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Investigation on AISI 253 Stainless Steel by Gas Nitriding Process for Sustainable Applications

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Abstract. Austenitic stainless steel is highly valued in many industries due to its unique properties, which make it appropriate for various sustainable applications like wind turbine blades, solar panel components, biomass converter equipments. AISI 253 stainless steel were chosen for this research and gas nitrided were underwent at a low temperature of about 550°C. The samples were nitride for 8 hours of nitriding, the sample was found to move from austenitic to expanded austenite phase. Extending the nitriding time to 16 hours resulted in the formation of ferrites and an increasing concentration of nitrogen in succeeding layers. The specimens were carried out with nitriding for 24 hours. Cr-N phase were formed was This new phase contributes to increase in surface hardness. Wear loss and volume loss were analyzed from the wear test. In this work , there was considerable improvement in the wear resistance after 24hours of nitriding. The samples nitrides for 24 hrs also had high hardness of 1080Hv and had negligible wear, volumetric wear loss of the specimens. The microstructure and surface morphology analysis of the nitrided samples was carried out using scanning electron microscopy which helped in establishing the microstructural behaviour of the AISI 253 stainless steel.

Keywords: AISI 253Stainless Steel, Gas Nitriding, Scanning Electron Microscopy, Surface Morphology

1 Introduction

It is well documented that stainless steel has high tensile strength, highly resistant to corrosion and is used widely in many fields and innumerable applications in the automotive industry, aerospace and in many other industries [1-3]. Under the category, AISI 253 is one of the widely known stainless steel preferred for the products, where good resistance to corrosion is required. Most importantly, under the operational conditions including the working environment, AISI 253 stainless steels experienced various heat treatment process

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and undergone with variable wear and tear conditions. The performance and the service life of the mechanical components were improved. [4-6].

As it was observed that , the mechanical properties of AISI 253 is identified to with be poor strengths and hardness. The wear challenges have led the material to emerge the use of Surface Engineering Techniques for enhancing the wear property of stainless steel material. Of all of these techniques, nitriding in using gaseous nitrogen has been most identified for its effectiveness of reconditioning the surface modification of stainless steel alloys with embossed sturdiness to increase the life of the component [7-9]. Gas nitriding is a procedure that is normally done on the surface of a material through the use of nitrogen at high temperatures with an aim of developing a surface layer that is composed of nitrides.

Though there exists a wealth of literature on the ways in which gas nitriding can be used to improve the wear resistance of a number of different engineering alloys [10-13], very few works were undergone on AISI 253 stainless steel through nitriding process. Evaluation of wear characteristics of gaseous ammonia on grade 253 stainless steel is important in improving its performance in applications where wear is significant. Therefore, understanding of the wear mechanisms and the changes in microstructure that occur during the gas nitriding process would be useful in shedding light on the vital issues of wear resistance in stainless steel alloys [14-16].

Thus, the purpose of this research work is to analyze the wear behavior of AISI 253 stainless steel when it is subjected to gaseous nitriding in a dry environment under sliding motion. In performing and to compare the results, experimental investigation were upon made untreated and treated parts to analyze the tribological properties of gas-nitrided AISI 253 stainless steel [17-19]. In addition, attempts are made to evaluate the microstructural changes arised by the means of the gas nitriding process and the behavior of wear were monitored. This study endeavors to contribute to the existing body of knowledge in surface engineering and tribology. The findings of this research hold the potential to inform the development of novel strategies for enhancing the wear resistance of stainless steel alloys, thereby facilitating their widespread adoption in critical engineering applications [20-23].

2 Experimental Work

2.1 Material Specification

AISI 253 is a high performance austenitic stainless steel that offers excellent resistance to oxidation and high-temperature corrosion. The Chemical Composition of AISI 253 are chromium 22%, Nickel 11%, Carbon 0.07%, Silicon 1.41%, Manganese 0.79%, Phosphorus 0.03, Iron Balance. As displayed on Fig.1, the specimens were manufactured to the following dimensions: 50mm in length, 8 mm in diameter [24-27].

Fig. 1. AISI253 sample

2.2 Material processing and testing

Gas nitriding treatment emerged as a promising solution to improve the performance of AISI 253 stainless steel. At a low temperature of approximately 450°C, the gaseous ammonia were penetrated on the material surface, resulting in a transformation of its microstructure and mechanical properties. The subsequent hardness measurements of samples treated for durations of 8 hours, 16 hours, and 24 hours revealed significant increases in hardness, with values reaching 732 HV, 919 HV, 1080 HV. The untreated AISI 253 stainless steel revealed out a hardness value of 340 HV, providing a baseline for comparison. However, to meet the demands of high-temperature applications such as components exposed to seawater and turbine blades, further enhancement of the material's properties was necessary [28-31].

Due to the formation of nitride layer on the surface, the stability of the material were improved by gas nitriding. Gas nitriding is an efficient method in optimising mechanical properties of austenitic stainless steel AISI 253 MA. The formation of a highly protective layer with Nitrides were introduced with Cr-N phase and tranformed the material into expanded austenite phase. When the surface of the material is carefully treated then it shows a dramatic change in its performance. In summary, the gas nitriding process is the method that offers the designed solution for material treatment of AISI 253 MA stainless steel to provide optimum performance in applications where high corossion resistance are preferred [32-36]. With the help of pin on disc tribometer, the behaviour of wear were analysed. The wear test machine specifications are as follows – Pek technology make, diameter of the disc 160 mm, thickness of the disc 8 mm, pin length 40 mm, pin diameter 12 mm, speed of the disc 2000 rpm, load 200 N, frictional force of 200 N. The specimens were undergone with 1000 speed rpm against a load of 20 N for a time period of 2 minutes under dry sliding conditions. The loss of wear were monitored. Therefore it becomes possible for engineers/ researcher to tap into the various surface treatment technologies in order to increase the performance, durability of material and components exposed to severe operations environment [37-40]. This has underlined the vital function of material processing and testing for mechanical property improvements.

3 Discussion on Results

3.1 Scanning Electron Microscope Microstructure

SEM also known as scanning electron microscopy is one of the strongly recommended and powered tools used in material science and engineering to investigate microstructures of material and surface topography at higher resolutions. SEM gives high resolution and as a result the micro structural characteristics such as the distribution of the sample phases, roughness and grain morphology can be clearly defined using the focussed electron beam that scans throughout the surface of the specimen [41-44]. Through this method, the researchers get to Examine the defects in materials, evaluate the structure of materials. For this research work, the SEM machine with following specifications were utilized for this research work: Hitachi make, Resolution: 3 nm secondary electron image, Accelerating voltage: 0.5-35 kV, Magnification: x15 to 100,000, EDAX Genesis Software: Point, line, and area EDS analysis with EDS mapping

Fig. 2. SEM Machine used for Research work

Few studies have been revealed on the AISI 253 stainless-steel material. The untreated sample surface were found to be with more holes and cracks and showed in Fig. 3. As the material is austenitic in nature and due to the poor hardness of the material, the microstructures were revealed with micro holes [39-42]. As a result, the peelings of the material were more, resulting wear loss of 11.42 mm^3. The austenitic phase change remains same and the hardness was identified as 335 HV.

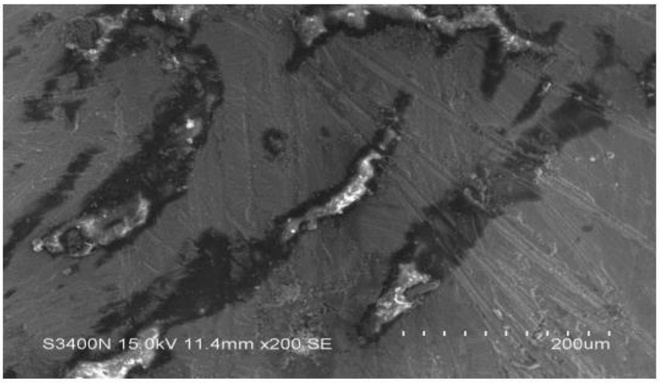

Fig. 3. AISI 253 Microstructure

Fig 4 indicated the surface morphology of Gas nitrided sample at 450°C for 8hours. Fine peels of material were acquired. The load upon the specimen were identified with micro cracks and holes. Due to reasonable hardness, low quantity material were peeled off, during the wear test. The change of enhanced austenitic phase change revealed out the combination of nitrides combined with chromium, nickel and iron. The hardness of the surface was improved. The wear loss were measured and determined as 7.86 mm^3.

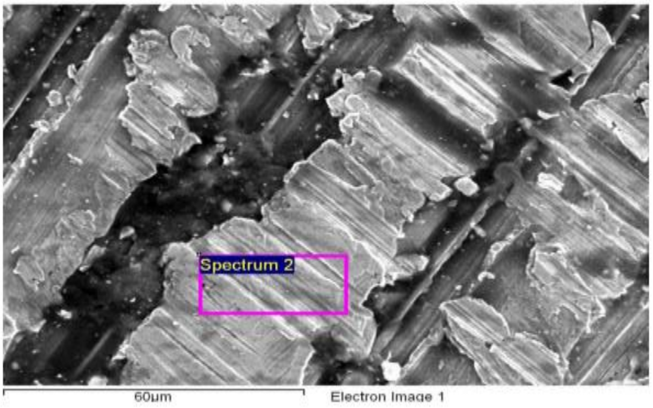

Fig. 4. Gas Nitrided sample surface at 8 hours

Fig 5 indicated Gas Nitrided sample microstructure that has been case hardened to 450°C for 16 hours. The hardness was enhanced as the treatment duration was increased. Due to the enhanced cooling process, the content of combined nitrides increases and stability of the material were improved. The hardness stability were maintained, and the wear loss to be noted as 4.41 mm^3. During the wear test, material peel was less compared to the specimen treated to 8 hrs. The grain structure was noted to be coarse with contents of iron nitrides .

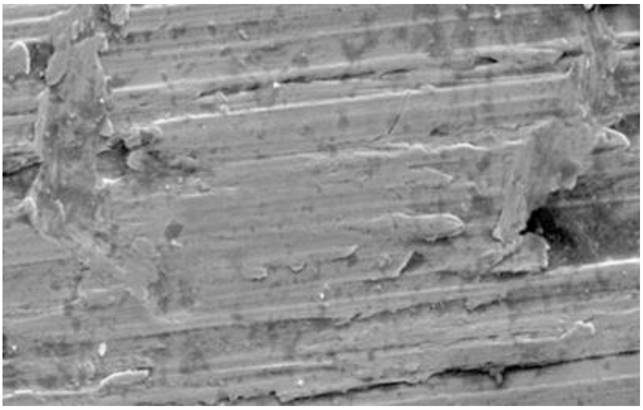

Fig. 5. Gas Nitrided sample surface at 16 hours

The surface morphology of Gas Nitrided sample treated to 450°C for 24 hours were seen in Fig 6. The hardness were highly increased and wear loss decreased. The reason behind is the duration of nitriding process. As the duration of hardening the surface were increased, the change of extended austenitic phase were obtained. Improvements in the Fe4N and CrN stages of compound layer formation were noticed. Hard layers were noted with nitride layers and the alloys in stainless steel were produced with hardened layer. Stability of the material were improved and the hardness were increased [43-46]. The wear loss to be noted as 1.81 mm^3.

Fig. 6. Gas Nitrided sample surface at 24 hours

4 Conclusions

Limited study has been undertaken on AISI 253 stainless steel subjected to gas nitriding techniques, which poses a problem for high-temperature sustainable applications such as seawater-exposed components and turbine blades. In response, a low-temperature gas nitriding procedure was investigated. The study's conclusions were as follows:

(i) Surface morphology study revealed the emergence of a white zone known as the S-stage, which indicates the expanded austenite. Continuing the heat treatment, the Cr-N stage emerged, which is distinguished by extremely hard nitrides made up of ferrite and nitride blends. All gas-nitrided samples exhibited a reasonably thick nitrided layer.

(ii) Wear loss for the untreated sample and the nitride samples was identified as 11.42 mm^3, 7.86 mm^3, 4.41 mm^3, 1.81 mm^3.
(iii) The creation of a hardened layer within the compound zone was responsible for the increased wear resistance. Hardness measurements revealed a rise with extended gas nitriding treatment: 732 HV for 8 hours, 919 HV for 16 hours, and 1080 HV for 24 hours. The untreated sample revealed out with a hardness of 335 HV. However, specimens treated for 16-24 hours showed improvement with the production of compound layers such Fe4N and CrN stages.
(iv) Very rare find outs are made on AISI 253 stainless steel material and further results can be achieved by varying the nitriding temperature and wear test parameters.

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