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Study of wear resistance in dry and lubricated regime of molybdenum coating obtained by thermal spraying

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Abstract

Surface treatments and metallic coatings offer multiple functional specifities to protect all types of metallic materials as well as composites, it is possible to renovate or modify physical characteristics through a multitude of techniques. This activity increases durability, corrosion protection, electrical conductivity or sliding characteristics. This is a necessary step in the production process of many metal workpieces. This surface treatment is suitable for parts of all sizes (bolts, pylons, car doors, etc.). Surface treatments can also protect workpieces against various perils and recover worn surface losses. The general principle of thermal spraying is to melt feedstock materials and inject it under high pressure on the substrate surface. This technique is commonly used in many industrial sectors. The thermal spraying of feedstock materials, such as molybdenum, which is a transition metal, has a high elasticity modulus, a high melting point and better mechanical properties (the addition of a small amount of molybdenum promotes the hardening of the steel). Molybdenum surface treatments thus provide a form of protection for parts against certain tribological and electrochemical risks. Surface treatments with molybdenum coatings greatly improve the protection of mechanical pieces against the severity of surface degradation phenomena such as tribo-corrosion. In the present work, the main goal is to study the dry and lubricated wear behavior of a molybdenum coating deposited by wire-arc spraying technique on a mild steel substrate. The coatings were characterized the coatings was viewed by a scanning electron microscope (SEM), Vickers micro-hardness and wear resistance using a pin-disc tribometer (pin/graphite disc). The result obtained showed that the applied load is a factor influencing the mass loss of molybdenum deposits, which are subjected to a sliding speed of 1m/s and have a slightly higher wear resistance than the ones of coatings subjected to a sliding speed of 0.5m/s. This result is observed for the two regimes studied (dry and lubricated). Under dry conditions, we also noted that the self-lubricating properties of molybdenum coatings did not significantly reduce mass loss.

Keywords: Wear, spraying-arc, Molybdenum, lubrication, micro-hardness, microstructure.

1. Introduction

Due to their mechanical properties and their low cost, low-carbon steels are the most widely used materials in the mechanical and chemical industry. However, their hardness, corrosion resistance and wear resistance limit their application in the harshest environment [1]. Friction has always been and remains a fascinating physical phenomenon since beginning of its history; he was able to capture curiosity and growth of much scientific research, due to its many effects on the industrial revolution, particularly on the surface properties of mechanical pieces [2-4]. However the failure of mechanically stressed structures often begins at the surface. Therefore, in order to increase the strength and reliability of pieces, it is therefore necessary to propose solutions that can limit or even to ennobling surface properties of a machine pieces. It is also interesting to have technologies to simplify product ranges or maintenance needs. Surface treatments and coatings have effectively an important contribution to overcome damage phenomena[5-7]. The general principle is to melt the feedstock materials and then spraying it's under high pressure on the metal surface, the plastic deformation of the molten droplets shaping the coating [8-12]. Several studies have been carried out on the beneficial characteristics of molybdenum [13-14]. In fact this one is a transition metal with a high modulus of elasticity and a high melting point. Molybdenum also has some interesting properties such as; its addition of a small amount promotes the hardening of steel. In recent studies, molybdenum has been shown to influence the microstructure and wear resistance of a nickel-based alloy. The effect of Mo content in plasma-sprayed Mo-NiCrBSi coating was investigated by Niranatlumpong et al [3]. Their results revealed that the presence of Mo on the surface of the coating prevents metal seizing between NiCrBSi and the steel counter surface. Q.Y. Hou et al [15] have studied the influence of molybdenum on the microstructure and wear resistance of a low Nickel based alloying, the results obtained show that the wear resistance for 6 wt% Mo-modified nickel-based alloy coating increased by 47.2%.

Bradai et al [16] characterized the microstructure and tribological behavior of two types of thermal spray coatings 18/8 stainless steel and molybdenum. The results obtained show that the friction coefficient of stainless steel deposits is lower than that of Mo coatings. In this present work, the main goal is to examine tribological behavior of a molybdenum coating deposited by wire-arc thermal spraying technique on a mild steel substrate. Dry and lubricated sliding friction tests of coatings were also performed. The micro-hardness properties were investigated on polished surfaces with a Vickers indenter under a load of 200 g. Also, the microstructure of the coatings was viewed by a scanning electron microscope (SEM), the influence of the applied load and sliding time on wear resistance of the coating are discussed.

2. Experimental procedure

2.1. Materials and spraying parameters

The substrate used in this study is a general engineering construction steel grade E335. The samples, was machined as cylindrical parts with a diameter of 10 mm and a length of 20 mm. The proportions by weight of the elements constituting the substrate and feedstock materials are represented in Table 1.

Table 1: Chemical composition (wt %) of the materials used.

Element (%)	Mo	C	Si	Fe	Others
Substrate	/	0.14	0.05	Bal	0.01
Molybdenum	99.9	/	/	/	0.1

Before spraying, the samples were ground, cleaned and degreased according to usual standards. Then the surface was sandblasted with corundum. Coatings with a mean thickness of 1 mm were processed with a MARK «arc spray 234 » spray gun using wires of 4.5 mm in diameter. Fig.1 shows a schematic of the projection method. An electrical arc is formed between two electrodes, continuously melted and fragmented into droplets by air compressed then accelerated at high velocity on the substrate to form the coatings. During coating elaboration, the spray gun is positioned perpendicular to the surface of the substrates at a controlled distance of approximately around 140 mm. A compressed air jet located about 80 mm from the samples is directed towards the surface of the deposits. The wire were sprayed onto grit blasted substrates using an Arc Spray 234 gun and the input parameters are 4,5 bar oxygen pressure, voltage 35 V, current 100 A, deposited weight 6 kg/h, covered area 8 m2/h/0.1 mm, rate of traverse 2 m/min, Spraying distance 140 mm, wires diameter 1.6 mm spray angle 90°.

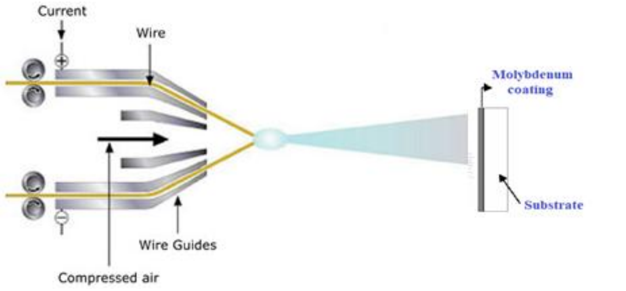

Figure 1. Schematic of the wire spraying technique and micrography of the obtained molybdenum coatings.

2.2. Structural and microstructural characterization

Sample surfaces were polished on SiC abrasive papers from P400 down to P2000 and then finished with a 1 µm diamond paste. Microstructural observations of the coatings were carried out at the SEM (PHILIPS type FEI Quanta 200).

2.3. Instrumented micro-indentation measurement

The molybdenum coating micro-hardness (Vickers scale) was measured by using a Vickers hardness tester B 3212001 type Zwick. The measurements were carried out on the cross-sections of the coatings. During tests a load of 300 g was selected for all the coatings during 15 s. The micro-hardness value was the average of 10 measurements.

2.4. Tribological characterization

Wear test was carried out a pin-on-disc. The specimens dimension was cylindrical pin of 10mm diameter and 20mm length. Friction tests under both dry and lubricated conditions were performed under different loads for 30 minutes. The pin-on-disc contact tests were performed under different loads (10, 20, 30 and 40 N) for a period of one hour. With a siding distance of 900 m and 1800m, sliding speed of 0.5 m/s and 1m/s. A Graphit disc was employed as the counter body with a new disc being used for each test. In order to study the wear behavior of coatings in severe and lubricating conditions, the wears experienced by the samples during the tests were determined by weighting each sample before and after the test. The weight loss suffered by the pins was measured using electronic weighing balance having an accuracy 10-5g. The contact temperature evolutions as a function of time were investigated.

3. Results and discussions

3.1. As-sprayed coating microstructure

The Figure 2 shows the morphology of molybdenum coating.

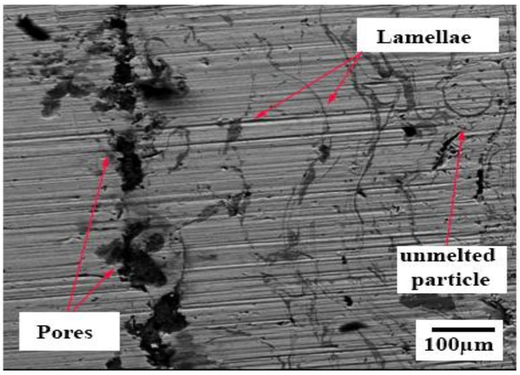

Figure 2. SEM image of microstructure molybdenum coating

The SEM observations of the coating molybdenum obtained by arc spray process showed a dense microstructure, compact and complex of several phases with the presence of porosities and unmelted particles (Figure 2). This microstructure is constituted by lamellae and globular pores and has not cracks because the stresses produced during the formation of these multilayers are not sufficient to produce it.

3.2. Mechanical characterizations

3.2.1. Micro-indentation measurements

Fig.3 shows micro-hardness measurements from the substrate to the coating surface at the longitudinal section.

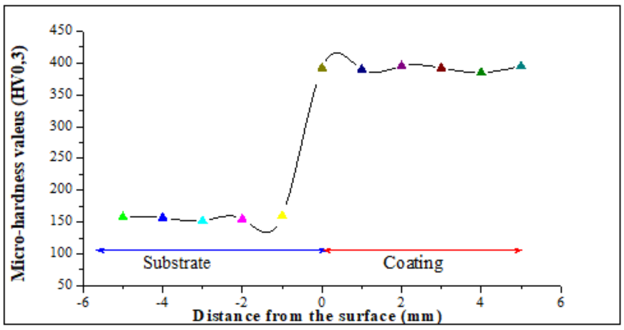

Figure 3. Micro-hardness variation of the Molybdenum coating as a function of the distance from the surface.

Micro-hardness variation of the Molybdenum coating (Fig.3) shows that a value was comprised between 395 HV0.3 for as-sprayed coating and 160 HV0.3 for the steel substrate. This result indicates that the improvement in the micro-hardness of molybdenum coating, tends to be dominated the both by cohesion between deposited particles and by the improved adhesion lamellae that warranted by self-adhesive properties of Molybdenum, which can form strong chemical bonds with many metals and alloys including itself. However, the distribution of micro-hardness values through the coating thickness has been slightly fluctuating with different micro-hardness zones. Logically, these results explain the dispersion of porosities and oxide phases in the coating.

3.2.2. Weight loss evolutions of the coatings as a function load.

Fig.4. Shows the evolution of the weight loss as a function of the normal applied load and sliding speed.

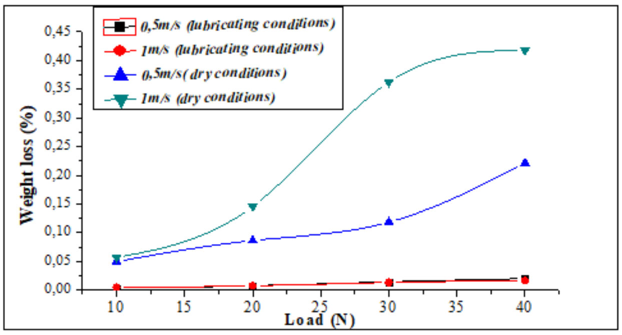

Figure 4. Weight loss evolution of the molybdenum-coatings as a function of normal load.

The results show the major influence of lubrication on the variation in the loss of coating weight. The evolution of the weight loss coatings under lubrication conditions possesses a very similar appearance (Fig.4). The weight loss of the samples remains stable as the speed and contact load increase to 1m/s and 40N respectively. On the other hand, under the sliding conditions used, a viscous fluid film between two surfaces in relative sliding allows the accommodation of normal forces and prevents solid-solid contact; this phenomenon provide a very low friction and negligible wear. These results allow to focus an important anti-friction and anti-wear function of molybdenum coatings under several conditions. Whereas, the results obtained under dry sliding conditions an increment in the wear rate(Fig. 5). Indeed, the high contact pressure load leads to increase of the stress field at the interface, whichsubserve a higher shears rate of the surface roughness, leading to an increase in the plastically deformed layers.

3.2.3. Weight loss evolutions of the coatings as a function time

Four tests under different sliding speed and load were run for each of the test conditions specified (dry sliding, lubricated sliding). Coating weight loss was measured through total distance of 900 and 1800 m. The evolution of the weight loss as a function of the time and sliding speed are graphically shown in (Fig.5).

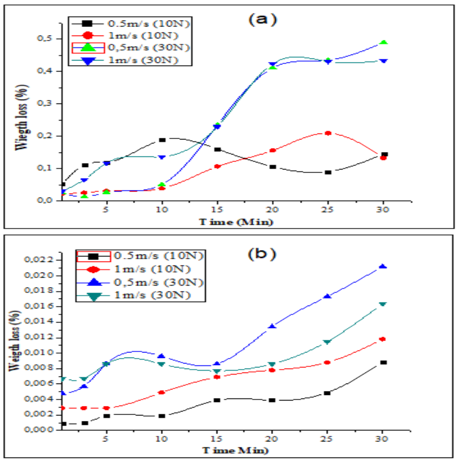

Figure 5. Weight loss evolution as a function of time: a)dry conditions, b) lubricated conditions

Fig.6-a.Shows an increase in sliding time leads to a significant increase in the weight loss of the coating. These results were attributed to the significant plastic deformation as the temperature contact increase. The highest values of weight loss coincided with successive cutting cycle of asperities onto the surface.

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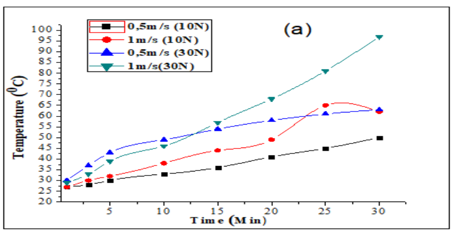
During first step beetween 0 and 600 s, there is an increasing in the weight loss of the treated coatings under load and speed 10N and 0.5m/s, Comparatively to the results obtained under the same loading conditions but at different speeds (1m/s), the weight loss of the coating is more importante its maximum value (0.20g) after 1500 s. It should be noted that the weight loss obtained under higher loads 30N at speeds of 0.5 and 1m/s respectively, is two time more importante than 10N. In many study, it has proved that hardness is one of the most explicit parameters behaviouringwear. Also, when tribological testing are operated with lubrication [1,15]. this results it can be explained by the both presence continuous presence of the thin lubricant film and molybdenum auto-lubricant proprieties contribute to develop a thin tribochimical film.

3.3. Contact temperature variation as a function of time

Data contact temperature between the two friction surfaces is presented in Figure.6.



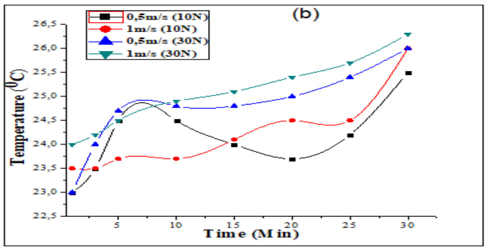


Figure 6. Variation of the contact temperature as a function of time; a) dry conditions; b) Lubricated conditions.

The evolution of the contact temperature as a function time shows a relatively identical behavior as shown in (Fig.6-a). However, this variation shows an increasing function dependent on both time and contact load. The increase in contact temperature shows explicitly dependence on contact pressure temperature and sliding speed. This variation becomes more and more important when the contact load increases from 10 to 30N (difference about 15°C). (Fig.6-a). It was found also a linear increasing in temperature as function of the load and sliding speed under 30N and 1m/s. In this case, the temperature reach a top about 970C. This increasing in temperature could be explain by the higher stresses, the most intensive shears of the surface roughness which cause a bigger contact area and the plastic deformations become important. Consequently, the thermal interaction followed by friction mechanism which is generates a local hot. Under lubricated mode, there is a slight fluctuation due to the reduction of the contact area between the both antagonistic surfaces, allowing a significant increase in temperature between the two antagonistic surfaces. While this phenomena becomes less active under sliding conditions in lubricated mode.(Fig.6.b).

3. Conclusion

In this paper, the aim is to study of wear resistance in dry and lubricated regime of molybdenum coating obtained by thermal spraying technique. On the basis of this study, it has been found that the following conclusions can be drawn:

1. The SEM observations of the coating molybdenum obtained by arc spray process showed a dense microstructure, compact and complex of several phases with the presence of porosities and unmelted particles.
2. Microhardness tests revealed that the Molybdenum coating is almost three times harder than the substrate E335.
3. The tribological results showed that the wear resistances of coatings under lubricated have fairly high wear characteristics than the Mo coatings tested under dry mode
4. The results showed that the temperature measured during the test under a load of 30N is higher than that obtained during the test under a load of 5N. It was found also a higher linear increasing in temperature as function of sliding speed under 1m/s in dry condition.

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