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Neural network analysis for erosive wear of hard coatings deposited by thermal spray: Influence of microstructure and mechanical properties

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ABSTRACT

An artificial neural network (ANN) analysis is used to obtain a model to predict the rate of erosive wear of hard coatings deposited by two different kinds of thermal spray techniques. High Velocity Oxygen Fuel (HVOF) and Flame Spray FlexiCords (FS/FC) techniques were used under various operational conditions. Different microstructural features that control the mechanical and the tribological performances of three groups of deposits: tungsten carbide, chromium carbide and metallic alloy coatings, were analyzed. The ANN technique involves database use to predict erosive wear evolution, having a large number of variables like deposition process, impingement angles and velocity of the erosive particles, porosity, roughness, microhardness and fracture toughness. Commercially available powders were used as feedstock for coatings deposited by HVOF. Commercial cord wires were used in the FS/FC coating deposition. The slurry erosion testing was performed using a laboratory made pot-type slurry erosion tester, at impact velocity of 3,61 m/s and 9,33 m/s combined with impact angle of 30° and 90°. From the results, it was observed that the microhardness and fracture toughness, as a combination factor, have the greatest influence on erosive rate followed by porosity. Samples coated with WC-CoCr cermet coating with fine WC carbides exhibit higher erosion resistance as compared with the other conventional cermet and metallic alloy coatings, mainly because of its homogenous microstructure and improved properties like low porosity, high microhardness and high fracture toughness. The numerical results obtained via neural network model were compared with the experimental results. The agreement between the experimental and numerical results is considered a good aspect.

1. Introduction

Wear is a complex and inevitable process that constantly accompanies the operations of various components of the industrial environment and requires stronger materials and better properties for applications that work under severe operating conditions, corrosive environments and are exposed to high temperatures, which, introduces in most cases a significant additional cost. An alternative to solve these problems is the thermal spray technique, which allows applying coatings of different nature, versatility and better properties to material surfaces with low added value, in order to improve their properties and performance. This technique has gained popularity nowadays because it allows obtaining surfaces with excellent properties such as: wear resistance, corrosion resistance, weight reduction and profitability [1].

For industrial applications, cermets-based coatings are widely used for surface modifications and enhancement of the wear resistance of mechanical components. Particularly successful and widely used in different wear conditions are the coatings WC-Co; however, the feasibility of using them in certain corrosive and erosive-corrosive environments is debatable, compared with the new WC-CoCr coatings [1,2], that create dense coatings with high hardness and good resistance to abrasion, erosion and erosion-corrosion. Coatings based on the CrC-NiCr system, although somewhat lower in hardness, show a high stability with increasing temperatures and good corrosion resistance [3,4].

The main techniques used for deposition with the aforementioned method are the air plasma spraying (APS) and the oxy-fuel flame at high speeds or hypersonic flame (HVOF). The high flow speed of the particles to be deposited with the HVOF method and the relatively low flame temperature used in this process causes less disruption of the stoichiometry of the deposit during the spraying compared to the plasma spraying [5,6]. This technique

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Table 1
Chemical composition of the deposited materials.

Deposited materials	Chemical Composition (% Wt)									
	Ctot	W	Co	Cr	B	Ni	Si	Al	Fe	Others
HVOF 1350	5,40	Bal.	10,10	4,20	–	–	–	–	–	< 0,10
FS/FC 1350	5,40	Bal.	10,00	4,00	–	–	–	–	–	–
HVOF 7525	11,00	–	–	Bal.	–	19,00	–	0,002	–	–
FS/FC 7525	12,91	–	–	Bal.	–	3,16	1,13	–	0,36	0,98
HVOF 88HV	0,80	16,50	–	15,00	3,00	Bal.	4,00	–	3,50	–
FS/FC RocDur62	0,62	–	–	14,10	2,92	Bal.	3,82	–	3,52	0,055

has the ability of producing high quality coatings so as to porosity, oxide content, density and hardness, thus allowing to obtain wear resistant coatings.

The thermal spraying method ***Flame Spray FlexiCords*** (FS/FC), is an alternative to the thermal spraying method by conventional flame (FS). The materials deposited through the FS/FC can be of different forms, such as: solid metal wires, flux cored wires and ceramic rods (ROKIDE). This technique is designed to suit specific needs, such as low porosity dense coatings (3%) and surface roughness, low internal residual stress, abrasion resistance and accessibility, where other deposition techniques are inappropriate.

In the erosion wear present in systems where components work under a mixture or fluids containing solid particles, there are many factors that influence their behavior [7]; therefore, predicting this phenomenon is a complex process. Under these operating conditions, the use of artificial neural networks is interesting to estimate the erosive wear behavior, due to their ability of correlating different factors and their interaction with the prediction of erosive wear behavior.

However, several researches conducted on the subject matter, only use the operating conditions related to the speed and angle of impact of the erosive particles to predict the behavior of erosive wear in coatings deposited by thermal spray technique [8,9], failing to consider factors such as porosity and surface roughness of the coatings. In the case of porosity, some researchers consider that it influences the mechanical properties, microhardness and wear resistance of the coatings, especially when the porosity value is higher than 3% [10,11] due to low adhesion of carbides to the binder matrix. In the case of the surface roughness, authors often claim that higher surface roughness coatings are more susceptible to erosion [12–14]. Again, previously developed models do not consider mechanical properties such as microhardness and fracture toughness, which are proven aspects that influence erosive wear resistance and are widely analyzed by the scientific community [15–17].

In this paper, a model using the method of artificial neural network was developed to predict the behavior of erosive wear in coatings deposited with HVOF deposition methods and FS/FC. The data used to design and validate the model were obtained through different analyzes and erosion wear tests, for which a mixing bowl with suspended solid particles in a rotational movement was used.

2. Materials and methods

2.1. Characteristics of the materials used as a deposit

The coatings to be evaluated were projected onto a steel substrate of low carbon content (AISI 1020), selected due to its high industrial applicability and relatively low cost. In all cases, the substrate surface was polished and sprayed with aluminum oxide in order to remove impurities and obtain the adequate roughness on the surface to be coated. For all coatings applied, an average value of thickness of 440 ± 17 μm was achieved.

The coatings studied were developed through the HVOF thermal spraying methods and FS/FC. The materials used as deposits in the HVOF method were commercial powders, agglomerated and sintered with different particle sizes of the powders. These were: tungsten carbide type WC-CoCr of nanometric structure (1350 VM/ WC-731-1 / Praxair, Concord, NH, USA with particle size −45/ +15 μm), a chromium carbide of conventional structure (Cr3C2-NiCr 75-25 HC Starck Amperit® 588,074, with particle size 45/ 15 μm) and a metallic composite material (Colmonoy 88HV / Wall Colmonoy Corporation with particle size 05.10 μm). In the case of FS/FC, the deposited materials were in the shape of strands and had a chemical composition similar to that of the previous ones; these are referred to by the manufacturers as HardKarb 1350 (WC 10Co 4Cr), KhromKarb FINE (75Cr_3C_2 /25NiCr) and RocDur62. The chemical composition of these materials are shown in Table 1, which also displays, for a better understanding of the analysis, the name of each material used as a deposit; this allows differentiating them according to the deposition method used. The materials in the table are grouped in pairs given their similar characteristics from the standpoint of their respective chemical composition.

Fig. 1 shows images of scanning electron microscopy of the powder used in the HVOF and FS/FC techniques respectively; enlarged details of the images display agglomerated and sintered particles with spherical morphology.

2.2. Characteristics of the projection processes used

The application parameters used in the thermal spray process were adjusted for each material, according to the recommendation of suppliers, as shown in Table 2.

2.3. Characterization of the coatings

All coatings were carefully cut in a cross-section with a diamond disc for the microstructural analyses and measurements made.

2.3.1. Microhardness and fracture toughness analysis

The experimental values of microhardness and fracture toughness of the coatings were obtained through the use of the Vickers indentation technique with an automated equipment SHIMADZU brand, model HMV-G with a capacity of 0,001 ÷ 2 kg load. For the microhardness testing, ten measurements were made on each sample in a horizontal line of the median plane of the cross section to minimize the effects of the edge and the interface with the substrate and a force of 0.3 kg was applied for 15 s. To determine tenacity, the procedure for the indentations was similar to that followed during the microhardness measurements, being in this case the applied load of 2 kg for HVOF deposits and 1 kg for those of FS/FC, in all cases during 20 s. The mean values of the microhardness measurements ($Hv_{0,3}$) and fracture toughness (K_c) are reported in this work.