Kinetics of Stainless Steel Material by Plasma nitriding Process for sustainable applications

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Abstract. Implantation of ion at low temperature and nitriding through plasma process at low-temperature prevents the corrosion resistance in stainless steel material. The outcome of nitriding process is to form precipitation of CrN on the surface. For the current research work, plasma nitriding techniques are adopted to nitride AISI 304 at low-temperatures at 5hrs, 10hrs, 15 hrs. The enriched layers are formed with combine nitrogen lead to increase in surface hardness. Austenitic and duplex steels produce expanded austenite on the material surface. Behavior of wear was monitored by pin on disc tester. The case depth were monitored and compared with a sample which is not treated. The morphology of surface were monitored and compared with the electron microscopic images. Finally hardness measurements were carried out with Rockwell hardness tester.

Keywords: Plasma nitriding, expanded austenite, Stainless steel, hardness, wear.

1 Introduction

Metallic materials can be made harder, more resilient to wear, and more resistant to corrosion by applying a surface hardening technique called plasma nitriding. It works especially well with ferrous materials like steel. The process creates hard nitride compounds by allowing nitrogen to diffuse into the material's surface [1-3]. After adding nitrogen gas to the furnace, the gas is subjected to an electric potential, which causes it to

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form a plasma. The nitrogen molecules are split up into extremely reactive nitrogen ions by this plasma. The passive layer presence in stainless steel preferred to have excellent resistance to corrosion [4-6]. However, the material can bear low load capability due to poor strength, hardness. To improve the surface hardness, various nitriding like liquid nitriding, plasma nitriding, gas nitriding resulted in decrease of corrosion resistance. As a result of nitriding at temperatures exceeding 400 °C, CrN precipitates on the surface of the material. Material with reasonable thin layers can be treated for extended nitriding durations [7-9]. The area of plasma nitriding had slowed down, due to its high cost. but other techniques like Ion implantation, liquid immersion of nitriding resulted with more efficient results.

Plasma nitriding has the potential to outperform gas nitriding procedures and has the tendency to improve wear resistance in steel. Plasma nitriding, in particular gives alloyed steels a high surface hardness that enhances resistance to wear, scuffs, cracks, galling and other minor defects [10-13]. The development of surface compressive stresses is the primary factor that increases fatigue strength. The components where both hardness and strength are preferred, plasma nitriding are a wise choice. Prior to PVD or CVD coating, plasma nitriding is frequently used to develop compound layer, diffusion layer. Ferritic and duplex stainless steels haven't gotten as much attention up until now to be surface hardened. Because of the composition and its property by nature, the nitride implantation is constrained [14-16].

The workpiece can be simultaneously nitrided on all sides using plasma nitriding. The plasma nitriding parameters like pulse frequency, ion energy, have a significant impact on material case depth. All ferrous materials, including high-porosity sintered steels, plain carbon steels and highly alloyed steels with 12% chromium and above are treated by plasma treatments [17-20]. Plasma nitriding produces hardness of 700 HV and above for materials like special alloyed chromium, aluminium nitrided steels and the applications is on large machinery parts like camshafts, spindles, clutch materials, die casting tools, cold forming tools, sustainable applications like solar power plant components. Around the components, a high-ionization-level glow discharge, or plasma, is produced. Nitrogen-rich nitrides are formed and gets decomposed. Later active nitrogen is formed on the surface [21-23]. A maximum of case depth 20 microns were formed on the compound layer present with enormous combine nitride contents. At low temperature plasma treatment, stainless steels,alloys based on nickel can retain the majority of corrosion resistance, wear resistance [24-26].

2 Experiment adopted

2.1 Material composition

For this project, austenitic stainless steel AISI 304 was used. Raw AISI 304 stainless steels composition was examined and it was discovered that 11% of Nickel, Carbon of 0.08%, Manganese of 1.89%, 0.69% Silicon, 0.039% of Phosphorus, 0.03% of Sulfur, 0.08% of Nitrogen, 18.59% of Chromium, rest iron content [27-31].

2.2 Test for Tribological wear

The specimens were sheared into four and the dimensions were 10 mm diameter, 40 mm length. The ends of the specimen were honed to "U" form made with lathe machine. The sheared specimens were treated to plasma nitriding procedure for 5hrs, 10hrs, 15hrs respectively as shown in Fig 1. Prior to nitriding process, all the specimens were cleaned by acetone [32-35]. Nitrogen is taken upto saturated stage, plasma nitriding were carried out.

Fig. 1. Untreated specimen

The samples were heated using an auxiliary heater and a plasma-nitriding device used in industry (pulsed d.c.). In contrast to prior experiments, argon was also utilized with quite lengthy nitriding periods, along with hydrogen and nitrogen. The ratio of the pulse length to its repetition was 50/100 milliseconds. The gas combinations employed were 40–70% N2, 10–40% H2, and 10–40% Ar [36-39]. The wear behavior were monitored by wear test tribometer and the specifications for the machine is mentioned: Creation Industries make, model TE165SPOD, 2000 rpm max speed, disc diameter 200 mm maximum, pin diameter 20 mm maximum as shown in Fig.2. For the current research work, 110 mm diameter disc with 10 mm thickness were utilized. The parameters were taken up for wear analysis: 20N load, constant speed of 1000 rpm for time duration 2mins. During the wear test, the loss of wear was determined [40-42]. The weight loss was calculated by measuring the difference between specimen held to post & pre wear test.

Fig. 2. Wear test Apparatus

Fig. 3. Electron microscope for scanning

3 Discussion of Results

All specimens were examined for hardness using a Rockwell hardness tester by applying a force of 150 kg for 20 sec. Stainless steel hardness was determined to 20 HRc. The specimens exposed for 5 hrs, 10 hrs and 15 hrs minutes were discovered to have hardness values of 21 HRc, 29 HRc, 32 HRc respectively. Fig 3 illustrates the scanning electron microscope for analyzing the morphology of surface. The specifications are Telefunken Company make, vacuum mode 2.9 nm (25 kV), 14.0 nm (0.9 kV), magnification of 15x to 90000x, and defined with an image size of 400mm x 300m, tungsten filament electron gun is utilized with landing voltage of 0.2 Kv to 30 Kv[43-45].

Table1. Case Depth Determination

Specimens	Case Depth in Microns
Specimen of untreated	--
Specimen treated to 5 hrs	12.8
Specimen treated to 10 hrs	14.6
Specimen treated to 15 hrs	15.4

The values of case depth were measured and it was noted that, no case depth were seen in an untreated specimen as shown in Table 1. For the plasma treated specimen, the obtained depth of case were 12.8, 14.6, 15.4 microns respectively. The untreated specimen surface was magnified. The material peel off was high seen in the microstructure. Due to poor hardness and strength, more wear loss was observed as 0.81 gms. The presence of cracks, holes and voids on the microstructure shown in Fig.4 revealed that the untreated sample is with poor hardness [46-48]. The load upon the sample subjected to speed of 1000 rpm is also a reason behind.

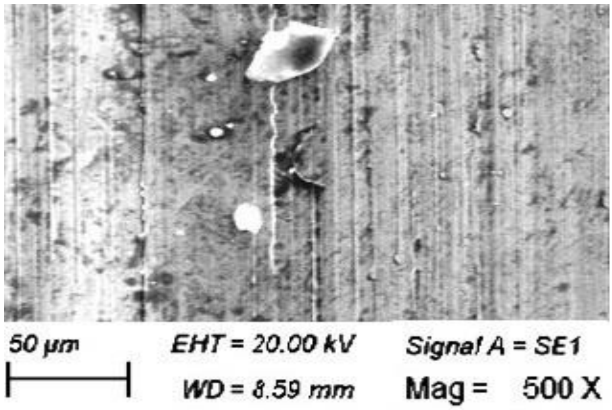

Fig. 4. SS304 specimen surface microstructure

According to the observation, it was seen that 5 hrs plasma treated sample revealed with mild fracture occurred at the surface level, material peel were noticed as shown in Fig 5. Nitrogen atoms gets mated with the alloying elements of stainless steel and were diffused in the surface, resulted in reasonable wear resistance. Loss of material wear was 0.56 gms, material peel was minimized compared to untreated specimen. Loss of wear been decreased as the treatment time increased [49-52]. This work examined the diffusion zone's characteristics, which includes tiny scratches seen in the compound layer and were examined given in Fig 5.

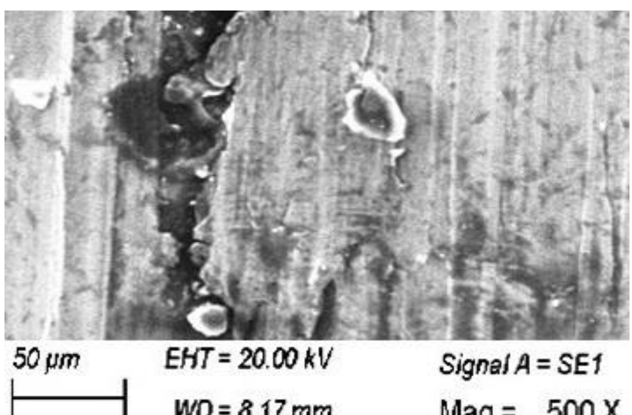

Fig. 5. Nitrided sample microstructure at 5 Hrs

Fig.6 revealed the surface morphology of plasma noted sample that was subjected to 10 Hrs. The microstructure exhibits the chromium nitrides were deposited in patched dark line structure. The minimized wear losses of 0.31 gms were noticed as the time of plasma treatment was increased and. The formation of Iron nitride in bonding zone, where nitrogen is diffused has enhanced the wear resistance. The black dark zone revealed the compound zone layer diffuse to the surface of the material, causing the precipitation of nitrides.

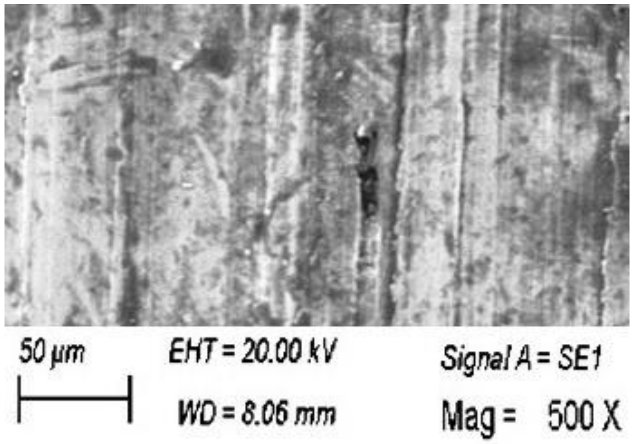

Fig. 6. Nitrided sample microstructure at 10 Hrs

Fig 7 disclosed the presence of high hardened layer had developed on surface plasma treated sample at 15 Hrs, the sample was protected from the external wear. Compared to all the samples, minor cracks were observed. The deposition of combined nitrided content had a grain structure to be in confined level that was processed for 15 Hrs. Due to this, the absence of cracks and holes were observed in the microstructure offering an excellent wear resistance. The material loss was measured and 0.12 gms were noted down.

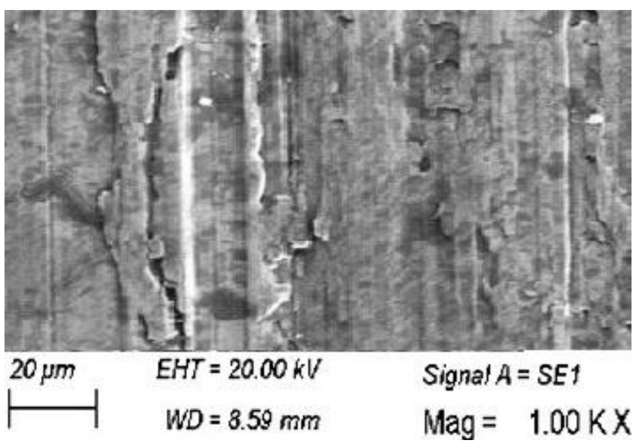

Fig. 7. Nitrided sample microstructure at 15 Hrs

4 Conclusion

Only few works were revealed upon AISI 304 plasma nitriding work and it is regarded as best case hardening method for stainless steel due to formation of nitride layer combined with nickel, chromium and iron. The following results are revealed out from this research work.

The microstructure revealed the wear resistance improvement and comparison were observed with increased temperature and treatment time. Diffusion layer thickness increased and nitrogen was diffused into the material surface, resulting in nitride precipitation. The case depth improved to 15.4 microns. The improvement in hardness were identified from 20 HRC to 34 HRC

In this study, wear behavior of AISI 304 graded stainless steel was examined both under nitrided and non-nitrided conditions. The microstructures of the nitride layer structures have a distinct boundary from the core material. The nitride layers looked darker at greater nitriding temperature, which indicates lower corrosion resistance.

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