Wear process monitoring of thermal spray coatings and surface topography analysis using a confocal laser scanning microscopy

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In this paper, thermal spray coatings are characterized for investigating the wear performance. The goal is to study the change of the surface topography before- and after the wear tests. The measurements are conducted using a confocal laser scanning microscope. Fractal analysis and roughness characterization is carried out to study the surface topography.

1 Introduction

Thermal spray coatings are now widely applied in the automobile and aerospace industry. The main function is to protect the engineering materials from e.g. wear, corrosion and erosion or to reduce the friction between the contact pairs [1][2][3]. In this study, a new generation of HVOF (High velocity Oxygen Fuel) sprayed coatings, which include Al_2O_3-, NiCrBSi-, WCCo- and WCCoCr-coatings are produced for the purpose of studying their wear behavior.

In order to realize a better quality control, surface metrology and surface characterization are two essential steps. Particularly, an appropriate measurement strategy and characterization method should be developed for individual applications. In this study, one of the key targets is the precise relocation of the sample after tribological tests. This helps the analysis and comparison of topography differences before and after the wear tests. On the other hand, an advanced characterization technique, namely the fractal analysis, is proposed to study the surface features. Two numerical methods will be introduced to compute the characteristic parameter fractal dimension.

2 Material and methods

The measurement objects are the already introduced four categories of HVOF sprayed coatings, where the materials are coated on the round substrate as shown in Fig. 1. The surface is measured by a commercial laser confocal microscope, where a special measurement setup is constructed to achieve the reproducible measurement. As shown in Fig. 1, this setup consists of a translation stage and a rotation stage. By combing them, the three degrees of freedom of the sample are restricted. By doing this, reproducible measurements can be realized.

After acquiring the surface topography, the surface characterization is conducted by roughness characterization and fractal analysis. The roughness characterization is carried out according to the ISO-25178 [4], where only the height parameters are evaluated.

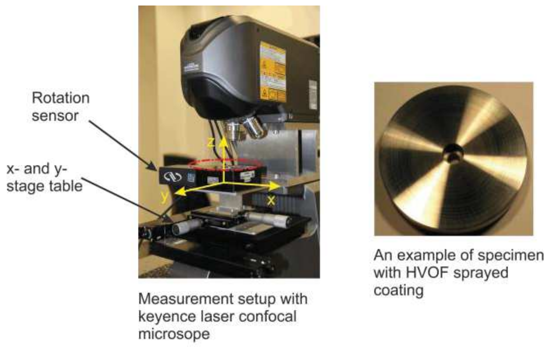

Fig. 1 *The experimental setup for a reproducible surface measurement.*

In the fractal analysis, two methods are applied to calculating the fractal dimension, which is considered as a scale-invariant parameter. The fractal dimension also describes how complex and irregular the surface is. The following sections will focus on its numerical calculation methods.

3 Fractal analysis

The first method is based on the calculation of the power spectral density (PSD) with the help of the Fourier transform, which can be expressed by the following two equations,

$$F(u_m, v_n) = \Delta x \Delta y \sum_{d=1}^{N} \sum_{c=1}^{M} Z(x, y) e^{-i 2\pi (x u_m + y v_n)} \quad (1)$$

$$PSD(u_m, v_m) = \frac{1}{MN \Delta x \Delta y} \left| F(u_m, v_n) \right|^2 \quad (2)$$

where Δx, Δy denote the image lateral resolution and M, N refer to the number of points of the image in x- and y-direction, respectively. After calculating the PSD, the PSD is transformed into the

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polar coordinate system as shown in Fig. 2. The radius ρ is defined by $\rho = \sqrt{{U_m}^2 + {V_n}^2}$.

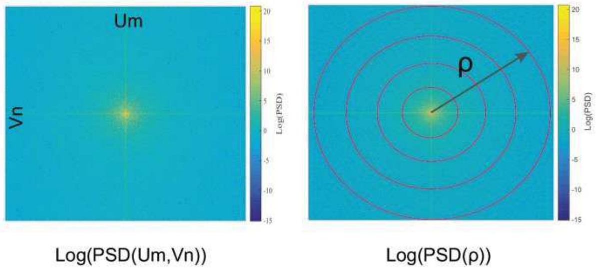

***Fig. 2** Log(PSD) of the surface (left) and its corresponding in polar coordinates (right).*

Later, a Log-Log plot between the PSD and the frequency can be obtained in any degree. Meanwhile, the linear regression can be conducted for the Log-Log plot (see dotted line in Fig. 3). The relationship between the slop β and the fractal dimension Df is

$$D_f = (5 - \beta)/2\ . \tag{3}$$

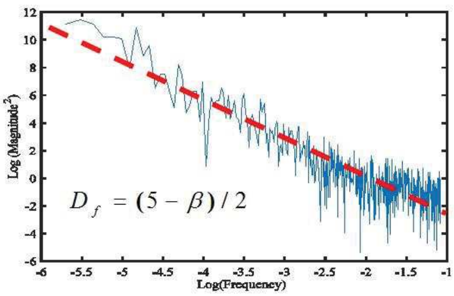

***Fig. 3** Plot: Log(Magnitude^2) VS Log(Frequency).*

The second method is based on areal triangular meshing. Fig. 4 presents the basic principle of the calculation, where the relationship between the meshing scale and the total areas of the triangles in each iteration is calculated. As shown in Fig. 4, a dataset is meshed by two triangles firstly and the areas of the spatial triangles are computed and added. In the second iteration, the whole dataset can be meshed by eight triangles as the meshing scale is halved. The iteration continues until the meshing scale reaches the resolution of the image. At last, a Log-Log plot between the total triangle areas and meshing scale in each iteration can be done. As shown in Fig. 4 (bottom right), there are two linear regressions, which can be carried out (red line and blue line). The fractal dimension is approximated based on the slope of the red line $D_f = (2 - \beta)$ since only the high frequency part is considered to have the fractal behavior. Moreover, the turning point from the blue linear fit to the red linear fit has a potential interpretation. Namely, it stands for the turning point from smooth to rough.

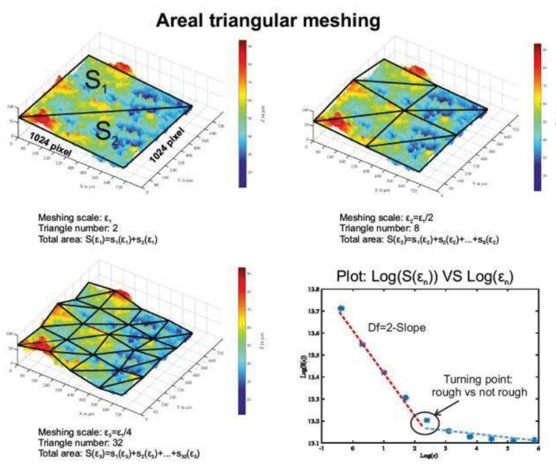

***Fig. 4** The schema of calculating the fractal dimension with areal triangular meshing method.*

4 Summary and outlook

In this paper, fractal methods are successfully applied to characterize HVOF spayed coatings. The fractal analysis provides an alternative way to study the complexity of the surface topography. Power spectrum density and areal triangular meshing are carried out in this study for calculating the fractal dimension, which has the scale invariant property.

As outlook, a correlation analysis between the fractal dimension and the parameters from wear tests will be studied in the future to research whether the fractal dimension is a representative parameter for these functional coatings.

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