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Speckle characterization of surface roughness obtained by laser texturing

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Abstract

In this work, results obtained from roughness characterization ofmicro-textured USIBOR steel samples are shown. Laser texturing is used for creating specific periodic microstructures with positive topographies by molten metal displacement technique. Three different methods based on speckle technique (contrast intensity, binary image analysis, spot size measurement) are testedfor a contactless inspection and determination of surface roughness. Characterization and calibration relationship are based on the correlation between measured roughness (with conventional methods) and results from speckle techniques.

Keywords: laser texturing, roughness, speckle

1. Introduction

Multimaterial structures made of metal reinforced with polymer composites offer a sound opportunity for innovation in advanced manufacturing sectors, as for example automotive and aeronautics. Multimaterial solutions present a higher structural integrity to weight ratio improving product performance. Nevertheless, manufacturing of these hybrid structures shows important challenges such as problems of adhesion due to low chemical affinity between metals and composites.

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Non-conventional technologies as laser texturing can improve the performance of metallic materials by providing special functionalities as improving the adhesion by changing the surface roughness [1]. The quality of the texturing must be assured and controlled to achieve the surface adhesion characteristics.

To ensure quality requirements surface characterization technologies frequently used in laboratory include contact profilometry, microscopy,ultrasonic techniques, or atomic forcemicroscopy. But even if these techniques provide surface data with high accuracy, theyare difficult to apply for as they need delicate adjustment, extremely shortworking distances, or contact with the surfaces measured. That´s why most recent advances are focused on in-line contactless approaches [2], with shorter measurement response time.

Among in-line contactless techniques developed recently (as light scattering, Fourier spectrum analysis…) those based on speckle phenomenon, are very interesting as their experimental deployment is relatively simple. Since it has been discovered, speckle phenomenon has been intensively investigated, especially statistical properties of its intensity variations in imaging plane or coherence conditions required for illumination. Then numerous processing methods allowing correlation between surface parameters, as average roughness and speckle characteristics has been developed.

In this work, we present results obtained from roughness characterization of three laser textured sampled (Fig. 1).Moreover, an approach based on speckle is proposed to obtain a contactless inspection method to characterize the surface roughness. This characterization is based on the correlation between measured roughness (with SEM and confocal microscope) and results obtained from different speckle methods. The aim of this work is to provide a first base comparison for selecting most adapted method for roughness range and provide data for technique adaption to higher inspection area and application requirement compliance.

2. Experimental procedure

The surface of the metal was texturized by using a single-mode fiber laser. A laser scanner is deflecting the laser beam to create grooves on the surface. Different shapes of the grooves are obtained by varying laser power, scanning speed and number of passes. The number of repetitions is also studied. The surface topography for each texture is analyzed by scanning electron microscope and confocal microscopy, providing average roughness for each studied sample. Average roughness measurement has been performed on samples A, B, and C (Fig. 2) providing respectively 20,4µm, 30,8µm and 50,7µm.

For surface condition monitoring, a speckle-pattern system was developed (Fig. 3). A CMOS sensor camera (with 1,2 Mega Pixels resolution) from Thorlabs and a 532 nm DPSS laser (TEM00, able to provide up to 250mW) (here power range is settled from 2 to 35 mW) are employed for generating objective and subjective speckle patterns of the textured samples. In experimental setup, angle has been fixed as low as possible ($\approx 10^\circ$ deg.) in order to reduce the effect of the direction of surface microstructurein surface roughness evaluation.

In objective speckle pattern configuration, the influence of distance L variations (Fig. 5) between sensor and sample has been studied allowing obtaining different speckle patterns. Size increase of speckle grain has been verified in far field condition. An objective (f=75mm focal length) has been added for subjective configuration.

Correlation of the speckle patterns with the corresponding average roughness measurements have been established using three different methods: contrast intensity evaluation, binary image analysis andsize evaluation of speckle spot.

2.1. Contrast method

The speckle contrast methods, are based on first-order statistics ofsurface speckle patterns. Thus, the speckle contrast (C) usually is defined as the quotient of standard deviation divided by the mean intensity of the speckle image. In this case laser spot size impinging on sample is around 1mm diameter.Speckle measurement has been performed in objective speckle pattern condition positioning CMOS sensor at 26 cm from sample and performed in subjective conditions.

Contrast value has been calculated for each acquired speckle image and correlated to the corresponding average roughness value (table1). Results (Fig. 4) show that relationship between contrast value decreases as roughness increases and relationship can be adjusted by linear regression.

2.2. Analysis of binary image method

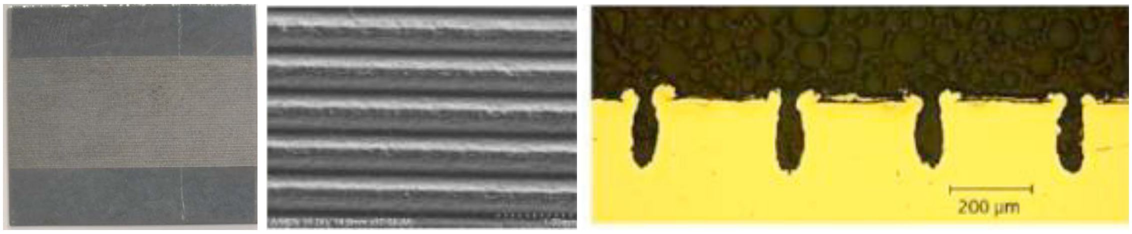
This method consists in analyzing speckle binary image (pixels with a value of (0) are displayed as black while pixels with the value of (1) corresponding to speckle grain are display as white). Bright regions obtained after original speckle image segmentation are counted and show linear relationship with degree of surface roughness.In this case, measurement has been performed in objective speckle pattern conditions for a projected laser spot diameter of 1mm and 10 mm and subjective speckle pattern for a laser spot size diameter of 1mm. Expansion and collimation of laser beam has been done with ain-house madeGalilean beam expander, using a divergent lens (f1=-25mm) and convergent lens(f2=250mm). Power laser has been adjusted to 5mW and CMOS sensor has been settled at 53 cm from sample. Segmentation for obtaining binary speckle pattern images (Fig. 5)has been realized with OTSU function adjusting the same thresholding level for all images. Bright region detection (Fig. 5) and counting(table 2) has been done using blob detection and labeling function. Correlation with bright region count and roughness show that counting is increasing with roughness and is adjusted with a lineal regression (Fig. 6).

2.3. Size of speckle spot method

Speckle spot size method is based in fact that spot speckle size increases with increasing surface roughness. For applying this method, three images of speckle spot have been acquired in subjective configuration (with lens objective, focal length f=75mm).

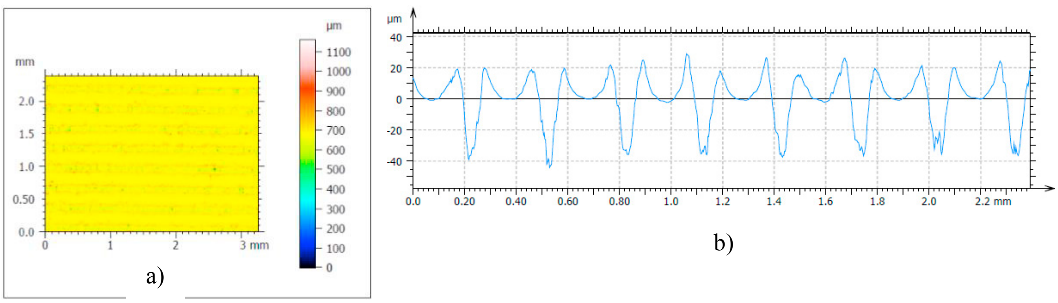
Laser beam has been expandedin order to project a laser spot of 10mm diameter. Images obtained has been processed for extracting area of interest (AOI) (Fig. 7). Contour function based on Clabelalgorithm has been applied to with definedthree level height (Fig. 8).Diameter of speckle spot measured in pixels is correlated with roughness showing a good linear regression, and increasing with roughness value (Fig. 7).

3. Tables and figures



a) *b)* *c)*

Fig. 1. Detail onmicro texture structure of sample; (a) general view of sample A; (b) detail of typical longitudinal micro-texture; (c) typical transversal micro-texture profile.



a) b)

Fig. 2. Roughness measure performed on sample A with confocal microscope. (a) topographical map; (b) average profile from 106 measures, Ra=20,4µm. Average roughness for samples B and C are respectively 30,8µm and 50,7µm.

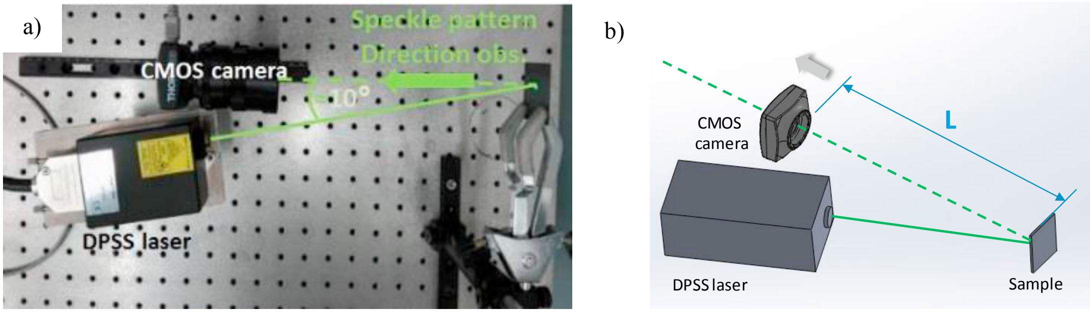


Fig. 3. Laboratory configuration and speckle pattern, (a) subjective speckle pattern configuration; (b) objective speckle pattern configuration.

Table I. Contrast values obtained for each sample A, B, C, in objective and subjective speckle pattern configuration (projected spot size≈1mm^2).

Sample	**Roughness (µm)**	**Contrast (obj. conf)**	**Contrast (subj.conf.)**
A	20,4	0,9189	0,5890
B	30,8	0,9101	0,5847
C	50,7	0,8702	0,5440

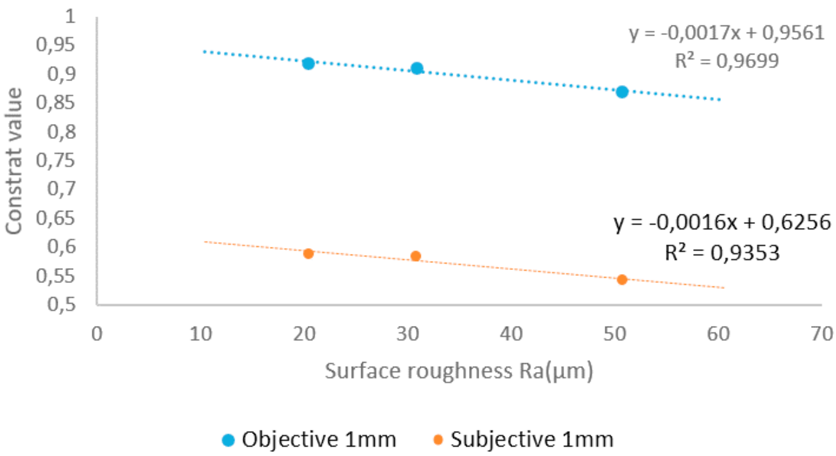


Fig. 4. Intensities contrast as a function of the average roughness (µm).

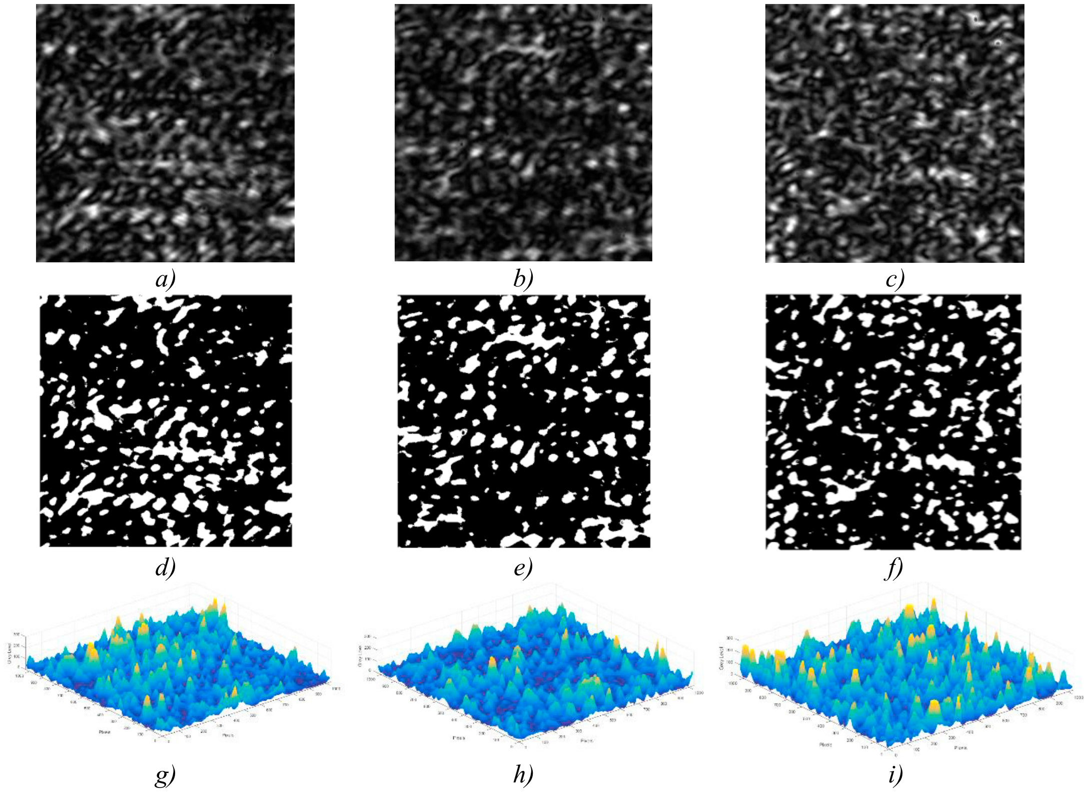


Fig. 5. Objective speckle patternsfor spot size of 1mm obtained for sample A,B, C at d=26cm from samples (a, b, c), binarized speckle patterns (d, e, f), and 3D binarizedspeckle pattern maps (g,h,i).

Table 2. Bright region count obtained in objective and subjective speckle pattern configuration (projected spot Ø≈1mm and 10mm).

Sample	**Roughness (µm)**	**Bright region (obj., Ø=1mm)**	**Bright region (obj., Ø=10mm)**	**Bright region (subj., Ø=1mm)**
A	20,4	373	3258	936
B	30,8	432	3291	961
C	50,7	468	3315	1321

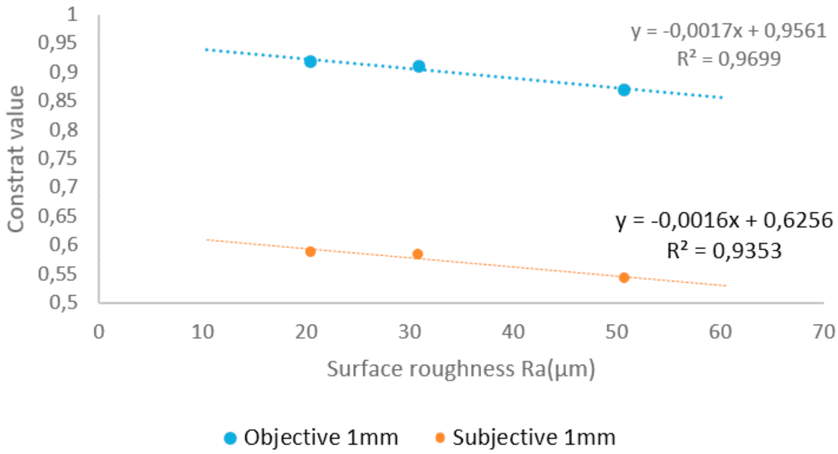


Fig. 6. Bright regions counts as a function of roughness (µm).

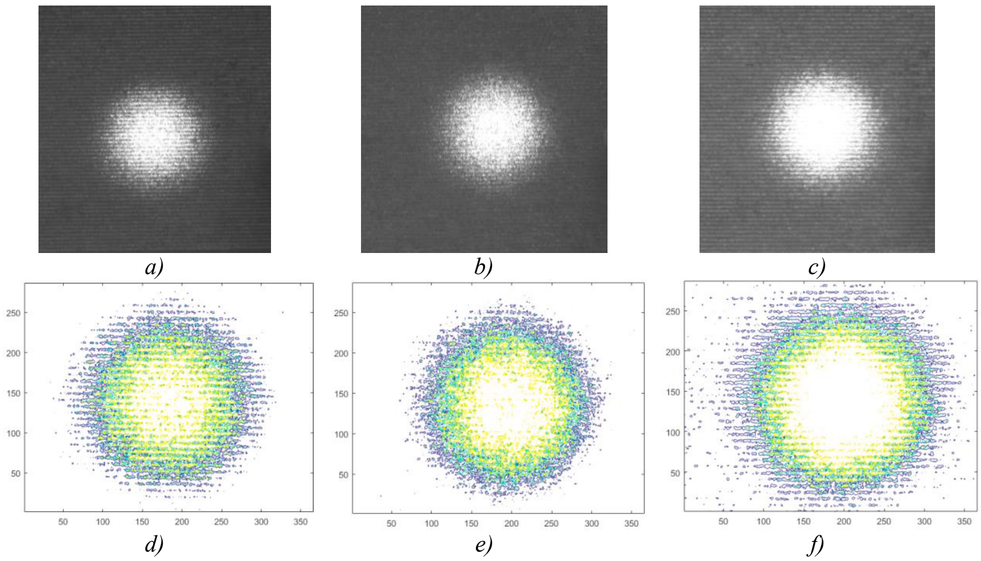


Fig. 7. AOI ofspot images obtained in subjective pattern configuration (a, b, c) and its processing (d, e, f) with respectively diameter spot size equal to 165, 175, 225 pixels.

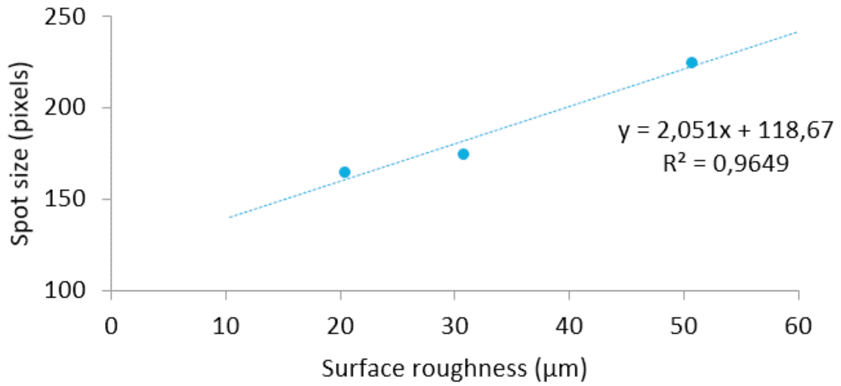


Fig. 8. Spot size diameter as a function of average roughness.

4. Conclusions

A final set of textures with different geometries based on laser texturing for elevation features were created, along with a complete and detailed characterization of the textures by confocal microscopy. Speckle patterns were acquired for every texture after an initial optimization of the laboratory parameters (laser power, distance, angle) in objective and subjective configuration. Three speckle methods for pattern image processing has been applied (contrast method, analysis of binary image method, Speckle spot size method), and correlated with the average roughness measure of USIBOR metallic surface. A good correlation for different speckle characterization was found.

Laser texturing is a versatile technique to modify the roughness of metallic surfaces. Roughness measurements using non-contact speckle technique can be obtained and correlated with those values obtained by conventional methods. Furthermore, the technologies based on laser processing and speckle are scalable for generating a complete texturing and inspection solution, which will be suitable in relevant industrial environments as automotive and aeronautics.

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