By developing a FEM model including the real characteristic of the mineral wool fibre structure, the effect of the structure on mechanical properties can be explored. The size of the representative volume elements for the prediction of the elastic properties is determined for two types of applied boundary conditions. For sufficiently large volumes, the predicted elastic properties are consistent with results from the literature and confirm the transverse isotropy of mineral wool.

Finally, the overall methodology is applied to study the compression of mineral wool products. X-ray tomography and the developed image analysis techniques are employed to quantify the change of the fibre structure under compression and confirm the reorientation of the fibres. A numerical model of the cyclic compression of mineral wool is developed and reproduces successfully the hysteresis observed experimentally. The results of the modelling indicate that the size of the hysteresis is linked to the friction coefficient between the fibres.

Elastic and compressive properties of mineral wool products can now be predicted and optimized with respect to the fibre structure, binder and fibre content using the micromechanical FEM model developed in this PhD study.
Characterization Of Biaxial Strain Of Poly(L-Lactide) Tubes

Poly(L-lactide) (PLLA) in its L-form has promising mechanical properties. Being a semi-crystalline polymer, it can be subjected to strain-induced crystallization at temperatures above Tg and can thereby become oriented. Following a simultaneous (SIM) biaxial strain process or a sequential (SEQ) biaxial strain process, the mechanical properties of biaxial strained tubes can be further improved. This study investigated these properties in relation to their morphology and crystal orientation. Both processes yield the same mechanical strength and modulus, yet exhibit different crystal orientation. Through further WAXS analysis it was found that the SEQ biaxial strain yields larger interplanar spacing and distorted crystals and looser packing of chains. However, this does not influence the mechanical properties negatively. A loss of orientation in SEQ biaxial strained samples at high degrees of strain was detected, but not seen for SIM biaxial strain, and did not correlate with mechanical performance in either case. However, post-annealing reduced the orientation to the same level in both cases, and the modulus and strength is decreased for both SIM and SEQ biaxial. It is therefore concluded that mechanical properties after biaxial strain are related to strain-induced amorphous orientation and the packing of crystals, rather than strain-induced crystallinity.
Cohesive zone modelling and the fracture process of structural tape

Structural tapes provide comparable toughness as structural adhesives at orders of magnitude lower stresses. This is potentially useful to minimize the effects of differences in thermal expansion in the joining of mixed materials. The strength properties are modelled using the cohesive zone model. Thus, a cohesive zone represents the tape, i.e. stresses in the tape are transmitted to the substrates through tractions determined by the separations of the surfaces of substrates. This simplification allows for structural analysis of large complex structures. The relation between the traction and the separation is measured experimentally using methods based on the path independence of the J-integral. Repeated experiments are performed at quasi-static loading. A mixed mode cohesive law is adapted to the experimental data. The law is implemented as a UMAT in Abaqus. Simulations show minor thermal distortions due to thermal loading and substantial structural strength in mechanical loading of a mixed material structure.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Skövde
Authors: Stigh, U. (Ekstern), Biel, A. (Intern), Svensson, D. (Ekstern)
Number of pages: 10
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ISSN: 2452-3216
Control and design of volumetric composition in pultruded hybrid fibre composites

Hybrid composites consist of two or more fibre phases in a common matrix phase. This is a challenge for the control and design of the volumetric composition and microstructural uniformity of such composites. In the present study, a model is presented for the prediction of the complete volumetric composition (i.e. volume fractions of fibres, matrix and porosity) in hybrid fibre composites. The model is based on a constant local fibre volume fraction criterion. Good agreement is found between model predictions and experimental data of pultruded hybrid kenaf/glass fibre composites with variable hybrid fibre weight mixing ratios. To demonstrate the suitability of the model, simulations are performed for four different cases of volumetric composition in hybrid kenaf/glass composites.

Controlled retting of hemp fibres: Effect of hydrothermal pre-treatment and enzymatic retting on the mechanical properties of unidirectional hemp/epoxy composites

The objective of this work was to investigate the use of hydrothermal pre-treatment and enzymatic retting to remove non-cellulosic compounds and thus improve the mechanical properties of hemp fibre/epoxy composites. Hydrothermal pre-
treatment at 100 kPa and 121 °C combined with enzymatic retting produced fibres with the highest ultimate tensile strength (UTS) of 780 MPa. Compared to untreated fibres, this combined treatment exhibited a positive effect on the mechanical properties of hemp fibre/epoxy composites, resulting in high quality composites with low porosity factor ($\alpha_{pf}$) of 0.08. Traditional field retting produced composites with the poorest mechanical properties and the highest $\alpha_{pf}$ of 0.16. Hydrothermal pretreatment at 100 kPa and subsequent enzymatic retting resulted in hemp fibre composites with the highest UTS of 325 MPa, and stiffness of 38 GPa with 50% fibre volume content, which was 31% and 41% higher, respectively, compared to field retted fibres.

**General information**

State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Department of Wind Energy, Composites and Materials Mechanics, Technical University of Denmark, Swedish University of Agricultural Sciences
Authors: Liu, M. (Intern), Silva, D. A. S. (Ekstern), Fernando, D. (Ekstern), Meyer, A. S. (Intern), Madsen, B. (Intern), Daniel, G. (Ekstern), Thygesen, A. (Intern)
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- Web of Science (2017): Indexed yes
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- Scopus rating (2016): CiteScore 4.82 SJR 1.402 SNIP 2.053
- Web of Science (2016): Indexed yes
- BFI (2015): BFI-level 2
- Web of Science (2015): Indexed yes
- Scopus rating (2015): SJR 1.53 SNIP 2.18 CiteScore 4.09
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 2
- Scopus rating (2014): SJR 1.67 SNIP 2.538 CiteScore 4.08
- BFI (2013): BFI-level 2
- Scopus rating (2013): SJR 1.59 SNIP 2.828 CiteScore 3.92
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
- BFI (2012): BFI-level 2
- Scopus rating (2012): SJR 1.559 SNIP 2.706 CiteScore 3.36
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 2
- Scopus rating (2011): SJR 1.443 SNIP 2.499 CiteScore 3.23
- ISI indexed (2011): ISI indexed yes
- BFI (2010): BFI-level 2
- Scopus rating (2010): SJR 1.553 SNIP 2.241
- BFI (2009): BFI-level 2
- Scopus rating (2009): SJR 1.536 SNIP 1.976
- BFI (2008): BFI-level 2
- Scopus rating (2008): SJR 1.388 SNIP 1.853
- Scopus rating (2007): SJR 1.222 SNIP 2.188
- Web of Science (2007): Indexed yes
- Scopus rating (2006): SJR 1.208 SNIP 2.268
- Scopus rating (2005): SJR 1.109 SNIP 2.103
- Web of Science (2005): Indexed yes
Delamination initiated by a defect

Composite materials in wind turbines are mainly joined with adhesives. Adhesive joining is preferable since it distributes the stresses over a larger area. This study shows how a defect can influence the fracture behaviour of adhesively joined composite. Repeated experiments are performed using double cantilever beam specimens loaded with bending moments. The specimens consist of two 8 mm thick GFRP-laminates which are joined by a 3 mm thick epoxy adhesive. A thin foil close to one of the laminates is used to start the crack. For some of the specimens a defect is created by an initial load-unload operation. During this operation, a clamp is used in order to prevent crack propagation in the main direction. For the specimens without defect, the crack propagates in the middle of the adhesive layer. For the specimens with defect, the crack directly deviates into the laminate. After about 25 mm propagation in the laminate, the crack returns to the adhesive. Compared to the adhesive the fracture energy for the laminate is significantly higher.
Design of Wind Turbine Blades
In this section the research program framework for European PhD network MARE-WINT is presented, particularly the technology development work focussing on reliability/maintenance and the models describing multi-body fluid structure interaction for the Rotor Blade structure. In order to give a context for the effort undertaken by the individual researchers this section gives a general background for Wind Turbine blades identifying the trends and issues of importance for these structures as well as concepts for “smarter” blades that address these issues.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: McGugan, M. (Intern)
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Title of host publication: MARE-WINT. New Materials and Reliability in Offshore Wind Turbine Technology
Publisher: Springer
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ISBN (Print): 978-3-319-39094-9
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Main Research Area: Technical/natural sciences
Electronic versions:
Design_of_Wind_Turbine_Blades.pdf
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10.1007/978-3-319-39095-6_2
Publication: Research - peer-review › Book chapter – Annual report year: 2016

Determination of a cohesive law for delamination modelling - Accounting for variation in crack opening and stress state across the test specimen width
The cohesive law for Mode I delamination in glass fibre Non-Crimped Fabric reinforced vinylester is determined for use in finite element models. The cohesive law is derived from a delamination test based on DCB specimens loaded with pure bending moments taking into account the presence of large-scale bridging and the multi-axial state of stress in the test specimen. The fracture resistance is calculated from the applied moments, the elastic material properties and the geometry of the test specimen. The cohesive law is then determined in a three step procedure: 1) Obtain the bridging law by differentiating the fracture resistance with respect to opening displacement at the initial location of the crack tip, measured at the specimen edge. 2) Extend the bridging law to a cohesive law by accounting for crack tip fracture energy. 3) Fine-tune the cohesive law through an iterative modelling approach so that the changing state of stress and deformation across the width of the test specimen is taken into account. The changing state of stress and deformation across the specimen width is shown to be significant for small openings (small fracture process zone size). This will also be important for the initial part of the cohesive law with high stress variation for small openings (a few microns), but the effects are expected to be smaller for large-scale-bridging where the stress varies slowly over an increase in crack opening of several millimetres. The accuracy of the proposed approach is assessed by comparing the results of numerical simulation using the cohesive law derived by the above method, with those of physical testing for the standard DCB Mode I delamination test (ASTM D 5528). (C) 2016 Elsevier Ltd. All rights reserved.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, SINTEF, University of Oslo
Authors: Joki, R. K. (Ekstern), Grytten, F. (Ekstern), Hayman, B. (Ekstern), Sørensen, B. F. (Intern)
Pages: 49-57
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Main Research Area: Technical/natural sciences

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Determination of mode-I cohesive strength for interfaces

The cohesive strength is one of the governing parameters controlling crack deflection at interfaces, but measuring its magnitude is challenging. In this paper, we demonstrate a novel approach to determine the mode-I cohesive strength of
an interface by using a 4-point single-edge-notch beam specimen. The test specimen is made of a glue cast onto a
unidirectional, glass-fiber laminate. A crack is cut in the glue, orthogonal to the interface, which creates a high normal
stress across the glue/laminate interface during loading. It is observed that a new crack can be initiated along the interface
in response to this stress, before the main crack starts to grow. Observations using 2D digital-image correlation showed
that an "apparent" strain across the interface initially increases linearly with the applied load, but becomes nonlinear upon
the initiation of the interface crack. The cohesive strength is determined, using a 2D, linear-elastic, finite-element model of
the experiment, as the stress value where the experimental measured 'apparent' strain value becomes non-linear across
the interface.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, LM Wind Power, University of
Michigan
Authors: Jørgensen, J. B. (Ekstern), Thouless, M. D. (Ekstern), Sørensen, B. F. (Intern), Kildegaard, C. (Ekstern)
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BFI (2016): BFI-level 1
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Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 0.172 SNIP 0.281 CiteScore 0.22
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Scopus rating (2013): SJR 0.183 SNIP 0.256 CiteScore 0.16
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Scopus rating (2012): SJR 0.161 SNIP 0.203 CiteScore 0.14
ISI indexed (2012): ISI indexed no
Scopus rating (2011): SJR 0.155 SNIP 0.149 CiteScore 0.1
ISI indexed (2011): ISI indexed no
Scopus rating (2010): SJR 0.151 SNIP 0.112
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Source: FindIt
Source-ID: 2342652667
Publication: Research - peer-review › Journal article – Annual report year: 2016

Effectiveness of the random sequential absorption algorithm in the analysis of volume elements with nanoplatelets
In this work, a study of the Random Sequential Absorption (RSA) algorithm in the generation of nanoplatelet Volume
Elements (VEs) is carried out. The effect of the algorithm input parameters on the reinforcement distribution is studied
through the implementation of statistical tools, showing that the platelet distribution is systematically affected by these
parameters. The consequence is that a parametric analysis of the VE input parameters may be biased by hidden
differences in the filler distribution. The same statistical tools used in the analysis are implemented in a modified RSA
algorithm to overcome this issue.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Padova
Authors: Pontefisso, A. (Intern), Zappalorto, M. (Ekstern), Quaresimin, M. (Ekstern)
Enhancement of fracture resistance of composite laminates by the creation of multiple delaminations
Cohesive zone modelling is used to study delamination. A secondary crack can open when the peak traction value of its cohesive law is less than that of the primary crack and the layer between the two interfaces is sufficiently thin.

Experimental determination of the micro-scale strength and stress-strain relation of an epoxy resin
An approach is developed for determining the stress-strain law and a failure stress appropriate for micro-mechanical models of polymer materials. Double cantilever beam test specimens, made of an epoxy polymer with notches having finite root radius, were subjected to pure bending moments in an environmental scanning electron microscope. The recorded images were used to measure strains around the notch with a 2D digital image correlation method. The strain in front of the notch was found to reach 20% before the failure initiation, which significantly exceeds the failure strain measured at the macro-scale (5–6%). The hardening exponent of a power law hardening material was obtained by the use of the J-integral, estimating the strain energy density around the notch. The hardening exponent was found to be within the range of 5–6 and the corresponding micro-scale failure stress was in the range of 220–300 MPa. Furthermore, the experimentally measured strains around the notch edge were compared with the strain field of the HRR-field. In addition, our experimental study shows that the strain fields between the notches with different notch root radii are comparable, if all length parameters are normalized with the width of deformed notch.

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Enhancement of fracture resistance of composite laminates by the creation of multiple delaminations
Cohesive zone modelling is used to study delamination. A secondary crack can open when the peak traction value of its cohesive law is less than that of the primary crack and the layer between the two interfaces is sufficiently thin.

Experimental determination of the micro-scale strength and stress-strain relation of an epoxy resin
An approach is developed for determining the stress-strain law and a failure stress appropriate for micro-mechanical models of polymer materials. Double cantilever beam test specimens, made of an epoxy polymer with notches having finite root radius, were subjected to pure bending moments in an environmental scanning electron microscope. The recorded images were used to measure strains around the notch with a 2D digital image correlation method. The strain in front of the notch was found to reach 20% before the failure initiation, which significantly exceeds the failure strain measured at the macro-scale (5–6%). The hardening exponent of a power law hardening material was obtained by the use of the J-integral, estimating the strain energy density around the notch. The hardening exponent was found to be within the range of 5–6 and the corresponding micro-scale failure stress was in the range of 220–300 MPa. Furthermore, the experimentally measured strains around the notch edge were compared with the strain field of the HRR-field. In addition, our experimental study shows that the strain fields between the notches with different notch root radii are comparable, if all length parameters are normalized with the width of deformed notch.

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Publication: Research - peer-review › Journal article – Annual report year: 2016
Ex-situ time-lapse x-ray CT study of 3D micro-structural fatigue damage evolution in uni-directional composites

In this study, the progress of damage under tension-tension fatigue of a uni-directional (UD) glass fibre composite made from a non-crimp fabric is studied using transilluminated white light imaging (TWLI) and X-ray computed tomography (CT). TWLI images are automatically captured throughout the fatigue test, and at two damage levels the test is stopped and the sample is examined by X-ray computed tomography. From the TWLI observations it is apparent that part of the measured initial stiffness drop might be caused by edge effects rather than off-axis cracking. Some of the off-axis cracks are seen to initiate already after the first cycle, whereas some grow gradually and others appear suddenly during cycling. The off-axis cracks are observed to saturate after a few thousand cycles. The UD fibre fracture damage in the region observed by X-ray CT is probably already saturated at the first interruption point, as no significant change is seen between the two X-ray images. However, the study indicates how TWLI can be used as an initial indicator to locate damage regions at an early stage for the future ex-situ X-ray CT experiments.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Manchester, LM Wind Power
Fatigue damage assessment of uni-directional non-crimp fabric reinforced polyester composite using X-ray computed tomography

In this study, the progression of tension-tension fatigue (R=0.1) damage in a unidirectional (UD) composite made from a non-crimp glass fibre fabric used for wind turbine blades is investigated using multi-scale 3D X-ray computed tomography (CT). Initially, a representative volume is examined at one specific damage level. UD fibre fractures are only observed close to the supporting thin transverse backing layers. Furthermore, UD fibre fractures are only observed at locations where backing fibre bundles intersect one another and are at the same time locally close to a UD bundle. In addition, to study the progression of damage as a function of stiffness degradation at higher resolution four samples are subjected to different numbers of cycles before examination by CT. One sample is examined during the initial stiffness drop, two samples during stable stiffness degradation, and one close to final failure. Damage is observed to occur as chains of individual fibre breaks or clusters of fibre fractures rather than large fracture planes. Our work indicates how fracture of UD fibres initiates from intersecting ±80° backing bundles extending progressively further into the UD layer. The fibre fracture zone becomes more diffuse further from the backing layer. Our work supports a scheme explaining stiffness degradation in terms of UD fibre damage accumulation and demonstrates the importance of 3D and ideally time-lapse imaging studies.
Fatigue damage observed non-destructively in fibre composite coupon test specimens by X-ray CT

This study presents a method for monitoring the 3D fatigue damage progression on a micro-structural level in a glass fibre/polymer coupon test specimen by means of laboratory X-ray Computed Tomography (CT). A modified mount and holder made for the standard test samples to fit into the X-ray CT scanner along with a tension clamp solution is presented. Initially, the same location of the test specimen is inspected by ex-situ X-ray CT during the fatigue loading history, which shows the damage progression on a micro-structural level. The openings of individual uni-directional (UD) fibre fractures are seen to generally increase with the number of cycles, and new regions of UD fibre fractures also appear. There are some UD fibre fractures that are difficult to detect since their opening is small. Therefore, the effect of tension on the crack visibility is examined afterwards using a tension clamp solution. With applied tension some additional cracks become visible and the openings of fibre fractures increases, which shows the importance of applied tension during the scan.

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Authors: Jespersen, K. M. (Intern), Mikkelsen, L. P. (Intern)
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FBG_SiMul V1.0: Fibre Bragg grating signal simulation tool for finite element method models

FBG SiMul V1.0 is a tool to study and design the implementation of fibre Bragg grating (FBG) sensors into any kind of structure or application. The software removes the need of an fibre optic expert user, becoming more obvious the sensor response of a structural health monitoring solution using FBG sensors. The software uses a modified T-Matrix method to simulate the FBG reflected spectrum based on the stress and strain from a finite element method model. The article describes the theory and algorithm implementation, followed by an empirical validation.

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Fiber pull-out test and single fiber fragmentation test - analysis and modelling
A mathematical model is developed for the analysis of the fiber debonding phase of a pull-out experiment where the matrix is supported at the same end as the fiber is loaded in tension. The mechanical properties of the fiber/matrix are described in terms of two parameters, a fracture energy for fiber/matrix debonding and a frictional sliding shear stress. Results for the debond length and fiber debond displacement are compared with results from similar models for single fiber pull-out experiments where the specimen is gripped at the end opposite to the end where the fiber is pulling-out and with results for a single fiber fragmentation test.

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Fibre Bragg Grating as a Multi-Stage Structure Health Monitoring Sensor
There is a clear need to implement models and measurement systems through the entire life of the wind turbine blade. In this chapter will be presented some work conducted to implement optical fibres as a multi-stage sensor, capable to measure different structural properties, and link them with all the different life stages and support a better design of the wind turbine blades. The characteristics and functionality of fibre Bragg grating sensors are briefly introduced. Their application as multi-stage structure health monitoring sensors for polymer laminate composite is then described. At the manufacturing stage, where the sensors can measure several parameters of infusion and curing, sensor feedback can help control the process, avoid residual strain, and contribute to the product certification; and then in operation where cracks can be detected and monitored. Experimental mechanical testing involving crack growth and fibre Bragg sensing is described that highlights the response from the fibre optic which will correctly detect the presence and growth of damage. Models to implement these results in a damage detection system for a wind turbine blade can then be developed.
Fibre Bragg Grating Sensor Signal Post-processing Algorithm: Crack Growth Monitoring in Fibre Reinforced Plastic Structures

A novel method to assess a crack growing/damage event in fibre reinforced plastic, using conventional single mode Fibre Bragg Grating sensors embedded in the host material is presented in this article. Three different damage mechanisms that can change the sensor output, longitudinal strain $\varepsilon_{xx}$, transversal stress $\sigma_{yy}$, and non-uniform strain $\varepsilon_{xx}(xx)$, were identified. These damage mechanisms were identified during the experimental testing and linked with the sensor output using a digital image correlation technique. A dedicated algorithm to extract information from the reflected spectrum that enables crack detection was developed. Double Cantilever Beams specimens made with glass fibre and bonded with structural adhesive, were instrumented with a Fibre Bragg Grating array embedded in the host material, and tested using an experimental fracture procedure. This method was successfully validated in three different loading conditions, where were obtained very promising results that enable crack growth monitoring.

Fractographic observations of the microstructural characteristics of flax fibre composites

Natural fibre composites possess a number of special microstructural characteristics, which need to be documented to aid in the further development of these materials. Using field emission scanning electron microscopy, fractographic observations of the microstructural characteristics of aligned flax fibre/thermoplastic composites are presented. The findings are presented in relation to the three operational parts in composites: fibres, matrix and fibre/matrix interface. For the flax fibres, the striated structure on the fibre surface is shown to consist of cellulose macrofibrils oriented in the fibre direction, which indicates that the external primary and secondary cell wall layers (P and S1) have been removed during fibre processing, leaving the S2 layer to form the outer surface. The observed fracture surfaces of the flax fibres support a
previously proposed failure mechanism of transverse failure followed by longitudinal splitting. For the thermoplastic matrix, concentric rings with different points of origin are observed in the matrix regions of the composite fracture surface. The concentric rings have a microporous structure consisting of nanoscale polymer fibrils. The concentric rings form mirror zones with no riverlines, followed by repeated mist and hackle zones with distinct radiating riverlines. For the flax fibre/thermoplastic matrix interface, microscale imprints of whole fibres, and nanoscale imprints of fibre surface structures are observed on the matrix surface. This demonstrates a good fibre/matrix compatibility enabling the two parts to be in intimate contact. The composite fracture surfaces show fibres that have been pulled-out in different lengths, in addition to fibres that have failed in the same plane as the fracture surface. Altogether, the present study provides novel observations, measurements and interpretations to be used in the further analysis and understanding of the properties of natural fibre composites. (C) 2015 Elsevier Ltd. All rights reserved.

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Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
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Scopus rating (2008): SJR 1.879 SNIP 2.293
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.408 SNIP 2.243
Fracture resistance enhancement of layered structures by multiple cracks

A theoretical model is developed to test if the fracture resistance of a layered structure can be increased by introducing weak layers changing the cracking mechanism. An analytical model, based on the J integral, predicts a linear dependency between the number of cracks and the steady state fracture resistance. A finite element cohesive zone model, containing two cracking planes for simplicity, is used to check the theoretical model and its predictions. It is shown that for a wide range of cohesive law parameters, the numerical predictions agree well quantitatively with the theoretical model. Thus, it is possible to enhance considerably the fracture resistance of a structure by adding weak layers.
Gliding arc surface modification of carrot nanofibre coating - perspective for composite processing

Surfaces of carrot nanofibre coatings were modified by a gliding arc in atmospheric pressure air. The treatment strengthened wetting of deionized water and glycerol, increased an oxygen content, C-O and C=O, and moderately roughened the surfaces. In the perspective of composite materials, these changes to the nanofibres can potentially improve their processability when they are to be impregnated with a polymeric matrix. However, longer exposure to the gliding arc reduced oxidation and roughness of the surface, and thus there exists an optimum condition to achieve good wetting to solvents.

General information
Hierarchical machining materials and their performance

Machining is an important technological process in many areas of industry. The efficiency of machining determines the quality of many industrial products. Machining efficiency and cost depend on the properties, strength, and microstructure of the machining materials. One of the promising ways to increase the reliability and wear resistance of machining tools is the development and use of hierarchical machining materials. In the area of machining materials, designed typically as binder/reinforcement composites, hierarchical structures are realized as lower-scale secondary reinforcements (such as nanoparticles in the binder, or polycrystalline, aggregate-like reinforcements, also at several scale levels). Such materials can ensure better productivity, efficiency, and lower costs of drilling, cutting, grinding, and other technological processes. This article reviews the main groups of hierarchical machining materials and their performance.
Hierarchical materials: Background and perspectives
Hierarchical design draws inspiration from analysis of biological materials and has opened new possibilities for enhancing performance and enabling new functionalities and extraordinary properties. With the development of nanotechnology, the
necessary technological requirements for the manufacturing of hierarchical materials are advancing at a fast pace, opening new challenges and opportunities. This article presents an overview of possible applications of and perspectives on hierarchical materials.

**General information**

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Minnesota
Authors: Mishnaevsky, L. (ed.) (Intern), Tsapatsis, M. (ed.) (Ekstern)
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Scopus rating (2014): SJR 2.074 SNIP 1.911 CiteScore 3.61
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ISI indexed (2013): ISI indexed yes
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Scopus rating (2012): SJR 2.126 SNIP 1.923 CiteScore 3.04
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ISI indexed (2011): ISI indexed yes
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BFI (2009): BFI-level 1
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Scopus rating (2008): SJR 2.201 SNIP 2.076
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.672 SNIP 1.816
Scopus rating (2006): SJR 1.515 SNIP 1.945
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.364 SNIP 2.234
Scopus rating (2004): SJR 1.156 SNIP 1.947
Web of Science (2004): Indexed yes
Scopus rating (2002): SJR 1.447 SNIP 2.294
Scopus rating (2001): SJR 1.577 SNIP 2.32
Hierarchical nanoreinforced composites: Computational analysis of damage mechanisms
The potential of hierarchical composites with secondary nanoreinforcement is discussed and analysed on the basis of the computational modelling. The concept of nanostructuring of interfaces as an important reserve of the improvement of the composite properties is discussed. The influence of distribution, shape, orientation of nanoparticles (carbon nanotube, graphene) in unidirectional polymer matrix composites on the strength and damage resistance of the composites is studied in computational studies. The possible directions of the improvement of nanoreinforced composites by controlling shapes, localization and other parameters of nanoreinforcements are reviewed.

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Authors: Mishnaevsky, L. (Intern), Pontefisso, A. (Intern), Dai, G. (Ekstern)
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ISI indexed (2013): ISI indexed no
Scopus rating (2012): SJR 0.161 SNIP 0.203 CiteScore 0.14
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Scopus rating (2011): SJR 0.155 SNIP 0.149 CiteScore 0.1
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Influence of specimen type and reinforcement on measured tension-tension fatigue life of unidirectional GFRP laminates
It is well known that standardised tension-tension fatigue test specimens of unidirectional (UD) glass-fibre-reinforced plastics (GFRP) laminates tend to fail at end tabs. The true fatigue life is then underestimated. The first objective of this study was to find for UD GFRP laminates a test specimen that fails in the gauge section. The second objective was to compare fatigue performance of two laminates, one having a newly developed UD powder-bound fabric as a reinforcement and the other having a quasi-UD stitched non-crimp fabric as a reinforcement. In the first phase, a
rectangular specimen in accordance with the ISO 527-5 standard and two slightly different dog-bone shaped specimens were evaluated by means of finite element modelling. Subsequent comparative fatigue tests were performed for the laminates with the three specimen types. The results showed that the test specimen type has a significant effect on the failure mode and measured fatigue life of the laminates. A significantly higher fatigue life was measured for the laminate with the powder-bound fabric reinforcement when compared to the laminate with the stitched reinforcement.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, Aalto University, Tampere University of Technology
Authors: Korkiakoski, S. (Ekstern), Brøndsted, P. (Intern), Sarlin, E. (Ekstern), Saarela, O. (Ekstern)
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Scopus rating (2015): SJR 1.693 SNIP 2.558 CiteScore 2.79
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BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.169 SNIP 2.913 CiteScore 2.74
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.748 SNIP 2.647 CiteScore 2.58
ISI indexed (2013): ISI indexed yes
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Scopus rating (2012): SJR 1.979 SNIP 2.991 CiteScore 2.41
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BFI (2011): BFI-level 1
Scopus rating (2011): SJR 2.182 SNIP 2.925 CiteScore 2.33
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.893 SNIP 2.476
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BFI (2009): BFI-level 1
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Scopus rating (2008): SJR 1.732 SNIP 2.265
Scopus rating (2007): SJR 1.433 SNIP 2.219
Scopus rating (2006): SJR 1.374 SNIP 2.298
Scopus rating (2005): SJR 2.033 SNIP 2.458
Web of Science (2005): Indexed yes
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Scopus rating (2003): SJR 1.149 SNIP 1.823
Scopus rating (2002): SJR 1.568 SNIP 1.444
Influence of the curing cycles on the fatigue performance of unidirectional glass fiber reinforced epoxy composites

During the manufacturing process of fiber reinforced polymers the curing reaction of the resin results in shrinkage of the resin and introduces internal stresses in the composites. When curing at higher temperatures in order to shorten up the processing time, higher curing stresses and thermal stresses are built up and frozen, as residual stresses occur. In the present work, a glass fiber reinforced epoxy composite laminate with an unidirectional architecture based on non-crimp fabrics with backing fibers is investigated. Three different curing cycles (time-temperature cycles) are used, leading to different levels of internal stresses. The mechanical properties, static strength and fatigue life time, are measured in three different directions of the material, i.e. the fiber direction, 0°, the 30° off axis direction, and the 90° direction transverse to the fiber direction. It is experimentally demonstrated that the resulting residual stresses barely influences the quasi-static mechanical properties of reinforced glass-fiber composites. It is found that the fatigue performance in the 0° direction is significantly influenced by the internal stresses, whereas the fatigue performance in the off axes directions so is not significantly influenced of these stresses. This is related to the observations that the damage mechanisms in the off axes directions are mainly related to shear failure in the matrix and in the interface between fiber and matrix and different from the damage mechanisms in the fiber direction, where the damage initiates in the transverse backing fibers and is directly related to fiber fractures in the load-carrying axial fiber bundles.
Investigation of Mechanical Properties of Unidirectional Steel Fiber/Polyester Composites: Experiments and Micromechanical Predictions

The article introduces steel fiber reinforced polymer composites, which is considered new for composite product developments. These composites consist of steel fibers or filaments of 0.21 mm diameter embedded in a polyester resin. The goal of this investigation is to characterize the mechanical performance of steel fiber reinforced polyester composites at room temperature. The mechanical properties of unidirectional steel fiber reinforced polyester composites (SFRP) are evaluated experimentally and compared with the predicted values by micro-mechanical models. These predictions help to understand the role of material and process parameters on material properties. Two types of SFRP were studied: polyester resin reinforced by both steel fabric containing unidirectional fibers and steel fibers wound on a metal frame with 0° orientations. The effects of the fiber volume fraction and the role of polymer yarns (weft) on mechanical properties were analyzed through tensile, compressive, and shear tests. These tests were performed as per the standard test procedures. In particular, issues related to processing difficulties, polymer yarns effect on properties, standardized testing, and properties under various loading conditions were addressed. Microscopic observations were analyzed to assess the laminate quality and the macroscopic fracture surfaces of shear test specimens were studied by standard techniques.
MARE-WINT. New Materials and Reliability in Offshore Wind Turbine Technology

This book provides a holistic, interdisciplinary overview of offshore wind energy, and is a must-read for advanced researchers. Topics, from the design and analysis of future turbines, to the decommissioning of wind farms, are covered. The scope of the work ranges from analytical, numerical and experimental advancements in structural and fluid mechanics, to novel developments in risk, safety & reliability engineering for offshore wind. The core objective of the current work is to make offshore wind energy more competitive, by improving the reliability, and operations and maintenance (O&M) strategies of wind turbines. The research was carried out under the auspices of the EU-funded project, MARE-WINT. The work seeks to bridge the gap between research and a rapidly-evolving industry.

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Matrices for natural fiber composites

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Method for independent strain and temperature measurement in polymeric tensile test specimen using embedded FBG sensors

A novel method to obtain independent strain and temperature measurements using embedded Fibre Bragg Grating (FBG) in polymeric tensile test specimens is presented in this paper. The FBG strain and temperature cross-sensitivity was decoupled using two single mode FBG sensors, which were embedded in the specimen material with a certain angle between them. It is demonstrated that, during temperature variation, both FBG sensors show the same signal response. However, for any applied load the signal response is different, which is caused by the different levels of strain acting in each sensor. Equations to calculate independently the strain and temperature are presented in the article, together with a measurement resolution study. This multi-parameter measurement method was applied to an epoxy tensile specimen, tested in a unidirectional tensile test machine with a temperature controlled cabinet. A full calibration procedure (temperature and strain) was performed to this material-sensor pair, where a calibration error < 1% was achieved. This was followed by a strain-temperature test case, where multiple two loading/strain stages of \( \varepsilon = 0.30\% \) and \( \varepsilon = 0.50\% \) were applied during a continuous variation of temperature, from 40 C to -10 C. The consistency of the expected theoretical results with the calibration procedure and the experimental validation shows that this proposed method is applicable to measure accurate strain and temperature in polymers during static or fatigue tensile testing. Two different calibration protocols are presented and analysed. © 2016 Elsevier Ltd. All rights reserved.
Microstructure, quantification and control of dislocations in bast-type plant fibres

Bast-type plant fibres are increasingly being used for structural composite applications where high quality fibres with good mechanical properties are required. A central aspect for this application is the existence of dislocations in the cell wall of plant fibres, i.e., regions of misaligned cellulose microfibrils, which are believed to form weak points leading to reduced mechanical properties. In the present study, microstructural observations of dislocations are made using high-magnification scanning electron microscopy. An experimental protocol using polarized optical microscopy and image analysis is presented for the quantification of dislocations in plant fibres. The protocol is evaluated with respect to its robustness, and the uncertainty of the determined content of dislocations. Based on in-situ straining of fibres under the optical microscopy, findings are presented to show that this leads to a reduction in the content of dislocations. This is indicating that dislocations in the cell wall of plant fibres are changeable structures. Preliminary work is presented where plant fibres are exposed to physical treatments involving moisture and mechanical straining in order to change the content of dislocations. The effect of the treatments is evaluated by tensile testing of single fibres.

General information

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Authors: Madsen, B. (Intern), Lester, C. L. (Ekstern), Mortensen, U. A. (Intern), Aslan, M. (Ekstern), Lilholt, H. (Intern)
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Modelling of volumetric composition and mechanical properties of unidirectional hemp/epoxy composites - Effect of enzymatic fibre treatment

The objective of the present study is to assess the effect of enzymatic fibre treatments on the fibre performance in unidirectional hemp/epoxy composites by modelling the volumetric composition and mechanical properties of the composites. It is shown that the applied models can well predict the changes in volumetric composition and mechanical properties of the composites when differently treated hemp fibres are used. The decrease in the fibre correlated porosity factor with the enzymatic fibre treatments shows that the removal of pectin by pectinolytic enzymes results in a better fibre impregnation by the epoxy matrix, and the mechanical properties of the composites are thereby increased. The effective fibre stiffness and strength established from the modelling show that the enzymatic removal of pectin also leads to increased mechanical properties of the fibres. Among the investigated samples, the composites with hydrothermally pre-treated and enzymatically treated fibres have the lowest porosity factor of 0.08 and the highest mechanical properties. In these composites, the effective fibre stiffness and strength are determined to be 83 GPa and 667 MPa, respectively, when the porosity efficiency exponent is set equal to 2. Altogether, it is demonstrated that the applied models provide a concept to be used for the evaluation of performance of treated fibres in composites.

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Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Department of Wind Energy, Composites and Materials Mechanics
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Multi-life-stage monitoring system based on fibre Bragg grating sensors for more reliable wind turbine rotor blades: Experimental and numerical analysis of deformation and failure in composite materials

One of today's greatest global challenges is the need for clean, reliable, and renewable sources of energy, and wind energy has a key role in this process. However, in order to compete with other less "green" sources of energy the cost to produce wind made electricity needs to be reduced. One way to achieve this is by improving the reliability of wind turbine components and optimising operation and maintenance strategies. This PhD project is part of the European research project MareWint, where the main objective is to develop an innovative approach for coupled multi physics cosimulation, testing, design and optimisation of offshore wind turbines. The MareWint main scientific objective is to optimise the design of offshore wind turbines, maximise reliability, and minimise maintenance costs. Integrated within the innovative rotor blades work-package, this PhD project is focused on damage analysis and structural health monitoring of wind turbine blades. The work presented sets the required framework to develop a monitoring system based on fibre Bragg gratings (FBG), which can be applied to the different life stages of a wind turbine blade. In this concept, the different measured physical parameters are used to improve the design process, and the implemented sensor are used to control the manufacturing and operation stage of a wind turbine rotor blade. The FBG sensors measurement principle is analysed from a multi-life-stage (design, material testing, manufacturing, and operation) perspective, and supported/validated by numerical models, software tools, signal post-processing, and experimental validation. The damage in the wind turbine rotor blade is analysed from a material perspective (fibre reinforced polymers) and used as a design property, meaning that damage is accepted in an operational wind turbine as long as it is monitored. Thus, a novel crack/damage detection method using FBG sensors is presented, and software/tools are developed for signal simulation and post-processing. The first part of the thesis is an introduction to the multi-life-stage monitoring system based on FBG sensors and the damage tolerant design of fibre reinforced materials, where the different theory and numerical models used are presented. The second part of the thesis is a compilation of scientific journal papers, in which the use of FBG sensors to monitor the different life-stages of the wind turbine rotor blade is described in more detail. In Paper P1, a methodology for reliable design and maintenance of wind turbine rotor blades based on a damage tolerance and structural health monitoring approach is presented. Paper P2 presents a novel method to obtain independent strain and temperature measurements using embedded FBG sensors in polymeric tensile tests. In paper P3, a novel method for assessing crack growth in fibre reinforced polymer or structural adhesive bonded structures by combining conventional measured parameters with parameters associated with measurement errors is presented. Paper P4 presents a FBG signal post-processing tool. In paper P5, a software development tool to simulate the FBG signal from a finite element method model is described. Paper P6 fits within the manufacturing stage, describing a residual strain measurement solution based on FBG sensors. In paper P7, the fracture process zone length in double cantilever beam specimens is analysed analytically and numerically.
of graphene on the damage evolution was studied in the computational experiments based on the developed code. The potential of hybrid (carbon nanotubes and graphene) nanoscale reinforcement was studied with view on its effect of damage resistance. It was demonstrated that idealized, cylinder like models of carbon nanotubes in polymers lead to an underestimation of the stress concentration and damage likelihood in the nanocomposites. The main damage mechanisms in CNT reinforced polymers are debonding and pull-out/fiber bridging, while in graphene reinforced polymers the main role is played by crack deviation and stack splitting, with following micro-crack merging. The potential of hybrid (carbon nanotubes and graphene) nanoscale reinforcement was studied with view on its effect of damage resistance. (C) 2016 Elsevier Ltd. All rights reserved.
Natural fibre selection for composite eco-design

Natural fibre composites (NFC) are gaining interest in manufacturing because they address some of the environmental problems of traditional composites: use of non-renewable resources, and large impacts related to their production and disposal. Since natural fibres are not yet optimized for composite production, it is crucial to identify the most appropriate applications, and determine the optimal fibre/matrix ratio. A methodology is proposed for early-stage decisions support on selection of bio-composite materials. Results help identify the application with the largest reduction in environmental burden and show that the fibre/matrix combination with the lowest environmental burden also has the best mechanical properties.

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Authors: Corona, A. (Intern), Madsen, B. (Intern), Hauschild, M. Z. (Intern), Birkved, M. (Intern)
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Optical Diagnostics of a Gliding Arc Discharge at Atmospheric Pressure

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, National University of Defense Technology, Lund University
Authors: Zhu, J. (Ekstern), Kusano, Y. (Intern), Li, Z. (Ekstern)
Recycling of shredded composites from wind turbine blades in new thermoset polymer composites

As the energy produced from wind increases every year, a concern has raised on the recycling of wind turbine blades made of glass fibre composites. In this context, the present study aims to characterize and understand the mechanical properties of polyester resin composites reinforced with shredded composites (SC), and to assess the potential of such recycling solution. A special manufacturing setup was developed to produce composites with a controlled content of SC. Results show that the SC in the composites was well distributed and impregnated. The composite stiffness was well predicted using an analytical model, and fibre orientation parameters for strength modelling were established. The stress-strain curves revealed composite failure at unusual low strain values, and micrographs of the fracture surface indicated poor adhesion between SC and matrix. To tackle this problem, chemical treatment of SC or use of an alternative resin, to improve bonding should be investigated.
Residual Strains and Their Relation to the Fatigue Damage Evolution in Composite Materials

The fatigue performance of unidirectional glass fibre reinforced epoxy is found to be highly dependent on at which curing temperature the composite is manufactured. Performing the curing at 110°C instead of at 40°C is found to reduce the lifetime dramatically with a factor of 10. Even though, the volumetric shrinkage of the epoxy at the two curing cycles is identical, the resulting residual strain in an embedded optical fibre measured using fibre Bragg Grating is found to be increased with a factor of 3. Together with, 3D x-ray tomography of partly fatigued test specimens there is an indication of a link between the measured increased residual strains with the governing fatigue damage mechanism.

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Segmentation of individual fibres in a uni-directional composite from 3D X-ray computed tomography data

General information
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Strong and light-weight materials made of reinforced honeycomb sandwich structures

In the transport sector, new strong and light-weight materials can reduce the weight of airplanes, cars and containers. This will lead to a reduction in CO2 emissions as less weight needs to be transported. The requirements for these light-weight materials are that they need to be strong and have a low cost, in order for them to compete with conventionally used materials like steel or aluminum. A great candidate for a material that can fulfil these requirements of being light, strong and low cost is a sandwich material. A sandwich material is a material that is made of a light-weight core with a thin layer of steel or fibre composite on top and bottom of the core. The core in a sandwich material is typically made of a honeycomb structure. Honeycomb structures have been used for more than 50 years. Until now honeycombs have been expensive to produce. However, with a new production method it is now possible to produce honeycombs structures at a low cost. In a large collaborative European project called INCOM, the possibility of reinforcing the honeycomb structure is investigated. The honeycomb structure is reinforced with sustainable fibres as the fibres are extracted from saw dust.

Structural health monitoring tools for late and end of life management of offshore wind turbines

The late and end of life stages in an offshore wind turbines (OWT) life cycle have unique features that must be considered. The initial focus on risks associated with start-up issues due to design, manufacturing or process elements gives way to a stable period of operation and maintenance optimisation and service condition monitoring. However, as with other structures, in time the issues of "wear and tear" and remaining life assessment become increasingly prevalent. The dynamics of operating an offshore wind farm varies considerably from existing oil & gas structures. With lower operating margins and the predominance of low redundancy structures, accurate structural health monitoring can play a strong role in safe management and enable increased operating time at end of life and decommissioning. Late life operations of offshore wind farms can pose significant challenges, balancing the potential for rising operations and maintenance costs with the ability to generate significant profitability from increased reliability and longer operations. Improvements in SHM can lead to corresponding improvements in the availability and management of offshore structures. The ability to accurately gather data on damage states and thus remaining life results in significant reduction in repair costs and the determination of cost effective decommissioning plans. Under given scenarios for end of life management and decommissioning there will be various structural systems that will provide hard limits on the viable economic lifetime of OWT and their associated farms. Using a risk based review of age and decommissioning related issues a breakdown of common damage and its causes can be presented, and from this both available and developing SHM techniques to address these late life issues are identified.
The application of J integral to measure cohesive laws under large-scale yielding

A method is developed to obtain the mode I cohesive law of elastic-plastic materials using a Double Cantilever Beam sandwich specimen loaded with pure bending moments. The approach is based on the validity of the J integral for materials having a non-linear stress-strain relationship without unloading of any material point. This assumption is not met exactly as there is a small where the material unloads. To examine the error of the method, a numerical parameter study is performed for a wide range of material and specimen parameters. The error of the method is below 16% and thus the method can be used to measure cohesive laws including their shape. (C) 2016 Elsevier Ltd. All rights reserved.
The influence of removing sizing on strength and stiffness of conventional and high modulus E-glass fibres

Two types of E-glass fibres, a conventional and a high modulus where the last one in the following will be denoted as ECR-glass fibre, were investigated regarding density, diameter, stiffness and strength. The fibres were analysed as pristine and after sizing removal treatments. The sizing was removed by either burning at 565 °C or soxhlet extraction with acetone. It was found that the density and the stiffness increased after removing the sizing by the two removal treatments whereas the diameter did not change significantly. The strength of the fibres decreased after burning as the sizing, protecting against water and fibre-fibre damage, had been removed. The strength of the fibres after extraction was not significantly different from the strength of the pristine fibres despite removing the sizing. This indicates that the bonded part of sizing is still protecting the glass fibre surface.

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Organisations: Department of Micro- and Nanotechnology, Amphiphilic Polymers in Biological Sensing, Department of Wind Energy, Composites and Materials Mechanics
Thermal recycling and re-manufacturing of glass fibre thermosetting composites

The impact of using thermally recycled glass fibre in re-manufactured composites was investigated. A unidirectional glass fibre thermosetting composite laminate was manufactured. The matrix in one part of the laminate was burnt off to recover the glass fibres. These recycled glass fibres were used to manufacture a new composite laminate with the same fibre architecture as the pristine one. The fibres, the matrix and the composite laminates were thoroughly characterised and analysed. The results show that good materials quality was obtained for both laminates. A difference in fibre packing behaviour was observed in the composites with the pristine and the recycled fibres, which lead to a lower fibre volume fraction in the latter one. The Young's modulus of the composites was not changed by the recycling process, if the lower fibre volume fraction is taken into account. However, a marked drop in the maximum stress of the composites was reported, which was found to be related to the loss in maximum stress of the fibres.
Use of micro-tomography for validation of method to identify interfacial shear strength from tensile tests of short regenerated cellulose fibre composites

The interfacial shear strength of short regenerated cellulose fibre/polylactide composites was characterized by means of an industry-friendly adhesion test method. The interfacial shear strength was back-calculated from the experimental tensile stress-strain curves of composites by using a micro-mechanical model. The parameters characterizing the microstructure of the composites, e.g. fibre length and orientation distributions, used as input in the model were obtained by micro-tomography. The investigation was carried out on composites with untreated and surface treated fibres with various fibre weight contents (5wt%, 10wt%, and 15wt% for untreated fibres, and 15wt% for treated fibres). The properties of fibres were measured by an automated single fibre tensile test method. Based on these results, the efficiency of the fibre treatment to improve fibre/matrix adhesion is evaluated, and the applicability of the method to measure the interfacial shear strength is discussed. The results are compared with data from previous work, and with other results from the literature.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, Luleå University, University of Jyväskyla, Luleå University of Technology
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Wind Turbine Blades: An End of Life Perspective

In 2016, the first offshore windfarm constructed in the world—located in Denmark, near Ravnsborg—is turning 25 years old, and will soon be decommissioned. After decommissioning, most of the material of the turbine can be recycled; only the composite materials found in the blades represent a challenge. This part looks at end of life solutions for this material. Wind turbine blade structure and material are described. The ends of life solutions existing and under development are detailed.

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X-ray based micromechanical finite element modeling of composite materials
This is a study of a uni-directional non-crimp fabric reinforced epoxy composite material typically used as the load carrying laminate in wind turbine blades. Based on a 3D xray tomography scan, the bundle and fibre/matrix structure of the composite is segmented. This segmentation is used in a multi-scale finite element model bridging the gap from the individual fibers organized in bundles to the stitched non-crimp fabric used for building up the load carrying laminates.

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A morphing trailing edge flap system for wind turbine blades

The development of a morphing trailing edge system for wind turbines, also called a flap system, is presented. The functionality is simple as the flap deflection is controlled by pressurized air or a fluid in a number of voids in the flap made of an elastic material. It is thus a robust system as no mechanical or metal parts are used. The prototypes tested in the laboratory and on a blade section in a wind tunnel in the period from 2007-2010 demonstrated the functionality and the aerodynamic performance of the flap concept. In a recent research and development project INDUFLAP from 2011-2014 the flap system has been further developed in corporation with the industrial partners Hydratech Industries (DK) and Rehau (DE). A new trailing edge flap design with spanwise voids (channels) and with a chord of 15cm suitable for a 1m chord blade section was developed. It was then manufactured by extrusion and glued together with a load carrying part with a connector part that allows an easy attachment on the blade section. After tests in the laboratory the flap was mounted on a 2m long blade section mounted on a newly developed test rig. A 10m long boom with the blade section was installed on a 100kW turbine hub where the original blades were taken down. It means that the flap system was tested under realistic rotating conditions with real atmospheric turbulent inflow and with a g loading up to 10g which represents the conditions on the outer part of a MW turbine blade. The measured performance of the flap system shows that 3 deg. flap deflection gives the same lift change as 1 deg. pitch of the whole blade section.
Authors: McGugan, M. (Intern), Leble, V. (Ekstern), Pereira, G. F. (Intern)
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Carbon nanotube reinforced hybrid composites: Computational modeling of environmental fatigue and usability for wind blades
The potential of advanced carbon/glass hybrid reinforced composites with secondary carbon nanotube reinforcement for wind energy applications is investigated here with the use of computational experiments. Fatigue behavior of hybrid as well as glass and carbon fiber reinforced composites with and without secondary CNT reinforcement is simulated using multiscale 3D unit cells. The materials behavior under both mechanical cyclic loading and combined mechanical and environmental loading (with phase properties degraded due to the moisture effects) is studied. The multiscale unit cells are generated automatically using the Python based code. 3D computational studies of environment and fatigue analyses of multiscale composites with secondary nano-scale reinforcement in different material phases and different CNTs arrangements are carried out systematically in this paper. It was demonstrated that composites with the secondary CNT reinforcements (especially, aligned tubes) present superior fatigue performances than those without reinforcements, also under combined environmental and cyclic mechanical loading. This effect is stronger for carbon composites, than for hybrid and glass composites.

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The potential of carbon nanotube reinforcement of metallic binders for the improvement of quality and efficiency of diamond cutting wheels is studied. The effect of multi-walled carbon nanotube (MWCNT) reinforcement on the mechanical properties i.e. hardness, Young modulus, strength and deformation behavior of copper and iron based binder for diamond cutting wheels is investigated experimentally and numerically. Computational micromechanical studies were carried out to clarify the mechanisms of the MWCNT material strengthening. It is demonstrated that the adding of MWCNTs leads to the decrease of grain size of the structural constituents of the binder, what in turn leads to the improved simultaneously hardness, Young modulus, plastic extension, bending strength and performances of the metallic binders. Comparing service properties of diamond end-cutting drill bits with and without MWCNT one observed the drastic increase of the cutting speed as a result of MWCNT reinforcement.
Characterization and biological depectinization of hemp fibers originating from different stem sections

The wide variation of mechanical properties of natural fibers limits their applications in matrix composites. The aim of this study is to evaluate the properties of hemp fibers from different stem sections (top, middle and bottom) and to assess fungal retting pretreatment of hemp from different stem sections with the white rot fungi Phlebia radiata Cel 26 and Ceriporiopsis subvermispora. For the untreated hemp fibers, no apparent difference in tensile behavior for fiber bundles from different stem sections was observed, and more than 90% tested samples demonstrated plastic flow behavior. Fiber strength and stiffness were highest for the fibers from the top and middle stem sections. These properties were related to the compositional make up and morphological properties of hemp fibers, notably the secondary fiber cell contents. In fungal retting, there was a strong dependence of depectinization selectivity on stem section, which decreased from bottom to top presumably due to the significantly higher lignin content in the bottom section than in the top section (middle section was in between). Consequently, the fungal retting caused a lower reduction in strength of fibers from the bottom section than in those from the top stem section, and essentially reversed the influence of stem section on fiber tensile strength through depectinization selectivity. At whole hemp stem level, the fungal retting with P. radiata Cel 26 exhibited better mechanical properties with an ultimate tensile strength, strain and stiffness of 736 MPa, 2.3% and 42 GPa, respectively, while fibers treated with C. subvermispora exhibited lower mechanical properties of 573 MPa, 1.9% and 40 GPa, respectively. The study thus also showed that less variable and high strength fibers may be reproduced using the dependence of depectinization selectivity on stem section for composite application.
Comparative Environmental Sustainability Assessment of Bio-Based Fibre Reinforcement Materials for Wind Turbine Blades

Over the recent decades biomaterials have been marketed successfully supported by the common perception that biomaterials and environmental sustainability de facto represents two sides of the same coin. The development of sustainable composite materials for wind turbine blades for small-scale wind turbines have therefore partially been focused on substitution of conventional fibre materials with bio-fibres assuming that this substitution was in the better for the environment and human health. The major question is if this material substitution, taking into account a multitude of environmental impact categories, not only climate change, actually is supporting sustainable development or if the development of sustainable composite materials is more complex and perhaps even contra-intuitive due to complex trade-offs. Based on a case study 4 different types of fibres and fibre mixtures (flax, carbon, glass and flax/carbon, flax/glass mixed fibres) are compared in terms of environmental sustainability. Applying one of the most recent life cycle impact assessment methods, we demonstrate that the environmental sustainability of natural fibre based composite materials is similar or even lower, within certain impact categories, than the conventional materials. This observation may seem contra-intuitive (i.e. most people would expect the bio-based to be most sustainable), but is primarily caused by the fact that the resin demand of biobased reinforcement materials is by far larger than that of conventional reinforcement materials. Since the environmental burden of the resin in addition is comparable to that of the fibres (especially in terms human health related impacts), the higher resin demand counterbalances the environmental sustainability improvements, obtained with the application of natural fibres.
Crack Detection in Fibre Reinforced Plastic Structures Using Embedded Fibre Bragg Grating Sensors: Theory, Model Development and Experimental Validation

In a fibre-reinforced polymer (FRP) structure designed using the emerging damage tolerance and structural health monitoring philosophy, sensors and models that describe crack propagation will enable a structure to operate despite the presence of damage by fully exploiting the material's mechanical properties. When applying this concept to different structures, sensor systems and damage types, a combination of damage mechanics, monitoring technology, and modelling is required. The primary objective of this article is to demonstrate such a combination. This article is divided in
three main topics: the damage mechanism (delamination of FRP), the structural health monitoring technology (fibre Bragg gratings to detect delamination), and the finite element method model of the structure that incorporates these concepts into a final and integrated damage-monitoring concept. A novel method for assessing a crack growth/damage event in fibre-reinforced polymer or structural adhesive-bonded structures using embedded fibre Bragg grating (FBG) sensors is presented by combining conventional measured parameters, such as wavelength shift, with parameters associated with measurement errors, typically ignored by the end-user. Conjointly, a novel model for sensor output prediction (virtual sensor) was developed using this FBG sensor crack monitoring concept and implemented in a finite element method code. The monitoring method was demonstrated and validated using glass fibre double cantilever beam specimens instrumented with an array of FBG sensors embedded in the material and tested using an experimental fracture procedure. The digital image correlation technique was used to validate the model prediction by correlating the specific sensor response caused by the crack with the developed model.

**General information**

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This article presents a novel method to assess a crack growing/damage event in fibre reinforced plastic, or adhesive using Fibre Bragg Grating (FBG) sensors embedded in a host material. Different features of the crack mechanism that induce a change in the FBG response were identified. Double Cantilever Beams specimens made with glass fibre glued with structural adhesive, were instrumented with an array of FBG sensors embedded in the material and tested using an experimental fracture procedure. A digital image correlation technique was used to determine the presence of the specific phenomena caused by the crack, and to correlate with the FBG sensor. A Material-Sensor model was developed in order to predict the sensor output response under a crack/delamination situation, which can be used as an analysis tool for future application of this measurement technology in more complex structures.
Damage tolerance and structural monitoring for wind turbine blades
The paper proposes a methodology for reliable design and maintenance of wind turbine rotor blades using a condition monitoring approach and a damage tolerance index coupling the material and structure. By improving the understanding of material properties that control damage propagation it will be possible to combine damage tolerant structural design, monitoring systems, inspection techniques and modelling to manage the life cycle of the structures. This will allow an efficient operation of the wind turbine in terms of load alleviation, limited maintenance and repair leading to a more effective exploitation of offshore wind.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Wind Turbines
Authors: McGugan, M. (Intern), Pereira, G. F. (Intern), Sørensen, B. F. (Intern), Toftegaard, H. L. (Intern), Branner, K. (Intern)
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BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.26 SJR 0.874 SNIP 1.024
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.78 SNIP 0.985 CiteScore 2.08
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.847 SNIP 1.256 CiteScore 2.39
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.12 SNIP 1.534 CiteScore 3.12
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.068 SNIP 1.387 CiteScore 2.89
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.964 SNIP 1.297 CiteScore 2.65
Damage tolerant design and condition monitoring of composite material and bondlines in wind turbine blades: Failure and crack propagation

This research presents a novel method to assess a crack growing/damage event in composite material, in polymer, or in structural adhesive using Fibre Bragg Grating (FBG) sensors embedded in the host material, and its application in a composite material structure: Wind Turbine Trailing Edge. A Structure-Material-Sensor Finite Element Method (FEM) model was developed to simulate the Fibre Bragg Grating sensor output response, when embedded in a host material (Composite material, polymer or adhesive), during a crack growing/damage event. This Structure-Material-Sensor model provides a tool to analyse the application of this monitoring technique in other locations/structures, by predicting the sensor output and deciding, based on this, the optimal sensor distribution/configuration.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Pereira, G. F. (Intern), Mikkelsen, L. P. (Intern), McGugan, M. (Intern)
Number of pages: 8
Publication date: 2015

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Title of host publication: Proceedings of EWEA Offshore 2015 Conference
Publisher: European Wind Energy Association (EWEA)
Main Research Area: Technical/natural sciences
Conference: EWEA Offshore 2015 Conference, Copenhagen, Denmark, 10/03/2015 - 10/03/2015
Electronic versions:
Damage_tolerant_design_and_condition_paper.pdf. Embargo ended: 10/03/2016
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015
Delamination fractures in composite materials

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Sørensen, B. F. (Intern)
Pages: 213-240
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Title of host publication: Modelling Damage, Fatigue and Failure of Composite Materials
Publisher: Woodhead Publishing
Editors: Talreja, R., Varna, J.
ISBN (Print): 9781782422860
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Chapter: 11
Series: Woodhead Publishing Series in Composites Science and Engineering
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Book chapter – Annual report year: 2015

Design, manufacturing and testing of Controllable Rubber Trailing Edge Flaps
The overall goal for the INDUFLAP project was realization of a test facility for development and test of Controllable Rubber Trailing Edge Flaps (CRTEF) for wind turbines. This report covers experimental work at DTU Wind Energy including design, manufacture and test of different configurations of flaps with voids in chord- or spanwise direction. Development of rubber flaps has involved further design improvements. Non-metallic spring elements and solutions for sealing of continuous extruded rubber profiles have been investigated.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Aeroelastic Design
Authors: Legastrup Andersen, T. (Intern), Aagaard Madsen , H. (Intern), Barlas, T. K. (Intern), Mortensen, U. A. (Intern), Andersen, P. B. (Intern)
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Main Research Area: Technical/natural sciences
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Design_manufacturing_and_testing.pdf
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Development of new biomass-based furan/glass composites manufactured by the double-vacuum-bag technique

The present study addresses the development of new biomass-based furan resin/glass fibre composites manufactured by the double-vacuum-bag technique using a two-stage cure cycle to allow removal of water from the resin. The volumetric composition and mechanical properties of the composites are measured and analysed with focus on the porosity content. The so-called matrix correlated porosity factor is determined to be 0.096, meaning that the furan matrix itself contains 8.8% porosity. In the optimal case of no matrix porosity, stiffness of the composites compares well with the stiffness of conventional thermosetting/glass composites, but with lower strength. The findings of the present study show that a more efficient water removal during manufacturing, a lower porosity content and a less brittle stress–strain behaviour of the furan matrix are to be addressed to further improve the properties of the composites.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Complutense University
Authors: Dominguez, J. C. (Ekstern), Madsen, B. (Intern)
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Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.42 SJR 0.517 SNIP 0.781
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.586 SNIP 0.88 CiteScore 1.4
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.606 SNIP 1.183 CiteScore 1.44
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.624 SNIP 1.207 CiteScore 1.45
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.607 SNIP 1.26 CiteScore 1.21
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.656 SNIP 1.283 CiteScore 1.23
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.678 SNIP 1.135
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.73 SNIP 1.076
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.791 SNIP 1.124
Scopus rating (2007): SJR 0.689 SNIP 1.216
Diamond and cBN hybrid and nanomodified cutting tools with enhanced performance: Development, testing and modelling

The potential of enhancement of superhard steel and cast iron cutting tool performance on the basis of microstructural modifications of the tool materials is studied. Hybrid machining tools with mixed diamond and cBN grains, as well as machining tool with composite nanomodified metallic binder are developed, and tested experimentally and numerically. It is demonstrated that both combination of diamond and cBN (hybrid structure) and nanomodification of metallic binder (with hexagonal boron nitride/hBN platelets) lead to sufficient improvement of the cast iron machining performance. The superhard tools with 25% of diamond replaced by cBN grains demonstrate 20% increased performance as compared with pure diamond machining tools, and more than two times higher performance as compared with pure cBN tools. Further, cast iron machining efficiency of the wheels modified by hBN particles was 80% more efficient compared to the tool with the original binder. Computational model of hybrid superhard tools is developed, and applied to the analysis of structure-performance relationships of the tools.
Dictionary Based Segmentation in Volumes

We present a method for supervised volumetric segmentation based on a dictionary of small cubes composed of pairs of intensity and label cubes. Intensity cubes are small image volumes where each voxel contains an image intensity. Label cubes are volumes with voxelwise probabilities for a given label. The segmentation process is done by matching a cube from the volume, of the same size as the dictionary intensity cubes, to the most similar intensity dictionary cube, and from the associated label cube we get voxel-wise label probabilities. Probabilities from overlapping cubes are averaged and hereby we obtain a robust label probability encoding. The dictionary is computed from labeled volumetric image data based on weighted clustering. We experimentally demonstrate our method using two data sets from material science – a phantom data set of a solid oxide fuel cell simulation for detecting three phases and their interfaces, and a tomogram of a glass fiber composite used in wind turbine blades for detecting individual glass fibers.

General information

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Organisations: Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Department of Wind Energy, Composites and Materials Mechanics, Department of Energy Conversion and Storage, Imaging and Structural Analysis
Number of pages: 12
Dictionary Based Segmentation in Volumes

Method for supervised segmentation of volumetric data. The method is trained from manual annotations, and these annotations make the method very flexible, which we demonstrate in our experiments. Our method infers label information locally by matching the pattern in a neighborhood around a voxel to a dictionary, and hereby accounts for the volume texture.

DTU-ESA millimeter-wave VAilidation STandard antenna (mm-VAST) - detailed design

A design of a well-characterized, mechanically and thermally stable multi-frequency VAilidation STandard antenna for mm-wave frequencies (mm-VAST) developed in an ESA project is presented. The antenna will facilitate inter-comparison and validation of antenna measurement ranges at K/Ka and Q/V bands in response to on-going deployment of satellite communication services at 20/30 GHz (K/Ka-band) as well as future commercial use of the 40/50 GHz bands (Q/V-band).
DTU-ESA millimeter-wave validation standard antenna (mm-VAST) – performance verification
A new multi-frequency Validation Standard (VAST) antenna covering upper microwave (K/Ka) and millimeter wave (Q/V) bands, and thus called mmVAST, was developed in cooperation between DTU and TICRA under contract from the European Space Agency. In this paper, the mechanical and electrical requirements as well as the design and manufacturing of the mm-VAST antenna are briefly presented. The focus is then given to the details of conducted mechanical and electrical tests aimed at verifying the performance of the manufactured antenna and to the obtained measurement results.

Effect of fiber positioning on mixed-mode fracture of interfacial debonding in composites
Under transverse tensile loading, fibers oriented perpendicular to the tensile direction can undergo fiber/matrix debonding. Experiments show that the first stage of fiber/matrix interface debonding is mode-I dominated fracture with very fast crack growth rate. Subsequent stable crack propagation along the interface is due to mixed mode I/II fracture. The aim of this study is to explore ways to stabilize the early stage of debonding so that it becomes possible to determine the mixed mode interfacial fracture properties for the entire mode-mixity range by in-situ observations. Therefore, the objective of this study is to stabilize crack initiation in the dominant mode-I fracture by changing the position of one fiber with its neighboring fiber or hole using the finite element analysis. The progressive fiber/matrix debonding is studied by focusing on the interaction of one fiber with its neighboring fiber or hole. The results show that decrease of the position angle stabilize the crack growth at the interface in the ligaments. This effect is more significant in the cases with small ligament thickness. In the two-fiber model and at very small ligaments the results show that the crack growth stops when the crack tips meet each other in the ligament and further crack growth is under dominant mode-II fracture. In the fiber-hole model, both the crack initiation and propagation are stabilized by decrease of the position angles at very thin ligaments. This paper suggests to use two fibers instead of a single fiber in order to ease the characterization of interfacial properties. [All rights reserved Elsevier]
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- BFI (2017): BFI-level 2
- Web of Science (2017): Indexed yes
- BFI (2016): BFI-level 2
- Scopus rating (2016): CiteScore 2.8 SJR 1.501 SNIP 1.713
- Web of Science (2016): Indexed yes
- BFI (2015): BFI-level 2
- Scopus rating (2015): SJR 1.502 SNIP 1.917 CiteScore 2.66
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 2
- Scopus rating (2014): SJR 1.643 SNIP 2.048 CiteScore 2.72
- Web of Science (2014): Indexed yes
- BFI (2013): BFI-level 2
- Scopus rating (2013): SJR 1.587 SNIP 2.148 CiteScore 2.6
- ISI indexed (2013): ISI indexed yes
- BFI (2012): BFI-level 2
- Scopus rating (2012): SJR 1.584 SNIP 2.262 CiteScore 2.33
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 2
- Scopus rating (2011): SJR 1.668 SNIP 1.911 CiteScore 2.11
- ISI indexed (2011): ISI indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 2
- Scopus rating (2010): SJR 1.599 SNIP 1.845
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 2
- Scopus rating (2009): SJR 1.86 SNIP 1.774
- Web of Science (2009): Indexed yes
- BFI (2008): BFI-level 1
- Scopus rating (2008): SJR 1.823 SNIP 1.87
- Web of Science (2008): Indexed yes
- Scopus rating (2007): SJR 1.689 SNIP 1.846
- Web of Science (2007): Indexed yes
- Scopus rating (2006): SJR 1.653 SNIP 1.994
- Web of Science (2006): Indexed yes
- Scopus rating (2005): SJR 1.782 SNIP 1.704
- Web of Science (2005): Indexed yes
- Scopus rating (2004): SJR 1.879 SNIP 1.833
- Web of Science (2004): Indexed yes
- Scopus rating (2003): SJR 2.131 SNIP 1.727
- Web of Science (2003): Indexed yes
- Scopus rating (2002): SJR 2.122 SNIP 1.443
- Web of Science (2002): Indexed yes
- Scopus rating (2001): SJR 1.475 SNIP 1.65
- Web of Science (2001): Indexed yes
The large variability in the mechanical properties of hemp fibers is an issue in relation to their use in high-grade composites. The objective of the present study was to determine the optimal growth stage for harvesting hemp fibers for use in composites and to evaluate the effect of field retting time on mechanical performance of the fibers. Reduction in bast content and thickness of the primary bast fiber layer in stems were found to be highly significant (P < 0.01) with plant maturity. A significant increase in these secondary fiber fraction occurred with maturity, reaching a maximum value of 10% at seed maturity. A highly significant reduction in cellulose deposition in fiber cell walls was reflected by reduced fiberwall thickness with plant maturity and was related to the development and ripening of hemp seeds. A statistically significant increase in lignin deposition and a slight decrease in pectins in hemp fiber cell walls were also noted with stem maturity. Microscopy observations and histochemical analyzes corroborated the results from the chemical analyzes and revealed variations in morphological aspects and spatial micro-distributions of carbohydrates and lignin within the cell structure of the hemp stems between early- and late growth phases. Fibers harvested at the beginning of flowering exhibited high tensile strength and strain, which decreased with plant maturity. Reduction in strength was related to the increase in proportion of secondary fibers and decrease in cellulose deposition leading to inferior properties of fibers. A negative effect of field retting occurred only after extended field retting (i.e., 70 days) which was presumably due to accelerated degradation of cellulose by the action of microorganisms.
Effects of moisture on glass fiber-reinforced polymer composites

Glass fiber polymer composites are used in wind turbine blades because of their high-specific strength and stiffness, good fatigue properties, and low cost. The wind industry is moving offshore to satisfy economies of scale with larger turbines. High humidity in this environment degrades mechanical performance of wind turbine blades over their lifetime. Here, environmental moisture conditions were simulated by immersing glass fiber-reinforced polymer specimens in salt water for a period of up to 8 years. The mechanical properties of specimens were analyzed before and after immersion to evaluate the degradation mechanisms. Single-fiber tensile testing was also performed at different moisture conditions. The water-diffusion mechanism was studied to quantify the diffusion coefficients as a function of salt concentration, sample geometry, and fiber direction. Three degradation mechanisms were observed: polymer plasticization, fiber stress corrosion, and interface degradation, where the latter was found to be the most detrimental for wind-industry applications.

General information

State: Published
Organisations: Department of Wind Energy, Department of Electrical Engineering, Composites and Materials Mechanics
Authors: Alzamora Guzman, V. J. (Intern), Brandsted, P. (Intern)
Number of pages: 10
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Main Research Area: Technical/natural sciences
Elastocaloric cooling device: Materials and modeling

In the last decade we have witnessed the development of alternative solid-state cooling technologies based on so-called ferroic (caloric) effects. A large effort nowadays is devoted to investigating solid-state refrigeration using the magnetocaloric effect (change of temperature upon application of a magnetic field). However, the possibility of inducing a thermodynamic transition by means of mechanical stress (martensitic transformation), i.e. the elastocaloric effect in superelastic materials, opens up new routes for solid-state refrigeration. In the recent years a large elastocaloric effect was demonstrated in Ni-Ti-based, Cu-based as well as Fe-based shape memory alloys. Although these studies showed a great potential of the elastocaloric effect, there has not yet been much activities on development of elastocaloric cooling devices. Some ideas on elastocaloric cooling device have already been presented, but there is still a lack of knowledge and information about its actual cooling potential.

Elastocaloric effect of Ni-Ti wire for application in a cooling device

We report on the elastocaloric effect of a superelastic Ni-Ti wire to be used in a cooling device. Initially, each evaluated wire was subjected to 400 loading/unloading training cycles in order to stabilize its superelastic behavior. The wires were trained at different temperatures, which led to different stabilized superelastic behaviors. The stabilized (trained) wires were further tested isothermally (at low strain-rate) and adiabatically (at high strain-rate) at different temperatures (from 312 K to 342 K). We studied the impact of the training temperature and resulting superelastic behavior on the adiabatic temperature changes. The largest measured adiabatic temperature change during loading was 25 K with a corresponding 21 K change during unloading (at 322 K). A special focus was put on the irreversibilities in the adiabatic temperature changes between loading and unloading. It was shown that there are two sources of the temperature irreversibilities: the hysteresis (and related entropy generation) and the temporary residual strain immediately after unloading, respectively. The latter results in the temporary bending of the wire and reduced negative adiabatic temperature change. The paper also shows the impact of the applied strain on the adiabatic temperature changes as well as the distribution of the elastocaloric effect over the wire during loading in the case of two wires trained at different temperatures and the virgin wire, respectively. In the end, we propose guidelines about the required material properties for an efficient elastocaloric cooling device. © 2015 AIP Publishing LLC.
ORIGINAL LANGUAGE: English

PHYSICS, SHAPE-MEMORY ALLOY, INDUCED MARTENSITIC-TRANSFORMATION, SINGLE-CRYSTALS, STRAIN-RATE, TEMPERATURE, TRICKS, DEFORMATION, EVOLUTION, BEHAVIOR
Embedded Fibre Bragg Grating Sensor Response Model: Crack Growing Detection in Fibre Reinforced Plastic Materials

This article presents a novel method to simulate the sensor output response of a Fibre Bragg Grating (FBG) sensor when embedded in a host material (Composite material or adhesive), during a crack growing/damage event. A finite element model of the crack growth mechanisms was developed, and different fracture modes were addressed. Then an output algorithm was developed to predict the sensor spectrum change during the different stages of the crack growing. Thus, it is possible to identify specific phenomenon that will only happen within the proximity of a crack, as compression field ahead the crack or non-uniform strain, and then identify the presence of such damage in the structure. Experimental tests were conducted in order to validate this concept and support the model. The FBG sensor response model was applied in a delamination of a Wind Turbine trailing edge, to demonstrate the applicability of this technique to more complicated structures, and to be used as a structural health monitoring design tool.
Fatigue behaviour of uni-directional flax fibre/epoxy composites

A study related to the fatigue behaviour of natural fibre-reinforced composites was conducted to expand their range of product applications. A uni-directional flax-epoxy composite was fabricated and several conditions of tension-tension fatigue tests were performed. During fatigue testing, the composite showed an increase of stiffness, a typical observation for natural fibre-reinforced composites, and this was found to be accompanied by accumulation of residual strain. A clear linear relationship was found between the stiffening effect and the residual strain. In addition, it was revealed that the fatigue behaviour was clearly influenced by the frequency of cyclic loading. Lower frequencies induced more significant stiffening and shorter fatigue life. These results suggest that fatigue damaging is progressing simultaneously with the stiffening effect in natural fibre-reinforced composites, and it is therefore important to involve creep damaging to the failure criteria for these composites.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Hitachi Ltd.
Authors: Ueki, Y. (Ekstern), Lilholt, H. (Intern), Madsen, B. (Intern)
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Publication date: 2015

Fatigue damage evolution in fibre composites for wind turbine blades

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Manchester
Authors: Jespersen, K. M. (Intern), Lowe, T. (Ekstern), Withers, P. J. (Ekstern), Mikkelsen, L. P. (Intern)
Number of pages: 1
Publication date: 2015
Main Research Area: Technical/natural sciences
Fatigue life in textile composites used for wind energy engineering

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, LM Wind Power
Authors: Zangenberg, J. (Ekstern), Brøndsted, P. (Intern)
Pages: 403-440
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Series: Woodhead Publishing Series in Composites Science and Engineering
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Book chapter – Annual report year: 2015

Finite Element Verification of Non-Homogeneous Strain and Stress Fields during Composite Material Testing
Uni-directional glass fiber reinforced polymers play a central role in the task increasing the length of wind turbines blades and thereby lowering the cost of energy from wind turbine installations. During this, optimizing the mechanical performance regarding material stiffness, compression strength and fatigue performance is essential. Nevertheless, testing composites includes some challenges regarding stiffness determination using conventional strain gauges and achieving correct material failure unaffected by the gripping region during fatigue testing. Challenges, which in the present study, has been addressed using the finite element method. During this, a verification of experimental observations, a deeper understanding on the test coupon loading and thereby improved test methods has been achieved.

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Authors: Mikkelsen, L. P. (Intern)
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Composites, Experimental Verification, Fatigue, Scripting
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Forskning i vindenergi på DTU/Rissø. Del 1-2

General information
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Organisations: Department of Wind Energy, Test and Measurements, Composites and Materials Mechanics, Meteorology, Wind Energy Systems
Authors: Jensen, P. H. (Intern), Hummelsheij, P. (Intern), Mikkelsen, T. K. (Intern), Løgstrup Andersen, T. (Intern), Ejsing Jørgensen, H. (Intern), Thomsen, K. (Intern), Sørensen, P. E. (Intern)
From Measurements Errors to a New Strain Gauge Design

Significant over-prediction of the material stiffness in the order of 1-10% for polymer based composites has been experimentally observed and numerical determined when using strain gauges for strain measurements instead of non-contact methods such as digital image correlation or less stiff methods such as clip-on extensometers. In the present work, this has been quantified through a numerical study for three different strain gauges. In addition, a significant effect of a thin polymer coating or biaxial layer in the erroneous using strain gauges has been observed. An erroneous which can be significantly decreased using an enhanced grid design of the measuring grid.
Generation of non-overlapping fiber architecture

Numerical models generating actual fiber architecture by including parameters such as the fiber geometry and arrangement are a powerful tool to explore the relation between the fiber architecture and mechanical properties. The generation of virtual architectures of fibrous materials is the first step toward the computation of their physical properties. In this work, a realistic 3D model is developed to describe the architecture of a complex fiber structure. The domain application of the model could include natural fibers composites, wood fibers materials, papers, mineral and steel wools and polymer networks. The model takes into account the complex geometry of the fiber arrangement in which a fiber can be modeled with a certain degree of bending while keeping a main fiber orientation. The model is built in two steps. First, fibers are generated as a chain of overlapping spheres or as a chain of overlapping sphero-cylinders. At the end of the first step, a system of overlapping fibers is obtained. In order to obtain a hard-core configuration where fibers cannot overlap other fibers, we use an iterative method called the force-biased algorithm. It applies virtual forces on each point of the fiber: a repulsion force to suppress the overlap between two fibers and a bending and stretching force to ensure that the fiber structure is kept unchanged. The model can be used as the geometrical basis for further finite-element modelling.

Identification of true microstructure of composites based on various flax fibre assemblies by means of three-dimensional tomography

Lately it has been demonstrated that natural fibres may be an environmentally superior alternative for, e.g., glass fibres. In order to estimate properties of composite materials made of natural fibres, models designed for synthetic fibres are often used. The models usually do not account for irregularities in the material, e.g., suboptimal fibre orientation due to the twisting angle of fibres in yarns. Use of models without taking those features into account might lead to unreliable results. Methods to quantify the microstructural properties of natural fibre composites with X-ray microtomography and three-dimensional image analysis are demonstrated in this work. The methods are applied to flax fibre composites made from three different kinds of pre-forms. Microstructural parameters estimated with the methods are used in micromechanical models for the stiffness of the composite. Comparison between rule-of-mixtures and classical laminate theory is made, highlighting the requirement for accurate parameter estimation and use of a model that accounts for significant structural features of the material.
Impact of non-hookean behaviour on mechanical performance of hybrid composites

Hybrid composites, based on unidirectional fibres of carbon and glass, in an epoxy matrix have been used to investigate the possibility of a hybrid effect. The hybrid effect is observed experimentally by values for both composite strength and composite failure strain, which are increased compared to a simple model. The introduction of an increase of the failure strain of the carbon fibre part (the "fibre") of the composite, described by a factor $H$ for the increase of the failure strain, results in theoretical curves for strength and failure strain, which are in general agreement with the experimental data. For the present hybrid composites a value of $H = .22$ is required, meaning a positive hybrid effect on "fibre" strain of 22%. It is thus concluded that the simple concept of a hybrid factor $H$ for the fibre failure strain can describe the observed hybrid effect satisfactorily.

General information
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Carbon fibres, Glass fibres, Hybrid composites, Stress strain curves, Modelling
Electronic versions:

Low temperature annealing of cold-drawn pearlitic steel wire

Cold-drawn pearlitic steel wires are nanostructured and the flow stress at room temperature can reach values above 6 GPa. A typical characteristic of the nanostructured metals, is the low ductility and thermal stability. In order to optimize both the processing and application of the wires, the thermal behaviour is of interest. This has been studied by annealing the wires for 1h at temperatures from ambient temperature to 300 °C (573 K). It is expected that a raising temperature may lead to structural changes and a reduction in strength. The change in strength is however not expected to be large. For this reason we have applied a very precise technique to measure the tensile properties of the wires from a strain of 10-4 to the maximum strain of about 1-2%. The structural changes have also been followed to estimate and relate strength changes to changes in structural parameters and morphology.

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Organisations: Department of Wind Energy, Materials science and characterization, Composites and Materials Mechanics
Authors: Zhang, X. (Intern), Bech, J. I. (Intern), Hansen, N. (Intern)
Number of pages: 8
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Main Research Area: Technical/natural sciences
Publication information
Journal: I O P Conference Series: Materials Science and Engineering
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BFI (2018): BFI-level 1
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Scopus rating (2016): CiteScore 0.39 SJR 0.187 SNIP 0.499
Web of Science (2016): Indexed yes
Measurements of 3D slip velocities and plasma column lengths of a gliding arc discharge

A non-thermal gliding arc discharge was generated at atmospheric pressure in an air flow. The dynamics of the plasma column and tracer particles were recorded using two synchronized high-speed cameras. Whereas the data analysis for such systems has previously been performed in 2D (analyzing the single camera image), we provide here a 3D data analysis that includes 3D reconstructions of the plasma column and 3D particle tracking velocimetry based on discrete tomography methods. The 3D analysis, in particular, the determination of the 3D slip velocity between the plasma column and the gas flow, gives more realistic insight into the convection cooling process. Additionally, with the determination of the 3D slip velocity and the 3D length of the plasma column, we give more accurate estimates for the drag force, the electric field strength, the power per unit length, and the radius of the conducting zone of the plasma column. © 2015 AIP Publishing LLC.
Mechanical Characterization and Fractography of Glass Fiber/Polyamide (PA6) Composites
The mechanical properties of the glass fiber reinforced Polyamide (PA6) composites made by prepreg tapes and commingled yarns were studied by in-plane compression, short-beam shear, and flexural tests. The composites were fabricated with different fiber volume contents (prepregs—47%, 55%, 60%, and commingled—48%, 48%, 49%, respectively) by using vacuum consolidation technique. To evaluate laminate quality in terms of fiber wet-out at filament level, homogeneity of fiber/matrix distribution, and matrix/fiber bonding standard microscopic methods like optical microscopy and scanning electron microscopy (SEM) were used. Both commingled and prepreg glass fiber/PA6 composites (with Vf ~ 48%) give mechanical properties such as compression strength (530–570 MPa), inter-laminar shear strength (70–80 MPa), and transverse strength (80–90 MPa). By increasing small percentage in the fiber content show significant rise in compression strength, slight decrease in the ILSS and transverse strengths, whereas semipreg give very poor properties with the slight increase in fiber content. Overall comparison of mechanical properties indicates commingled glass fiber/PA6 composite shows much better performance compared with prepregs due to uniform distribution of fiber and matrix, better meltimpregnation while processing, perfect alignment of glass fibers in the composite. This study proves again that the presence of voids and poor interface bonding between matrix/fiber leads to decrease in the mechanical properties. Fractographic characterization of postfailure surfaces reveals information about the cause and sequence of failure. © 2014 Society of Plastics Engineers

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Aalborg University, Comfil ApS
Authors: Raghavalu Thirumalai, D. P. (Intern), Pillai, S. (Ekstern), Charca, S. (Ekstern), Oshkovr, S. A. (Ekstern), Knudsen, H. (Ekstern), Legstrup Andersen, T. (Intern), Bech, J. I. (Intern), Thybo Thomsen, O. (Ekstern), Lilholt, H. (Intern)
Number of pages: 20
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Main Research Area: Technical/natural sciences

Publication information
Journal: Polymer Composites
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BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.562 SNIP 0.887 CiteScore 1.88
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.593 SNIP 0.811 CiteScore 1.7
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.624 SNIP 0.955 CiteScore 1.58
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.654 SNIP 1.053 CiteScore 1.58
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.684 SNIP 1.025 CiteScore 1.56
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.571 SNIP 0.992 CiteScore 1.4
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.541 SNIP 0.764
Micromechanical Investigation of Fatigue Damage in Uni-Directional Fibre Composites

In this study, 3D x-ray computed tomography (XCT) is used to study fatigue damage mechanisms of a uni-directional (UD) glass fibre composite used in wind turbine blades. The challenges related to using 3D XCT for fatigue damage assessment over time is outlined, and a cut-out of a specimen previously subjected to tension-tension fatigue loading is examined. Broken UD load-carrying fibres are observed locally close to the thin off-axis backing support layers and are spreading out in a local damage zone in the UD bundle close to the backing. The common factors of the fatigue damaged regions found in this study were intertwining backing bundles in direct contact with the UD bundle and a locally high fibre volume fraction at the backing. Other factors like fibre misalignment and fibre radii could have an effect; however this is not obvious from the obtained results. Further studies on a larger dataset should be performed to examine this in more detail.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, LM Wind Power
Authors: Jespersen, K. M. (Intern), Zangenberg Hansen, J. (Ekstern), Mikkelsen, L. P. (Intern)
Number of pages: 10
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Title of host publication: Proceedings of 6th International Conference on Fatigue of Composite
Main Research Area: Technical/natural sciences
Electronic versions:
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Projects:
Micromechanical Investigation of Fatigue Damage in Uni-Directional Fibre Composites
Micromechanical Investigation of Fatigue Damage in Uni-Directional Fibre Composites
Source: PublicationPreSubmission
Source-ID: 108625214
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

Micromechanical modelling of nanocrystalline and ultrafine grained metals: A short overview
An overview of micromechanical models of strength and deformation behaviour of nanostructured and ultrafine grained metallic materials is presented. Composite models of nanomaterials, polycrystal plasticity based models, grain boundary sliding, the effect of non-equilibrium grain boundaries and nanoscale properties are discussed and compared. The examples of incorporation of peculiar nanocrystalline effects (like large content of amorphous or semi-amorphous grain boundary phase, partial dislocation GB emission/glide/GB absorption based deformation mechanism, diffusion deformation, etc.) into the continuum mechanical approach are given. The possibilities of using micromechanical models to explore the ways of the improving the properties of nanocrystalline materials by modifying their structures (e.g.,
dispersion strengthening, creating non-equilibrium grain boundaries, varying the grain size distributions and gradients) are discussed.

**General information**
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, National University of Science and Technology MISIS
Authors: Mishnaevsky, L. (Intern), Levashov, E. (Ekstern)
Pages: 365-373
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Main Research Area: Technical/natural sciences

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Journal: Computational Materials Science
Volume: 96
ISSN (Print): 0927-0256
Ratings:
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Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.37 SJR 0.926 SNIP 1.259
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.993 SNIP 1.348 CiteScore 2.3
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.129 SNIP 1.677 CiteScore 2.47
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.965 SNIP 1.337 CiteScore 2.15
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.022 SNIP 1.647 CiteScore 2.14
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.996 SNIP 1.46 CiteScore 1.97
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.961 SNIP 1.257
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 0.978 SNIP 1.308
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.919 SNIP 1.3
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.682 SNIP 1.029
Scopus rating (2006): SJR 0.852 SNIP 1.474
Scopus rating (2005): SJR 1.161 SNIP 1.327
Scopus rating (2004): SJR 0.915 SNIP 1.06
Scopus rating (2003): SJR 0.61 SNIP 0.775
Micromechanical Time-Lapse X-ray CT Study of Fatigue Damage in Uni-Directional Fibre Composites

This study considers fatigue damage evolution in a uni-directional (UD) glass fibre composite used for wind turbine blades which is manufactured from a non-crimp fabric. It is the initial part of a time-lapse study where the damage progression is followed in a sample during a fatigue test. In the current study 3D X-ray Computed Tomography (XCT) is used to characterise the fatigue damage in the material at three different stages of the fatigue life of a tension-tension fatigue test. 3D XCT is performed on rectangular samples (4x4x110mm) cut out from pre-fatigued full-size fatigue test specimens. The geometry of the cut-out is similar to that which will be used in the time-lapse study.

As the micro-mechanical damage mechanisms are small features, it is necessary to obtain a high scan resolution which sets a limit to how large the field of view can be. Therefore, it is necessary to perform several scans on each sample to locate damaged regions even for the cut out sample geometry. For the chosen down-scaled sample geometry it was possible to visualize individual broken UD fibres, matrix cracks, and delaminations in the scans. Broken UD fibres are observed locally close to intertwining regions of the supporting backing bundles where they are in direct contact with the UD bundles. Additionally matrix cracks are observed in the off-axis backing layer at locations where the UD fibres are broken.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Manchester, LM Wind Power
Authors: Jespersen, K. M. (Intern), Lowe, T. (Ekstern), Withers, P. J. (Ekstern), Zangenberg Hansen, J. (Ekstern), Mikkelsen, L. P. (Intern)
Number of pages: 9
Publication date: 2015

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Publisher: ICCM20 Secretariat
Main Research Area: Technical/natural sciences
Conference: 20th International Conference on Composite Materials (ICCM20), Copenhagen, Denmark, 19/07/2015 - 19/07/2015
Electronic versions: ICCMPaper_KMUN_Final.pdf

Relations
Projects:
Micromechanical Time-Lapse X-ray CT Study of Fatigue Damage in Uni-Directional Fibre Composites
Micromechanical Time-Lapse X-ray CT Study of Fatigue Damage in Uni-Directional Fibre Composites
Source: PublicationPreSubmission
Source-ID: 112442210
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

Micro-Scale Experiments and Models for Composite Materials with Materials Research
Numerical models are frequently implemented to study micro-mechanical processes in polymer/fibre composites. To ensure that these models are accurate, the length scale dependent properties of the fibre and polymer matrix have to be taken into account. Most often this is not the case, and material properties acquired at macro-scale are used for micro-mechanical models. This is because material properties at the macro-scale are much more available and the test procedures to obtain them are well defined. The aim of this research was to find methods to extract the micro-mechanical
properties of the epoxy resin used in polymer/fibre composites for wind turbine blades combining experimental, numerical, and analytical approaches. Experimentally, in order to mimic the stress state created by a void in a bulk material, test samples with finite root radii were made and subjected to a double cantilever beam test in an environmental scanning electron microscope. Deformation around the notches was measured using a digital image correlation method. Analytically, the experimental results were related to the HRR theory, and the concept of strain energy density was used to find the micro-scale stress-strain relationship and failure strength. In the numerical approach, the experimentally measured strain fields were matched with the numerically predicted strain fields for different power law hardening material models. In addition, this study includes evaluation of the strain gauge accuracy, when devices are applied on polymer and polymer/composite materials.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Mechanical Engineering
Authors: Zike, S. (Intern), Mikkelsen, L. P. (Intern), Sørensen, B. F. (Intern), Tvergaard, V. (Intern)
Number of pages: 152
Publication date: 2015

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Main Research Area: Technical/natural sciences
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Electronic versions:
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Projects:
Micro-Scale Experiments and Models for Composite Materials with Materials Research
Publication: Research › Ph.D. thesis – Annual report year: 2015

Modelling Compression of Uni-Directional Composite Materials

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Technical University of Denmark
Authors: Mikkelsen, L. P. (Intern), Koutsos, S. T. (Ekstern)
Number of pages: 2
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Modelling_Compression.pdf

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Extended abstract
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Source-ID: 118027373
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Modelling of Micro-structure from 3D X-ray CT of Fiber Composite

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Modelling the double cantilever beam test with bending moments by using bilinear discontinuous cohesive laws

A theoretical model of the double cantilever beam tests with bending moments (DCB-UBM) is presented. The specimen is modelled as the assemblage of two laminated beams connected by a cohesive interface. It is assumed that the traction-separation laws – i.e. the relationships between the interfacial stresses and relative displacements – are described by bilinear discontinuous functions. An analytical solution for pure modes I and II is determined by solving the related differential problem. Furthermore, analysis based on the path-independent J integral is carried out. Formulas are given to determine the cohesive law parameters from experiments. Experimental tests have been conducted on glass fibre reinforced specimens under pure mode I and II loading conditions. The predictions of the theoretical model turn out to be in very good agreement with the experimental results.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, University of Pisa
Authors: Valvo, P. S. (Ekstern), Sørensen, B. F. (Intern), Toftegaard, H. L. (Intern)
Number of pages: 11
Publication date: 2015

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Title of host publication: Proceedings of the 20th International Conference on Composite Materials
Publisher: ICCM20 Secretariat
Main Research Area: Technical/natural sciences
Conference: 20th International Conference on Composite Materials (ICCM20), Copenhagen, Denmark, 19/07/2015 - 19/07/2015
Composite delamination, Cohesive law, Double cantilever beam test, Analytical solution, Experimental testing
Electronic versions:
Paper
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

Nanostructured interfaces for enhancing mechanical properties of composites: Computational micromechanical studies

Computational micromechanical studies of the effect of nanostructuring and nanoengineering of interfaces, phase and grain boundaries of materials on the mechanical properties and strength of materials and the potential of interface nanostructuring to enhance the materials properties are reviewed. Several groups of materials (composites, nanocomposites, nanocrystalline metals, wood) are considered with view on the effect of nanostructured interfaces on their properties. The structures of various nanostructured interfaces (protein structures and mineral bridges in biopolymers in nacre and microfibrils in wood; pores, interphases and nanoparticles in fiber/matrix interfaces of polymer fiber reinforced composites and nanocomposites; dislocations and precipitates in grain boundaries of nanocrystalline metals) and the methods of their modeling are discussed. It is concluded that nanostructuring of interfaces and phase boundaries is a powerful tool for controlling the material deformation and strength behavior, and allows to enhance the mechanical properties and strength of the materials. Heterogeneous interfaces, with low stiffness leading to the localization of deformation, and nanoreinforcements oriented normally to the main reinforcing elements can ensure the highest damage resistance of materials.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mishnaevsky, L. (Intern)
Pages: 75-84
Publication date: 2015
Non-destructive automatic determination of aspect ratio and cross-sectional properties of fibres

A novel method for computerised estimation of the aspect ratio distribution and various cross-sectional geometrical properties of fibres in short-fibre reinforced composites is proposed. The method, based on X-ray micro-computed tomography, is non-destructive and does not require user intervention. Based on results on specially fabricated model material, the accuracy and precision of the method seems adequate. The method is applied in analysing a manufacturing process of wood fibre reinforced thermoplastic composite. The results indicate a significant decrease of the aspect ratio of fibres during the processing steps. Finally, the feasibility of the method is assessed by estimating parameters of a micromechanical model for flax fibre composites and comparing the results with those from tensile tests. © 2015 Elsevier Ltd. All rights reserved.
Observation of gliding arc surface treatment

An alternating current (AC) gliding arc can be conveniently operated at atmospheric pressure and efficiently elongated into the ambient air by an air flow and thus is useful for surface modification. A high speed camera was used to capture dynamics of the AC gliding arc in the presence of polymer surfaces. A gap was observed between the polymer surface and the luminous region of the plasma column, indicating the existence of a gas boundary layer. The thickness of the gas boundary layer is smaller at higher gas flow-rates or with ultrasonic irradiation to the AC gliding arc and the polymer surface. Water contact angle measurements indicate that the treatment uniformity improves significantly when the AC gliding arc is tilted to the polymer surface. Thickness reduction of the gas boundary layer, explaining the improvement of surface treatment, by the ultrasonic irradiation was directly observed for the first time.

General information

State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Physics, Plasma Physics and Fusion Energy, Lund University, Danish Technological Institute, FORCE Technology
Authors: Kusano, Y. (Intern), Zhu, J. (Ekstern), Ehn, A. (Ekstern), Li, Z. (Ekstern), Aldén, M. (Ekstern), Salewski, M. (Intern), Leipold, F. (Intern), Bardenshtein, A. (Ekstern), Krebs, N. (Ekstern)
Pages: 282-288
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information
Journal: Surface Engineering
Online Monitoring of Composite Overwrapped Pressure Vessels (COPV)

Composite overwrapped pressure vessels (COPV) have been increasingly pointed to as the most effective solution for high pressure storage of liquid and gaseous fluids. Reasonably high stiffness-to-weight ratios make them suitable for both static and mobile applications. However, higher operating pressures are sought continuously, to get higher energy densities in such storage systems, and safety aspects become critical. Thus, reliable design and test procedures are required to reduce the risks of undesired and unpredicted failures. An in-service health monitoring system may contribute to a better product development, design and optimization, as well as to minimize the risks and improve the public acceptance. Within the scope of developing different COPV models for a wide range of operating pressures and applications, optical fiber Bragg grating (FBG) sensors were embedded in the liner-composite and composite-composite interfaces during their manufacturing processes. The idea is to allow the online strain monitoring during preliminary testing and service-life. The ability of these measuring systems to effectively assess the strain fields has been investigated. Simultaneously, a finite element analysis (FEA) was made using the ABAQUS® platform. In this numerical analysis, accurate and realistic simulation of the different materials, geometry and loading conditions was approached. Particularly, the anisotropic nature of the wound laminate and the varying orientation of the fibers were attained. However, the cohesive zones were not attributed independent properties. Comparison between experimental and numerical data was addressed. In general, although the experimental-numerical data agreement was not as good as desired, a preliminary insight to both the structural health monitoring (SHM) system and the numerical modeling approaches was actually achieved. Full characterization and validation shall be further addressed in the continuation of the present work.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Instituto de Engenharia Mecânica e Gestão Industrial, Universidade do Porto
Authors: Pereira, G. F. (Intern), Figueiredo, J. (Ekstern), Faria, H. (Ekstern), Marques, A. T. (Ekstern)
Number of pages: 10
Publication date: 2015

Signal-based nonlinear modelling for damage assessment under variable temperature conditions by means of acousto-ultrasonics

Damage assessment can be considered as the main task within the context of structural health monitoring (SHM) systems. This task is not only confined to the detection of damages in its basic algorithms but also in the generation of early warnings to prevent possible catastrophes in the daily use of the structures ensuring their proper functioning. Changes in environmental and operational conditions (EOC), in particularly temperature, affect the performance of SHM systems that constitutes a great limitation for their implementation in real world applications. This paper describes a health monitoring methodology combining the advantages of guided ultrasonic waves together with the compensation for temperature effects and the extraction of defect-sensitive features for the purpose of carrying out a nonlinear multivariate diagnosis of damage. Two well-known methods to compensate the temperature effects, namely optimal baseline selection and optimal signal stretch, are investigated within the proposed methodology where the performance is assessed using receiver operating characteristic curves. The methodology is experimentally tested in a pipeline. Results show that the methodology is a robust practical solution to compensate the temperature effects for the damage detection task. Copyright (c) 2015 John Wiley & Sons, Ltd.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics, MAN Diesel & Turbo SE, Universidad Pontificia Bolivariana, Universidad Santo Tomas, Polytechnic University of Catalonia, University of Siegen
Authors: Torres-Arredondo, M. -. (Ekstern), Sierra-Perez, J. (Ekstern), Tibaduiza, D. -. (Ekstern), McGugan, M. (Intern), Rodellar, J. (Ekstern), Fritzén, C. -. (Ekstern)
Number of pages: 16
Pages: 1103-1118
Publication date: 2015
Small scale plasticity and compressive properties of composites

The compression strength of uni-directional composite materials is mainly governed by the fiber-misalignment and the plasticity of the matrix material [1]. Therefore, in order to improve the compression behavior of uni-directional composite materials, a focus on those terms is necessary. In the present work, the influence of the mechanical properties of the matrix material on the compression strength is studied by changing the temperature during mechanical testing and thereby making it possible changing the matrix properties keeping all other properties in the experimental setup constant. It is demonstrated how going from the more ductile high temperature case to the brittle low temperature case will increase the compression strength significantly with more than 30%. This behavior are validated experimentally as well as numerically using a non-linear smeared out composite material law [2] implemented in the commercial finite element code Abaqus [3]. In addition, in a supplementary study, taken into account the length scale effect of the yielding behavior using a strain
gradient dependent plasticity law [4] implemented as a user element [5], it is possible investigating the scale effect on the
yielding behavior sub-micron small region between the fibers in a conventional composite material. During this, the effect
of higher order boundary condition suppressing the plastic deformation at the fiber/matrix interfaces is analyzed. It is
demonstrated that taken such effects into account significantly enhanced the stresses level during shear deformation.
Shear deformation governing the compressive failure mechanism in uni-directional composite materials.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern)
Publication date: 2015
Event: Abstract from International Symposium on Nanoengineered Composites, Roskilde, Denmark.
Main Research Area: Technical/natural sciences

Strength of cellulosic fiber/starch acetate composites with variable fiber and plasticizer content
In this experimental study, the performance of injection-molded short flax and hemp fibers in plasticized starch acetate
were analyzed in terms of strength. Parameters involved in the analysis are a variable fiber and plasticizer content. The
measured strength of the composites varies in the range of 12–51 MPa for flax fibers and 11–42 MPa for hemp fibers,
which is significantly higher than the properties of the unreinforced starch acetate matrix. The micro-structural parameters
used in modeling of composite strength were obtained from optical observations and indirect measurements. Some of
these parameters were qualitatively verified by X-ray microtomography.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Lulea University of Technology, VTT -
Technical Research Centre of Finland, University of Jyväskylä
Authors: Joffe, R. (Ekstern), Madsen, B. (Intern), Nättinen, K. (Ekstern), Miettinen, A. (Ekstern)
Pages: 1007–1017
Publication date: 2015
Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed Yes
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Scopus rating (2016): CiteScore 1.42 SJR 0.517 SNIP 0.781
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.586 SNIP 0.88 CiteScore 1.4
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.606 SNIP 1.183 CiteScore 1.44
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.624 SNIP 1.207 CiteScore 1.45
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.607 SNIP 1.26 CiteScore 1.21
Structural Design of the DTU-ESA MM-Wave Validation Standard Antenna

A new specially designed antenna to be used for inter-comparisons and validation of antenna test facilities is under development in cooperation between DTU and TICRA under a contract from the European Space Agency. The antenna is designed to be extremely thermally and mechanically stable in the range of temperatures 20±5°C under arbitrary orientation in the gravity field. The antenna has a characteristic length of approximately 500mm. And in order to obtain very low measuring error, the allowable deformations of the reflector and feeds are down to 2.5μm.

The antenna is modelled structurally using the commercial finite element package MSC.Patran with MSC.MARC as solver. The solid parts of the antenna are meshed with 10-noded tetrahedral elements, which have quadratic shape functions and the entire model has approximately 325,000 elements. The individual solid part of the antenna is connected via a glued contact formulation in MSC.MARC. Because of the size and the complexity of the model a computer cluster is applied to solve the analyses.

This paper describes the structural solution to meet these extremely strict stability requirements and the structural analyses done in order to verify that they can be met. The paper also discusses the challenges of integrating an aluminum feed cluster with high thermal expansion coefficient in a CFRP support frame with very low thermal expansion coefficient.

General information
State: Published
Organisations: Department of Wind Energy, Wind Turbines, Composites and Materials Mechanics, Department of Electrical Engineering, Electromagnetic Systems, TICRA
Authors: Branner, K. (Intern), Berring, P. (Intern), Markussen, C. M. (Intern), Kim, O. S. (Intern), Jørgensen, R. (Ekstern), Pivnenko, S. (Intern), Breinbjerg, O. (Intern)
Number of pages: 10
Publication date: 2015

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Publisher: ICCM20 Secretariat
Main Research Area: Technical/natural sciences
Conference: 20th International Conference on Composite Materials (ICCM20), Copenhagen, Denmark, 19/07/2015 - 19/07/2015
Structural health monitoring method for wind turbine trailing edge: Crack growth detection using Fibre Bragg Grating sensor embedded in composite materials

In this article a novel method to assess a crack growing/damage event in composite material using Fibre Bragg Grating (FBG) sensors embedded in a host material and its application into a composite material structure, Wind Turbine Trailing Edge, is presented.

A Structure-Material-FBG model was developed, which simulates the FBG sensor output response, when embedded in a host material, during a crack growing/damage event. This Structure-Material-FBG model provides a tool to analyse the application of this monitoring technique in other locations/structures, by predicting the sensor output and deciding, based on this, the optimal sensor distribution/configuration.

All the different features in the fracture (cracking) mechanism that can induce a change in the FBG response were identified. With this, it was possible to identify specific phenomenon that will only happen in the proximity of a crack, such as compression fields ahead the crack or non-uniform strain fields, and then identify the presence of such damage in the structure. Experimental tests were conducted to fully characterize this concept and support the model. Double Cantilever Beams (DCB), made with two glass fibre beams glued with structural adhesive, were instrumented with one array of FBG sensors embedded into the host material, and digital image correlation technique was used to determine the presence of the specific phenomena caused by the crack, and to correlate with the FBG sensor.

Testing of a new morphing trailing edge flap system on a novel outdoor rotating test rig

The morphing trailing edge system or flap system, CRTEF, has been developed over the last 10 years at DTU Wind Energy. After a promising wind tunnel test of the system in 2009 the INDUFLAP project has been carried out from 2011-2014 to transfer the technology from laboratory to industrial manufacturing and application. To narrow the gap between wind tunnel testing and full scale prototype testing we developed the rotating test rig. The overall objectives with the rotating test rig are: 1) to test the flap system in a realistic rotating environment with a realistic g-loading; 2) to measure the flap performance in real turbulent inflow and 3) to test the flap system in a realistic size and Reynolds number when comparing with full scale applications. The rotating test rig consists of a 2.2m blade section attached to a 10m boom and mounted on a 100kW turbine platform. It was installed in June 2014 and a short measurement campaign was conducted in the autumn 2014. An important result of testing the flap system on the rotating test rig was operation of the flap system up to 30 rpm. which a g-loading of 9-10g comparable with the conditions on a 2-3MW turbine. Another important result was the measured performance of the flap system. We found that about 5.0deg. flap angle gives the same load change as 1deg. pitch. This is somewhat lower than simulations have shown which are in the range of 2 to 3 deg. flap angle to 1deg. pitch angle for a 15% flap. The realistic, turbulent inflow is probably a major cause of this lower performance.

General information
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Authors: Pereira, G. F. (Intern), Mikkelsen, L. P. (Intern), McGugan, M. (Intern)
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Testing of a new morphing trailing edge flap system on a novel outdoor rotating test rig

General information
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Organisations: Department of Wind Energy, Aeroelastic Design, Composites and Materials Mechanics
Authors: Aagaard Madsen, H. (Intern), Barlas, A. (Intern), Løgstrup Andersen, T. (Intern)
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

Testing temperature on interfacial shear strength measurements of epoxy resins at different mixing ratios

The interfacial properties as Interfacial Shear Stress (IFSS) in fibre reinforced polymers are essential for further understanding of the mechanical properties of the composite. In this work a single fibre testing method is used in combination with an epoxy matrix made from Araldite 506 epoxy resin and triethylenetetramine (TETA) hardener. The IFSS was measured by a microbond test developed for a Thermal Mechanical Analyzer. The preliminary results indicate that IFSS has an inverse dependency of both testing temperature and the mixing ratio of hardener and epoxy resin. Especially interesting was the decreasing dependency of mixing ratio at higher temperature.

General information
State: Published
Organisations: Department of Micro- and Nanotechnology, Amphiphilic Polymers in Biological Sensing, Department of Wind Energy, Composites and Materials Mechanics, University of Strathclyde
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Interfacial shear strength, Microbond test, Adhesion, Epoxy resin
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Paper
Publication: Research - peer-review › Article in proceedings – Annual report year: 2015

The application of J integral to measure cohesive laws in materials undergoing large scale yielding

We explore the possibility of determining cohesive laws by the J-integral approach for materials having non-linear stress-strain behaviour (e.g. polymers and composites) by the use of a DCB sandwich specimen, consisting of stiff elastic beams bonded to the non-linear test material, loaded with pure bending moments. For a wide range of parameters of the non-linear material, the plastic unloading during crack extension is small, resulting in J integral values (fracture resistance) that deviate maximum 15% from the work of the cohesive traction. Thus the method can be used to extract the cohesive laws directly from experiments without any presumption about their shape. Finally, the DCB sandwich specimen was also
analysed using the I integral to quantify the overestimation of the steady-state fracture resistance obtained using the J integral based method.

**General information**
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Sørensen, B. F. (Intern), Goutianos, S. (Intern)
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Fracture mechanics testing, Delamination, J integral, Non-linear stress-strain
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**The DTU-ESA Millimeter-Wave Validation Standard Antenna – Manufacturing and Testing**
A new precision tool for antenna test range qualification and inter-comparisons at mm-waves – the mm-VAST antenna – is under development at the Technical University of Denmark (DTU) in collaboration with TICRA under a European Space Agency (ESA) contract. The DTU-ESA mm-VAST antenna will facilitate accurate measurements of the next generation satellite communication antennas at K-, Ka-, Q-, and V-bands. The development is focused in particular on the mechanical and temperature stability of the antenna under various operational conditions. In this contribution, we present the details of the antenna mechanical design, fabrication and assembling procedures. The performance verification test plan as well as first measurement results are also discussed.

**General information**
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Organisations: Department of Electrical Engineering, Electromagnetic Systems, Department of Wind Energy, Wind Turbines, Composites and Materials Mechanics
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Source: PublicationPreSubmission
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**The Elastocaloric Effect: A Way to Cool Efficiently**

**General information**
State: Published
Organisations: Department of Energy Conversion and Storage, Electrofunctional materials, Department of Wind Energy, Composites and Materials Mechanics, Universitat de Barcelona
Authors: Tusek, J. (Intern), Engelbrecht, K. (Intern), Millán-Solsona, R. (Ekstern), Mañosa, L. (Ekstern), Vives, E. (Ekstern), Mikkelsen, L. P. (Intern), Pryds, N. (Intern)
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Thermoset composite recycling: Properties of recovered glass fiber

Recycling of glass fiber thermoset polymer composite is a challenging topic and a process able to recover the glass fibers original properties in a limited cost is still under investigation. This paper focuses on the recycling technique separating the glass fiber from the matrix material. Four different recycling processes, mechanical, burn off, pyrolysis and glycolysis are selected are compared based on the properties of the glass fiber recovered. The intention is to use the same characterization methodology.

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State: Published
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Very large wind turbine rotor blades require damage tolerance and damage monitoring

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Wind Turbines
Authors: Sørensen, B. F. (Intern), Toftegaard, H. L. (Intern), McGugan, M. (Intern), Pereira, G. F. (Intern), Branner, K. (Intern)
Number of pages: 1
Volumetric composition and shear strength evaluation of pultruded hybrid kenaf/glass fiber composites

In the present study, six different combinations of pultruded hybrid kenaf/glass composites were fabricated. The number of kenaf and glass rovings was specifically selected to ensure constant local fiber volume fractions in the composites. The volumetric composition of the composites was determined by using a gravimetrically based method. Optical microscopy was used to determine the location of voids. The short-beam test method was used to determine the interlaminar shear strength of the composites, and the failure mode was observed. It was found that the void volume fraction of the composites was increased as a function of the kenaf fiber volume fraction. A linear relationship with high correlation ($R^2 = 0.95$) was established between the two volume fractions. Three types of voids were observed in the core region of the composites (lumen voids, interface voids and impregnation voids). The failure of the samples started with horizontal shear cracks that propagated into the core region, and ultimately the samples failed by a vertical crack. The interlaminar shear strength was found to decrease as a function of the hybrid fiber mixing ratio.
Volumetric composition of nanocomposites

Detailed characterisation of the properties of composite materials with nanoscale fibres is central for the further progress in optimization of their manufacturing and properties. In the present study, a methodology for the determination and analysis of the volumetric composition of nanocomposites is presented, using cellulose/epoxy and aluminosilicate/polylactate nanocomposites as case materials. The buoyancy method is used for the accurate measurements of materials density. The accuracy of the method is determined to be high, allowing the measured nanocomposite densities to be reported with 5 significant figures. The plotting of the measured nanocomposite density as a function of the nanofibre weight content is shown to be a first good approach of assessing the porosity content of the materials. The known gravimetric composition of the nanocomposites is converted into a volumetric composition. An analytical model, previously established for conventional fibre composites, is used for the analysis of the volumetric composition. For the aluminosilicate/polylactate nanocomposites, based on the established linear relationship between the porosity content and the fibre volume content, the fibre correlated porosity factor is determined to be 0.18. Geometrical considerations of the packing of parallel nanofibres in a square array are used to make the assumption that the maximum obtainable fibre volume content in the nanocomposites will not exceed 6 % due to the small fibre spacing that restricts full matrix impregnation. The predicted volumetric composition and density of the aluminosilicate/polylactate nanocomposites is in good agreement with the experimental data. It is demonstrated that the model provides a valuable tool for the prediction and analysis of the volumetric composition of composites with nanoscale fibres.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, VTT - Technical Research Centre of Finland, Monash University Malaysia
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Density, Fibre content, Void content, Fibre packing
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A real-structure based 3-D micromechanical computational model of poly (lactic acid) nanocomposites reinforced by randomly oriented halloysite nanotubes (HNTs) was developed and compared with an idealized model (conventional model) and experimental results. The developed idealized model consists of nanotubes with fixed aspect ratio and the proposed alternative real-structure based model takes the experimentally observed variations of HNTs sizes, impurities and aspect ratios into account. The requirements of the 3-D HNTs nanocomposite models have been explored by testing idealized, real structure based models, as well as models with hollow and solid cylinder-like reinforcements with varied amounts of HNTs. A unit cell model with cylindrical reinforcements (representing HNTs) and at least 30 inclusions gave promising results, provided the model includes actual information about HNTs size ranges and aspect ratios. Numerical studies were validated with experimental investigations and the developed real-structure based model gave more accurate results than idealized and analytical models. (C) 2014 Elsevier Ltd. All rights reserved.
3D X-Ray Computed Tomography (XCT) of Fatigue Damage Evolution in UD Glass Fibre Composite

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Jespersen, K. M. (Intern), Lowe, T. (Ekstern), Withers, P. (Ekstern), Mikkelsen, L. P. (Intern)
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Main Research Area: Technical/natural sciences
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Relations
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DTU Energy Conversion 2nd International PhD Summer School
Projects:
3D X-Ray Computed Tomography (XCT) of Fatigue Damage Evolution in UD Glass Fibre Composite
Publication: Research › Poster – Annual report year: 2014

A Critical Review of Future Materials for Wind Turbine Blades
Wind turbine industry is continuously evaluating materials systems to replace the current thermoset composite technologies. Since turbine blades are the key component in the wind turbines and the size of the blade is increasing in todays wind design, the materials selection has become crucial focusing several factors like less weight, less price, higher performance, longer life, ease of processing, and capability of recycling. In the present market scenario, wind industry needs to improve their business for onshore and for off-shore applications demonstrating the new blade designs and stating higher performance under severe environmental conditions. The current article reviews various materials alternatives and demonstrates the advantages and disadvantages for future wind turbine blade developments.
A J integral based method to measure fracture resistance and cohesive laws in materials exhibiting large scale plasticity

A method is developed to extract the fracture resistance and mode I cohesive law of nonlinear elastic-plastic materials using a Double Cantilever Beam (DCB) sandwich specimen loaded with pure bending moments. The method is based on the J integral which is valid for materials having a non-linear stress-strain relationship as long as there is no unloading at any material point. A numerical parameter study is performed for a wide range of material and specimen parameters to examine the accuracy of the method. In the range examined, the error of the method is less than 11% and thus it can be used to measure the fracture resistance experimentally and determine the mode I cohesive law including its shape.
Analysis of glass fibre sizing

Glass fibre reinforced polymer composites are widely used for industrial and engineering applications which include construction, aerospace, automotive and wind energy industry. During the manufacturing glass fibres, they are surface-treated with an aqueous solution. This process and the treated surfaces are called sizing. The sizing influences the properties of the interface between fibres and a matrix, and subsequently affects mechanical properties of composites. In this work the sizing of commercially available glass fibres was analysed so as to study the composition and chemical structures. Soxhlet extraction was used to extract components of the sizing from the glass fibres. The glass fibres, their extracts and coated glass plates were analysed by Thermo-Gravimetric Analysis combined with a mass spectrometer (TGA-MS), and Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) spectroscopy. Commercially available silane coupling agents were also analysed by ATR-FTIR in order to identify components in the sizing. The results indicate that the analysed fibres have both bonded and physisorbed sizing, containing a film former and a coupling agent.

Are reactive thermoplastic polymers suitable for future wind turbine composite materials blades?

The present article reviews the potential use of reactive polymers for manufacturing of composite materials for a wind turbine blade. Composite industry attempts to use the benefits of processes like resin infusion for developing large structures. After careful review in the literature, it was found that only two potential reactive thermoplastic resin systems qualify for different processing requirements for blade manufacturing. Hence, the article focuses on the issues with the use of reactive polymers like APA-6 (Caprolactam) and CBT (Cyclic Butylene Terephthalate) resin systems for composite materials.
Atmospheric Pressure Plasma Processing for Polymer Adhesion: A Review

Atmospheric pressure plasma processing has attracted significant interests over decades due to its usefulness and a variety of applications. Adhesion improvement of polymer surfaces is among the most important applications of atmospheric pressure plasma treatment. Reflecting recent significant development of the atmospheric pressure plasma processing, this work presents its fundamental aspects, applications, and characterization techniques relevant to adhesion.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Kusano, Y. (Intern)
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Biaxial stretching of poly(L-lactide) tubes for improvement of mechanical properties

General information
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Organisations: Department of Micro- and Nanotechnology, Amphiphilic Polymers in Biological Sensing, Department of Energy Conversion and Storage, Imaging and Structural Analysis, Department of Wind Energy, Composites and Materials Mechanics, Mixed Conductors
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Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2014

Chemorheological study of a polyfurfuryl alcohol resinsystem — Pre-gel curing stage
The rheological and chemorheological behavior of a new biomass-based polyfurfuryl alcohol (FA) resinaimed to be used as a matrix in composite materials is studied in this work. The viscosity dependenceon the shear rate and temperature of the resin is studied under steady and oscillatory conditions. TheFA resin exhibits a Newtonian flow behavior within the shear rate range tested. The dependence of viscositoften cured resin on temperature is measured and modeled. The flow activation energy, as calculated by the Arrhenius model, is 63.3 kJ mol−1. The chemorheological study of the curing processshowed that the flow activation energy of the resin is increased when the amount of catalyst is increased.Furthermore, the curing parameters of the FA resin using three amounts of catalyst of 2, 4, and 6% (w/w),are obtained by the Arrhenius model. The curing activation energy is found to be about 96 kJ mol−1and with no dependence on the amount of catalyst. However, a significant difference of the logarithm of the pre-exponential curing parameter is found. This parameter increases from 28.9 to 30.7 when the amount of catalyst is increased from 2 to 6% (w/w). Based on the established values of the Arrheniusmodel parameters, predictions are made for the evolution of viscosity of the resin during isothermalcuring with different temperatures, and different amounts of catalyst. This is of great importance in the design of the curing processes of the FA resin during development and improvement of compositemanufacturing processes.© 2013 Elsevier B.V. All rights reserved.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Complutense University
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Composite recycling: Characterizing end of life wind turbine blade material

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Beauson, J. (Intern), Bech, J. I. (Intern), Brøndsted, P. (Intern)
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Consequence of reduced necrotic bone elastic modulus in a Perthes' hip

Introduction
Perthes is a destructive hip joint disorder characterized as a malformation of the femoral head which affects young children. Several studies have shown the change of mechanical properties of the femoral head in Perthes’ disease. However, the consequence of the changes in bone mechanical properties in a Perthes’ hip is not well established. Due to the material differences, changes in bone mechanical properties might lead to localization of stress and deformation. Thus, the objective of this study was to investigate the effects of reduced elastic modulus of necrotic bone in the femoral head using Finite Element Analysis (FEA).

Methods
The femoral and necrotic bone of the affected hip of a Perthes’ patient was segmented from the MR images using Simpleware. The segmented parts were exported to SolidWorks to build the 3D solid model and Comsol for FEA. A load of 750 N (300% body weight) was applied on the top of the femoral head. The distal part of the femur was fixed. The same Poisson’s ratio 0.3 was set for the femoral and necrotic bone. The elastic modulus (E) of femoral bone was 500 MPa. To investigate the effects of reduced elastic modulus, the necrotic bone E was reduced as 400 MPa, 100 MPa, 10 MPa and 1 MPa.

Results
The results show that the bone deformation markedly increased when the necrotic bone E was 1 MPa. The maximum displacements were 1.79 mm, 1.80 mm, 1.92 mm and 3.74 mm for E = 400 MPa, E = 100 MPa, E = 10 MPa and E = 1 MPa, respectively. The displacement patterns were uniformly distributed when the necrotic bone E was 400 MPa and 100 MPa. Conversely, the displacements were more localized (concentrated at the necrotic bone) when the necrotic bone E was 10 MPa and 1 MPa.

Conclusions
The deformation patterns of a Perthes’ hip reveals that the disease may be more aggravated due to localization of bone deformation as a result of reduction of the elastic modulus of necrotic bone. The method in this study may be useful in surgical planning.

Correction of Gauge Factor for Strain Gauges Used in Polymer Composite Testing
Strain gauges are used together with the corresponding gauge factor to relate the relative electrical resistance change of the strain gauge with the strain of the underlying material. The gauge factor is found from a calibration on a stiff material - steel. Nevertheless, the gauge factor depends on the stiffness of the calibration material and ideally the calibration should be done on a similar material as tested. In practice, the gauge factor found by the strain gauge manufacturer is often used. The paper documents that even for moderately stiff materials such as glass-fibre composites a significant error is found on the strain measurements obtained by the strain gauges. This is documented both experimentally and numerically. A stiffness, also test sample and strain gauge geometry dependent correction coefficient of the gauge factor is proposed. A correction coefficient covers material stiffnesses ranging from 1 GPa to 200 GPa.
Correction of Gauge Factor for Strain Gauges Used in Polymer Composite Testing

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Damage evolution under cyclic multiaxial stress state: A comparative analysis between glass/epoxy laminates and tubes

In this work an experimental investigation on damage initiation and evolution in laminates under cyclic loading is presented. The stacking sequence [0/θ2/0/-θ2]s has been adopted in order to investigate the influence of the local multiaxial stress state in the off-axis plies and the possible effect of different thickness between the thin (2-plies) and the thick (4-plies) layers. Results are presented in terms of S–N curves for the initiation of the first cracks, crack density evolution, stiffness degradation and Paris-like curves for the crack propagation phase. The values of the off-axis angle θ has been chosen in order to obtain local multiaxial stress states in the off-axis plies similar to those in previous studies for biaxially loaded tubes. Results concerning damage initiation and growth for these two specimen configurations are shown to be consistent for similar local multiaxial stress states.

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Scopus rating (2016): CiteScore 5.19 SJR 2.05 SNIP 2.294
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Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
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Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 1.38 SNIP 2.458 CiteScore 3.31
ISI indexed (2013): ISI indexed yes
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Scopus rating (2012): SJR 1.215 SNIP 2.128 CiteScore 2.58
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BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.105 SNIP 2.497 CiteScore 2.49
ISI indexed (2011): ISI indexed yes
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BFI (2009): BFI-level 2
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Scopus rating (2008): SJR 1.086 SNIP 1.7
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Damage tolerant design: failure and crack propagation in composites

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Pereira, G. F. (Intern), Mikkelsen, L. P. (Intern), McGugan, M. (Intern)
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Electronic versions:
Damage_tolerant_design.pdf
Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

Design and simulation of the rotating test rig in the INDUFALP project
The general description and objectives of the rotating test rig at the Risø campus of DTU are presented, as used for the aeroelastic testing of a controllable rubber trailing edge flap (CRTEF) system in the INDUFALP project. The design of all new components is presented, including the electrical drive, the pitch system, the boom, and the wing/flap section. The overall instrumentation of the components used for the aeroelastic testing is described. Moreover, the aeroelastic model simulating the setup is described, and predictions of steady and dynamic loading along with the aeroelastic analysis of the setup are documented. Finally, the measured structural dynamics of the rig setup are presented.

General information
State: Published
Organisations: Department of Wind Energy, Aeroelastic Design, Composites and Materials Mechanics
Authors: Barlas, T. K. (Intern), Aagaard Madsen , H. (Intern), Løgstrup Andersen, T. (Intern)
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Number: 0063(EN)
Main Research Area: Technical/natural sciences
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Design of a fibrous composite preform for wind turbine rotor blades

The present work addresses the different factors and challenges one must cope with in the design process of a composite preform used for the load-carrying main laminate of a wind turbine rotor blade. The design process is split up into different key elements, each of which are presented and discussed separately. The key elements are all interconnected, which complicate the design process and involves an iterative procedure. The aim is to provide an overview of the process that governs the design of composite preforms for wind turbine blades. The survey can be used as an information source on composite preform manufacturing. Basic knowledge on wind turbine blade technology and composites is assumed. © 2013 Elsevier Ltd. All rights reserved.
DTU-ESA millimeter-wave validation standard antenna – requirements and design

Inter-comparisons and validations of antenna measurement ranges are useful tools allowing the detection of various problems in the measurement procedures, thus leading to improvements of the measurement accuracy and facilitating better understanding of the measurement techniques. The maximum value from a validation campaign is achieved when a dedicated Validation Standard (VAST) antenna specifically designed for this purpose is available. The driving requirements to VAST antennas are their mechanical stability with respect to any orientation of the antenna in the gravity field and thermal stability over a given operational temperature range. In addition, VAST antennas must possess electrical characteristics that are typical for satellite antennas and challenging to measure. A multi-band millimeter-wave VAST (mm-VAST) antenna for the K/Ka-bands and Q/V bands is currently under development in collaboration between the Technical University of Denmark (DTU) and TICRA under contract from the European Space Agency. In this paper, the electrical and mechanical requirements of the DTU-ESA mm-VAST antenna are discussed and presented. Potential antenna types fulfilling the electrical requirements are briefly reviewed and the baseline design is described. The emphasis is given to definition of the requirements for the mechanical and thermal stability of the antenna, which satisfy the stringent stability requirement for the mm-VAST electrical characteristics.

Dynamics, OH distributions and UV emission of a gliding arc at various flow-rates investigated by optical measurements

We demonstrate a plasma discharge which is generated between two diverging electrodes and extended into a gliding arc in non-equilibrium condition by an air flow at atmospheric pressure. Effects of the air flow rates on the dynamics, ground-state OH distributions and spectral characterization of UV emission of the gliding arc were investigated by optical methods. High-speed photography was utilized to reveal flow-rate dependent dynamics such as ignitions, propagation, short-cutting events, extinctions and conversions of the discharge from glowtype to spark-type. Short-cutting events and ignitions occur more frequently at higher flow rates. The anchor points of the gliding arc are mostly steady at the top of the
electrodes at lower flow rates whereas at higher flow rates they glide up along the electrodes most of the time. The afterglow of fully developed gliding arcs is observed to decay over hundreds of microseconds after being electronically short-cut by a newly ignited arc. The extinction time decreases with the increase of the flow rate. The frequency of the conversion of a discharge from glow-type to spark-type increases with the flow rate. Additionally, spatial distributions of ground-state OH were investigated using planar laser-induced fluorescence. The results show that the shape, height, intensity and thickness of ground-state OH distribution vary significantly with air flow rates. Finally, UV emission of the gliding arc is measured using optical emission spectroscopy and it is found that the emission intensity of NO γ (A-X), OH (A-X) and N₂ (C-B) increase with the flow rates showing more characteristics of spark-type arcs. The observed phenomena indicate the significance of the interaction between local turbulence and the gliding arc.

**General information**

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Organisations: Department of Physics, Plasma Physics and Fusion Energy, Department of Wind Energy, Composites and Materials Mechanics, Lund University
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Effect of Polymer Form and its Consolidation on Mechanical Properties and Quality of Glass/PBT Composites

The aim of this study was to understand the role of the processing in determining the mechanical properties of glass fibre reinforced polybutylene terephthalate composites (Glass/PBT). Unidirectional (UD) composite laminates were manufactured by the vacuum consolidation technique using three different material systems included in this study: Glass/CBT (CBT160 powder based resin), Glass/PBT (prepreg tapes), and Glass/PBT (commingled yarns). The different types of thermoplastic polymer resin systems used for the manufacturing of the composite UD laminate dictate the differences in final mechanical properties which were evaluated by through compression, flexural and short beam transverse bending tests. Microscopy was used to evaluate the quality of the processed laminates, and fractography was used to characterize the observed failure modes. The study provides an improved understanding of the relationships between processing methods, resin characteristics, and mechanical performance of thermoplastic resin composite materials.

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Web of Science (2010): Indexed yes
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Effect of Processing Conditions on Fracture Resistance and Cohesive Laws of Binderfree All-Cellulose Composites

The fracture properties of all-cellulose composites without matrix were studied using Double Cantilever Beam (DCB) sandwich specimens loaded with pure monotonically increasing bending moments, which give stable crack growth. The experiments were conducted in an environmental scanning electron microscope to a) perform accurate measurements of both the fracture energy for crack initiation and the fracture resistance and b) observe the microscale failure mechanisms especially in the wake of the crack tip. Since the mechanical behaviour of the all-cellulose composites was non-linear, a general method was first developed to obtain fracture resistance values from the DCB specimens taking into account the non-linear material response. The binderfree all-cellulose composites were prepared by a mechanical refinement process that allows the formation of intramolecular bonds between the cellulose molecules during the drying process. Defibrilation of the raw cellulose material is done in wet medium in a paper-like process. Panels with different refining time were tested and it was found than an increase in fibre fibrillation results in a lower fracture resistance. © 2014 Springer Science+Business Media Dordrecht.
Effects of equal channel angular extrusion on microstructure, strength and ballistic performance of AA5754 plates

The microstructure, hardness, tensile properties and ballistic performance have been investigated in thick plates of the AA5754 alloy both in a coarse-grained as-received condition and after 4 passes of equal channel angular extrusion (ECAE) conducted at elevated temperatures. It is found that ECAE refines the microstructure to an average subgrain size of 0.3 μm, which results in significantly increased hardness and strength. Although ductility decreases due to ECAE, the uniform elongation is still fairly large, ~10%. The ballistic performance of the ECAE-processed material is found to be substantially better than that of the as-received condition.

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Environmental effect on the mechanical properties of commingled-yarn-based carbon fibre/polyamide 6 composites

The main objective of this experimental investigation was to evaluate the changes from accelerated ageing on selected properties of carbon fibre/polyamide 6 composites based on hybrid yarns. In this study, two types of mechanical tests were performed to measure the environmental influence on the material properties. They are three-point bending to measure the flexural strength and stiffness, and short beam three-point bending to measure the interlaminar shear strength. The 10-mm-thick quasi-isotropic carbon fibre/polyamide 6 composites with 52% volume fraction of carbon fibre to be tested were manufactured by autoclave consolidation. The test samples were dried, and subsequently exposed to 60 and 100% relative humidity at different lengths of time up to 2500 h, followed by drying at 23 and 50% relative humidity. Few samples were additionally completely dried at 70 in vacuum for 21 months. Tests were also performed on as manufactured and dried material at low temperature (–45) and high temperature (115). The measured mechanical properties decreased with exposure time at 60 and 100% relative humidity. Both the bending stiffness and the strength degrade to a level of about 65%, whereas interlaminar shear strength drops to about 87% of the property values of the unexposed (initially dried) material. The bending stiffness and strength at –45 are about 87% of the properties at room temperature, whereas at 115 the stiffness drops to 75% and the strength drops to 60% of the properties at room temperature. The interlaminar shear strength values also drop to about 75% at both –45 and 115. Extreme temperatures and long-time exposure to humidity of quasi-isotropic carbon fibre/polyamide 6 laminates can thus reduce the bending stiffness and strength by up to 35% and the interlaminar shear strength by up to 25%.

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Experimental and theoretical assessment of flexural properties of hybrid natural fibre composites

The concept of hybridization of natural fibre composites with synthetic fibres is attracting increasing scientific attention. The present study addresses the flexural properties of hybrid flax/glass/epoxy composites to demonstrate the potential benefits of hybridization. The study covers both experimental and theoretical assessments. Composite laminates with different hybrid fibre mixing ratios and different layer configurations were manufactured, and their volumetric composition and flexural properties were measured. The relationship between volume fractions in the composites is shown to be well predicted as a function of the hybrid fibre mixing ratio. The flexural modulus of the composites is theoretically assessed by using micromechanical models and laminate theory. The model predictions are compared with the experimentally determined flexural properties. Both approaches show that the flexural modulus of the composites is consistently increased when the flax fibre fabrics are replaced by glass fibre fabrics from the inner layers to the outer layers. The observed deviations between the experimental and theoretical values are explained by the simplifying model assumptions applied for the configuration of the composites, in particular the flax fibre composites. This needs to be addressed in further work.

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Experimental approach for mixed-mode fatigue delamination crack growth with large-scale bridging in polymer composites

An experimental apparatus utilizing double cantilever beam specimens loaded with uneven bending moments was developed to study the mixed-mode fatigue crack growth in composites. The approach is suitable when large-scale bridging of cracks is present. To illustrate the testing method, cyclic growth of delaminations in a typical fibre-reinforced polymer composite was investigated under a constant cyclic loading amplitude. Pure mode I, mode II and mixed-mode crack growth conditions were examined. The results, analysed using a J-integral approach, show that the double cantilever beam loaded with uneven bending moments configuration provides a robust approach to investigate the fatigue crack growth of composites for pure mode and mixed-mode cracking. A steady-state crack growth regime was observed for mode I and mixed-mode loading. For mode II loading, steady-state was absent, and a progressively decreasing crack growth rate observed. In addition to details concerning the equipment, a general discussion of the development of cyclic bridging laws for delamination growth in the presence of large-scale bridging is provided.
Fatigue damage propagation in unidirectional glass fibre reinforced composites made of a non-crimp fabric

Damage progression in unidirectional glass fibre reinforced composites manufactured of a non-crimp fabric subjected to tension-tension fatigue is investigated, and a quantitative explanation is given for the experimentally observed stiffness degradation. The underlying damage-mechanisms are examined using three distinct microscopic analyses, and the transverse crack density is measured. It is documented that the stiffness loss in fatigue is directly related to fibre fractures in the load-carrying axial fibre bundles, initialised by interface debonding and cracking in the transverse backing bundles. A simple stiffness spring model validates the stiffness loss observed. A fatigue damage scheme is presented, which
suggests that damage initiates due to failure of the backing bundle causing a stress concentration in the axial load carrying fibres. This stress concentration, along with fretting fatigue, gives rise to axial fibre fractures and a loss of stiffness, eventually leading to final failure. The uniqueness of the present work is identification of the mechanisms associated with tension fatigue failure of unidirectional non-crimp fabrics used for wind turbine blades. The observed damage mechanisms need further attention and understanding in order to improve the fatigue life-time of unidirectional glass fibre reinforced non-crimp fabrics.

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Web of Science (2007): Indexed yes
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Fatigue of hybrid glass/carbon composites: 3D computational studies

3D computational simulations of fatigue of hybrid carbon/glass fiber reinforced composites is carried out using X-FEM and multifiber unit cell models. A new software code for the automatic generation of unit cell multifiber models of composites with randomly misaligned fibers of various properties and geometrical parameters is developed. With the use of this program code and the X-FEM method, systematic investigations of the effect of microstructure of hybrid composites (fraction of carbon versus glass fibers, misalignment, and interface strength) and the loading conditions (tensile versus compression cyclic loading effects) on fatigue behavior of the materials are carried out. It was demonstrated that the higher fraction of carbon fibers in hybrid composites is beneficial for the fatigue lifetime of the composites under tension-tension cyclic loading, but might have negative effect on the lifetime under compression-compression, and has mixed effect for the tension-compression cyclic loading. Further, it was observed that while the fiber misalignment has some potential for increasing the fracture toughness of the hybrid composites, it speeds up the fiber damage and leads to the shortening of fatigue life. © 2014 Elsevier Ltd.
Fatigue of multiscale composites with secondary nanoplatelet reinforcement: 3D computational analysis

3D numerical simulations of fatigue damage of multiscale fiber reinforced polymer composites with secondary nanoclay reinforcement are carried out. Macro–micro FE models of the multiscale composites are generated automatically using Python based software. The effect of the nanoclay reinforcement (localized in the fiber/matrix interface (fiber sizing) and distributed throughout the matrix) on the crack path, damage mechanisms and fatigue behavior is investigated in numerical experiments. It was observed that the composites with secondary nanoreinforcement localized in the fiber sizing ensure higher lifetime and damage resistance than those with nanoreinforcement dispersed throughout the matrix. Crack bridging by nanoparticles was observed mainly in composites with randomly oriented nanoplatelets and clusters, while the crack path deviation was strongest in the composites with aligned nanoplatelets. Multiscale composites with exfoliated nanoreinforcement and aligned nanoplatelets ensure the better fatigue resistance than those with intercalated/clustered and randomly oriented nanoreinforcement.

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**FEM model of Embedded Fibre Bragg Grating Sensor Response: Crack Growing Detection**

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**Gradient ultrafine-grained titanium: Computational study of mechanical and damage behavior**
A computational model of ultrafine-grained (UFG) titanium with random and gradient distribution based on Voronoi tessellation and the composite model of nanomaterials is developed. The effect of grain size, non-equilibrium state of the grain boundary phase (characterized by the initial dislocation density and diffusion coefficient) and gradient of grain sizes on the mechanical behavior and damage initiation of the UFG titanium are studied in numerical experiments. Using computational experiments, the authors determined the likely damage criterion (dislocation-based model) and found several effects that can positively influence the mechanical response and strength of UFG titanium (homogeneity of grain sizes, dispersoids/precipitates in grain boundaries and initial dislocation density in grain boundaries). It is shown that the homogeneous structures of UFG titanium ensure higher yield stress and lower likelihood of damage than gradient structures. The availability of dispersoids or precipitates in UFG titanium changes its damage mechanisms and delays the evolution of damage.

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Graphene reinforced nanocomposites: 3D simulation of damage and fracture

3D computational model of graphene reinforced polymer composites is developed and applied to the analysis of damage and fracture mechanisms in the composites. The graphene/polymer interface properties are determined using the inverse modeling approach. The effect of composite structure, in particular, of the aspect ratio, shape, clustering, orientation and volume fraction of graphene platelets on the mechanical behavior and damage mechanisms of nanocomposites are studied in computational experiments. It was shown that the Young modulus of the nanocomposites increases with increasing aspect ratio, volume content, elastic properties of graphene/polymer interface layer, and decreasing the degree of intercalation. The tensile strength follows similar tendencies, except for the aspect ratio and clustering degree, where the opposite effects are observed. Nanocomposites with randomly oriented sheets of graphene demonstrate much lower Young modulus and strength as compared with the composites with the aligned graphene sheet reinforcement. It was further concluded that the structural imperfections of graphene reinforcement (like crumpling shape or random misalignment) have considerable effect on the composite performances.
Hierarchical nanoreinforced composites for highly reliable large wind turbines: Computational modelling and optimization

The major precondition for the successful development of wind energy in Europe is the high reliability of wind turbines, in particular, large off-shore turbines. The qualitative enhancement of the reliability of wind turbine blades can be achieved by the development of new highly damage materials, with modified, hybrid or nanomodified structures. In this project, we seek to explore the potential of hybrid (carbon/glass), nanoreinforced and hierarchical composites (with secondary CNT, graphene or nanoclay reinforcement) as future materials for highly reliable large wind turbines. Using 3D multiscale computational models of the composites, we study the effect of hybrid structure and of nanomodifications on the strength, lifetime and service properties of the materials (see Figure 1). As a result, a series of recommendations toward the improvement of composites for structural applications under long term severe service conditions have been developed.

Hybrid and hierarchical nanoreinforced polymer composites: Computational modelling of structure–properties relationships

Hybrid and hierarchical polymer composites represent a promising group of materials for engineering applications. In this paper, computational studies of the strength and damage resistance of hybrid and hierarchical composites are reviewed. The reserves of the composite improvement are explored by using computational micromechanical models. It is shown that while glass/carbon fibers hybrid composites clearly demonstrate higher stiffness and lower weight with increasing the carbon content, they can have lower strength as compared with usual glass fiber polymer composites. Secondary nanoreinforcement can drastically increase the fatigue lifetime of composites. Especially, composites with the nanoplatelets localized in the fiber/matrix interface layer (fiber sizing) ensure much higher fatigue lifetime than those with the nanoplatelets in the matrix.
A computational study of the effect of microstructure of hybrid carbon/glass fiber composites on their strength is presented. Unit cells with hundreds of randomly located and misaligned fibers of various properties and arrangements are subject to tensile and compression loading, and the evolution of fiber damages is analyzed in numerical experiments. The effects of fiber clustering, matrix properties, nanoreinforcement, load sharing rules on the strength and damage resistance of composites are studied. It was observed that hybrid composites under uniform displacement loading might have lower...
strength than pure composites, while the strength of hybrid composites under inform force loading increases steadily with increasing the volume content of carbon fibers.
Micro-macro understanding of fatigue of fibre composites

Degradation of composite materials during cyclic loading is being better understood. Better understanding enables better material models and the development of more durable composite materials that have longer life for e.g. wind turbine rotor blades

Micro-mechanical failure in fiber-reinforced composites

Micromechanical failure mechanisms occurring in unidirectional fiber-reinforced composites are studied by means of the finite element method as well as experimental testing. This study highlights the effect of micro-scale features such as fiber/matrix interfacial debonding, matrix cracking and microvoids on the microscopic and macroscopic mechanical response of composite materials. To this end, first a numerical study is carried out to explore ways to stabilize interfacial crack growth under dominant Mode-I fracture using the cohesive zone model. Consequently, this study suggests a method to determine the normal interfacial properties. Afterward, two different numerical approaches (I) the regular fiber distribution approach and (II) the random fiber distribution strategy are established to evaluate the effect of the microscale features on the overall stress-strain response of unidirectional composites. In the first approach, the J2 plasticity model is
implemented to model the elasto-plastic behavior of the matrix while in the second strategy the modified Drucker-Prager plasticity model is utilized to account for brittle-like and pressure dependent behavior of an epoxy matrix. In addition, the failure locus of the composite lamina under different loading conditions is obtained by means of computational micromechanics and compared with the predictions of Puck’s model. The results are in very good agreement with the predictions of Puck’s model under different interfiber failure modes. In order to validate the numerical microstructural approach accurately, an experimental test was carried out to be compared with the numerical results. It was found that the micromechanical model could accurately predict the crack initiation emanating from microvoids as well as crack propagation along the interfaces. The results of this thesis show that the strength of composite is significantly reduced by weak interfacial properties and the presence of voids. The size and shape of microvoids can also microscopically lead to different crack paths. Finally, the present numerical strategy seems to be a promising tool to predict the macroscopic and microscopic mechanical response of composites.

**General information**

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Organisations: Department of Mechanical Engineering, Solid Mechanics, Department of Wind Energy, Composites and Materials Mechanics  
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**Micro-Plasto-Hydrodynamic Lubrication a Fundamental Mechanism in Cold Rolling**

This paper presents recent investigations in Micro-Plasto-Hydrodynamic (MPH) lubrication. Industrial evidences of the existence of MPH lubrication mechanism for cold rolling processes are presented. A new lubrication model developed for strip drawing processes is then applied to predict the MPH lubrication initiation and MPH lubrication extension along the tool-piece solid contacts initially in boundary lubrication regime. Finally, it is shown how this new MPH lubrication model can be implemented in a cold rolling model to maximize mills capabilities, determine optimum rolling oils properties and predict roughness transfer.

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Microscale damage mechanisms and degradation of fiber-reinforced composites for wind energy applications: results of Danish–Chinese collaborative investigations

Recent research works in the area of experimental and computational analyses of microscale mechanisms of strength, damage and degradation of glass fiber polymer composites for wind energy applications, which were carried out in the framework of a series of Sino–Danish collaborative research projects, are summarized in this article. In a series of scanning electron microscopy in situ experimental studies of composite degradation under off-axis tensile, compressive and cyclic loadings as well as three-dimensional computational experiments based on micromechanics of composites and damage mechanics, typical damage mechanisms of wind turbine blade composites were clarified. It was demonstrated that the damage mechanisms in the composites strongly depend on the orientation angle of the applied loading with the fiber direction. The matrix cracking was observed to be the main damage mechanism for tensile axial (or slightly off-axis axial) loading; for all other cases (off-axis tensile, compressive and cyclic tensile loadings), the interface debonding and shear control the damage mechanisms.

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Microstructural characterization of stone wool fibre network

Understanding the mechanical properties of fibrous network as complex as stone wool materials requires a relevant description of their microstructure and architecture. In this study, different methods have been proposed to characterize the fibre orientation, diameter and length of fibres as well as the number density of fibre contacts. The methods are based on image analysis of 3D datasets which have been obtained by x-ray tomography. Validation of the proposed methods was demonstrated by testing generated virtual fibrous network with known fibre characteristics.
Mixed Mode cohesive law with interface dilatation

Experimental investigations of adhesive joints and fibre composites have shown that under Mode II cracking, the fracture process induces a displacement normal to the fracture plane. This effect can be attributed e.g. to roughness of the fracture surface under dominating tangential crack face displacements. As the crack faces displace relatively to each other, the roughness asperities ride on top of each other and result in an opening (dilatation) in the normal direction. Furthermore, the interaction of the crack surfaces in the contact zone gives rise to compressive normal stresses and frictional shear stresses opposing the crack face displacements. A phenomenological Mixed Mode cohesive zone law, derived from a potential function, is developed to describe the above mentioned fracture behaviour under monotonic opening. The interface dilatation introduces two new lengths. The cohesive law is implemented in the commercial finite element program Abaqus. The model is validated and tested against experimental results under various mode mixities. © 2013 Elsevier Ltd. All rights reserved.
Nanostructured titanium-based materials for medical implants: Modeling and development

Nanostructuring of titanium-based implantable devices can provide them with superior mechanical properties and enhanced biocompatibility. An overview of advanced fabrication technologies of nanostructured, high strength, biocompatible Ti and shape memory Ni-Ti alloy for medical implants is given. Computational methods of nanostructure properties simulation and various approaches to the computational, "virtual" testing and numerical optimization of these materials are discussed. Applications of atomistic methods, continuum micromechanics and crystal plasticity as well as analytical models to the analysis of the reserves of the improvement of materials for medical implants are demonstrated. Examples of successful development of a nanomaterial-based medical implants are presented. (C) 2014 Elsevier B.V. All rights reserved.
Natural Composites: Cellulose Fibres and the related Performance of Composites
Biobased materials are becoming of increasing interest as potential structural materials for the future. A useful concept in this context is the fibre reinforcement of materials by stiff and strong fibres. The biobased resources can contribute with cellulose fibres and biopolymers. This offers the potential for stiff and strong biocomposite materials, but these have some limitations and obstacles to full performance. The focus will be on the ultra-structure, and the strength and stiffness of cellulose fibres, on the (unavoidable) defects causing large reductions in strength and moderate reductions in stiffness, on the packing ability of cellulose fibres and the related maximum fibre volume fraction in composites, on the moisture sorption of cellulose fibres and the related mass increase and (large) hygral strains induced, and on the mechanical performance of composites.
Non-equilibrium grain boundaries in titanium nanostructured by severe plastic deformation: Computational study of sources of material strengthening

A computational model of ultrafine grained (UFG) or nanostructured titanium (Ti), based on a finite element (FE) unit cell model of the material and a dislocation density based model of plastic deformation has been developed. FE simulations of tensile deformation of UFG Ti with different fractions and properties of the grain boundary (GB) phase have been carried out. The effect of different degrees of deviation from the equilibrium state of the grain boundaries (GBs) on the mechanical behaviour of nanostructured Ti have been investigated using the combined composite/dislocation dynamics based model. In particular, the effects of different diffusion coefficients in the GB phase, of a high initial dislocation density in the grain boundaries, as well as of atomic scale precipitates are investigated for affecting the deformation behaviour of UFG or nanostructured Ti. © 2013 Elsevier B.V. All rights reserved.
Optimal Design of Composite Structures Under Manufacturing Constraints

This thesis considers discrete multi material and thickness optimization of laminated composite structures including local failure criteria and manufacturing constraints. Our models closely follow an immediate extension of the Discrete Material Optimization scheme, which allows simultaneous determination of the appropriate laminate thickness and the material choice in the structure. The optimal design problems that arise are stated as nonconvex mixed integer programming problems. We resort to different reformulation techniques to state the optimization problems as either linear or nonlinear convex mixed integer 0–1 programming problems. The manufacturing constraints have been treated by developing explicit models with favorable properties.

In this thesis we have developed and implemented special purpose global optimization methods and heuristic techniques for solving this class of problems. The continuous relaxation of the mixed integer programming problems is being solved by an implementation of a primal–dual interior point method for nonlinear programming that updates the barrier parameter adaptively. The method is chosen for its excellent convergence properties and the ability of the method to react swiftly to changes of scale in the problem. As opposed to the original Discrete Material Optimization methodology, we obtain discrete feasible solutions to the stated mixed 0–1 convex problems by the application of advanced heuristic techniques. Our heuristics are based on solving a finite sequence of well–posed optimization problems. They provide us with a discrete feasible solution or correctly determine problem infeasibility. Our aim is to solve the considered problems to proven global optimality. We propose a combination of the convergent Outer Approximation and Local Branching algorithms to perform the global optimization. The efficiency of the proposed models is examined on a set of well–defined discrete multi material and thickness optimization problems originating from the literature. The inclusion of manufacturing limitations along with structural considerations in the early design phase results in structures with better structural performance reducing the need of manually post–processing the found designs.
Orientation of PLLA tubes under simultaneous biaxial strain

General information
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Particle tracking velocimetry of a gliding arc discharge

A 35 kHz AC gliding arc discharge at atmospheric pressure is generated between two diverging electrodes and extended by an air flow. The gas flow velocity is measured by particle tracking velocimetry (PTV) while the moving velocity of the plasma column of the gliding arc discharge is measured by analyzing the movie taken by a high-speed camera. The two-dimensional velocity vector of the gas flow and of the gliding arc in the imaging plane was determined.

Plasma treatment of carbon fibres and glass-fibre-reinforced polyesters at atmospheric pressure for adhesion improvement

Atmospheric pressure plasma treatment is useful for adhesion improvement, because cleaning, roughening and addition of polar functional groups can be expected at the surfaces. Its possible applications in the wind energy industry include plasma treatment of fibres and fibre-reinforced polymer composites before assembling them to build wind turbine blades. In the present work, unsized carbon fibres are continuously treated using a dielectric barrier discharge plasma in helium at atmospheric pressure, and carbon fibre reinforced epoxy composite plates are manufactured for the mechanical test. The plasma treatment improved fracture toughness, indicating that adhesion between the fibres and the epoxy was enhanced by the treatment. In addition, glass-fibre-reinforced polyester plates are treated using a gliding arc and an ultrasound enhanced dielectric barrier discharge, improving the wettability and/or the adhesive strength with a vinylester resin.
Protocol for Quantification of Defects in Natural Fibres for Composites

Natural bast-type plant fibres are attracting increasing interest for being used for structural composite applications where high quality fibres with good mechanical properties are required. A protocol for the quantification of defects in natural fibres is presented. The protocol is based on the experimental method of optical microscopy and the image analysis algorithms of the seeded region growing method and Otsu’s method. The use of the protocol is demonstrated by examining two types of differently processed flax fibres to give mean defect contents of 6.9 and 3.9%, a difference which is tested to be statistically significant. The protocol is evaluated with respect to the selection of image analysis algorithms, and Otsu’s method is found to be a more appropriate method than the alternative coefficient of variation method. The traditional way of defining defect size by area is compared to the definition of defect size by width, and it is shown that both definitions can be used to give unbiased findings for the comparison between fibre types. Finally, considerations are given with respect to true measures of defect content, number of determinations, and number of significant figures used for the descriptive statistics.

Recycling of wind turbines
Recycling solid residues recovered from glass fibre-reinforced composites – A review applied to wind turbine blade materials

For the sustainable development of modern societies, optimized life cycle management of any technologies must be considered, from their development and implementation to their end of life (EoL). This is of main concern for the wind energy sector. Rapidly growing, this industrial sector will have to face large amounts of future wind turbine (WT) blades coming to EoL. Among the EoL solutions available for WT blades, i.e. reuse, remanufacturing, recycling, incineration or disposal, this literature review focuses on recycling and particularly the recycling of shredded composite (SC) materials and recovered glass fibre (GF) into new polymer composites. WT blades are mainly made of glass fibre reinforced polymer (GFRP) using thermosetting resins. Shredding this material and recovering GF are possible recycling solutions for WT blade. Based on a detailed literature review, the formulations of new composites elaborated with the residues are presented in a novel standardized way based on weight fractions. The mechanical properties of the composite manufactured are thereafter compared and discussed.
Stability of alternating current gliding arcs

A gliding arc is a quenched plasma that can be operated as a non-thermal plasma at atmospheric pressure and that is thus suitable for large-scale plasma surface treatment. For its practical industrial use the discharge should be extended stably in ambient air. A simple analytical calculation based on Ohm's law indicates that the critical length of alternating current (AC) gliding arc discharge columns can be larger than that of a corresponding direct current (DC) gliding arc. This finding is supported by previously published images of AC and DC gliding arcs. Furthermore, the analysis shows that the critical length can be increased by increasing the AC frequency, decreasing the serial resistance and lowering the gas flow rate. The predicted dependence of gas flow rate on the arc length is experimentally demonstrated. The gap width is varied...
to study an optimal electrode design, since the extended non-equilibrium discharge can be extinguished due to the ignition of an arc discharge at the closest electrode gap. It is experimentally found that as the gap is wider, the discharge column tends to be longer.

**General information**

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Scopus rating (2010): SJR 0.817 SNIP 0.775
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Scopus rating (2007): SJR 1.397 SNIP 0.903
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Scopus rating (2003): SJR 0.904 SNIP 0.831
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Scopus rating (2002): SJR 0.883 SNIP 0.708
Sustain diffusion alternating current gliding arc discharge in atmospheric pressure air

Rapid transition from glow discharge to thermal arc has been a common problem in generating stable high-power non-thermal plasmas especially at ambient conditions. A sustained diffusion gliding arc discharge was generated in a large volume in atmospheric pressure air, driven by an alternating current (AC) power source. The plasma column extended beyond the water-cooled stainless steel electrodes and was stabilized by matching the flow speed of the turbulent air jet with the rated output power. Comprehensive investigations were performed using high-speed movies measured over the plasma column, synchronized with simultaneously recorded current and voltage waveforms. Dynamic details of the novel non-equilibrium discharge are revealed, which is characterized by a sinusoidal current waveform with amplitude stabilized at around 200 mA intermediate between thermal arc and glow discharge, shedding light to the governing mechanism of the sustained spark-suppressed AC gliding arc discharge. © 2014 AIP Publishing LLC.
Towards an industrial manufactured morphing trailing edge flap system for wind turbines

A flap actuation system, the Controllable Rubber Trailing Edge Flap (CRTEF), for distributed load control on a wind turbine blade has been developed in the period from 2006 to 2010 at DTU. The function of the system and its capability to change the lift on a blade section was measured during a wind tunnel experiment in 2009 with promising results. This led in 2011 to initiation of a new research project INDUFLAP with the main aim to transfer the flap technology to industry as concerns manufacturing and testing. Three industrial partners are participating in the project. Rehau (DE) and Dansk Gummi
Industri (DK) work on flap manufacturing and Hydratech Industries (DK) is developing the powering system for the flaps and the control system. DTU is the coordinator of the project. Flap prototypes have been manufactured in a continuous thermoplastic extrusion process and a unique rotating test rig has been developed and build, based on a 100kW turbine platform. A 2m (span) x 1m (chord) blade section with the flap system is mounted at the end of a 10m long boom rotated up to 50-60 rpm. Measurements comprise surface pressure measurements for detailed monitoring of the flap actions.

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**Towards an Industrial Manufactured Morphing Trailing Edge Flap System for Wind Turbines**

Several numerical studies in the past 10 years have shown big potentials for load reduction on MW turbines using distributed control for alleviation of the fluctuating loads along the blade span. However, the requirements by the wind turbine industry of robust actuator solutions where the strongest specifications mean no metal and electrical parts in the blades have so far limited the use of the smart blade technology on wind turbines.

In the 3½ year project INDUFLAP (2011-2024), funded by the Danish Energy Agency through the EUDP programme, a flap system developed at DTU and tested on a laboratory level, is transferred into an industrial manufacturing process and tested on a novel rotating test rig. The industrial partners are Rehau, Hydratech Industries and Dansk Gummi Industri.

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**Translational, rotational and vibrational temperatures of a gliding arc discharge at atmospheric pressure air**

Gliding arc discharges have generally been used to generate non-equilibrium plasma at atmospheric pressure. Temperature distributions of a gliding arc are of great interest both for fundamental plasma research and for practical applications. In the presented studies, translational, rotational and vibrational temperatures of a gliding arc generated at atmospheric pressure air are investigated. Translational temperatures (about 1100 K) were measured by laser-induced Rayleigh scattering, and two-dimensional temperature imaging was performed. Rotational and vibrational temperatures (about 3600 K and 6700 K, respectively) were obtained by simulating the measured emission spectra of OH.

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2D micromechanical analysis of SiC/Al metal matrix composites under tensile, shear and combined tensile/shear loads

The influence of interface strength and loading conditions on the mechanical behavior of the metal-matrix composites is investigated in this paper. A program is developed to generate automatically 2D micromechanical Finite element (FE) models including interface, in which both the locations and dimensions of Silicon-Carbide (SiC) particles are randomly distributed. Finite element simulations of the deformation and damage evolution of SiC particle reinforced Aluminum (Al) alloy composite are carried out for different microstructures and interphase strengths under tensile, shear and combined tensile/shear loads. 2D cohesive element is applied to describe the fracture and failure process of interphase, while the damage models based on maximum principal stress criterion and the stress triaxial indicator are developed within Abaqus/Standard Subroutine USDFLD to simulate the failure process of SiC particles and aluminum alloy matrix, respectively. A series of computational experiments are performed to study the influence of particle arrangements, interface strengths and loading conditions of the representative volume element (RVE) on composite stiffness and strength properties. © 2013 Elsevier Ltd.
3D in situ observations of glass fibre/matrix interfacial debonding

X-ray microtomography was used for 3D in situ observations of the evolution of fibre/matrix interfacial debonding. A specimen with a single fibre oriented perpendicular to the tensile direction was tested at a synchrotron facility using a special loading rig which allowed for applying a load transverse to the fibre. Three distinguishable damage stages were observed: (i) interfacial debond initiation at the free surface, (ii) debond propagation from the surface into the specimen and (iii) unstable debonding along the full length of the scanned volume. The high resolution microtomography provides both qualitative and quantitative 3D data of the debonding initiation and propagation. Thus, microtomography is demonstrated as a promising technique which can assist micromechanical model development. © 2013 Elsevier Ltd. All rights reserved.

General information
Fibers, Glass, Three dimensional, Tomography, Debonding
Adhesion improvement of fibres by continuous plasma treatment at atmospheric pressure

Carbon fibres and ultra-high-molecular-weight polyethylene (UHMWPE) fibres were continuously treated by a dielectric barrier discharge plasma at atmospheric pressure for adhesion improvement with epoxy resins. The plasma treatment improved wettability, increased the oxygen containing polar functional groups at the surface, and subsequently improved adhesion to the epoxy and fracture resistance of epoxy composites. Hansen solubility parameters (HSP), quantitatively describing physical interactions among molecules, were measured for the UHMWPE fibre surfaces. The result identifies two distinct types of surfaces in both the plasma treated and the untreated fibres. One type is typical of polyethylene polymers while the other is characteristic of the oxygenated surface at much higher values of HSP.

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Adhesion improvement of glass-fibre-reinforced polyester composites by gliding arc discharge treatment

A gliding arc is a plasma that can be operated at atmospheric pressure and applied for plasma surface treatment for adhesion improvement. In the present work, glass-fibre-reinforced polyester plates were treated using an atmospheric pressure gliding arc discharge with an air flow to improve adhesion with a vinylester adhesive. The treatment improved wettability and increased the polar component of the surface energy and the density of oxygen-containing polar functional groups at the surfaces. Double cantilever beam specimens were prepared for fracture mechanics characterisation (fracture resistance as a function of nominal mode mixity) of the laminate adhesive interface. It was found that gliding arc treatment significantly increases the interfacial fracture energy and fracture resistance in comparison with a standard peel ply treatment, although the mixed mode fracture energy of the gliding arc treated specimen was not as high as that of the laminate itself.

General information
Advances in wind turbine blade design and materials

Wind energy is gaining critical ground in the area of renewable energy, with wind energy being predicted to provide up to 8% of the world’s consumption of electricity by 2021. Advances in wind turbine blade design and materials reviews the design and functionality of wind turbine rotor blades as well as the requirements and challenges for composite materials used in both current and future designs of wind turbine blades.

Part one outlines the challenges and developments in wind turbine blade design, including aerodynamic and aeroelastic design features, fatigue loads on wind turbine blades, and characteristics of wind turbine blade airfoils. Part two discusses the fatigue behavior of composite wind turbine blades, including the micromechanical modelling and fatigue life prediction of wind turbine blade composite materials, and the effects of resin and reinforcement variations on the fatigue resistance of wind turbine blades. The final part of the book describes advances in wind turbine blade materials, development and testing, including biobased composites, surface protection and coatings, structural performance testing and the design, manufacture and testing of small wind turbine blades.

Advances in wind turbine blade design and materials offers a comprehensive review of the recent advances and challenges encountered in wind turbine blade materials and design, and will provide an invaluable reference for researchers and innovators in the field of wind energy production, including materials scientists and engineers, wind turbine blade manufacturers and maintenance technicians, scientists, researchers and academics.

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Organisations: Department of Wind Energy, Composites and Materials Mechanics, Wind Turbine Materials and Constructions (WMC)
Authors: Brøndsted, P. (ed.) (Intern), Nijssen, R. (ed.) (Ekstern)
Number of pages: 484
Publication date: 2013

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Main Research Area: Technical/natural sciences
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A fractional derivative approach to full creep regions in salt rock

Based on the definition of the constant-viscosity Abel dashpot, a new creep element, referred to as the variable-viscosity Abel dashpot, is proposed to characterize damage growth in salt rock samples during creep tests. Ultrasonic testing is employed to determine a formula of the variable viscosity coefficient, indicating that the change of the variable viscosity coefficient with the time meets a negative exponent law. In addition, by replacing the Newtonian dashpot in the classical Nishihara model with the variable-viscosity Abel dashpot, a damage-mechanism-based creep constitutive model is proposed on the basis of time-based fractional derivative. The analytic solution for the fractional-derivative creep constitutive model is presented. The parameters of the fractional derivative creep model are determined by the Levenberg–Marquardt method on the basis of the experimental results of creep tests on salt rock. Furthermore, a sensitivity study is carried out, showing the effects of stress level, fractional derivative order and viscosity coefficient exponent on creep strain of salt rock. It is indicated that the fractional derivative creep model proposed in the paper provides a precise description of full creep regions in salt rock, i.e., the transient creep region (the primary region), the steady-state creep region (the secondary region) and the accelerated creep region (the tertiary region).

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, China University of Mining And Technology
Authors: Zhou, H. W. (Ekstern), Wang, C. P. (Ekstern), Mishnaevsky, L. (Intern), Duan, Z. Q. (Ekstern), Ding, J. Y. (Ekstern)
Pages: 413-425
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Mechanics of Time Dependent Materials
Volume: 17
Analysis of composition and microstructural uniformity of hybrid glass/carbon fibre composites

In hybrid fibre composites, the intermixing of the two types of fibres imposes challenges to obtain materials with a well-defined and uniform microstructure. In the present paper, the composition and the microstructural uniformity of hybrid glass/carbon fibre composites mixed at the fibre bundle level are investigated. The different levels of compositions in the composites are defined and experimentally determined. The composite volume fractions are determined using an image analysis based procedure. The global fibre volume fractions are determined using a gravimetrical based method. The local fibre volume fractions are determined using volumetric calculations. A model is presented to predict the interrelation of volume fractions in hybrid fibre composites. The microstructural uniformity of the composites is analysed by the determined variation in composite volume fractions. Two analytical methods, a standard deviation based method and a
A new theoretical model of the quasistatic single-fiber pullout problem: Analysis of stress field

A new theoretical model is developed in order to predict the stress transfer during the quasistatic single-fibre pullout process. The theoretical approach retains all relevant stress and strain components, and satisfies exactly the interfacial continuity conditions and all the stress boundary conditions. For both matrix and fibre, the equilibrium equations along radial direction are satisfied strictly, while the equilibrium equations along axial direction are satisfied in the integral forms. Three normal stress-strain relationships are strictly satisfied, while the radial displacement gradient with respect to the axial direction is neglected for shear stress-strain relationship. The general solutions of the axial and radial displacements in both fibre and matrix are obtained in explicit forms. In the debonded region, a modified Coulomb’s friction law, in which the frictional coefficient is a decreasing function of pullout rate, is applied to determine the interfacial frictional stress. The new analytical approach allows performing more detail theoretical analysis on the stress transfer between fibre and matrix, and distributions of stress, strain and displacement in fibre and matrix. Numerical results of the stress distributions, in both fully bonded region and fully debonded region, are presented for a typical glass/epoxy composite system with different fibre volume fraction and model length. In fully bonded region, the theoretical results from present model are more accurate compared with those from Lame solution, and agree well with the results from finite element model. In fully debonded region, present model can predict the initial pullout stress under different geometrical conditions and static friction coefficient, also can predict more reasonable stress distribution than Lame solution. © 2013 Elsevier Ltd. All rights reserved.
Deformation, Finite element method, Forecasting, Friction, Mechanical properties, Residual stresses, Stress concentration, Stress-strain curves, Fibers

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Source-ID: n:oai:DTIC-ART:compendex/384043523::27352
Publication: Research - peer-review • Journal article – Annual report year: 2013
Biobased composites: materials, properties and potential applications as wind turbine blade materials

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Madsen, B. (Intern), Brøndsted, P. (Intern), Løgstrup Andersen, T. (Intern)
Publication date: 2013

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ISBN (Print): 978 0 85709 426 1
Chapter: Part 3
Series: Woodhead Publishing Series in Energy
Number: 47
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Book chapter – Annual report year: 2013

Bonding characteristics of glass seal/metalllic Interconnect for SOFC applications: Comparative study on chemical and mechanical properties of the interface

Glass and glass–ceramics have been extensively used as seal material in planar solid oxide fuel cell (SOFC) stack. The main objective of the present work was to investigate the joining properties of a silicate based glass-ceramic as seal material with two different ferritic stainless alloys as interconnect, i.e. SS430 and Crofer 22APU. For a straight-forward approach to evaluate sealing materials, sandwiched samples will allow interfacial strength measurements and macroscopic overview on the interfacial situation of a glass–ceramic material. A convenient method for determining the interfacial fracture energies is double cantilever beam (DCB) test. The method allows to measure the crack-growth resistance of these materials to be able to use fracture mechanics design methods. Stable crack growth is necessary to get reliable and unambiguous fracture toughness data. If the fracture toughness values are determined from test configurations that do not allow stable crack growth, then the measurement may be related more to crack initiation than crack growth. In such cases, the calculated value of the fracture toughness may depend on the geometry of the machined notch.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Mixed Conductors, Department of Wind Energy, Composites and Materials Mechanics, Tarbiat Modares University
Authors: Abdoli, H. (Ekstern), Alizadeh, P. (Ekstern), Boccaccini, D. (Intern), Frandsen, H. L. (Intern), Sørensen, B. F. (Intern), Molin, S. (Intern), Agersted, K. (Ekstern)
Bondlines – Online blade measurements (October 2012 and January 2013)
Some local deformations in an operating Wind Turbine blade (V80) have been measured during October 2012. Displacement and load values generated between the trailing edge panels at blade radius R9.2m, R10.2m, and R11.2m were obtained. A fluctuating loading of between 100 - 200N existed when the two panels were connected, and with a displacement of between 6.5 - 10mm when the panels were free to flex as they do in normal operating conditions. Shear distortion within the main loading spar of the blade (at approximately R10m) showed a fluctuating cross beam shear distortion of about 9mm.
The trailing edge displacement was re-measured (during January 2013) following a reinforcement of the blade to prevent trailing edge distortion. This trial showed that the new displacement values were below 1mm during similar operating conditions.
This report describes the planning for and procurement of hardware for the on-site measurements. The data output is then summarised. The full data files will be used to improve models and sub-component testing of these structures, as well as the continuing development of the reinforcement approaches designed to prolong structural life.
Damage evolution in nanoclay-reinforced polymers: A three-dimensional computational study

Initiation and growth of microcracks in the nanoclay reinforced polymer composites were analyzed in numerical experiments using 3D micromechanical unit cell models. An original program code for the automatic generation of FE unit cells with multiple disk-shaped nanoplatelets, with high aspect ratio, clustered or exfoliated, randomly arranged or inclined, was developed. A four phase model of nanocomposites which includes the effective interface between the nanoplatelets and polymer, as well as interplatelet and outer phases, was used in the simulations. Different crack growth criteria were compared, including the 3D Benzeggagh and Kenane law (BK law) criterion, the 3D Wu and Reuter law (power law) criterion and the Reeder law criterion. The effects of the platelet aspect ratio, clustering and orientation effects on the crack propagation are studied in numerical experiments. It was observed that the increasing aspect ratio leads to the increasing Young modulus, but decreasing strength. The clustering of disks had an adverse effect, meaning increased strength and lower stiffness. In the simulations, damage mechanisms such as crack deflection and delamination were observed.
DCB Test Sample Design for Micro-Mechanical Testing

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Zike, S. (Intern), Mikkelsen, L. P. (Intern), Sørensen, B. F. (Intern)
Number of pages: 9
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Title of host publication: The 19th International Conference on Composite Materials
Publisher: ICCM19 Secretariat
Main Research Area: Technical/natural sciences
Conference: 19th International Conference on Composite Materials, Montréal, Canada, 28/07/2013 - 28/07/2013
Electronic versions:
DCB TEST
Source: dtu
Source-ID: u::8531
Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

Design and manufacturing of a morphing flap for wind turbine blades
This document describes the current status of the flap prototype development in the INDUFLAP project funded by the EUDP programme from the Danish Ministry of Energy.

General information
State: Published
Organisations: Aeroelastic Design, Department of Wind Energy, Composites and Materials Mechanics, REHAU AG + Co
Authors: Andersen, P. B. (Intern), Aagaard Madsen, H. (Intern), Løgstrup Andersen, T. (Intern), Schettler, T. (Ekstern)
Number of pages: 8
Publication date: 2013

Host publication information
Title of host publication: Proceedings of 6th ECCOMAS Conference on Smart Structures and Materials (SMART 2013)
Publisher: Politecnico di Torino
Determination of the gel point of a polyfurfuryl alcohol resin and characterization of its curing rheokinetics

The determination of the gel point of a resin is a key in order to design and optimize the manufacturing process of composite materials. In this work, the gel point of a biobased polyfurfuryl alcohol (FA) resin has been determined by rheological isothermal tests at different curing temperatures. The obtained gel times using three different amounts of catalyst (2, 4 and 6 % wt.) were correlated to temperature by the Macosko model; to predict the gel time at any temperature within the studied range. Furthermore, the evolution of the complex viscosity of the FA resin after its gel point has been studied as a function of the amount of catalyst and temperature. The rate of viscosity change was compared to the rate of viscosity change during the pre-gel stage, and a clear reduction was observed. Thus, the two different curing stages (pregel and post-gel) can be clearly identified by the rheological behavior of the resin system. The evolution of the viscosity has been modeled using widely used rheokinetic models. Finally, since rheological properties such as viscosity and complex modulus (G*) are highly sensitive to the molecular weight of a polymeric system, and they can be used as indicators of the degree-of-cure of a resin, the measured complex modulus of the FA resin has been used to determine degree-of-cure profiles for FA resins with different amounts of catalyst, and at a range of temperatures.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Complutense University
Authors: Dominguez, J. C. (Ekstern), Madsen, B. (Intern)
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Main Research Area: Technical/natural sciences

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ISI indexed (2013): ISI indexed no
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ISI indexed (2012): ISI indexed no
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ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
BFI (2009): BFI-level 1
BFI (2008): BFI-level 1
Original language: English
Electronic versions:
DETERMINATION_OF_THE_GEL_POINT.pdf
Publication: Research - peer-review » Conference article – Annual report year: 2013

Determination of the minimum size of a statistical representative volume element from a fibre-reinforced composite based on point pattern statistics

In a previous study, Trias et al. [1] determined the minimum size of a statistical representative volume element (SRVE) of a unidirectional fibre-reinforced composite primarily based on numerical analyses of the stress/strain field. In continuation of this, the present study determines the minimum size of an SRVE based on a statistical analysis on the spatial statistics of the fibre packing patterns found in genuine laminates, and those generated numerically using a microstructure.
Effect of consolidation pressure on volumetric composition and stiffness of unidirectional flax fibre composites

Unidirectional flax/polyethylene terephthalate composites are manufactured by filament winding, followed by compression moulding with low and high consolidation pressure, and with variable flax fibre content. The experimental data of volumetric composition and tensile stiffness are analysed with analytical models, and the composite microstructure is assessed by microscopy. The higher consolidation pressure (4.10 vs. 1.67 MPa) leads to composites with a higher maximum attainable fibre volume fraction (0.597 vs. 0.530), which is shown to be well correlated with the compaction behaviour of flax yarn assemblies. A characteristic microstructural feature is observed near the transition stage, the so-called local structural porosity, which is caused by the locally fully compacted fibres. At the transition fibre weight fraction, which determines the best possible combination of high fibre volume fraction and low porosity, the high pressure composites show a higher maximum performance in terms of tensile stiffness (40 vs. 35 GPa). The good agreement with the model calculations (fibre compaction behaviour, and composite volumetric composition and mechanical properties), allows the making of a property diagram showing stiffness of unidirectional flax fibre composites as a function of fibre weight fraction for consolidation pressures in the range 0–10 MPa.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Karadeniz Technical University, Swansea University
Authors: Aslan, M. (Ekstern), Mehmood, S. (Ekstern), Madsen, B. (Intern)
Pages: 3812–3824
Publication date: 2013
Main Research Area: Technical/natural sciences
Effect of processing on fracture of binderfree all-cellulose composites

Binderfree all-cellulose composites were prepared by a mechanical refinement process that allows the formation of intramolecular hydrogen bonds between the cellulose molecules during the drying process. The extent of this hydrogen bond network strongly depends on the duration of the refinement process. The fracture properties are studied at five different refining times. Due to the non-linear mechanical response of the binderfree all-cellulose composites, a method is first developed to obtain the fracture properties (fracture resistance and mode I cohesive law). The method uses a Double Cantilever Beam (DCB) sandwich specimen loaded with pure bending moments and it is based on the J integral. It is found that an increase of the refining times results a) in an increase of the crack initiation fracture energy and in a decrease of the steady-state fracture energy, and b) in an increase of the mode I peak cohesive traction.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Queen Mary University of London
Authors: Goutianos, S. (Intern), Arevalo, R. (Ekstern), Sørensen, B. F. (Intern), Peijs, T. (Ekstern)
Pages: 233-240
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ISI indexed (2013): ISI indexed no
BFI (2012): BFI-level 1
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BFI (2010): BFI-level 1
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BFI (2008): BFI-level 1
Original language: English
Electronic versions:
Effect_of_processing.pdf
Publication: Research - peer-review › Conference article – Annual report year: 2013

Experimental and numerical study of the micro-mechanical failure in composites

The fibre/matrix interfacial debonding is found to be the first microscale failure mechanism leading to subsequent macroscale transverse cracks in composite materials under tensile load. In this paper, the micromechanical interface failure in fiber-reinforced composites is studied experimentally and by numerical modeling by means of the finite element analysis. Two fibers embedded in the matrix are subjected to a remote transverse tensile load (see Fig. 1a). The trapezoidal cohesive zone model proposed by Tvergaard and Hutchinson [14] is used to model the fracture of the fiber-matrix interfaces. This study is based on the comparison between the results of numerical modeling and those corresponding to the experimental tests by employing two parameters: The angle from the load direction to the crack tip and the crack normal opening. This comparison aims to investigate the interfacial properties and also assess the progressive fiber-matrix debonding by focusing on the interaction of two fibers with dissimilar interfacial strengths.

General information
State: Published
Experiments and Analyses for Determining Fibre/Matrix Interface Parameters – Understanding Debonding Problems

A new experimental technique is developed to monitor the initiation and propagation of a debond crack during a fibre pull-out experiment. The advanced experimental setup consists of a high resolution video camera and a laser extensometer mounted at a tensile test machine. The test setup enables the measurement of the fibre/matrix displacement and debond length. A micromechanical model is used for analysing the experimental data. It allows the evaluation of the following parameters: the interface debond energy $G_{IIc}$ and the frictional sliding shear stress $\tau_s$ at the fibre/matrix interface, and the misfit strain $\Delta \varepsilon_T$, accounting for initial residual stresses. Specimens of a single steel fibre embedded centrally in a polyester matrix are tested using the experimental setup and the model. A practical experimental procedure for establishing the interface parameters is suggested, and an example demonstrates the procedure and yields a set of interface parameters.
Fatigue as a design driver for composite wind turbine blades

**General information**
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Knowledge Centre Wind turbine Materials and Constructions
Authors: Nijssen, R. (Ekstern), Brøndsted, P. (Intern)
Publication date: 2013

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ISBN (Print): 978-0-85709-426-1
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Series: Woodhead Publishing Series in Energy
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Fatigue R=0.1 E-series Reichhold

**General information**
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Rasmussen, S. (Intern)
Publication date: 2013

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Publication: Research › Report – Annual report year: 2013
Fibre waviness and misalignment measurement of unidirectional glass/LPET commingled composites – Effect on mechanical properties

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Centro de Investigacion Cientifica de Yucatan, Comfil ApS
Authors: Raghavalu Thirumalai, D. P. (Intern), Lilholt, H. (Intern), Aviles, F. (Ekstern), Løgstrup Andersen, T. (Intern), Knudsen, H. (Ekstern)
Pages: 349-363
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BFI (2012): BFI-level 1
ISI indexed (2012): ISI indexed no
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BFI (2010): BFI-level 1
BFI (2009): BFI-level 1
BFI (2008): BFI-level 1
Original language: English
Electronic versions:
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Publication: Research - peer-review › Conference article – Annual report year: 2013

Implementing Advanced Materials Models in a Commercial Finite Element Code

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern), Mishnaevsky, L. (Intern)
Number of pages: 2
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Main Research Area: Technical/natural sciences
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Keynote presentation
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Improved Compression Strength of Carbon/Glass/Epoxy Hybrid Composites

General information
State: Published
Influence of Temperature on Mechanical Properties of Jute/Biopolymer Composites

Biopolymers and natural fibers are receiving wide attention for the potential to have good performance composites with low environmental impact. A current limitation of most biopolymers is however their change in mechanical properties at elevated temperatures. This study investigates the mechanical properties of two biomass-based polymers, polylactic acid (PLA) and cellulose acetate (CA), as a function of ambient temperature in the range from 5 to 80°C. Tests were done for neat polymers and for jute fiber/biopolymer composites. Micromechanical models were applied to back-calculate the reinforcement efficiency of the jute fibers. The elastic modulus of neat PLA is constant until a temperature of about 45°C, after which it is decreased rapidly. For neat CA, the elastic modulus is almost constant in the whole temperature range. The maximum stress of the neat biopolymers is consistently reduced. For the jute fiber composites, both the elastic modulus and maximum stress are reduced when the temperature is increased. For the elastic modulus, this is shown to be due to a reduction in the reinforcement efficiency of the jute fibers; i.e., a reduction in the back-calculated effective elastic modulus of the fibers. Altogether, the results demonstrate that the thermal sensitivity parameters typically provided for polymers, e.g., the glass transition temperature and the heat deflection temperature, cannot be used as sole parameters for determining the gradual change in mechanical properties of polymers and composites. © 2012 Wiley Periodicals, Inc.
Interface debond crack growth in tension–tension cyclic loading of single fiber polymer composites

Fiber/matrix interface debond crack growth from a fiber break is defined as one of the key mechanisms of fatigue damage in unidirectional composites. Considering debond as an interface crack its growth in cyclic loading is analyzed utilizing a power law, where the debond growth rate is a power function of the change of the strain energy release rate in the cycle. To obtain values of two parameters in the power law cyclic loading of fragmented single fiber specimen is suggested. Measurements of the debond length increase with the number of load cycles in tension–tension fatigue are performed for glass fiber/epoxy single fiber composites. Analytical method in the steady-state growth region and FEM for short debonds are combined for calculating the strain energy release rate of the growing debond crack. Interface failure parameters in fatigue are determined by fitting the modeling and experimental results. The determined parameters for interface fatigue are validated at different stress levels.

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General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics, Lulea University of Technology
Authors: Pupurs, A. (Ekstern), Goutianos, S. (Intern), Brøndsted, P. (Intern), Varna, J. (Ekstern)
Polymer–matrix composites (PMCs), Debonding, Fatigue, Finite element analysis (FEA)

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Source-ID: n:oat:DTIC-ART:elsevier/373182147::21242
Life cycle strain monitoring in glass fibre reinforced polymer laminates using embedded fibre Bragg grating sensors from manufacturing to failure

A holistic approach to strain monitoring in fibre-reinforced polymer composites is presented using embedded fibre Bragg grating sensors. Internal strains are monitored in unidirectional E-glass/epoxy laminate beams during vacuum infusion, curing, post-curing and subsequent loading in flexure until failure. The internal process-induced strain development is investigated through use of different cure schedules and tool/part interactions. The fibre Bragg grating sensors successfully monitor resin flow front progression during infusion, and strain development during curing, representative of the different cure temperatures and tool/part interfaces used. Substantial internal process-induced strains develop in the transverse fibre direction, which should be taken into consideration when designing fibre-reinforced polymer laminates. Flexure tests indicate no significant difference in the mechanical properties of the differently cured specimens, despite the large differences in measured residual strains. This indicates that conventional flexure testing may not reveal residual strain or stress effects at small specimen scale levels. The internal stresses are seen to influence the accuracy of the fibre Bragg gratings within the loading regime. This study confirms the effectiveness of composite life cycle strain monitoring for developing consistent manufacturing processes.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Civil Engineering, Section for Building Design, Wind Turbines, Section for Structural Engineering, Department of Mechanical Engineering
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BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.42 SJR 0.517 SNIP 0.781
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.586 SNIP 0.88 CiteScore 1.4
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.606 SNIP 1.183 CiteScore 1.44
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.624 SNIP 1.207 CiteScore 1.45
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.607 SNIP 1.26 CiteScore 1.21
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.656 SNIP 1.283 CiteScore 1.23
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Martensitic transformations in nanostructured nitinol: Finite element modeling of grain size and distribution effects

A computational model of martensitic phase transformation in nanostructured nitinol is developed which takes into account the grain size effect. On the basis of the theoretical analysis of the thermodynamic transformation criterion and the energy barrier for phase transformation, it was demonstrated that the energy barrier for martensitic phase transformation in nanocrystalline nitinol increase drastically with decreasing the grain size. Finite element simulations of phase transformations and structure evolution in nanocrystalline nitinol under mechanical (tensile) loading are carried out for different structures of the materials. It was observed that the volume content of martensitic phase decreases drastically with reducing the grain size. When the grain size is smaller than some critical value (around 50–80nm, both in our simulations and in experimental data), the martensitic phase transformation are totally suppressed. Graded and localized distributions of grain sizes of nitinol were compared with nitinol samples with homogeneous grain size distribution. In the materials with localized region of small grains, it was observed that the martensite rich regions form first on the border between the coarse and fine grained regions, and expand inside the region with small grains along the shear band direction.

General information
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Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Liu, H. (Intern), Mishnaevsky, L. (Intern)
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Publication date: 2013
Main Research Area: Technical/natural sciences

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BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.37 SJR 0.926 SNIP 1.259
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.993 SNIP 1.348 CiteScore 2.3
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.129 SNIP 1.677 CiteScore 2.47
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.965 SNIP 1.337 CiteScore 2.15
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.022 SNIP 1.647 CiteScore 2.14
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.996 SNIP 1.46 CiteScore 1.97
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.961 SNIP 1.257
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 0.978 SNIP 1.308
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.919 SNIP 1.3
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Mesh dependency of smeared-out non-linear composite finite element models of compressive failure mechanism in composite materials
Microstructure and Mechanical Properties of Aligned Natural Fibre Composites

Recently, there has been a great interest in developing and maturing natural fibre composites for structural applications. Natural fibres derived from plants such as flax and hemp have the potential to compete with traditional glass fibres as reinforcements in polymer matrices, due to good specific properties (stiffness-to-density ratio). The perspective of using natural fibres is to have a sustainable, biodegradable, CO2-neutral alternative to glass fibres. However, so far, it has not been possible to take full advantage of the natural fibre properties when using them for composite applications. Several challenges have to be addressed and solved, many of which pertain to the fact that the fibres are sourced from a natural resource: 1) Inconsistent properties, depending on plant species, growth and harvest conditions, and fibre extraction techniques. 2) Strength values of composites are lower than expected based on tests of single fibres. 3) Compared to continuous glass fibres, natural fibres are relatively short, which makes it difficult to achieve an optimized fibre architecture. 4) Natural fibres are hydrophilic, meaning that they do not bond well with standard polymer matrix systems, most of which are hydrophobic.

The present ph.d. thesis is primarily concerned with challenges 2 (unexpected low strength of composites) and 3 (optimization of fibre architecture).

Reasons for the lower than expected strength of natural fibre composites are investigated by performing X-ray tomographic microscopy during tensile tests of small composite specimens. With this technique, 3D images can be obtained with spatial resolution < 1 µm. By studying the 3D microstructure of the composite specimens at a number of arrested load steps, a number of damage mechanisms have been identified: (i) Interface splitting cracks typically seen at the interfaces of bundles of unseparated fibres, (ii) matrix shear cracks, and (iii) fibre failures typically seen at fibre defects. The three damage mechanisms initiated at about 50, 75 and 90% of the failure stress, respectively.

After harvesting the plants, the fibre bundles in the plants are extracted, and separated into individual fibres. If this separation is not complete, bundles consisting of 5-15 fibres will remain among the fibres. Important insight was gained on the significance of avoiding bundles of unseparated fibres. It was found that such bundles are likely to result in fibre/matrix debonding cracks, which can lead to ultimate failure by large splitting cracks. Also, the fibre bundles were observed to...
have a tendency to fail across the entire cross section of the bundle. This will lead to a large stress concentration, which can result in specimen failure.

Since individual natural fibres are relatively short (50-70mm), they are traditionally spun into fibre yarns in order to be able to handle the fibres. However, spinning the fibres effectively equates to introducing a large amount of fibre misalignment, which decreases the composite stiffness properties. Through development of a model based on the geometry of a yarn with fibre twisting and yarn helicity, the relation between fibre misalignment and composite tensile stiffness was examined. The model incorporates a ±-stiffening effect, similar to what is used in laminate theory. Experimental studies were performed with composites fabricated from yarns with different amounts of fibre twist and yarn helicity. By fitting the proposed model to the experimental data, good agreement was obtained. From the model predictions, it was found that yarn helicity is actually more detrimental than fibre twisting with regards to composite stiffness.

Finally, studies are performed on the fracture toughness of natural fibre composites. Initially, a novel approach is proposed for calculating the fracture toughness from data obtained from double cantilever beam tests. The developed approach is based on determination of the curvatures of the beams during the tests and it is not necessary to have any knowledge of the layup sequence, or stiffness and thickness of individual layers. This is especially beneficial for complicated/unknown beam layups. It was proposed that the beam curvatures are determined using strain gauges. After developing the approach, it was used to determine the fracture toughness of flax/PLA (polymer based on lactic acid) specimens made from yarns with different twisting angles. It was found that a high twisting angle greatly decreases the fracture toughness of the composite, such that specimens made with yarns with no fibre twisting were more than 10 times tougher than specimens with a high degree of twisting.

Thus, based on the work in the present ph.d. thesis, it is found that achieving a method for separating the fibres completely without damaging them, is important for optimizing the composite strength. Furthermore, it is found that achieving a good fibre alignment is important for both the composite stiffness and the composite fracture toughness. These suggestions for manufacturers of natural fibre composites, are presented with an overall purpose of contributing to optimizing natural fibre composites for load-bearing usage.

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**Monitoring debond crack propagation and pullouts for a composite interface – Pullout tests**

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**Multivariate data-driven modelling and pattern recognition for damage detection and identification for acoustic emission and acousto-ultrasonics**

Different methods are commonly used for non-destructive testing in structures; among others, acoustic emission and ultrasonic inspections are widely used to assess structures. The research presented in this paper is motivated by the need to improve the inspection capabilities and reliability of structural health monitoring (SHM) systems based on ultrasonic guided waves with focus on the acoustic emission and acousto-ultrasonics techniques. The use of a guided wave based approach is driven by the fact that these waves are able to propagate over relatively long distances, and interact sensitively and uniquely with different types of defect. Special attention is paid here
to the development of efficient SHM methodologies. This requires robust signal processing techniques for the correct interpretation of the complex ultrasonic waves. Therefore, a variety of existing algorithms for signal processing and pattern recognition are evaluated and integrated into the different proposed methodologies. As a contribution to solve the problem, this paper presents results in damage detection and classification using a methodology based on hierarchical nonlinear principal component analysis, square prediction measurements and self-organizing maps, which are applied to data from acoustic emission tests and acousto-ultrasonic inspections. At the end, the efficiency of these methodologies is experimentally evaluated in diverse anisotropic composite structures.

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Optical diagnostics of a gliding arc

Dynamic processes in a gliding arc plasma generated between two diverging electrodes in ambient air driven by 31.25 kHz AC voltage were investigated using spatially and temporally resolved optical techniques. The life cycles of the gliding arc were tracked in fast movies using a high-speed camera with framing rates of tens to hundreds of kHz, showing details of ignition, motion, pulsation, short-cutting, and extinction of the plasma column. The ignition of a new discharge occurs before the extinction of the previous discharge. The developed, moving plasma column often short-cuts its current path triggered by Townsend breakdown between the two legs of the gliding arc. The emission from the plasma column is shown to pulsate at a frequency of 62.5 kHz, i.e., twice the frequency of the AC power supply. Optical emission spectra of the plasma radiation show the presence of excited N2, NO and OH radicals generated in the plasma and the dependence of their relative intensities on both the distance relative to the electrodes and the phase of the driving AC power. Planar laser-induced fluorescence of the ground-state OH radicals shows high intensity outside the plasma column rather than in the center suggesting that ground-state OH is not formed in the plasma column but in its vicinity.

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Optimal Design of Composite Structures by Advanced Mixed Integer Nonlinear Optimization

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Performance of Biodegradable Polymers used in Mechanically Loaded Implants

Total hip arthroplasty is the most common surgical procedure performed in the orthopaedic field, and it is considered the cornerstone in the treatment of osteoarthritis in the hip joint. It has been estimated that between 0.5-1% of the population in most Western Countries requires a total hip arthroplasty at some point in their life. The weakening of the natural stabilizers in the hip joint during the surgery, makes the patients susceptible to dislocation, in the first 3-6 months after the surgery. Studies show that approximately 3-5% of patients experience a dislocation at some stage. The factors predisposing for early dislocation have not been completely established, making it difficult to take successful preventative measures. The objective of this PhD thesis was to design an implantable, biodegradable device to guard against these dislocations.

The hip dislocation preventer should allow for easy adaptation, and mounting onto most types of hip implants, without changing the basic design of the present implant. The objective is to have a structure, which will put a restrain on the artificial hip implant as it moves into the extreme positions associated with dislocation, without further affecting the normal movement relative to the hip implant. Therefore, the stress strain profile of the device, would have to include an initial strain region, where the stress remain low, after which the stress should increase rapidly as the devise locks, preventing the dislocation. To achieve this, the design of the hip dislocation preventer should be a cone shaped mesh, encapsulating the hip implant.

Using the the basic geometry of the hip implant, a simple model was developed, describing the most common movement pattern associated with hip dislocation. The requirements concerning the initial strain region, was determined from the model. The analysis was done using two different attachment solutions, and two different locking scenarios. The results showed, that the initial strain region of the hip dislocation preventer would have to be at least 30%, and that the mesh should be able to withstand loads between 1700 N and 5000 N. Furthermore, the analysis show, that if the devise is designed to allowing the hip some degree of subluxation, the range of movement of the hip would be increased by approximately 15-19°, relative to the solution without subluxation. However, this also increases the requirements of the
initial strain region by 8-13%. The conclusion to the requirement analysis was that both attachment solutions proposed in the project, are possible in theory, depending on the distance of the mounting point on the modified acetabular cup. The hip dislocation preventer should work as a restrictive force during the first 3-6 months, when the joint is most vulnerable to dislocations. After this period, it should slowly degrade, enabling the joint to become stronger. From the results found in the literature, poly-L-lactic acid (L-PLA) was chosen as a suitable material. In order to characterize the material, L-PLA yarns were degraded in phosphate buffered saline for 6 months. Each month, a set of test consisting of, uniaxial tensile tests, at two different deformation rates, stress relaxation tests, and creep tests were performed. The uniaxial tensile test generally show very little change in the elastic modulus, yield stress, and mean strain at break, during the first 5 to 6 months. A significant drop in the elastic modulus was observed between month 5 and 6 at both loading rates, which corresponds well with the degradation period of L-PLA. A larger number of experiments, and a longer degradation period is required, in order to determine if the small fluctuations in the properties, is a general property of the material. The stress at break was found to gradually decrease during the 6 months, and the deformations rate was found to have a significant effect on the yield stress and the stress at break, but not on the elastic modulus and strain at break. Both the stress relaxation, and the creep test show that there is a change in the material in the initial degradation period, and the results could indicate, that the material experiences less relaxation and creep, a month after the in vitro degradation period. However, there is a large variance in the data, and more tests are needed to determine if this observation is correct. The overall conclusion of the material tests of the L-PLA yarns is, that the six month degradation in vitro, did not effect the tensile properties in a way that would significantly effect their functionality. The L-PLA yarns would therefore maintain their integrity during the critical period, where the hip dislocation preventer should be functional. The tensile properties of the L-PLA yarns were used to analyse, how a plain weave mesh would behave during different types of elongations. A model proposed by Kawabate et al in 1973 was modified, and used to analyse the problem, using different weave densities. Comparing the results found using the model, with the limits found during the strain analysis, showed that in order to maintain the full range of motion of the hip, the weave would have to be oriented in a 45° angle to the direction of deformation. From the model the initial strain region was predicted to lie between 35-40%, and the tensile force that the fabric can withstand, without going into plastic deformation was between 2000-5000 N. From the analysis and the material tests it was found that using a plain woven LPLA mesh, the strength and flexibility needed of the hip dislocation preventer would be attainable.

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Polymer Nanocomposites for Wind Energy Applications: Perspectives and Computational Modeling
Strength and reliability of wind blades produced from polymer composites are the important preconditions for the successful development of wind energy. One of the ways to increase the reliability and lifetime of polymer matrix composites is the nanoengineering of matrix or fiber/matrix interfaces in these composites. The potential and results of nanoclay reinforcements for the improvement of the mechanical properties of polymer composites are investigated using continuum mechanics and micromechanics methods and effective phase model. It is demonstrated that nanoreinforcement allows to increase the stiffness and strength of composites.

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Prediction of process induced shape distortions and residual stresses in large fibre reinforced composite laminates: With application to Wind Turbine Blades

The present thesis is devoted to numerical modelling of thermomechanical phenomena occurring during curing in the manufacture of large fibre reinforced polymer matrix composites with thick laminate sections using vacuum assisted resin transfer moulding (VARTM). The main application of interest in this work is modelling manufacturing induced shape distortions and residual stresses in commercial wind turbine composite blades. Key mechanisms known to contribute to shape distortions and residual stress build-up are reviewed and the underlying theories used to model these mechanisms are presented. The main mechanisms of thermal-, chemical- and mechanical origin are: (i) the thermal expansion mismatch of the constitutive composite materials, layer and tooling, (ii) chemical cure shrinkage of the composite matrix material and (iii) the tooling (i.e. the mould, inserts etc.) influence on the composite part.

In the modelling approach taken in the current study, 1D and 3D thermomechanical models are utilized. A 1D thermomechanical model in a finite difference (FD) framework, capable of predicting heat transfer, internal heat generation, cure degree development, as well as process induced in-plane strains and residual stresses is initially presented. This 1D model is the framework for the first attempt at a void growth model, capable of predicting the laminate through-thickness discretized void size distribution, as a function of processing parameters.

Using a 3D thermomechanical finite element (FE) model in ABAQUS, different constitutive modelling approaches are investigated, including a cure hardening instantaneous linear elastic (CHILE) approach, a viscoelastic approach and a path-dependent approach. The latter is a limiting case of viscoelasticity. These approaches are investigated with regards to their accuracy in predicting process induced strain and stress development in thick section laminates during curing, and more precisely regarding the evolution of the composite thermoset polymer matrix mechanical behaviour during the phase transitions experienced during curing. The different constitutive approaches are utilized in various case studies and compared, where possible, to experimental results from measured in situ internal total strains in laminates using embedded fibre Bragg grating (FBG) sensors. Due to reasonable model accuracy, ease of implementation and use of relatively simply obtained material characterization data, the CHILE and path-dependent approaches are found to be most favorable. It is shown that use of the viscoelastic approach to accurately predict process induced strains and stresses in modelling manufacturing cases where mild tooling constraints on the composite part exist, is not viable. In a final case study, process induced shape distortions in a commercial wind turbine blade root subsection, courtesy of LM Wind Power A/S, are analyzed using the CHILE constitutive approach. It is shown how large non-uniform through-thickness part thermal- and corresponding cure gradients are the main driving factors for process induced shape distortions.

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Preliminary characterization of glass fiber sizing
Glass fiber surfaces are treated with sizing during manufacturing. Sizing consists of several components, including a film former and a silane coupling agent that is important for adhesion between glass fibers and a matrix. Although the sizing highly affects the composite interface and thus the strength of the composites, little is known about the structure and chemistry of the sizing. A part of sizing was extracted by soxhlet extraction. The fibers were subsequently burned and some fibers were merely burned for analysis of glass fiber and sizing. The results showed that the analyzed fibers had amounts of bonded and physisorbed sizing similar to what has been presented in literature. An estimated sizing thickness
was found to be approximately 100 nm. It is indicated that an epoxy-resin containing film former and a polyethylene oxide lubricant are present, yet no silanes or other sizing components were identified in the extractant.

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**Pretreatment of the macroalgae Chaetomorpha linum for the production of bioethanol - Comparison of five pretreatment technologies**

A qualified estimate for pretreatment of the macroalgae Chaetomorpha linum for ethanol production was given, based on the experience of pretreatment of land-based biomass. *C. linum* was subjected to hydrothermal pretreatment (HTT), wet oxidation (WO), steam explosion (STEX), plasma-assisted pretreatment (PAP) and ball milling (BM), to determine effects of the pretreatment methods on the conversion of *C. linum* into ethanol by simultaneous saccharification and fermentation (SSF). WO and BM showed the highest ethanol yield of 44 g ethanol/100 g glucan, which was close to the theoretical ethanol yield of 57 g ethanol/100 g glucan. A 64% higher ethanol yield, based on raw material, was reached after pretreatment with WO and BM compared with unpretreated *C. linum*, however 50% of the biomass was lost during WO. Results indicated that the right combination of pretreatment and marine macroalgae, containing high amounts of glucan and cleaned from salts, enhanced the ethanol yield significantly. © 2013 Elsevier Ltd.

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Process conditions and volumetric composition in composites
The obtainable volumetric composition in composites is linked to the gravimetric composition, and it is influenced by the conditions of the manufacturing process. A model for the volumetric composition is presented, where the volume fractions of fibers, matrix and porosity are calculated as a function of the fiber weight fraction, and where parameters are included for the composite microstructure, and the fiber assembly compaction behavior. Based on experimental data of composites manufactured with different process conditions, together with model predictions, different types of process related effects are analyzed. The applied consolidation pressure is found to have a marked effect on the volumetric composition. A power-law relationship is found to well describe the found relations between the maximum obtainable fiber volume fraction and the consolidation pressure. The degree of fiber/matrix compatibility and the related amount of interface porosity is found to have a negligible effect on the volumetric composition. Only for the extreme case where an interface gap of 250 nm is considered to exist along the entire fiber perimeter, the porosity of the composites is noticeable above zero, but still the fiber and matrix volume fractions are only slightly changed. Air entrapment in the matrix due to non-ideal process conditions is found to have a marked effect on the volumetric composition. For composites with such type of matrix porosity, the porosity content is decreased when the fiber content is increased. Altogether, the model is demonstrated to be a valuable tool for a quantitative analysis of the effect of process conditions. Based on the presented findings and considerations, examples of future work are mentioned for the further improvement of the model.
Quantitative analysis of length-diameter distribution and cross-sectional properties of fibers from three-dimensional tomographic images

A number of rule-of-mixture micromechanical models have been successfully used to predict the mechanical properties of short fiber composites. However, in order to obtain accurate predictions, a detailed description of the internal structure of the material is required. This information is often obtained from optical microscopy of polished cross-sections of a composite. This approach gives accurate yet local results, but a rather large number of optical images have to be processed to achieve a representative description of the morphology of the material. In this work a fully automatic algorithm for estimating the length-diameter distribution of solid or hollow fibers, utilizing three-dimensional X-ray tomographic images, is presented. The method is based on a granulometric approach for fiber length distribution measurement, combined with a novel algorithm that relates cross-sectional fiber properties to fiber length. The work opens up a possibility to assess multivariate distributions of fiber length and diameter, cross-sectional area or other microstructural fiber properties. As an example, the description of the microstructure of different composites with natural fibers is presented, along with verification of the results.
Quantitative study on the statistical properties of fibre architecture of genuine and numerical composite microstructures

A quantitative study is carried out regarding the statistical properties of the fibre architecture found in composite laminates and that generated numerically using Statistical Representative Volume Elements (SRVE’s). The aim is to determine the reliability and consistency of SRVE’s for representation of the composite microstructure as well as investigate the effect of a varying fibre radii distribution on the fibre architecture. Based on digital image analysis, the fibre architecture of unidirectional glass fibre composites with varying fibre content is recognised. The fibre architecture found is compared to a numerical microstructure generator using Monte Carlo simulations. It is shown that the numerical microstructure generator produces fibre arrangements that are statistically similar to the observed, which indicates a reliable and consistent SRVE. The microstructural effects of a parametric variation of the parameters for fibre radii distribution are simulated, and the influence on the fibre architecture is investigated.

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Selection of environmental sustainable fiber materials for wind turbine blades - a contra intuitive process?
Over the recent decades biomaterials have been marketed successfully supported by the common perception that biomaterials and environmental sustainability de facto represents two sides of the same coin. The development of sustainable composite materials such as blades for small-scale wind turbines have thus partially been focused on the substitution of conventional fiber materials with bio-fibers. The major question is if this material substitution actually, is environmental sustainable. In order to assess a wide pallet of environmental impacts and taking into account positive and negative environmental trade-offs over the entire life-span of composite materials, life cycle assessment (LCA) can be applied. In the present case study, four different types of fibers (carbon, glass, flax and carbon/flax mixture) are compared in terms of environmental sustainability and cost. Applying one of the most recent life cycle impact assessment methods, it is demonstrated that the environmental sustainability of the mixed carbon/flax fiber based composite material is better than that of the flax fibers alone. This observation may be contra-intuitive, but is mainly caused by the fact that the bio-material resin demand is by far exceeding the resin demand of the conventional fibers, and since the environmental burden of the resin is comparable to that of the fibers, resin demand is in terms of environmental sustainability important. On the other hand is the energy demand and associated environmental impacts in relation to the production of the carbon and glass fibers considerable compared to the impacts resulting from resin production. The ideal fiber solution, in terms of environmental sustainability, is hence the fiber composition having the lowest resin demand and lowest overall energy demand. The optimum environmental solution hence turns out to be a 70:30 flax:carbon mix, thereby minimizing the use of carbon fibers and resin. On top of the environmental sustainability assessment, a cost assessment of the four fiber solutions was carried out. The results of the economical assessment which turns out to not complement the environmental
sustainability, pinpoint that glass fibers are the most effective fiber material.

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ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
BFI (2009): BFI-level 1
BFI (2008): BFI-level 1
Original language: English
Electronic versions:
Selection_of_environmental_sustainable_fiber.pdf
Publication: Research - peer-review › Conference article – Annual report year: 2013

**Stiffness of carbon fibre epoxy composite tube**

**General information**
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern)
Publication date: 2013

**Publication information**
Publisher: DTU Wind Energy
Original language: English
Series: DTU Wind Energy I
Number: 160
Main Research Area: Technical/natural sciences

**Bibliographical note**
This is a confidential report only available for the customer and the accredited test persons. Please contact responsible for the test laboratory for further information.
Publication: Research › Report – Annual report year: 2013

**Strain Gauge Application in Soft Material Testing**

**General information**
Surface modification of nanofibrillated cellulose films by atmospheric pressure dielectric barrier discharge

A dielectric barrier discharge in a gas mixture of tetrafluoromethane (CF4) and O2 was used for tailoring the surface properties of nanofibrillated cellulose (NFC) films. The surface chemical composition of plasma-modified NFC was characterized by means of X-ray photoelectron spectroscopy and time-of-flight secondary ion mass spectrometry, while surface morphology was illustrated by atomic force microscopy. Wettability was characterized through the static sessile drop method. The adhesion between NFC and polylactide (PLA) laminated films was tested by the double cantilever beam technique. As a result of atmospheric pressure plasma treatment, the water contact angle of NFC films increased and the values were comparable with those of PLA films. On the other hand, surface chemical characterization revealed inhomogeneity of the plasma treatment and limited improvement in adhesion between NFC and PLA films. Further research in this direction is required in order to enhance the uniformity of the plasma treatment results.

General information

State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Energy Conversion and Storage, Imaging and Structural Analysis, Department of Chemical and Biochemical Engineering, The Danish Polymer Centre
Authors: Siró, I. (Intern), Kusano, Y. (Intern), Norrman, K. (Intern), Goutianos, S. (Intern), Plackett, D. (Intern)
Pages: 294-308
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information

Journal: Journal of Adhesion Science and Technology
Volume: 27
Issue number: 3
ISSN (Print): 0169-4243
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.362 SNIP 0.591 CiteScore 1.03
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.355 SNIP 0.637 CiteScore 0.99
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.4 SNIP 0.664 CiteScore 1.05
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.437 SNIP 0.769 CiteScore 1.19
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
**Scopus rating**
- (2012): SJR 0.448 SNIP 0.851 CiteScore 1.06
- ISi indexed (2012): ISi indexed yes
- BFI (2011): BFI-level 1
- Scopus rating (2011): SJR 0.444 SNIP 0.698 CiteScore 0.93
- ISi indexed (2011): ISi indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 1
- Scopus rating (2010): SJR 0.482 SNIP 0.758
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 1
- Scopus rating (2009): SJR 0.531 SNIP 0.791
- BFI (2008): BFI-level 1
- Scopus rating (2008): SJR 0.443 SNIP 0.672
- Scopus rating (2007): SJR 0.555 SNIP 0.848
- Scopus rating (2006): SJR 0.592 SNIP 0.9
- Scopus rating (2005): SJR 0.585 SNIP 1.216
- Scopus rating (2004): SJR 0.674 SNIP 0.889
- Scopus rating (2003): SJR 0.695 SNIP 1.09
- Scopus rating (2002): SJR 0.499 SNIP 0.774
- Scopus rating (2001): SJR 0.866 SNIP 1.046
- Scopus rating (2000): SJR 0.783 SNIP 1.215
- Scopus rating (1999): SJR 0.827 SNIP 1.207

**Original language:** English

Adhesion, Compatibility, Contact angle, Hydrophobicity, Polylactide, Nanofibrillated cellulose, Surface roughness

**DOIs:**
10.1080/01694243.2012.705522

**Publication:** Research - peer-review › Journal article – Annual report year: 2012

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**Testing composites for wind turbine blades**

**General information**
- **State:** Published
- **Organisations:** Department of Wind Energy, Composites and Materials Mechanics
- **Authors:** Mikkelsen, L. P. (Intern)
- **Number of pages:** 1
- **Publication date:** 2013
- **Event:** Abstract from International Conference on Future Technologies for Wind Energy, Laramie, Wyoming, United States.
- **Main Research Area:** Technical/natural sciences

**Host publication information**
- **Title:** Abstract from International Conference on Future Technologies for Wind Energy, Laramie, Wyoming, United States
- **Publisher:** Canadian Association for Composite Structures and Materials
- **Main Research Area:** Technical/natural sciences
- **Conference:** 19th International Conference on Composite Materials, Montréal, Canada, 28/07/2013 - 28/07/2013

**Epoxy, Glass fibres, Carbon fibres, Hybrid fabric, Compression properties**

**Electronic versions:**
- Tensile_and_compression.pdf

**Publication:** Research - peer-review › Article in proceedings – Annual report year: 2013

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**Tensile and compression properties of hybrid composites – A comparative study**

**General information**
- **State:** Published
- **Organisations:** Department of Wind Energy, Composites and Materials Mechanics
- **Authors:** Raghavalu Thirumalai, D. P. (Intern), Legstrup Andersen, T. (Intern), Markussen, C. M. (Intern), Madsen, B. (Intern), Lilholt, H. (Intern)
- **Pages:** 1029-1035
- **Publication date:** 2013
- **Event:** Proceedings of the 19th International Conference on Composite Materials (ICCM19)

**Host publication information**
- **Title of host publication:** Proceedings of the 19th International Conference on Composite Materials (ICCM19)
- **Publisher:** Canadian Association for Composite Structures and Materials
- **Main Research Area:** Technical/natural sciences
- **Conference:** 19th International Conference on Composite Materials, Montréal, Canada, 28/07/2013 - 28/07/2013
- **Epoxy, Glass fibres, Carbon fibres, Hybrid fabric, Compression properties**

**Electronic versions:**
- Tensile_and_compression.pdf

**Publication:** Research - peer-review › Article in proceedings – Annual report year: 2013
The effects of fibre architecture on fatigue life-time of composite materials

Wind turbine rotor blades are among the largest composite structures manufactured of fibre reinforced polymer. During the service life of a wind turbine rotor blade, it is subjected to cyclic loading that potentially can lead to material failure, also known as fatigue. With reference to glass fibre reinforced composites used for the main laminate of a wind turbine rotor blade, the problem addressed in the present work is the effect of the fibre and fabric architecture on the fatigue life-time under tension-tension loading. Fatigue of composite materials has been a central research topic for the last decades; however, a clear answer to what causes the material to degrade, has not been given yet. Even for the simplest kind of fibre reinforced composites, the axially loaded unidirectional material, the fatigue failure modes are complex, and require advanced experimental techniques and characterisation methodologies in order to be assessed. Furthermore, numerical evaluation and predictions of the fatigue damage evolution are decisive in order to make future improvements.

The present work is focused around two central themes: fibre architecture and fatigue failure. The fibre architecture is characterised using real material samples and numerical simulations. Experimental fatigue tests identify, quantify, and analyse the cause of failure. Different configurations of the fibre architecture are investigated in order to determine and understand the tension-tension fatigue failure mechanisms. A numerical study is used to examine the onset of fatigue failure. Topics treated include: experimental fatigue investigations, scanning electron microscopy, numerical simulations, advanced measurements techniques (micro computed tomography and thermovision), design of test specimens and preforms, and advanced materials characterisation. The results of the present work show that the fibre radii distribution has limited effect on the fibre architecture. This raises the question of which fibre radii distribution ensures optimum mechanical properties, damage tolerance, and fatigue performance. The experimental fatigue results and analyses identify and explain the onset of tension fatigue failure. It is documented that improvements of the fibre architecture and specimen design are needed in order to provide next generation of fatigue resistant composite materials for wind turbine rotor blades.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Electrical Engineering, LM Wind Power Blades
Authors: Hansen, J. Z. (Intern), Brøndsted, P. (Intern), Østergaard, R. (Ekstern)
Number of pages: 188
Publication date: 2013

Publication information
Publisher: DTU Wind Energy
Original language: English

Series: DTU Wind Energy PhD
Number: 0018(EN)
Main Research Area: Technical/natural sciences
Electronic versions:
JZAN_CT_scan
JZAN_Temp_GPV_05_Butterfly
JZAN_Temp_GPV_10_ISO
DTU_Wind_Energy_PhD_0018_EN_.pdf

Relations
Projects:
The effects of fibre architecture on fatigue life-time of composite materials
Publication: Research › Ph.D. thesis – Annual report year: 2013

Ultrasound enhanced 50 Hz plasma treatment of glass-fiber-reinforced polyester at atmospheric pressure

Glass-fiber-reinforced polyester (GFRP) plates are treated using a 50Hz dielectric barrier discharge at a peak-to-peak voltage of 30 kV in helium at atmospheric pressure with and without ultrasonic irradiation to study adhesion improvement. The ultrasonic waves at the fundamental frequency of around 30 kHz with the sound pressure level of approximately 155
dB were introduced vertically to the GFRP surface through a cylindrical waveguide. The polar component of the surface energy was almost unchanged after the plasma treatment without ultrasonic irradiation, but drastically increased approximately from 20 up to 80 mJ/m² with ultrasonic irradiation. The plasma treatment with ultrasonic irradiation also introduced oxygen- and nitrogen-containing functional groups at the GFRP surface. These changes would improve the adhesion properties of the GFRP plates.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Energy Conversion and Storage, Imaging and Structural Analysis, Department of Physics, Plasma Physics and Fusion Energy, FORCE Technology, University of Southern Denmark, Danish Technological Institute
Authors: Kusano, Y. (Intern), Norrman, K. (Intern), Singh, S. V. (Intern), Leipold, F. (Intern), Morgen, P. (Ekstern), Bardenshtein, A. (Ekstern), Krebs, N. (Ekstern)
Pages: 825–833
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Adhesion Science and Technology
Volume: 27
Issue number: 7
ISSN (Print): 0169-4243
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.362 SNIP 0.591 CiteScore 1.03
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.355 SNIP 0.637 CiteScore 0.99
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.4 SNIP 0.664 CiteScore 1.05
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.437 SNIP 0.769 CiteScore 1.19
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.448 SNIP 0.851 CiteScore 1.06
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.444 SNIP 0.698 CiteScore 0.93
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.482 SNIP 0.758
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.531 SNIP 0.791
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.443 SNIP 0.672
Scopus rating (2007): SJR 0.555 SNIP 0.848
Scopus rating (2006): SJR 0.592 SNIP 0.9
Scopus rating (2005): SJR 0.585 SNIP 1.216
Scopus rating (2004): SJR 0.674 SNIP 0.889
Scopus rating (2003): SJR 0.695 SNIP 1.09
Scopus rating (2002): SJR 0.499 SNIP 0.774
Scopus rating (2001): SJR 0.866 SNIP 1.046
Uncertainty modelling and code calibration for composite materials

Uncertainties related to the material properties of a composite material can be determined from the micro-, meso- or macro-scales. These three starting points for a stochastic modelling of the material properties are investigated. The uncertainties are divided into physical, model, statistical and measurement uncertainties which are introduced on the different scales. Typically, these uncertainties are taken into account in the design process using characteristic values and partial safety factors specified in a design standard. The value of the partial safety factors should reflect a reasonable balance between risk of failure and cost of the structure. Consideration related to calibration of partial safety factors for composite material is described, including the probability of failure, format for the partial safety factor method and weight factors for different load cases. In a numerical example, it is demonstrated how probabilistic models for the material properties formulated on micro-scale can be calibrated using tests on the meso- and macro-scales. The results are compared to probabilistic models estimated directly from tests on the macro-scale. In another example, partial safety factors for application to wind turbine blades are calibrated for two typical lay-ups using a large number of load cases and ratios between the aerodynamic forces and the inertia forces.

General information
State: Published
Organisations: Department of Wind Energy, Wind Turbines, Composites and Materials Mechanics, Aalborg University
Authors: Toft, H. S. (Forskerdatabase), Branner, K. (Intern), Mishnaevsky, L. J. (Intern), Sørensen, J. D. (Intern)
Pages: 1729-1747
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Composite Materials
Volume: 47
Issue number: 14
ISSN (Print): 0021-9983
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2016): CiteScore 1.42 SJR 0.517 SNIP 0.781
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.586 SNIP 0.88 CiteScore 1.4
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.606 SNIP 1.183 CiteScore 1.44
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.624 SNIP 1.207 CiteScore 1.45
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.607 SNIP 1.26 CiteScore 1.21
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.656 SNIP 1.283 CiteScore 1.23
**Volumetric composition in composites and historical data**

The obtainable volumetric composition in composites is of importance for the prediction of mechanical and physical properties, and in particular to assess the best possible (normally the highest) values for these properties. The volumetric model for the composition of (fibrous) composites gives guidance to the optimal combination of fibre content, matrix content and porosity content, in order to achieve the best obtainable properties. Several composite materials systems have been shown to be handleable with this model. An extensive series of experimental data for the system of cellulose fibres and polymer (resin) was produced in 1942 – 1944, and these data have been (re-)analysed by the volumetric composition model, and the property values for density, stiffness and strength have been evaluated. Good agreement has been obtained and some further observations have been extracted from the analysis.

**General information**

State: Published  
Organisations: Department of Wind Energy, Composites and Materials Mechanics  
Authors: Lilholt, H. (Intern), Madsen, B. (Intern)  
Pages: 279-294  
Publication date: 2013  
Conference: 34th Risø International Symposium on Materials Science, Roskilde, Denmark, 02/09/2013 - 02/09/2013  
Main Research Area: Technical/natural sciences

**Publication information**

Volume: 34  
ISSN (Print): 0907-0079  
Ratings:  
BFI (2018): BFI-level 1  
BFI (2017): BFI-level 1  
BFI (2016): BFI-level 1  
BFI (2015): BFI-level 1  
BFI (2014): BFI-level 1  
BFI (2013): BFI-level 1
Water-cooled non-thermal gliding arc for adhesion improvement of glass-fibre-reinforced polyester

A non-equilibrium quenched plasma is prepared using a gliding-arc discharge generated between diverging electrodes and extended by a gas flow. It can be operated at atmospheric pressure and applied to plasma surface treatment to improve adhesion properties of material surfaces. In this work, glass-fibre-reinforced polyester plates were treated using an atmospheric pressure gliding-arc discharge with air flow to improve adhesion with a vinylester adhesive. The electrodes were water-cooled so as to operate the gliding arc continually. The treatment improved wettability and increased the density of oxygen-containing polar functional groups on the surfaces. Double cantilever beam specimens were prepared for fracture mechanic characterization of the laminate adhesive interface. It was found that gliding-arc treatment significantly increases the fracture resistance in comparison with a standard peel-ply treatment.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Physics, Plasma Physics and Fusion Energy, Lund University
Authors: Kusano, Y. (Intern), Sørensen, B. F. (Intern), Løgstrup Andersen, T. (Intern), Toftegaard, H. L. (Intern), Leipold, F. (Intern), Salewski, M. (Intern), Sun, Z. (Ekstern), Zhu, J. (Ekstern), Li, Z. (Ekstern), Alden, M. (Ekstern)
Pages: 135203
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Volume: 46
Issue number: 13
ISSN (Print): 0022-3727
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.07 SJR 0.645 SNIP 0.917
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.693 SNIP 1.046 CiteScore 2.1
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.069 SNIP 1.383 CiteScore 2.53
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.18 SNIP 1.469 CiteScore 2.6
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.244 SNIP 1.394 CiteScore 2.31
Wire tensile test kobber Poly-Tech

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Rasmussen, S. (Intern)
Publication date: 2013

Publication information
Publisher: DTU Wind Energy
Original language: English

Series: DTU Wind Energy I
Number: 68
Main Research Area: Technical/natural sciences
DTU Wind-I-68, 13-44-44019 I-74, 13-44-44019 I-74 DTU Wind-I-68

Bibliographical note
This is a confidential report only available for the customer and the accredited test persons. Please contact responsible for the test laboratory for further information.
Wood versus plant fibers: Similarities and differences in composite applications

The work on cellulose fiber composites is typically strictly divided into two separated research fields depending on the fiber origin, that is, from wood and from annual plants, representing the two different industries of forest and agriculture, respectively. The present paper evaluates in parallel wood fibers and plant fibers to highlight their similarities and differences regarding their use as reinforcement in composites and to enable mutual transfer of knowledge and technology between the two research fields. The paper gives an introduction to the morphology, chemistry, and ultrastructure of the fibers, the modeling of the mechanical properties of the fibers, the fiber preforms available for manufacturing of composites, the typical mechanical properties of the composites, the modeling of the mechanical properties with focus on composites having a random fiber orientation and a non-negligible porosity content, and finally, the moisture sensitivity of the composites. The performance of wood and plant fiber composites is compared to the synthetic glass and carbon fibers conventionally used for composites, and advantages and disadvantages of the different fibers are discussed. © 2013 Bo Madsen and E. Kristofer Gamstedt.
Attribute Based Selection of Thermoplastic Resin for Vacuum Infusion Process: A Decision Making Methodology

The composite industry looks toward a new material system (resins) based on thermoplastic polymers for the vacuum infusion process, similar to the infusion process using thermosetting polymers. A large number of thermoplastics are available in the market with a variety of properties suitable for different engineering applications, and few of those are available in a not yet polymerised form suitable for resin infusion. The proper selection of a new resin system among these thermoplastic polymers is a concern for manufactures in the current scenario and a special mathematical tool would be beneficial. In this paper, the authors introduce a new decision making tool for resin selection based on significant attributes. This article provides a broad overview of suitable thermoplastic material systems for vacuum infusion process available in today’s market. An illustrative example—resin selection for vacuum infused of a wind turbine blade—is shown to demonstrate the intricacies involved in the proposed methodology for resin selection.
Challenges Testing Composite Materials for Wind Turbine Blades

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Brøndsted, P. (Intern), Mikkelsen, L. P. (Intern)
Pages: 33-34
Publication date: 2012

Host publication information
Title of host publication: Abstracts. Indo-Danish Workshop On Future Composites Technologies for Wind Turbine Blades
Main Research Area: Technical/natural sciences
Conference: Indo-Danish Workshop On Future Composites Technologies for Wind Turbine Blades, Delhi, India, 08/10/2012 - 08/10/2012
Wind turbine blade, Test methods, Polymers, Composites, Fibre reinforcements

Characterisation of Flax Fibres and Flax Fibre Composites. Being cellulose based sources of materials
Cellulosic fibres, like wood and plant fibres, have the potential for use as load-bearing constituents in composite materials due to their attractive properties such as high stiffness-to-weight ratio that makes cellulosic fibre composites ideal for many structural applications. There is thus a growing interest among composite manufacturers for such low-cost and low-weight cellulosic fibre composites. In addition, wood and plant fibre based composites with thermoplastic polymeric matrices are recyclable, and they are cost attractive alternatives to oil based fibre reinforced polymer composites that currently have the largest market share for composite applications. However, the most critical limitation in the use of cellulosic fibre composites for structural applications is the lack of well described fibre properties, in particular, the tensile strength. This is due to variations in fibre morphology, fibre processing conditions, and applied test methods. Other limitations such as dimensional instability and low fibre-matrix adhesion have already been intensively investigated, and solutions have been found for many commercial applications. Therefore, a better understanding of the mechanical performance of these fibres, and with a focus on increasing their strength will make it possible for them to reach their full potential as reinforcement in composites. The present PhD study deals with several important subjects related to the use of flax fibres in composites. The emphasis is on the relationship between the complex microstructure and the tensile properties of flax fibres and their composites, based on textile flax yarn and a thermoplastic polymeric matrix.

Single flax fibres were isolated from flax fibre bundles which have been processed in two different steps of natural treatments (retting) and mechanical treatments (scutching and hackling). Microscopic observations of the defects formed in the fibres and their fracture surfaces after tensile testing show that large fracture areas are formed in a complex way due to defects in the fibre cell wall, and due to anisotropy of the internal cell wall structures. This is in contrast to the crack growth in brittle ceramic and glass fibres. Moreover, two typical stress-strain curves (linear and non-linear) measured for the flax fibres were found to be correlated with the amount of defected region in the fibres. The defects are induced in larger numbers and larger sizes during processing of the fibres, and this is found to be correlated with a decrease in tensile strength of the fibres. It is found that processing reduces the tensile strength from average values of 1450 MPa for naturally processed single fibres to 810 MPa for mechanically processed single fibres.

The large variation in tensile properties of flax fibres leads to an examination of the effect of defects and applied test methods. The fibres show a large coefficient of variation (CV) in the range 20-60% in general for all measured tensile properties. One reason for these relative large variations can be attributed to the assumption of a circular cross sectional area of the fibres. On average, these results in a 39% lower tensile strength than when the true fibre cross sectional area is used, and moreover, the variable aspect ratio of the cross section of fibres significantly affects the variation of the results. Also, the large variation in
properties is likely to be attributed to the distribution of defects along the fibres since the large defects lead to low mechanical properties, whereas smaller defects result in less reduced mechanical properties.

On the level of composites, the effect of consolidation pressure on the tensile properties of flax fibre composites was investigated. A porosity corrected rule of mixtures model, and a volumetric composition model for composites were used to model the experimental data. Flax fibre yarns and thermoplastic low-melting temperature polyethylene terephthalate (LPET) filaments were aligned in assemblies of different fibre weight fractions in the range 0.24 to 0.83 to manufacture unidirectional composites using two different consolidation pressures of 1.67 and 4.10 MPa. The maximum attainable fibre volume fraction is found to be 47% for the low pressure composites, whereas it is found to be 60% for the high pressure composites. The stiffness of the flax fibre/LPET composites is measured to be in the range 16 to 33 GPa depending on the consolidation pressure of the composites. The high pressure composites are found to have superior tensile properties in comparison with the low pressure composites. The tensile strength (mean ± std. dev.) of the low pressure composites was found to be 183±7 MPa while that of the high pressure composites was found to be 209±6 MPa at a fibre volume fraction of 22%. The effect of fibre correlated porosity and structural porosity in the composites is found to be highly important for the volumetric composition and tensile behaviour of the composites. The total porosity is measured in the range 2.4 to 32%, and it is found to be increased dramatically when the fibre weight fraction is increased above a transition value, as predicted by the volumetric composition model. This leads furthermore to a scatter in the experimental data of stiffness at high fibre weight fractions. The qualitative analysis of the composite cross sections by microscopy also shows that the low and high pressure composites have a similar microstructure at low fibre weight fractions. However, when the fibre content is increased, a difference in porosity content can be observed from the composite cross sections. The nominal tensile strength of the unidirectional flax fibre/LPET composites is measured in the range 180 to 340 MPa. However, in many cases, the tensile strength determined of unidirectional composites is not valid due to the fact that failure does not occur in the gauge section. It is actually common that unidirectional composites fail close to the grips, and they then split along the specimen in the tensile direction. Traditionally, the problem has been approached by the use of local reinforcement of the specimen in the gripping areas, the so-called tabs, but the problem has not been efficiently solved in practice. A key problem is that the stress state at the end of the tab can be singular, leading to premature failure of the tensile specimen. In the present study, the dependence of the order of the stress singularity at the vertex of dissimilar isotropic and orthotropic materials is investigated in terms of the elastic mismatches between the specimen and the tab materials, and the tab angle. Finite element modelling is performed to analyse the situation of a stress singularity. The results are aimed at creating a better specimen/tab design to accomplish failure in the gauge section of the tensile specimens, and thereby determine the true tensile strength of the materials. It is found that the stress singularity in the tab wedge is reduced with a decreased tab angle and with a decreased stiffness of the tab material. A simple criterion is proposed for the assessment of the severity of the stress singularity. In practice, gauge section failures should be achievable by selecting a test specimen design based on combinations of a stiff material in the tab section combined with a soft material (eg. epoxy adhesive) at the wedge end of the tab, forming a wedge. The wedge tip should have a small wedge angle in the range 5° and 10° depending on the stiffness ratio.

The conclusion of the PhD study is that flax fibres are an important source of cellulosic fibres. When the appropriate composite processing methods and the accurate test methods are used, flax fibre composites are demonstrated to be promising material candidates for structural applications as an attractive alternative to synthetic fibre composites.

**General information**

State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Aslan, M. (Intern), Sørensen, B. F. (Intern), Madsen, B. (Intern)
Number of pages: 168
Publication date: 2012

**Publication information**

Publisher: DTU Wind Energy
ISBN (Electronic): 978-87-92896-07-0
Original language: English

Series: DTU Wind Energy E
Number: 0005

Note re. dissertation: This PhD thesis is based on research done for a project "WoodFibre3D" undertaken between 2008 and 2012 at the Section of Composites and Materials Mechanics, Department of Wind Energy (former Risø National Laboratory for Sustainable Energy), Technical University of Denmark. The PhD study has been supervised by: Main supervisor; Professor, PhD, Bent F. Sørensen (DTU Wind Energy) Co-supervisor; Senior Scientist, PhD, Bo Madsen (DTU Wind Energy) The "WoodFibre3D" project was financially supported by Danish Agency for Science, Technology and Innovation project (grant no 274-07-0300). The research has also been partly funded under "NATEX" project at the European Community’s Seventh Framework Programme (grant no 214467). Their supports are gratefully acknowledged. As part of my PhD project, I have conducted laboratory experiments, participated in two international and two national conferences, visited universities in Europe, participated in several project meetings as a member of a European project group "WoodFibre3D", and contributed to international scientific journals.

Main Research Area: Technical/natural sciences

Electronic versions:
Composite materials for wind energy applications: micromechanical modeling and future directions

The strength and reliability of wind turbine blades depend on the properties, mechanical behavior and strengths of the material components (glass or carbon fibers and polymer matrix), and the interaction between them under loading. In this paper, ideas, methods and concepts of micromechanical modeling of materials for wind turbine blades are briefly reviewed. Using the variety of the modeling methods reviewed here, one can predict the strength, stiffness and lifetime of the materials, optimize their microstructures with view on the better usability for wind turbines, or compare the applicability of different groups of the materials to the application in wind turbine blades. Some examples of the analysis of the microstructural effects on the strength and fatigue life of composites are shown.
Computational testing and design of materials for wind energy and structural applications

The requirements to wind turbine blades and other elements are quite high. In the ideal case, a wind turbine should work for 20-30 years without or with minimum maintenance. That is why the damage resistance and strength of wind blade materials is of great importance. A way to enhance the strength and reliability of wind blades is to develop new advanced materials with improved structures. In this work, several computational micromechanical models of wind blade materials are presented. The possibility of computational testing of materials and their numerical optimization are discussed.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mishnaevsky, L. (Intern)
Pages: 1-5
Publication date: 2012

Design and test of box girder for a large wind turbine blade

This report is covering the structural design and full scale test of a box girder as a part of the project “Demonstration of new blade design using manufacturing process simulations” supported by the EUDP program. A box girder with a predetermined outer geometry was designed using new inventions, which create an inner structure in the box girder. With a combination of advanced FEM analysis and the inventions it was possible to reduce the material thickness of the cap by up to 40%. The new design of the box girder was manufactured at SSP Technology A/S, where it was demonstrated that the manufacturing process could include the new inventions. Subsequently the box girder was manufactured at the blade test facility at DTU Wind Energy.

A series of test was performed with the blade to investigate the behaviour during loading, and finally the girder was loaded to ultimate failure. The report includes the description of the test setup, the test and an overview over the results from the test performed on the box girder. During the final test the box girder failed at 58% of the expected ultimate load. Unfortunately, no definite conclusion could be made concerning the failure mechanism.

General information
State: Published
Organisations: Department of Wind Energy, Wind Turbines, Composites and Materials Mechanics
Authors: Nielsen, P. H. (Intern), Tesauro, A. (Intern), Bitsche, R. (Intern), McGugan, M. (Intern), Lynnov, C. (Ekstern), Sørensen, F. (Ekstern), Knudsen, H. (Ekstern), Berring, P. (Intern), Branner, K. (Intern), Lagerbon, M. (Intern),
Determination of the J integral for laminated double cantilever beam specimens: The curvature approach

A new approach is proposed for measuring the J integral (and thus the fracture resistance) of interface cracks in multiply laminates. With this approach the J integral is found from beam curvatures and applied moments. Knowledge of ply layup and stiffness is not required. In order to test the accuracy of the proposed approach, double cantilever beam specimen loaded with uneven bending moments (DCB-UBM) specimens were tested and analysed using the curvature approach and a method based on laminate beam theory. Beam curvatures were determined using a configuration of strain gauges. Good agreement was obtained between the two approaches. © 2012 Elsevier Ltd. All rights reserved.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Rask, M. (Intern), Sørensen, B. F. (Intern)
Pages: 37-48
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Engineering Fracture Mechanics
Volume: 96
ISSN (Print): 0013-7944
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.39 SJR 1.247 SNIP 1.676
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.362 SNIP 1.945 CiteScore 2.44
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.619 SNIP 2.214 CiteScore 2.28
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.483 SNIP 2.047 CiteScore 2.25
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.367 SNIP 2.112 CiteScore 1.82
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Development of Trailing Edge Flap Technology at DTU Wind

General information
State: Published
Organisations: Department of Wind Energy, Aeroelastic Design, Composites and Materials Mechanics
Authors: Aagaard Madsen , H. (Intern), Beller, C. (Intern), Legstrup Andersen, T. (Intern)
Number of pages: 33
Publication date: 2012

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
Blade_workshop_Juni_2012.pdf
Publication: Research › Sound/Visual production (digital) – Annual report year: 2012

European Wind Energy - Development Trends and Implications for Wind Turbine Blade Design and Materials Selection

General information
Experimental Determination and Numerical Modelling of Process Induced Strains and Residual Stresses in Thick Glass/Epoxy Laminate

In this work, a cure hardening instantaneous linear elastic (CHILE) model and a path dependent (PD) constitutive approach are compared, for the case of modelling strain build-up during curing of a thick composite laminate part. The PD approach is a limiting case of viscoelasticity with path dependency on temperature and cure degree. Model predictions are compared to experimentally determined in-situ strains, determined using FBG sensors. It was found that both models offer good approximations of internal strain build-up. A general shortcoming is the lack of capturing rate-dependent effects such as creep.

Failure analysis of steel/polyester composites - compression properties

Fatigue damage propagation in unidirectional glass fibre reinforced composites

Damage progression in unidirectional glass fibre reinforced composites exposed to tension fatigue is investigated, and a quantitative explanation is given for the observed stiffness loss. The stiffness degradation during fatigue is directly related to fibre breaks in the load-carrying axial fibre bundles. The underlying mechanisms are examined using digital microscopy, and it is postulated that fatigue damage initiates due to stress concentrations between the backing (transverse) layer and
the unidirectional layer, followed by a cyclic fretting and axial fibre debonding. This fretting mechanism needs further attention and understanding in order to improve the fatigue life-time of glass fibre reinforced composites.

**General information**

State: Published

Organisations: Department of Wind Energy, Composites and Materials Mechanics, LM Wind Power

Authors: Hansen, J. Z. (Intern), Alzamora Guzman, V. J. (Intern), Østergaard, R. (Ekstern), Brøndsted, P. (Intern)

Number of pages: 8

Publication date: 2012

**Host publication information**

Title of host publication: ECCM15 - 15th European Conference On Composite Materials

Main Research Area: Technical/natural sciences

Conference: ECCM15, Venica, Italy, 24/06/2012 - 24/06/2012

Fatigue damage, Stiffness degradation, Fibre breaks

Electronic versions:

JZAN_ECCM15.pdf

Source: dtu

Source-ID: u::6795

Publication: Research - peer-review › Article in proceedings – Annual report year: 2013

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**Flexural Properties of Hybrid Natural Composite-Micromechanics and Experimental Assessment**

**General information**

State: Published

Organisations: Department of Wind Energy, Composites and Materials Mechanics

Authors: Raghavalu Thirumalai, D. P. (Intern), Madsen, B. (Intern), Toftegaard, H. L. (Intern), Markussen, C. M. (Intern)

Pages: 469-472

Publication date: 2012

**Host publication information**


Publisher: Indian Institute of Technology

ISBN (Print): 978-81-8487-248-4

Main Research Area: Technical/natural sciences

Conference: 3rd Asian Conference on Mechanics of Functional Materials and Structures (ACMFMS 2012), New Delhi, India, 05/12/2012 - 05/12/2012

Publication: Research - peer-review › Article in proceedings – Annual report year: 2012

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**Future Materials for Wind Turbine Blades - A Critical Review**

Wind turbine industry is continuously evaluating material systems to replace the current thermoset composite technologies. Since turbine blades are the key component in the wind turbines and the size of the blade is increasing in today’s wind design, the material selection has become crucial focusing several factors like less weight, less price, higher performance, longer life, ease of processing, and capability of recycling. In the present market scenario, wind industry needs to improve their business for onshore and for off-shore applications demonstrating the new blade designs and stating higher performance under severe environmental conditions. The current article reviews various material alternatives and demonstrates the advantageous and disadvantageous for future wind turbine blade developments.

**General information**

State: Published

Organisations: Department of Wind Energy, Composites and Materials Mechanics

Authors: Raghavalu Thirumalai, D. P. (Intern)

Number of pages: 8

Publication date: 2012

**Host publication information**


Main Research Area: Technical/natural sciences


Publication: Research - peer-review › Article in proceedings – Annual report year: 2012
Future Perspectives and Challenges of Thermoplastic Wind Blades

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Raghavalu Thirumalai, D. P. (Intern)
Pages: 7-8
Publication date: 2012

Host publication information
Title of host publication: Abstracts. Indo-Danish Workshop On Future Composites Technologies for Wind Turbine Blades
Main Research Area: Technical/natural sciences
Conference: Indo-Danish Workshop On Future Composites Technologies for Wind Turbine Blades, Delhi, India, 08/10/2012 - 08/10/2012
Commingled yarns, Prepregs, APA6 resins, Process parameters, Turbine blades
Electronic versions:
Workshop_Proceedings_24_10.pdf
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2012

Generalized solution of design optimization and failure analysis of composite drive shaft

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Kollipalli, K. (Ekstern), Shivaramakrishna, K. (Ekstern), Raghavalu Thirumalai, D. P. (Intern)
Publication date: 2012

Host publication information
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Article in proceedings – Annual report year: 2012

Hemp yarn reinforced composites – III. Moisture content and dimensional changes

Based on a comprehensive set of experimental data it is demonstrated that the moisture properties of aligned hemp fibre yarn/thermoplastic matrix composites are showing low moisture sorption capacity and low dimensional changes. Using a reference humidity of 65% RH, and a common span of ambient humidity levels of 33% and 85% RH, the relative moisture content of composites with a high fibre fraction is ranging from −0.009 at 33% RH and +0.016 at 85% RH, and this lead to relative transverse hygral strains in the range of only −0.007 to +0.011. The axial hygral strain is practically zero. The moisture content of the composites is shown to be well predicted by a mixtures relationship using the measured moisture contents of the constituents. The dimensional changes of the composites are well predicted by micromechanical models of the transverse and axial hygral strains.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Civil Engineering, Section for Construction Materials
Authors: Madsen, B. (Intern), Hoffmeyer, P. (Intern), Lilholt, H. (Intern)
Pages: 2151-2160
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Composites Part A: Applied Science and Manufacturing
Volume: 43
Issue number: 11
ISSN (Print): 1359-835X
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
Influence of ultrasonic irradiation on ozone generation in a dielectric barrier discharge

An atmospheric pressure dielectric barrier discharge (DBD) was generated in an N2/O2 gas mixture at room temperature with and without ultrasonic irradiation to investigate ozone production. Powerful ultrasonic irradiation with the sound pressure level of approximately 150 dB into the DBD can enhance ozone production especially when the DBD was driven at a frequency of 15 kHz.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Department of Physics, Plasma Physics and Fusion Energy, Department of Chemical and Biochemical Engineering, CHEC Research Centre, Technical University of Denmark, FORCE Technology, Danish Technological Institute
In situ measurement using FBGs of process-induced strains during curing of thick glass/epoxy laminate plate: experimental results and numerical modelling
For large composite structures, such as wind turbine blades, thick laminates are required to withstand large in-service loads.

During the manufacture of thick laminates, one of the challenges met is avoiding process-induced shape distortions and residual stresses. In this paper, embedded fibre Bragg grating sensors are used to monitor process-induced strains during vacuum infusion of a thick glass/epoxy laminate. The measured strains are compared with predictions from a cure hardening instantaneous linear elastic (CHILE) thermomechanical numerical model where different mechanical boundary conditions are employed. The accuracy of the CHILE model in predicting process-induced internal strains, in what is essentially a viscoelastic boundary value problem, is investigated. A parametric study is furthermore performed to reveal the effect of increasing the laminate thickness. The numerical model predicts the experimental transverse strains well when a tied boundary condition at the tool/part interface is used and the tool thermal expansion is taken into account. However, the CHILE approach is shown to overestimate residual strains after demoulding because of the shortcomings of the model in considering viscoelastic effects. The process-induced strain magnitude furthermore increases when the laminate thickness was increased, owing mainly to a decrease in through-thickness internal transverse stresses.

**General information**
State: Published
Organisations: Department of Mechanical Engineering, Manufacturing Engineering, Department of Civil Engineering, Section for Building Design, Department of Wind Energy, Composites and Materials Mechanics
Authors: Nielsen, M. W. (Intern), Schmidt, J. W. (Intern), Hattel, J. H. (Intern), Løgstrup Andersen, T. (Intern), Markussen, C. M. (Intern)
Pages: 1241-1257
Publication date: 2012
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Wind Energy
Volume: 16
Issue number: 8
ISSN (Print): 1095-4244
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.37 SJR 1.104 SNIP 2.306
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.196 SNIP 2.086 CiteScore 3.06
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.272 SNIP 3.75 CiteScore 3.42
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.275 SNIP 2.464 CiteScore 2.75
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.126 SNIP 2.39 CiteScore 2.36
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.024 SNIP 2.718 CiteScore 2.49
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.487 SNIP 2.013
Web of Science (2010): Indexed yes
In situ observations of microscale damage evolution in unidirectional natural fibre composites

Synchrotron X-ray tomographic microscopy (XTM) has been used to observe in situ damage evolution in unidirectional flax fibre yarn/polypropylene composites loaded in uniaxial tension at stress levels between 20% and 95% of the ultimate failure stress. XTM allows for 3D visualization of the internal damage state at each stress level. The overall aim of the study is to gain a better understanding of the damage mechanisms in natural fibre composites. This is necessary if they are to be optimized to fulfill their promising potential. Three dominating damage mechanisms have been identified: (i) interface splitting cracks typically seen at the interfaces of bundles of unseparated fibres, (ii) matrix shear cracks, and (iii) fibre failures typically seen at fibre defects. Based on the findings in the present study, well separated fibres with a low number of defects are recommended for composite reinforcements.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Imaging and Structural Analysis, Department of Wind Energy, Composites and Materials Mechanics, Paul Scherrer Institut
Authors: Rask, M. (Intern), Madsen, B. (Intern), Sørensen, B. F. (Intern), Fife, J. L. (Ekstern), Martyniuk, K. (Intern), Lauridsen, E. M. (Intern)
Pages: 1639-1649
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Composites Part A: Applied Science and Manufacturing
Volume: 43
Issue number: 10
ISSN (Print): 1359-835X
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.82 SJR 1.402 SNIP 2.053
Web of Science (2016): Indexed yes
Manufacturing Techniques for Wind Turbine Blades - Present State of the Vacuum Infusion Process

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Markussen, C. M. (Intern)
Pages: 11-12
Publication date: 2012

Host publication information
Title of host publication: Abstracts. Indo-Danish Workshop On Future Composites Technologies for Wind Turbine Blades
Main Research Area: Technical/natural sciences
Conference: Indo-Danish Workshop On Future Composites Technologies for Wind Turbine Blades, Delhi, India, 08/10/2012 - 08/10/2012
Material Selection and Design Aspects of Small Wind Turbine Blades

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Imperial College London, Politecnico di Milano
Authors: Mikkelsen, L. P. (Intern), Bottoli, F. (Ekstern), Pignatti, L. (Ekstern), Legstrup Andersen, T. (Intern), Madsen, B. (Intern)
Pages: 15-16
Publication date: 2012

Host publication information
Title of host publication: Abstracts. Indo-Danish Workshop On Future Composites Technologies for Wind Turbine Blades
Main Research Area: Technical/natural sciences
Conference: Indo-Danish Workshop On Future Composites Technologies for Wind Turbine Blades, Delhi, India, 08/10/2012 - 08/10/2012
Optimized fiber layups, Bio-based fiber reinforced composites, Small wind turbine blades

Measuring the stress field around an evolving crack in tensile deformed Mg AZ31 using three-dimensional X-ray diffraction
The stress field around a notch in a coarse grained Mg AZ31 sample has been measured under tensile load using the individual grains as probes in an in situ high energy synchrotron diffraction experiment. The experimental set-up, a variant of three-dimensional X-ray diffraction microscopy, allows the position, orientation and full stress tensor of each illuminated grain to be determined and, hence, enables the study of evolving stress fields in coarse grained materials with a spatial resolution equal to the grain size. Grain resolved information like this is vital for understanding what happens when the traditional continuum mechanics approach breaks down and fracture is governed by local heterogeneities (e.g. phase or stress differences) between grains. As a first approximation the results obtained were averaged through the thickness of the sample and compared with an elastic–plastic continuum finite element simulation. It was found that a full three-dimensional simulation was required to account for the measured transition from the overall plane stress case away from the notch to the essentially plane strain case observed near the notch tip. The measured and simulated stress contours were shown to be in good agreement except at the highest applied load, at which stress relaxation at the notch tip was observed in the experimental data. This stress relaxation is attributed to the initiation and propagation of a crack. Finally, it was demonstrated that the measured lattice rotations could be used as a qualitative measure of the shape and extent of the plastic deformation zone.

General information
State: Published
Organisations: Department of Physics, Composites and Materials Mechanics, Department of Wind Energy, Technische Universität Berlin, Argonne National Laboratory
Authors: Oddershede, J. (Intern), Camin, B. (Ekstern), Schmidt, S. (Intern), Mikkelsen, L. P. (Intern), Sørensen, H. O. (Intern), Lienert, U. (Ekstern), Poulsen, H. F. (Intern), Reimers, W. (Ekstern)
Pages: 3570-3580
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Acta Materialia
Volume: 60
ISSN (Print): 1359-6454
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Crack propagation, Stress and strain, High energy X-ray diffraction, Plastic deformation, Finite element modeling

Original language: English

Crack propagation, Stress and strain, High energy X-ray diffraction, Plastic deformation, Finite element modeling

Electronic versions:
Measuring_the_stress_field.pdf

DOIs:
10.1016/j.actamat.2012.02.054

Publication: Research - peer-review › Journal article – Annual report year: 2012
Mechanical processing of bast fibres: The occurrence of damage and its effect on fibre structure

Currently, separation processes used for natural fibres for composite reinforcing textiles cause a significant amount of damage to the fibres. Microscopic analysis showed that industrially processed flax (Linum usitatissimum L.) fibres contained significantly more defects than green or retted ones and that further mechanical processing did not significantly increase the amount of defects. In this study it has been shown, by analysing the degree of polymerisation of cell wall components indirectly by viscosity measurements, that mechanically induced defects do not significantly cleave the cell wall polymers. Acid hydrolysis, however, induced more degradation of the cell wall polymers in fibres having a greater degree of damage, indicating that that defects are more susceptible to certain chemical reactions and which in turn might cause problems for example, during chemical modification of fibres due to heterogeneous reactivity. Analogous findings were observed in hemp (Cannabis sativa L.) fibre damaged in the laboratory under controlled conditions, emphasising the need to develop extraction and separation processes that minimise mechanical damage to the fibres.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Department of Wind Energy, Composites and Materials Mechanics, Aalto University
Authors: Hänninen, T. (Ekstern), Thygesen, A. (Intern), Mehmood, S. (Intern), Madsen, B. (Intern), Hughes, M. (Ekstern)
Pages: 7-11
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Industrial Crops and Products
Volume: 39
ISSN (Print): 0926-6690
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.051 SNIP 1.787 CiteScore 3.7
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.086 SNIP 1.738 CiteScore 3.26
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.969 SNIP 2.072 CiteScore 3.69
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.002 SNIP 1.933 CiteScore 2.96
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.968 SNIP 2.081 CiteScore 3.16
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.938 SNIP 1.761
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 0.833 SNIP 1.542
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.731 SNIP 1.38
Methodology for characterisation of glass fibre composite architecture

The present study outlines a methodology for microstructural characterisation of fibre reinforced composites containing circular fibres. Digital micrographs of polished cross-sections are used as input to a numerical image processing tool that determines spatial mapping and radii detection of the fibres. The information is used for different analyses to investigate and characterise the fibre architecture. As an example, the methodology is applied to glass fibre reinforced composites with varying fibre contents. The different fibre volume fractions (FVFs) affect the number of contact points per fibre, the communal fibre distance and the local FVF. The fibre diameter distribution and packing pattern remain somewhat similar for the considered materials. The methodology is a step towards a better understanding of the composite microstructure and can be used to evaluate the interconnection between fibre architecture and composite properties.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, LM Wind Power
Authors: Hansen, J. Z. (Intern), Larsen, J. (Ekstern), Østergaard, R. (Ekstern), Brøndsted, P. (Intern)
Pages: 187-193
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Plastics, Rubber & Composites
Volume: 41
Issue number: 4/5
ISSN (Print): 1465-8011
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.264 SNIP 0.517 CiteScore 0.86
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.259 SNIP 0.392 CiteScore 0.63
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.331 SNIP 0.731 CiteScore 0.69
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.394 SNIP 0.808 CiteScore 0.76
Micromechanical analysis of nanocomposites using 3D voxel based material model

A computational study on the effect of nanocomposite structures on the elastic properties is carried out with the use of the 3D voxel based model of materials and the combined Voigt–Reuss method. A hierarchical voxel based model of a material reinforced by an array of exfoliated and intercalated nanoclay platelets surrounded by interphase layers is developed. With this model, the elastic properties of the interphase layer are estimated using the inverse analysis. The effects of aspect ratio, intercalation and orientation of nanoparticles on the elastic properties of the nanocomposites are analyzed. For modeling the damage in nanocomposites with intercalated structures, “four phase” model is suggested, in which the strength of “intrastack interphase” is lower than that of “outer” interphase around the nanoplatelets. Analyzing the effect of nanoreinforcement in the matrix on the failure probability of glass fibers in hybrid (hierarchical) composites, using the micromechanical voxel-based model of nanocomposites, it was observed that the nanoreinforcement in the matrix leads to slightly lower fiber failure probability.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mishnaevsky, L. (Intern)
Pages: 1167-1177
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Composites Science and Technology
Micromechanics of hierarchical materials: A brief overview

A short overview of micromechanical models of hierarchical materials (hybrid composites, biomaterials, fractal materials, etc.) is given. Several examples of the modeling of strength and damage in hierarchical materials are summarized, among them, 3D FE model of hybrid composites with nanoengineered matrix, fiber bundle model of UD composites with hierarchically clustered fibers and 3D multilevel model of wood considered as a gradient, cellular material with layered composite cell walls. The main areas of research in micromechanics of hierarchical materials are identified, among them, the investigations of the effects of load redistribution between reinforcing elements at different scale levels, of the possibilities to control different material properties and to ensure synergy of strengthening effects at different scale levels and using the nanoreinforcement effects. The main future directions of the mechanics of hierarchical materials are listed, among them, the development of "concurrent" modeling techniques for hierarchical materials, optimal microstructure design at multiple scale levels using synergy effects, and the mechanical modeling of atomistic effects.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mishnaevsky, L. J. (Intern)
Pages: 60-72
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Reviews on Advanced Materials Science
Volume: 30
Issue number: 1
ISSN (Print): 1605-8127
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.607 SNIP 0.962 CiteScore 1.91
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.535 SNIP 0.842 CiteScore 1.57
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.508 SNIP 0.983 CiteScore 1.38
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.524 SNIP 1.012 CiteScore 1.26
ISI indexed (2013): ISI indexed no
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.467 SNIP 0.825 CiteScore 0.99
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.432 SNIP 0.654 CiteScore 0.75
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.456 SNIP 0.526
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.412 SNIP 0.53
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.642 SNIP 0.762
Scopus rating (2007): SJR 0.725 SNIP 0.925
Scopus rating (2006): SJR 0.61 SNIP 0.749
Scopus rating (2005): SJR 0.483 SNIP 0.682
Scopus rating (2004): SJR 0.262 SNIP 0.502
Original language: English
Source: dtu
Modeling of nano-reinforced polymer composites: Microstructure effect on Young's modulus

A computational numerical-analytical model of nano-reinforced polymer composites is developed taking into account the interface and particle clustering effects. The model was employed to analyze the interrelationships between microstructures and mechanical properties of nanocomposites. An improved effective interface model which is based on Mori–Tanaka approach and includes the nanoparticle geometry and clustering effects was developed. A program code for the automatic generation of two-dimensional multiparticle unit cell models of nanocomposites and finite element meshes on the basis of "grid method" algorithm was developed in the ABAQUS Scripting Interface. In the computational studies, it was observed that the elastic modulus increases with the increasing the aspect ratio of nanoparticles. The thickness and properties of effective interface layers and the shape and degree of particles clustering have strong influence on the mechanical properties of nanocomposite.
Natural composites: Strength, packing ability and moisture sorption of cellulose fibres, and the related performance of composites

Biobased materials are becoming of increasing interest as potential structural materials for the future. A useful concept in this context is the fibre reinforcement of materials by stiff and strong fibres. The bio-resources can contribute with cellulose fibres and (bio) polymers from hemicelluloses. This offers the potential for stiff and strong biocomposite materials, but these have some limitations and obstacles to full performance. The focus will be on the structure, strength and stiffness of cellulose fibres, on the (unavoidable) defects causing large reductions in strength and moderate reductions in stiffness, on the packing ability of cellulose fibres and the related maximum fibre volume fraction in composites, on the moisture sorption of cellulose fibres and the related mass increase and (large) hygral strains induced, and on the mechanical performance of composites.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Lilholt, H. (Intern), Madsen, B. (Intern)
Number of pages: 12
Publication date: 2012

Host publication information
Main Research Area: Technical/natural sciences
Cellulose fibres, Structure, Strength, Stiffness, Defects, Fibre packing ability, Moisture sorption, Composite performance
Electronic versions:
NATURAL_COMPOSITES.pdf
Publication: Research - peer-review › Article in proceedings – Annual report year: 2012

Path dependence of truss-like mixed mode cohesive laws
A general theoretical analysis is presented to prove that, under mixed mode fracture, truss-like mixed mode cohesive laws (cohesive laws that are coupled in a special manner such that the traction vector follows the separation/opening vector) are path independent only in the limited case where the fracture resistance (and effective traction) is independent of the phase angle of openings. To verify the theoretical analysis, a specific class of truss-like cohesive laws, coupled with a failure criterion for damage initiation and an effective opening displacement is used. It is shown analytically and numerically that these cohesive laws are path dependent.
Properties and performance of flax yarn/thermoplastic polyester composites

Aiming at demonstrating the potential of unidirectional natural fiber-reinforced thermoplastic composites in structural applications, textile flax yarn/thermoplastic polyester composites with variable fiber volume fractions have been manufactured by a filament-winding process followed by a vacuum-assisted compression molding process. The microstructure of the composites shows that the flax fiber yarns are well impregnated by the polyester matrix, and this supports the measured low porosity content of the composites. The experimental tensile modulus and ultimate tensile stress of the composites in the axial and transverse directions are well simulated by rule of mixtures models. In the axial direction, at a fiber volume fraction of 0.50, the experimental tensile modulus and ultimate tensile stress are 32 GPa and 350 MPa, respectively. In comparison, for glass fiber composites at a fiber volume fraction of 0.50, the tensile modulus and ultimate tensile stress are calculated to be 38 GPa and 1800 MPa, respectively. The flax yarn composites show better specific tensile modulus than the glass fiber composites with values of 23 GPa/g/cm³ and 20 GPa/g/cm³, respectively. An analysis of data from previous studies of unidirectional natural fibre composites demonstrates comparatively good reinforcement efficiency of the flax yarn fibers with an effective tensile modulus and ultimate tensile stress of the fibers in the area of 70 GPa and 800 MPa, respectively. Altogether, it is demonstrated that composites with high-quality textile flax yarn are well suited for structural applications when stiffness and weight saving are the central selection criteria.

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics, Swansea University
Authors: Madsen, B. (Intern), Mehmood, S. (Ekstern)
Pages: 1746–1757
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Reinforced Plastics & Composites
Volume: 31
Issue number: 24
ISSN (Print): 0731-6844
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.24 SJR 0.418 SNIP 0.648
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.489 SNIP 0.846 CiteScore 1.32
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.686 SNIP 1.021 CiteScore 1.58
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.6 SNIP 1.027 CiteScore 1.35
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
A model was developed for the prediction of the tensile strength of thin, symmetric 3-layer sandwich specimens. The model predictions rationalize the effect of heat-treatment temperature on the strength of sandwich specimens consisting of an YSZ (Yttria-Stabilized Zirconia) substrate coated with porous NiO-YSZ layers. The model accounts for two different failure modes. Coated YSZ specimens heat-treated below 1200°C were predicted to fail from flaws in the substrate while specimens heat-treated at higher temperatures were predicted to fail from channeling cracks forming in the coating and
propagating into the substrate. These predictions are consistent with microstructural observations of the fracture surfaces. A good agreement was found between the measured strength values and model predictions. © 2012 Elsevier Ltd. All rights reserved.
Surface charging, discharging and chemical modification at a sliding contact

Electrostatic charging, discharging, and consequent surface modification induced by sliding dissimilar surfaces have been studied. The surface-charge related phenomena were monitored by using a home-built capacitive, non-contact electrical probe, and the surface chemistry was studied by X-ray photoelectron spectroscopy (XPS). The experiments were performed on the disk surface of a ball-on-rotating-disk apparatus; using a glass disk and a Teflon (polytetrafluoroethylene) ball arrangement, and a polyester disks and a diamondlike carbon (DLC) coated steel ball arrangement. The capacitive probe is designed to perform highly resolved measurements, which is sensitive to relative change in charge density on the probed surface. For glass and Teflon arrangement, electrical measurements show that the ball track acquires non-uniform charging. Here not only the increase in charge density, but interestingly, increase in number of highly charged regions on the ball track was resolved. Threefold increase in the number of such highly charged regions per cycle was detected immediately before the gas breakdown-like incidences compared to that of other charge/discharge incidences at a fixed disk rotation speed. We are also able to comment on the behavior and the charge decay time in the ambient air-like condition, once the sliding contact is discontinued. XPS analysis showed a marginal deoxidation effect on the polyester disks due to the charging and discharging of the surfaces. Moreover, these XPS results clearly indicate that the wear and friction (sliding without charging) on the surface can be discarded from inducing such a deoxidation effect.

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The effect of O₂ in a humid O₂/N₂/NOₓ gas mixture on NOₓ and N₂O remediation by an atmospheric pressure dielectric barrier discharge

A numerical model for N₂O remediation in humid air plasma produced with a dielectric barrier discharge at atmospheric pressure is presented. Special emphasis is given to NO₂ and N₂O reduction with the decrease of O₂ content in the feedstock gas. A detailed reaction mechanism including electronic and ionic processes, as well as the contribution of radicals and excited atomic/molecular species is proposed. The temporal evolution of the densities of NO, NO₂, and N₂O species, and some other by-products, is analyzed, and the major pathways for the NₓOᵧ remediation are discussed for one pulse. Subsequently, simulations are presented for a multi-pulses case, where three O₂ contents are tested for optimization of the remediation process. It is found that when the gas mixture O₂/N₂/H₂O/NOₓ has no initial O₂ content, the best NOₓ and N₂O remediation is achieved.
The Influence of Steel Fiber Plasticity on Kink-Band Formation

General information
State: Published
Organisations: Department of Wind Energy, Composites and Materials Mechanics
Authors: Mikkelsen, L. P. (Intern), Raghavalu Thirumalai, D. P. (Intern)
Publication date: 2012

Host publication information
Title of host publication: Proceedings of XXIII International Congress on Theoretical and Applied Mechanics
Main Research Area: Technical/natural sciences
Conference: ICTAM 2012, Beijing, China, 19/08/2012 - 19/08/2012
Publication: Research - peer-review › Article in proceedings – Annual report year: 2012

Ultrasound enhanced plasma surface modification at atmospheric pressure
Efficiency of atmospheric pressure plasma treatment can be highly enhanced by simultaneous high power ultrasonic irradiation onto the treating surface. It is because ultrasonic waves with a sound pressure level (SPL) above ~140 dB can reduce the thickness of a boundary gas layer between the plasma and the material surface, and thus, many reactive species generated in the plasma can reach the surface before they are inactivated and can be efficiently utilised for surface modification. In the present work, glass fibre reinforced polyester plates were treated using a dielectric barrier discharge and a gliding arc at atmospheric pressure to study adhesion improvement. The effect of ultrasonic irradiation with the frequency diapason between 20 and 40 kHz at the SPL of ~150 dB was investigated. After the plasma treatment without ultrasonic irradiation, the wettability was significantly improved. The ultrasonic irradiation during the plasma treatment consistently enhanced the treatment efficiency. The principal effect of ultrasonic irradiation can be attributed to enhancing surface oxidation during plasma treatment. In addition, ultrasonic irradiation can suppress arcing, and the uniformity of the treatment can be improved.

General information
State: Published
Organisations: Composites and Materials Mechanics, Department of Wind Energy, Imaging and Structural Analysis, Department of Energy Conversion and Storage, Department of Physics, Plasma Physics and Fusion Energy, Department of Micro- and Nanotechnology, FORCE Technology
Authors: Kusano, Y. (Intern), Singh, S. V. (Intern), Norman, K. (Intern), Drews, J. M. (Intern), Leipold, F. (Intern), Rozlosnik, N. (Intern), Bardenshtein, A. (Ekstern), Krebs, N. (Ekstern)
Pages: 453-457
Publication date: 2012
Main Research Area: Technical/natural sciences
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.29 SJR 0.406 SNIP 0.716
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.423 SNIP 0.659 CiteScore 1.13
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.453 SNIP 0.862 CiteScore 1.34
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.594 SNIP 0.843 CiteScore 1.54
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.619 SNIP 0.919 CiteScore 1.5
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.375 SNIP 0.752 CiteScore 0.88
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.353 SNIP 0.564
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.257 SNIP 0.383
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.336 SNIP 0.467
Scopus rating (2007): SJR 0.256 SNIP 0.513
Scopus rating (2006): SJR 0.358 SNIP 0.698
Scopus rating (2005): SJR 0.286 SNIP 0.481
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.491 SNIP 0.602
Scopus rating (2003): SJR 0.367 SNIP 0.619
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.483 SNIP 0.83
Scopus rating (2001): SJR 0.401 SNIP 0.705
Scopus rating (2000): SJR 0.601 SNIP 0.983
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 0.503 SNIP 0.965
Original language: English
Polyester, Adhesion, Ultrasound, Surface treatment, Atmospheric pressure plasma
DOIs:
10.1179/1743294411Y.0000000084
Source: orbit
Source-ID: 271570
Publication: Research - peer-review › Journal article – Annual report year: 2012

Wind Turbines – An Enabling Application for Structural Health Monitoring?

General information
State: Published
50-Hz plasma treatment of glass fibre reinforced polyester at atmospheric pressure enhanced by ultrasonic irradiation

Glass fibre reinforced polyester (GFRP) plates are treated using a 50-Hz dielectric barrier discharge at peak-to-peak voltage of 30 kV in helium at atmospheric pressure with and without ultrasonic irradiation to study adhesion improvement. The ultrasonic waves at the fundamental frequency of around 30 kHz with the sound pressure level of approximately 155 dB were introduced vertically to the GFRP surface through a cylindrical waveguide. The polar component of the surface energy was almost unchanged after the plasma treatment without ultrasonic irradiation, but drastically increased approximately from 20 mJ m-2 up to 80 mJ m-2 with ultrasonic irradiation. The plasma treatment with ultrasonic irradiation also introduced oxygen and nitrogen containing functional groups at the GFRP surface. These changes would improve the adhesion properties of the GFRP plates.

Adhesion improvement of glass fibre reinforced polyester composite by atmospheric pressure plasma treatment

Glass fibre reinforced polyester (GFRP) plates are treated using a 50-Hz dielectric barrier discharge at peak-to-peak voltage of 30 kV in helium at atmospheric pressure with and without ultrasonic irradiation to study adhesion improvement. The ultrasonic waves at the fundamental frequency of around 30 kHz with the sound pressure level of approximately 155 dB were introduced vertically to the GFRP surface through a cylindrical waveguide. The polar component of the surface energy was almost unchanged after the plasma treatment without ultrasonic irradiation, but drastically increased approximately from 20 mJ m-2 up to 80 mJ m-2 with ultrasonic irradiation. The plasma treatment with ultrasonic irradiation also introduced oxygen and nitrogen containing functional groups at the GFRP surface. These changes would improve the adhesion properties of the GFRP plates.
Generation and Applications of Atmospheric Pressure Plasmas

General information
State: Published
Organisations: Composites and Materials Mechanics, Department of Wind Energy, Sophia University
Authors: Kogoma, M. (Ekstern), Kusano, M. (Ekstern), Kusano, Y. (Intern)
Publication date: 2011

Publication information
Publisher: Nova Science Publishers, Incorporated
ISBN (Print): 978-1-61209-717-6
Original language: English
Series: Physics Research and Technology
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 274916

Hip supporting device
The present invention relates to a device for limiting movements in one or more anatomical joints, such as a device for limiting movement in the human hip joint after hip replacement surgery. This is provided by a device for limiting movement in the human hip joint, said device comprising: at least a first member (1) adapted to conform to a leg, a second member (2) adapted to engage at least one shoulder, and a third member (3) connecting said at least first member and said second member, wherein the third member is substantially soft and/or flexible and adapted to limit one or more specific movements of said leg by anchoring the tensile load of said movement (s) in the shoulder (s).

General information
State: Published
Organisations: Department of Electrical Engineering, Department of Wind Energy, Composites and Materials Mechanics
Authors: Brøndsted, P. (Intern), Kot, K. K. (Intern)
Publication date: 2011

Publication information
Country: Denmark
IPC: A61F5/01
Patent number: WO2011144698 A1
Date: 24/11/2011
Original language: English

Bibliographical note
DTU reference number: 92675

Measuring Cohesive Laws for Interfaces in Sandwich Structures
Extraction of cohesive laws are conducted for interfaces in sandwich structures. Separation between face and core are driven by pure bending moments applied to double cantilever beam (DCB) specimens. By varying the ratio between moments applied to the beams the test is conducted for different mode mixities. The sandwich specimens consists of glass fiber faces and Divinycell H200 foam core with a pre-crack between face and core made with teflon film. Arbitrary stiffening of the sandwich faces with steel bars adhered to the faces reduces rotations and ensures that the method is usable for a wide range of materials. The J integral is employed in closed form and the opening of the pre-crack tip is recorded by a commercial optical measurement system. Cohesive laws are extracted by differentiating J with respect to the normal and tangential opening of the pre-crack tip. Results for one specimen are presented and discussed.

General information
State: Published
Organisations: Coastal, Maritime and Structural Engineering, Department of Mechanical Engineering, Department of Electrical Engineering, Department of Wind Energy, Composites and Materials Mechanics, Risø National Laboratory for Sustainable Energy
Authors: Lundsgaard-Larsen, C. (Intern), Sørensen, B. F. (Intern), Berggreen, C. C. (Intern), Østergaard, R. C. (Intern)
Multi-axial fatigue damage laws for composite materials at the macro-scale
Fatigue behaviour of polymer composite materials at the sub-structural and structural scale

Publications:
Ex-situ X-ray computed tomography data for a non-crimp fabric based glass fibre composite under fatigue loading
Fatigue damage observed non-destructively in fibre composite coupon test specimens by X-ray CT
Micromechanical Time-Lapse X-ray CT Study of Fatigue Damage in Uni-Directional Fibre Composites
Individual fibre segmentation from 3D X-ray computed tomography for characterising the fibre orientation in unidirectional composite materials
Three dimensional fatigue damage evolution in non-crimp glass fibre fabric based composites used for wind turbine blades
Micromechanical Investigation of Fatigue Damage in Uni-Directional Fibre Composites
Fatigue Damage Evolution in Fibre Composites for Wind Turbine Blades

Bio4Self
Department of Wind Energy
Composites and Materials Mechanics
Period: 01/03/2016 → …
Number of participants: 5
Project ID: H2020
Project participant:
Beauson, Justine (Intern)
Mikkelsen, Lars Pilgaard (Intern)
Madsen, Bo (Intern)
Christensen, Jacob (Intern)
Mishnaevsky, Leon (Intern)

Alliance for Imaging and Modelling of Energy Applications
The CINEMA research alliance will develop unique 3D micro-structural characterization methods, which make it possible to investigate components under realistic conditions and in real time. This will enable correlation between performance and local changes in the microstructure.

Department of Energy Conversion and Storage
Imaging and Structural Analysis
Department of Physics
Neutrons and X-rays for Materials Physics
Department of Wind Energy
Composites and Materials Mechanics
Department of Applied Mathematics and Computer Science
Image Analysis & Computer Graphics
Scientific Computing
Mixed Conductors
Statistics and Data Analysis
University of Copenhagen
Northwestern University
University of Manchester
MaxLab
LM Wind Power
Haldor Topsoe AS
Xnovo Technology ApS
Rockwool International
Amminex Emissions Technology A/S
Period: 01/01/2014 → 31/12/2018
Number of participants: 26
Acronym: CINEMA
Project participant:
Mikkelsen, Lars Pilgaard (Intern)
Sørensen, Bent F. (Intern)
Bowen, Jacob R. (Intern)
Kuhn, Luise Theil (Intern)
Larsen, Rasmus (Intern)
Hansen, Per Christian (Intern)
Frandsen, Henrik Lund (Intern)
Gundlach, Carsten (Intern)
Dahl, Anders Bjørholm (Intern)
Yang, Shu-Yi (Intern)
Poulsen, Stefan Othmar (Intern)
Lyckegaard, Allian (Intern)
Lauridsen, Erik Mejdal (Intern)
Sørensen, Henning Osholm (Ekstern)
Project Manager, organisational:
Sørensen, Hanne (Intern)
Phd Student:
Jespersen, Kristine Munk (Intern)
Beil, Johannes (Ekstern)
Andersen, Michael (Intern)
Emerson, Monica Jane (Intern)
De Angelis, Salvatore (Intern)
Birkelund, Klaus (Ekstern)
Jacobsen, Hjalte Sylvest (Intern)
Chapelle, Lucie (Intern)
Supervisor:
Frandsen, Henrik Lund (Intern)
Project Manager, academic:
Andreasen, Jens Wenzel (Intern)
Project Coordinator:
Poulsen, Henning Friis (Intern)

Relations
Activities:
DTU Energy Conversion 2nd International PhD Summer School
WIlson K. S. Chiu
Gerardina Carbone
High resolution ptychographic tomography of soft matter
Publications:
3D X-Ray Computed Tomography (XCT) of Fatigue Damage Evolution in UD Glass Fibre Composite
Enabling Flexible Polymer Tandem Solar Cells by 3D Ptychographic Imaging
Dictionary Based Segmentation in Volumes
Micromechanical Investigation of Fatigue Damage in Uni-Directional Fibre Composites
Improving organic tandem solar cells based on water-processed nanoparticles by quantitative 3D nanoimaging
Fatigue damage evolution in fibre composites for wind turbine blades
Micromechanical Time-Lapse X-ray CT Study of Fatigue Damage in Uni-Directional Fibre Composites

Project
Future Technologies for Wind Energy: Blade materials, Turbine reliability, Computation tools, and Experimental methods
International Network Programme - USA & India

Department of Wind Energy
Composites and Materials Mechanics
Department of Electrical Engineering

Period: 01/01/2013 → 31/12/2013
Number of participants: 3

**Wind Energy**
Project ID: 12-132723

Project participant:
Raghavalu Thirumalai, Durai Prabhakaran (Intern)
Sørensen, Bent F. (Intern)
Mishnaevsky, Leon (Intern)

Project


Project approved under “International Network Program” with India – 360,000DKK

Scientific Network Activities [planned jointly with Indian Universities]:

1. Indo-Danish Workshop on “Future Composites Technologies for Wind Turbine Blades” October 8-9, 2012, Indian Institute of Technology, New Delhi, India

http://indodanish.iitd.ac.in/


http://www.wemep2012.com/

Department of Wind Energy
Composites and Materials Mechanics

Period: 01/02/2012 → 31/12/2012
Number of participants: 3

Project participant:
Raghavalu Thirumalai, Durai Prabhakaran (Intern)
Sørensen, Bent F. (Intern)
Mishnaevsky, Leon (Intern)

Documents:
1. Indo-Danish Workshop on “Future Composites Technologies for Wind Turbine Blades”, October 8-9, 2012, Indian Institute of Technology, New Delhi, India
   International Conference on Wind Energy: Materials, Engineering, and Policies, BITS Pilani, Hyderabad Campus, Hyderabad, India

**Theoretical analysis, design and virtual testing of biocompatibility and mechanical properties of titanium-based nanomaterials**

EU FP7 Project Coordinator “Virtual Nanotitanium” (Theoretical analysis, design and virtual testing of biocompatibility and mechanical properties of titanium-based nanomaterials) Collaborative Project in Nanosciences NMP

Department of Wind Energy
Composites and Materials Mechanics

Period: 01/10/2011 → 31/03/2014
Number of participants: 2
Acronym: VINAT (Virtual Nanotitanium)
Some of the most critical components of a wind turbine are the rotor blades, which are usually made of polymer matrix composites and are the largest rotating components of a wind turbine. Different types of damage can develop at different length scales in wind turbine rotor blades. Therefore, the Danish Centre for Composite Structures and Materials for Wind Turbines (DCCSM) aims to develop a coherent, multiscale-based understanding of the mechanical behaviour of composite materials and structures for wind turbine blades. The length scale goes from nano- and microscale (materials) to product scale (the whole blade, which currently can be more than 60 meters in length), and covers manufacturing, materials design, damage detection, modelling and prediction of damage evolution in wind turbine blades. A coherent multiscale understanding of composite materials and structures will enable full optimisation, viz., optimisation at all length scales.

The Centre aims for the creation of new knowledge (e.g. material models), new experimental methods and new modeling methods. The Centre spans wide thematically and disciplinarily. The specific PhD, Post Doc and research projects funded by DCCSM (Core and Shell activities) are focused at smaller, well-defined topics. Therefore, the Centre will coordinate the research activities in Denmark in the area of composite structures and materials for wind turbines. That includes the Core and Shell activities of DCCSM and research projects that are not funded by the DSF funds but are thematically covered by the Centre. Such projects are called "Crust" projects.

DSF Strategic Research Centre (sags. nr. 09-067212).

Department of Wind Energy
Composites and Materials Mechanics
Department of Micro- and Nanotechnology
Amphiphilic Polymers in Biological Sensing
Wind Turbines
Solid Mechanics
Department of Mechanical Engineering

Department of Civil Engineering

Section for Structural Engineering
Period: 01/04/2010 → 31/03/2017
Number of participants: 11
Acronym: DCCSM

Project participant:
Almdal, Kristoffer (Intern)
Mikkelsen, Lars Pilgaard (Intern)
Branner, Kim (Intern)
Mishnaevsky, Leon (Intern)
Legarth, Brian Nyvang (Intern)
Berggreen, Christian (Intern)
Stang, Henrik (Intern)
Phd Student:
Zike, Sanita (Intern)
Hansen, Jens Zangenberg (Intern)
Ashouri Vajari, Danial (Intern)

Approving authority:
Sørensen, Bent F. (Intern)

Relations
Publications:
Correction of Gauge Factor for Strain Gauges Used in Polymer Composite Testing
Fatigue damage propagation in unidirectional glass fibre reinforced composites made of a non-crimp fabric
Determination of the minimum size of a statistical representative volume element from a fibre-reinforced composite based on point pattern statistics
Quantitative study on the statistical properties of fibre architecture of genuine and numerical composite microstructures
Methodology for characterisation of glass fibre composite architecture
Design of a fibrous composite preform for wind turbine rotor blades
The effects of fibre architecture on fatigue life-time of composite materials
A numerical study of the influence of microvoids in the transverse mechanical response of unidirectional composites
Micro-Scale Experiments and Models for Composite Materials with Materials Research
From Measurements Errors to a New Strain Gauge Design

Project

3D virtual testing of composites for wind energy applications: Computational mesomechanics approach

Department of Wind Energy

Composites and Materials Mechanics
Period: 01/05/2009 → 31/05/2011
Number of participants: 1
Project Coordinator:
Mishnaevsky, Leon (Intern)

Project

Development of wind energy technologies in Nepal on the basis of natural materials

Department of Wind Energy

Composites and Materials Mechanics
Period: 01/11/2007 → 31/08/2011
Number of participants: 1
Project Manager, academic:
Mishnaevsky, Leon (Intern)

Project
Activities:

**Specimen design and instrumentation for monitoring fatigue crack growth initiating at ply drops**

*Period: 8 Nov 2017 → 9 Nov 2017*

Stergios Goutianos (Speaker)
Leonardo Di Crescenzo (Speaker)
Malcolm McGugan (Speaker)
Bent F. Sørensen (Speaker)

Department of Wind Energy
Composites and Materials Mechanics
Degree of recognition: International

Documents:
ISMEM2017_gout

**Related event**

*2nd International Symposium on Multiscale Experimental Mechanics: Multiscale Fatigue*

*08/11/2017 → 09/11/2017*

Lyngby, Denmark

**Investigation of the flow in a rain erosion tester**

*Period: 27 Feb 2017*

Christian Bak (Speaker)
Niels N. Sørensen (Other)
Anders Smærup Olsen (Other)
Jakob Ilsted Bech (Other)
Mac Gaunaa (Other)
Yukihiro Kusano (Other)

Department of Wind Energy
Aerodynamic design
Composites and Materials Mechanics

**Description**

Presentation on the workshop about erosion of wind turbine blades
Degree of recognition: National

**Related event**

*Erosion Day Workshop*

*27/02/2017 → 27/02/2017*

Roskilde, Denmark

**Compression Fatigue Testing and Damage in UD Glass Fibre Composites**

*Period: 12 Dec 2016*

Anthony Fraisse (Other)
Povl Brendsted (Speaker)

Department of Wind Energy
Composites and Materials Mechanics

**Description**

The objective of this project was to optimize the geometry of compression compression fatigue specimens. FEM, and experimental parametrical study have been performed in order to define a possible geometry. Repeatable and representative results were achieved and damage mechanisms were identified by performing 3D
Tomography ex situ study.
Degree of recognition: International
Documents:
3.2.+DTU+Wind+Energy

Related event
Wind Turbine Blade Manufacturer
12/09/2016 → 14/09/2016
Düsseldorf, Germany
Activity: Talks and presentations › Conference presentations

NAFEMS Nordic Steering Committee (NNSC) (External organisation)
Period: 2015 → …
Lars Pilgaard Mikkelsen (Participant)
Department of Wind Energy
Composites and Materials Mechanics
Degree of recognition: International
Links:
https://www.nafems.org/about/regional/nordic/committee/

Related external organisation
NAFEMS Nordic Steering Committee (NNSC)
Activity: Membership › Membership of committees, commissions, boards, councils, associations, organisations, or similar

Innovation from JSME 2015
Period: 14 Nov 2015 → 15 Nov 2015
Kristine Munk Jespersen (Participant)
Department of Wind Energy
Composites and Materials Mechanics

Description
Poster presentation
Japanese conference
Documents:
iJSMEposter_formatresearch (1)
2015-11-12 iJSME Hiroshima speed presentation (1)

Related event
Innovation from JSME 2015
14/11/2015 → 15/11/2015
Hiroshima, Japan
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

Challenges of using composite materials for large wind turbine blades
Period: 2 Nov 2015
Lars Pilgaard Mikkelsen (Lecturer)
Department of Wind Energy
Composites and Materials Mechanics

Description
Seminar at: Yamagata University, Yonezawa City, Japan
Organized by Japan Society of Mechanical Engineers
Documents:
Abstract-LPMikkelsen

Links:
http://www.jsme.or.jp/th/presen/H27/H27.html

Related event

Seminar organized by Japan Society of Mechanical Engineering
02/11/2015 → …
yonezawa city, Japan
Activity: Talks and presentations › Conference presentations

Scientific Computing Using Python - 1
Period: 2 Jun 2015 → 4 Jun 2015
Kristine Munk Jespersen (Participant)
Department of Wind Energy
Composites and Materials Mechanics

Related event

Scientific Computing Using Python - 1: Python + Scientific Computing
02/06/2015 → 04/06/2015
Aalborg, Denmark
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

Fracture Mechanics for Laminated Composite Structures
Kristine Munk Jespersen (Participant)
Department of Wind Energy
Composites and Materials Mechanics
Documents:
FractureMechCourse_poster_kmun

Related event

Ph.D. Course 2015: Fracture Mechanics for Laminated Composite Structures
18/05/2015 → 22/05/2015
Aalborg, Denmark
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

DTU Energy Conversion 2nd International PhD Summer School
Kristine Munk Jespersen (Participant)
Department of Wind Energy
Composites and Materials Mechanics
Department of Energy Conversion and Storage

Description
Participation in DTU Energy Conversion 2nd International PhD Summer School along with poster presentation. The poster has been attached to this description.
Documents:
IMAGINE Poster by kmun

Related event

25/08/2014 → 29/08/2014
Hundested, Denmark
DCAMM's Videnskabelige Råd (External organisation)
Period: 2013 → …
Lars Pilgaard Mikkelsen (Participant)
Department of Wind Energy
Composites and Materials Mechanics
Links:
http://www.dcamm.dk/

Related external organisation

DCAMM's Videnskabelige Råd
Activity: Membership › Membership of committees, commissions, boards, councils, associations, organisations, or similar

19th International Conference on Composite Materials
Period: 29 Jul 2013
Sanita Zike (Participant)
Department of Wind Energy
Composites and Materials Mechanics
Description
Participation in the conference included poster presentation and published paper in the conference proceedings
Documents:
DCB TEST SAMPLE DESIGN FOR MICRO-MECHANICAL TESTING
Poster
Links:
http://www.iccm19.org/

Related event

19th International Conference on Composite Materials
28/07/2013 → 02/08/2013
Montréal, Canada
Activity: Attending an event › Participating in or organising a conference

6th International Conference on Composites Testing and Model Identification
Period: 22 Apr 2013 → 24 Apr 2013
Sanita Zike (Participant)
Department of Wind Energy
Composites and Materials Mechanics
Description
Participating with poster presentation
Documents:
Poster: Strain Gauge Application in Soft Material Testing

Related event

6th International Conference on Composites Testing and Model Identification
22/04/2013 → 24/04/2013
Aalborg, Denmark
Activity: Attending an event › Participating in or organising a conference

DCAMM 14th Internal Symposium
Period: 13 Mar 2013 → 15 Mar 2013
Sanita Zike (Participant)
Department of Wind Energy
Composites and Materials Mechanics

Description
Participation with oral presentation: Micro-Scale Experiments and Models for Composite Materials

Related event
DCAMM 14th Internal Symposium
13/03/2013 → 15/03/2013
Nyborg, Denmark
Activity: Attending an event › Participating in or organising a conference

DTU Wind Energy’s Board of Studies (Studienævn) (External organisation)
Period: 2012 → …
Lars Pilgaard Mikkelsen (Participant)
Department of Wind Energy
Composites and Materials Mechanics

Related external organisation
DTU Wind Energy’s Board of Studies (Studienævn)
Activity: Membership › Membership of committees, commissions, boards, councils, associations, organisations, or similar

Polymers - Experimental characterization and numerical predictions
Period: 19 Sep 2012 → 20 Sep 2012
Sanita Zike (Participant)
Department of Wind Energy
Composites and Materials Mechanics

Related event
Polymers - Experimental characterization and numerical predictions
19/09/2012 → 20/09/2012
Roskilde, Denmark
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

Composites Design Workshop VII
Sanita Zike (Participant)
Department of Wind Energy
Composites and Materials Mechanics
Links:
http://www.stanford.edu/group/composites/Workshop/previous.html (Workshop homepage)

Related event
Composites Design Workshop VII
14/08/2012 → 23/08/2012
United States
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.
Multiscale Modelling of Complex Materials
Period: 21 May 2012 → 25 May 2012
Sanita Zike (Participant)
Department of Wind Energy
Composites and Materials Mechanics
Links:
http://media.cism.it/courses%2FC1201%2F1--Sadowski-Trovalusci7___.pdf (Course description)

Related event
Multiscale Modelling of Complex Materials
21/05/2012 → 25/05/2012
Udine, Italy
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

Risø DTU Board of Studies (External organisation)
Period: 2007 → 2012
Lars Pilgaard Mikkelsen (Participant)
Department of Wind Energy
Composites and Materials Mechanics

Related external organisation
Risø DTU Board of Studies
Activity: Membership › Membership of committees, commissions, boards, councils, associations, organisations, or similar

Press clippings:

Forskningens døgn - forskning for fremtiden
Lars Pilgaard Mikkelsen
29/04/2017

Description
Forskningens døgn er en årlig tilbagevendende begivenhed, der afholdes over hele landet. I Roskilde har forskellige uddannelsesinstitutioner og foreninger opslået en række teltet, og viser eksempler på, hvad de arbejder med.
Department of Wind Energy, Composites and Materials Mechanics, Department of Applied Mathematics and Computer Science

Forskningens døgn i Roskilde 2017
Event: Exhibition

Media coverage (1)
Forskningens døgn i Roskilde
29/04/2017
Kanal Roskilde (Local), Denmark, Television
29 min.
https://www.youtube.com/watch?v=hVh8FuWcy-k&t=880s
Lars Pilgaard Mikkelsen
Press / Media

Biofibre på spring til industrien
Bo Madsen
29/05/2015
Department of Wind Energy, Composites and Materials Mechanics

Media contribution (1)
Biofibre på spring til industrien
29/05/2015