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Pitch measurements validation of a structural coloured steel insert using Scanning Confocal Microscopy (SCM) and Atomic Force Microscopy (AFM)

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Abstract

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 micro structures 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 ± 31 nm while for AFM is 972 ± 15 nm. At last, from these results, the estimation of EVT accuracy is presented.

Scanning Confocal Microscopy, Dynamic Force Microscopy, Elliptical Vibration Texturing, Structural Colouration

1. Introduction

Providing a product with enhanced surface functionality is a current challenge in research to set a new way to increase the value-added for the end-users. Optics represents an interesting field of application in which surface functionalisation can be improved. A bio-inspired application as such is structural colouration.

In nature, several animals skins as fish scales, birds feathers, butterflies wings but even human eyes show unique colouring properties, which do not depend on pigments. The colouring principle derives from the physical phenomenon of structural colouration, which arises from the interaction of incident light with the topology of the surface [1]. When a surface texture consists of periodic micro-features in the near visible range (300 – 1000 nm), light diffracts in such a way that the observer perceives an unnatural colouration of the sample. The possibility to reproduce astonishing and unnatural colouring effects on consumer products is the ultimate objective of this research.

A successful way to induce structural colouring on sample products consists of texturizing micro-gratings on the reference surface. Gratings are periodic structures showing a constant depth and pitch. Colouring depends on the dimension of both pitch and depth of the gratings, as well as the slope of the texturized features [2]. In this study, gratings manufactured by Elliptical Vibration Texturing (EVT) are analysed [3]. The texturized sample is a 20 mm x 20 mm flat squared steel insert with a nominal grating pitch of 1000 nm.

In order to assess the accuracy of EVT, two measurement strategies are compared to analyse the gratings pitch. Moreover, considering time related and measuring uncertainty aspect, the objective of this study is to validate the possibility to use either atomic force microscopy or confocal microscopy for the scope.

2. Measuring strategies

Scanning Confocal Microscopy (SCM) and Atomic Force Measurements (AFM) are selected. For both the cases, the sample is aligned with a low magnification optical objective. On the insert, a defined local reference system allows repositioning in defined coordinates. The resulting images ideally lay in the same region, neglecting repositioning or alignment errors. In Figure 1, the sample images are reported.

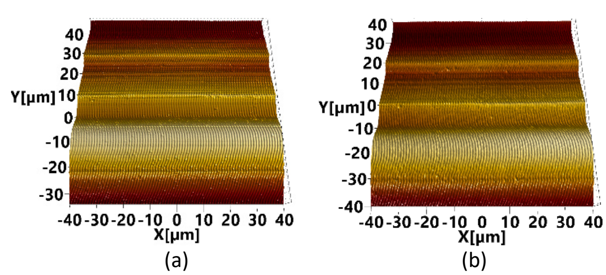

Figure 1. Image comparison sampled with SCM (a) and AFM (b)

2.1 Scanning Confocal Microscopy (SCM)

A laser scanning confocal microscope, commercially provided by Olympus (http://www.olympus-ims.com) is employed. The microscope is used with a high magnification objective (50x), which has a working distance of 350 µm and a numerical aperture of 0.95. The set-up ensures a square field of view of 259 x 259 μm^2. The ten repeated measured images have the highest possible resolution, which for the case is 4096 x 4096 $pixels^2$ size, corresponding to a nominal pixel squared length of 63 nm. The microscope exploits a blue laser source with a wavelength of 405 nm. Sparrow's diffraction theory limit [4], as reported in Equation 1, provides an estimation of the diffraction limit of the measuring set-up, which for the case is 311 nm.

$$R_l = 0.73\,\frac{\lambda}{A_N} \qquad (1)$$

The calculated resolution is just 3 times smaller than the features nominal dimension, which is 1000 nm. Even though the confocal microscope is operated at the limit of its performance, considering also the optical functionality of the sample, the set up (15 min) and measurement time (5 min) are up to 88% faster.

2.2 Atomic Force Microscope (AFM)

The second measuring strategy consists in the use of an AFM manufactured by Park Systems (http://www.parkafm.com). A sharp silicon probe mounted on the cantilever measures the part surface using Intermittent contact mode (IC-AFM). IC-AFM mode uses the influence of atomic interaction forces on the oscillation of the probe to trace the contours of the surface with a nanometre scale resolution [5].

The approximate amplitude of the vertical oscillation is 20 nm with a horizontal scan speed of 8 µm/s. The image covers a square size of 80 µm x 80 µm with a resolution of 4096 x 256 $pixels^2$. Five repeated measurements enable the precision assessment. The selected set-up requires an average time of 1 hour and a sampling time of each image of 43 min. Moreover, the silicon based tips suffers wear during measurements and need continuous replacement. In addition, drift of the cantilever can occur. The AFM appears to be of more difficult implementation in an industrial manufacturing environment.

3. Results

In order to compare the two procedures, the images from the SCM are masked and cut to 80 µm x 80 µm. A further image resampling allows the images to have the same resolution of the AFM images to 4096 pixels x 256 pixels. The resolution ensures a pixel size of 20 nm on the x-direction and 313 nm on the y-direction. Gratings pitch calculation starts by extracting five average profiles in five different y-location of the image (-30; -15; 0; 15; 30 µm). Each average embeds three parallel profiles on the x-direction sampled at a distance of 1 pixel from each other. In Figure 2 (a), the average third profile is represented.

Pitch calculation exploits FFT algorithm. In Figure 2 (b), the dominant frequency indicates the average pitch estimation. In Figure 3, the graph reports the average of the ten measures for SCM and the five for AFM, with the respective uncertainty. To do so, dedicated standard guidelines such as the Guide to the Expression of Uncertainty in Measurement (GUM) [6,7] is adopted. The global average pitch is 1002 ± 31 nm, while for the

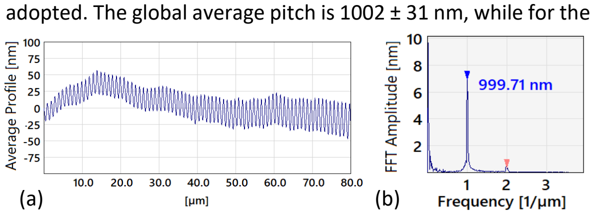

Figure 2. Average profile of the structural coloured texture and (a) average pitch estimation by FFT algorithm (b)

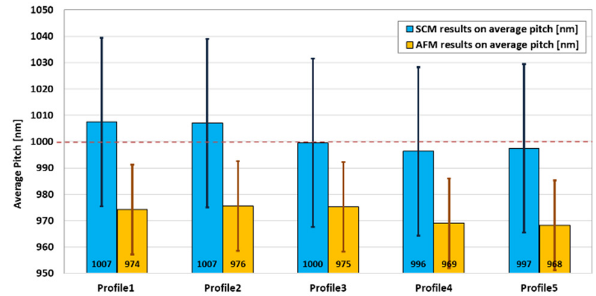

Figure 3. Average and uncertainty of pitch estimation calculated on the SCM (a) and AFM (b) repeated sample measurements

case of AFM measures, the global average is instead 972 ± 15 nm. Considering the measurement uncertainty, the results are in accordance with each other. The different accuracy of the measurement is addressed to a possible systematic error related to SCM calibration and not to the impossibility of resolving the profiles themselves.

Altogether, the possibility to use SCM allows a time saving of approximately 7 hours on just 10 measurements, considering sampling and set up times. The selection of AFM, on contrary reduced the measurement uncertainty from 31 nm to 16 nm. Considering AFM results, EVT process accuracy is below 10 nm to reproduce a nominal a periodic feature of 1000 nm.

4. Conclusions

In this study, two measuring strategies undertake the challenge of measuring 1000 nm nominal pitch gratings of a structural coloured steel insert. SCM shows a consistent result with AFM used in Dynamic Force Microscopy setting. The expanded uncertainty calculated for SCM is almost twice as large than the AFM one, due to calibration and physical principal. However, measuring time is significantly smaller for SCM than AFM. A final consideration from this study provides EVT process accuracy to the below 10 nm range.

Acknowledgements

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