Effect of Heat Treatment on Wear Behaviour of Austenitic Stainless Steel

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Abstract Stainless steel is one of the most widely used steels for structural applications. This paper quantifies the effect of heat treatment on the wear resistance behaviour of stainless steel 304 grades using pin on disc method. Ageing at different temperature ranges imparts hardness to the SS304 specimen which in turn affects the wear resistance characteristic. Different wear parameters have been calculated using Archard's equation and wear scar diameter method. Microstructure has been studied using optical microscopy. Scanning electron microscopy has been used to investigate the wear mechanism.

Keywords Wear · Stainless steel · Archard's equation · Wear mechanism

1 Introduction

Austenitic stainless steel with its superior mechanical and tribological properties is now used extensively in strategic applications. Stainless steel 304 grade is a preferred material for structures with high structural integrity and aggressive service environments. It cannot be usually heat treated, but can be annealed at different temperature ranges to bring it into application of refrigeration, chemical, paper and food processing industry. Some applications such as conveyor belt, screws and bolts have relative sliding motion against different components. This leads to wear of the mating surface and can ultimately lead to component's failure [1]. Stainless steel 304 possesses adequate toughness and sufficient ductility to resist failure for a considerable long duration of time. They can also be readily welded with similar and dissimilar metals for various applications [2]. 304 grade austenitic stainless steel is

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Table 1 Chemical composition of SS 304 steel (%wt)

Element	C	Cr	Si	Mn	Ni	P	Fe
Composition	0.025	18.2	0.5	1.6	8.5	0.045	Balance

Table 2 Chemical composition of EN 31 steel

Element	C	Cr	Si	Mn	S	P	Fe
Composition	1.1	1.3	0.25	0.55	0.042	0.040	Balance

a high alloy Cr–Ni–Mo steel. It has high pitting resistance equivalent number which makes it significantly corrosion resistant. The literature reveals that the previous researchers have worked in the field of estimating wear characteristic of austenitic stainless family [3–7].

But very limited literature is available regarding the effect of heat treatment on austenitic stainless steel 304 grade's wear characteristics [8]. This paper aims to investigate the effect of heat treatment on hardness, its correlation with microstructure and related wear behaviour. Pin on disc technique has been used to study the wear behaviour in laboratory. Various wear property parameters have also been calculated using Archard's equation and scar diameter method. Wear mechanism has been studied using scanning electron microscopy (SEM).

2 Material

Stainless steel 304 plate was received in the dimension of 250 × 250 mm. The chemical composition of stainless steel 304 is given in Table 1.

The pins made out of SS304 were made to slide against the disc made of EN 31 bearing steel. Table 2 gives the chemical composition of EN31 bearing steel used.

3 Experiment

3.1 Specimen Preparation

Pins were prepared from the SS304 plate in the dimensions shown in Fig. 1.

Fig. 1 Geometry of pin specimen

Table 3 Heat treatment of pin specimen

Specimen nomenclature	Solid solution annealing			Sensitization		
	Temperature (°C)	Soak time	Cooling medium	Temperature (°C)	Soak time	Cooling medium
HT 1	1050	60	Water	500	60	Air
HT 2	1050	60	Water	620	270	Air
HT 3	1050	60	Water	650	270	Air
NHT	As received specimen, no heat treatment					

3.2 Heat Treatment

The pin specimens were subjected to the following heat treatment as shown in Table 3.

3.3 Pin on Disc Wear Test

The pin on disc test was conducted on Ducom wear testing machine with a load of 5 N at a rotating speed of 500 rpm for 15 min duration. The volume loss in material was calculated using two methods: (i) change in scar diameter (ii) weight loss of pin due to material removal. Figure 2 represents the schematic of wear testing machine used in this experiment.

4 Results and Discussion

4.1 Microstructural Examination:

The specimens in as-received and heat-treated condition were polished with emery paper up to a grade of 2000 and then with a diamond paste. The mirror polished

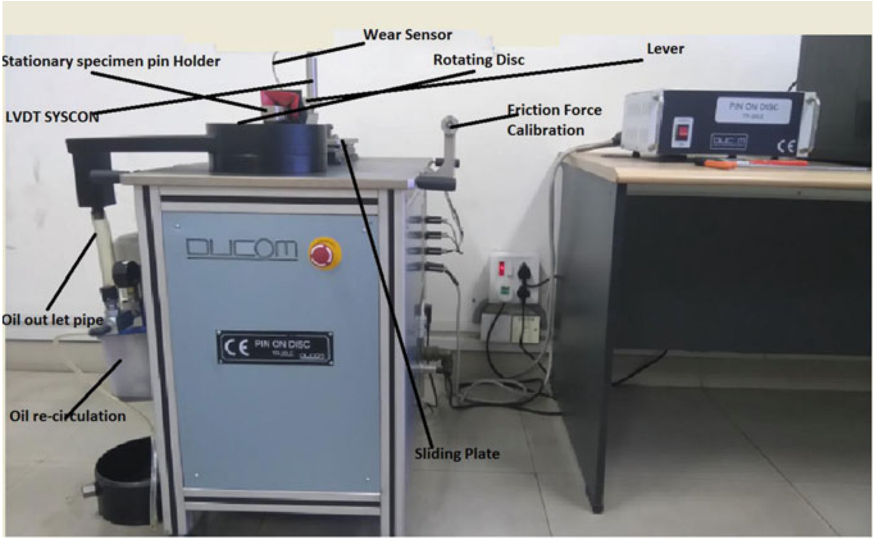

Fig. 2 Pin on disc wear test setup

specimens were then etched with Villela reagent to reveal the microstructure. Optical microscope was used to observe the developed microstructure owing to the heat treatment. The microstructure images in Fig. 3 clearly indicate that heat treatment has lead to grain coarsening. This in turn will affect the hardness of the specimen, thereby influencing the material loss due to wear.

4.2 Microhardness Measurement

Microhardness measurement carried out with a load of 10gf with a dwell time of 10 s is shown in Fig. 4.

4.3 Dry Sliding Wear Test

Dry sliding wear test was performed for specimens with a load of 5 N. The wear track radius was kept 60 mm with a rotational speed of 500 rpm for 15 min. Sliding distance is represented mathematically as per Eq. 1.

$$\mathrm{SD} = \frac{\pi DNT}{1000} \tag{1}$$

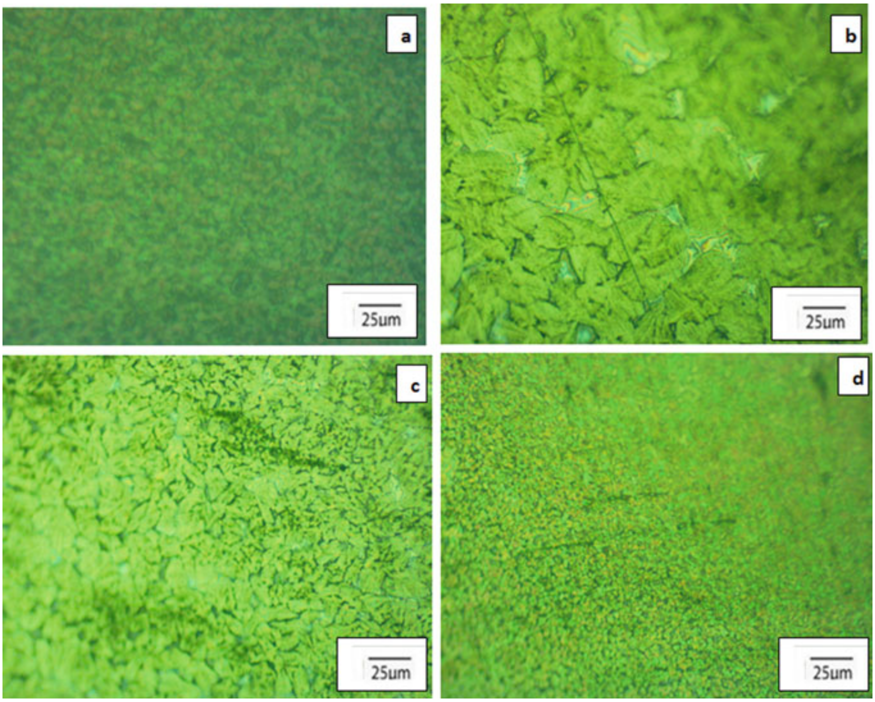

Fig. 3 Microstructure of SS 304 specimen **a** non-heat-treated NHT **a** HT 1, **b** HT 2, **c** HT 3, **d** HT 4

Fig. 4 Hardness measurement

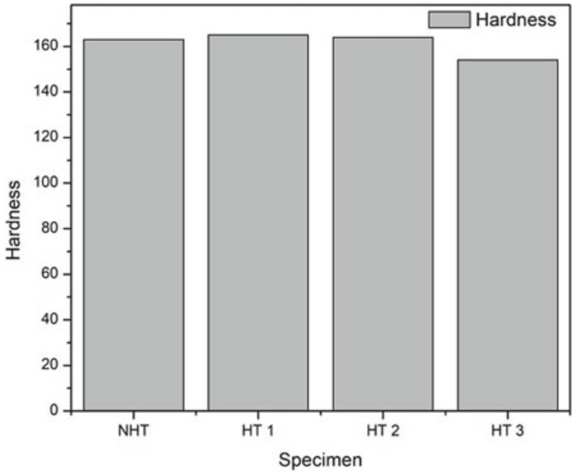

Table 4 Wear based on loss in weight

Specimen	Initial weight (W_i)	Final weight (W_f)	Loss in weight (ΔW)	Volume loss (mm^3)	Wear (mm^3/m)
HT 1	8.0837	8.0790	0.0047	0.05853	4.14×10^{-4}
HT 2	7.7866	7.7632	0.0234	2.9140	20.6×10^{-4}
HT 3	7.9982	7.9654	0.0278	3.4620	24.5×10^{-4}
NHT	7.4296	7.3938	0.0308	3.8536	27.1×10^{-4}

where SD is the sliding distance in metre, D is the wear track diameter in mm, N is the rotation of disc measured in rpm, and T is the time of pin sliding over disc in minutes. Here, D is 60 mm, N is 500 and T is 15. This makes the sliding distance to be 1413 m in total. Before and after each run of 15 min, the pin specimens were weighed on an electronic weigh balance with and accuracy of ±0.1 mg. Table 4 represents the initial and final weight of pin specimens. This weight loss data is used to calculate the volume loss as per Eq. 2. Volume loss is further used for calculating the volume loss per unit sliding distance which is generally referred as average wear in mm^3/m.

$$\Delta V = \frac{\Delta W}{\rho} \tag{2}$$

where ΔV is the volume loss in mm^3, ΔW is the weight loss in grams occurring due to wear and ρ is the density of pin material in g/cm^3.

$$Q = \frac{\Delta V}{\mathrm{SD}} \tag{3}$$

Here, Q is the average wear occurring in mm^3/m, SD is the sliding distance in metres which is 1413 m in this case.

A comparative plot of all specimens for wear occurring measured mm^3/m is shown in Fig. 5. The data in Table 4 and Fig. 5 clearly indicate that the highest loss in weight due to wear occurs in non-heat-treated specimen. Heat treatment improves the wear resistance characteristics, specifically in HT 1 condition where weight loss reduces multiple folds as compared to others.

Wear coefficient and wear resistance are another important parameters which are used to define the wear resistance characteristics of a material. Equations 4 and 5 represent the mathematical expression for these parameters as per Archard's equation.

$$K = \frac{Q * H}{Fn} \tag{4}$$

$$R_w = \frac{1}{K} \tag{5}$$

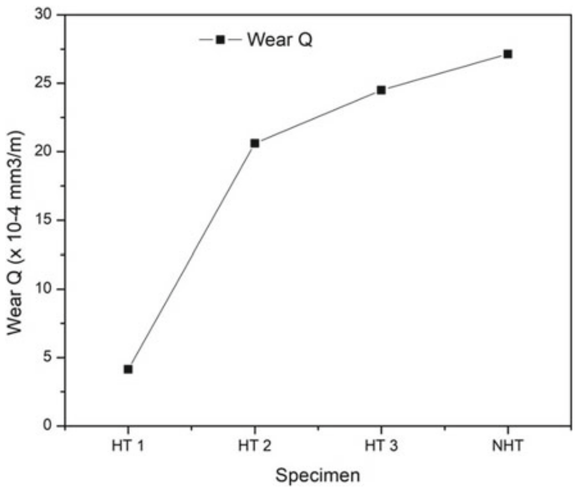

Fig. 5 Comparison of wear among specimens

Table 5 Wear coefficient and wear resistance

Specimen	Q (mm^3/m)	Wear coefficient (K)	Wear resistance (R_w)
HT 1	4.14×10^{-4}	13.60×10^{-3}	73.53
HT 2	20.6×10^{-4}	67.22×10^{-3}	14.88
HT 3	24.5×10^{-4}	75.46×10^{-3}	13.25
NHT	27.1×10^{-4}	88.48×10^{-3}	11.30

where K is the wear coefficient, Q is the average wear in mm^3/m, H is the hardness of pin specimen and R_w is the wear resistance. Table 5 represents the wear coefficient and wear resistance value for all the specimens calculated using the above-mentioned equations.

Figure 6 shows comparative plot of wear coefficient and wear resistance.

4.4 Wear Calculation on the Basis of Wear Scar Diameter

Each pin specimen after undergoing the rotationary sliding motion on disc developed scar on its surface. This scar is mainly due to the material loss at the interface of pin and disc. The scar is measured precisely using vernier calipers, and then based on mathemtical formular given in Eq. 6, the volume loss is calculated.

$$\text{Volume Loss} = \pi * (\text{wear scar diameter in mm})^4/64 * (\text{sphere radius in mm}) \quad (6)$$

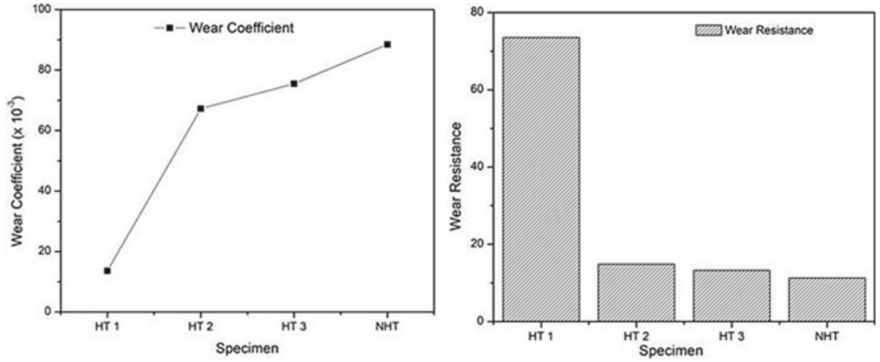

Fig. 6 Comparative plot of wear coefficient and wear resistance

Table 6 Wear scar diameter and volume loss

Specimen	Wear scar diameter (mm)	Volume loss (mm^3)
HT 1	2	0.261
HT 2	3	1.325
HT 3	3.5	2.454
NHT	4	4.186

Table 6 represents the data of wear performance calculated as per the wear scar diameter method.

4.5 Wear Mechanism

Scanning electron microscopy was used to estimate the wear mechanism occurring. SEM images shown in Fig. 7 were taken at the face of pin's sliding surface. The

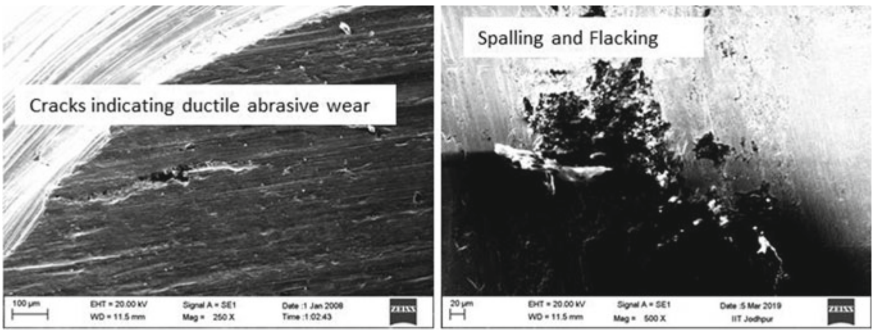

Fig. 7 Wear mechanism

material removal is suggested to occur by ploughing mechanism. The cuts developed at the pin's face suggest ductile abrasive wear, whereas the SEM images taken at the end of sliding shows the spalling and flacking.

5 Conclusion

- Austenitic stainless steel of 304 grade has been given suitable heat treatments.
- Pin on disc technique has been used to estimate the dry sliding wear behaviour in three heat-treated and one non-heat-treated as-received condition of specimens.
- Wear characteristic parameters namely; loss in weight, volume loss, average wear, wear coefficient and wear resistance have been calculated using Archard's equation.
- Wear scar diameter has also been used to calculate the volume loss occurring.
- Heat treatments improve the wear resistance of SS 304 steel.
- Heat treatment 1 specimen exhibits the best wear resistance, with its resistance value turning out to be almost 6.5 times better than that of material in as-received condition.
- Heat treatment 2 and Heat treatment 3 show an improvement of marginal 1.13 and 1.1 times in wear resistance as compared to as-received non-heat-treated specimen.
- Applications involving rigorous wear due to sliding, SS304 can be suggested to be used in heat treatment 1 condition for better performance.

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