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Comparison of coherence scanning interferometry, focus variation and confocal microscopy for surface topography measurement

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Abstract

The most common optical technologies for surface topography measurement are coherence scanning interferometry (CSI), focus variation microscopy (FV) and imaging confocal microscopy (CM). Due to the benefits and drawbacks of each, these instruments are all suited to different measurement tasks, depending on the features present on the surface. In this paper, the surface topographies of two surfaces (an optical flat and a metal additive manufactured [AM] surface) with different slope angles were measured using CSI, FV and CM techniques, on an instrument capable of exploiting all three technologies using interferometric (CSI) and brightfield (FV and CM) 50× magnification objective lenses. Measurement noise obtained by CSI presents a significantly lower value than other technologies due to its sub-nanometre vertical resolution. The surface topography of a 30° tilted optically smooth surface shows the ability of CM to measure higher slope angles compared to CSI, due to the relatively higher numerical aperture of brightfield objective lenses. Although the contrast-based reconstruction algorithm prevents FV from reconstructing smooth surfaces for the instrument used, it makes FV a powerful means for surface topography measurement of complex AM surfaces; verified by comparing the surface topographies of an AM surface obtained by FV, CM and CSI.

Coherence scanning interferometry, confocal microscopy, focus variation, surface topography

1. Introduction

Over the past few decades, there has been an increased need for measurement of the areal surface topography and the shape of engineering surfaces [1]. The topography of engineering surfaces plays an important role in almost any technical application. Studies have shown that the mechanical and optical properties of an object strongly depend on the micro-geometrical structures on the surface [2, 3]. A list of surface measurement methods that produce a topographical image of the surface (mathematically as a height function of lateral position) is given in ISO 25178 part 6 [4]. Coherence scanning interferometry (CSI), imaging confocal microscopy (CM) and focus variation (FV) microscopy are the most common optical techniques for areal surface topography measurement (see [5] for a recent review of these techniques). Due to the capabilities of each technique, various factors need to be considered when choosing the most appropriate technique for acquiring accurate surface topography data. These factors strongly depend on the features present on the surface.

In this work, the advantages and disadvantages of three different optical surface topography measurement techniques (CSI, CM and FV) are investigated with respect to various measurement tasks. For this purpose, the surface topography of different samples - an optical flat and a metal additively manufactured (AM) surface - has been measured using a single optical instrument operating in CSI, CM and FV modes, with their corresponding 50× magnification objective lenses.

2. Methodology

CSI uses interference microscopy to extract the height map. This technique is able to resolve small height deviations down to sub-nanometre levels regardless of the magnification of the objective being used, exploiting the information embedded in the interference fringes [6]. Measurement noise, obtained using CSI and CM modes, is compared to show the capability of the vertical resolution in CSI against non-interferometric techniques. Nevertheless, the requirement for interferometric elements (for example, a beam splitter and a reference mirror) between the objective lens and the surface under test restricts the overall optical system to relatively low numerical apertures (NAs). Here, the surface topography of a tilted optically smooth surface is measured using CSI and CM modes to show the effect of NA on the maximum slope angle that can be obtained using these optical instruments. To show the ability of an optical technique to measure the topography of a complex rough surface with high slope angles and curvatures, surface topography measurements of a metal AM surface obtained using FV, CSI and CM are compared. Measurements were performed using a 50× magnification interferometric (NA of 0.55 in CSI) and brightfield (NA of 0.8 in CM and FV) objective lens, both providing a field of view (FOV) of 337 µm × 283 µm, spatial sampling distance of 0.14 µm, and the same piezoelectric stage, providing the same vertical scanning steps.

3. Results and discussion

3.1. Measurement noise

A fused silica reference optical flat, which exhibits nanometre-scale surface height structure, was used to determine the measurement noise. The default method for evaluating measurement noise, the subtraction method requires two consecutive measurements at the same location of the artefact. It is quantified by the root mean square (RMS) of the difference of the two height maps. Figure 1 shows noise maps obtained by the subtraction method [7] using (a) CM and (b) CSI mode. The FV result was not included since the FV contrast-based reconstruction algorithm used by this instrument prevents the surface topography of optically smooth surfaces being measured. The RMS of the noise map for the CM and CSI modes is 2.8 nm and 0.3 nm, respectively. The measurement noise results are in agreement with the literature results [8].

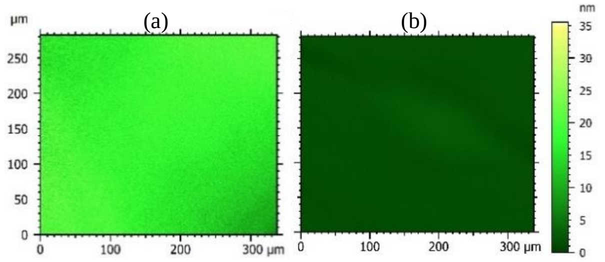

Figure 1. Noise map of 50× magnification objective lens configuration obtained using the subtraction method for (a) CM and (b) CSI mode.

3.2. Tilted optically smooth surface

The NA defines the maximum slope angle that can be measured via specular reflection by an optical instrument. Figure 2 shows the surface topography of an optically smooth surface that is tilted about 30° around the *y*-axis, obtained using (a) CM and (b) CSI modes. A maximum slope angle of 53° corresponds to the 50× magnification objective lens of the CM mode. As shown in Figure 2, CM is able to measure the 30° tilted surface, while the CSI presents a large number of non-measured pixels (shown in black). A part of the FOV is trimmed due to the limited maximum scan length of the instrument.

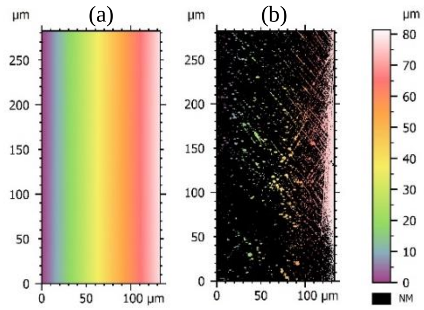

Figure 2. Surface topography map of a 30° tilted optically smooth surface obtained using (a) CM and (b) CSI modes.

3.3. AM surface

Although CM benefits from high NA, it suffers from a poor signal when measuring rough and highly tilted surfaces, due to the intensity-curve-based reconstruction algorithm [9]. In FV, reconstruction is based on the contrast present in the bright field image. Hence, in the case of complex rough surfaces containing high slope angles and low curvatures, FV can achieve better results when compared to CM. Furthermore, the measurement process is time-efficient compared to CM. Figure 3 shows the topography map of an AM surface (*Sq* ≈ 9 µm) obtained using (a) CM, (b) FV and (c) CSI modes. The AM sample was produced by laser-based powder bed fusion of Ti-6Al-4V. In Figure 3, non-measured pixels corresponding to high local slope angles are shown in black. Despite having a lower NA, CSI is able to measure areas with high slope angles due to the height sensitivity feature of the interferometric technique.

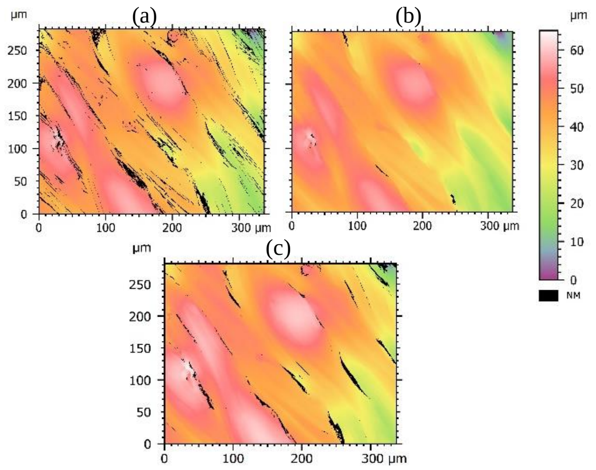

Figure 3. Surface topography map of an AM surface (*Sq* ≈ 9 µm) obtained using (a) CM, (b) FV and (c) CSI modes.

4. Conclusions

In this work, the surface topographies of various surfaces are compared using CSI, FV and CM techniques, on an optical surface topography measurement instrument capable of exploiting all three technologies using 50× magnification objective lenses.

A measurement noise map was obtained using an optically smooth flat and the subtraction method using CM and CSI modes. The root-mean-square of the measurement noise map for the CM and CSI modes is 2.8 nm and 0.3 nm, respectively, verifying the sub-nanometre vertical resolution of CSI.

The surface topographies of a tilted optically flat were obtained using CM and CSI. Results verify the capability of CM (NA = 0.8) to measure larger slope angles compared to CSI (NA = 0.55) due to the higher NA intrinsic to a non-interferometric objective lens.

The surface topographies of a metal AM surface (*Sq* ≈ 9 µm) containing high slope angles and curvatures, obtained using CM, FV and CSI were also compared. Despite having the same NA, FV achieves better results for complex AM surfaces compared to CM, due to the texture-based reconstruction algorithm. Although CSI has a lower NA compared to CM and FV, having a low vertical resolution makes it suitable for surface topography of AM surfaces.

Acknowledgements

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