

COMPARISON OF CoNiCrAlY COATINGS PRODUCED BY HVOF AND CGDS-SPRAYING TECHNIQUE

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Abstract

CoNiCrAlY bond coats manufactured by the high-velocity oxygen-fuel spraying (HVOF) and cold gas dynamic spraying (CGDS) deposition technique have been investigated and comparison of phase modification is presented in the paper. Even though both techniques accelerate powder particles with high kinetic energy, the resulting coatings differ considerably in their microstructures. In the former, high pressure is created by burning gases such as acetylene, propane or kerosene at high pressure and generating high temperature (3500 to 4500 °C) in the gun. This gives high acceleration to powder particles which melt and deposit on substrate layer by layer with splat cool mechanism. On the other hand, large kinetic energy is generated in cold spray by passing carrier gases such as He or N₂ through converging-diverging nozzle, with lower gun temperature of around 600 °C. Here the particles are not liquid droplets because of lower temperature and the deposition mechanism is not a splat cooling, but a high impact of solid particles, which results in plastic deformation, making very adherent coating. In this work, CoNiCrAlY powder was deposited on Inconel 718 substrate using HVOF and CGDS deposition process. The bond coats microstructural features were characterized by means of SEM and XRD analyses. The experimental results demonstrated that the CoNiCrAlY bond coats prepared by both HVOF and CGDS technique displayed the lower porosity for CGDS microstructure, and therefore CGDS represents an interesting and promising alternative for their manufacturing.

Keywords: TBC, Bond coat, CoNiCrAlY coatings, cold spray, HVOF spraying

1. INTRODUCTION

Thermally sprayed coatings have been widely applied in industrial components in several industries in a wide range of functionalities and engineering designs. One of the most important and widely used applications of thermal spray coatings is their use as thermal barrier coating (TBC) [1-4]. Thermal barrier coatings consist typically of metallic bond coat and ceramic top coat normally applied onto superalloy substrate. Two general methods used for applying the ceramic layer are electron beam assisted physical vapor deposition (EB-PVD) and air plasma spraying (APS). The metallic bond coat is normally applied using air plasma spraying (APS), low pressure plasma spraying (LPPS) or vacuum plasma spraying (VPS). More recently high velocity oxygen fuel (HVOF) technique has been used in order to produce denser bond coats. The predominant drawback to these techniques is that their inherent high temperatures inevitably lead to changes in the coating microstructure, namely oxide inclusions [5]. In HVOF spraying technique, a powder material is melted and propelled at high velocity towards a surface. The HVOF process uses extremely high kinetic energy and controlled thermal energy output to produce low-porosity coatings with high bond strength, fine as-sprayed surface finishes [6]. Cold gas dynamic spraying (CGDS) uses kinetic energy rather than thermal energy to produce coatings. In this process, fine powder particles are accelerated in a supersonic flow and undergo severe plastic deformation upon impacting the substrate to form a coating. This technique has been used to produce coatings from various materials with different types of microstructure including conventional, nanocrystalline, amorphous and metastable structures [7]. CGDS operates at significantly lower temperatures than thermal spray processes and consequently its coatings exhibit no grain growth. In addition, it uses inert gases which hinder in-process particle surface oxidation. These advantages make CGDS an interesting alternative for the deposition of bond coats [8-9]. The present study investigates and compares two techniques

of coating deposition -HVOF and CGDS-spraying methods. CoNiCrAlY coating have been manufactured by CGDS to verify their feasibility and investigate whether microstructural and chemical changes occurred throughout the deposition process.

2. EXPERIMENTAL

Ni-based Inconel 718 alloy was used as a substrate materials, with the nominal composition shown in **Table 1**. The powder feedstock material used in this study is a commercially available CoNiCrAlY alloy with a nominal composition shown in **Table 2**. This gas atomized powder has spherical morphology. Typical images of the morphology of the CoNiCrAlY powder can be observed in **Fig. 1**.

Table 1 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

Table 2 Chemical composition of CoNiCrAlY powder

Element	Co	Ni	Cr	Al	Y	C	O
Wt %	38.98	31.75	20.77	7.86	0.5	0.009	0.05

CoNiCrAlY coatings were deposited onto Inconel substrates by two kinds of technique: HVOF and CGDS-spraying techniques. The coatings thickness in both cases (HVOF and CGDS) were about 70 μm . The CGDS coating was manufactured using the cold spray system model PCS-1000 (Plasma Giken, Co., Ltd., Japan). For the present study, helium was used as the main propellant gas with a nozzle inlet gas temperature and pressure of 600 $^{\circ}\text{C}$ and 2.0 MPa respectively. In comparison, current commercial CGDS systems can operative with helium at temperatures and pressures of up to 800 $^{\circ}\text{C}$ and 4.0 MPa respectively [10]. This suggests that the CGDS process has not been stretched to its limit in the present study and that further coating optimization is therefore possible. The bond coat was produced by using an HVOF spraying system Model K2/JP 5000 (Plasma Metal s.r.o., CZE) using oxygen as carrier gas with gas pressure and flow of 1.5 MPa and 920 l/min. respectively. The spray distance was 360 mm. the coatings after deposition have been subjected to morphology analysis using scanning electron microscopy (Carl Zeiss Ultra Plus) and energy dispersive X-ray analysis using a Philips X'PERT PRO diffractometer using filtered Co K α radiation ($\lambda = 1.790307 \text{ \AA}$). The porosity (at both cases HVOF and CGDS) was estimated using image analysis by software "ImageJ".

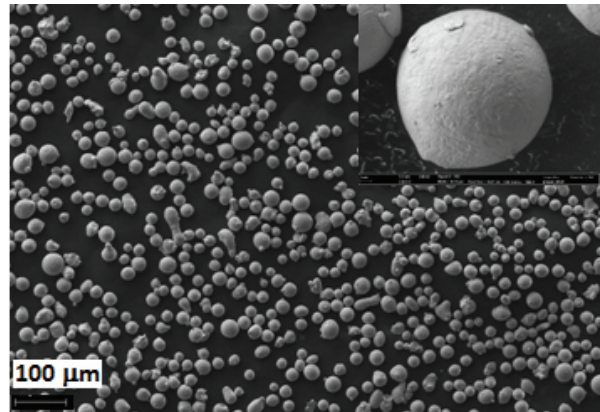


Fig. 1 Microstructure of CoNiCrAlY powder

3. RESULTS AND DISCUSSION

3.1. Surface analysis

Figs. 2-3 show SEM images of the as-deposited CoNiCrAlY coatings manufactured by HVOF and CGDS methods. The coating presents the lower porosity for the CGDS microstructure, lower roughness of the CGDS comparing to HVOF and location with very poor bonding in large extent for HVOF comparing to CGDS method.

The coating porosity analysis for each deposition are summarized in **Table 3**. The HVOF coating (**Fig. 2**) exhibits limited porosity and crack content. Porosity measurements for the HVOF coating resulted in an average porosity of $4.25 \pm 0.7\%$. The pores found within the HVOF coating are typically small in size with an average equivalent diameter of about $1.5 \mu\text{m}$. This is attributed to insufficient localized plastic deformation of impinging particles upon impact, thus resulting in the formation of small voids between two adjacent particles. Conversely, the limited porosity, large coating build-up thickness achieved and absence of cracks within the coating structure demonstrate that most impinging particles have sufficient kinetic energy to achieve adequate plastic deformation. Coatings deposited by CGDS (**Fig. 3**) feature the most desirable structure with minimal porosity, absence of crack and a clean interface with the substrate. These coatings revealed an average porosity of $0.7 \pm 0.5\%$, which is significantly lower in comparison with its HVOF counterpart. The pores within the CGDS coating are finer than those found in the HVOF coating, thus demonstrating a better compaction effect of the deposited particles during the spraying.

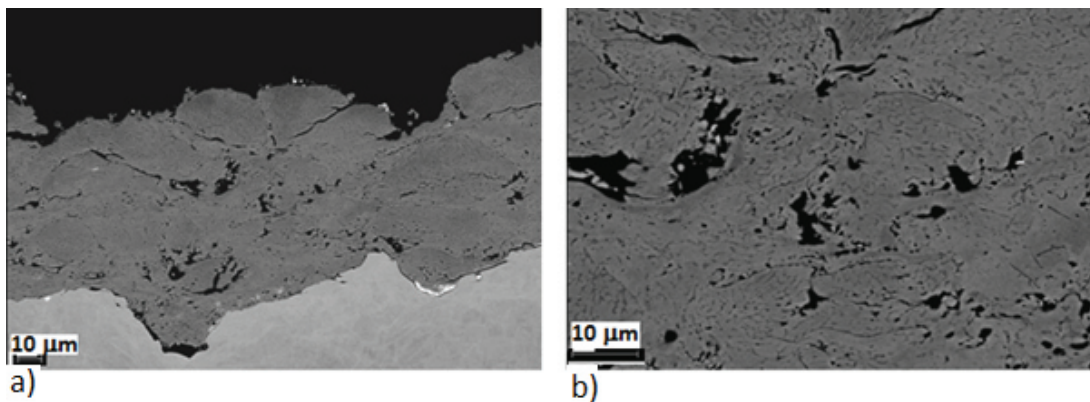


Fig. 2 Microstructure of CoNiCrAlY powder deposited by HVOF spraying technique

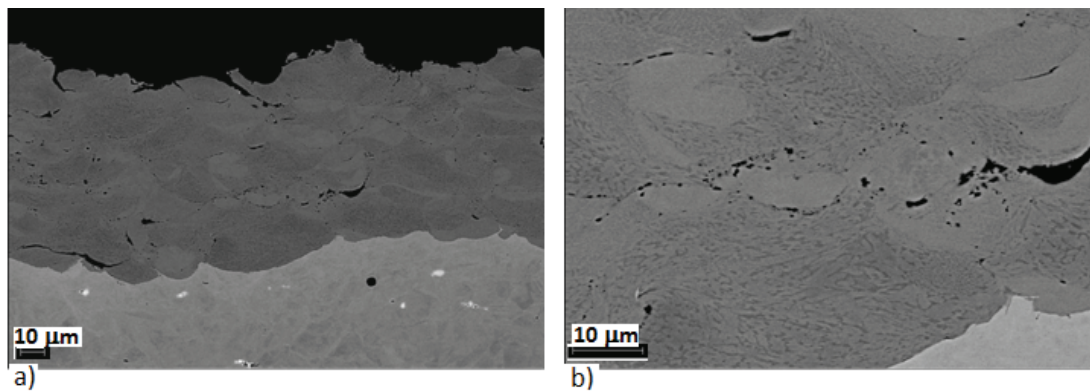


Fig. 3 Microstructure of CoNiCrAlY powder deposited by CGDS spraying technique

Table 3 As-deposited coating porosity

Material	Coating porosity (%)
HVOF coating	4.25 ± 0.7
CGDS coating	0.7 ± 0.5

3.2. XRD patterns of the CoNiCrAlY coatings

Fig. 4 presents the XRD patterns of the CoNiCrAlY coatings at both HVOF and CGDS spraying techniques.

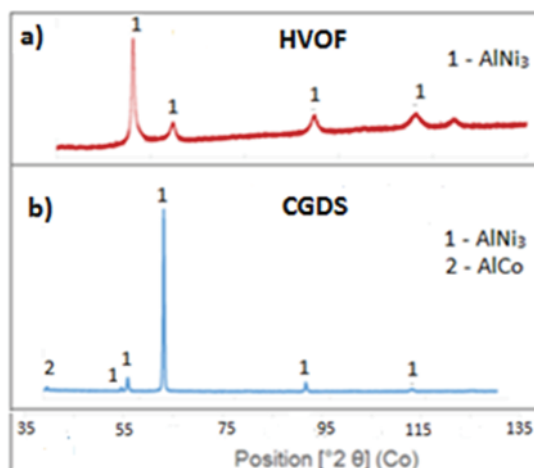


Fig. 4 X-ray diffraction patterns of as-sprayed CoNiCrAlY coatings a) HVOF b) CGDS

The XRD-examination of the as-sprayed coatings showed signals of the matrix γ/γ' -AlNi₃ phase (at both HVOF and CGDS) and at CGDS also β -phase AlCo. The absence of β -phase in HVOF as-sprayed coating confirms the transformation of microstructure during deposition, as reported by Richter et.al. [10]. According to them, this might be due to the dissolution of the β -phase into the γ - matrix due to severe plastic deformation of the particles upon impact. The large deformation of the particles upon impact led to a change in the lattice structure of the β -phase crystal lattice, thereby causing the β -phase to adopt a similar crystal structure to that of the γ - matrix [8].

4. CONCLUSION

Based on the results obtained in this study, the following conclusions can be made: CoNiCrAlY coatings were successfully deposited by HVOF and CGDS. The bond coat having thickness of about 70 μm prepared by both HVOF and CGDS technique displayed the lower porosity for the CGDS microstructure. The CoNiCrAlY bond coat to Inconel substrate interface displayed locations with very poor bonding, in large extent for the states prepared by HVOF comparing to CGDS. This work therefore confirm the use of improvements of the bond coat deposition process when applying low-temperature processing methods such as CGDS and therefore CGDS represents an interesting and promising alternative for their manufacturing.

ACKNOWLEDGEMENTS

The work have been supported by the financial support from the Operational Programme Education for Competitiveness No. CZ.1.07./2.3.00/30.0005 and within the project NETME plus centre (Lo1202), project of Ministry of Education, Youth and Sports under the “national sustainability programme”. Support of Czech Science Foundation project GACR 13/35890S is further acknowledged.

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