STUDY THE WEAR MECHANISM OF A PLASMA ELECTROLYTIC NITROCARBURISED (PEN/C) 316L AUSTENITIC STAINLESS STEEL

F. Mahzoon*[1], S. A. Behgozin[2], N. Afsar Kazerooni[1] and M. E. Bahrololoom[1]

* *mahzon@shirazu.ac.ir*

Received: January 2013 Accepted: June2013

[1] **Materials Science and Engineering Department, Shiraz University, Shiraz, Iran**

[2] **Bahonar Technical and Vocational college, Shiraz, Iran.**

Abstract: *The wear mechanism of plasma electrolytic nitrocarburised (PEN/C) 316L stainless steel samples was studied after a pin on disc wear test. The surface morphology of samples after application of PEN/C process was studied using scanning electron microscope technique. The sliding tracks resulting from the wear tests on the treated specimens indicated no signs of plastic deformation and adhesive wear, but the slider wear particles were trapped in the micro-craters of the counterface. The results showed that this mechanism may further improve the tribological performance of the system by increasing the wear resistance and lowering friction. PEN/C treated surfaces are therefore believed to have the potential to limit metal-to-metal wear mechanisms on a microscale, if contact pressures are sufficiently low.*

Keywords: *wear, plasma electrolytic process, friction, 316 stainless steel*

1. INTRODUCTION

Surface properties, such as roughness and morphology are important parameters for many applications such as coating adhesion, tribological performance, etc. The basic concept of tribology is that friction and wear are best controlled with a thin layer of material separating bodies during sliding, rolling and impacting [1]. It is now well established that the friction and wear behaviour of the pair of materials in contact are affected by the properties of the material adjacent to the contact area [2].

Tribosystems consisting of plastic materials in dry sliding against harder materials such as steel have proved to be favourable for the formation of interfacial films, commonly called a third body, between the slider and the counterface. The formation and transfer of these films lead to relatively lower wear and consequently a low coefficient of friction [3]. In metal on metal bearings an often reported wear mechanism is abrasion because scratches and grooves are always obvious [4]. For some metals such as austenitic stainless steels the inadequate tribological properties lead to a sever wear mode characterized by high wear rates and a large unstable friction coefficient. As these steels are used for many applications primarily due to their good corrosion resistance, a wide range of surface modification techniques (shot peening, laser, dynamic ion mixing and coating [5]) have been developed to achieve required specifications including wear resistance. One way to improve the surface hardness and wear resistance of austenitic stainless steels is by using a plasma electrolytic nitrocarburising (PEN/C) process. The unique surface morphology and micro roughness created by electrolytic plasma technology (EPT) makes it an effective tool to improve metal surface properties [6].

The technique of PEN/C is traditionally based on the diffusional saturation of a metal surface by ionized species of typically nitrogen and/or carbon during high-voltage electrolysis of suitable organic electrolytes [7]. In plasma electrolytic nitrocarburising (PEN/C) process the plasma generated in the vapour-gaseous envelope produces a number of nitrogen- and carbon-containing active species, which (under the action of both the applied voltage and other factors, such as convection and/or hydrodynamic forces) bombard the sample surface and ensure a high rate of diffusional flow inward to the growing surface layer [8]. Good reviews of electrolytic plasma processing from surface engineering and scientific prospectives have been conducted by Yerokhin et al. and Belevantsev et al. [6].

This investigation was carried out to determine the wear mechanism of a PEN/C treated 316L stainless steel sample, after operating a pin on disc wear test on it. The results then were compared to those for substrate and the role of observed unique wear mechanism for PEN/C treated sample, and the consequent effects of it on the wear behaviour of 316L stainless steel were considered.

2. EXPERIMENTAL PROCEDURE

In the present investigation an optimized electrolyte bath based on urea containing NH_4Cl, Na_2CO_3 and other additives [9] was used to treat the surfaces of 20mm×13mm×1mm coupons of 316L stainless steel specimens. In this aqueous solution, ammonium chloride decomposes and gives active nitrogen ions, which consequently could diffuse, competitively with carbon, into the surface. The samples were connected to the negative output of a DC power supply and immersed in the solution in which a large plate of stainless steel surrounded it and acts as the anode. During the test the substrates were biased with a negative voltage of 180 V for 10 minutes of treatment time at a current density of 0.25~0.3 Acm^{-2}. The treated samples then were used to study the wear mechanism of the surface layers.

The wear tests were performed using a rotating pin-on-disc wear testing machine with a relative speed of $2cms^{-1}$ and repeated several times to confirm the validity of the results. The diameter of wearing circumferential trajectory was adjusted to be 7 mm. These tests were carried out against a 5mm diameter SAE 52100 steel pin. The sliding distance was 200m with a normal load of 2.5 N. The coefficient of friction was monitored with the aid of a linear variable displacement transducer and was continuously recorded throughout the tests. The surface roughness (R_a) of the specimens before and after PEN/C treatment was measured using a Mitutoyo roughness tester.

The surface morphology and wear mechanisms of the coating were observed by a S360 Oxford scanning electron microscope (SEM).

3. RESULTS AND DISCUSSION

The Surface morphology of the samples after application of PEN/C process is shown in Fig.1. These treated surfaces indicate the complex character of the interaction of the intensive electrolytic plasma with the metal surface. High temperatures in plasma bubbles lead to localized melting of the surface layer of the specimen. After collapse of the plasma bubble, this surface is quenched by the surrounding electrolyte, leading to a unique surface microstructure [10].

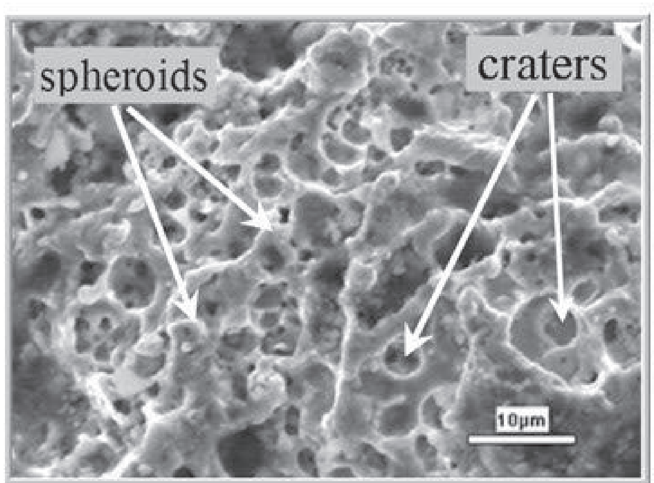

Fig. 1. The surface morphology of PEN/C treated sample. Craters and spheroids are shown in the picture.

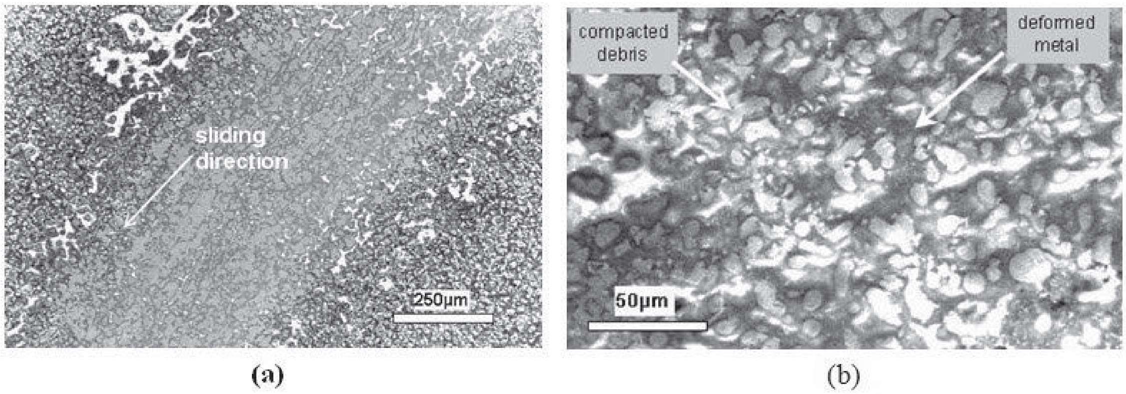

Fig. 2. The wear track morphology for the treated sample.

Micro-craters and spheroids which are the result of the plasma bubble implosion and the quenching of the localized melted surface layer, respectively [6], are excellent sites for mechanical interlocking, adhesion of lubricants, paints, coatings, etc. The morphology of wear track of the treated sample after a pin on disc wear test is presented in Fig. 2.

During sliding, fracture at asperity usually follows a path in the weaker or softer component [11]. Examination of the worn surfaces of the PEN/C treated samples has been reported by Nie et al. and they suggested that the deformation and fatigue induced scaling of the oxide layer formed on the surface of the treated sample [8]. Moderate adhesive /abrasive wear mechanisms also have been reported for treated samples at 250 V [10]. In the present study, as it is shown in Fig 2 the worn surface does not show adhesive deformation ; instead by considering the two sides of the wear track which show the not-worn parts, the flattening of the coating is predominant. It seems that because of the high hardness of the coating, the slider abrades and leads to mechanical damage of both the pin and the coating.

The trapped parts of the slider wear particles in the micro-craters of the counterface are visible in Fig 2-a. In fact the micro-cones or the spheroids seem to be flattened by the contact pressures. Since the nominal contact area increases gradually with plastic deformation of the cones, the surface is able to adjust the required contact area to the applied forces. Depressions in between the spheroids can trap wear particles which are carried between the rotating pin and the stationary testing sample. This trapping process conventionally starts at the edges of the flattened cones which hinder debris movement [12]. Then the agglomerated and compacted debris are trapped in the craters in between cones. Fig. 2-b shows the middle of the wear track of the PEN/C modified sample after 200m or 10000 cycles of wear process.

The mechanism of wear in the treated samples can be explained as follows:

In the initial stage of sliding, the microcones on the modified surface are plastically deformed thereby increasing the load bearing area followed by decreasing the contact pressures. The deformation process is accompanied by wear and the generation of debris. Fresh particles are trapped by the remaining depressions in between the cones and hence they do not leave the tribological system. This is the first step in lowering the amount of wear [8].

It has been reported that [13] metallic particles are oxidized and agglomerated to establish compact layers. However, particles were only found to agglomerate at certain locations, where they can be trapped and compacted (e.g. grooves). In this work, it can be seen that at the first stages of sliding, the cavities begin to fill with oxidized and compacted particles which are mainly separated from the slider. The consequent result of this process is the formation of a smooth

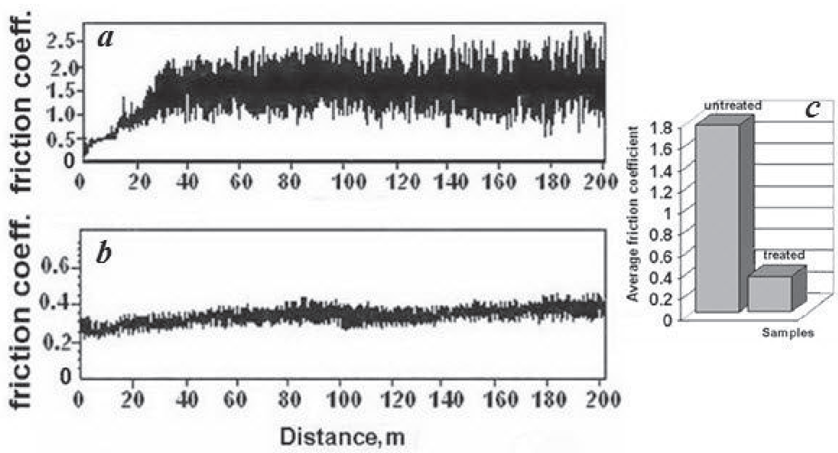

Fig. 3. The friction coefficient factor against sliding distance for (a) untreated and (b)PEN/C treated samples. (c) Average value of friction coefficient factor

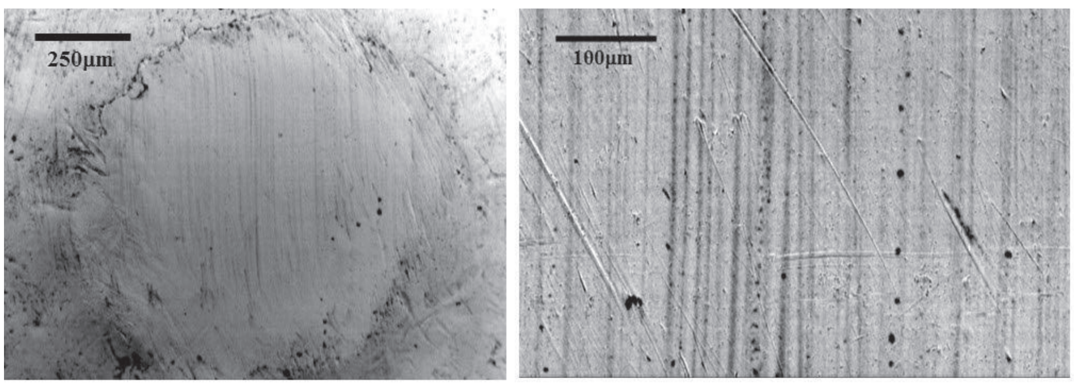

Fig. 4. SEM images of the worn pin surface.

heterogeneous surface which might increase the wear resistance and lower the friction (Fig. 3). In the initial contacts with the pin, the cones on the treated surface are able to respond plastically to the applied load. Indeed, no adhesion was observed on the modified samples up to 10,000 cycles. The SEM observation of the worn pin surfaces (Fig. 4) also shows parallel grooves and light scratches which are the result of abrasion and particle transformation. The relatively high roughness value of PEN/C treated surface (Ra ≈ 6.1μm) might cause particle arising due to the fracture of asperities during the wear process. It has been reported that abrasion may be induced by foreign particles (contaminants from outside the system), or most likely, from system inherent particles, like fractured carbides, compacted wear debris, and plastically deformed parts of the metal matrix [2].

4. CONCLUSIONS

A plasma electrolytic nitrocarburising (PEN/C) treatment on 316L austenitic stainless steel was presented which can improve the tribological performance of the system by increasing wear resistance and lowering friction. The wear mechanism of the treated surface was found to be abrasive in which the generated wear particles was transferred, agglomerated, compacted and trapped in the craters in between cones and do not leave the tribological system. A smooth hybrid surface which is the result of plastic deformation of surface cones in the initial stage of sliding, might further improve the wear properties of the system.

REFERENCES

1. Affatato, S., Spinelli, M., Zavalloni, M., Mazzega-Fabbro, C. and Viceconti, M., "Tribology and total hip joint replacement: Current concepts in mechanical simulation, Med. Eng. Phys.", 2008, 30, 1305
2. Wimmer, M. A., Loos, J., Nassutt, R., Heitkemper, M. and Fischer, A., "The acting wear mechanisms on metal-on-metal hip joint bearings: in vitro results", Wear, 2001, 250, 129
3. Benabdallah, H. S., "Reciprocating sliding friction and contact stress of some thermoplastics against steel", J. Mater Sci., 1997, 32, 5069
4. Sieber, H. P. Rieker, C. B. and Kottig,P., "Analysis of 118 second generation metal-on-metal retrieved hip implants", J. Bone Joint Surg. Br., 1999, 81, 46
5. Akita, M. and Tokaji, K., "Effect of carburizing on notch fatigue behaviour in AISI 316 austenitic stainless steel", Surf. Coat. Tech, 2006, 200, 6073
6. Gupta, P., Tenhundfeld, G., Daigle, E. O. and Ryabkov, D., "Electrolytic plasma technology: Science and engineering—An overview", Surf. Coat. Tech., 2007, 201, 8746
7. Yerokhin, A. L., Leyland, A., Tsotsos, C., Wilson, A. D. Nie, X. and Matthews, A., "Duplex surface treatments combining plasma electrolytic nitrocarburising and plasma-immersion ion- assisted deposition", Surf. Coat. Tech., 2001, 142-144, 1129
8. Nie, X., Tsotsos, C., Wilson, A., Yerokhin, A. L., Leyland, A. and Matthews, A., "Characteristics of a plasma electrolytic nitrocarburising treatment for stainless steels", Surf. Coat. Tech., 2001, 139, 135
9. Mahzoon, F., Bahrololoom, M. E. and Javadpour, S., "Optimization of a novel bath for plasma electrolytic nitrocarburizing of 316L stainless steel and study of tribological properties of the treated steel surfaces", Surf. Eng., 2009, 25, 628
10. Yerokhin, A. L., Nie, X., Leyland, A., Matthews, A. and Dowey, S. J., "Plasma electrolysis for surface engineering", Surf. Coat. Tech., 1999, 122, 73
11. Chang, C. N. and Chen, F. S., "Wear resistance evaluation of plasma nitrocarburised AISI 316L stainless steel", Mater. Chem. Phys., 2003, 82, 281
12. Büscher R. and Fischer, A., "Sliding wear behaviour of an electrochemically modified austenitic high-nitrogen steel surface", Wear, 2003, 254, 1318
13. Stott, F. H., "The role of oxidation in the wear of alloys", Tribol. Int., 1998, 31, 61