Effects of Plasma Nitriding Process on AISI 304 Stainless Steel

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Abstract. AISI 304 stainless steel is a type of austenitic stainless steel that contains a high percentage of chromium and nickel. It is one of the most widely used grades of stainless steel and is commonly used in a variety of applications, including kitchen equipment, food processing equipment, and chemical processing equipment. AISI 304 stainless steel is a versatile and widely used material due to its excellent corrosion resistance, durability, and non-magnetic properties. Low-temperature processes like ion implantation, plasma nitriding can prevent the corrosion resistance of stainless steels by diffusion of plasma into the surface of the material, forming precipitation of Chromium nitride. For this research work, plasma nitriding is carried out on AISI 304 at low-temperatures 550^0C for the time duration of 8 hrs, 16 hrs and 32 hrs. The formation of nitrogen-enriched layers with high nitrogen content promoted to increase in surface hardness. Wear test were carried out with pin on disc machine and the samples were undergone with hardness tests. The microstructures of plasma treated samples were compared with untreated microstructures. It was noted that phase change occurred from austenite to expanded austenite forming a hard layer from the surface level improving the wear resistance of the material.

1 Introduction

Stainless steel has excellent corrosion resistance and is highly resistant to a wide range of corrosive environments. It is also highly durable, and its strength and toughness can be improved through cold working. Additionally, it is non-magnetic, making it useful for applications that require non-magnetic properties [1-3]. Some common applications for AISI 304 stainless steel include: Kitchen equipment, such as sinks, pots, pans, Food processing equipment, such as tanks, piping, chemical processing equipment, such as tanks

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and valves Heat exchangers, automotive components, Medical instruments, implants, Architecture and construction, such as handrails and structural elements [4-6].

Due to the presence of a passive layer in nature, stainless steels have exceptional corrosion resistance. However, they have a rather low load-bearing capability, improvement surface hardness is required. Traditional nitriding by plasma and gas process resulted in decrease in corrosion resistance as a result when treated between 600-700°C leading to chromium nitride precipitates on the surface [7-10]. Hence lower temperatures plasma nitriding are preferred for obtaining good wear resistance.

One of the benefits of plasma nitriding on stainless steel is that it can significantly increase the surface hardness and wear resistance of the material without compromising its corrosion resistance properties [11-14]. This is because the plasma nitriding process creates a thin layer of nitrogen compounds on the surface of the stainless steel, which acts as a barrier against corrosion. The plasma characteristics have a significant impact on the temperature region in ion implantation due to sufficient pulse frequency. Because of low ion energies during gas nitriding process, plasma nitriding process are highly preferred where the material requires resistance to wear and must be free from corrosion [15-18]. The case depth was rich in plasma nitriding process and has improved more wear resistance. High hardness were obtained when compared with other nitriding process. The phase change obtained from expanded austenite from austenite and the process was carried out at 750 °C [19-23].

2 Experimental Procedures

2.1 Composition of Material
For this research work, austenitic stainless steel AISI 304 were taken and the composition was examined as 10% Nickel, 0.09% Carbon, 1.99% Manganese, 0.79% Silicon, 0.048% Phosphorus, 0.02% Sulfur, 0.09% Nitrogen,19.63% Chromium and remaining is iron [24-28].

2.2 Tests for Hardness and Wear

AISI 304 samples were chopped for dimensions of 8 mm in diameter and 42 mm in length. The specimen's edges were honed into a "U" form using a lathe machine. The samples were subjected to the plasma nitriding process for 8 hrs, 16 hrs and 32 hrs respectively. Prior to plasma nitriding, the work pieces underwent degreasing procedure. With a mixture of nitrogen and hydrogen gases, plasma nitriding process was carried out [29-32]. The nitriding were carried out at 550°C. The hardness of untreated samples of AISI 304 stainless steel was measured, it was found that they ranged from 21 HRC for untreated sample 23 HRC, 42 HRC, 55 HRC for sample treated to 8 hrs, 16 hrs and 32 hrs respectively. Wear test were carried out by pin on disc machine: model TE165SPOD, made by Creation Industries. Diameters of 100 mm, 10 mm thick disc were utilized for wear test [26-28]. For the wear test, the following conditions were chosen: 20 N load, 1000 rpm of speed, and time of 2 mins. Wear loss was observed during the wear test. By Calculating, the difference between a pre- and post-wear test, weight loss is observed [33-36].

**Fig.1.** AISI 304 Stainless Steel Sample

3 Results and Discussion

After the wear test, surface morphology was examined using a scanning electron microscope. On the surface of the untreated specimen, the material peel off was very high. It was noted that in untreated specimens, surface fractures occur and material peels were noticed at various location as shown in Fig.2. Due to Poor hardness and ductility, various defects like holes, cracks and some voids were visible. Also due to the load acting on the untreated sample, the surface gets fractured. No case depth was identified.
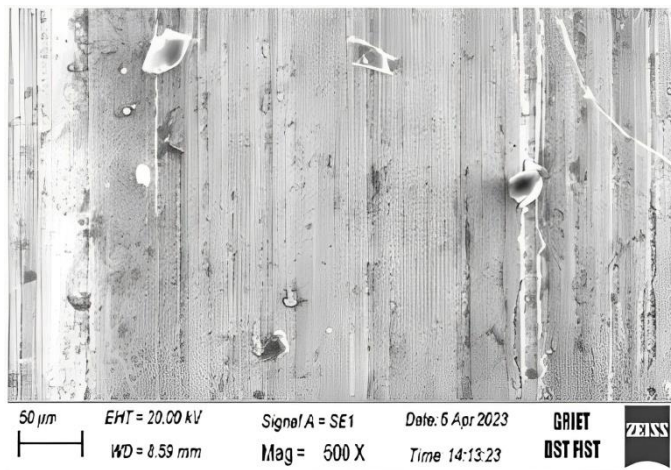

Fig. 2. Microstructures of AISI 304 specimen

From Fig.3, it was noted that the sample treated to 8hrs were diffused with both carbon and nitrogen sedimentation in a dark dotted line patched structure. Wear loss decreased throughout the wear test as treatment time was increased. In comparison with untreated specimen, it was found that there were fewer material peels and cracks. The levels of nitrogen and carbon atom diffusion resulted in improvement of wear resistance. Iron nitride formation in the bonding zone has increased the wear resistance of the substrate due to diffusion of nitrogen. The case depth was sound to be 18 microns. .
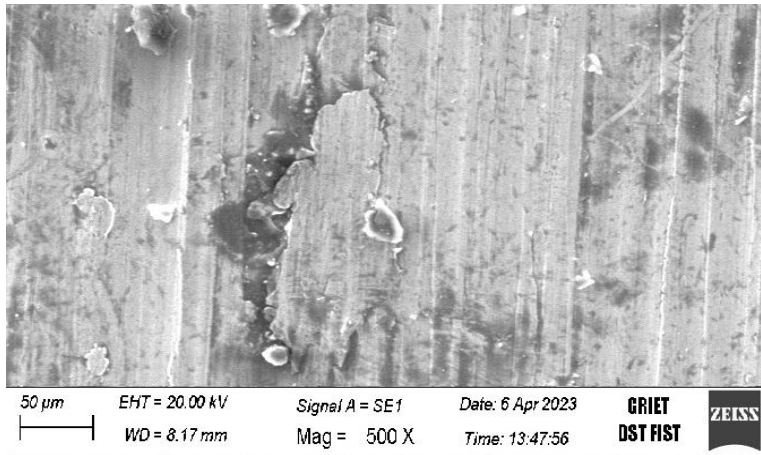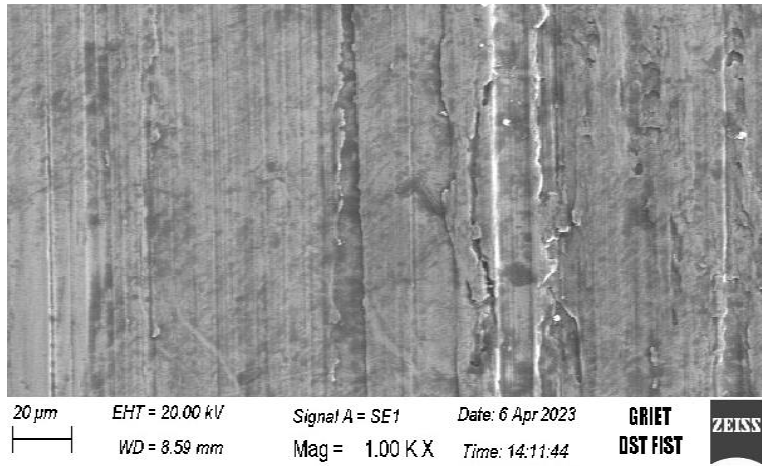
Fig. 3. Microstructures of the nitride samples at 8hrs
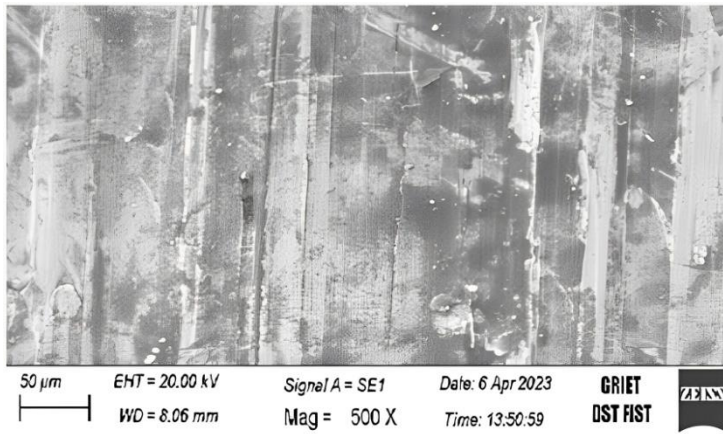
Fig.4. Microstructures of the nitride samples at 16 hrs

From the Fig.4, it was observed that highly hardened layers were developed on the surface of the treated specimen, protecting the material from exterior wear. In comparison to specimen treated to 8 hrs, it was found that there were fewer material peels and cracks. Wear loss decreased throughout the wear test as treatment time increased. High levels of nitrogen and carbon atom diffusion resulted in observable wear resistance. Untreated specimens with coarse grain structure, specimens treated to 8 hrs and 16 hrs, the grain structure were confined. The cracks were reduced and the dark dotted line represents the mixture of chromium nitride, iron nitride, molybdenum nitride and cementite content. Hard wear resistant layers were obtained and the case depth was found to be as 27 microns.

Fig. 5. Microstructures of the nitride samples at 32 hrs

Fig.5 depicts the specimen processed to 32 hrs time had a quite well diffused layer comprised with iron and chromium nitride that had been strengthened by adding carbon and nitrogen to stainless steel. In comparison to other treated specimens, it was found that there were fewer material peels and cracks. Wear loss decreased throughout the wear test as treatment time increased. High levels of nitrogen and carbon atom diffusion generated improved wear resistance. A coating comprised of a mixture of nitrogen and carbon atoms were observed creating a hard and wear resistant layer creating a case depth of 36 microns. The phase changes were made from austenite to expanded austenite.

4 Conclusion

The wear behaviors of AISI 304 grade stainless steel were examined for treated and untreated samples. The following conclusions were obtained.

1. The case depth was found to be 18 microns, 27 microns, 36 microns for the sample treated to 8 hrs, 16 hrs and 32 hrs respectively.
2. The specimen hardness were determined and it was found to be 16 HRc for untreated specimen, 23 HRc, 42 HRc, and 55 HRc for the samples treated at 8 hrs, 16 hrs and 32 hrs respectively.
3. From the wear test, it was noted that the sample treated to 32 hrs has improved the wear resistance when compared to the other treated samples. Its because of the hard layer comprising with chromium nitride and iron nitride formed on the surface level. The phase transformations from austenite to expanded austenite were obtained.

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