

Metrology and Characterisation of Thermally Sprayed Coatings

M. Bretschneider, M. Kästner, E. Reithmeier

Institute of Measurement and Control Engineering, Leibniz Universität Hannover, Nienburger Straße 17, 30167 Hannover, Germany

Abstract

Modifying highly loaded surfaces of cylinders of piston engines is a method of minimising wear and friction. There already exist coatings like ALUSIL which are used in the cylinders of some BMW and Porsche engines. The advantages of these coatings are very hard silicon particles that protrude from the aluminium matrix in which the silicon is embedded. Below the silicon particles there is volume to store oil, improving the tribological performance. Another method of modifying a surface is thermal spraying which generates pores. A common way of characterising these thermally sprayed coatings is using a micrograph and thus only using a cut instead of the whole surface.

This paper describes a method to characterise the pores. The metrology of these coatings is based on a white light interferometer that provides areal measurements. A segmentation method based on watershed transformation is suggested to segment the pores that can store the oil improving the tribological properties of the surface. Several characterisation methods describe the surface not only in an integral way but also with properties of each pore like area, depth, volume and direction.

Keywords: thermally sprayed coating, atmospheric plasma spraying, metrology, segmentation, functional characterisation

1. Introduction

Within the research group “microstructuring of thermomechanically high stressed surfaces”, financed by the German Research Foundation (in German: Deutsche Forschungsgemeinschaft, abbreviated DFG) as research group 576, several aspects of microstructures like simulation, production and characterisation are researched [1].

Atmospheric plasma spraying (APS) is a production method to provide coatings: Metallic powder in a high-temperature plasma jet is melted and accelerated onto a sample. On this sample the molten powder superposes with different other molten powder drops that are already on the sample. The result of these superposed drops is an inherent porous microstructure with a stochastic distribution of the pores [2].

In this paper measurement and characterisation methods for these microstructures are discussed. The applied optical measurement technique is white light interferometry. Based on these measurements the microstructures are segmented and several characteristics are computed. The characteristics are classified in 1D characteristics like height and width, 2D ones like area and 3D characteristics like volume.

2. Measurement

It is common practice by the producers of thermally sprayed coatings to measure the resulting surface with a micrograph that represents a cut and so only small part of the whole surface.

In order to get more information about the surface, it is measured with an areal optical roughness measuring device. There are several areal measuring devices for this purpose like white light interferometers or confocal laser scanning microscopes. The white light interferometer Veeco Wyko NT 1100 has been used for this purpose

(see Figure 1(a)). This measuring device performs areal measurements with a measuring field of 0.4 mm² up to 2 mm² depending on the objective and its magnification.

Due to the fact that the distribution of the microstructures is stochastic as shown in Figure 1(b) one single measurement is not sufficient to contain all the kinds of pores. Thus, several measurements with the same parameters like objective and lamp intensity but on different parts of the surface are made. Figure 1(c) shows the histogram of the volumes of the pores that are computed in the next step. It shows that there are a lot of small

pores, developing similar to the function $f(x) = \frac{1}{x}$ with fewer pores with greater volumes. Comparing

histograms based on a combination of different amounts of measurements, it is evident that a combined measuring field of about 4 x 4 mm² is enough to contain all types of the pores.

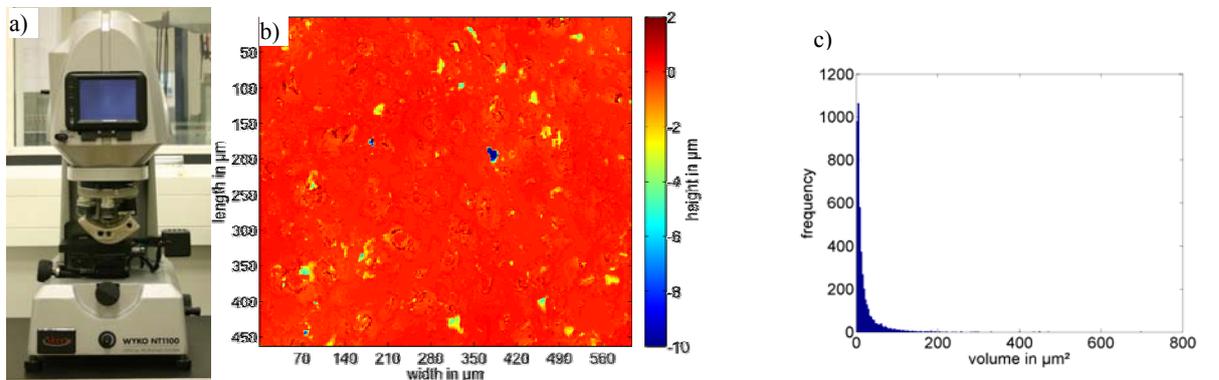


Fig.1 (a) measuring device white light interferometer; (b) measurements of the structures; (c) histogram of several measurements

3. Segmentation and Characteristics

For further analysis the microstructures have to be identified and separated from the other non-structured parts of the surface. Several segmentation methods can be used for this purpose. A common method is the watershed transformation [3] that floods the measured data with virtual water and raises the level of this virtual water (see Figure 2). Thus, the structures with the largest depth are filled with this virtual water first. While the water level rises the structures with a smaller depth are being filled. If the level reaches a specific value, the water floods the whole surface and not only the structures. On this value watersheds are constructed on the edges of the microstructures that keep the water in the structures and avoid the flooding of the whole surface.

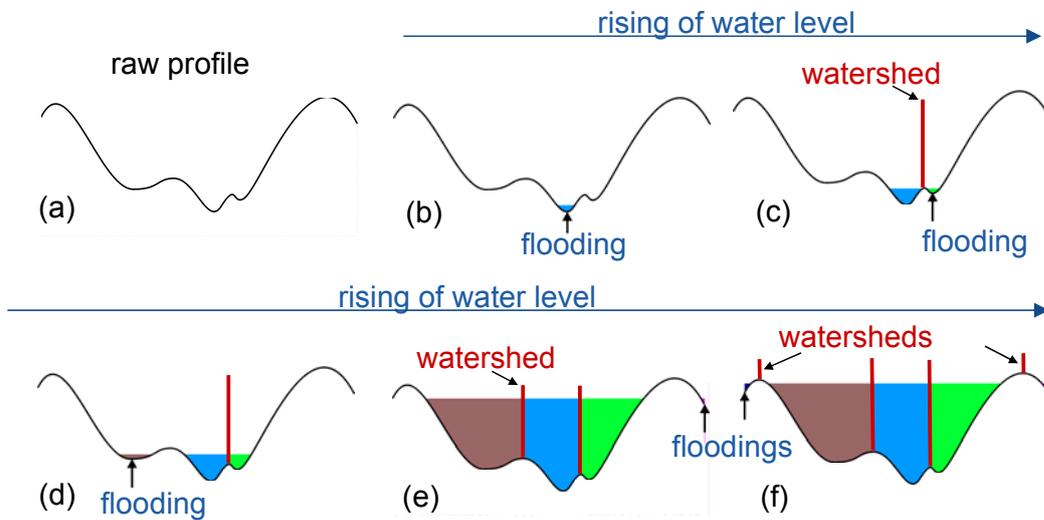


Fig. 2 principle of the watershed transformation: water level rises from (b) to (f)

The result of the watershed transformation of the measurement shown in Figure 1(b) can be seen in Figure 3(a). It is a bitmask that shows where all the segmented regions can be found. This bitmask has to be processed with a regions finding algorithm [3] that finds neighbored measuring data point and segments this data to single regions. The recognized regions are shown in Figure 3(b).

Several characteristics like depth d , length l , width w , volume V , area A and cross direction α are computed for each region. A histogram of the volume of the pores was already shown in Figure 1(c).

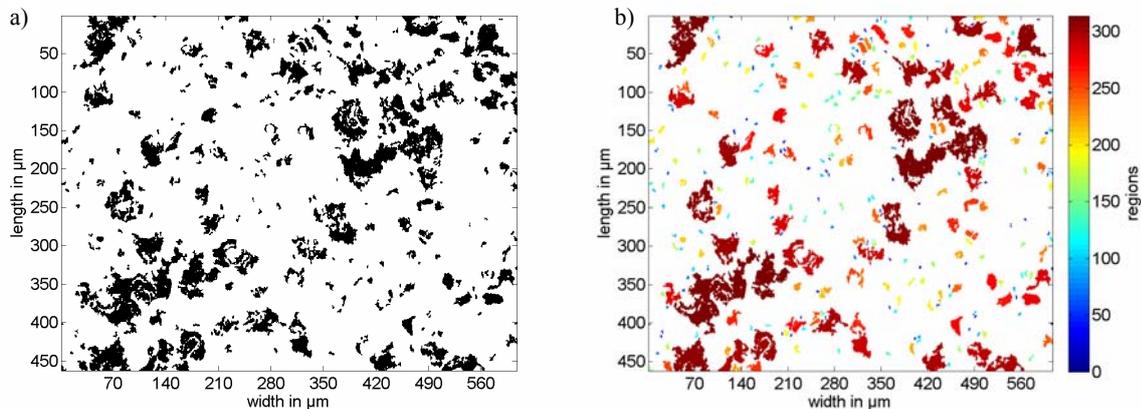


Fig. 3 (a) result of the watershed transformation of the measurement shown in Figure 1(b); (b) segmented regions

Additionally, several porosity ratios are being calculated: The area ratio A_V relates the sum of the area of the n pores to the whole measuring field A_{meas} :

$$A_V = \frac{\sum_{i=1}^n A_i}{A_{meas}}$$

A similar ratio can be computed for the volumes V of the n pores that are related to the product of the measuring field A_{meas} and the maximal depth $\max(d_i)$ of the pores:

$$V_V = \frac{\sum_{i=1}^n V_i}{A_{meas} \cdot \max(d_i)}$$

Due to the fact that $\max(d_i)$ of the previous ratio V_V could easily be influenced by noise, another ratio – the specific volume ratio $V_{V,sp}$ – is computed out of the volumes and the measuring field. In contrast to both the other ratios this ratio has a unit:

$$V_{V,sp} = \frac{\sum_{i=1}^n V_i}{A_{meas}}, [V_{V,sp}] = \mu m$$

Figure 4 displays the results of the different porosities of two materials with different spraying parameters. The materials are 50FeF0 and FeCr-13. The spraying parameters are the plasma enthalpy and the spray distance.

The three different porosities have a similar developing. Comparing the increasing spraying distance at the same plasma enthalpy there is an increase in the porosity in most cases. The exceptions are 50Fe50Mo with medium plasma enthalpy and FeCr-13 with high plasma enthalpy where the medium distance produces the highest porosity.

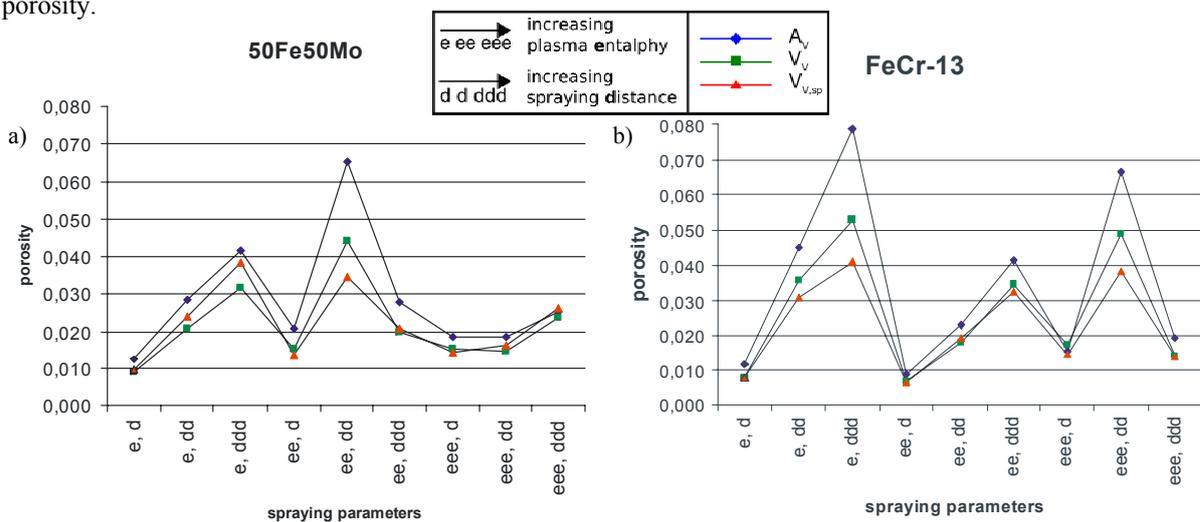


Fig. 4. different porosities made with different spraying parameters

4. Conclusion and Outlook

A method has been shown to evaluate the properties of the stochastic surfaces produced with atmospheric plasma spraying. In further experiments the tribological performance of thermally sprayed coatings made with different spraying parameters will be evaluated. Based on these experiments a correlation of the surface characteristics with the tribological performance will identify the characteristics that are functional. A similar correlation of other microstructures has been done in [4].

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