



6th New Methods of Damage and Failure Analysis of Structural Parts [MDFa]

Microstructure modification of CGDS and HVOF sprayed CoNiCrAlY bond coat remelted by electron beam

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Abstract

In the present work two techniques are combined to optimize bond coat properties before thermal barrier coating (TBC) application, the cold gas dynamic spraying (CGDS) and electron beam remelting (EB). Results of the work focused on comparison of high velocity oxygen fuel (HVOF) and CGDS CoNiCrAlY bond coats are firstly presented. Then the effect of the electron beam remelting of the CoNiCrAlY coating manufactured by HVOF and CGDS deposition techniques is deeply investigated. The CoNiCrAlY bond coat to Inconel substrate interface displayed locations with very poor bonding, in larger extent for the states prepared by HVOF comparing to CGDS. The bond coats prepared by both ways being EB remelted are typically removal of the defects on the substrate to bond coat interface. The microstructure of the bond coat after this treatment is formed by Inconel fine grain layer being followed by the surface layer consisting of elongated dendritic microstructure. An increased porosity has been observed in interdendrital space in larger extent for CGDS samples.

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1. Introduction

Surface engineering and coatings technology play crucial role in the operation of all high-temperature equipment, particularly for gas turbine engines. Coatings are generally applied to provide oxidation, corrosion or thermal protection depending on the nature of the operating environment and thermal loads to be endured. The coating

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should possess the required mechanical properties, adhesion and metallurgical stability in contact with the substrate. Porosity, oxide stringers and clusters, fissures and cracks may open corrosion paths through the coating to the substrate. Therefore, it is important to obtain coatings with both low porosity and oxide content. High-quality (low-porosity and low-oxide content) coatings are required to provide optimum protection against hot corrosion and oxidation as shown by Brandl et al. (2004).

Thermally sprayed MCrAlY coatings could be used as stand-alone overlay and as a bond-coat for thermal barrier coatings and are one of the most important protective coatings applied against hot corrosion and high temperature oxidation. For these industrial application and from the viewpoint of global environmental problems, the use of more efficient energy resources is required. Therefore, the development of high-quality MCrAlY coatings, especially with high coating/substrate adhesion, is needed as shown by Utu et al. (2005).

The bond coat is normally applied using air plasma spraying (APS), low pressure plasma spraying (LPPS), vacuum plasma spraying (VPS), more recently by high velocity oxygen fuel (HVOF). HVOF spraying has shown capability to make coatings of oxidation resistant alloys with a dense microstructure and relatively low oxygen content as shown by Shibata et al. (2006). In recently years, cold gas dynamic spray (CGDS) deposition of metallic bond coat has been studied. CGDS is an emerging thermal spray technique. The sprayed particles do not melt and impinge on the substrate at a high velocity. The big advantage of this method is that CGDS works in lower temperature than other thermal coating processes including HVOF method. CGDS is a high-rate deposition process that provides low-porosity and low-oxide content coatings as shown by Ichikawa et al. (2007).

The coatings also contain some porosity caused by low impact energy (unmelted particles), shadowing effects (unmelted particle/spray angle), shrinkage and stress effects. These all constitute drawbacks when the thermally sprayed coatings are used to prevent corrosion. The most efficient and reliable technique involves remelting of the sprayed coating by using an electron beam as shown by Petrov et al. (1997).

In the present work two techniques are combined to optimize bond coat properties before TBC application, CGDS and EB remelting. Comparison of selected properties for HVOF and CGDS CoNiCrAlY bond coat and Inconel substrate are presented and the effect of the EB remelting of the CoNiCrAlY coating manufactured by HVOF and CGDS deposition techniques is deeply investigated here.

2. Experimental

CoNiCrAlY coatings were deposited onto Ni-based alloy Inconel 718 using HVOF and CGDS-spraying techniques. The chemical composition of CoNiCrAlY powder is shown in Table 1. The coatings thickness in both cases (HVOF and CGDS) were about 70 μm .

Table 1. BC powder composition

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

The electron beam system used was K26 15-150 ProBeam facility. Maximum beam input power was 15 kW at 150 kV and 100 mA. The electron beam was oscillated/scanned with an amplitude of 7 mm onto the specimen surface. An incident electron beam was absorbed by the coating surface, and then the sprayed coating was remelted from its surface. The experiments were performed under four EB remelting conditions according to parameters shown in Table 2.

Table 2. EB remelting conditions used

Specimen	EB current	Processing speed
A	6.2 mA	20 mm/s
B	4.6 mA	20 mm/s
C	4.6 mA	15 mm/s
D	4.6 mA	10 mm/s

The CoNiCrAlY coatings have been subjected before and after electron beam remelting to morphology analysis using scanning electron microscopy (Carl Zeiss Ultra Plus) and energy dispersive X-ray analysis. A Philips X'Pert PRO diffractometer was used in order to identify microstructural phases.

3. Results and discussion

Fig. 1 shows images from SEM of the CoNiCrAlY coatings (cross-section) deposited onto Inconel 718 using the HVOF and CGDS spraying techniques. Before electron beam treatment the coating presents the lower porosity for the CGDS microstructure, lower roughness of the CGDS comparing to HVOF and locations with very poor bonding in large extent for HVOF comparing to CGDS method.

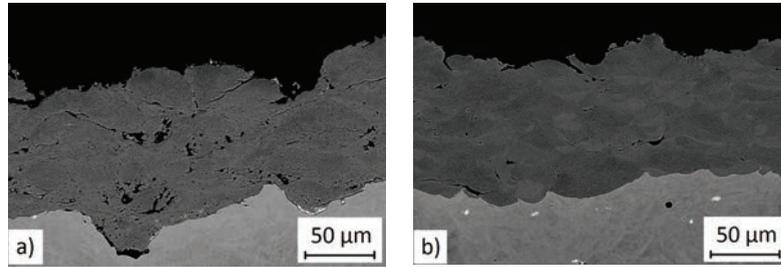


Fig. 1 Microstructure of CoNiCrAlY bond coat deposited by a) HVOF b) CGDS spraying technique

After the electron beam treatment, the CoNiCrAlY coatings present a rapidly solidified surface. Fig. 2-5 shows SEM micrographs of the cross section of the CoNiCrAlY coatings after the electron beam remelting (Table 2).

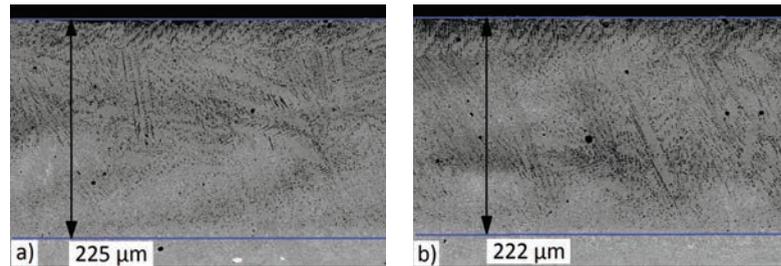


Fig. 2 Microstructure of Bond Coat (specimen "A") deposited by a) HVOF b) CGDS spraying technique and EB remelted

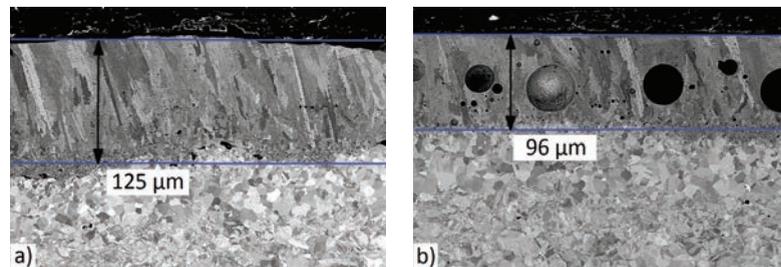


Fig. 3 Microstructure of Bond Coat (specimen "B") deposited by a) HVOF b) CGDS spraying technique and EB remelted

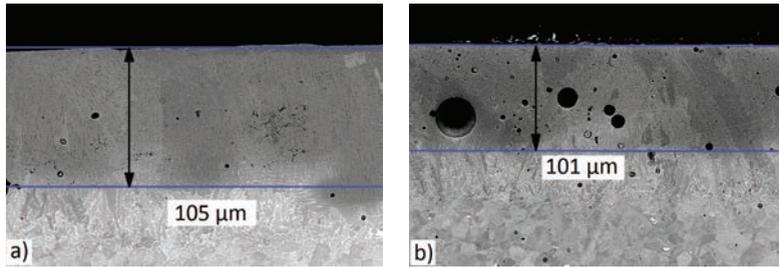


Fig. 4 Microstructure of Bond Coat (specimen “C”) deposited by a) HVOF b) CGDS spraying technique and EB remelted

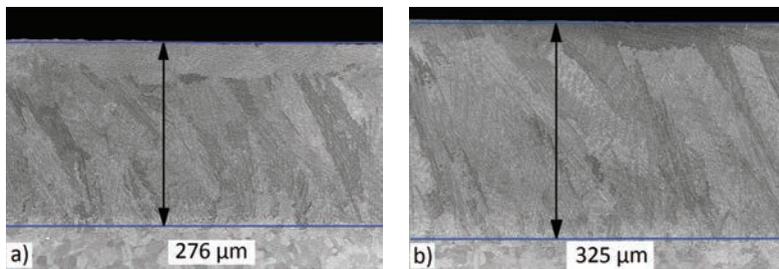


Fig. 5 Microstructure of Bond Coat (specimen “D”) deposited by a) HVOF b) CGDS spraying technique and EB remelted

Fig. 2 presents microstructures of bond coat deposited by both spraying methods after EB treatment (6.2 mA and 20 mm/s). The depth of remelting layer was (at both) about 200 μm, which was full remelting. There is not significant difference in microstructure between HVOF and CGDS method. The structure of remelting layer is characterized by long dendrites and absence of material in interdendrital space, which is not very good for TBC treatment.

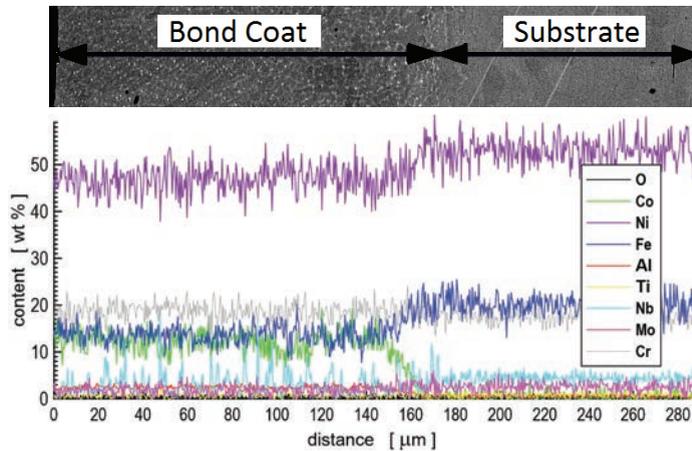


Fig. 6 SEM analysis of CoNiCrAlY powder deposited by HVOF techniques, very deep remelting about 300 μm (specimen “D”)

Bond coat microstructure after different EB remelting parameters can be seen in Figs. 2-5. The homogeneity of the structure is affected mainly by the processing speed. Comparison of the effect of different EB to specimen processing speed is obvious from Fig. 3-5, the EB current was the same (4.6 mA), whereas the processing speed varied from 20 mm/s (in Fig. 3) to 15 mm/s (Fig. 4) and 10 mm/s (Fig. 5). In Fig. 3 and 4 the depth of remelted

layer was about 100 μm . From Fig. 3 follows that there is a full BC remelting but very poor interface in both the HVOF and CGDS samples in addition to small pores observed in remelted BC layer (in the HVOF) and large ones (in CGDS). The similar situation occurred for treatment condition shown in Fig. 4. Here some defects and large pores (in CGDS) are still present comparing to small ones (in HVOF). In Fig. 5 is very deep remelting has been reached, there is no difference between BC and substrate, pores are fully absent. The depth of remelting layer is almost 300 μm (at both). The structure became finer, but full mixing of substrate with bond coat is observed.

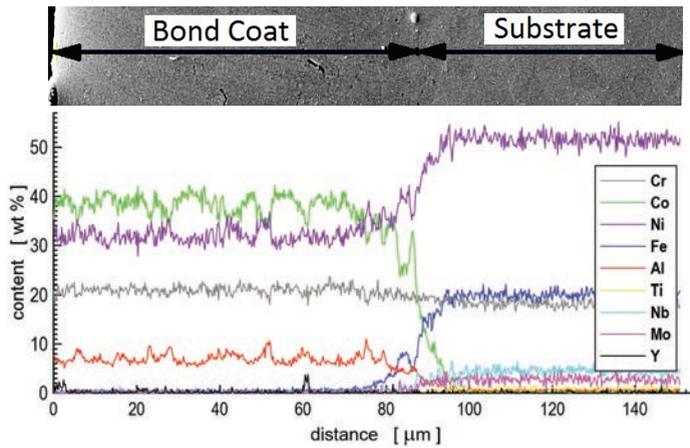


Fig. 7 SEM analysis of CoNiCrAlY powder deposited by HVOF techniques, EB remelting up to depth 100 μm (specimen "B")

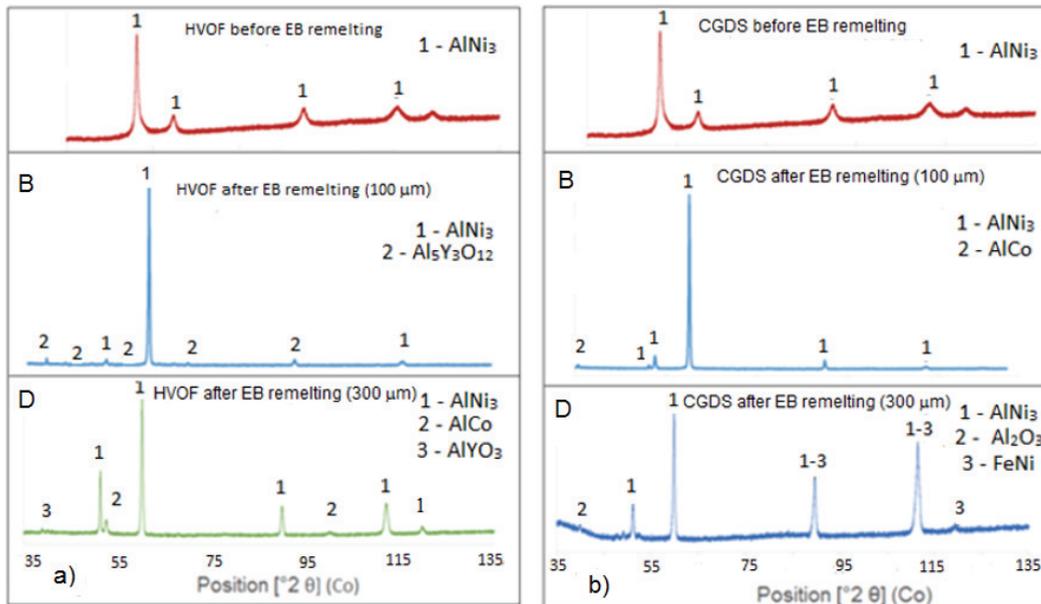


Fig. 8 X-ray diffraction patterns of the as-sprayed CoNiCrAlY coating a) HVOF b) CGDS – before EB remelting (as received), B. After EB remelting up to depth 100 μm , D. After EB remelting in very deep depth (about 300 μm)

From SEM analysis of chemical composition for very deep remelting (at both –HVOF and CGDS) it can be seen the same tendency, full mixing of substrate with bond coat. In comparing for electron beam remelting up to depth 100 μm , where was observed the difference of chemical composition between bond coat and substrate (Fig. 6, 7).

The XRD of the CoNiCrAlY-coatings before and after remelting (at both HVOF and CGDS) are presented in Fig. 8. The XRD-examination of the as-sprayed coatings showed peaks of the matrix γ -AlNi₃ phase. The remelted coating has a phase compositions similar to as-sprayed initial state (before EB remelting). In addition, some new phases identified as AlCo, AlYO₃, Al₅Y₃O₁₂ for HVOF method and AlCo, Al₂O₃, FeNi for CGDS bond coat preparation method appeared. During electron beam treatment the conditions (temperature and quenching velocity) for the crystallization of the aluminium oxide phase were reached, so the X-ray diffraction measurements detected this new phase appearance. This AlYO₃ is observed as droplets on the modified surface during solidification after electron beam remelting. These droplets consist mainly of aluminium with small yttrium-rich grains as shown by Utu et al. (2005).

4. Conclusions

The CoNiCrAlY bond coat prepared by cold gas dynamic spraying has been investigated comparing the phase and chemical composition the coating prepared by high velocity oxygen fuel technique. In addition the electron beam remelting of the thermal spray coatings has been carried out to study the effect of the remelting parameters on the resulting microstructures.

For the bond coat having thickness of about 70 μ m prepared by both HVOF and CGDS technique the lower porosity for the CGDS microstructure has been observed. The CoNiCrAlY bond coat to Inconel substrate interface displayed locations with very poor bonding, in larger extent for the states prepared by HVOF comparing to CGDS.

The bond coats (prepared by both procedures investigated) being EB remelted up to depth about 100 μ m and more are typical by removal of the initial defects and pores on the substrate to bond coat interface. The microstructure of the bond coat after this treatment is formed by Inconel fine grains being followed by the surface layer consisting of elongated dendritic microstructure of the remelted CoNiCrAlY compound. The longitudinal axis of dendrites has been oriented predominantly perpendicularly to the Inconel surface. However an increased porosity has been observed in interdendritical space near specimen surface, in addition large pores accompanied the treatment in larger extent for CGDS samples. The bond coats prepared by both ways being EB remelted into depth more than 100 μ m resulted into formation of only a few defects, complete mixing of substrate with bond coat was observed however.

The pulsed electron beam surface modification technique produced positive changes in the bond coat layer as a necessary step for the thermal barrier coating fabrication. In addition the EB treatment provided a smooth surface, low porosity level mainly on the interface between bond coat and substrate comparing to bond coat surface without this modification. The technology parameters window for successful application of the CGDS bond coat application and subsequent EB remelting has been shown to be relatively narrow.

Acknowledgements

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