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DETECTION OF ADHERENCE IMPERFECTIONS AT THE INTEFACE OF SUBSTRATE-COATING LAYER BY USING INFRARED THERMOGRAPHY

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The paper presents Infrared Thermography (IRT) for non-destructive examination of the imperfections in the coatings layers deposited by Electric Arc Spraying (EASP), designed to assess the dimension and position of the lack of adhesion, as a typical imperfection placed at the interface between the coating layer and the base material. Metallographic analyses were used to confirm the absence or presence of imperfections, enabling establishment of the etalon for non-destructive examination and detection of adherence imperfections at the coating–substrate interface layer, together with optimum process parameters, obtained by experiments.

Keywords: coatings, electric arc spraying, non-destructive testing, infrared thermography, microstrucure

INTRODUCTION

Thermal spray process is used to obtain coatings layers used as thermal barrier, or to facilitate increasing the corrosion and/or wear resistance in aggressive environments [1]. Electric arc spraying (EASP) is a thermal spraying process characterized by high efficiency, mainly due to the small number of preparatory operations of the surface component [2]. Using this method the operating costs can be reduced, only the surface blasting process being necessary. A thermal spraying coating layer is typically characterized by: structure, adhesion, density and porosity. The adherence is one of the basic characteristics of coating layers, which ensures strength, durability and protection of coated components [3, 4].

Thermal spraying often result in imperfections at the interface between substrate and coating layers, causing cracking and/or peelings. Non-destructive evaluation (NDE) of coating layers is a current demand, since conventional NDE techniques do not allow their quantitative assessment. Active IRT is considered as suitable non-contact and non-destructive technique to obtain the in-time evolution of material surface's thermal map, in order to get information regarding the size and position of sub-superficial lack of adhesion defects. The aim of this research is to present an experimental program that facilitates identification of the imperfections located at the interface between the base material and the coating layer, as well as to determine their size, in relation to a particular calibre with simulated defects of known dimensions. This program was conceived based on previous expertise regarding digital image processing [5].

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MATERIAL AND METHODS

Experiments were conducted on a set of S235 steel plates with dimensions: 200×200×3 mm. These plates (samples) were coated by EASP, according to EN 657, using Al wire (Aluminium Metco). Based on data from the product catalogue and preliminary experiments, the central point was established and afterwards the variation domain of the selected factors. On the ten plates a single run through the central area of each sample was applied, as shown in [5]. The technological parameters for factorial experiment are also presented in [5].

Thickness measurement was performed with a coating measurement system Pocket-LEPTOSKOP type, Karl Deutsch (Germany) and the roughness measurements with a Mitutoyo SJ.201P (Japan) roughness meter.

RESULTS AND DISCUSSION

Thickness and roughness measurements were performed for all 10 samples of steel plate coated with Aluminium, using different EASP parameters, as shown in [5]. These results were used to establish mathematical relationships between the process parameters to control the thickness of coating layers by EASP. The main process parameters are:

I – arc current intensity / A
U – arc voltage / V
v – spraying speed / cm/min
D – spraying distance / mm
p – air pressure / MPa.

The regression function using real values to calculate the coating layer thickness (*CLT*) is given by equation derived in [5]:

$$CLT=1665{,}57+2{,}54125\cdot I–6{,}991\cdot v–$$
$$–7{,}865\cdot D–0{,}002425\cdot I\cdot v+0{,}000875\cdot I\cdot D+0{,}02814\cdot v\cdot D$$

This regression equation was used and validated during the realization of calibration block. Thus, to achieve an average layer thickness of 350 μm the following technological parameters were used: I = 200 A, v = 200 cm/min, D = 183 mm, U = 28 V, [5]. We also mention that having a Gaussian layer thickness distribution and a given size of calibration block, three passes were made using a step 45 mm, to achieve a relatively uniform thickness throughout its area.

The surface quality and the roughness of the coating layer respectively, are important both for the manufacture of calibration block and for many other industrial applications. The calibration block should have a small roughness in order to obtain reference thermographs without disturbing signals to come up to the superficial layer. In industrial applications where components are further protected by painting, a small surface roughness results in financial savings through a lower primer or paint consumption. In the following section presents the obtained results using active pulse IRT on a S235 steel plate, coated with Aluminium by EASP with a layer of 350 μm average thickness. The sample examination process was recorded with an experimental IRT system, [5]. Two different examination technique were used: with and without contrast material applied on the sample surface. The purpose of contrast material is to enhance the thermal contrast, while reducing false indication of imperfection. Depending on the application, different fluids can be used as contrast material (water, oil or solvents). In this case the sample and the calibration block were moistened using tap water. The thermographs for the sample and the calibration block are presented in [5]. Generally speaking, one can observe, beside the simulated imperfections revealed as hot-regions, some spots which are “hotter” than the rest of the plate, i.e. regions which are cooling down slower than the rest of the coated surface, without being necessarily the presence of a simulated or existing imperfection at the coating layer – substrate interface. This behaviour could lead to a misinterpretation of the thermographs, making it harder to identify the real imperfections / defects or could even cover up the real lack of adhesion defects. After the analysis of the coated surface morphology for these areas, it was possible to determine the cause of this behaviour and to apply a procedure which attenuates or even eliminates these “ghost” heat output signal, [5].

The proposed procedure is based on moistening the examination surface, spraying the surface of the specimen with water (or another liquid), and thus using a wet surface for active IRT examination.

The false/ghost heat output, recorded after heating the surface with the flash lamp, is caused by the clusters of droplets which might appear on the surface, especially on the edge of the thermal spraying cone or due to the instabilities of the process. These clusters have a rather small contact volume with the previous coating layer (Figure 1a) or with the substrate, and this fact decreases the conduction heat transfer towards the substrate and the main heat transfer, which cools down the surface, through convection in air. Comparatively, Figure 1b presents a surface area of the coated component without imperfections, where heat is transferred through conduction towards the substrate.

The liquid (water) layer improves the heat convection through the increased heat transfer coefficient and thus the false radiation heat output is diminished or even extinct. The procedure does not affect the identification of these superficial imperfections since they are detectable through other inspection methods, i.e. by visual inspection or roughness measurements, but the applied liquid has to be selected depending on the coating – substrate material characteristics and the exploitation conditions of the examined component.

Lack of adherence between substrate and coating layer is difficult to assess using conventional NDE. For example if we are using ultrasound technique, the thickness of coated layer is too small, examination from the coated surface is not possible, and if it is desired to

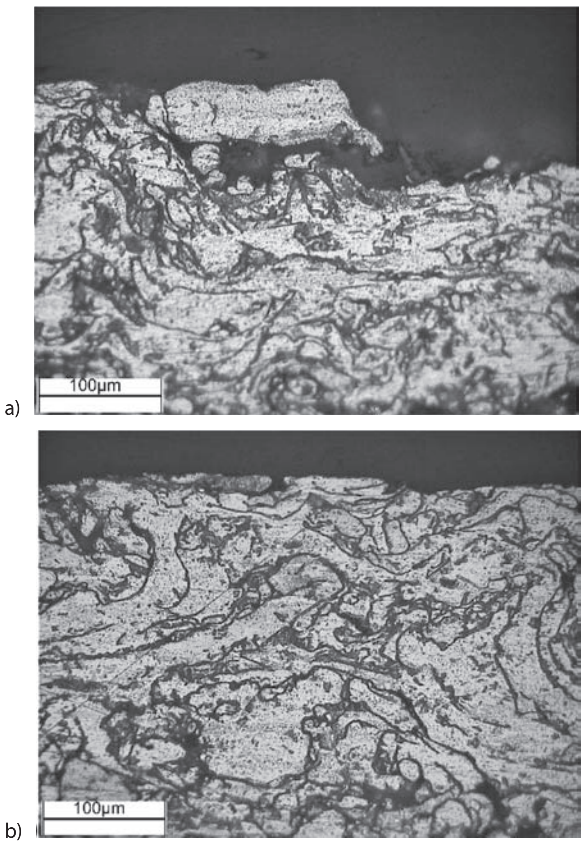

Figure 1 Microscopic analysis of the coating layer (a) grains of spayed material not adhering properly to the component surface; (b) image of the area without imperfections

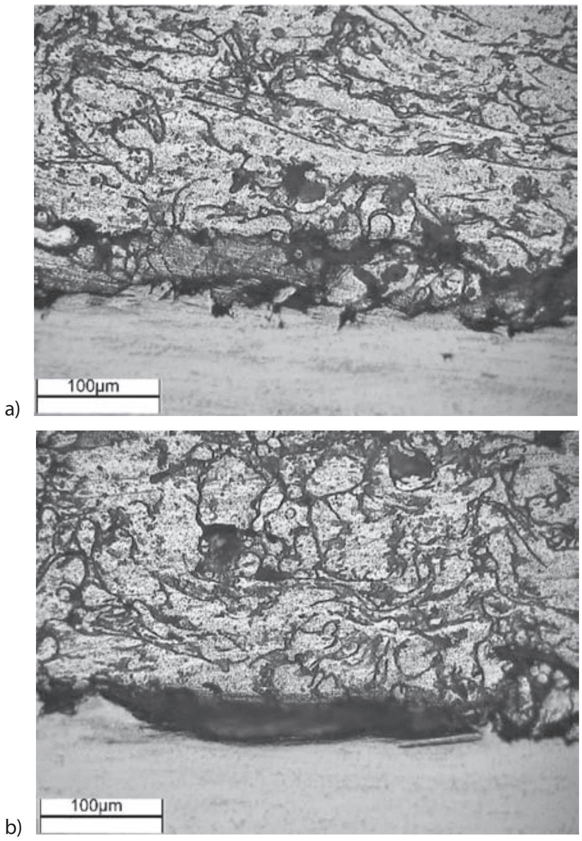

Figure 2 Microscopic analysis: (a) image of the interface area without imperfections and (b) image of the interface area with lack of adhesion imperfection

adopt an examination geometry from opposite side, the bottom echo can be easily misinterpreted as a defect.

Thus, to validate the method and to demonstrate presence or absence of adherence imperfection, the metallographic analysis was used. Samples were taken from sound and defects areas indicated by thermographs. The metallographic tests confirmed the absence, Figure 2a, or presence of imperfections, Figure 2b.

CONCLUSIONS

Using experimental results, mathematical relationship has been established describing the interdependence between the main technological parameters of the electric arc thermal spraying process in order to control the thickness and roughness of the coating layers. This correlation was used to determine optimum process parameters, used to realize the etalon for non-destructive examination and detection of adherence imperfections at the coating–substrate interface layer. Finally, metallographic analysis was used, as the only reliable method, to confirm the absence or presence of imperfections.

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