Investigation of Wear Characteristics on Gas Nitrided AISI 304 Stainless Steel under Dry Sliding Conditions

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Abstract: Stainless steel is a popular material used in various industries due to its excellent corrosion resistance, high strength, and durability. Gas nitriding has been found significantly to improve wear resistance. Chosen for this research work AISI 304 were examined and the impact of gas nitriding to 12 hrs, 24 hrs and 36 hrs were analyzed for better wear behavior. To evaluate the tribological behavior, wear tests were carried out using pin on disc tribometer. The samples were undergone with hardness tests and the microstructures were examined through scanning electron microscope The difference between the compound layer and the diffusion layer were analyzed on the microstructure. The results of untreated samples and nitride samples were compared.

Keywords: Stainless steel, Gas nitriding, Wear, Hardness, Tribology

1 Introduction

Stainless steel is a modern material whose generic name is used to various grades of steel because of its resistance to corrosion. Stainless steel is the perfect material for many applications since it needs less maintenance, is reasonably priced, and is recyclable [1-3]. It is defined as an alloy of ferrous metals for its minimum chromium content of 10%. Iron, which makes up the majority of steel alloys, has a carbon content that ranges from 0.02% to 1.7% by weight and fluctuates depending on the grade. Particularly in the aviation industry, when alloy type and stainless steel grade are not specified, stainless steel is known as corrosion resistant steel [4-6].

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Understanding stainless steel's characteristics, capabilities in terms of corrosion resistance, product shape availability, and surface polish is essential for successful application in construction field. It is utilised in situations where corrosion and heat resistance are necessary. It is selected based on its mechanical performance, manufacturing efficiency, availability, and corrosion resistance [7-9]. When choosing a grade for a given application, corrosion resistance and mechanical performance are typically the most crucial considerations. In order to improve steel properties, various substances including Sulphur, Phosphorus, Chromium, Manganese etc. are also added. It can be manufactured using the same processes as carbon and other common metals. Most are more productive than carbon steels, but when cold worked, austenitic steels exhibit significant increases in strength and hardness. Because of its properties, stainless steel is used all over the world [10-12].
The key process of nitriding austenitic steel increases its hardness and resistance to wear. These treatments are done above 530°C due to the poor nitrogen diffusivity in austenite. However, the steel's corrosion resistance is significantly reduced in these circumstances because passive layers comprised of iron and chromium nitride are formed [13-16]. It was discovered that the development of new phases occurs during gas or ion treatment below 500°C. Expanded austenite is a phase that has strong mechanical qualities, including hardness and wear resistance, but it also has no detrimental effects on the material's ability to withstand corrosion. Gas nitriding was the focus of the majority of scientific investigations into this subject [17-20].
Austenitic Stainless steel has become the most widely accepted material were corrosion resistance is highly preferred. Since 1980s, better austenitic stainless steels have been developed. These materials are frequently utilised in low temperature applications, such as petrochemical operations, nuclear power plants, and food processing facilities [21-24]. However, due to its weak resistance to wear, this material's application on surfaces is severely constrained. There are numerous surface treatments available to enhance tribological properties. Nitriding, one of the surface hardening techniques available, has the benefit of great dimension stability [25-28]. In order to increase stainless steel's surface hardness, strength, and resistance to wear, nitrogen was added using conventional nitriding techniques.
One of the most common problems in today's sector is the wear and tear of machine parts or tools, which leads to financial losses for society. Financial depreciation losses also include costs associated with replacement costs and downtime. Wear is recognized from which abrasive wear occurs [27-30]. Most industrial wear problems are caused by abrasives. Unfortunately the steel's corrosion resistance is greatly restricted for practical usage due to the presence of nitrides of chromium and/or iron in the nitrided layers produced under specific conditions [31-33].

2 Experimental Procedure

2.1 Material Composition

For this research, AISI 304 was selected. The stainless steel samples used in the current research work had the following composition: Ni - 8.48%, Cr - 18.98%, Ti - 0.83%, C - 0.3%, Mn - 3.31%, remaining Fe. Four pieces of AISI 310 stainless steel were chopped to 10mm diameter and 42 mm length as shown in Fig 1. The specimen edges were honed to "U" shape using a lathe machine [34-36]. Prior to the treatment, the samples were subjected

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to mechanical and electrochemical polishing. The nitriding treatment was carried out in an ammonia environment.

Fig.1. AISI 304 Stainless steel specimen

2.2 Tribological wear test

The specimens were undergone with gas nitriding for time duration of 12 hrs, 24 hrs and 36 hrs respectively. The specimens were heated to 600^0C and iron nitride compounds were deposited to enrich the specimen's surfaces. The case depth were found to be 14 Microns for the Untreated AISI 304 sample, 18 Microns, 23 Microns and 28 Microns for the gas nitrided samples at 12 hrs, 24 hrs, 36 hrs respectively

A pin on disc machine, Model TE15S, developed by Creator Industries were utilized for conducting the wear test [36-39]. A hardened steel disc of 110 mm in diameter and 12 mm thick were used as a disc material for the wear test. Wear test were conducted by applying a force of 30N at a speed of 1200 rpm for a period of 2 minutes. The weight reduction and wear loss were recorded.

3 Results and Discussion

3.1 Scanning Electron Microscope

The microstructures of the specimens subjected to wear test were analyzed using a scanning electron microscope from Em-Crafts Co. Ltd., specifically the Genesis/Veritas Series Model, with a resolution of 3.5nm, 5000x magnification, and an acceleration voltage ranging from 0.5kv to 35kv.The surface morphologies of untreated AISI 304 stainless steel were investigated. As the untreated sample lacks a case depth, a significant level of material peel was discovered. The materials phase is still austenitic and has low ductility and hardness. The fractures and holes in Fig. 2 are the result of the load pushing the sample against the revolving disc. The surviving layer displays the basic metal, while the white layer illustrates material flaking off during wear testing. The entire untreated specimen experienced considerable material loss. As the grain structure was found to be coarse in nature, wear loss was found to be high.

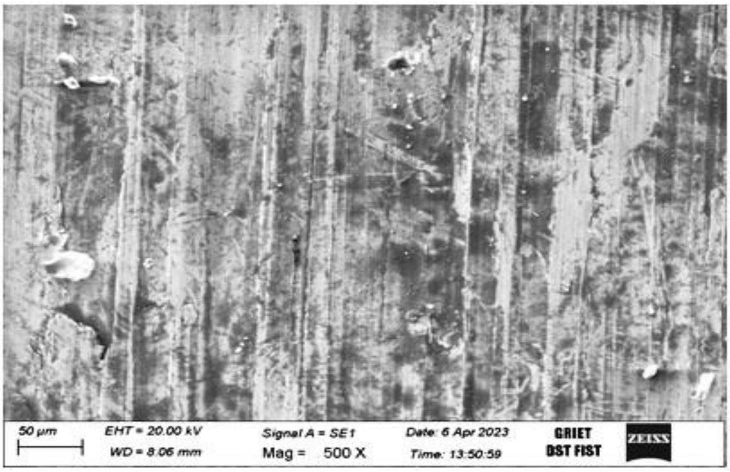

Fig.2. Microstructure of Untreated AISI 304 Specimen

The white layer seen in Fig.3 revealed that the treated sample at 12 hrs exhibited improved wear resistance compared to the untreated sample. The nitriding processes have created a layer of hard material that prevents significant material loss during the wear test. The underlying metal visible in the remaining layer indicates that the treated sample maintained its structural integrity, as there were huge deformations in the untreated sample. The phase change from austenitic gets slowly transformed to expanded austenite creating a hard layer on the surface. The gas nitriding process done at 12 hrs were effective in enhancing the wear resistance and have potential applications in industries where wear resistance is highly referable.

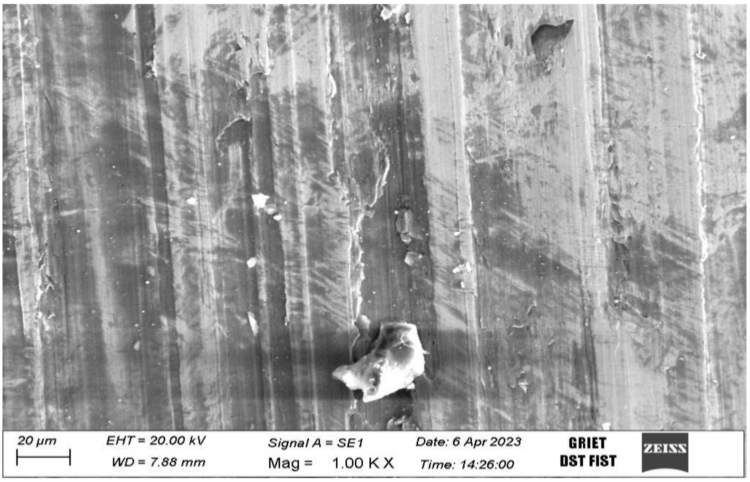

Fig.3. Microstructure of Gas Nitrided Specimen at 12 Hours

The gas nitriding process involved introducing nitrogen gas into the surface of the material for 24 hrs, resulting in the formation of a protective layer that reduced the amount of material loss during the wear test as shown in Fig 4. When the material was magnified to 100 micrometers, it became apparent that a layer consisting of chromium and nitrogen had formed on its surface. This layer acted as a protective barrier against adhesive and abrasive wear, which further reduced the material loss during the wear test. In addition to the protective layer, the gas nitriding process also resulted in a phase transformation of the material into expanded austenite, which further improved the wear resistance. The the presence of the protective layer and expanded austenite phas has reduced amount of material loss.

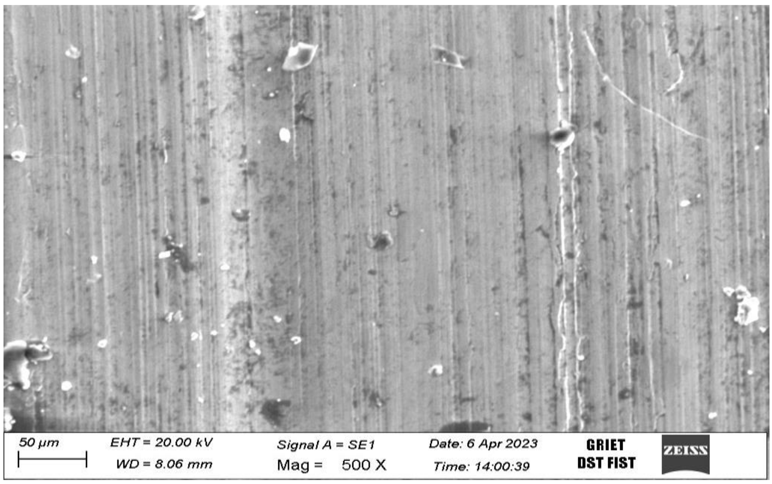

Fig.4. Microstructure of Gas Nitrided Specimen at 24 Hours

The 36 hrs treatment resulted in a highly durable and hardened surface that offered protection against external damage, leading to minimal wear loss during the wear test. Upon closer examination, the grain structure was found to be finer and had fewer fractures compared to other treated sample, indicating a higher level of durability and strength. The increased nitrogen levels during the treatment process led to the precipitate nitrogen on the surface of the specimen, as seen in Fig 5 .The formation of chromium nitride on the surface contributed to the development of a harder and more wear-resistant surface, which provided increased protection against wear and tear. Overall, the 36-hour treatment process led to a significant improvement in the material's wear resistance and durability, making it suitable for use in high-stress environments.

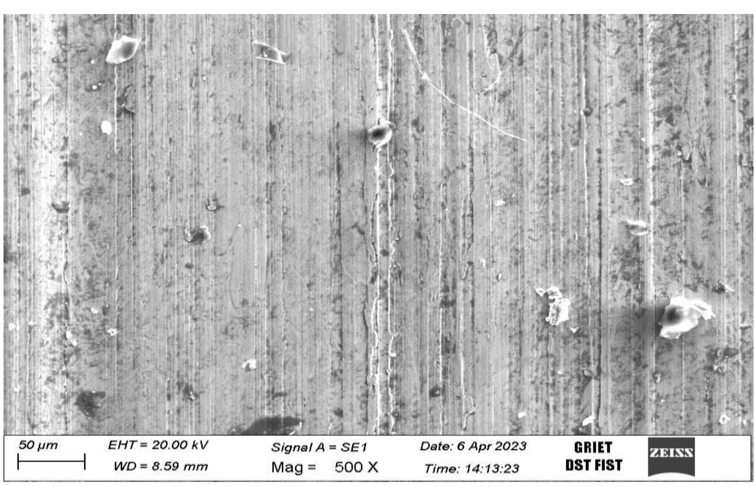

Fig.5. Microstructure of Gas Nitrided Specimen at 36 Hours

The stainless steel specimen that underwent processing for 36 hours had a well-structured layer that was strengthened by the addition of carbon and nitrogen .During the wear test, it was noticed that specimen treated for 36 hrs exhibited fewer material peels and cracks in comparison to the other treated specimens. An increase in processing time resulted in decreased wear loss during the wear test, which was attributed to noticeable wear resistance due to high levels of nitrogen and carbon atom diffusion. A coating consisting of a mixture of nitrogen and carbon atoms was found on a specimen exposed for 36hours, with a high concentration that offered exceptional wear resistance. Furthermore, a finer grain structure was observed in the sample treated for 36 hours compared to an untreated specimen. The sample's surfaces were imparted with high wear resistance due to the optimal ratio of carbon and nitrogen atoms**.**

4. Conclusion

This research work aimed to examine the wear behavior of AISI 304 grade stainless steel treated with gas nitriding process as very few research works were made previously. The main conclusions are as follows:

1. The duration of nitriding has a significant impact on the wear behavior of AISI 304 stainless steel. The depth of the case and the amount of wear loss both decrease as the nitriding duration is increased from 12 to 36 hours. Among the three nitrided samples, the specimen treated for 36 hours exhibits superior wear resistance.
2. A comparison was made between the wear resistance of the untreated AISI 304 stainless steel sample and that of the nitrided samples. The results showed that the specimen treated for 36 hours exhibited a wear loss of 0.03 grams and whereas wear losses of 2.81 grams were obtained in untreated AISI 304 sample.
3. The specimen with the highest hardness were associated with a significant amount of expanded austenite, leading to excellent wear resistance properties. A hardness of 360 H_V were obtained for the sample treated at 36 hrs and 290 H_V were obtained to untreated AISI 304 sample.

Author Contributions

Author 1 – Experimental work
Author 2 – Analysis of Results
Author 3 – Drafting of Documents
Author 4 - Project administration, Writing - Review & Editing

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