Properties of Plant Fiber Yarn Polymer Composites: An Experimental Study

The properties of plant fibre composites and their potential for industrial products have been increasingly addressed in research studies over the last few decades. During this period a growing number of such products have been introduced e.g. in the building industry, the furniture industry, and particularly in the automotive industry. The scientific work has so far been focused mainly on plant fibre composites with a random fibre orientation, which produces moderate mechanical properties. Exploration of the full reinforcement potential of plant fibres requires composites with aligned fibres. The thesis presents experimental investigations and modelling of the properties of aligned plant fibre composites based on textile hemp yarn and thermoplastic matrices. The textile hemp yarn has been characterised. It is high in cellulose and with fibres well separated from each other; i.e. only few fibres are situated in bundles. The twisting angle is low; i.e. about 15 o for the outermost fibres in the yarn. The moisture sorption capacity of the yarn fibres is much lower than that of raw hemp fibres. Stiffness and strength of the fibres as calculated from composite data are in the ranges 50-65 GPa and 530-650 MPa respectively. These properties show that textile hemp yarn is well suited as composite reinforcement. The relationship between fibre volume fraction and porosity has been studied. A model has been developed that predicts porosity from experimentally determined parameters such as fibre lumen dimensions and fibre compactness. The latter parameter in particular is found to be important. Composite porosity starts to increase dramatically when the fibre volume fraction approaches a specific maximum value. This is accurately predicted by the compactness of the fibres. The moisture sorption properties of aligned hemp yarn composites have been investigated. Moisture diffusion is non-Fickian, and is characterised by so-called two-stage diffusion behaviour, which is a well-known phenomenon in synthetic fibre composites. The rate of moisture diffusion is largest along the fibres, and also different in the two transverse directions. These anisotropic moisture diffusion properties imply that specific diffusion coefficients have to be assigned to each of the three directions. The moisture induced swelling/shrinkage of the composites at the two humidities 35 and 85 % RH, with respect to a reference humidity of 65 % RH, is relative small. The swelling/shrinkage in the transverse directions is less than ±1 %, whereas the dimensions in the axial direction are almost unchanged. For composites with high fibre content, the dimensional swelling/shrinkage is well predicted from the product of density and moisture content of the composites. This simple predictability of the moisture-related dimensional changes is beneficial with respect to an industrial use of aligned plant fibre composites. The mechanical properties of aligned hemp yarn composites subjected to tension have been investigated. For composites with fibre volume fraction in the range 0.30-0.34, stiffness is in the range 16-20 GPa and tensile strength is in the range 190-220 MPa. Generally, these properties are superior to previously reported properties of aligned plant fibre composites having comparable fibre volume fraction. The study included parameters such as testing direction, yarn type, matrix type, fibre volume fraction, process temperature and conditioning humidity. The tensile properties of the composites are highly affected by the testing direction; e.g. axial ultimate stress is reduced from 205 to 125 MPa at an off-axis angle of only 10 o. The off-axis properties are well modelled by a planar model of a homogenous and orthotropic material. The reinforcement efficiency varies between types of hemp yarn. Even for two batches of the same type of hemp yarn, only bought at different times, the reinforcement efficiency is not identical. This underlines a critical aspect in the use of plant fibres; i.e. their properties are less controllable in comparison to the properties of synthetic fibres. The axial tensile properties of the composites are affected only little by the degree of fibre/matrix compatibility. Even for composites with a strong fibre/matrix bonding, no clear improvement in axial properties are observed, but the failure characteristics of the composites are changed dramatically. A model is presented to predict the tensile properties of the composites as a function of the fibre volume fraction. Axial stiffness and ultimate stress are well predicted by the model. The model includes the effect of porosity, and demonstrates how tensile properties of the composites are reduced when the porosity is increased. The process temperature is mainly affecting axial tensile strength of the composites; e.g. when the process temperature is increased from 180 to 220 oC, axial ultimate stress is decreased from 240 to 170 MPa. The results emphasize the importance of a low process temperature. The conditioning humidity is mainly affecting axial stiffness and strain at ultimate stress of the composites; e.g. when the conditioning humidity is increased from 35 to 85 % RH, axial stiffness is decreased from 18 to 14 GPa, and axial strain at ultimate stress is increased from 0.026 to 0.037. The results underline that plant fibre composites need to be carefully conditioned before testing in order to compare results between series of experiment.