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Process chain for fabrication of anisotropic optical functional surfaces on polymer components

D. Li[1], Y. Zhang[1], F. Regi[1], G. Tosello[1], M. H. Madsen[2], J. B. Nielsen[3], H. Aanæs[3], J. R. Frisvad[3]

[1] *Technical University of Denmark, Department of Mechanical Engineering, DK-2800 Kgs. Lyngby, Denmark*
[2] *Danish National Metrology Institute, DK-2800 Kgs. Lyngby, Denmark*
[3] *Technical University of Denmark, Department of Applied Mathematics and Computer Sciences, DK-2800 Kgs. Lyngby, Denmark*

Email: dongyli@mek.dtu.dk

Abstract
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 contrast between horizontally orthogonal textured surfaces from a certain viewing angle. The process chain comprised three steps: tooling, replication and quality assurance. Tooling was achieved by precision micro milling. Replication processes such as injection moulding, hot embossing, blow moulding, etc. were employed according to the specific type of product. In order to implement the traceability of the manufacturing process, the geometry and dimension of the micro structure on the tool and the replica were assessed via metrological methods. The functionality of the anisotropic surfaces on the polymer replicas were evaluated by a gonioreflectometer and image processing. Eventually, according to the function evaluation of polymer products, the process chain steps will be optimized by tuning the tooling and moulding processes.

Keywords: micro structures, anisotropic surfaces, process chain, moulding, milling, DOE

1. Introduction

Functional surfaces are under intensive investigations thanks to the many applications both at industrial and consumer level. Extensive studies on their application and manufacturing processes have been performed [1, 2]. The present paper explored a novel optical function by structured surfaces on polymer and the process chain for its manufacturing.

The function to be achieved was the maximization of the reflectance from a certain viewing angle and direction, and the minimization from its horizontally orthogonal position. In order to obtain such micro structures, micro milling was employed to pattern an insert for polymer replication processes. The tooling and replication quality were assured by use of metrological methods. The process chain was optimized according to the function and to the quality.

2. Process chain description

This section describes respectively the surface functionality, the tooling, the replication and the quality assurance steps.

2.1. Functionality

The contrast was defined by the difference between reflected light intensities. To achieve the contrast between orthogonal viewing angles, the functional surface was structured with serrated ridges, as showed in **Figure 1**. These structures led to different reflectance intensities according to the surface rotation around the z axis by 90°. The demonstration of the working principle is shown in **Figure 2**.

The functionality of the surfaces on the polymer replicas was evaluated using a microscope as a gonioreflectometer [3]. The microscope captured the images of the sample from all the viewing angles by rotating the sample holder and tilting the objective lens. The intensity values for each configuration were obtained via image processing tools.

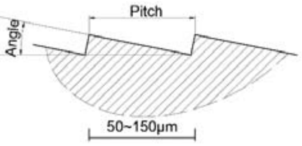

Figure 1. The proposed structures on anisotropic surfaces.

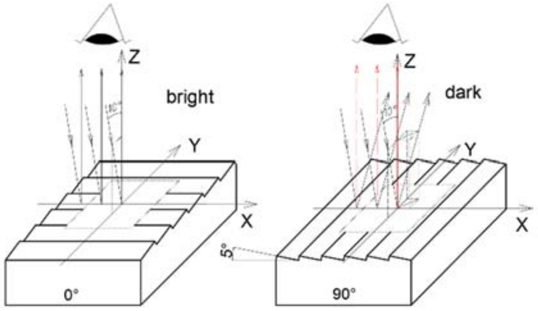

Figure 2. Demonstration of contrast generation.

2.2. Tooling

High accuracy and repeatability are required in tooling processes. Micro milling was investigated and a five-axis milling machine was employed for the machining of inserts which can be used in injection moulding and hot embossing. The milling parameters were optimized experimentally.

2.3. Replication

Hot embossing was studied to establish the most suitable set of parameters for the replication of the structures able to optimize the surface function on plastics such as ABS.

2.4. Quality assurance

In order to implement traceability for the manufacturing process, the geometry and dimension of the micro structure on the tool and on the replica were measured by means of a laser confocal microscope, Olympus LEXT. **Figure 3** shows an example of the measured area and the average profile on the tool. A 100x magnification lens was used for this measurement. The roughness was measured on the highlighted area (indicated by the white frame in **Figure 3**) by image post-processing using the software SPIP®.

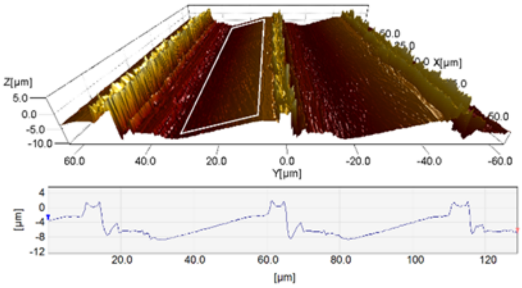

Figure 3. 3D topography (top) and profile (bottom) of the micro structured functional surface.

3. Process chain optimization

3.1. Functionality optimization

The functionality was highly influenced by the dimension of the surface structures. In order to achieve the maximum contrast, the pitch and ridge angles were varied for testing. **Figure 4** shows the matrix with featured squares on a steel piece. The ridge angle of structures differs in each row (5°, 10°, 15°, 20°) while the pitch varies by column (50 µm, 75 µm to 100 µm).

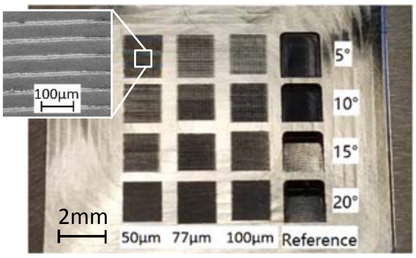

Figure 4. Layout of the testing squares in structure optimization. The pitches and angles are varied for testing.

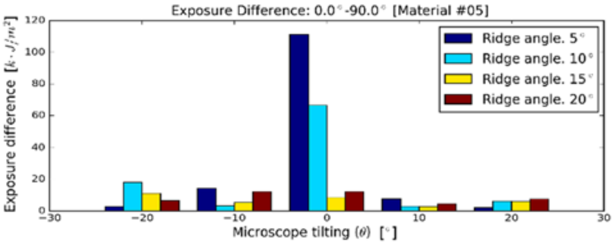

Figure 5. Contrasts between surfaces (pitch 50 µm) rotated by 0° and 90°, contrast is obtained by the difference of the reflectance ([kJ/m^2])

Figure 5 shows the contrasts between the polymer surface reflectance at 0° and at 90° for four different ridge angles but with the same pitch of 50 µm. The viewing angle, defined as θ, was varied within -20˚ and +20˚. The result from the analysis showed that the geometry with 5° ridge and 50 µm pitch led to the best contrast in respect to the other surfaces.

3.2. Optimization of tooling

A Design of Experiments (DOE) was applied to optimize the micro milling process and obtain the highest tool surface quality. Low roughness was preferred due to the optical function of the surface.

A 2-level full factorial DOE with 4 factors [4] was conducted to machine the structures with 5° of ridge angle and 50 µm of pitch with the purpose of understanding the impact trend of the milling parameters on surface quality. The factors are displayed in **Table 1**. The levels were set according to the recommendations from the tool supplier. The surface roughness parameters Sa and Sdq according to ISO/DIS 25178-2 were used as the responses for the DOE. Lower Sa and Sdq were preferred in order to achieve higher reflectivity. The data was obtained using the same method of quality assurance as described in **Section 2.4**. The impact of the studied factors on the finishing of metal structures is illustrated in **Figure 6**, and the results showed that: (a) the tool size did not affect the slope of the surface (Sdq) and that the larger size could reduce Sa; (b) higher spindle speed produced lower surface roughness and lower Sdq; (c) oil/water cooling and higher feed speed were preferred since higher surface flatness produced improved reflectivity properties.

Table 1. Level setup of factors, based on the recommendations of the tool manufacturer (ARNO®)

Factors	Cutter	Spindle speed	Cooling	Feed speed
Low	Φ3mm	8500 rpm	oil+ air	700 mm/min
High	Φ4mm	9600 rpm	oil+ water	1000 mm/min

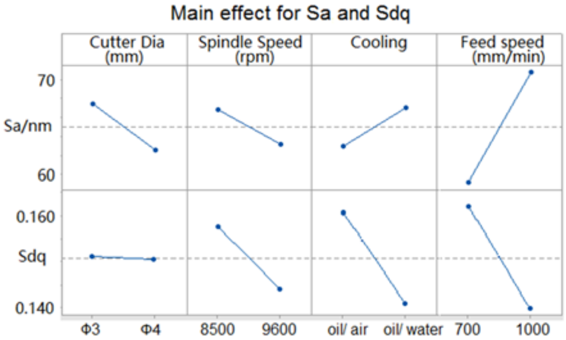

Figure 6. The impact of the factors (at 2 levels) on the finish of structure surfaces.

4. Conclusion

This paper introduced a process chain for the manufacture of micro-structured surfaces. The scope was to generate visible contrast on polymer (ABS) using a relatively simple structure and economical manufacturing methods. The optimization of the tooling process and of the functionality were presented. The optimal structure was 5° ridge and 50 µm pitch. The impact trends of milling parameters for surface quality were determined with a DOE. Future work will focus on polymer surface functionality and will be dedicated to the establishment of an optimal process chain for fabrication of anisotropic optical functional surface on polymer.

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