Innovative solutions for roughness problems related to MCrAlY coatings manufacturing by HVOF I: Base Material/Bond Coat Interface

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Abstract

MCrAlY (where M is Ni, Co or NiCo) coatings are used as single overlay coating or as bond coat for thermal barrier coating (TBC) systems. Vacuum plasma spray (VPS) MCrAlY coatings are considered today to be a state of the art. Nevertheless, high velocity oxygen fuel (HVOF) sprayed MCrAlY coating is gaining in popularity due to its quality and cost effectiveness. On the other hand, HVOF process has some limits: It requires heavy sand blasting of the substrates to obtain an adequate base metal roughness for the good adhesion of the deposited MCrAlY coatings and this causes high interface pollution. Moreover, HVOF process allows to obtain relatively low surface roughness of the MCrAlY coatings, which leads to a poor adhesion of the ceramic yttria partially stabilized zirconia (YPSZ) top coat. Studies performed by the authors tried to resolve these two problems by providing an adequate pollution free interface between substrate and coating and a rough surface of the HVOF coating in order to be used as bond coat for overlaying TBC coating.

This paper is the first part of two and addresses the development of a surface preparation method, in order to obtain a completely pollution free surface of the substrate with an adequate roughness to be coated afterwards with HVOF. A new surface preparation process, named eXclen®, was set up and HVOF was used to apply MCrAlY coating on the prepared base material. Optical and electronic microscopies were used to evaluate the quality of the interface Base Material (BM)/Bond Coat (BC). It was possible to observe the absence not only of foreign entrapped particles, but also of any chemical contamination or alteration of both coating and substrate materials. The BM/BC interface quality and MCrAlY coating adhesion resulted to satisfy the Original Equipment Manufacturer (OEM) requirements.

Key words: MCrAlY, HVOF, thermal barrier coating, interface, sand blasting

1. Introduction

The development of more efficient gas turbines for aircraft propulsion and power generation has always been related to the results of research in the concurrent fields of design and materials technology. Increases in temperature and therefore in efficiency led to a wide use of thermal spray coatings in order to improve the surface characteristics of the structural superalloys.

Namely the systems called TBCs (Thermal Barrier Coatings) consist of air plasma sprayed top coat of (6–8 wt.%) Y_2O_3, partially stabilized ZrO_2 and MCrAlY bond coat (where M is Ni, Co or NiCo) deposited by different thermal spray processes.

Usually, the specifications of the main OEMs (original equipment manufacturers) require the deposition of MCrAlY alloys by low-pressure plasma spray (LPPS) or vacuum plasma spray (VPS). Other methods such as air plasma spray (APS) and high velocity oxygen fuel (HVOF) may be desirable due to their lower cost.

HVOF coating is today under evaluation as an alternative for the LPPS/VPS process. The HVOF pro-

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cess shows some advantages such as the lower cost for the installation and maintenance of the plants and the similar coating quality [1–3].

On the other hand, the state of the art, HVOF process, used for deposition of MCrAlY coatings, shows some disadvantages:

– a final coating richer in oxides in comparison with LPPS/VPS MCrAlY coating,

– the necessity of heavy sand blasting of the substrates to guarantee a good coating adhesion, but this leads to high pollution of the interface between coating and substrate [4–6],

– a relatively low surface roughness of MCrAlY coatings deposited by HVOF, which makes it difficult to be used as bond coat for TBC, therefore being of great limitation to the exploitation of HVOF as extensive MCrAlY deposition process [5, 6].

The developments performed by the authors were aimed to overcome these problems and are reported in two papers, of which this presented is the first part.

One of the main elements involved in the adhesion of the whole thermal barrier system is the surface preparation of the substrate. Usually a grit blasting process is used, which leads to a certain level of roughness required for a good adhesion of the sprayed MCrAlY coating. The necessity of good preparation and proper roughness of the surface to be coated, is very important for the adhesion of the as-sprayed coating before the diffusion heat treatment, when the adhesion is predominantly still mechanical. Moreover, the surface preparation has a different level of importance depending on which thermal spray process is used for the deposition, in particular HVOF or LPPS/VPS [4–6].

In fact, the different dynamics of the coating deposition involved in these processes are heavily influenced by the roughness requirements and consequently by the specifications of the grit blasting. Normally LPPS/VPS technology requires a lower degree of roughness of the substrate surface, this allows a more "gentle" grit blasting parameters and an abrasive media with smaller grain size [7].

This results in a lower amount of entrapped abrasive particles on the substrate, and consequently in a cleaner interface. Furthermore the components, before the application of the coating, are subjected to further cleaning process by means of transferred arc. The result of this procedure is that the level of contamination at the interface substrate/coating is quite low.

In the case of MCrAlY deposition by HVOF process the surface roughness required for good coating adhesion is higher than in the above considered case of LPPS/VPS deposition. In this case surface preparation parameters are more severe with a lower distance and coarser grain size, leading to a higher amount of entrapped particles and thus a higher amount of contamination [5, 6].

The most commonly used techniques for preparing the surface of blades and vanes for the coating applications by LPPS and HVOF, are the following:

– dry blasting by corundum (aluminium oxide Al_2O_3) or silicon carbide (SiC),

– wet blasting by corundum.

Corundum is commonly used as an abrasive material for blasting, with different grain sizes and different purity (from the chemical point of view). This material is generally allowed by all OEMs' specifications, which fix maximum limits to the interface contamination. High contamination of substrate/coatings interface due to presence of corundum is dangerous because it could constitute a "barrier" to the adhesion as well as to the diffusion of the coatings elements in the substrates and vice versa. The use of SiC as an abrasive is allowed only by some OEMs (in some cases SiC is permitted for HVOF coating preparation but not for VPS/LPPS, the contrary in other cases). The concern relating to the use of SiC is related with the possible damage to the base material and to the coating, caused by the combination of silicon and carbon with oxygen as well as with other elements present both in the base materials and in the coating. On the other hand, SiC allows to get a "near to zero" contaminated coating/substrate interface because eventually entrapped particles dissolve during diffusion heat treatment. Several industries have adopted this solution, "downplaying" estimations of the damage that SiC could cause with respect to the ones that a big presence of corundum could cause.

This paper presents the finalization of a project aimed to develop a surface preparation process, which would achieve a completely clean base material/bond coat interface due to the use of the abrasive [8]. In particular the tuning of the process and the extension of the process from a "lab" scale to the industrial scale is presented. Finally a pilot lot of turbine blades were prepared with the developed surface preparation and coated by HVOF process.

2. Experimental

Starting from the results of previous tests [8], the new preparation process uses a different abrasive material than corundum or SiC with a following washing phase, and resulted in a surface, which is able to "host" the HVOF or LPPS MCrAlY coatings, without the presence of entrapped abrasive particles. The new identified abrasive material was used for testing in order to understand his abrasive effect. The resultant surface morphology and the "usability" at an industrial level was assessed. For the development phase, a suction sandblasting machine was used, the same as used for usual grit blasting with corundum or SiC in normal production components. The Inconel 738 LC substrates used for the samples were obtained from commercial turbine components. The following variables were changed during the development phase: abrasive grain size, process parameter (pressure, distance), washing procedure. The samples obtained were analysed by Mitutoyo SJ-301 profilometer with cutoff $\lambda_c = 0.8$ mm (measurement length 4 mm), collecting the roughness values in terms of the abrasive and grit blasting parameters used.

ESEM QUANTA 200 FEI Scanning Electron Microscope and EDS (Energy Dispersion System) EDAX – ZAF Quantification (Standardless) were used with the aim to evaluate the efficacy of different washing procedures by investigating the presence of contaminating elements extraneous to the nominal base material composition. This screening phase allowed identification of the correct combination of "abrasive specifications-grit blasting parameters-washing procedure" in order to get a complete surface preparation procedure which could minimize the interface contamination. The developed parameters were used for the preparation of samples to be coated with MCrAlY by means of a Praxair JP5000 HVOF torch. The samples obtained were cross-sectioned, and metallographic analysis was performed at the coating/substrate interface, by means of both optical and SEM microscopes.

The further step was the use of the developed preparation process on a real component (stage 2 single vane), in order to verify on a complex geometry the results obtained on flat samples. The following phases followed:

– Surface preparation,
– MCrAlY coating deposition by HVOF,
– Diffusion heat treatment.

The coated component was sectioned and metallographically analysed by means of optical and SEM microscopy. Furthermore the developed preparation process was applied to a pilot lot of stage 2 blades, in order to verify its repeatability; the following phases followed:

– Surface preparations,
– MCrAlY coating deposition by HVOF,
– Diffusion heat treatment,
– Surface finishing by peening (this constitutes a good test of the coating adhesion) [9],
– Verification of the coating adhesion by means of qualitative thermography [10].

3. Surface preparation process results

3.1. Analysis of treated surface

After a first development phase [8] when several parameters were changed, a combination of "abrasive specifications-grit blasting parameters-washing procedure" was chosen and applied to Inconel 738 LC flat substrates. The average roughness values obtained by means of the new preparation method are shown in Table 1 and it met the standard for good adhesion based on the grit blasted samples surface roughness [4–7].

It is possible to verify by SEM analysis, the absence on the surface of elements extraneous to the nominal composition of the base material (as shown in Fig. 1 and Table 2).

Table 1. Average roughness values of treated surface with different grit blasting sets

Roughness of Inconel 738LC alloy surface after eXclean process $\lambda_c = 0.8$ mm					
Ra/σ (μm)		Rz/σ (μm)		Rq/σ (μm)	
3.77	0.32	22.43	1.51	4.73	0.36

Table 2. Measured mean composition of the base material surface after eXclean surface preparation (A). For comparison, the nominal composition of the Inconel 738 LC substrate is also reported as provided by the purchaser (B)

Element	(A) Measured mean composition (wt.%)	(B) Inconel 738 LC Nominal composition (wt.%)
Cr	16.6	15.6–16.4
Ni	62.6	bal
Co	8.6	8.1–9.1
Al	3.3	3.1–3.8
Ti	3.2	3.1–3.6
Mo	1.5	1.4–2.0
Ta	3.3	1.4–2.0
W	Present, but not quantifiable	2.3–2.8
Nb	0.8	0.7–1.2

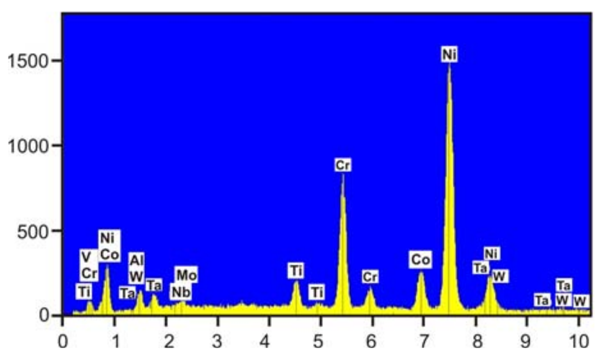

Fig. 1. EDS spectrum of the surface treated with new surface preparation.

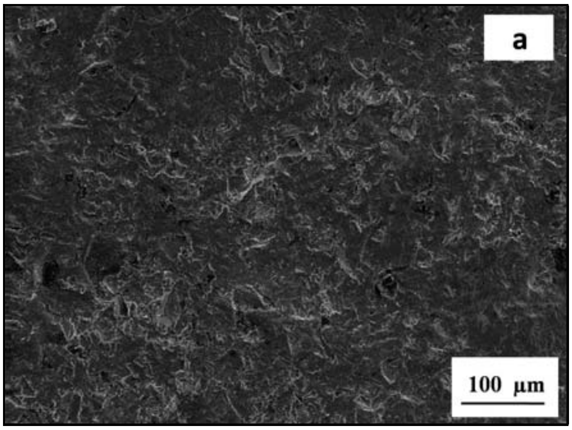

Fig. 2a. SEM image of the treated surface with new preparation technique. Non-entrapped particles are revealed.

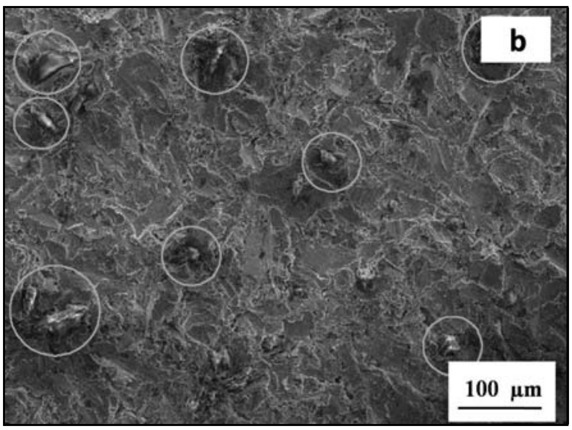

Fig. 2b. SEM image of the treated surface with corundum 24 mesh. Circles in light grey indicate the entrapped particles.

From the results of microscopies, optical and SEM, it was observed that there were no abrasive media embedded into the treated surface. This allows the use of "more forceful" parameters, achieving higher surface roughness. A comparison between the developed preparation process and a standard preparation by blasting with 24 mesh corundum (the same happens with SiC), is shown in Figs. 2a,b.

No embedded abrasive particles are present on the surface prepared with the new technique (Fig. 2a). On the other hand, embedded particles could be well detected on the surface prepared with corundum (Fig. 2b).

The absence of entrapped particles shows that the new preparation process has very low sensitivity to the "human factor", whereas with Al_2O_3 and SiC blasting the operator must stay under a certain angle of incidence, otherwise the amount of entrapped particles becomes unacceptable.

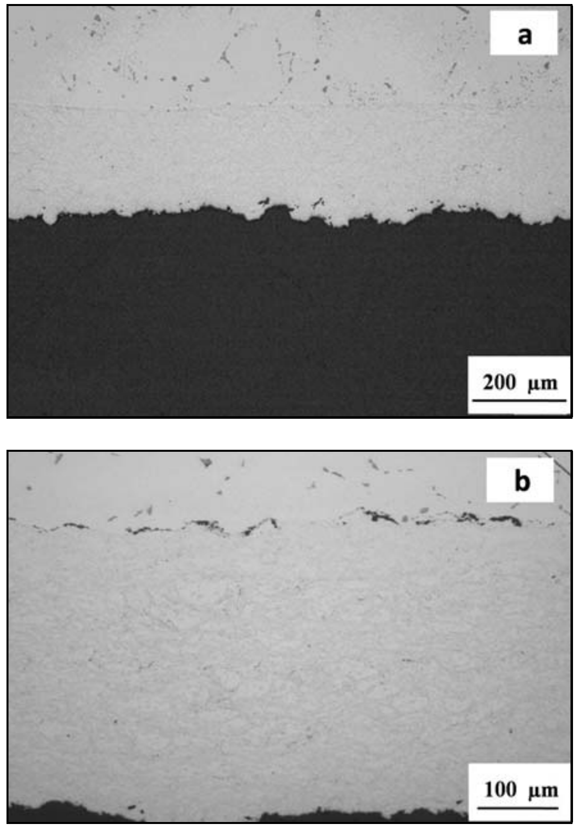

Fig. 3. Micrograph of the interface coating/substrate with: (a) new preparation, (b) standard preparation.

3.2. Analysis of coated samples

By using the developed preparation process, some Inconel 738 LC samples were prepared and then coated by HVOF. Optical micrographs of sections were taken after surface preparation, coating deposition and heat treatment. They show a clean coating/substrate interface, with total absence of extraneous elements, confirming the expectations coming by the first characterization of the treated surface (Fig. 3a).

The improvements shown by this process are evident, comparing samples prepared by the new method to those following the standard corundum grit blasted procedure. In the first case the interface does not have any interruption between coating and substrate, whereas in the second case, the interface is delineated by the presence of entrapped corundum on the substrate surface (Figs. 3a,b).

SEM/EDS analyses were performed on the coated flat samples confirming the results previously obtained by the observation of the just prepared and not coated surfaces (as shown in Figs. 4a,b): the total absence of any element extraneous to the coating or base material composition. These results are similar to the ones obtained by SiC preparation at a simple visual ob-

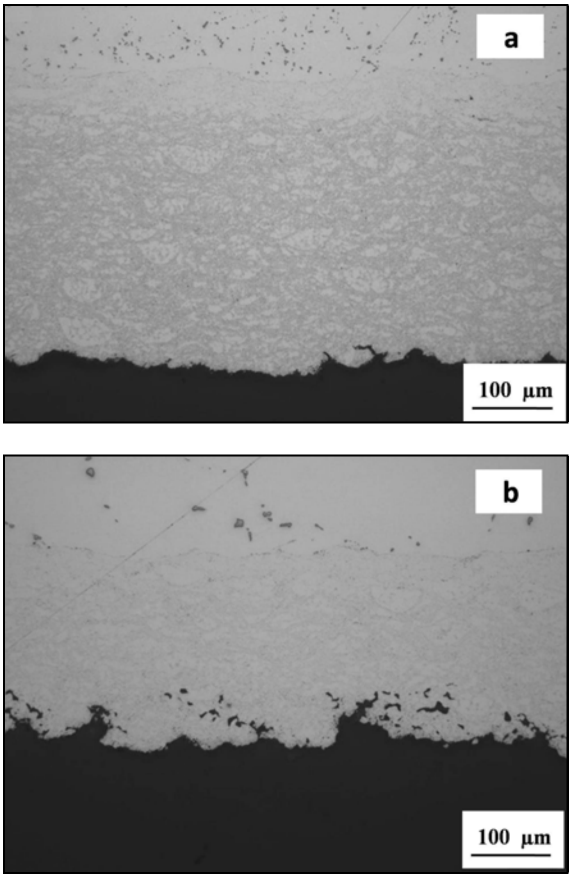

Fig. 4a,b. Micrograph of the section of the first industrial component with new surface preparation (middle aerofoil, trailing edge pressure site).

servation, but with chemical composition analysis, in the object case, no extraneous elements are detected, whereas in the case of SiC preparation trace of Si could be found [7].

3.3. Application of the new process on industrial components

The developed surface preparation process was applied to an industrial component (stage 2 vane). The coated and diffused component was submitted to qualitative thermography in order to investigate eventual points of detachment of the coating, and furthermore metallographic characterization was carried out. The presence of eventual coating adhesion failure by means of qualitative thermography did not show any detached points. Metallographic analysis carried out by optical microscopy confirmed the results obtained on the coated flat samples. An absolute absence of any traces of contamination in the interface can be noted as shown in Fig. 4. This was the application of the new process on the first industrial component.

An excellent result was also obtained at the fillet between platform and aerofoil, one of the most critical points of the turbine blades coated with HVOF, where very good adhesion of the coating to the surface was observed, as shown in Fig. 5.

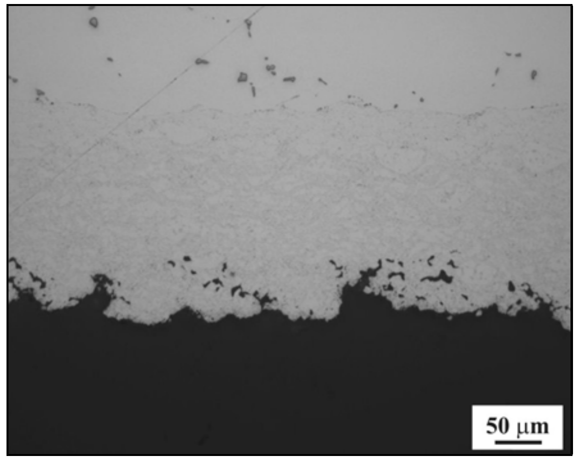

Fig. 5. Micrograph of the section of the first industrial component with new surface preparation (radius at pressure site).

Further process validation has been carried out by applying the new surface preparation process to a pilot lot of stage 2 blades coated by HVOF. These components underwent heat treatments for diffusion and ageing and at the end to a shot-peening surface finishing. This last process heavily stresses the coating that, if not perfectly adhered, could detach. In all the cases good adhesion of the coating was observed.

4. Conclusion

The study presented in this paper addressed the development of a new surface preparation process and of an HVOF process in order to deposit MCrAlY coating to be used as single overlay coating or as bond coat for thermal barrier coating systems.

The new surface preparation process (definition of abrasive materials and application procedures) was able to provide a base material/bond coat interface absolutely free of the contamination due to entrapment of abrasive particles. This is particularly important for HVOF coating processes, where state of the art blasting with corundum results in very high contamination. Furthermore the new method overcomes the concerns relating to the use of SiC and Al_2O_3 abrasive media.

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