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A comparison of reflectance properties on polymer micro structured functional surface

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Abstract
In this study, a functional micro-structure surface has been developed as a combination of arrays of ridges. The scope of the surface is to achieve specific directional optical properties: that is, under constrained lighting, to maximize the reflectance from a certain viewing direction, and to minimize it from its horizontally orthogonal position, i.e. maximize the contrast between two horizontally orthogonal view positions at the same inclination.
The sample is composed of 12 different anisotropic surfaces, designed as a combination of ridges defined by their pitch distance of 50, 75 and 100 µm, and their angle in respect to the surface of 5, 10, 15 and 20 degrees. The geometry was obtained by precision milling of a tool steel bar and replicated through silicone replica technology, in silicone thermoset material, and by hot embossing using Acrylonitrile Butadiene Styrene (ABS) thermoplastic material. Several colours of the silicone and of the ABS materials have been tested to characterize their influence on the reflectance. A digital microscope has been used as a gonioreflectometer to determine the directional surface reflectance of each surface at varying light and camera positions, allowing for determining optimum surface microstructure for maximizing contrast between two horizontally orthogonal views.
This paper focuses on the optimum microstructure ridge parameters for maximizing orthogonal contrast on polymer replicas. The presented results show that the replication processes and the polymeric material have a strong impact on the contrast under constrained lightening. Specifically, the reflectance properties are strongly influenced by the geometry of the structure and by the colour.

surface texture, anisotropic surface, hot embossing, silicone replica

1. Introduction

The functional properties of micro-structured surfaces have gained increasing interests due to the many applications such as wetting, adhesion, thermal and/or electrical conductivity [1]. In this study, directional optical properties were achieved with a microstructure composed of a close array of ridges (**Figure 1**). The scope was to, under constrained lighting, maximize the reflectance from a certain viewing angle and direction, and minimize it from its horizontally orthogonal position, i.e. maximize the contrast between two horizontally orthogonal view positions at the same inclination (**Figure 2**).
Constrained lightening conditions refer to fixed configurations of light and camera relative to one another.
It is possible to use mathematic models to predict the reflectance properties of the surface. Nonetheless, this study focuses on its experimental evaluation.

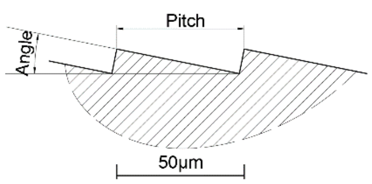

Figure 1. Anisotropic structure geometry: definition of pitch and angle.

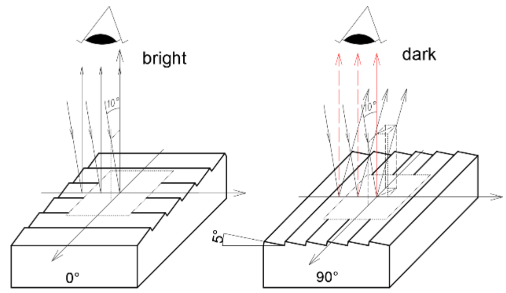

Figure 2. Demonstration of orthogonal contrast generation.

2. Replication

The surface is machined on a steel bar by a precision five-axis milling machine. The milling parameters have been chosen experimentally and optimized accordingly. The roughness of the slopes was measured using a confocal microscope and SPIP software: the analysis revealed an average value for the Sa parameter of 81 nm and of 108 nm for Sq.
Replicas were obtained using Acrylonitrile Butadiene Styrene (ABS), through the hot embossing process, and using silicone rubber through replica technology [2].

3. Measurements Instrument and Strategy

The radiometric measurements were carried out using a Hirox RH-2000 digital microscope operated as a gonioreflectometer. The microscope was modified to hold a constant LED based lightsource at a fixed baseline relative to the optics, ensuring a constant camera-lightsource angle, sometimes referred to as θ_d. Calibrated High Dynamic Range imaging, based on the approach of Debevec and Malik [3], was utilized to convert observations into physical units of radiant exposure.

4. Data Collection

In this section a small overview of the parameters and of the samples involved in the measurements is reported.
Four samples in the two different materials and exhibiting diverse colours have been produced. The average roughness of the slopes was measured to evaluate the general quality of the replication (**Table 1**).
Pitch distance between the ridges was kept constant at 50 µm, while the ridge angle was varied for each of the four samples. Theta [°] is the tilting angle of the microscope; it varies from -20° to +20° with 10° steps. Phi [°] refers to the azimuthal rotation of the structure, as exemplified in **Figure 2**; radiant exposure has been measured at 0°, 90° and 180° phi.
The main output, the radiant exposure $\left[\frac{kJ}{m^2}\right]$, is measured up to an unknown scale k, and under constant lighting conditions, i.e. intensity and distance to surface, it is proportional to the reflectance of the surface.
The contrast is evaluated as the difference between the radiant exposure obtained for the sample at positions 0° and 90°, and between 90° and 180° of the phi parameter, keeping constant the other parameters.

Table 1. Summary of the colours and materials of the samples and their average roughness calculated as Sa and Sq.

Sample	Material	Colour	Sa [nm]	Sq [nm]
S5	ABS	Dark Green	171	223
S6	ABS	Blue	135	188
S9	Silicone	Light Green	118	161
S11	Silicone	Brown	102	147

5. Analysis Results

The analysis of the collected data was focused on the determination of:

- Preferable ridge angle that maximazes the contrast between perpendicular structures;
- Colour and material that maximizes the contrast;
- Colour and material that gives the highest reflectance.

Figure 3 shows the data means analysis of the reflectance, while **Figure 4** presents a similar study on the contrast.
The vertical direction of the microscope (theta 0) produces the highest average reflectance, while the tilting strongly reduces it (**Figure 3**).
For what concerns the ridge, smaller ridge angles are preferred: the 10-degree ridge gives the best solution also in terms of contrast (**Figure 4**).
Finally, blue and light green have the highest absolute reflectance (**Figure 3**), but perform poorly in terms of contrast (**Figure 4**), and while the difference is small, ABS guarantees a better contrast. The directionality of the geometry makes the contrast 0° - 90° stronger than the 90° - 180°.

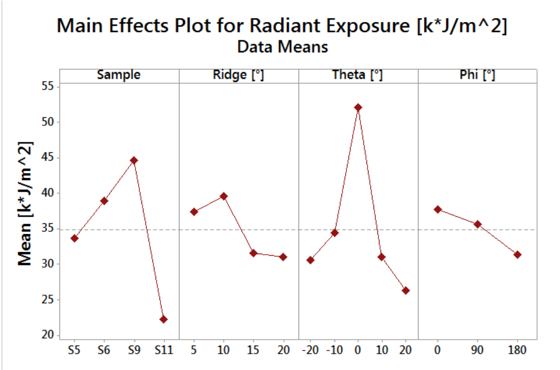

Figure 3. Main effects plot for the absolute reflectance. The name of the samples are listed in **Table 1**. Theta refers to the tilting angle of the microscope. Phi refers to the rotation angle of the sample.

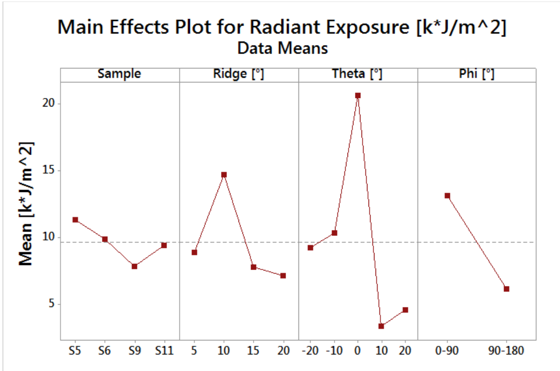

Figure 4. Main effects plot for the contrast. The name of the samples are listed in **Table 1**. Theta refers to the tilting angle of the microscope. Phi refers to the rotation angle of the sample.

6. Conclusion

An evaluation of the reflectance performance of an anisotropic surface for different colours and materials has been conducted. The structure with a 10-degree ridge angle has given an orthogonal contrast 50 % higher with respect to the other angles. Furthermore, darker colours minimize the absolute reflectance and maximize the contrast.

7. Conclusion

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