

A Comparative Study of Wear Effect on the Microstructures Behavior of CoNiCrAlY Coatings fabricated by APS, HVOF and CGDS Coatings

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Abstract

This work focuses on the micro-abrasion wear and microstructural properties of CoNiCrAlY coatings fabricated on nickel based super alloy substrates by using the atmospheric plasma spraying (APS), high-velocity oxygen fuel (HVOF), cold gas dynamic spraying (CGDS) methods. Tribological tests were performed on the samples in order to understand the wear mechanism of thermally sprayed coatings and influence of the coating microstructure on wear mechanism. The microstructures of as sprayed and worn coatings were investigated by scanning electron microscopy. Initial surface topography was examined by surface profilometer. Coating hardness measurements were performed with a micro-hardness tester. The micro-abrasion tests were carried out with some different durations. The lateral fracture was observed as wear mechanism on the specimens. The wear surface resistance have changed with coating process and surface features of specimens depending on the coating process.

Keywords: Wear, CoNiCrAlY, CGDS, HVOF, APS, Surface roughness, Bond coat

1. Introduction

Coating methods are generally used to improve the performance of industrial parts. There are different coating methods according to the application. There are many different types ranging from hard, high wear resistance coatings to soft lubricating coatings or applications where low wear ratio is needed [1]. Thermal spray coating method has long been used in aviation industry to produce coating that can resist erosion and wearing [2]. Powders with 10-100 μm dimension have been applied to, by widely studying, metallic and ceramic materials to create a more wear resisting surface layers [3]. While choosing the metallic abrasable material that will be used in high temperature applications, coatings need to have high oxidation and erosion resistance in service temperatures during use [4]. One of the most important coating structures to protect turbine seal applications, blades, duct segments, turbine sections of aircraft jet engines and such materials from high temperature oxidation, heat corrosion and erosion damages is the MCrAlY material [5-6]. Bond coatings that are used on substrate material are typically produced with APS, LPPS, VPS and HVOF methods [7-8]. One of the biggest disadvantages of usage area in application is that high temperature that takes place in production of methods cause oxide inclusions in coating microstructure and crack-like formations [7]. Coatings with superior properties with regard to dense coating structure and mechanical properties and that has no oxide index can be produced when plastic deformation dependant production is performed instead of heat effect's being an active parameter in coating production with the use of the method that is called CGDS and has been used in bond coating production in recent years [9]. CGDS coating method works in lower temperatures than other thermal coating processes, produces coating depending on the high kinetic energy and plastic deformation that happens later on [10]. In the method, powder particles are accelerated and are undergone plastic deformation on substrate with supersonic flow speed and as a result coating is produced [7]. Ball crater micro abrasion test, also known as micro abrasion test method, is a method that is used to identify the abrasive wear resistance of coating and materials. The method is based on the application of wear process and rotation of a spherical ball with its own weight on the specimen in the presence of an abrasive. Wear volume can be identified with optical or profilometric methods [11-13]. In this study, CoNiCrAlY powders were deposited onto Inconel 600 substrates by APS, HVOF and CGDS methods. Wear performance of the MCrAlY coatings has been investigated. Coatings with CoNiCrAlY that are produced with CGDS method show more superior wear performance than coatings produced with other methods after the tests.

2. Experimental

2.1 Material and methods

The samples consisted of a CoNiCrAlY bond coat (BC) and CoNiCrAlY powder with a particle size range of 5-37 μm was used as starting materials. The substrates, Inconel 600 Nickel based super alloy coupons in the form of 25x25x3.5 mm, were grit blasted to clean and roughen the surface to increase the resulting coating adherence. After grit blasting the samples were cleaned ultrasonically in ethanol. In this study, APS, HVOF and CGDS techniques were used to produce CoNiCrAlY coating layers. The used spraying systems were a GTV K2 HVOF system, a Plasma Giken CGDS system and a GTV F6 APS system. All powders were standard thermal spray powders and delivered by Sulzer Metco. All spraying parameters are shown in the Table 1. The thicknesses of the CoNiCrAlY coating layers were about 100-140 μm .

Table 1. APS, HVOF, CGDS spray parameters for bond coats powder deposition

APS CoNiCrAlY Bond Coatings			
Arc Current	Electrical power	Argon flow rate	
600 A	40 kW	65 slpm	
Hydrogen flow rate	Powder feed rate	Stand-off distance	
14 slpm	30 g/min	140 mm	
HVOF CoNiCrAlY Bond Coatings			
Combustion medium		Powder Carrier Gas	Powder Feed Rate
O ₂ (880 slpm) and kerosene (25 l/h)		Argon (15 slpm)	50g/min
Powder feed gas flow		Stand-off distance	
12 slpm		330 mm	
CGDS CoNiCrAlY Bond Coatings			
Spray Pressure	Gas Temperature	Working gas	
3 Mpa / 30 bar	600 °C	Nitrogen (1000 slpm)	
Gun speed rate	Stand-off distance		
20 mm/sn	15 mm		

After grit blasting, average surface roughness values were obtained through measurements that are carried out at different points on each specimen ranging between 5 and 10 points in accordance with the standard of DIN EN ISO 3274 norm on surface roughness measurement values of substrate, bond and top coating. Micro-hardness measurement of coatings has been carried out with Duramin brand test devices in accordance with DIN EN ISO 4516 norm. Measurements have been carried out under 100 g weight for 15 seconds with Vickers indenter tip. Ball rotating micro-abrasion experiments were conducted with one ball made of AISI 52100 steel (nominal chemical composition of 1.04 wt.% C, 0.35wt.% Mn, 0.25 wt.% Si, 1.45 wt.% Cr, bal. Fe), which presented a diameter (D) of 25.4mm (1 inch). The abrasive used was black silicon carbide (SiC) with average particle size of 5-10 μm . The abrasive slurry was prepared as a mixture of 25% of SiC and 75% of distilled water, in volume. Conventional characterization techniques, such as scanning electron microscopy (SEM), microhardness, and profilometer analyses were employed to study the microstructure of the abraded and coating zone. Micro abrasion test parameters are given in Table 2.

Table 2. Micro abrasion test parameters for whole coating systems

Coating Methods	APS, HVOF and CGDS techniques		
Test condition for CoNiCrAlY coatings	1	2	3
Test time (min)	3	5	7
Sliding distance (m)	36.72	61.2	85.68
Shaft rotational speed (rpm)	160	160	160
Ball rotational speed (rpm)	102,5	102,5	102,5
Ball tangential sliding velocity (m/s)	0,136	0,136	0,136
Drop time (s)	20	20	20
Repetitions	3	3	3

3. Results and Discussions

3.1 Characterizations of the coatings

When the microstructure properties are analysed after coating production, APS bond coatings are seen to have oxide content and discontinuities crack-like gaps and low amount of unmelted particle structure because of process production. HVOF bond coatings have low porosity content in local areas as well as having a dense coating structure. In CGDS bond coatings, this situation has dense coating structure and local porosity content because the coating method is based on plastic deformation. Surface roughness measurements are applied as after grit blasting, after bond coating and after top coating of the specimen. Surface roughness measurement of the grit-blasted substrate as well as all as-sprayed coatings are summarized in Table 3.

Table 3. Average surface roughness values of the substrate and the as-sprayed coatings

Materials	R_a (μm)	Materials	R_a (μm)	Materials	R_a (μm)
Inconel 600 blasted)	(grit- 4.34	Inconel 600 blasted)	(grit- 4.80	Inconel 600 (grit-blasted)	4.93
APS-BC	5.27	HVOF-BC	5.56	CGDS-BC	6.75

The microhardness values of coatings are shown in Table 4.

Table 4. Microhardness average values of TBCs

Coating abbreviation	Microhardness (Hv)
APS - CoNiCrAlY	340 \pm 25
HVOF - CoNiCrAlY	440 \pm 30
CGDS - CoNiCrAlY	490 \pm 50

4. Wear Results

Figure 1 shows the volume loss at coating layer volume that are produced with 3 different surface coating method depending on the sliding distances of the ball. As it can be seen in surface profilometers, materials whose surface has been coated with CGDS method show the lowest wear crater depth at the end of micro abrasion test that is performed at 160 rpm for 7 minutes, and specimen that are coated with HVOF and APS method follow it respectively. The reason for this can be associated with the hardness of the specimen. Because specimen coated with CGDS method show the highest surface hardness among the specimen and specimen coated with HVOF and APS method follow it respectively (Table 4). When the roughness values of the specimens are studied, it is seen that CGDS has the highest roughness value and HVOF and APS follow it respectively. Although CGDS that has high roughness value in initial time wear has high volume loss, the layers wear resistance increased when the hard and brittle rough is cleaned. It is possible to say this also for the other specimen. When evaluated as coating methods, coatings produced with HVOF and APS methods follow CGDS coatings respectively. As mentioned in micro-structure properties, this situation is closely associated with coating production methods.

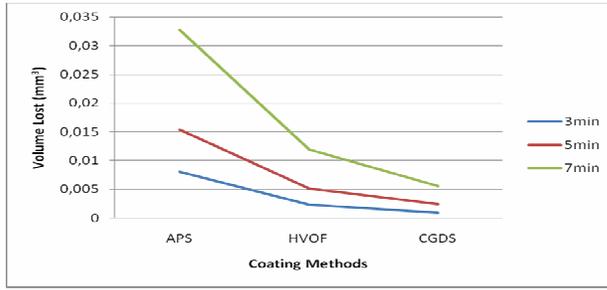


Figure 1. Volume losses as a result of erosion according to coating method

Typical surface profiles of the substrate and coatings wear tested against both types of balls are presented in Fig. 2-4.

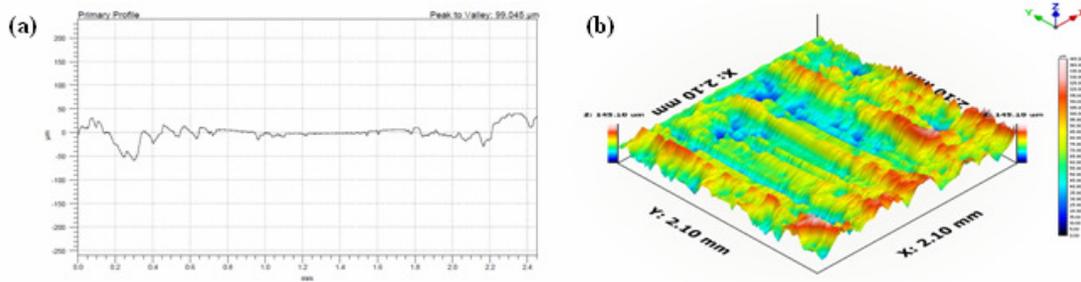


Figure 2. Surface profile of CoNiCrAlY coatings produced by CGDS wear tested against (a) substrate, and (b) surface topography of the worn coating

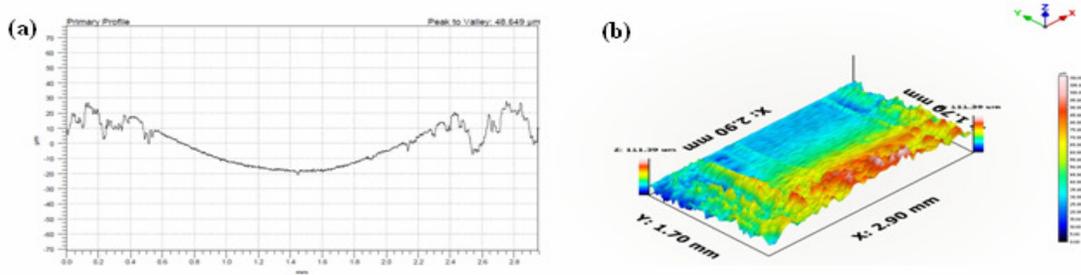


Figure 3. Surface profile of CoNiCrAlY coatings produced by APS wear tested against (a) substrate, and (b) surface topography of the worn coating

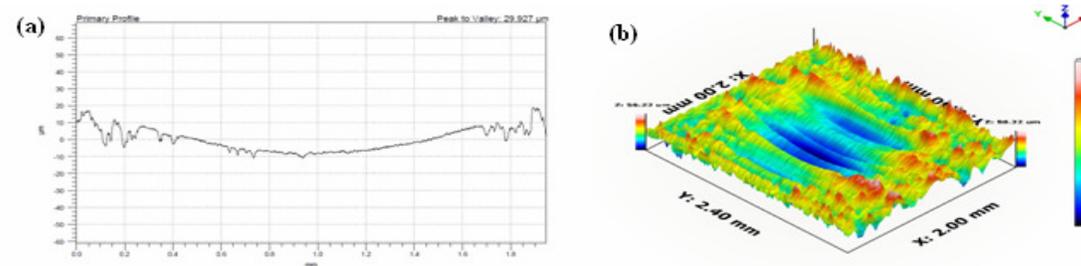


Figure 4. Surface profile of CoNiCrAlY coatings produced by HVOF wear tested against (a) substrate, and (b) surface topography of the worn coating

Micro abrasion SEM wear surface picture of the specimen are shown in Fig. 5 (a-c) respectively. Lateral fracture type abrasion is seen as wear mechanism. There is no important difference between wear mechanisms of specimens.

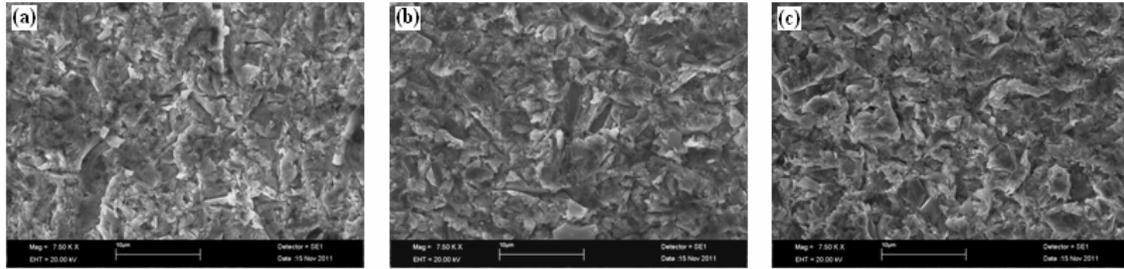


Figure 5. SEM micrograph of the wear track on the CoNiCrAlY coatings; (a) APS- CoNiCrAlY coatings, (b) HVOF- CoNiCrAlY coatings, (c) CGDS- CoNiCrAlY coatings

4. Conclusions

This study has investigated the wear performance and microstructural characterization of CoNiCrAlY bond coatings that were produced by APS, HVOF and CGDS, respectively.

The major results are summarized as follows:

- 1) Specimen produced with CGDS method show the highest surface hardness among the specimen and specimen produced with HVOF and APS method follow it respectively.
- 2) The highest roughness value is seen at the coating specimen produced with CGDS method and coating specimens produced with HVOF and APS methods follow it respectively. When the wear performances of coating systems during the early states are evaluated, CGDS coatings are seen to have lower performance than coatings produced with HVOF and APS methods. This situation is the result of surface roughness effect's being the operative mechanism in the erosion's starting period. Because of the loss of surface roughness effect depending on erosion, dense structure and high hardness of coating layer, CGDS coatings show the best performance in abrasion performances in progressive processes of wear (last state and later on).
- 3) The lowest volume loss is seen in coating specimen produced with CGDS method among the specimens and specimen that are abraded with HVOF and APS follow it respectively.

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