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TRIBOLOGICAL BEHAVIOUR OF DUPLEX TREATED AISI 4140 STEEL

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Abstract

In the present study, characterisitics of arc PVD- CrN coatings formed on plasma nitrided and as-received surfaces of an hardened AISI 4140 steel before and after nitiriding have been examined by microhardness, adhesion and wear tests. CrN coating deposited on the nitrided surface exhibited remarkable advanced properties as compared to the CrN coating deposited on the as-received surface.

Keywords: Adhesion, Hardness, Nitriding, PVD, Steel, Wear,

1. Introduction

It is generally accepted that the performance of steels and components used in a tribological, corrosive or mechanical loaded environment is mainly governed by their surface properties. Nitriding is as an effective thermo-chemical surface hardening technique applied for many years to improve the wear resistance of ferrous alloys [1]. Many researchers have confirmed that the improvement in surface hardness and wear resistance are due to the formation of compound layer and/or nitride precipitates whose composition depends on the type of material under investigation [2-5]. As the compound layer mostly polyphase iron nitrides (ε:$Fe_{2-3}N$, γ^{I}:Fe_4N) forms on the surfaces of structural steels [6].

On the other hand, covering of the surfaces by hard compounds via various deposition techniques appeared as an attractive surface modification process to ensure surfaces with high hardness and high wear resistance. Among these deposition techniques, Physical Vapor Deposition (PVD) is the most popular one in the industry. It should be noted that the large hardness difference in between the coating and the substrate may lead insufficient bonding of the coating to the substrate, which appears as the weak point of the PVD technique [7-10]. In this respect, combination of nitriding and PVD processes has been proposed mostly for steels to eliminate the weak point of the PVD process [11].

On the basis of the explanations given above, characteristics and wear performances of the CrN coatings deposited by means of a PVD technique on a AISI 4140 structural steel before and after plasma nitriding treatment were compared in this study.

2. Experimental Details

The substrate material used in this study was AISI 4140 steel with the chemical composition of (in wt.%) 0.39% C, 0.30% Si, 0.68% Mn, 0.012% P, 0.002% S, 1.15% Cr, 0.20% Mo, 0.08% Ni, 0.016% Al, 0.01% V and balance Fe. Disc shaped samples (26 mm in diameter and 10 mm in thickness) were received in the hardened state, having the average hardness of 35 HRC. In the scope of this study samples were CrN coated by arc-PVD technique before and after plasma nitriding, which were identified as single and duplex surface treatments, respectively.

Plasma nitriding was conducted in a gas mixture containing 25% N_2 + 75% H_2 at 500 ^{o}C for 8 h. Arc-PVD process was conducted for 80 min at -110 V bias voltage, 50 A cathode current and 5 mtorr N_2 pressure at

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temperatures in between 279 (start) - 293 °C (finish). CrN coating was applied to the as-received and plasma nitrided samples, which were identified as single and dublex treated steels, respectively. Before the CrN coating of the nitrided samples, their surfaces were shot peened and then polished.

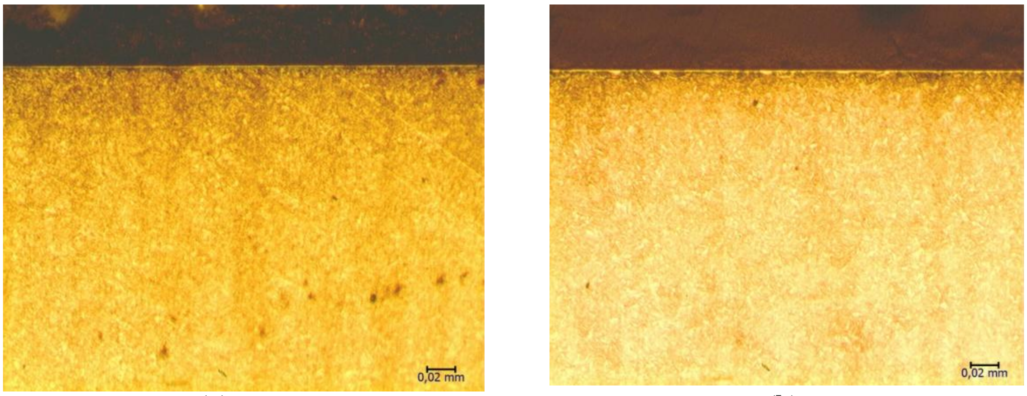
The single and dublex treated samples were subjected to microstructural survey, hardness measurements, Rockwell C adhesion tests and dry sliding wear tests. Microstructural survey covered Ligth optical microscope (LOM) examination and X-ray diffraction (XRD) analysis. XRD analysis was carried out by utilizing Cu Kα radiation. Hardness measurements were conducted on the surface of the samples with a Vickers pyramid indenter under indentation test loads varied from 25 g to 10 000 g. Rockwell C adhesion tests were conducted on a standard Rockwell hardness tester, by indenting the Rockwell C diamond indenter on the samples under normal load of 150 kg. After the adhesion tests, the damage patterns developed on the samples were detected by a LOM. Dry sliding wear tests were applied on a reciprocating type wear tester at normal atmospheric condition. Wear tests were carried out by rubbing Al_2O_3 ball having a diameter of 6 mm to the samples under a normal load of 5N. Sliding stroke, total sliding distance and sliding velocity were 2 mm, 50 m and 3.0 ms^{-1}, respectively. Results of the wear tests were evaluated by the wear tracks developed on the surface of the steels after measuring their width and depth by a profilometer.

3. Results and Discussion

Figure 1 show cross-sectional LOM micrographs for the single and duplex treated AISI 4140 steel. The thickness of the CrN coatings was about 2 μm. No discontinuities and inhomogeneties such as cracks, pores are presented at the interface even at high magnifications.

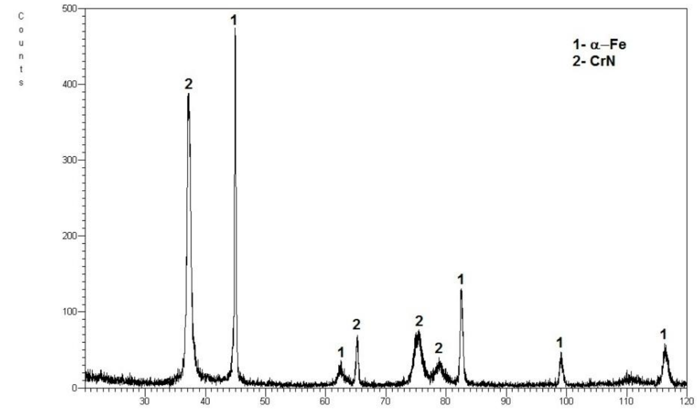
The XRD patterns of single and duplex treated steels are given in Figure 2. On the diffraction pattern of the single treated steel (Figure 2a), α-Fe and CrN peaks were detected. In the case of the duplex treated steel (Figure 2b), the diffraction pattern contained an additional diffraction peaks of iron nitrides (γ'-Fe_4N and ε-Fe_3N) phases. It is therefore suggested that, beneath the CrN coating of the duplex treated steel iron nitirdes were precipiated as the result of the nitrogen diffusion.

The results of the surface hardness measurements conducted under different indentation loads (in between 10 and 10.000 g) are depicted in Figure 3 with respect to penetration depth of the pyramid indenter, which was calculated from the 3D geometry of the imprints after measuring their diagonals. It can be seen from Figure 3 that, the duplex treated AISI 4140 steel has a surface hardness of 1900 HV (corresponding to the indentation test load of 10 g), which decreased to 750 HV at about penetration depth of about 38 μm (corresponding to the indentation load of 10.000 g). For the single treated AISI 4140 steel, the maximum surface hardness was measured as 1000 HV (at indentation load of 10 g). The indentation load of 10 000 g yielded the hardness of about 400 HV at penetration depth of about 40 μm. The decrease of the hardness with increasing indentation depth can be due to contribution of the relatively soft substrate at higher penetration depths of the indenters. According to Figure 3, the contribution of CrN coating to the surface hardness was dominated at indentation depths lower than about 5 μm which corresponds about indentation loads lower than 50 g. Higher surface hardness of the duplex treated steel than the single treated steel at the same indentation depths can be attributed support of the nitrogen diffusion during plasma nitriding process.

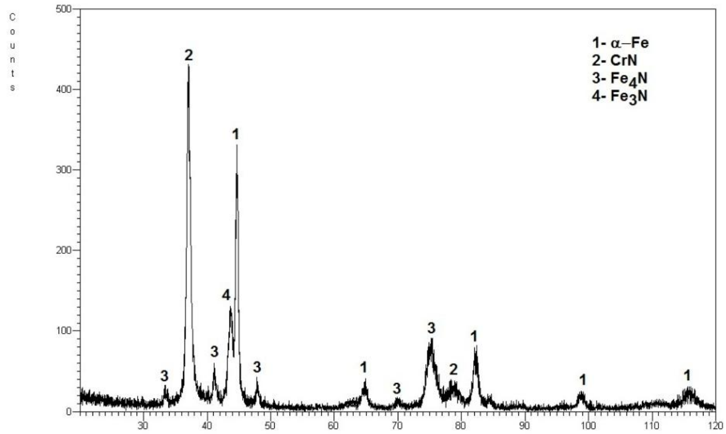


(a) **(b)**

Figure 1. The cross section LOM micrographs of a) single and b) duplex treated steels.



(a)



(b)

Figure 2. XRD patterns of the a) single and b) duplex treated steels.

Figure 4 shows the damages formed on the CrN coatings of the single and duplex treated steels after Rockwell C adhesion tests. Examination of the Rockwell imprint and adjacent region revealed the failure mode of the single treated steel as coating detachment and lateral flaking (Figure 4a), where no coating detachment and lateral flaking were observed for the duplex treated steel sample. The failure mode of the duplex treated steel sample was only chipping (Figure 4b). It can be clearly seen in Figure 4b that the adhesion of duplex treated steel is higher than that of the single treated steel. If the Daimler- Benz Rockwell-C adhesion qualification system (HRC-DB) is concerned, adhesion of the CrN layers of single and duplex treated steels were quatified as HF 5 and HF 1, respectively [9]. In accordance with the surface hardness measurements (Figure 3), Rockwell C indentation tests revealed that application of nitriding process before PVD coating enhance load carrying capacity and adherence of CrN coating.

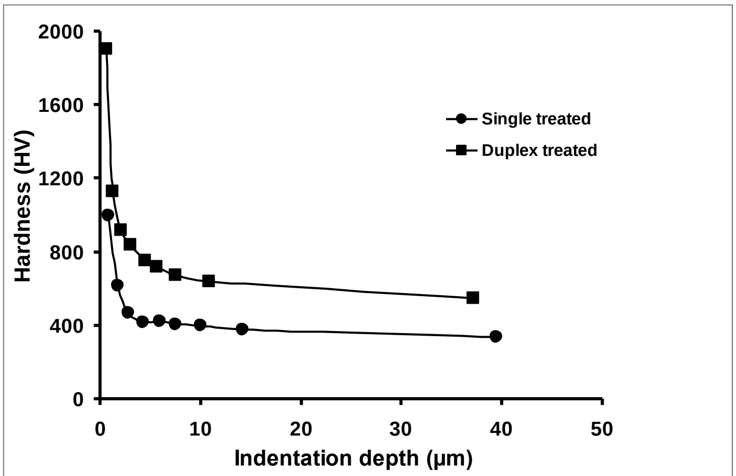
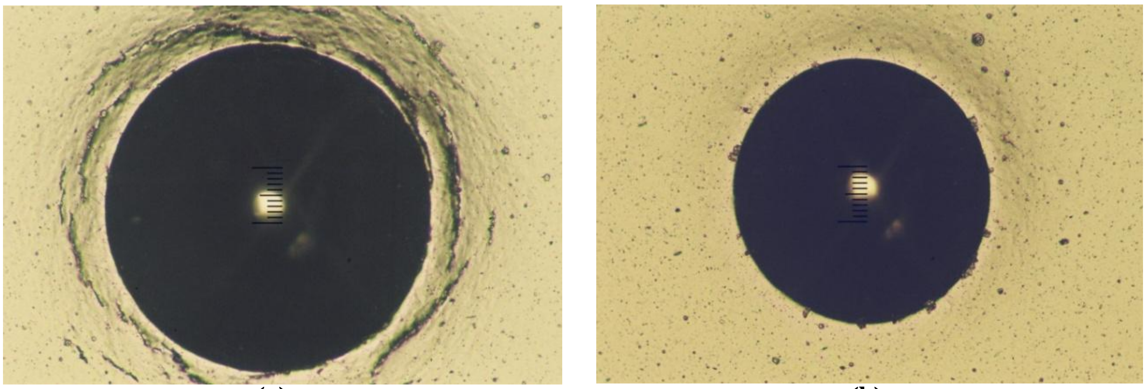


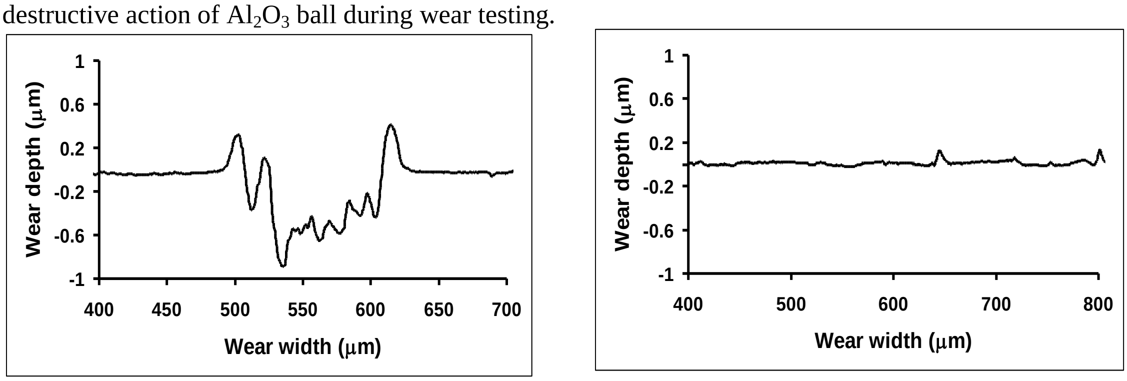
Figure 3. Surface hardness profile of the single and duplex treated steels.



(a) (b)

Figure 4. SEM micrographs showing the damage formed around the indents during Rockwell C tests: (a) the single treated and (b) the duplex treated steels.

The results of the dry sliding wear tests conducted by rubbing Al_2O_3 ball on surfaces of the the single and duplex treated steels are presented in Figure 5 as the 2D-profile images of the wear tracks developed on the CrN coatings. As shown in Figure 5a, wide and deep wear track was formed on the single treated steel. In the case of the duplex treated steel, no measurable wear track was detected on the surface. Thus, rubbing of Al_2O_3 ball polished the outermost surface of the duplex treated steel. In this study, it should be noted that Al_2O_3 ball did not create any measurable wear track on the surface of the duplex treated steel under the same wear testing condition. The depth of the wear track was measured as 0.9 μm for the single treated steel, which were lower than the thickness of CrN coatings. The results of dry sliding wear tests carried out by rubbing of Al_2O_3 ball revealed that, duplex treatment provided remarkable wear resistance as compared to single treatment. In accordance with the results of the hardness measurements and Rockwell C adhesion tests, application of plasma nitriding before PVD process provided extra support for the CrN coating against destructive action of Al_2O_3 ball during wear testing.



(a) (b)

Figure 5. Wear tracks profiles of the (a) single treated and (b) duplex treated steels.

4. Conclusions

Duplex surface treatment (consisted of arc PVD-CrN coating after plasma nitiriding) applied to an hardened AISI 4140 steel provided higher surface hardness, adhesion strength and superior wear resistance as compared to the single surface treatment (arc PVD-CrN coating)

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