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COMPARATIVE STUDY ON THE TRIBOLOGICAL BEHAVIOR OF METAL AND CERAMIC MODEL COATINGS

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Abstract: *The present study concerns parametric analysis on the tribological behaviour of two model coatings, one metallic and the other ceramic, deposited onto the same carbon steel substrate by Atmospheric Plasma Spraying (APS). The metallic coating, selected as a representative of ductile mechanical behaviour, was a CuNiIn, 200 μm thick. The ceramic coating, selected as a representative of brittle mechanical behaviour, was titanium oxide (TiO_2) of the same thickness. The influence of the normal load applied and of the counterbody on the evolution of the friction coefficient and the wear mechanisms was evaluated by testing the two model coatings against sliding in a ball-on-disc apparatus. The behaviour of the different tribosystems was correlated to the friction micro-mechanisms that are activated at the contact interface, during sliding.*

Keywords: *Atmospheric Plasma Spraying, Metallic Coatings, Ceramic Coatings, Parametric Analysis, Friction Coefficient, Wear Mechanisms.*

1. INTRODUCTION

Metallic and ceramic coatings deposited onto metallic substrates via thermal spraying techniques are widely used for anti-wear protection when mechanical components are subjected to frictional and/ or tribochemical loading [1-3].

Thermal spraying belongs to the class of semi-molten state coating techniques. It is a general term used for the description all the techniques consisting of the injection of the selected feedstock (e.g. powder, wire or liquid) into an area of high temperature, where the material to be deposited is heated, accelerated and directed onto the substrate surface. The coatings are formed by the immediate solidification on the surface of the substrate which is, in general, of much lower temperature (ambient temperature).

Among thermal spraying techniques, Atmospheric Plasma Spraying (APS) is a rather simple process from a practical point of view,

In Memory of Prof. G.P. Petropoulos (1959-2010)

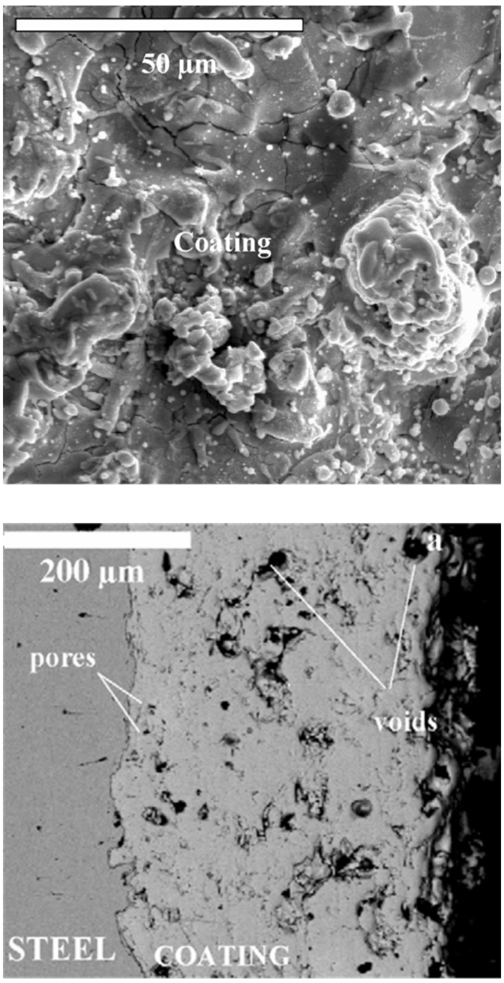
basically consists of the injection of the selected powders into a direct current plasma jet, where they are molten, accelerated and directed onto the substrate surface.

Coatings are formed by the immediate solidification of the molten droplets on the substrate surface of lower temperature where they form the so-called splats. Due to this particular deposition process, atmospheric plasma sprayed coatings tend to have highly defective microstructures, with lamellar microcracks, un-molten particles, weak interfaces and voids between solidified splats [4]. The microstructure and consequently the mechanical properties of these coatings depend strongly on the spraying conditions, in particular on variables related to the injected powder particle size, as well as on the substrate's temperature and mechanical properties.

The present study is dealing with the tribological performance of a metallic and a ceramic APS coating, used as model coatings. Parametric analysis revealed as crucial factor for the behavior of the tribosystem, the metal to metal, or metal to ceramic nature of the coating/counterbody interface, during sliding.

2. EXPERIMENTAL PART

For an objective comparison, the two coatings were deposited onto the same common steel substrate, applying the deposition conditions suggested by the manufacturer of the commercial powders to be sprayed, and for duration sufficient to obtain 200 μm thick surface layers, for both the metallic and the ceramic coating. The metallic coating selected was CuNiIn and the ceramic one TiO_2. The microstructure of the ceramic coating obtained is shown in Figure. 1. The coating exhibits the typical microstructure of APS-deposited ceramic coatings characterized by pores and micro-voids, whilst its surface roughness is defined by the geometrical characteristics of the splats after solidification. Compared to that the metallic one is characterized by less porosity and surface roughness due to higher viscosity of the molten metallic feedstock.



(a)

(b)

Figure 1. Characteristic micrographs of the ceramic coating (SEM images): (a) Top view, (b) Cross-section.

The influence of the normal load applied and of the counterbody on the evolution of the friction coefficient and the wear mechanisms was evaluated by testing the two model coatings against sliding in a ball-on-disc apparatus (CSM Instruments). Three series of tests per each coating were performed using Al_2O_3, Si_3N_4 and 100Cr6 steel ball counterbodies (Ø6) by applying normal loads of 1, 2.5 and 10 N. For all tests, the sliding velocity, the temperature and the relevant humidity were kept constant and equal to 0.5 $m.s^{-1}$, 20 ºC and 25 %, respectively.

3. RESULTS AND DISCUSSION

In the case of Al_2O_3 ball used as counterbody sliding against the ceramic APS coating, the friction coefficient was found to be constant, converging to an average value of 0,42±0,07 [5], for all the testing parameters. The evolution of friction coefficient as a function of the sliding distance, for all the normal loads applied, is presented in Figure 2.

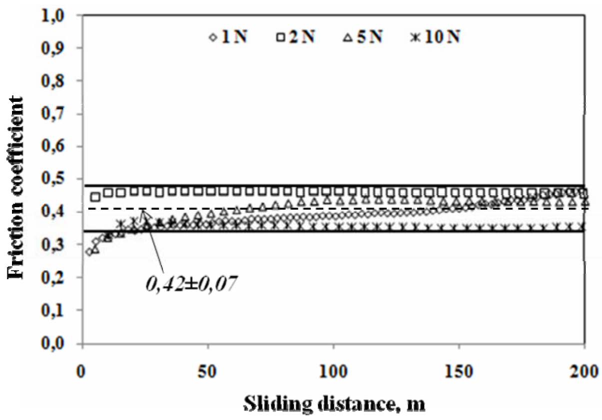


Figure 2. Evolution of friction coefficient for the tribosystem TiO_2/ Al_2O_3.

In the case of Al_2O_3 ball used as counterbody sliding against the metallic APS coating, the evolution of friction coefficient as a function of the sliding distance is shown in Figure 3. A different behaviour of the friction coefficient is observed. For the cases of the lower loads applied (1 and 2 N), the presence of three successive stages can be clearly distinguished and correlated to micro-phenomena taking place at the coating/ counterbody interface:

(a) In the first sliding stage, the friction coefficient tends to a value around 0.25, which is related to the initial wear of the metallic coating protrusions, via their plastic deformation at the micro-contact areas.

(b) In the second sliding stage, the friction coefficient increases to a value of around 0.40. This transition can be attributed to the increase of the real contact area that induces higher drag forces during sliding.

(c) In the last sliding stage, the friction coefficient remains practically constant, around an average value of 0.45 [6]. Such a behaviour can be explained by the intervention of the metallic debris remaining at the contact interface, where they are adherent after having been plastically deformed.

The duration of each stage depends on the normal load applied. The severe testing conditions in the cases of the higher loads (5 and 10 N), in the one hand diminish the duration of the first stage and, in the other hand accelerate the transition to the steady-state final sliding stage.

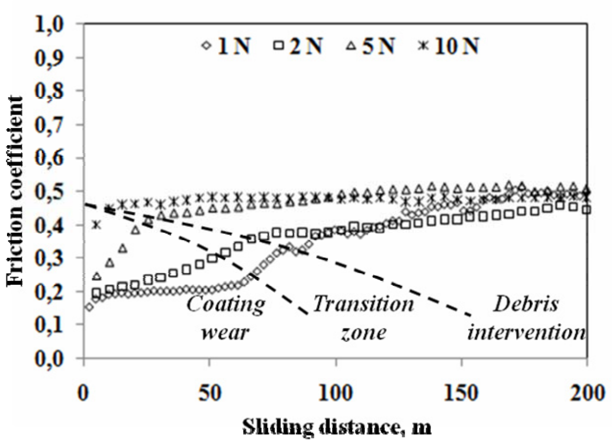


Figure 3. Evolution of friction coefficient for the tribosystem CuNiIn / Al_2O_3.

In the case of the steel (100Cr6) ball used as counterbody sliding against the metallic APS coating, the evolution of friction coefficient as a function of the sliding distance is shown in Figure 4. The strong influence of the normal load applied is obvious: for lower loads, higher friction coefficient values were recorded. A "parallel shift" of the curves corresponding to increasing values of normal load to lower values of friction coefficient can be clearly observed. The average values for each case are presented in Table 1.

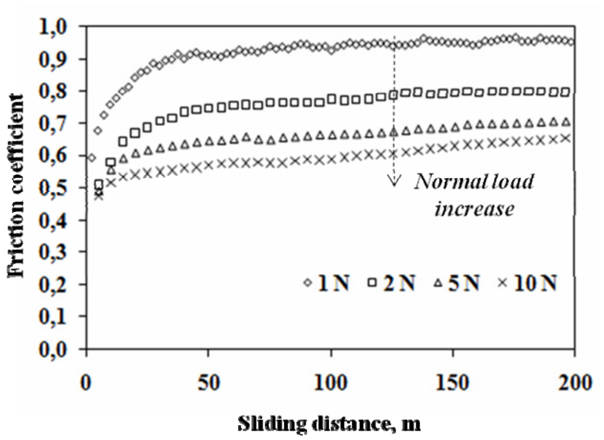


Figure 4. Evolution of friction coefficient for the tribosystem CuNiIn / 100Cr6.

Table 1. Average values of friction coefficient for the tribosystem CuNiIn / 100Cr6.

Normal load applied (N)	Average Friction Coefficient
1	0.92
2	0.72
5	0.64
10	0.55

For low applied load (1 N), the adhesion forces between the two metallic surfaces have a dominant role, inhibiting sliding. By increasing the normal load applied, the plastic deformation of the two bodies in contact, as well as the formation of a metallic debris interlayer, result in the diminution of the drag force developed at the interface and, consequently the reduction of the friction coefficient.

A similar trend of the influence of the applied load on the friction coefficient evolution was also observed in the case of the Si_3N_4 ball used as counterbody sliding against the ceramic APS coating (Figure 5). For every normal load applied, after a coverage of ~10 m sliding distance (running-in period), the friction coefficient attains a practically constant value (Table 2).

This behaviour of two brittle materials sliding vs. each other, can be attributed to the friction mechanism that is controlled by the micro-fracture taking place at the coatings protrusions, due to the coating roughness (Figure 1a). The influence of the surface topography is more pronounced in the case of the 1 N normal load, where significant fluctuations have been recorded. By applying higher normal loads, surface polishing takes place that facilitates relative sliding between the two ceramic bodies.

The differences observed relevant to case where Al_2O_3 ball was used as counterbody to the same ceramic coating, should be attributed to the different mechanical properties of the Si_3N_4 counterbody that alter the Hertz pressure and, consequently, modify wear micro-mechanisms.

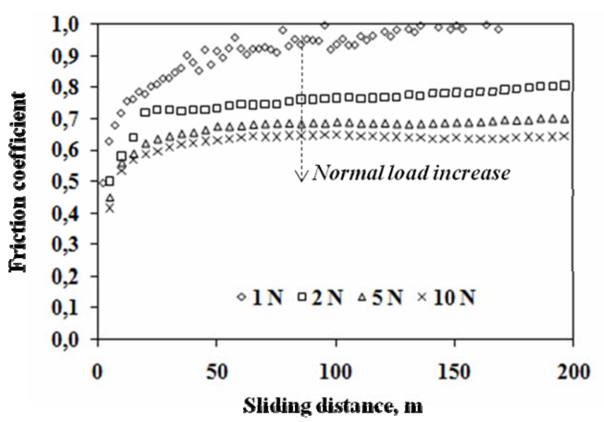


Figure 5. Evolution of friction coefficient for the tribosystem TiO_2 / Si_3N_4.

Table 2. Average values of friction coefficient for the tribosystem TiO_2/ Si_3N_4.

Normal load applied (N)	Average Friction Coefficient
1	0.98
2	0.77
5	0.69
10	0.64

Finally, in the two cases of metal to ceramic tribosystems (CuNiIn/ Si_3N_4 and TiO_2 / 100Cr6) similar behaviour has been recorded, exhibiting an opposite trend than all the previous systems (Figure 6). An increase of the normal load applied resulted in an increase on the friction coefficient recorded.

This macroscopically observed increase of the friction coefficient is due to the action of two competitive mechanisms; the ceramic body acts as a "plough" inserted into the metallic one and should overcome the plastic deformation of the latter at the front of the sliding track. Higher applied forces result in deeper penetration of the ceramic ball or the hard protrusion into the metallic body, affecting a larger volume that is plastically deformed; and thus, higher friction coefficient.

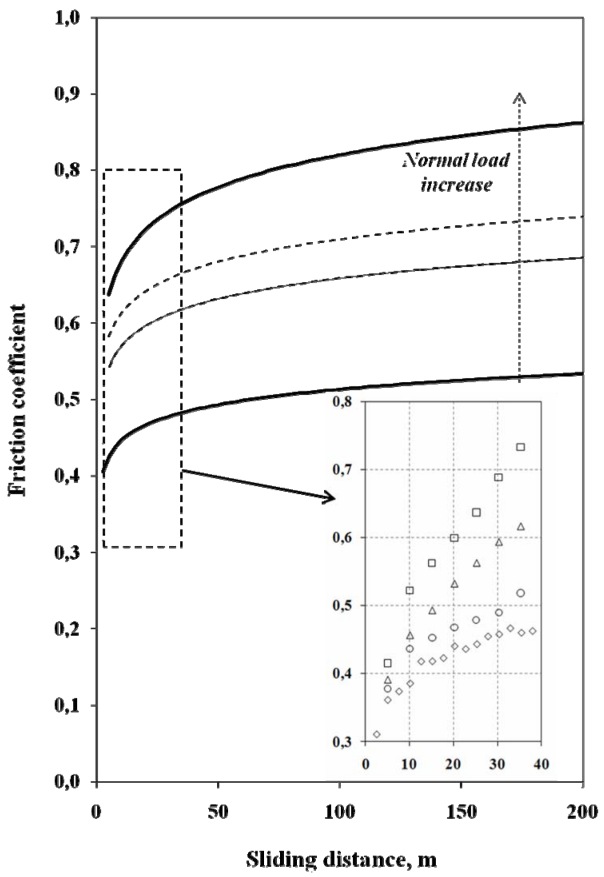


Figure 6. Evolution of friction coefficient for the metal to ceramic tribosystems: CuNiIn/ Si_3N_4 and TiO_2/ 10Cr6.

4. CONCLUSIONS

The sliding behaviour of two typical APS coatings, a metallic and a ceramic one, deposited onto steel substrate was studied. The parametric analysis, based on the classical friction micro-mechanisms activated during operation of several tribosystems, allowed distinguishing different performance of ceramic to ceramic, metal to metal and metal to ceramic systems. The dominant parameters influencing the friction coefficient values are the surface roughness of the brittle bodies, the plastic deformation of the ductile ones, as well as the intervention of wear debris remaining at the contact interface.

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