The Influence of Nitrogen on The Wear Resistance of Ferritic Stainless Steel

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Abstract. Ferritic stainless steel has low properties of wear resistance and hardness. Normal heat treatment on AISI 430 Ferritic Stainless Steel cannot be treated utilised to achieve this task. However, it can be treated through nitriding method. Nitrogen is well known to improve mechanical, wear and corrosion resistance of stainless steels. Normal heat treatment on AISI Ferritic Stainless Steel is not suitable to achieve this task. Thus, the aim of this work is to investigate the influence of nitriding on wear resistance properties of AISI 430 Ferritic Stainless Steel. The influence of nitriding on the steel were observed. Microstructures, hardness test and scratch resistance analysis for wear resistance were conducted and analysed. Nitriding was carried out at 1200°C for 1 h, 3 h and 5h using nitrogen gas as a medium. Martensitic transformation from ferrite was observed on the as-received samples. From microstructure observations, the influence of nitriding also could be seen. Martensite structure shows higher hardness compare to ferrite structure. Therefore, the hardness for 5 h nitrided sample is higher than 1 and 3 h nitrided sample as more martensite structures was formed at 5 h nitrided sample. Scratch resistance was conducted to analyse the influence of nitriding for wear resistance properties. The depth of penetration obtained shows how much improvement on tribology properties are made. Results from testing conducted shows that the improvement of wear resistance properties is dependent on nitriding time. The longer the nitriding time, the more nitrogen is diffused into the sample. As more nitrogen atoms diffused into the steel, improvement on wear resistance properties are higher.

1. Introduction

High-temperature gas nitriding or solution nitriding was introduced as a method of adding nitrogen to stainless steels [1-3]. This method involves a diffusion process for nitrogen to permeate the surface of stainless steel through heat treatment in N₂ atmosphere at elevated temperature. There are three types of nitriding; gas nitriding, liquid/salt bath nitriding and ion/plasma nitriding. In this case study, the gas nitriding process to nitride the stainless steel was selected due to its simplicity, low cost and suitability to nitride the sample at any size.
Gas nitriding is a case-hardening process whereby nitrogen is introduced into the surface of a solid ferrous alloy by holding the metal at a suitable temperature in contact with a nitrogenous gas; usually ammonia resulting in the formation of hardened surface with in fatigue, wear and seizing resistance on machine components or tool. The depth, structure and properties of the surface layer depend on the particular alloying elements contained in the steel and on the processing variables [4].

In this case study, AISI 430 Ferritic Stainless Steel was used. Grade 430 contains chromium that has good corrosion resistance and formability characteristics with useful mechanical properties. Its ability to resist nitric acid attack permits its use in specific chemical applications however automotive trim and appliance components represents its largest fields of applications. These grades can be processed to develop an aesthetically pleasing, bright finish and, hence, are sometimes used for automotive trim and appliance molding. Ferritic stainless steels are used in the manufacture of engine mufflers, nuts, bolts and heat resistant tools. In some cases, such steels require high surface hardness. These grades can be hardened by cold rolling, but cannot be hardened as much as the austenitic alloys [5].

Tribology refers to the science and technology concerned with interacting surfaces in relative motion, including friction, lubrication, wear and corrosion. In many instances, low friction is desirable. The satisfactory operation of joints, for example, whether hinges on doors or human hip joints, demands a low friction force. Work done in overcoming friction in bearing and other mechanical component of machines is dissipated as heat, and its reduction will lead to an overall increase in efficiency [6]. Whenever surfaces move over each other, wear will occur: damage to one or both surfaces, generally involving progressive loss of material. In most cases wear is detrimental, leading to increased clearances between the moving components, unwanted freedom of movement and loss of precision - often vibration, increased mechanical loading and yet more rapid wear, and sometimes fatigue failure. As in the case of friction, though high wear rates are sometimes desirable; grinding and polishing, for example, employ wear processes to remove material rapidly and in a controlled manner, and a small amount of wear is often anticipated and even welcomed during the ‘running-in’ process in particular kinds of machinery [7].

One of the method of reducing friction, and often wear is to lubricate the surface. However in this case study, the method of nitriding was used to reduce friction and wear on AISI 430 Ferritic Stainless Steel. Thus, the wear resistance properties for as-received sample and nitrided sample were compared to investigate the influence of nitriding for this type of stainless steel. Scratch resistance test was used in this case study.

2. Materials and method

Material used in the study was AISI 430 steel with the composition of 0.04 wt% C, 0.28 wt%Si, 16.3 wt%Cr, 0.36 wt%Mn and Fe balance. Nitriding was carried in the tube furnace at 1200°C for 1 h, 3 h and 5 h.

Metallography was prepared by mounting using bakelite. The samples were observed under the Zeiss optical microscope Wear resistance was performed using scratch resistance equipment with SEM model. Hardness Testing was conducted using LECS LM247 AT micro-hardness Vickers.

3. Results and discussions

3.1 Microstructure observation

Fig. 1 shows the microstructure of as-received samples with mainly the presence of ferrite phases.
After nitriding for 1 h, the transformation of ferrite to martensite on the surface was present and depicted as in Fig. 2. The diffusion of nitrogen was initiated from the surface to the inner core of the steel. The formation of martensites were developed with the formation of needle like structure and concentrated near the surface. It was estimated that one quarter of nitried layer was formed i.e. 2.5 mm.

After 3 h of nitriding, more transformation of martensites from ferrites were observed and this is shown in Fig. 3. The figure illustrates thicker formation of martensites compare to 1 h nitrided sample. Some part was almost covered by transformed martensite.

When nitriding the sample for 5 h, the whole thickness of the steel was transformed from ferrites to martensites and this is shown in Fig. 4. This indicates that high concentration of nitrogen was diffused into 5 h sample when compared to nitriding the samples for 1 h and 3 h.
3.2 Scratch resistance analysis

Scratch analysis was conducted to obtain the wear resistance properties of the nitride samples. Nitrided samples have low penetrations depth when compared to as-received sample. The normal force was set at 50N.

Fig. 5 shows the depth of penetration for as-received sample which is in the range of -350 to -550 µm. For the 1 h nitrided sample as in Fig. 6, the depth of penetration is in the range of -200 to -300 µm which is less than the as-received sample. The depth of 3 h nitrided sample as in Fig. 7 is in the range of -49 to -60 µm. This sample has less depth of penetration compared to the later samples. The 5 h nitrided samples as in Fig. 8 has the least depth of penetration of -50 µm which is a consistent depth of penetration throughout the sample thickness. This shows that the concentration of nitrogen is homogeneous throughout the layer of steel,
Fig. 7: scratch resistance - 3 hours nitriding

Fig. 8: scratch resistance - 5 hours nitriding

The overall depth of penetration of the scratch test is summarized in Fig. 9. The figure shows that 5 h nitrided sample has the lowest wear resistant of -50 µm and this is followed by the 3ah and the 1 h nitrided samples. The as-received has the lowest wear resistant of -550 µm.

Fig. 9: Overall scratch tests

3.3 Hardness Test

The hardness values at the surface for the as-received, 1 h, 3 h and 5 h nitrided samples are 200, 400, 420 and 430 Hv, respectively (Fig. 10). It shows that the highest concentration of nitrogen contributes to the highest hardness. In this case, it reveals that 5 h nitrided sample has the highest hardness and the as-received sample has the lowest hardness value. The samples revealed that the core location have the lower hardness compared to near the surface of the nitride samples. This can be inferred that higher
concertation of nitrogen with a longer holding time of nitriding produces the highest hardness compared to a lower holding time for nitriding.

![Fig. 10: Hardness Test - all samples](image)

4. Conclusions

The influence of nitrogen on AISI 430 Ferritic Stainless Steel by nitriding affect the transformation of ferrite to martensite, high wear resistance and high hardness. The highest wear resistance is for 5 h nitrided sample with the depth of -50 µm depth of penetration and the least wear resistant is the as-received unnitrided sample with a depth of penetration -550 µm. The results reveal that sample nitrided for 5 h achieved the highest transformation of martensite from ferrite, the highest wear resistance and hardness value. Longer holding time, more nitrogen diffused and more improvement was made on the tribological properties of the steel. Wear resistance properties are improved by nitriding. As the time for nitriding increased, more nitrogen diffused into the samples. Higher nitrogen concentration was found near the surface when compared to the inner core of the sample. Hence, the longer the nitriding time, more improvement is made to tribological properties, in particular.

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