HIGH TEMPERATURE TRIBOLOGICAL CHARACTERIZATION OF TiAl LASER CLADDING COATING ON Ti6Al4V ALLOY

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ABSTRACT

Ti6Al4V alloy has proven to be an important engineering material due to the excellent strength, weight ratio, high corrosion resistance and biocompatibility. However, the alloy is susceptible to mechanical degradation in applications involving sliding wear or abrasion. In order to improve wear resistance, coatings by laser cladding of intermetallic Ti48Al2Cr2Nb on Ti6Al4V have been developed. Different process parameters: laser power (W), scanning speed (mm/min), powder feeding rate (g/min) and preheating temperature of substrate (°C) were optimized, resulting in a microstructure of the coatings considered appropriate, with good metallurgical bond, though cracks and pores were observed [1]. The composition and microstructure of the coatings were evaluated using optical microscopy (OM), scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis, further the tribological properties were evaluated using a ball on disk tribometer, with Al_2O_3 ball, constant speed of 0.1 m/s, 10 N load at room temperature and 500 °C. We measure the 3D surface topography obtained from the wear scar and calculated the wear rate. The coatings microstructure consists of γ-TiAl phase and α_2-Ti_3Al. The wear test results at room temperature show a lower wear rate for the coating compared to the substrate. At high temperature the coating have a higher friction coefficient and a higher rate of wear is obtained when compared with the substrate, obtaining differences between the coatings depending on the wear mechanism observed in the worn surface.

KEY WORDS: friction, wear, Ti6Al4V, Ti48Al2Cr2Nb, laser cladding.

1.- INTRODUCTION

Titanium and its alloys are widely used materials due to its excellent combination of properties that give it the ability to be used in many applications. One of the most used, in about 50% of the applications of titanium alloys is the Ti6Al4V, which contains α-stabilizers with 4-6% β-stabilizers allowing amounts significant of β phase by quenching from the β phase field or two phase ($\alpha + \beta$) field. The two phase field allows heat treatments resulting in a variety of mechanical properties. Such alloys have lower weight than some low strength steels used in aerospace applications and better corrosion resistance that some aluminum alloys [1,2].

Furthermore, this alloy is one of the most commonly used, with a maximum service temperature of 300 °C, being the highest temperature that can be used titanium alloy today about 600 °C, knowing that the operating temperature can be increased by proper cooling, coating processes or thermochemical treatments [2,3]. However, this alloy is susceptible to mechanical degradation in applications involving sliding wear or abrasion; because it has a high friction coefficient and low hardness, which limits their application [4-8].

Surface modification of titanium parts can extend its scope. The laser beam due to its high coherence and directionality is widely used in surface modification of metals, so the disadvantages of titanium alloys can be compensated with treatments of surface modification by laser damaged parts in service, in addition to better dimensional control and access dimensions of complex parts [8].

The laser cladding process can be described as the addition of a material in layers on the substrate surface using the energy of a powerful laser beam, having a wide window of parameters to be used, including: laser power (W), scanning speed (mm/min), powder feed rate (g/min) and preheating temperature of substrate (°C) and whereas a coating with good metallurgical bond, dense and with good thickness is required [9].

Due to its attractive properties, titanium aluminides are especially considered for high temperature in aerospace and automotive applications. These properties include low density (3.9-4.1 g/cm^3), high specific resistance to creep (yield strength/density), high specific stiffness (modulus/density) and good oxidation resistance. Particularly between 600°C and 800°C, its specific resistance is higher than titanium alloys and similar of nickel based superalloys [2,10,11].

TiAl alloys have limited ductility and toughness at room temperature and low strain capacity at high temperatures, which decreases its application field [2,10] and promote numerous researches to obtain a fine grain size to improve these properties.

In this paper we evaluate the friction and wear behavior at high temperature in static air at 500 °C and at room temperature for two optimized laser coatings of Ti48Al2Cr2Nb on Ti6Al4V and compare with the substrate.

2.- EXPERIMENTAL PROCEDURE

2.1.- Materials and laser cladding system

Ti48Al2Cr2Nb (at.%) powder supplied by TLS Technik with 100-200 μm particle size, as shown figure 1,was clad on Ti6Al4V (wt.%) sheet substrate (4 mm thickness). Coatings 50 x 50 mm^2 area were obtained using a laser cladding system Nd:YAG laser (wavelength 1064 nm) TRUMPH model HL1006D with a maximum output power of 1 kW. For this investigation the laser focused diameter was set in 2 mm, samples were placed at 8 mm (z axis) from the nozzle, the movement system consists of four axes XYZC commanded by a Siemens digital CNC, with an overlap of 40% track, helium was used as a shielding gas (4 l/min) and as a powder carrier gas (10 l/min). The substrate is heated before and during processing at 350 °C to ensure metallurgical bond. Optimized parameters from previous studies to execute coatings [12], corresponding to scanning speed of 300 mm/min, powder feeding rate of 2 g/min, laser power of 700 W (defined as Rec01) and 900 W (defined as Rec02), corresponding to specific laser energy of 70 J/mm^2 and 90 J/mm^2 respectively.

2.2.- Coating characterization and testing

Samples of coatings were metallographically prepared by cut transverse section to the clad direction, roughing, grinding and etching with Kroll reactive (92% water, 2% HNO_3 and 6% HF). The microstructure and the worn surface generated in the wear tests of the samples were analyzed by scanning electron microscopy with a microscope Jeol JSM6300 including microanalysis using energy dispersive spectroscopy (EDS) for the quantification of the chemical composition using an X-ray detector Oxford Instruments microanalysis system (20 µm²) installed in the microscope and an optical microscope Nikon LV100. The overall phase composition is obtained by means of XRD (Philips X'Pert) using monochromatic Cu Kα radiation (λ = 0.15406 nm), the diffraction patterns were analyzed using X rays X'Pert Plus (PANalytical) program into 2θ degrees range from 20° to 90°.

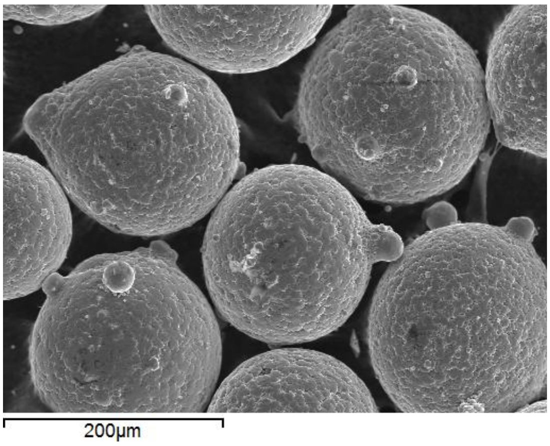

Figure 1. Detail of powder morphology Ti48Al2Cr2Nb (SEM, 20 kV, SE mode).

Dry sliding wear tests were conducted in three samples by condition under static air using a ball-on-disc configuration tribometer MICROTEST MT2/60/ SCM/T, in samples of 15 x 15 mm with roughness Ra = 0.15 ± 0.06 µm roughing obtained with SiC grain paper 500. The samples were rotating sliding against a stationary ball counterpart of 5 mm diameter under a contact load of 10 N, with a sliding length of 500 m, linear sliding speed of 0.1 m/s, at room temperature (24 °C) and high temperature (500 °C), with a nominal wear track diameter of 10 mm. The counterpart balls were commercially available balls Al_2O_3, 99.7% purity, grade 25 (0.05 µm Ra hardness HV 2400) manufactured by Precision Ball & Gauge Co. The wear rate was calculated by the equation.

$$K = \frac{V}{W \cdot x} \tag{1}$$

Where K is the specific wear rate (mm^3/ (N.m)); V is the wear volume (mm^3), W is the normal force on the ball (N) y x is the total sliding distance (m). The temperature near the ball was measured by a contact type “K” thermocouple and registered during the test. Wear 3D profiles were obtained by an inductive contact profilometer Taylor Hobson Talysurf 50 (range 2.5 mm).

3.- RESULTS AND DISCUSSION

3.1.- Coatings characterization

Figure 2 shows micrographs of Rec01and Rec02 coatings where can be seen a microstructure consisting of two phases: γ-TiAl (dark phase) and α_2-Ti_3Al (clear phase), for Rec01 coating can be distinguished a thick lamellar microstructure (Fig 2a and 2c) and for the Rec02 a fine lamellar microstructure (Fig. 2b and 2d). The specific energy lasers used in the process and the solidification rate and cooling have an influence on microstructure [13,14].

Figure 3a shows the XRD patterns of Ti48Al2Cr2Nb powder alloy and laser coatings, where can be identified the γ-TiAl and α_2-Ti_3Al phases. For Rec01 coating higher presence of peaks corresponding to γ-TiAl phase and for Rec02 an increased presence of peaks corresponding to the α_2-Ti_3Al phase, corresponding to that observed by optical microscopy. This is due to the presence of higher amount of specific energy that causes a cooling closer to equilibrium. The EDS microanalysis on SEM shows the chemical composition change of Rec01 coating from the surface to base metal, which is considered adequate corresponding to chemical composition of the powder and substrate, as shown in figure 3b.

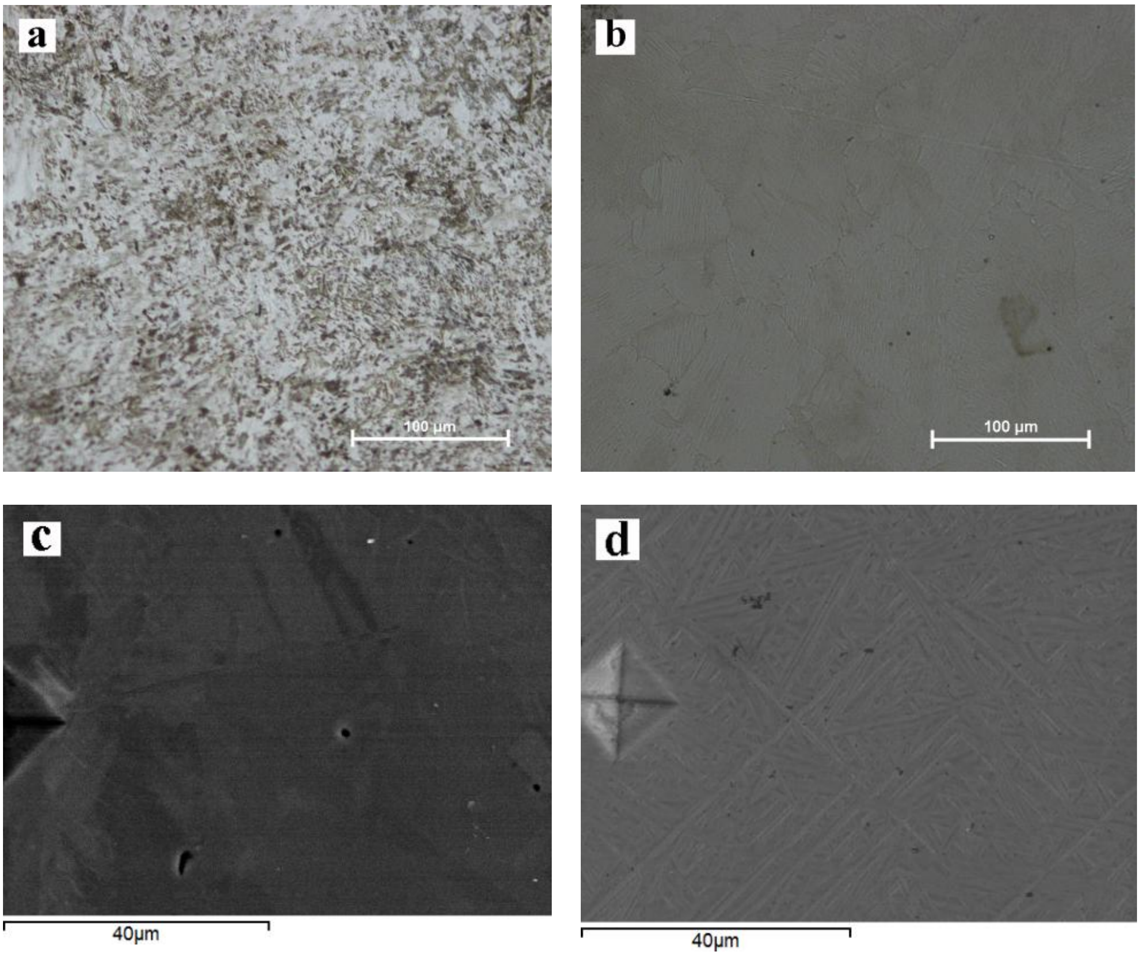

Figure 2. Micrographs obtained by optical microscopy: a) Rec01 b) Rec02. Obtained by Scanning Electron Microscopy (SE mode): c) Rec01 d) Rec02

3.2.- Tribological behavior

Figure 4 shows changes in the friction coefficient of the substrate and the coatings, according to the sliding distance, where the steady state is clearly seen. During this state can be observed larger range of values at room temperature than at high temperature. It can be seen that the substrate has a lower friction coefficient in both cases, indicating that no friction behavior has improved. As regard the wear mass loss, expressed as volume is removed at room temperature has higher volume removed in the substrate compared to the coatings as well as increased wear rate calculated, the opposite occurs at elevated temperatures, according to data presented in table 1.

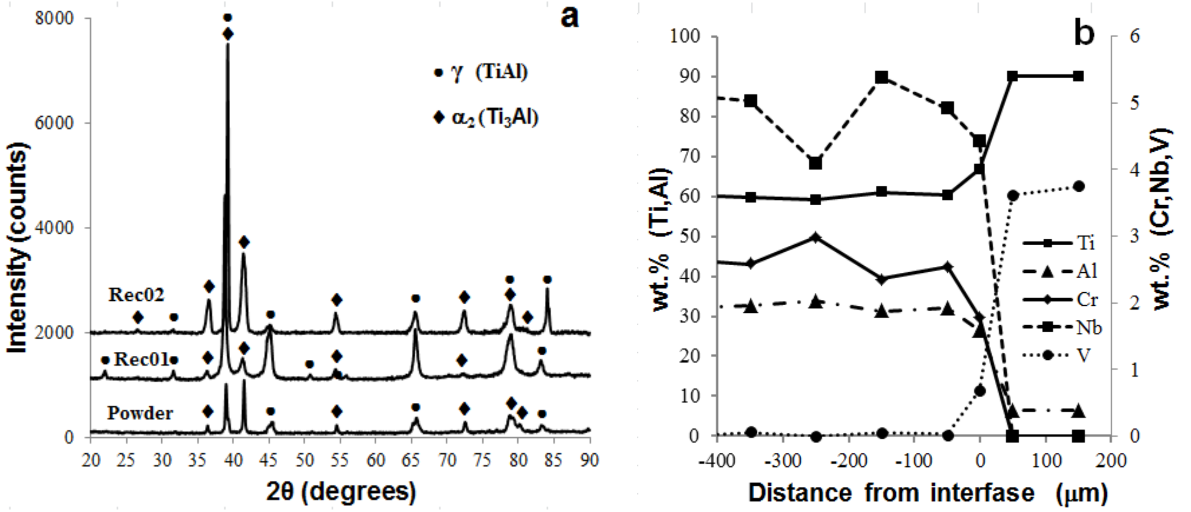

Figure 3. a) XRD patterns of Ti48Al2Cr2Nb powder alloy and Rec01 and Rec02 coatings. b) Chemical composition of the Rec01 coating obtained by EDS through SEM.

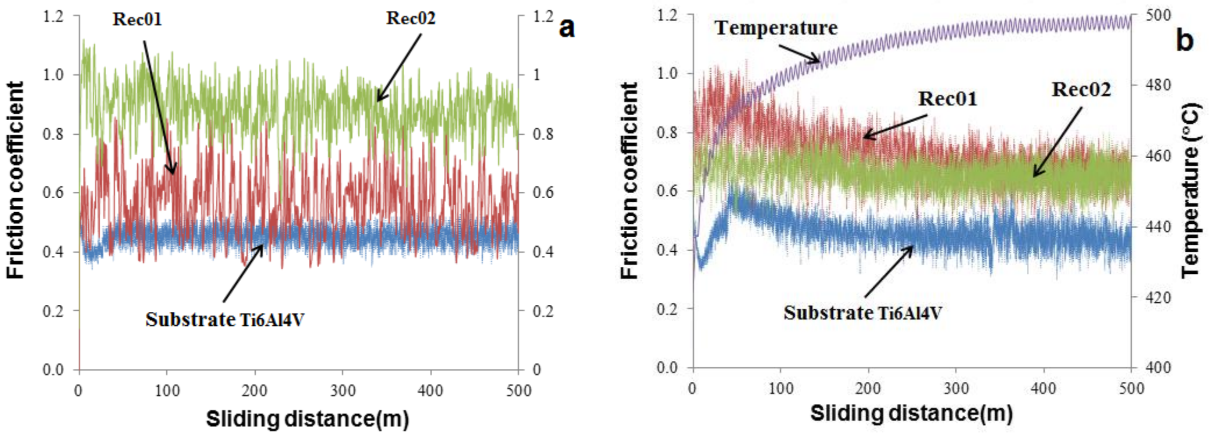

Figure 4. Friction coefficient as a function of sliding distance. a) Room temperature b) Elevated temperature

Table 1.Summary results in sliding wear tests.

Alloy	Test temperature (°C)	Friction coefficient (Adim)	Volume removed (mm^3)	Wear rate, K (10^{-4} $mm^3/(N\cdot m)$)
Substrate Ti6Al4V	24	0.43 ± 0.034	3.62 ± 0.21	7.24 ± 0.42
	500	0.45 ± 0.045	1.79 ± 0.26	3.58 ± 0.52
Rec01 Coating	24	0.57 ± 0.004	0.97 ± 0.30	1.95 ± 0.06
	500	0.69 ± 0.014	2.32 ± 0.29	4.64 ± 0.58
Rec02 Coating	24	0.86 ± 0.036	1.45 ± 0.13	2.91 ± 0.27
	500	0.63 ± 0.026	3.69 ± 0.49	7.39 ± 0.99

The SEM micrographs of figure 5a and 5b shown that the substrate suffered severe abrasive wear evidenced by plastic deformation, parallel valleys and grooves appear following the direction of sliding caused by the ball, which is expected because the hardness of the ball is greater than the substrate, the ball penetrates the coating producing abrasive wear, this occurs at room temperature and elevated temperature. Furthermore, material removals at high temperature are also observed by adhesion.

On the other hand it is observed, in the Rec01coating at room temperature pure deep abrasion without surface modification, this corresponding to the improvement provided by the coating, as shown in figure 5c, the figure 5d shows abrasive and adhesive wear. In Figures 6a and 6b can be seen the 3D profiles of tracks at room temperature where the differences in amplitude and depth of the wear which relates to the tribological behavior presented are verified [15]. We can see that the wear track of the substrate was wider than the Rec01 coatings but less deep and it can be seen the plastic deformation at the edge in the substrate.

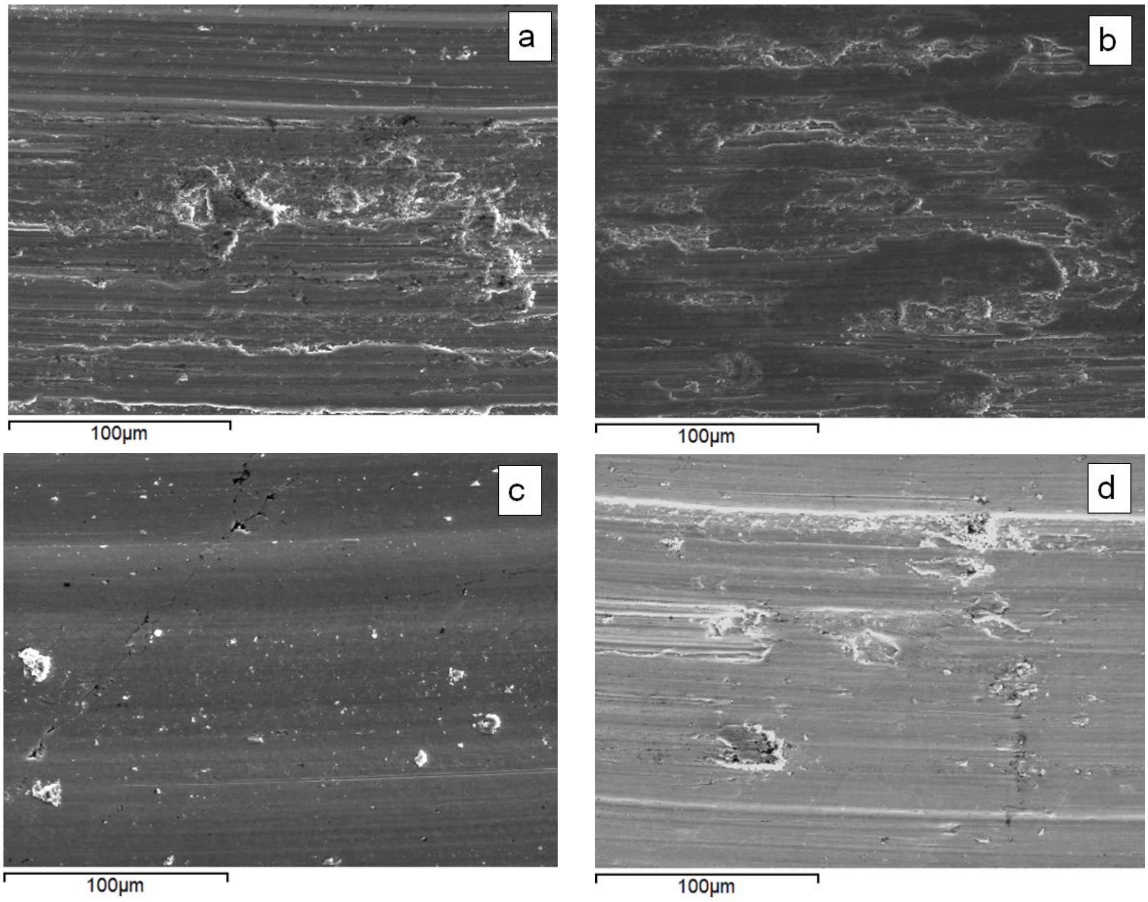

Figure 5. SEM micrographs of morphologies of wear tracks tested at room temperature and elevated temperature: a) and b) Substrate Ti6Al4V c) and d) Rec01 coating

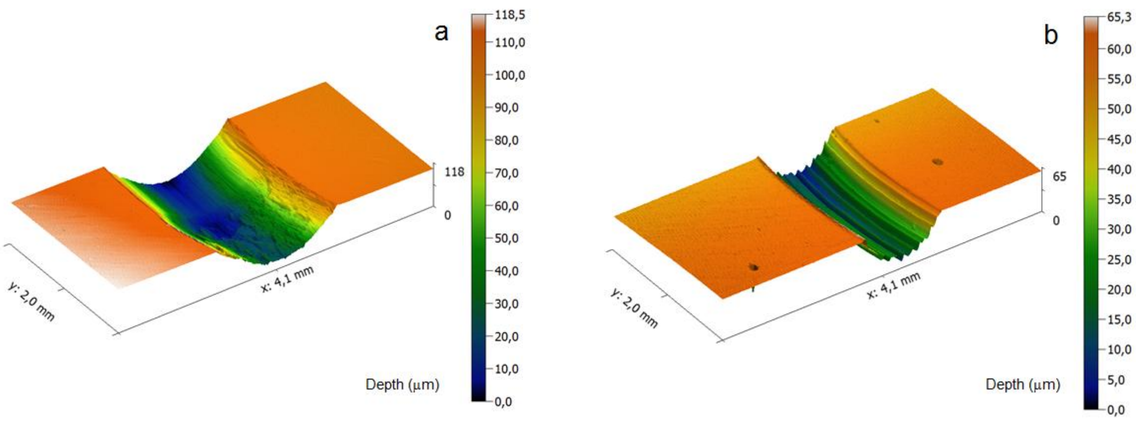

Figure 6. 3D profile of wear scars at room temperature. a) Substrate Ti6Al4V. b) Rec01 coating

4.- CONCLUSIONS

Has been possible to obtain laser cladding coatings of Ti48Al2Cr2Nb on Ti6Al4V sheets, using a preheat temperature (350 °C) of the substrate during the process, introducing a low amount of macroscopic defects, and acceptable metallurgical bond and geometrical characteristics.

The microstructure obtained is composed by lamellae γ-TiAl phase and α_2-Ti_3Al, fine or coarse depending on specific laser energy input. The presence of these phases was confirmed by XRD analysis, coatings chemical composition obtained by EDS, revealed the low dilution with base metal used.

The wear resistance is improved by the coating at room temperature, resulting in a lower wear rate and less abrasive wear mechanism on the wear scar surface. At elevated temperature the presence of oxides as third body improves wear resistance of the substrate, for obtaining a compact and resistant layer; which does not occur with the coatings, which have abrasive and adhesive wear with notches and presence of the surface scratched during the sliding wear test.

5.- ACKNOWLEDGEMENTS

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