EXPERIMENTAL INVESTIGATION ON EFFECT OF HEAT TREATMENT ON TRIBOLOGICAL PROPERTIES OF STAINLESS STEEL FOR MARINE AND OFFSHORE APPLICATIONS

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ABSTRACT

Stainless steel material has a wide variety of applications in chemical industries, food industries & mainly in marine and offshore applications because of its high corrosion resistance. Though it is highly resistive to corrosion, it exhibits lesser resistance to wear. This hampers the applications of stainless steel material in tribo-corrosive applications. Using coating is one of solutions to avoid wear which may be uneconomical and impossible to maintain the coating for a longer period of time. In the present study, stainless steel 304, 316, & 430 are taken for study which has majority of marine and offshore applications. The tribological properties studied are hardness, friction coefficient, and wear resistance. Surface hardness using Vickers hardness test and Wear resistance of the materials were studied for different exposure period to corrosive atmosphere. ASTM G48 Standard accelerative corrosion testing method was used to carry out corrosion. Results show that as the time period of exposure increases initially the surface hardness decreases for few days and later there is a slight increase and remains constant for non-heat treated materials. Wear rate increases as time of exposure increases. Heat treatment was carried out for Tempering and quenching. Annealed specimens have higher wear rate than Tempered specimens as the time period of exposure increases. This may be due to grain refinement and less internal stresses in annealed materials. In tempered materials there is considerable increase in hardness and wear resistance as the material gets tougher but lesser compared to the specimens without heat treatment.

KEYWORDS: Pitting Corrosion, Stainless Steel, Wear rate, Coefficient of Friction, Hardness

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1. INTRODUCTION

Stainless steel 304, 316, 430 exhibit excellent resistance to corrosion and have better mechanical properties. In view of these properties, stainless steel materials have wide applications in petrochemical, chemical, structural, food industries and marine & offshore applications [1]. These materials are also used in applications where surface hardness and wear resistance are also of great importance. Hence study of tribo-corrosive properties of materials like SS 304, 316 & 430 is quite essential in the present scenario. Pitting corrosion is one of the most dangerous, rapidly spreading and exponentially growing type of corrosion, especially observed in the materials used for marine and offshore applications. Several researches have been carried out on heat treatment of stainless steel materials. Heat treatment has been found to vary their properties depending on applications where they are used. Mahesh B.D. et al. studied the grain structure, hardness and wear behavior of super duplex stainless steel AISI 250 by doing heat treatment followed by water & oil quenching. Quenching improves the hardness and wear

resistance of AISI 250 material[2]. AISI 304 Lean duplex stainless steel has a two phase microstructure with same amount of austenite (Chromium-nickel) & ferrite (chromium). Both gives an extraordinary mechanical property (hardness, impact toughness etc) & corrosion resistance [2,3].

Figure 1.1: Structures and components failed due to corrosion

Figure 1.1 shows various types of pitting corrosion occurring in different applications. Naveen et al. studied wear properties of AISI 304 as a function of heat treatment by oil quenching. Four variables i.e. sliding velocity, sliding distance, varying load & weight loss are considered to calculate wear volume. By heat treatment, hardness increased because sigma phase present plays a major role on tribological properties of stainless steel. [3] KuanJaing et al. investigated the effect of sintering heat treatment in the slurry coating process on the hardness, microstructure & tribological properties. Results show that sintering heat treatment influences the hardness & wear resistance significantly. S Kumar et. al. [5] studied sliding wear characteristics of with and without heat treatment of SS 304 stainless steel. Different cooling conditions are being as furnace cooling, air, cutting grade oil and water at room temperature. Microstructure and micro-hardness of respective specimen are studied. Normalized samples show less wear compared to oil quenched samples. Annealed samples show medium wear with a stable trend.[9] Nadum [6] studied SS 304 material mechanical properties like tensile, hardness, fatigue and wear by with and without heat treatment. For heat treatment normalizing for 1150, 1100, 1150° C is done along with tempering process at 300° C to remove internal stresses. It reveals that thermal treatment has favorable influence in mechanical properties at optimum properties for 1100° C.[10] Maximum hardness and minimum coefficient of friction were obtained by Cobalt-boride (Co-B) coatings at 15.16% along with heat treated at 400° C.[7, 14] Corrosion resistance decreases as a function of heat effect and surface roughness.[8 19] Heat treatment affects the corrosion resistance of stainless steel. By all the above literature, we will come to know that heat treatment affects the tribological properties of stainless steel. But yet study of effect of heat treatment for tribological properties (tribo-corrosion) on corrosion of stainless steel is required. Hence study of corrosion on wear behavior of stainless steels with and without heat treatment is aimed in this work.

2.EXPERIMENTAL STUDY

2.1 Materials:

Stainless steel 304, 316 and 430 materials which are easily available, economical and have wide applications have been selected for study of Corrosion effect on hardness, wear rate and coefficient of friction considering for with and without heat treatment for different corrosion time periods. These materials were purchased by Tables 1 & 2 show the chemical compositions and mechanical properties of Stainless Steel materials used.

Table 2.1: Chemical Composition of Stainless steel 304, 316 & 430

Grade		C%	Mn%	Si%	P%	S%	Cr%	Mo%	Ni%	N%
304	Max.	0.07	2.0	0.75	0.045	0.030	18.5	-	10.5	0.10
316	Max.	0.08	2.0	0.75	0.045	0.030	18	3.00	14.0	0.10
430	Max.	0.12	1	1	0.04	0.030	18	-	0.5	-

Table 2.2: Mechanical properties of Stainless steel 304, 316 & 430

Grade	Tensile Strength(MPa) min.	Yield Strength 0.2% Proof (MPa) min.	Elongation (% in 50mm) min.	Rockwell Hardness (HR B) max.
304	515	205	40	92
316	515	205	40	95
430	450	310	22	85

2.2 Experiment and Testing

2.2.1 Procedure for Pitting Corrosion

Corrosion test were carried out as per ASTM G48 standards. Pour 600 ml of ferric chloride test arrangement into the 1000 ml test beaker. On the off chance that example bigger than the standard are utilized, give an answer volume of at any rate 5 ml/cm²(30 ml/in²) of explicit surface zone. Move the test measuring glass to a steady temperature shower and permit the test answer for go to the balance temperature of intrigue. Suggested temperatures for assessment are 22 ± 2°C and 50 ± 2°C. Below is procedure of experiment.

- Place the sample in a glass support and submerge in the test arrangement after the solution has reached an ideal temperature. Keep test arrangement temperature constant throughout the test.
- Cover the test vessel with a watch glass. Specimens kept in a solution for 48 hours, 96 hours, 144 hours, and 192 hours.
- Remove the specimen after scheduled time from the solution. Wash with water and clean with a nylon bristle brush under running water to eliminate consumption items. Plunge in methanol and air-dry.
- Weigh each specimen to 0.001gram or better and reserve for examination.

Figure 2.2: Solution of ferric chloride and de-ionized water Figure 2.3. Placing of specimens in Ferric Chloride solution.

Figure 2.2 & 2.3 show the solution of ferric chloride and distilled water stirred well in which the specimens are dipped and kept for accelerated corrosion. The test temperature was maintained at room temperature throughout the experiment.

Hardness Test

Vickers hardness testing was carried out at a load of 30kg and dwell time of 10 to 15 Seconds. Two diagonals of the diamond shaped indentation were measured and mean were taken, respective hardness number was found as Vickers hardness number. Readings were taken at three different places, thrice and the mean was considered.

Wear Test

Pin on disc experiment was conducted on the entire specimen for studying the tribological properties. These specimens were subjected to different heat treatment processes and corrosive time exposure. ASTM G99-95a standard test procedure was adopted to conduct wear test. Load of 2kg and disc speed of 400rpm was taken. The travelling distance for the specimen on disc was taken as 2000 meters. Specimen was of 10mm diameter and 50mm in length.

Microscopic Study

Study of wear surface at microscopic level after processing is important for the tribological properties of the specimen. It gives a clear picture regarding wear microstructure study. Here in this work we have used Computerized Optical Microscope of 40X magnification and taken images of the surfaces before and after wear. Specimens of with and without heat treatment, with and without corrosion were taken for study. The specimens were first polished very well and washed with acetone to get clear images. Then the microscopic images of all the specimens were taken and analysis is being done.

3. RESULTS AND DISCUSSIONS

The results of mechanical and optical microscopic investigations are discussed under the following sections.

3.1 Hardness Test

Hardness test was conducted on each specimen. Three readings were taken and the mean of it was considered for with and without heat treatment for 0, 48, 96, 144, & 192 hours of exposure to corrosion using accelerated pitting corrosion experiments. Load of 30kg was considered for stainless steel and dwell time of 12 seconds.

Figure 3.1 shows the Vickers hardness results of SS 304 without heat treated material shows that there is a remarkable decrease in hardness number as the time period of exposure to corrosion atmosphere increases. For heat treated materials as corrosion time period increases & hardness decreases, but when compared to heat treated and without heat treated, heat treated materials have higher hardness number and can resist corrosion as time period of corrosion increases.

Figure 3.1: Time of corrosion versus VHN for SS 304, SS316 & SS430.

Vickers hardness results for SS 316 without heat treatment shows that there is more decrease in hardness number of material. For heat treated material hardness number is increased till 144 hours of exposure and then it is decreased. But when it is compared in between heat treated and without heat treated, heat treated material has higher hardness than without heat treated. Vickers hardness results of SS 430 without heat treatment decreases as time period of exposure to corrosion atmosphere increases. For heat treated material hardness is being increased till 144 hours and then it is decreased. But when it is compared in between heat treated and without heat treated, heat treated material has higher hardness than without heat treated.

3.2 Tribological Properties

Wear test was conducted on each specimen. Three readings of each time period of corrosion were considered for with and without heat treatment. Time periods 0 hours, 48 hours, 144 hours, & 192 hours of exposure to corrosion atmosphere using accelerated corrosion method was conducted. Based on ASTM standards and literature survey, the disc radius of 50mm, and disc speed of 400rpm, for a distance of 2000m was considered and experiment was carried out.

Figure 3.2 shows the wear rate of SS 304 without heat treatment is increased as the time period of exposure to corrosion atmosphere is increased. For heat treated material, wear rate is increased till 144 hours and then further it is decreased. When compared to both heat treated and without heat treated, without heat treatment material has more resistance to wear compared to heat treatment.

Figure 3.2: Plot showing Wear Rate versus Time of corrosion of SS 304, SS 316 & SS 430.

Wear rate for SS 316 without heat treatment is decreased for 2 days but again increased as the time period of exposure to corrosion atmosphere is increased. For heat treated material wear rate is increased as the corrosion time period increases. When both heat treated and without heat treated are compared, without heat treated has more wear rate compared to with heat treated. Wear rate for SS 316 without heat treatment increases as time period of exposure to corrosion atmosphere increases. For heat treated material wear rate decreases as time period of exposure increases. When both heat treated and without heat treated are compared, without heat treated materials have less wear rate than heat treated at initial stage and for larger time period of exposure to corrosion atmosphere, heat treated materials have better wear rate.

Figure 3.3: Plot showing Coefficient of Friction of SS 304

Figure 3.3 shows the Coefficient of friction for SS 430 without heat treatment decreases for 48 hours, but then as time period of exposure to corrosion atmosphere increases coefficient of friction increases. For heat treated material coefficient of friction increases till 144 hours and then it is decreased for 192 hours. But when both heat treated and without heat treated are compared, heat treated has low coefficient of friction than without heat treatment. SS 316 without heat treatment specimen's coefficient of friction, which increases till 96 hours and then decreases as time period of exposure to corrosion atmosphere increases. For heat treated material also coefficient of friction increases with respect time period. But when both heat treated and without heat treated are compared, heat treated has lower coefficient of friction than without heat treatment. Coefficient of friction of SS 430 without heat treatment, which increases till 96 hours of corrosion

period, and then it is decreased. For heat-treated specimens, coefficient of friction increases for 48 hours and further decreases. Both when both are compared, without heat treatment has higher coefficient of friction than heat-treated specimens.

3.3 Microscopic Study:

Figure 3.10 Shows the optical microphotographs of wear loss on the surface of stainless steel 304, 316, & 430, with and without heat treatment, corroded and non-corroded.

Figure 3.10. Optical Micrographs showing (a) SS 304 non corroded without heat treatment.(b) SS 304 corroded without heat treatment. (c) SS 304 non corroded with heat treatment.(d) SS 304 corroded with heat treatment.(e) SS 316 non corroded without heat treatment. (f) SS 316 corroded without heat treatment.(g) SS 316 non corroded with heat treatment. (h) SS 316 corroded with heat treatment.(i) SS 430 non corroded without heat treatment.(j) SS 430 corroded without heat treatment.(k) SS 430 non corroded with heat treatment and (l) SS 430 corroded with heat treatment.

Comparing all the three types of stainless steel with corrosion and without corrosion, we can easily observe pit growth in corroded specimens because of which wear rate is more. When it is compared with heat treated and without heat treated, heat treated specimens has refined grain structure and very ductile in nature compared to non-heat treated specimens. By observing all microscopic images, SS 304 (fig. a, c) and SS 316 (fig. e, g) has higher wear rate compared to SS 430 which reveals that SS 430 (fig. i, k) is highly resistive to wear. Heat treatment above 800°C is been done for austenitic stainless steel (SS304 fig. b, d and SS316 fig. f, h) to get fully austenitic solid. Below which they precipitate chromium rich carbides. Using lower carbon content reduces this problem i.e. sensitization. When SS 304 is compared to martensitic and ferritic steels, the nickel content adds higher corrosion resistance property to SS 304. SS 430 (fig. j, l) known as ferritic stainless steel because of having more chromium and less carbon when compared to martensitic grades. It has a stable phase in all temperatures. For this reason, with heat treatment also they won't get hardened and have lower strength but high ductility, toughness and resistive to wear.

4.CONCLUSIONS& FUTURE WORK

- Hardness test was conducted on all three specimens with & without heat treatment for different time period of exposure to corrosion environment. Results reveal that for SS 304 Hardness properties increases with heat treatment & decreases as the corrosion period increases. For SS 316 & SS 430 heat treated specimens, there is a remarkable resistance to corrosion compared to non-heat treated specimens, but as time of exposure increases hardness of these specimens decreases because of pits occurring at the surface and weaken the bounding of grains at the microstructure of these materials.
- Specimens of SS 304, SS 316 & SS 430 without heat treatment have better resistance to wear when compared to heat treated specimens. But when it comes to the exposure time to the corrosion environment, as exposure time increases wear rate increases for both type of specimens.
- Coefficient of friction of SS 304, SS 316, & SS 430 is less for heat treated specimens compared to non-heat treated specimens. But as the exposure to corrosion atmosphere increases, there is a decrease in coefficient of friction compared to non-corroded specimens. This is being due to pits penetrating and also expanding larger in size and multiplying in number. These pits also disturb the bonding between the grains and weaken the resistance to wear.
- Detailed study of rearrangement of grains, microstructure study will give a clear picture regarding loss in surface strength of materials as the time period of exposure to corrosion environment increases.
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