Experimental investigation and thermo-mechanical modelling for tool life evaluation of photopolymer additively manufactured mould inserts in different injection moulding conditions

There is a growing interest for integrating additive manufacturing (AM) technology in different manufacturing processes such as injection moulding (IM) due to the possibility of achieving shorter manufacturing times and increased cost effectiveness. This paper evaluates IM inserts fabricated by the AM vat photopolymerisation method. The inserts are directly manufactured with a photopolymer material, integrated on an injection moulding tool and subsequently used for IM. Therefore, particular attention has to be paid in order to develop the soft tooling process chain and the IM experimental procedure as detailed in this study. Different combinations of IM parameters are investigated in this work in order to determine the influence of the various process settings on the inserts’ performance (lifetime, crack propagation, consistency of the mould surface features). The mould inserts were analysed by three-dimensional optical metrology and evaluated with regard to the different surface features that were affected by the IM process. A three-dimensional thermo-mechanical with phase change model for the analysis of the effects of the IM process on the additive manufactured tools was accomplished in the FE software COMSOL Multiphysics. The potential causes for the insert failure are identified both by means of the IM experiments and the numerical model. The developed model could also predict the thermally induced deformations produced in the mould and identify where this phenomenon would eventually lead to defects in the shape of the parts. The influence of three different temperatures of the insert at 25 °C, 50 °C and 100 °C on the failure of the insert was investigated. Also a detailed discussion about the solidification and temperature changes is given.
A method for the characterization of the reflectance of anisotropic functional surfaces

The functional properties of micro-structured surfaces have gained increasing interest thanks to many applications such as wetting, adhesion, thermal and/or electrical conductivity. In this study, directional optical properties, i.e. contrast between two regions of a surface, were achieved with an anisotropic microstructure composed of a close array of ridges. The anisotropic surface, designed as a combination of ridges, has been milled on a steel bar and replicated through hot embossing of Acrylonitrile butadiene styrene (ABS) and through replica technology using silicone rubber. The directional reflectance of the surface for a range of design-specific view-illumination configurations was determined using a method that involves a Hirox RH-2000 digital microscope, used as a gonireflectometer. This method allows the empirical determination of the optimum surface microstructure for maximizing contrast between two horizontally orthogonal views. The results show that even if the uncertainty related to the instrumentation is up to 20% in some cases, this procedure is suitable for the characterization of the surface of both metal and plastic counterpart.

General information
State: Published
Organisations: Department of Mechanical Engineering, Manufacturing Engineering, Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Contributors: Regi, F., Nielsen, J. B., Li, D., Zhang, Y., Frisvad, J. R., Aanaes, H., Tosello, G.
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Source-ID: 2434400864
Research output: Research - peer-review; Journal article – Annual report year: 2018

A Soft Tooling Process Chain for Injection Molding of a 3D Component with Micro Pillars

The purpose of this paper is to present the method of a soft tooling process chain employing Additive Manufacturing (AM) for fabrication of injection molding inserts with micro surface features. The Soft Tooling inserts are manufactured by Digital Light Processing (vat photo polymerization) using a photopolymer that can withstand relatively high temperatures. The part manufactured here has four tines with an angle of 60°. Micro pillars (Ø200 μm, aspect ratio of 1) are arranged on the surfaces by two rows. Polyethylene (PE) injection molding with the soft tooling inserts is used to fabricate the final parts. This method demonstrates that it is feasible to obtain injection-molded parts with microstructures on complex geometry by additive manufactured inserts. The machining time and cost is reduced significantly compared to conventional tooling processes based on computer numerical control (CNC) machining. The dimensions of the micro features are influenced by the applied additive manufacturing process. The lifetime of the inserts determines that this process is more suitable for pilot production. The precision of the inserts production is limited by the additive manufacturing process as well.

General information
State: Published
Organisations: Department of Mechanical Engineering, Manufacturing Engineering
Contributors: Zhang, Y., Pedersen, D. B., Mischkot, M., Calaon, M., Baruffi, F., Tosello, G.
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Publication date: 2018
Assessment of sub-mm features replication capability in injection moulding using a multi-cavity tool produced by additive manufacturing

This research investigates the effect of injection moulding process parameters on photopolymer mould inserts produced with the Digital Light Processing (DLP) additive manufacturing (AM) method. The main motivation of applying AM to produce mould inserts, is the potential of reducing lead time and manufacturing cost, as well as achieving a more flexible manufacturing method in case of non-mass produced products such as prototypes. In this research mould inserts of 20 x 20 x 2.7 mm with mould cavities as small as 5 x 4 mm in dimensions are tested. The parts are analyzed and evaluated by the measurements of different features and the influence of the IM process.
Assessment of sub-mm features replication capability in injection moulding using a multi-cavity tool produced by additive manufacturing
This research investigates the effect of injection moulding process parameters on photopolymer mould inserts produced with the Digital Light Processing (DLP) additive manufacturing (AM) method. The main motivation of applying AM to produce mould inserts, is the potential of reducing lead time and manufacturing cost, as well as achieving a more flexible manufacturing method in case of non-mass produced products such as prototypes. In this research moulds inserts of 20 x 20 x 2.7 mm with mould cavities as small as 5 x 4 mm in dimensions are tested. The parts are analyzed and evaluated by the measurements of different features and the influence of the IM process.

A study of laser surface modification of polymers: A comparison in air and water
Laser surface modification is a technique to modify polymer surfaces for various applications. In our earlier work [Physics Procedia, 83:211–217, 2016], we showed that when the laser surface modification process was carried out in water instead of air, the obtained surface characteristics were remarkably different, which led to a significant improvement in the metal deposition characteristics using electroless plating. In this work, we try to explain the underlying fundamental mechanisms that contribute to this improvement in surface characteristics through concurrent experimental and modeling research. The observed images of laser modified surfaces suggest that a hemispherical hump is formed in the case of water at lower laser fluences that breakup with an increase in fluence. Such a behavior was not observed when the process was carried out in air. We explain this phenomenon by simulating the temperature profiles in the polymer during the laser heating process in air and water. The results suggest that subsurface heating effects occur when the process is carried out in water. We further argue that this phenomenon is mainly responsible for the formation of the complex structure that was observed in our previous work.
Comparison of selected processes for surface microstructuring of complex mould for an implanted device

Polymer products with functional surfaces are applied in many fields such as medical devices and biotechnology. However, most technologies for the fabrication of microstructured functional surfaces are still limited to flat geometries or geometries with constant curvature. This paper describes and compares three approaches for fabricating micro- or nanostructured surfaces; those process chains are suitable for patterning of the surface of 3D shape cavity for injection moulding. The desired surface features have been approved by cell proliferation test. The first approach is to use prefabricated plate with microstructured surface as an insert inside the cavity. The second approach is to directly pattern the surface by a femtosecond laser combined with mask projection technique. The third approach is to produce the cavity part using an anodizing process followed by metal deposition, and in this way, sub-microfeatures were obtained all over the cavity surface. The aim of this paper is to find solutions to implementing the desired features on the entire surfaces of a 3D-shaped ring; this research will also benefit the production of other complex parts with functional micro- or nanostructured surface.

General information
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Organisations: Department of Mechanical Engineering, Manufacturing Engineering
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BFI (2019): BFI-level 1
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 1
Dimensional Accuracy and Repeatability of 3D Printed Mould Inserts by DLP

Mask projection vat photopolymerization technology provides a method for additive manufacturing (AM) of high resolution surface features. In the present project, the technology is used to generate injection moulding inserts containing a double-curved freeform surface with bi-directional reflectance patterns. Orienting these patterns 0° and 90° relative to the viewing direction generates surface contrast with “dark” and “bright” areas (Fig. 1). This allows for incorporation of information barcodes in the polymer insert which subsequently replicates into every injection moulded part for e.g. enhanced product traceability, B2B information or end-user interaction at a significant reduction in lead-time compared to conventional tooling of inserts.

General information
State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Technical University of Denmark
Contributors: Thorn, S., Bertelsen, J. G., M. Ribo, M., Li, D., Regi, F., Davoudinejad, A., Zhang, Y.
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Peer-reviewed: Yes
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Dimensional Accuracy and Repeatability of Mould Inserts Manufactured by Mask Projection Vat-Photopolymerization

Mask projection vat-photopolymerisation (MPVP) technology provides a method for additive manufacturing (AM) of high resolution surface features. In the present project, the technology is used to generate injection moulding inserts containing a double-curved freeform surface with bi-directional reflectance patterns (Fig. 1 & 2). Orienting the anisotropic patterns by 0° and 90° relative to the viewing direction generates surface contrast with “dark” and “bright” areas (Fig. 5). This allows for incorporation of information barcodes in the polymer insert which subsequently replicates into every injection moulded part, e.g. enhanced product traceability, B2B information or end-user interaction.

General information
State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Technical University of Denmark
Contributors: Bertelsen, J. G., Thorn, S., M. Ribo, M., Li, D., Regi, F., Davoudinejad, A., Zhang, Y., Tosello, G.
Number of pages: 1
Publication date: 2018
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Research output: Research - peer-review › Poster – Annual report year: 2018

Evaluation of an improved micro milling strategy for the generation of tool steel micro features with optical functionality

This paper discusses a new micro milling strategy for manufacturing optical functionality on steel. The micro-structures, a combination of arrays of micro-ridges, has been developed to achieve the function. The function is to maximize the contrast of the reflected light from orthogonally patterned features. The burr formation and insufficient material removal, influenced by the tool wear and the machine accuracy, were the main challenges in this process. The cutting strategy was investigated in order to reduce the burr formation during the process. By the new strategy, the ridge machining order was reversed. The evaluation of the feature geometries proved that new strategy could improve the feature quality. The ultimate goal was to improve the surface functionality.

General information
Evaluation of part consistency with photopolymer inserts in different injection moulding process parameters

Using additive manufacturing (AM) processes for direct fabrication of complex three-dimensional objects in a fewer time in comparison to the subtractive method is the advancement of this technology. This study connecting the AM with injection moulding (IM) process. AM inserts are directly manufactured by photopolymer material and used in IM process. Different combinations of IM parameters are used in order to find out the influence of various settings on the fabrication of the parts with soft inserts. The effects of injection moulding parameters are investigated by the use of a design of experiment (DOE) and optical metrology. DOE analysis concludes that the IM speed and cooling time are significant factors, for the geometry of the features. The height of bricks and knobs are also measured on the IM parts for assessment of different batches before any cracks appear on the inserts.

General information
State: Published
Organisations: Department of Mechanical Engineering, Manufacturing Engineering
Contributors: Davoudinejad, A., Charalambis, A., Zhang, Y., Calaon, M., Tosello, G., Hansen, H. N.
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Event: Poster session presented at 18th International Conference of the European Society for Precision Engineering and Nanotechnology (Euspen 18), Venice, Italy.
Keywords: Additive manufacturing, Digital Light Processing, Soft tooling lifetime, Injection moulding
Research output: Research - peer-review › Poster – Annual report year: 2018

Investigation of product and process fingerprints for fast quality assurance in injection molding of micro-structured components

Injection molding is increasingly gaining favor in the manufacturing of polymer components since it can ensure a cost-efficient production with short cycle times. To ensure the quality of the finished parts and the stability of the process, it is essential to perform frequent metrological inspections. In contrast to the short cycle time of injection molding itself, a metrological quality control can require a significant amount of time and the late detection of a problem may then result in increased wastage. This paper presents an alternative approach to process monitoring and the quality control of injection
molded parts with the concept of "Product and Process Fingerprints" that use direct and indirect quality indicators extracted from part quality data in-mold and machine processed data. The proposed approach is based on the concept of product and process fingerprints in the form of calculated indices that are correlated to the quality of the molded parts. A statistically designed set of experiments was undertaken to map the experimental space and quantify the replication of micro-features depending on their position and on combinations of processing parameters with their main effects to discover to what extent the effects of process variation were dependent on feature shape, size, and position. The results show that a number of product and process fingerprints correlate well with the quality of the micro features of the manufactured part depending on their geometry and location and can be used as indirect indicators of part quality. The concept can, thus, support the creation of a rapid quality monitoring system that has the potential to decrease the use of off-line, time-consuming, and detailed metrology for part approval and can thus act as an early warning system during manufacturing.

**General information**

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Organisations: Department of Mechanical Engineering, Manufacturing Engineering, University of Applied Sciences Northwestern Switzerland
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- Web of Science (2017): Impact factor 2.222
- Web of Science (2017): Indexed yes
- Scopus rating (2016): CiteScore 1.83 SJR 0.395 SNIP 0.791
- Web of Science (2016): Impact factor 1.833
- Web of Science (2016): Indexed yes
- Scopus rating (2015): CiteScore 1.78 SJR 0.463 SNIP 0.925
- Web of Science (2015): Indexed yes
- Scopus rating (2014): CiteScore 2.1 SJR 0.625 SNIP 1.341
- Web of Science (2014): Impact factor 1.269
- Scopus rating (2013): CiteScore 1.73 SJR 0.479 SNIP 1.107
- Web of Science (2013): Impact factor 1.286
- ISI indexed (2013): ISI indexed no
- Scopus rating (2012): CiteScore 1.28 SJR 0.472 SNIP 1.285
- ISI indexed (2012): ISI indexed no
- Scopus rating (2011): SJR 0.222 SNIP 0.882
- ISI indexed (2011): ISI indexed no
Original language: English
Keywords: Precision injection molding, Process fingerprint, Process monitoring, Product fingerprint, Quality control

**Modeling of nanosecond pulsed laser processing of polymers in air and water: Paper**

Laser ablation of polymers in water is known to generate distinct surface characteristics as compared to that in air. In order to understand the role of ambient media during laser ablation of polymers, this paper aims to develop a physics-
based model of the process considering the effect of ambient media. Therefore, in the present work, models are
developed for laser ablation of polymers in air and water considering all the relevant physical phenomena such as
laser–polymer interaction, plasma generation, plasma expansion and plasma shielding. The current work focuses on near-infrared laser radiation (\(\lambda = 1064 \text{ nm}\)) of nanosecond pulse duration. The laser–polymer interaction at such wavelengths is
purely photo-thermal in nature and the laser–plasma interaction is assumed to occur mainly by inverse-bremsstrahlung
photon absorption. The computational model is based on the finite volume method using the Crank–Nicholson scheme.
The model predicts that underwater laser ablation results in subsurface heating effect in the polymer and confinement of
the laser generated plasma, which makes it different from laser ablation in air. Plasma expansion velocities are much
lower in water than in air. This results in an enhanced plasma shielding effect in the case of water. The predicted results of
ablation depth versus fluence from the model are in qualitative agreement with those observed in experiments.

**General information**
- **State:** Published
- **Organisations:** Department of Mechanical Engineering, Manufacturing Engineering
- **Contributors:** Marla, D., Zhang, Y., Hattel, J. H., Spangenberg, J.
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- **Volume:** 26
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  - Web of Science (2018): Indexed yes
  - BFI (2017): BFI-level 2
  - Scopus rating (2017): CiteScore 1.8 SJR 0.821 SNIP 0.93
  - Web of Science (2017): Impact factor 1.793
  - Web of Science (2017): Indexed yes
  - BFI (2016): BFI-level 2
  - Scopus rating (2016): CiteScore 1.82 SJR 1.076 SNIP 1.05
  - Web of Science (2016): Impact factor 1.891
  - Web of Science (2016): Indexed yes
  - BFI (2015): BFI-level 2
  - Scopus rating (2015): CiteScore 1.73 SJR 1.225 SNIP 1.057
  - Web of Science (2015): Impact factor 1.859
  - BFI (2014): BFI-level 2
  - Scopus rating (2014): CiteScore 1.81 SJR 1.305 SNIP 1.157
  - Web of Science (2014): Impact factor 2.167
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  - BFI (2013): BFI-level 2
  - Scopus rating (2013): CiteScore 1.25 SJR 1.083 SNIP 1.197
  - Web of Science (2013): Impact factor 1.492
  - ISI indexed (2013): ISI indexed yes
  - BFI (2012): BFI-level 2
  - Scopus rating (2012): CiteScore 2.05 SJR 1.461 SNIP 1.794
  - Web of Science (2012): Impact factor 1.932
  - ISI indexed (2012): ISI indexed yes
  - Web of Science (2012): Indexed yes
  - BFI (2011): BFI-level 2
  - Scopus rating (2011): CiteScore 1.96 SJR 1.151 SNIP 1.362
  - Web of Science (2011): Impact factor 2.298
  - ISI indexed (2011): ISI indexed yes
On the effect of machining strategy in micro milling of tool steel surface micro features with optical functionality

This paper presents a new micro milling strategy for manufacturing optical functionality on steel surfaces. The micro structures, a combination of arrays of micro-ridges, have been machined on tool steel surfaces. The desired function is to maximize the contrast of the reflected light from orthogonally patterned features. The micro-ridges are 800 μm long, 50 μm wide and 5° tilted.

General information

State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering
Contributors: Li, D., Davoudinejad, A., Regi, F., Zhang, Y., Tosello, G.
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Event: Abstract from Euspen Special Interest Group Meeting 2018: Structured & Freeform Surfaces, Cachan, France.
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Pitch measurements validation of a structural coloured steel insert using Scanning Confocal Microscopy (SCM) and Atomic Force Microscopy (AFM)

The optical principle of structural colouration provides to a surface unnatural and iridescent colouring properties. Surface topography combined with lighting characteristics are the physical driver of the phenomenon. Structural colouring arises from the presence on the specimen of nanoscale features distanced by a length comparable to the near visible light spectrum (300-1000 nm). The microstructures behave as a bandpass filter for certain light wavelengths, enabling an unnatural colouring effect. Elliptical Vibration Texturing (EVT) is an on development technology for fast texturing of gratings on metal inserts for structural colouration purposes. To identify the accuracy of EVT, in this study, two different
microscopes assess an EVT grating with a 1000 nm nominal pitch on a steel flat surface. On first, optical-based metrology is selected adopting a Laser Scanning Confocal Microscope (SCM) with a 405 nm blue source to tackle the measuring purpose. Secondly, an Atomic Force Microscope (AFM) in Intermittent contact mode (IC-AFM) is adopted. Considering the differences in set-up time and scanning range, the objective of this research is to identify the most favourable measuring technique. On the sample images, five average profiles on different locations provide consistent information about the process repeatability. Pitch estimation comes by means of FFT algorithm on the extracted profiles. The average result for SCM measures is $1002 \pm 31$ nm while for AFM is $972 \pm 15$ nm. At last, from these results, the estimation of EVT accuracy is presented.

**General information**

State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Chinese University of Hong Kong, Dansk Fundamental Metrology A/S
Contributors: Loaldi, D., Zhang, Y., Calaon, M., Yang, Y., Guochin, P., Garnæs, J., Tosello, G.
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Event: Abstract from 18th International Conference of the European Society for Precision Engineering and Nanotechnology (euspen 18), Venice, Italy.
Keywords: Scanning Confocal Microscopy, Dynamic Force Microscopy, Elliptical Vibration Texturing, Structural Colouration

A comparison of reflectance properties on polymer micro-structured functional surface

In this study, a functional micro-structure surface [1] has been developed as a combination of arrays of micro ridges. The scope of the surface is to achieve specific directional optical properties: that is, under constrained lighting, maximizing the reflectance from a certain viewing direction, and minimizing it from the corresponding horizontally orthogonal position, i.e. maximize the contrast between two horizontally orthogonal view positions at the same inclination (Figure 1). The sample is composed of 12 different anisotropic surfaces, that are designed as a combination of ridges defined by their pitch distance and their angle in respect to the surface (Figure 2). The geometry was obtained by precision milling of a tool steel bar and replicated through silicone replica technology [2], and by hot embossing using Acrylonitrile Butadiene Styrene (ABS). A digital microscope has been used as a gonioreflectometer to determine the directional surface reflectance of each surface to varying light and camera positions. The presented results show that the replication processes and the polymeric material have a strong impact on the contrast under constrained lightening. More specifically, the reflectance properties are strongly influenced by the geometry of the structure and by the colour.

**General information**

State: Published
Organisations: Department of Mechanical Engineering, Manufacturing Engineering, Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Danish Meteorological Institute
Contributors: Regi, F., Li, D., Nielsen, J. B., Zhang, Y., Tosello, G., Madsen, M. H., Frisvad, J. R., Aanæs, H.
Number of pages: 1
A preliminary study on replication and quality correlation of on-part and on-runner polymer injection moulded micro features

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Organisations: Department of Mechanical Engineering, Manufacturing Engineering
Contributors: Giannekas, N., Tosello, G., Zhang, Y.
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Electronic versions: poster_euspen_faregi_final_1.pdf
Research output: Research - peer-review › Poster – Annual report year: 2017

A Soft Tooling process chain employing Additive Manufacturing for injection molding of a 3D component with micro pillars

The purpose of the research presented in this paper is to investigate the capability of a soft tooling process chain employing Additive Manufacturing (AM) for preproduction of an insert with micro features by injection molding. The Soft Tooling insert was manufactured in a high temperature photopolymer by Digital Light Processing (vat photopolymerization). The mold cavity was formed by two insert halves, by design; both inserts have four angled tines, with micro holes (Ø200 μm, 200 μm deep) on the surface. Injection molding with polyethylene was used with the soft tool inserts to manufacture the final production components. The diameter and height of the pillars that were replicated on the molded components were characterized by means of a 3D profilometer. The influence of the injection molding parameters on the replication was evaluated using a 2-levels DOE of three factors. The uniformity of the pillars are also evaluated regarding the diameter and height.

General information
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Organisations: Department of Mechanical Engineering, Manufacturing Engineering, Technical University of Denmark
Contributors: Zhang, Y., Pedersen, D. B., Segebrecht Geitje, A., Mischkot, M.
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Scopus rating (2016): CiteScore 2.47 SJR 1.093 SNIP 1.746
Web of Science (2016): Impact factor 2.322
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Web of Science (2015): Impact factor 1.771
Scopus rating (2014): CiteScore 1.77 SJR 1.025 SNIP 2.013
Scopus rating (2013): CiteScore 1.74 SJR 0.909 SNIP 1.496
Scopus rating (2012): CiteScore 1.72 SJR 0.945 SNIP 1.759
Scopus rating (2011): CiteScore 1.2 SJR 0.602 SNIP 2.232
Scopus rating (2010): SJR 0.796 SNIP 1.215
Scopus rating (2009): SJR 0.264 SNIP 0.39
A study on replication and quality correlation of on-part and on-runner polymer injection molded micro features

Injection molding is increasingly gaining place in manufacturing of polymer components as it can ensure a cost efficient production with short cycle times. To ensure the quality of the produced parts and the stability of the process it is essential to perform frequent metrological inspections. In contrast to injection molding's short cycle time, a metrological quality control can require a significant amount of time. The late detection of the problem can result to high losses and scrap rate. This paper presents an alternative approach to process monitoring and part quality control with fast off/in-line metrology of physical part quality indicators ("Product Fingerprint"). The proposed approach is based on the concept of metrology applied to dedicated micro features, positioned on the runners, similar or equal to those in the part in order to access the quality of the produced plastic parts. A designed experiment was employed to map the experimental space and quantify the pillars replication depending on position and processing parameter combinations. The pillars were assessed and the main effects of the processing parameters, were calculated to reveal that the effects of process parameter change were similar in all measurement positions. Results showed that the product fingerprints have a correlation to the quality of on-part micro features. The concept can support the creation of a fast part quality monitoring system that has the potential to decrease the use of off-line time-consuming detailed metrology for part approval.

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Organisations: Department of Mechanical Engineering, Manufacturing Engineering
Contributors: Giannekas, N., Tosello, G., Zhang, Y.
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Keywords: Precision injection moulding, Quality Control, Process monitoring

Evaluation of optical functional surfaces on the injection moulding insert by micro milling process

This study presents the optimization of micro milling process for manufacturing injection moulding inserts with an optical functional surface. The objective is the optimal surface functionality. Micro ridges were used as the microstructures to realize the function to generate contrast between orthogonally textured areas by reflecting light in different directions. In order to maximize the contrast, a sample was machined with the same structures and dimensions, according to a Design of Experiments (DOEs) to optimize the milling parameters by considering the contrast as a response. The contrast was evaluated based on the image processing method. The proper cutting condition was selected in order to obtain machined surface with the highest contrast and the results presented by DOE analysis. The correlations between the cutting parameters, the burrs height, and the function were determined. The contrast was found to be proportional to the spindle speed and feed rate and “oil+air” was considered as the preferred cooling method.

General information
State: Published
Organisations: Department of Mechanical Engineering, Manufacturing Engineering, Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics
Contributors: Li, D., Davoudinejad, A., Zhang, Y., Regi, F., Tosello, G., Nielsen, J. B., Aanæs, H., Frisvad, J. R.
Number of pages: 3
Publication date: 2017

The objective of this research is to investigate the influence of injection molding parameters on the dimensional replication of microstructure surfaces in injection molding with additively manufactured soft tooling inserts in a photopolymer material. The replication degree of micropillars on injection-molded tine rings was assessed and a Design of Experiments (DOE) approach was used to investigate which factors influence the replication. A full factorial analysis with three factors at two levels lead to the conclusion that a high mold temperature increases the replication degree of the pillar diameter and decreases the replication degree of the pillar height. A high melt temperature increases the pillar diameter independently from the pillar height. A higher injection speed affects both pillar diameter and height negatively. In addition, the study showed a significant difference in the replication degree between inserts on the injection side and the ejector side of the mold respectively. Also, a position closer to the injection gate supports a higher replication degree. Insert wear was found insignificant within the experimental range of up to 100 injection cycles.

Injection Moulding Pilot Production: Performance Assessment of Tooling Process Chains Based on Tool Inserts Made from Brass and A 3d Printed Photopolymer

Additive Manufacturing is becoming a viable option for the production of injection molding inserts in pilot production settings. This work compares an insert made from brass using conventional machining with an insert made from a proprietary photopolymer using Digital Light Processing (DLP) through the application of precision injection molding. The performance of the inserts is analyzed focusing on design, metrological aspects, tool lifetime, and thermal performance. In the experiment, a disk-shape geometry (diameter41.5 mm, thickness 3.5 mm) was injection molded in Low-Density Polyethylene in a two-cavity mold. The inserts as well as selected injection molded parts were analyzed with an optical 3D micro-coordinate measuring machine. It was found that additive manufacturing technology can lead to a significantly more cost effective pilot production, both in terms of development time and investment. DLP technology enables fast production of micro-features, however insert production with DLP is less reliable than milling e.g. when considering process repeatability. Photopolymer and brass inserts lead to differences in optical surface appearance on the injection molded parts. The lifetime of the photopolymer inserts is challenging to predict reliably. Depending on how many parts need to be produced, the use of several photopolymer inserts instead of one brass insert is a means to overcome the shorter lifetime and can represent a cost-effective alternative to machined inserts. In order to exploit the advantages of using additive manufactured injection mold inserts, specific tool design rules have to be applied.
**Investigation of Tooling for Anisotropic Optical Functional Surfaces**

This paper studied steel inserts with anisotropic surfaces for injection moulding. The inserts surfaces were machined by a five-axis micro-milling machine and the surface structures will be replicated by injection moulding. The aim of the surface structuring is to maximize visible contrast between horizontally orthogonal textured surfaces from a certain viewing angle, of both the insert and the polymer replicas. The contrast is defined by the difference of the reflectance between two areas with horizontally orthogonal textures under a certainly fixed light source. The brightness of the surface is assessed by processing the images obtained from a digital microscope Hirox RH-2000 [1]. Figure 1 illustrates the studied surface structure and the microscope. The optical axis of microscope can be tilted within 90 degrees from the horizontal level, which simulates the viewing angle; the analysed surface texture can be rotated horizontally by the adjusting the stage so only one surface was used to achieve orthogonal textures and images at different rotation angle can be captured. Via image processing tool, the reflectance (brightness of the obtained images) will be analysed and therefore the contrast can be calculated.

**General information**

**State:** Published  
**Organisations:** Department of Mechanical Engineering, Manufacturing Engineering, Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Danish Meteorological Institute  
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**Modeling the Anisotropic Reflectance of a Surface with Microstructure Engineered to Obtain Visible Contrast after Rotation**

Engineering of surface structure to obtain specific anisotropic reflectance properties has interesting applications in large scale production of plastic items. In recent work, surface structure has been engineered to obtain visible reflectance contrast when observing a surface before and after rotating it 90 degrees around its normal axis. We build an analytic anisotropic reflectance model based on the microstructure engineered to obtain such contrast. Using our model to render synthetic images, we predict the above mentioned contrasts and compare our predictions with the measurements reported in previous work. The benefit of an analytical model like the one we provide is its potential to be used in computer vision for estimating the quality of a surface sample. The quality of a sample is indicated by the resemblance of camera-based contrast measurements with contrasts predicted for an idealized surface structure. Our predictive model is also useful in optimization of the microstructure configuration, where the objective for example could be to maximize reflectance contrast.

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**Organisations:** Department of Applied Mathematics and Computer Science, Image Analysis & Computer Graphics, Department of Mechanical Engineering, Manufacturing Engineering  
**Contributors:** Luongo, A., Falster, V., Doest, M. E. B., Li, D., Regi, F., Zhang, Y., Tosello, G., Nielsen, J. B., Aanæs, H., Frisvad, J. R.  
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**Process chain for fabrication of anisotropic optical functional surfaces on polymer components**

This paper aims to introduce a process chain for fabrication of anisotropic optical functional surfaces on polymer products. The surface features under investigation are composed of micro serrated ridges. The scope was to maximize the visible
The impact of tool wear on the functionality of replicated polymer surface with micro structures

Wear happened frequently in the tooling process of mold for polymer production. The scope of this paper is to understand how the wear of the milling tool affected the function of the replicated polymer surface. This study is part of the process chain of fabrication of optical functional surfaces on polymer components. The aiming function of the surfaces is to maximize the reflectance from a certain viewing angle and direction, and minimize from its horizontally orthogonal position, i.e. to maximize the contrast between two horizontally orthogonal view positions at the same inclination. A five-axis micro milling machine was employed to pattern the surface of a steel insert for subsequent polymer replication.

In order to conduct the study, 1200 pixels (0.8 x 0.8 mm²) was machined on the surface of a steel insert using the same mill tool (Ф0.5 mm, ARNO®); each of the pixels contains 16 ridges which is illustrated in figure 1 (a). The obtained surface structures were replicated using liquid silicon rubber (LSR).

The mill tool was inspected by scanning electron microscope (SEM) before and after the machining. Noticeable wear was observed. The weight of the studied tool was measured before and after machining for comparison. The obtained surface features on the insert and the LSR replica were measured using a confocal 3D laser scanner. The reflectance of the surfaces on the LSR replica was evaluated using a gonioreflectometer[1]. The gonioreflectometer captured the images of every 100th pixel from all the viewing angles by rotating the sample holder and tilting the objective lens. The reflectance for each configuration were obtained via image processing tools.

Results in this study include: 1. Tool wear was visualized by SEM images, which is shown in figure 1 (b). 2. However, the weight decrease could not be detected due to lack of precision in the measurement. 3. The number of defects on the obtained surface structures increased significantly along with the process. 4. The reflectance of these pixels on the LSR replica decreased from the first machined one to the last one.

As a conclusion, the tool (Ф 0.5mm, ARNO®) used in this study worn after machining for approximately 100 pixels, considering the function loss of replica surface. Future work will be dedicated to the methods that can prolong the tool life.
not scaled down as the absolute dimension. In practice a tolerance level of 10 -100 μm seems to be the preferred level no matter the absolute dimension.

**A computational model for heterogeneous heating during pulsed laser irradiation of polymers doped with light-absorbing microparticles**

Doping of polymers with light-absorbing microparticles to increase their optical properties is a commonly used pre-treatment technique in laser processing of polymers. The presence of these particles plays an important role during laser heating of the polymer that influences its surface characteristics. This work presents a study based on a computational model of laser heating of polymer doped with light-absorbing microparticles accounting for the heterogeneous nature of heating. The work aims at gaining a fundamental insight into the nature of the heating process and to understand the role of microparticles. The results suggest that apart from the laser intensity and pulse duration, the properties of the microparticles including their size and distribution also play an important role during the laser heating of polymers.

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- BFI (2015): BFI-level 1  
- Scopus rating (2015): CiteScore 1.38 SJR 0.519 SNIP 0.768  
- Web of Science (2015): Impact factor 1.444  
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- BFI (2014): BFI-level 1  
- Scopus rating (2014): CiteScore 1.74 SJR 0.62 SNIP 0.965  
- Web of Science (2014): Impact factor 1.704
Adaptive Layer Height During DLP Materials Processing

This research aims to show how manufacturing speeds during vat polymerisation can be vastly increased through an adaptive layer height strategy that takes the geometry into account through analysis of the relationship between layer height, cross-section variability and surface structure. This allows for considerable process speedup during the Additive Manufacture of components that contain areas of low cross-section variability, at no loss of surface quality. The adaptive slicing strategy was tested with a purpose built vat polymerisation system and numerical engine designed and constructed to serve as a Next-Gen technology platform. By means of assessing hemispherical manufactured test specimen and through 3D surface mapping with variable-focus microscopy and confocal microscopy, a balance between minimal loss of surface quality with a maximal increase of manufacturing rate has been identified as a simple angle-dependent rule. The
achievable increase in manufacturing rate was above 38% compared to conventional part slicing.

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Research output: Research - peer-review › Article in proceedings – Annual report year: 2016

**A Self-Peeling Vat for Improved Release Capabilities During DLP Materials Processing**
This paper describes research to increase the competitiveness of vat polymerisation by increasing the manufacturing rate while lowering the normal forces that induce part stress during the lift procedure of vat based systems. This is achieved through introducing a polymerisation vat that allows for an eased release of the manufactured part from the vat by means of a flexible membrane system. A membrane of fluorinated ethylene polymer will through elastic deformation automatically peel off the part as the part is lifted during layer changes. Peeling has been qualified by means of a truncated inverted cone as test geometry. As the cross-sectional diameter of the cone increase throughout the build-job, the geometry will release from the glass based build platform at the point where the peeling force exceed the adhesion force between platform and part. At failure point the lateral surface area of the top and bottom of the truncated cone is used as a measure of the performance of the vat with respect to release-capability. This has been tested at increasing manufacturing rates. The new self-peeling vat outperformed industrial state-of-the-art vats by 814% percent.

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**Improvement in Surface Characteristics of Polymers for Subsequent Electroless Plating Using Liquid Assisted Laser Processing**
Metallization of polymers is a widely used process in the electronic industry that involves their surface modification as a pre-treatment step. Laser-based surface modification is one of the commonly used techniques for polymers due to its speed and precision. The process involves laser heating of the polymer surface to generate a rough or porous surface. Laser processing in liquid generates superior surface characteristics that result in better metal deposition. In this study, a comparison of the surface characteristics obtained by laser processing in water vis-à-vis air along with the deposition characteristics are presented. In addition, a numerical model based on the finite volume method is developed to predict the temperature profile during the process. Based on the model results, it is hypothesized that physical phenomena such as vapor bubble generation and plasma formation may occur in the presence of water, and it is because of these effects that causes an increase in surface porosity.

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Injection molding of micro pillars on vertical side walls using polyether-ether-ketone (PEEK)

This paper investigates the replication of microstructures on a vertical wall by PEEK injection molding. A 4-cavity insert was used in the injection molding. Pre-fabricated nickel plates with \( \phi 4 \) \( \mu \)m micro holes on the surface were glued on vertical walls in the cavities. 3 cavities were coated by CrN, TiN and TiB\(_2\) respectively, the remaining one was not coated as a reference. The effect of coating was compared via the morphology of the micropillars on the polymer parts. 4000 injection molding cycles were repeated. The roughness of the coated surface was measured. The reasons for the demolding result were discussed.

Two process chains for creating functional surfaces on mold for 3D geometry

Polymer products with functional surfaces are applied in many fields such as medical and bio technology [1][2]. It is believed that certain types of micro- or nano- structured surfaces can enhance tissue anchoring [3]. However, most technologies for the fabrication of micro-structured functional surfaces are still limited to flat geometries or geometries with constant curvature [4]. Typically products that need micro structuring on the surface have a three dimensional and complex geometry. There are huge demand for investigation in establishing the micro structures on the surface of a 3D mold. This paper describes and compares 2 approaches for fabricating micro- structured surfaces suitable for patterning of 3D shape cavity for injection moulding. The application investigated for the research is a part of a fixture for electrodes to be implanted inside human body. It is a ring with four wings as illustrated by Figure 1.
Application of Functional Nano-Patterning to Polymer Medical Micro Implants

Improvement of cells adhesion to medical implants can be achieved through specific surface nano-patterns. The application of nano-patterns to planar surfaces can be obtained in a number of ways. However, the application of functional nano-patterns to complex 3D surfaces is a challenging task. In this paper the application of a nano-pattern deriving from aluminium anodizing to 3D micro mould inserts for replication of polymer medical micro implants is described. A process chain earlier developed at DTU was applied, where the main steps include the fabrication of an aluminium master, anodizing, etching of aluminium oxide, nickel and copper electroplating and selective etching of the aluminium master. The resulting nanostructure consists of tightly packed hemispherical features with average diameter of approximately 400 nm. Characterization of the obtained nanostructure on the micro mould inserts was carried out by means of atomic force microscopy and scanning electron microscopy. Results show that the specific nano-pattern was successfully generated on the 3D mould inserts exploiting the proposed process chain.

Comparison of 3 methods on fabricating micro- /nano- structured surface on 3D mold cavity

The methods to manufacture micro- or nano- structures on surfaces have been an area of intense investigation. Demands are shown for technologies for surface structuring on real 3D parts in many fields. However, most technologies for the fabrication of micro-structured functional surfaces are still limited to flat or simple shaped geometries. In this paper, 3 approaches for fabricating micro and nano- structured surfaces on a mold cavity for injection moulding are investigated and compared. The first approach is to use pre-fabricated plate with micro-structured surface as an insert for the mold, in this way micro holes (Ø4 μm) was obtained. The second approach is to produce the cavity part using anodizing process chain, and in this way sub-micro structures can be obtained all over the cavity surface. The third approach is to machine the surface inside the cavity directly by femtosecond laser combined with mask projection technique.
Replication of Micro pillars by PEEK injection moulding with CrN coated Ni tool
A micro-structured nickel insert was investigated for polyether ether ketone (PEEK) injection moulding. The micro-features were circular holes 4 μm in diameter and 2 μm deep, with a 2-μm edge-to-edge distance. Six thousand moulding cycles were operated. Half of the insert was coated by approximately 200 nm CrN. PEEK parts produced by the coated side and uncoated side were compared. Coating thickness was measured at intervals of production and employed to characterize the coating wear. Pillar geometry at fixed locations on PEEK parts was studied by scanning electron microscope (SEM). Energy-dispersive X-ray spectroscopy (EDS) was conducted on the PEEK parts in order to study the possible nickel and silver contamination. The results show that the studied coating had a very low wear, and no nickel or silver contamination on PEEK was detected for both parts produced by coated and uncoated sides. Coating improved demoulding by reducing small indentations on pillars.

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Contributors: Zhang, Y., Hansen, H. N., Sørensen, S.
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Web of Science (2017): Impact factor 2.601
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BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.3 SJR 1.046 SNIP 1.608
Web of Science (2016): Impact factor 2.209
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 1.8 SJR 0.889 SNIP 1.325
Web of Science (2015): Impact factor 1.568
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 2.03 SJR 1.082 SNIP 1.841
Web of Science (2014): Impact factor 1.458
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 2.26 SJR 1.134 SNIP 2.131
Web of Science (2013): Impact factor 1.779
ISI indexed (2013): ISI indexed yes
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BFI (2012): BFI-level 1
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ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
In this paper, liquid silicon rubber (LSR) parts with micro pillars are studied. The LSR parts were produced by injection moulding and are used as anchoring device for electrode implants inside humans. Micro-structures with specific dimension on implant surfaces can reduce encapsulation by the human body, thereby improving implant performance. This paper presents a method of applying micro structure on 3D parts. A Ni-plate with micro holes on the surface was cut into inserts and stuck in a cavity for injection moulding. 1000 injection moulding cycles were performed. Key dimensions of the pillars were monitored at intervals of the production on LSR parts on different locations. This paper focuses on characterization methods for the dimensions of the pillars on LSR parts. Due to the transparency and elasticity of LSR material, conventional stylus or optical instruments cannot be used to measure the height of the pillars. A confocal microscope with infinite focus was used instead. Moreover, SEM was employed to illustrate the topography visually. It is believed that the uniformity of the height of the pillar array is critical for proliferation of human cells, hence the standard deviation of the height was studied with the aid of SPIP®. The replication degree of LSR pillars is calculated based on the height measurement. The injection moulding process is also discussed in this paper.
Replication of micro structured surface by injection moulding of PEEK

A micro-structured Ni insert was investigated for PEEK injection moulding. The micro features are circular holes 4 μm in diameter and 2 μm deep, with a 2 μm edge-to-edge distance. 6000 moulding cycles was operated. Half of the insert was coated by 200nm CrN. PEEK parts produced by the coated side and non-coated side were compared. Coating thickness was measured at intervals of production and employed to characterize the coating wear. Pillars geometry at fixed locations on PEEK parts was studied by SEM. EDS was conducted on the PEEK parts in order to study the Ni and Ag contamination. The results show the studied coating has a very low wear, and no Ni or Ag contamination on PEEK was detected for both parts produced by coated side and uncoated side. Coating improved demolding by reducing small indentations on pillars. The method to apply micro structured Ni plate on 3D parts injection moulding is proposed.

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Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2014

An explanation of the mechanism for laser induced selective activation using diffusion theory

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Scopus rating (2014): CiteScore 0.33 SJR 0.278 SNIP 0.428
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ISI indexed (2013): ISI indexed no
Scopus rating (2012): CiteScore 0.3 SJR 0.219 SNIP 0.486
ISI indexed (2012): ISI indexed no
Scopus rating (2011): CiteScore 0.33 SJR 0.201 SNIP 0.436
ISI indexed (2011): ISI indexed no
Scopus rating (2010): SJR 0.213 SNIP 0.442
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Scopus rating (2008): SJR 0.13 SNIP 0.232
Scopus rating (2007): SJR 0.11 SNIP 0.123
Original language: English

Bibliographical note
Dimensional verification of high aspect micro structures using FIB-SEM

Micro-structured surfaces are increasingly used for advanced functionality. In particular, micro-structured polymer parts are interesting due to the manufacturing via injection moulding. A micro-structured nickel surface was characterized by focussed ion beam-scanning electron microscope (FIB-SEM) assisted by Spip®. The micro features are circular holes 10μm in diameter and 20μm deep, with a 20μm pitch. Various inspection methods were attempted to obtain dimensional information. Due to the dimension, neither optical instrument nor atomic force microscope (AFM) was capable to perform the measurement. A cross sectioned sample was prepared for conventional SEM in order to inspect the geometry of the holes, but the cutting angle used when making the cross section had a significant influence on the obtained results. Via FIB-SEM, the process was recorded by images when slicing the sample layer by layer by ion-beam. In this way, the dimension and the geometry of the holes are characterized.

Verification of a characterization method of the laser-induced selective activation based on industrial lasers

In this article, laser-induced selective activation (LISA) for subsequent autocatalytic copper plating is performed by several types of industrial scale lasers, including a Nd:YAG laser, a UV laser, a fiber laser, a green laser, and a short pulsed laser. Based on analysis of all the laser-machined surfaces, normalized bearing area curves and parameters are used to characterize the surface quantitatively. The range of normalized bearing area curve parameters for plate-able surface is suggested. PBT/PET with 40 % glass fiber was used as the substrate material. For all of the studied lasers, the parameters were varied in a relatively large range, and matrixes of the laser-machined surface were obtained. The topography of those laser-machined surfaces was examined by scanning electronic microscope (SEM). For each sample examined by SEM, there was an identical workpiece plated by for 90 min. The obtained copper thickness was measured. It is confirmed that copper only deposits on the surface that has a porous structure. The bonding strength between the copper layer and the substrate was also measured.
An Explanation of the Selective Plating of Laser Machined Surfaces using Surface Tension Components

General information
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Organisations: Department of Mechanical Engineering, CERE – Center for Energy Resources Engineering, Department of Chemical and Biochemical Engineering
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Scopus rating (2016): CiteScore 1.03 SJR 0.372 SNIP 0.606
Web of Science (2016): Impact factor 1.073
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 0.99 SJR 0.351 SNIP 0.613
Web of Science (2015): Impact factor 0.863
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 1.05 SJR 0.398 SNIP 0.656
Web of Science (2014): Impact factor 0.961
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 1.19 SJR 0.441 SNIP 0.764
Web of Science (2013): Impact factor 1.153
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Selective metallization of polymers using laser induced surface activation (LISA)—characterization and optimization of porous surface topography

Laser induced selective activation (LISA) is a molded interconnected devices technique for selective metallization of polymers. On the working piece, only the laser-machined area can be metalized in the subsequent plating. The principle of the technology is introduced. Surface analysis was performed on the laser-machined polymer using an Alicona InfiniteFocus® microscope. Based on previous experiments, bearing area curve and its parameters are chosen to characterize the surface. In this paper, by comparison of plateable and non-plateable surfaces, and two types of plateable surface made by different lasers, it is found that the normalized bearing area curve is an effective method to characterize porous surface for the subsequent plating. The normalized parameters are available to make a quantitative analysis.

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BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 2.8 SJR 0.994 SNIP 1.697
Web of Science (2017): Impact factor 2.601
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.3 SJR 1.046 SNIP 1.608
Web of Science (2016): Impact factor 2.209
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 1.8 SJR 0.889 SNIP 1.325
Web of Science (2015): Impact factor 1.568
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 2.03 SJR 1.082 SNIP 1.841
Web of Science (2014): Impact factor 1.458
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BFI (2013): BFI-level 1
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Web of Science (2013): Impact factor 1.779
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BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 1.75 SJR 0.971 SNIP 2.099
Web of Science (2012): Impact factor 1.205
ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 1.61 SJR 0.817 SNIP 1.673
Web of Science (2011): Impact factor 1.103
ISI indexed (2011): ISI indexed yes
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Scopus rating (2010): SJR 0.785 SNIP 1.445
Web of Science (2010): Impact factor 1.071
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.797 SNIP 1.384
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.52 SNIP 1.029
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.441 SNIP 0.747
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.477 SNIP 1.109
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.608 SNIP 0.944
Scopus rating (2004): SJR 0.56 SNIP 0.9
Scopus rating (2003): SJR 0.653 SNIP 0.911
Scopus rating (2002): SJR 0.687 SNIP 1.003
Scopus rating (2001): SJR 0.462 SNIP 1.064
Characterization of Laser Machined Polymer Surface Using Bearing Area Curve Parameters for Future Plating

General information
State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Institute for Product Development
Publication date: 2010

Host publication information
Title of host publication: ICOMM/4M2010
Source: orbit
Source-ID: 261941
Research output: Research - peer-review › Article in proceedings – Annual report year: 2010

Electroless Plating on Plastic Induced by Selective Laser Activation

General information
State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Institute for Product Development
Contributors: Zhang, Y., Tang, P. T., Hansen, H. N., Nielsen, J. S.
Pages: 43-47
Publication date: 2010
Peer-reviewed: Yes

Publication information
Journal: Plating and Surface Finishing
Volume: 97
Issue number: 2
ISSN (Print): 0360-3164
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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
Scopus rating (2013): SJR 0.113 SNIP 0.198
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.128 SNIP 0.136
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.105 SNIP 0.115
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.124 SNIP 0.105
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.128 SNIP 0.026
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.172 SNIP 0.091
Laser Induced Selective Activation For Subsequent Autocatalytic Electroless Plating

The subject of this PhD thesis is "Laser induced selective activation for subsequent autocatalytic electroless plating." The objective of the project is to investigate the process chains for micro structuring of polymer surfaces for selective micro metallization. Laser induced selective activation (LISA) is introduced and studied as a new technique for producing 3D moulded interconnect devices (3D-MIDs). This technique enables the metallization of polymer surface modified by laser and subsequently activated by a PdCl2/SnCl2 system. Various technologies exist on an industrial level for manufacturing MIDS, e.g. LDS®, 2-shot injection moulding, etc. Compared with them, LISA shows economic and environmental advantages. First, the range of available polymers is wide, and no pretreatment such as filler premix is need. Commercial polymer such as polyethylene and polystyrene, polycarbonate, ABS, etc. can be directly used in the LISA process. Second, in the wet steps, no chromic acid or other similar toxic compounds are used. The principle of the PdCl2/SnCl2 activation system is explained based on previous researchers' studies. Investigations were conducted as to how the laser tracks keep the activation colloids based on three hypotheses. The first hypothesis is that laser machining leads to chemical changes of the polymer, which results in chemical bonding with the activation colloids. Chemical changes on the laser track were investigated by XPS or FTIR spectroscopy, but no evidence shows that chemical bonds exist. However, it is still not excluded that chemical bonding is part of the mechanism. The second hypothesis is that the laser track has a stronger attraction work to the activation solution. This is proved by a calculation using van Oss et al., theory based on contact angle measurement. The third hypothesis is that the activation and rinsing process can be described by diffusion. This hypothesis is proved using Fick's diffusion laws combined with the short-time-plating experiment. The influence of laser parameters on the surface structure is investigated for Nd:YAG, UV, and fiber lasers. The mechanism of the surface structure formation reason is discussed and the Nd:YAG laser parameters' effect on the structure of the laser track is investigated. There is a trend showing that the height of the laser track increases with the laser energy output. A characterization method for the porous surface based on the bearing area curve and its parameters is proposed. Comparison of two activation methods based on plating velocity was performed. It was found that the plating velocity is independent of the height of the laser track, as long as the structure is sponge-like and continuous. The adhesive strength of the copper coating is related to the laser structure. High laser energy input will lead to high laser track, on which the copper coating has a stronger adhesion than on the track made by lower energy, even though the coatings have similar thickness. The LISA method was tested in the case of an antenna. Two simple antenna shapes, planar dipole, and planar loop were studied, as well as a co-planar stripline. The antennas made by LISA exhibited impedance characteristics expected from the respective antenna shapes and comparable to antennas made by PCB technology.

General information
State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering
Contributors: Zhang, Y.
Publication date: 2010

Publication information
Publisher: DTU Mechanical Engineering
Original language: English
Electronic versions:
Yang_final.pdf
Source: orbit
Source-ID: 276625
Research output: Research › Ph.D. thesis – Annual report year: 2010
**Electroless Plating on Plastic Induced by Selective Laser Activation**

This paper presents a new method for selective micro metallization of polymers. A Nd:YAG laser is employed to draw patterns on polymer surfaces that are submerged in a liquid (usually water). After subsequent activation with palladium chloride and followed by auto-catalytic electroless plating, copper deposit only on the laser tracks. The mechanism of the palladium activation step is analyzed based on experimental results and theoretical calculations. It is believed that the laser introduces porous and rough structures on the surface, which favours the palladium attachment. Looking from the surface property’s point of view, the basic polymer surface tends to attract palladium in an acidic solution. Using the laser treatment mentioned above, standard grades of thermoplastic materials such as ABS, SAN, PE, PC and others have been successfully metalized. The metalized tracks are down to 300 μm in width with 50μm between two tracks, but further optimization is expected in this field. Due to the porous and rough structure of the laser track, excellent adhesion between metallization and substrate is obtained. On top of the first copper layer, additional metal such as nickel, gold, palladium or tin can be deposited.

**General information**

State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Institute for Product Development
Contributors: Zhang, Y., Tang, P. T., Hansen, H. N., Nielsen, J. S.
Publication date: 2009

**Host publication information**

Title of host publication: Electroless Plating on Plastic Induced by Selective Laser Activation
Electronic versions:
Yang Zhang Kentucky.pdf
Source: orbit
Source-ID: 248723
Research output: Research - peer-review » Article in proceedings – Annual report year: 2009

**LASER INDUCED SELECTIVE ACTIVATION UTILIZING AUTO-CATALYTIC ELECTROLESS PLATING ON POLYMER SURFACE**

This paper presents a new method for selective micro metallization of polymers induced by laser. An Nd: YAG laser was employed to draw patterns on polymer surfaces using a special set-up. After subsequent activation and auto-catalytic electroless plating, copper only deposited on the laser tracks. Induced by the laser, porous and rough structures are formed on the surface, which favours the palladium attachment during the activation step prior to the metallization. Laser focus detection, scanning electron microscopy (SEM) and other instruments were used to analyze the topography of the laser track. Characterization of the deposited copper layer was used to select and improve laser parameters. Several types of polymers with different melting points were used as substrate. Using the above mentioned laser treatment, standard grades of thermoplastic materials such as ABS, SAN, PE, PC and others have been selectively metallised.

**General information**

State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Institute for Product Development
Contributors: Zhang, Y., Nielsen, J. S., Tang, P. T., Hansen, H. N.
Publication date: 2009

**Host publication information**

Title of host publication: LASER INDUCED SELECTIVE ACTIVATION UTILIZING AUTO-CATALYTIC ELECTROLESS PLATING ON POLYMER SURFACE
Keywords: thermoplastics, Laser, electroless plating, MID
Source: orbit
Source-ID: 248721
Research output: Research - peer-review » Article in proceedings – Annual report year: 2009

**Laser induced selective activation utilizing auto-catalytic electroless plating on polymer surfaces**

**General information**

State: Published
Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Institute for Product Development
Contributors: Zhang, Y., Tang, P. T., Nielsen, J. S., Hansen, H. N.
Publication date: 2008

**Host publication information**

Title of host publication: Proc. 8th International Congress on Molded Interconnect Devices
Source: orbit
Source-ID: 232893
Research output: Research - peer-review » Conference abstract in proceedings – Annual report year: 2008
Projects:

**End-of-Life-Tires Rubber Recycling and Powder Injection Moulding**
Basso, A., PhD Student, Department of Mechanical Engineering
Zhang, Y., Main Supervisor, Department of Mechanical Engineering
Hansen, H. N., Supervisor, Department of Mechanical Engineering
Linnemann, L., Supervisor
01/01/2019 → 31/12/2021
Project: PhD

**Integrating Micro and Nano structures on Steel Surfaces - Process Chain Implementation and Validation**
Loaldi, D., PhD Student, Department of Mechanical Engineering
Tosello, G., Main Supervisor, Department of Mechanical Engineering
Calaon, M., Supervisor, Department of Mechanical Engineering
Zhang, Y., Supervisor, Department of Mechanical Engineering
Grundforskningsfonden
15/09/2017 → 14/09/2020
Award relations: Integrating Micro and Nano structures on Steel Surfaces - Process Chain Implementation and Validation
Project: PhD

**Process chains to manufacture micro structures on 3D surfaces by replication**
Li, D., PhD Student, Department of Mechanical Engineering
Zhang, Y., Main Supervisor, Department of Mechanical Engineering
Bissacco, G., Supervisor, Department of Mechanical Engineering
Davoudinejad, A., Supervisor, Department of Mechanical Engineering
Tang, P. T., Supervisor, Institute for Product Development
Tosello, G., Supervisor, Department of Mechanical Engineering
Privatist
01/09/2016 → 31/08/2019
Award relations: Process chains to manufacture micro structures on 3D surfaces by replication
Project: PhD

**Process technologies for functional anisotropic surfaces generation in Quick Response Code applications**
Regi, F., PhD Student, Department of Mechanical Engineering
Zhang, Y., Main Supervisor, Department of Mechanical Engineering
Tosello, G., Supervisor, Department of Mechanical Engineering
Samfinansieret - Andet
01/08/2016 → 31/07/2019
Award relations: Process technologies for functional anisotropic surfaces generation in Quick Response Code applications
Project: PhD

**Precision Injection Moulding of Micro Features using Integrated Process/Product Quality Assurance**
Giannekas, N., PhD Student, Department of Mechanical Engineering
Tosello, G., Main Supervisor, Department of Mechanical Engineering
Hansen, H. N., Supervisor, Department of Mechanical Engineering
Zhang, Y., Supervisor, Department of Mechanical Engineering
Nielsen, C. V., Examiner, Department of Mechanical Engineering
Griffiths, C. A., Examiner
Samfinansieret - Andet
01/01/2016 → 28/02/2019
Award relations: Precision Injection Moulding of Micro Features using Integrated Process/Product Quality Assurance
Project: PhD

**New production paradigms for wind turbines**
Jensen, M. L., PhD Student, Department of Mechanical Engineering
Hansen, H. N., Main Supervisor, Department of Mechanical Engineering
Haahr, A., Supervisor
Pedersen, D. B., Supervisor, Department of Mechanical Engineering
Laser Induce Selective Activation For Subsequent Autocatalytic Electroless Plating
Zhang, Y., PhD Student, Department of Management Engineering
Hansen, H. N., Main Supervisor, Department of Management Engineering
Tang, P. T., Supervisor, Department of Management Engineering
De Grave, A., Supervisor, Department of Management Engineering
De Chiffre, L., Examiner, Institute for Product Development
Eberhardt, W., Examiner
Leisner, P., Examiner, Department of Manufacturing Engineering
DTU-lønnet stipendie
01/10/2007 → 02/02/2011
Award relations: Laser Induce Selective Activation For Subsequent Autocatalytic Electroless Plating
Project: PhD

Micro Injection Moulding for Micro Fuel cells Production
Wöhner, T., PhD Student, Department of Mechanical Engineering
Hansen, H. N., Main Supervisor, Department of Mechanical Engineering
Islam, A., Supervisor, Department of Mechanical Engineering
Tosello, G., Supervisor, Department of Mechanical Engineering
Zhang, Y., Examiner, Department of Mechanical Engineering
Tang, P. T., Examiner, Department of Product Development
Savio, E., Examiner
Institut, samfinansiering
15/12/2012 → 25/11/2016
Award relations: Micro Injection Moulding for Micro Fuel cells Production
Project: PhD

Activities:

Feasibility study on integrated process/product quality assurance framework for precision injection moulding based on vibration monitoring
Period: 29 May 2017 → 31 May 2017
Nikolaos Giannekas (Other)
Rene Gammelby (Other)
Guido Tosello (Other)
Dmitri Tcherniak (Other)
Yang Zhang (Other)
Department of Mechanical Engineering
Manufacturing Engineering

Description
Feasibility study on integrated process/product quality assurance framework for precision injection moulding based on vibration monitoring
Degree of recognition: International
Documents:
EUSPEN2017_Poster_nikgia

Related organisation
Feasibility study on integrated process/product quality assurance framework for precision injection moulding based on vibration monitoring
Giannekas, N. (Other), Rene Gammelby (Other), Tosello, G. (Other), Dmitri Tcherniak (Other), Zhang, Y. (Other)
A preliminary study on replication and quality correlation of on-part and on-runner polymer injection moulded micro features

Period: 7 May 2017 → 9 May 2017
Nikolaos Giannenas (Guest lecturer)
Guido Tosello (Other)
Yang Zhang (Other)

Department of Mechanical Engineering
Manufacturing Engineering

Description
A preliminary study on replication and quality correlation of on-part and on-runner polymer injection moulded micro features
PRN 2017- Polymer replication on Nanoscale Conference
Degree of recognition: International
Documents:
PRN2017_Poster_nikgia

Related event
Polymer Replication on Nanoscale 2017
08/05/2017 → 09/05/2017
Aachen, Germany
Activity: Talks and presentations › Conference presentations