STUDY OF THE ELECTRON BEAM REMELTING OF A CGDS DEPOSITED CONICRALY LAYERS

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Abstract

Cold Gas Dynamic Spraying (CGDS) method was used in order to obtain very dense and good adhesive CoNiCrAlY-coatings deposited onto nickel-based alloy and subsequently remelted by electron beam (EB) up to depth of about 90 µm. The CGDS process- a relatively new coating technology is based on the high velocity impingement of small solid particles on the substrate. In this process, the particles are accelerated by supersonic gas jet at the heated gas temperature, which is usually lower than the melting point of the powder material. The objective of this work is to investigate the influence of the parameters used in electron beam remelting even the effect of double EB remelting on the microstructural changes and state of the coating. Changes of the coatings morphology and structure were analyzed by scanning electron microscopy (SEM) and X-ray diffraction technique (XRD). The experimental results demonstrated that there are advantages at using the pulsed EB surface modification technique. The double remelting process improved the coating properties in terms of porosity, strength and chemical homogeneity.

Keywords: Cold gas dynamic spray, electron beam remelting, CoNiCrAlY coatings, bond coat

1. INTRODUCTION

Thermal barrier coatings (TBCs) are used to protect and insulate hot-section metal components in advanced gas turbines applications such as aircraft and power generation, and in diesel engines [1, 2]. Use of the TBCs can result in a temperature reduction of 100 to 300 °C at the metal surfaces, thereby improving the durability of the metal components and enhancing engine performance. The protection offered by the alloy bond coat (BC) against high-temperature oxidation relies on the ability of the alloy to produce and maintain a stable, continuous, slow-growing and adherent oxide scale on its surface. MCrAlY-coatings (M = Co, Ni or both) are used worldwide as bond coats in TBCs systems to reduce the thermal expansion mismatch between a top ceramic coat and base metal (such as Ni-alloy) and it gives extra oxidation resistance [3, 4]. Generally, for high-performance applications, MCrAlY coatings are produced by vacuum plasma spraying (VPS), provide good adherence to the metallic substrate and low porosity, but VPS is more expensive compared to other thermal spray processes. Thus, high-velocity oxygen fuel (HVOF) thermal spraying was attempted as an alternative to VPS to deposit MCrAlY coatings. However, oxidation of the powder particles during HVOF spraying is inevitable, due to the free-oxygen content in the combustion gas and the high temperatures required to melt the powder to ensure a certain homogeneity of the coating. Recently, cold gas dynamic spraying (CGDS) has emerged as a promising new coating process. In the CGDS process solid particles of size range characteristically between 10 and 50 um are accelerated in a supersonic inert gas flow (usually nitrogen or helium, although air can also be used) and directed towards the object at a velocity higher than the material dependent critical velocity, they plastically deform and adhere to the substrate or to the already deposited layer of material through what is believed to be primarily mechanical interlocking [6, 7]. Therefore, CGDS is a promising technique to deposit nanostructured MCrAlY coatings having a microstructure similar to that of the original feedstock particles for TBC applications. Several papers [8, 9] have been dedicated to systematic investigation of CGDS deposition of MCrAlY coatings.

Electron beam (EB) remelting process is one of the most efficient and reliable techniques for altering and further anchoring of the particle-deposited layers. EB remelting treatment is of great significance in developing the protective capability of MCrAlY coatings and allows improving requirements of long service life at high temperature for the coatings [10]. The purpose of the present study is to investigate the dependence of the parameters used in electron beam remelting on the microstructural changes in order to optimize an EB remelting process of CoNiCrAlY coatings.

2. EXPERIMENTAL

Five specimens used for the experimental investigations, consisting of Ni-based alloy Inconel 718 plates as substrate (20 mm x 10 mm x 4 mm) and a 70 - 75 um thick CoNiCrAlY coating, were manufactured by cold gas dynamic spraying technique. The chemical composition of CoNiCrAlY powder and substrate composition are shown in **Table 1** and **Table 2**.

Table 1 Chemical composition of CoNiCrAlY powder

Element	Co	Ni	Cr	Al	Y	C	O
wt. %	36.91	34.38	19.35	6.16	1.47	0.98	0.74

Table 2 Chemical composition of substrate material (Inconel 718)

Element	Ni	Fe	Cr	Nb	C	Mo	Ti	Al	O
wt. %	49.85	19.69	17.81	4.6	3.03	2.65	1.00	0.73	0.64

Electron beam surface treatment was carried out using K26 15-150 machine. Maximum beam input power was 15 kW at 150 kV and 100 mA. The electron beam was oscillated with amplitude of 7 mm on the specimen surface. The experiments were performed at five EB remelting conditions. Two of the five samples were subjected to a little different EB treatment - to double EB remelting. The detailed EB remelting conditions are shown in **Table 3** and **Table 4**. The CoNiCrAlY coatings have been subjected before and after electron beam remelting to morphology analysis using scanning electron microscopy (SEM, Carl Zeiss Ultra Plus).

Table 3 EB remelting conditions

Sample	EB current (mA)	Processing speed ($mm \cdot s^{-1}$)
A	4.6	15
B	3.7	15
C	3	15

Table 4 Double EB remelting conditions

Sample	EB current I. (mA)	EB current II. (mA)	Processing speed ($mm \cdot s^{-1}$)
D	3	3	15
E	3	2.7	15

3. RESULTS AND DISCUSSION

The morphology of the as-received CoNiCrAlY powder is shown in **Figure 1**. As can be seen from this figure, the powder has spherical morphology and the size of the particles falls within the specified range of 5 -20 µm.

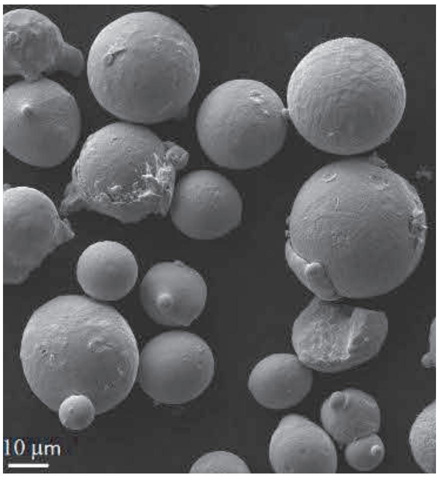

Figure 1 SEM image of CoNiCrAlY powder

Cross section of as-sprayed coating deposited onto Inconel 718 by CGDS technique is shown in **Figure 2a**. The coating presents the structure with minimal porosity (0.7 ± 0.5%) [10], note the absence of cracks and clean interface with the substrate free of oxidation.

3.1. EB remelting

Figures 2b - **3** shows SEM analysis of the cross section microstructure of CoNicrAlY coatings after electron beam treatment according to EB remelting conditions in **Table 3** up to depth of about 85 - 90 µm.

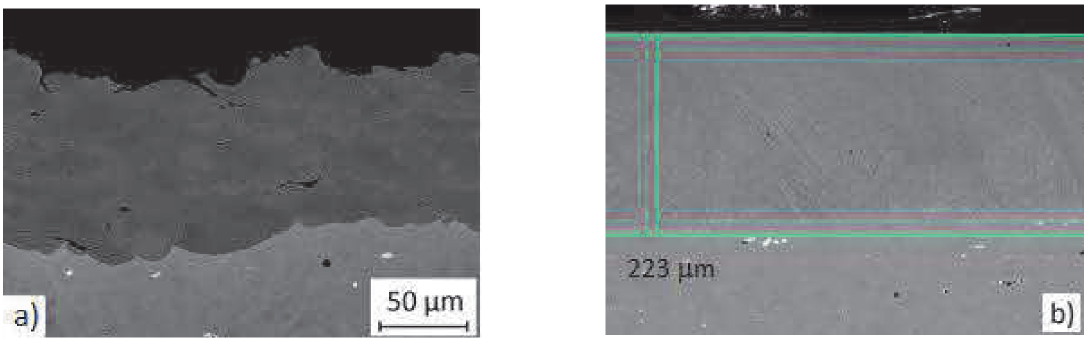

Figure 2 Microstructure of CoNicrAlY coatings a) before b) after EB remelting (sample “A”)

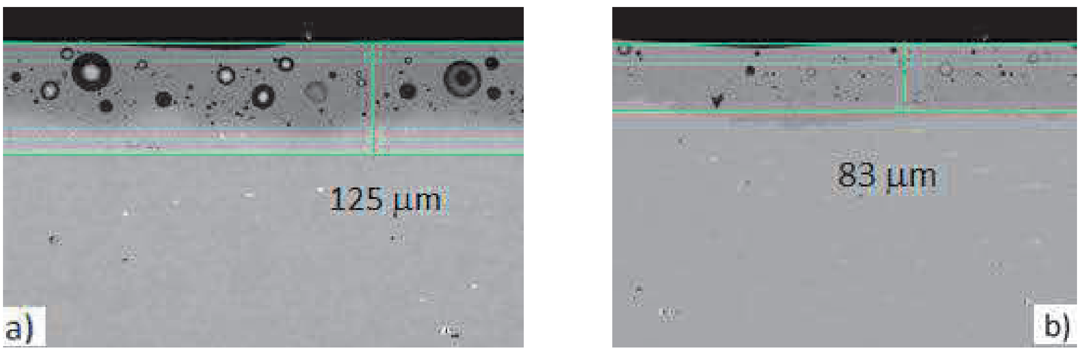

Figure 3 Microstructure of EB remelting CoNiCrAlY coatings a) sample “B” b) sample “C”

Figure 2b presents microstructure of CoNicrAlY coating after EB treatment (4.6 mA and 15 mm·s^{-1}). The depth of remelting layer was about 223 µm, which was full remelting. The structure of remelting layer is characterized by long dendrites and absence of material in interdendritical space, which is not very goog for TBC treatment. Comparison between two differently treated coatings (**Figures 3a, b**) were the processing speed was the same (15 mm·s^{-1}), but the EB current has been varied (in **Figure 3a** - 3.7 mA and in **Figure 3b** - 3 mA) is shown. In **Figure 3a** the depth of remelting layer was about 125 µm and also full remelting with large pores. The similar situation occurred in **Figure 3b**. Although, the depth of remelting layer was decreased from 125 µm to 83 µm, but large pores and some defects were still observed.

3.2. Double EB remelting

As mentioned above, we tried to optimize EB remelting conditions on the CoNiCrAlY coating deposited by CGDS technique, but the results were not very optimal for our purposes. Either very deep remelting layer or some disorders such large pores and cracks were observed in the remelted layer. Based on these observations we tried to use double electron beam remelting treatment. **Figure 4a, b** shows SEM images of CoNiCrAlY coatings after double EB remelting at various electron beam conditions (**Table 4**). The processing speed was the same (15 mm·s^{-1}) but the EB current has been varied.

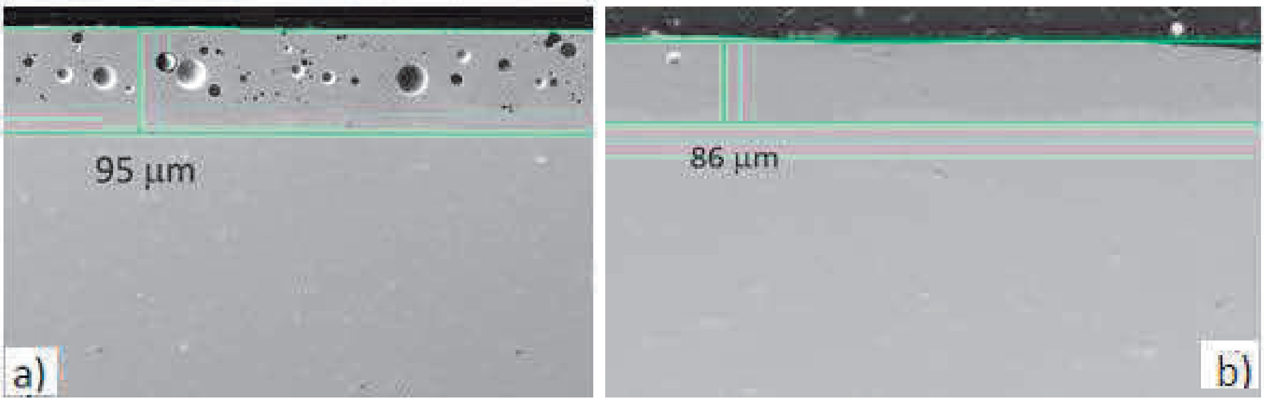

Figure 4 Microstructure of double EB remelting CoNiCrAlY coatings a) sample “D” b) sample “E”

Figure 4a shows the microstructure after double EB remelting, the current of first and second remelting was the same (3 mA). The depth of remelting layer was about 95 µm, which is not very deep but we still observed large pores in remelting layer. After decreasing the beam current for second EB remelting from 3 mA to 2.7 mA, the depth of remelting layer decreased from 95 µm to 86 µm and the count of pores were reduced significantly and the structures are refined.

4. CONCLUSION

Electron beam treatment of ConicrAlY thermal spray coating has been carried out to study the influence of the remelting parameters on the morphology of the structure. The results show that the coating deposited by CGDS technique being EB remelted into depth more than 100 µm resulted in formation of large pores, some defects and complete mixing of substrate with coating. Similar situation was observed in the case of decreasing of remelting layer down to depth of 85 µm, although the remelting layer was adequate, we still observed the large pores in remelting layer. The double EB treatment produced positive changes in the bond coat layer, provided a smooth surface, low porosity level mainly on the interface between bond coat and substrate comparing to bond coat surface without this modification. In generally the electron beam treatment provides a good route for improving the surface of the coatings and produced positive changes in the bond coat layer as a necessary step for the thermal barrier coating fabrication.

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