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ANALYSIS OF HVOF-SPRAYED MCrAlY COATINGS USING SEM IMAGE PROCESSING

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The paper presents an analysis algorithm for SEM images of HVOF-sprayed MCrAlY coatings as used in high-temperature environments. The grain size, orientation and deformation obtained for different oxygen fluence and different MCrAlY powders of spherical morphology are determined, in order to evaluate the coating process.

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1. Introduction

The gas turbines provide one of the hardest environments for materials today. Turbine components are subject to severe mechanical loading conditions, high temperature oxidation, and corrosive media. Developing, selecting and designing materials resistant to a specific environment can avoid problems like oxidation and corrosion. Protective coatings can be applied to increase the durability and field performance especially of turbine blades.

In modern high-temperature (>1273 K) coating systems, MCrAlY (M = Ni, Co) alloys are used as a bond coating between a ceramic thermal barrier topcoat (TBC) and the Ni-base superalloy component, such as a blade or vane in a gas turbine engine [1]. The superalloy is designed to provide the mechanical strength of the load-bearing components at high operating temperatures. The TBC, in conjunction with component cooling, serves to reduce the component-surface temperature to about 150 K [1], thereby allowing for a higher operating temperature, which results in an enhanced efficiency of energy conversion.

MCrAlY's are a family of materials, which have a base metal (M) of cobalt, nickel and/or iron, plus chromium, aluminium, yttrium and sometimes other alloying elements. MCrAlY's are used as overlay coating for turbine components improving their resistance and provide a longer lifetime for turbine even under hard environmental conditions. High temperature oxidation resistance is achieved by one or more alloy components, which have to form a dense, stable, slow-growing, external oxide layer such as Al_2O_3.

Generally, for high-performance applications, MCrAlY coatings are produced by vacuum plasma spraying (VPS). VPS coatings provide good adherence to the metallic substrate, low porosity, and a minimum of internal oxidation. The presence of yttrium in the coatings improves the adherence of the oxide scales, irrespective of the alloy composition and the nature of oxide scale formed (Cr_2O_3 or Al_2O_3).

In the last few years, a new thermal-spraying process, high-velocity oxygen fuel (HVOF), was developed and used to produce MCrAlY coatings. The application of HVOF spraying has implications for the oxidation of powder particles, because of the free-oxygen content in the combustion gas and high temperatures required to melt the powder to assure a certain homogeneity level of the coating. There are two elements in the metallic powder, aluminium and yttrium, which have a high affinity for oxygen. These elements are oxidized during thermal spraying, so that the as-sprayed coatings contain oxides, such as Al_2O_3. After annealing, the oxides are uniformly distributed in the material. The HVOF coatings showed good oxidation behaviour at high temperature in

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various atmospheres (synthetic air, He–O_2 mixture or He–synthetic air), which suggested that the HVOF process can be used as a technological alternative to the more expensive VPS technology [2].

Al content in the coating alloy is important, because selective oxidation of the Al occurs only on the surface of alloys with adequate Al contents. However, a high Al content in coatings leads to coating brittleness and a strong tendency to crack [3]. Such cracks can propagate into the substrate material and lead to premature failure of the coated component. It has been proved that a fine grain size has a positive effect on the oxidation behaviour of alumina forming alloys [3].

These different coatings need characterization methods, destructive or non-destructive [4]. In order to better evaluate the coating, accurate information on coating thickness profiles and morphological features is highly desirable, particularly when evaluating a new coating process or when process parameters have changed.

2. Digital image processing algorithm

The objective of the work presented in this paper was to process SEM images of HVOF MCrAlY coatings in order to study the grains size, their orientation and deformation obtained for different oxygen flows and different MCrAlY powders of spherical morphology in order to be able to evaluate the quality of the coating process.

As an example, the coating in Fig. 1 was evidently deposited by partially melted particles and is important to know the size of these particles and their orientation in order to better understand the microstructure of the coating layer.

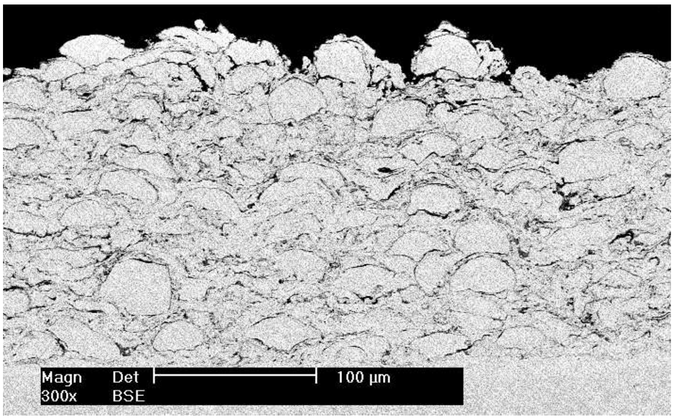


Fig. 1. Initial image of MCrAlY alloy.

The first step was to obtain a binarized image by applying a proper threshold to the region of interest in the given SEM image. Due to adjacent values of grey levels, the binarized image usually presents scattered pixels, which must be eliminated. This process is done by performing an “opening” graphical operation with a special structure element graphical object.

In the next step all the objects are labelled and the number of pixels of each object is counted. Now it is possible to sort the objects based on their apparent surface area. An unfolding of the grain size distribution is possible [5] in order to consider the real sizes of the grains.

It is possible that due to the low quality of the images the objects require an individual (manual) processing for filling the gaps or splitting into multiple parts.

The equivalent linear size of the grains is calculated considering the diameter of a circle of the same surface area.

In order to determine the orientation of the objects, the largest dimension of each one has to be found. The first step consists in detecting the centre of gravity of each feature. A rotation around this point is applied having a suitable increment, and the largest horizontal and vertical dimensions are registered. Once the longest dimension is determined, its angle gives the orientation of the object.

A form factor for each object is calculated as the ratio between the largest dimension and the equivalent diameter. This factor is needed to evaluate the efficiency of the coating process.

3. Results and conclusions

An application was developed in Matlab in order to study the microstructure of the coatings. The first objective was to determine the quantity of the particles with size larger than 15 µm. The binarized image, after elimination of the upper and lower regions of the image, can be seen in Fig. 2.

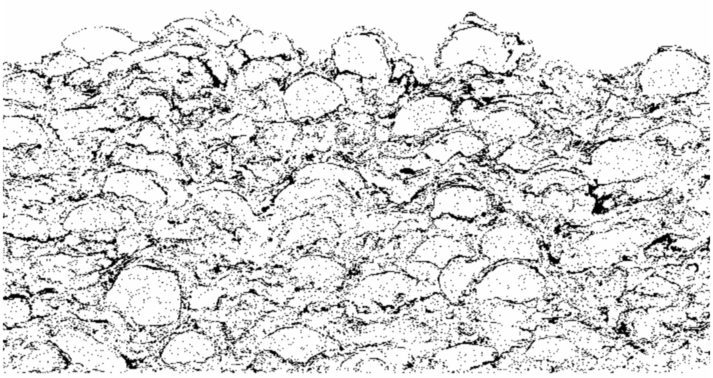


Fig. 2. Binarized image after eliminating the upper and lower regions.

The scattered pixels were eliminated by "opening" with a *strel* object: a size 4 disk. All the features from the image are labelled and coloured for a better visualization. The resulting image (in black-and-white) is presented in Fig. 3.

After all objects are labelled and the number of pixels of each object is counted, the objects having the area greater than the equivalent area of a circle having a diameter of 15 µm are selected. The resulting image can be seen in Fig. 4. The equivalent area was determined based on the scale at bottom part of the image in Fig. 1.

An individual processing was performed to fill some gaps or split some objects into multiple parts when the necessity of the operation was obvious.

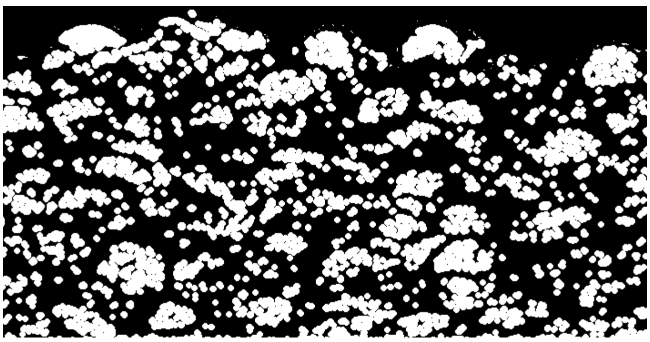


Fig. 3. All the objects from the image after de-noising.

In the end, 45 objects matching the criteria mentioned above were obtained. The total area of these objects represents a percentage of 22.48 of the region of interest.

For the equivalent diameters, a histogram with equally spaced bins of 2.5 µm (Fig. 5) and the Pareto diagram (Fig. 6) were plotted. Analyzing the equivalent diameters, one can see that a significant percentage, 67%, belongs to the first three classes of Pareto's diagram, which represents the domain 15 – 22.5 µm.

In order to detect the orientation of the objects, a rotation around the centre point is applied having an increment of 3.6 degrees. The results can be seen in Fig. 7a. This histogram has a good fit to normal distribution. The longest dimension has values in the range 21-50 µm.

A shape descriptor was calculated for each object. The histogram for this shape descriptor (elongation) is presented in Fig. 7b. The elongation has values in the range 1.1 to 1.9.

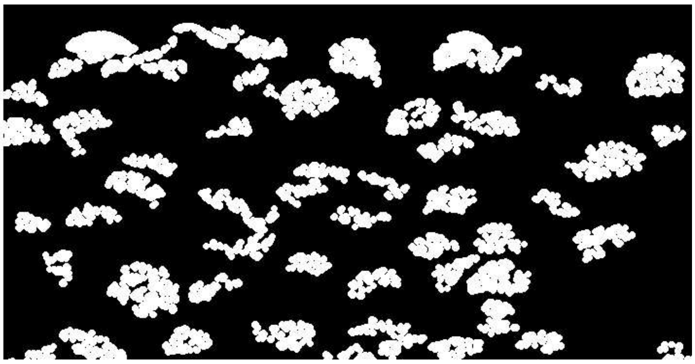


Fig. 4. Features having area larger than 225 μm^2.

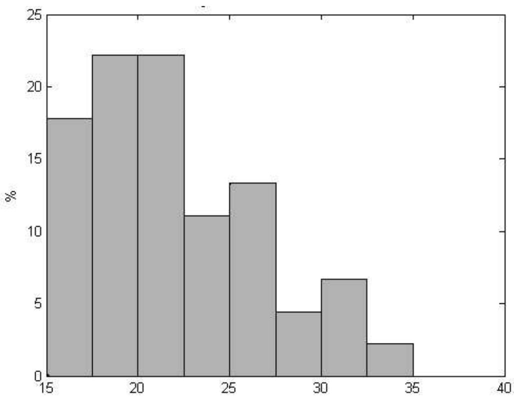


Fig.5. Histogram of equivalent diameters.

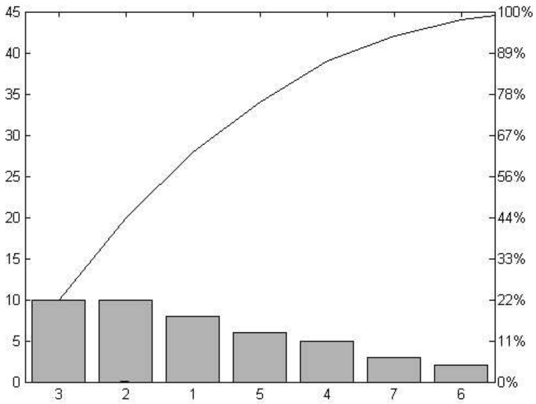
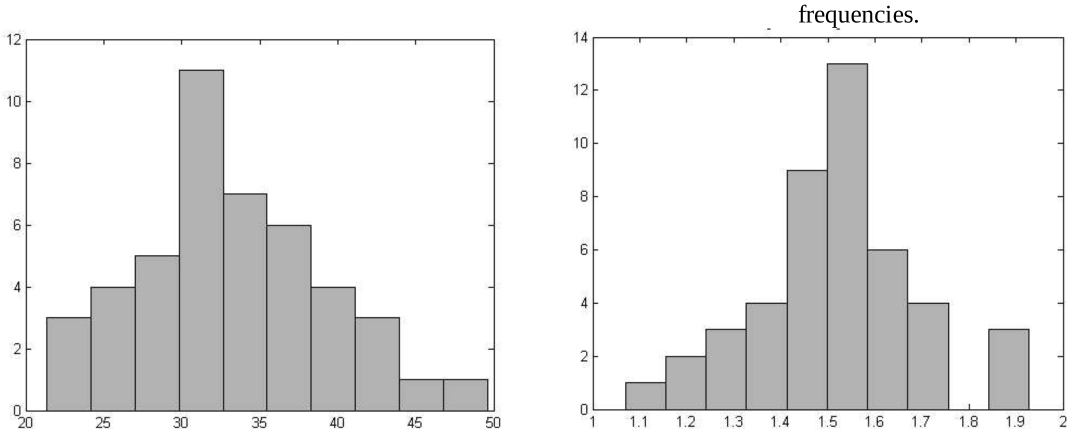


Fig. 6. Pareto diagram of diameters' relative frequencies.



(a) (b)

Fig. 7. Histograms for the longest dimension (a) and elongation (b) of the features.

In conclusion, the proposed digital image processing algorithm proves to be a proper characterization method for morphology of the coatings. Information about the particle size, their orientation and morphology can be obtained correlated with MCrAlY coating process parameters, making it possible to optimize the coating process.

References

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