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Wear and corrosion behaviour of Al_2O_3-TiO_2 coatings produced by flame thermal projection

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Abstract. Evaluated the wear resistance and the coatings corrosion behaviour of Al_2O_3-TiO_2 prepared by thermal spraying by flame on AISI 1020 carbon steel substrates, previously coated with an alloy base Ni. For this purpose, were controlled parameters of thermal spraying and the use of powders of similar but different chemical composition is taken as a variable commercial reference for ceramic coating. SEM images allowed to know the morphology of the powders and coatings. Electrochemical techniques (Tafel) were applied to evaluate the protection against corrosion. Coatings were tested for wear with a tribometer configuration bola-disco. It was determined that the phases present in coatings are directly relate to the behaviour against corrosion and wear them. Keywords: wear, corrosion, thermal imaging.

1. Introduction

Ceramic coatings deposited are on the surface of a component in order to improve its properties [1], the inorganic coatings are deposited on the metallic surface without altering the original properties of resistance and hardness of the substrate [2]; there are a number of factors that need to be taken into account when making a composite coating such as: substrate compatibility, adhesion, porosity, wear resistance, corrosion resistance, resistance to sudden thermal changes and the possibility of their repair [3]. The properties of the coatings are evaluated by measuring the microhardness, ductility, wear resistance, coefficient of friction and corrosion resistance, which vary according to particle type, size, volume percentage and distribution in the tank [4,5], the thermal projection is a technique that consists of the deposition of coatings with torches that generate the necessary heat to melt the material and accelerate it towards the substrate by means of compressed gas and then the particles collide on the surface forming layers that adhere to irregularities of the surface and allows obtaining high-melting ceramic coatings [6]. Aluminides possess a sufficient concentration of aluminium to form a layer of alumina when exposed to atmospheres of air and oxygen, which makes them have excellent resistance to oxidation and corrosion in aggressive chemical environments [7]. TiO_2 is a hard material with high melting point, its coatings are used in applications such as photocatalysis, bone implants, electrical devices, and renewable energy and gas sensors [8].

This work uses commercial steel carbon AISI 1020, cutting and machining in specimens of $2.54cm$ in diameter and a cm thick, prepare surfaces using Sand-blasting, sand of zirconia, high speed abrasive sand particles impact clean, remove corrosion and give surface finishing (roughness) required for the coating to stick by mechanical anchor i.e. it serves as grip coating. Applies a layer basis with commercial nickel powder CPM 1205TM AISI 1020 steel substrates and coatings of alumina-titania using commercial powders of different chemical composition and different then House producer: Saint Gobain

108 (SG108), 25060 MetaCeram (MC25060), Metco™ 131VF (M131VF); prepared by thermal spraying by flame. The characteristics of the ceramic coatings are affect by projection parameters, by powders to projecting, chemical characteristics, morphology, and particle size distribution, among others [9]. All these characteristics influence the roughness, surface finish, porosity, hardness and tenacity of the coatings. At work are characterized Alumina-Titania ceramic powders used to produce coatings evaluates the chemical and morphological characteristics. Relate the morphology and particle size distribution of porosity and wear of coatings properties.

2. Experimental development

2.1. Characterization of starting powders

The anchor powders and alumina-titania ceramic materials used to apply coatings, chemical characteristics and particle size distribution are evaluated, each of which is assigned a code: CPM1205TM1 anchor layer sample 1=CAM1, Powder for coating SG108 sample 2=SGM2, Powder for coating M131VF sample 3=VFM3, Powder for coating MC25060 sample 4=MCM4; the results are shown in Tables 1 to 3. The data in Table 2 and 3 and Figure 1(b), (c), (d) were taken from the doctoral thesis, authorized by Fabio Vargas [10].

Table 1. Chemical composition of the dust of anchorage.

Material	Element % by weight				
	Ni	Si	Fe	Al	Cu
CAM1	97.62	1.16	0.34	0.18	0.07

Table 2. Chemical composition of powder coatings.

Ceramic powders	% by weight of compound		
	Al_2O_3	TiO_2	Others
SGM2	59.00	40.00	1
VFM3	60.00	40.00	
MCM4	59.64	39.12	1.24

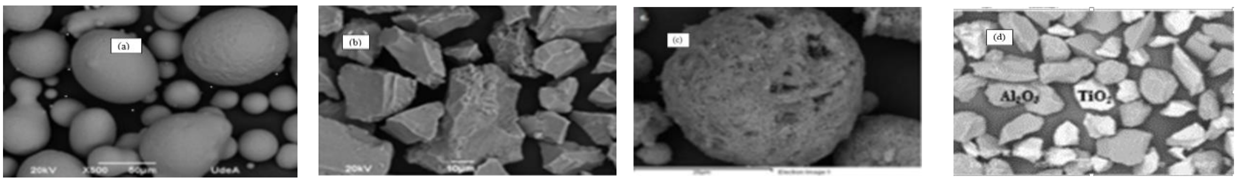
Table 3. The powders grain size distribution.

Ceramic powder	$d_{10\%}$	$d_{50\%}$	$d_{90\%}$
SGM2	15.88	27.20	39.76
VFM3	2.17	11.12	25.02
MCM4	21.18	32.40	49.37

The Table reads $d_{10} = 15.88$ and $d_{90} = 39.76$, indicates that at least 10% by volume of the powder has size less than $15.88\mu m$ and 90% of the particles have one size $39.76\mu m$.

2.2. Morphology powder

Micrograph using SEM allowing to obtain images where the morphological characteristics of the powders can be seen. The microstructure of the anchor and to project the material of the coating materials is shown in Figure 1.



(a) (b) (c) (d)

Figure1. Powder morphology (a) CAM1, (b) SGM2, (c) VFM3, (d) MCM4.

3. Coatings

Deposited Areste 1, the GIPIMME group of the University of Antioquia, with camera armed with a torch Eutectic Castolin-Terodyn 2000, with an infrared pyrometer RAYTEK deposited CAM1, material layer that serves as anchor between the substrate and ceramic coating; and then apply the layer of commercial ceramic powder, SGM2, VFM3 and MCM4. For CAM1 layer, the projection distance remained constant at $15cm$ and an oxidizing flame is used ($59.46l/min$ of O_2 by $21.18l/min$ of C_2H_2), while for the ceramic layer 1:4 worked with $9cm$ as super oxidant projection, a burning distance in the relationship. For VFM3 powder, the flow was 9 gr/min and 8 screening passes.

3.1. Characterization of coatings

The roughness of 1020 clean uncoated steel (AL) and coatings is determined with a model SRT-1000 roughness tester. The results are shown in Table 4.

Table 4. Roughness of coatings.

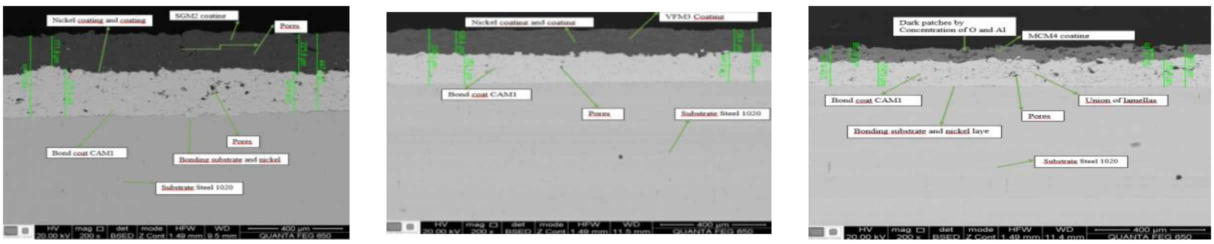
AL (µm)	AL-CAM1 (µm)	AL-CAM1-SGM2 (µm)	AL-CAM1-VFM3 (µm)	AL-CAM1-MCM4 (µm)
4.98 ± 0.06	8.02 ± 0.28	7.61 ± 0.09	6.98 ± 0.06	7.92 ± 0.21

The technique used for the analysis of surface coatings Energy-Dispersive X-rays Spectroscopy (EDS). The chemical composition of the coatings is presented in the Table 5.

Table 5. Chemical composition of coatings.

Material	Element % Wt				
	C	O	Al	Ti	Fe
AL-CAM1-SGM2	1.96	30.76	36.6	29.47	1.22
AL-CAM1-VFM3	-----	33.42	38.62	27.95	-----
AL-CAM1-MCM4	-----	29.46	6.53	64.01	-----

SEM Analysis of the ceramic coatings SEM shows the cross section of the coatings at 200X where the characteristics of the molten particles are observed. The microstructure of the coatings made by thermal projection is shown in Figure 2.



(a) (b) (c)

Figure 2. Coating microstructure (a)AL-CAM1-SGM2, (b)AL-CAM1-VFM3, (c) AL-CAM1-MCM4.

3.2. Electrochemical analysis

A solution of sodium chloride (NaCl) is used to 3.5% as an electrolyte, the reference electrode is Ag/AgCl and against electrode of coal. To perform the tests the electrochemical cell is connect to a team of electrochemical analysis using software and equipment of impedance GAMRY 1000. The results are presented in Table 6 and Figure 3. Tafel curves are shown of the coatings prepared.

In the potentiostatic tests, the uncoated steel has a corrosion potential of -547mV and a corrosion rate of 9.35mpy, the substrate with nickel layer has a corrosion potential of -299mV, quite high and a speed of corrosion of 4.98mpy, compared to the uncoated substrate the nickel-plated substrate is protected. The AL-CAM1-SGM2 has an Ecorr of -577mV lower than uncoated steel but presents a corrosion rate of 4.85mpy which indicates that it is self-protected by the effects of Ni and Ti having passivation properties. The AL-CAM1-VFM3 coating has an Ecorr of -548mV and a velocity of 7.07mpy and this electrochemical behaviour must be the reason for new studies. The AL-CAM1-MCM4 coating has a corrosion potential of -512mV and a corrosion rate of 4.38mpy indicating that it is protected.

Table 6. Analysis of corrosion coatings Tafel curves.

Material	Beta A	Beta C	I_{corr} (μA)	E_{corr} (mV)	Corrosion rate (mpy)	Chi Squared
AL	82.8×10^{-3}	432.3×10^{-3}	20.50	-547.0	9.35	341.00×10^{-3}
AL-CAM1	172.1×10^{-3}	176.1×10^{-3}	10.90	-299.0	4.98	210.20×10^{-3}
AL-CAM1-SGM2	103.9×10^{-3}	73.6×10^{-3}	10.60	-577.0	4.85	30.55×10^{-12}
AL-CAM1-VFM3	125.7×10^{-3}	131.3×10^{-3}	15.50	-548.0	7.07	17.30×10^{-12}
AL-CAM1-MCM4	80.3×10^{-3}	122.2×10^{-3}	9.58	-512.0	4.38	28.50×10^{-12}

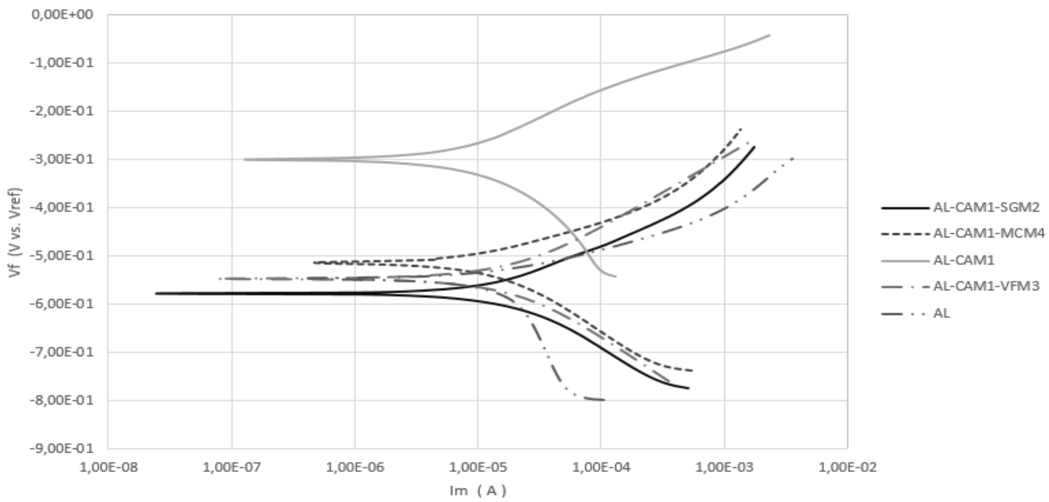


Figure 3. Comparative graph. Curves Tafel of the elaborated coatings.

The wear rate was determined by the average of five measurements of the transverse area in radial direction of traces of wear and tear, using a BRUKER Dektak XT profilometer with a force of $3mg$, a range of scanning of $524\mu m$ and a radius of $2\mu m$ probe. The coefficient of friction of the coatings tested was determined by tribometer Pin on disk the coefficient was obtained as a function of time. The results are presented in Table 7 and 8.

Table 7. Tribological analysis: wear.

Sample	Loss of volume (mm)	Wear rate samples ceramics (mm^3/Nm)	Mass loss Anti-body (g)
AL-CAM1-SGM2	1.03 ± 0.14	$5.13 \times 10^{-3} \pm 6.79 \times 10^{-4}$	1.5×10^{-6}
AL-CAM1-VFM3	0.93 ± 0.24	$4.67 \times 10^{-3} \pm 1.19 \times 10^{-3}$	8.2×10^{-6}
AL-CAM1-MCM4	1.30 ± 0.22	$5.48 \times 10^{-3} \pm 1.09 \times 10^{-3}$	6.9×10^{-6}

Table 8. Coefficient of friction coatings.

Type of coating	Friction coefficient
AL-CAM1-SGM2	0.70
AL-CAM1-VFM3	0.85
AL-CAM1-MCM4	0.80

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4. Conclusions

Coatings made with Al_2O_3 and TiO_2 have good corrosion resistance compared to the uncoated substrate. Good corrosion resistance with different temperatures and applied techniques is reported in the investigations. Coatings made by APS with Al_2O_3 and nanostructured TiO_2 have smooth morphologies without obvious grooves that provide wear resistance compared to microstructure powders [11]. The chemical composition of powder coatings is very similar; the melting temperature of the alumina is higher than that of the nickel, it is for this reason that in the microstructure of the coatings patches of different shades are observed that are related to the size of the particle of the projected powder since the smaller particles are cast and the largest are semi funded.

Evaluated the corrosion resistance of metal pump pistons with coatings made with different percentages of Al_2O_3 and TiO_2 and report high corrosion resistance in acid and saline environments attributed to lack of interconnected pores [12]. The reduction of oxidation in the tests compared to the uncoated steel is attributed to the barrier forming the ceramic layer on the substrate and the ability of the nickel layer to prevent the passage of oxygen to the substrate.

The coating AL-CAM1-VFM3 presents an electrochemical behaviour that must be the reason of new studies, since the increase of the corrosion rate can be associated with more complex phenomena like tortuosity or electro-catalysis of some phases of the titanium oxide.

In the coatings, it is observed that the roughness of the coatings is due to the size and shape of the particles and the projection parameters. As the particle size is reduced, the roughness of the coating is reduced. The presence of cracks and pores in the coatings is influenced by the size of the particles and by the projection parameters, as they determine the heat at which the particle is melted, the velocity and the projection distance. The wear behaviour of the projected coatings improves as the particle size of the projected material decreases and is related to the roughness of the surface.

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