

Finite Element Wear Behaviour Modeling of Super duplex stainless steel AISI 2507 Using Ansys

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Abstract: In this paper the finite element simulation approach has been employed for the work that has been recently carried out by Davanageri et al.(2017). The super duplex stainless steel AISI 2507 material was heat treated at 850°C with different ageing time (30, 60, 90 minutes), followed by water quench. The heat treatment was carried out to encourage the precipitation of inter-metallic secondary sigma phase (σ). The study of dry sliding wear behavior was carried out with the pin-on-disc equipment. The heat treatment and ageing time increases the hardness of the duplex steel, resulting in improved wear resistance. The Archard wear model and finite element software ANSYS WORKBENCH-16 was used to determine the wear volume loss. The specific wear rate or dimensional wear coefficient is the most significant factor in the wear volume calculation and it varies with material and operating parameters. The study shows that frictional coefficient varies with material properties (hardness) at similar operating condition. Finally the results reveal that there is a good agreement that exists between the simulated (FE) values and those of the experimental values.

1. Introduction

Duplex (austeno-ferritic) stainless steels (DSS) are well recognized for their good mechanical properties due to the presence of the two phases, austenite (γ) and ferrite (δ) [1-2]. DSS is one of the major structural members used in chemical fields due to its high strength, corrosion resistance, and hardness [1-4]. Super duplex stainless steel shows an extensive property of pitting resistance equivalent number (PREN) greater than 40, hence it is widely used in marine applications. DSS when exposed to temperature in the range 500°C to 950°C precipitates secondary inter metallic phases like R phase, Chi phase and sigma phase. Heat treatment of DSS increases the mechanical properties like strength and hardness of duplex stainless steel at a temperature of 850°C and reduces the toughness, due to the precipitation of sigma phase and secondary austenite phase [3-6]. The increase in the hardness is directly related to the abundant sigma phase precipitation in the microstructure during the heat treatment. The considerable amount of research has reported to improve the mechanical properties of duplex stainless steel [4-8]. Predicting wear is one of the most important challenges in



the whole engineering field. DSS are widely used in paper, chemical, petrochemical, refinery, nuclear, marine and automobile industry where in major components like pumps, valves, and bearings and fasteners have relative sliding motion and self mating condition and a very few attempts have been made to predict the material loss on the contacting surfaces of duplex stainless steel. Wear is defined as the material loss that occurs on the surface of contacting bodies in relative motion. Wear leads to the gradual removal of particles from the contacting surface because of the dependent motion between them [7-10]. The wear performance of materials is influenced by several factors viz., condition of contact between surface, contact temperature, pressure, frictional forces, coefficient of friction and hardness of the material. Several works has been done to study the wear behaviour and finite element simulations to predict the wear performance of materials [10-19]. Experimental study and FEM simulation of wear performance of different composite materials and metals are one of the major research fields in tribology. Pin on disc is one of the main experimental set up for wear analysis and for FEM analysis different software packages like ANSYS and ABAQUS were used. The first attempt to develop wear model to predict the wear performance made by Archard [11] and this model was incorporated in wide range of wear studies and results obtained shows good agreement with experimental wear studies. Firaol et al. 2015 studied about the detailed analysis of wear measurement and wear analysis of overhead line contact wire using ANSYS workbench software [13]. The simulation of contact wire is performed on pin on disc model, where the model is used for sliding contact analysis. Researchers proposed a method of calculation of wear through FEM analysis and further, wear analysis is based on Archards wear model[14]. A study was carried out to investigate the sliding wear and calculation of wear is based on the Lim and Ashbys wear map, Archards wear law and selected the ANSYS software was used for analysis [14]. Sullivan developed a mathematical model to relate the applied load and the wear which also includes other factors collectively can assumed as Archards wear coefficient[15]. Authors have conducted the experiment of FE analysis of sliding wear in metals. Model is formulated in legrangian frame work. Archard law is used for the wear calculation. Model is validated using rotation of brass pin in steel disc [16]. Veenhuizen et al. 2006 carried out study of wear in both FEA and pin on disc experimental methods for CVT belt. FE analysis of wear is done in ABAQUS software and wear fracture of belt was analyzed using FE methods and suggested remedies. Experimental determination of wear life has both cost and time effect [17]. The simulation of wear and life prediction can helps product developers in many manners as, designing better products, propose better maintenance plans to hold off failures and prevent financial losses. In this paper, recently published work (Davanageri et al.2017) on wear behaviour of AISI2507 Super Duplex Stainless Steel results were tested [22]. The finite element simulation of the wear test is carried out in ANSYS using Archards FEA model.

2. Material and methodology

The chemical composition of super duplex stainless steel is shown in Table 1 and detailed experimental procedure to carry out the heat treatment, wear test and hardness test are available in the (Davanageri et al.2017). The process parameters used in wear test are shown in the Table 2.

Table.1 Chemical composition of AISI 2507 SDSS (wt. %) [22].

C	Cr	Ni	Mo	Mn	Si	N	Fe
0.019	25.387	6.714	3.77	0.738	0.328	0.028	Bal

Table.2 Process parameters [22].

Parameters	Units	Range				
Normal load	N	10	20	30	40	50
Sliding velocity	m/s	3	3	3	3	3
Sliding distance	m	800	800	800	800	800

2.1 Determination of wear volume and wear coefficient.

The wear volume loss was determined by the weight loss method and details are given below.

$$\Delta W = W_1 - W_2 \quad \text{----- (1)}$$

Where

ΔW is the weight loss of the specimen.

W_1 is the initial weight of the specimen.

W_2 is the final weight of the specimen.

Volume loss of the specimen is calculated as given below.

$$V = \frac{W_1 - W_2}{\rho} \times 1000 \quad \text{m}^3 \text{----- (2)}$$

Where V is volume loss of the specimen

ρ is the density of the specimen

The dimensional wear coefficient obtained by the following equation

$$k = \frac{V}{F \times S} \quad \text{m}^3/(\text{N-m}) \quad \text{----- (3)}$$

Where, S is the sliding distance and F is the normal load

3. Results and Discussion

In this paper the finite element simulation approach has been employed for the work that has been recently carried out by Davanageri et al. 2017 [22]. The results reveal that the hardness of the heat treated specimens increase with increase in ageing time as shown in figure 1. Further, the wear test results indicates that wear resistance increase with increase in the ageing time in heat treated specimens compared to the solution treated specimen and shown in figure 2. It was found that the hardness and wear resistance increases while the coefficient of friction decreases (figure 3) owing to the precipitation of secondary sigma phase during the heat treatment

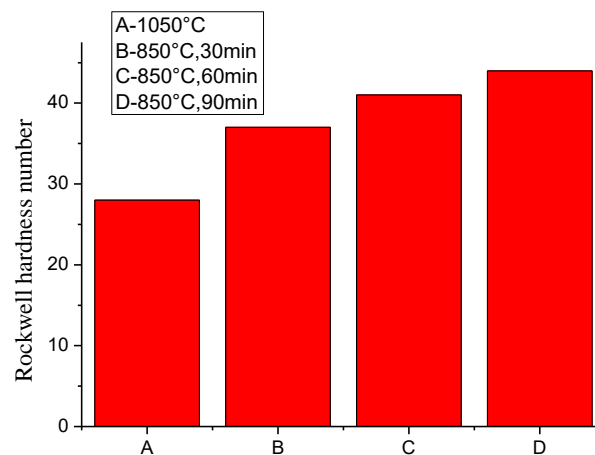


Figure 1. Rockwell hardness number of cone indenter (120°) for 150 kgf. [22].

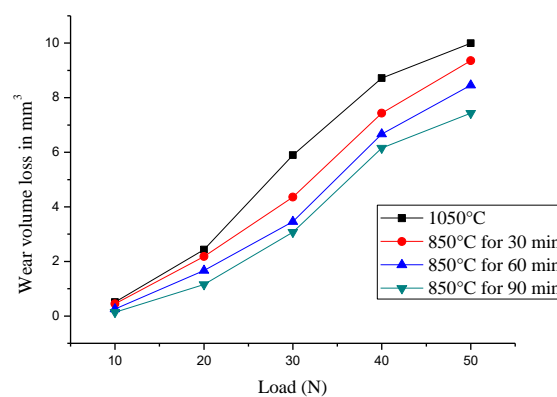


Figure 2. Variation of load vs. wears [22].

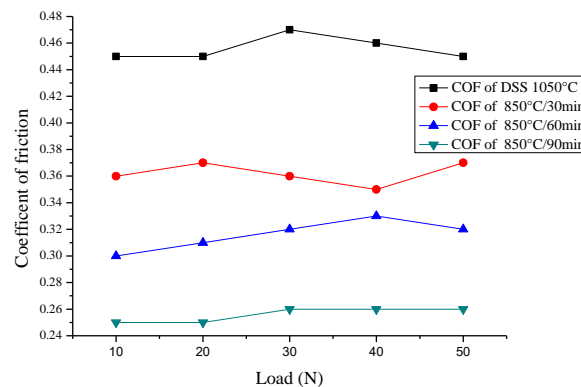


Figure 3. Variation of coefficient of friction vs. Load [22].

3.1 Finite element modeling and simulation

The effectiveness of finite element analysis in prediction of wear is, its capability to consider accurately both the parameters i.e. the contact pressure and frictional stresses developed and the relative progressive change occurred in the surface geometry due to material removal in three dimensional components. Many authors have reported the use of finite element analysis to simulate and predict the wear [11-19]. Feasibly the most conclusive way to authenticate the FEM results is to compare them with the known experimental results. FEM analysis of pin on disc wear test is carried out using ANSYS WORKBENCH-16. The direct measurement of wear loss is not possible through the software. To determine the wear loss, the average value of contact pressure between pin (specimen) and disc, also frictional stresses during the rotation is determined using ANSYS software. Further with help of Archard wear volume was calculated. In finite element analysis the wear phenomenon was considered as nonlinear process. The solution for nonlinear problems was obtained by considering transient structural analysis. The various steps involved in transient analysis are listed below.

- Inputting the engineering data's of the materials
- Modelling of the pin and disc geometry
- Meshing of the geometry
- Identify the contact pairs.
- Designate contact and target surfaces.
- Define the contact surface
- Define the target surface.
- Define/control the motion of the target surface
- Apply necessary boundary conditions
- Define solution options and load steps
- Solve the problem
- Review the results

3.2 Modelling of the pin and disc geometry

The model shown in Figure 4 (a and b) consists of two parts, the lower part is a steel (EN64) disc steel that rotates with predetermined velocity and upper part of it is a specimen (pin of 10 mm diameter) that stays stationary on rotating disc. For the application of load on the rotating disc a rigid contact surface is used. Here the famous Archard [11] approach taking into account the wear process is introduced to formalize the wear kinetics. The model was developed based on equal and steady state wear rate assumption. The geometric modelling can be done on Geometry of ANSYS Workbench for creating 3D prototype that used for wear simulation and contact analysis.

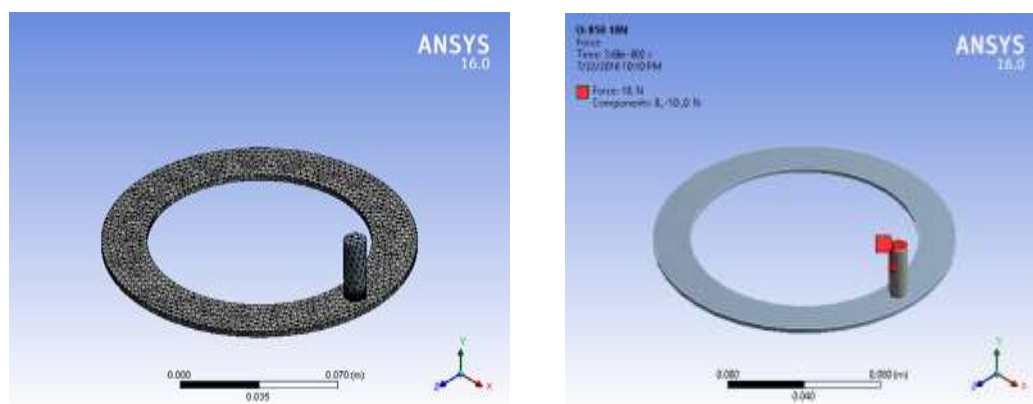


Figure 4. (a) Meshed geometry of a pin-on-disc wear test in ANSYS (b) Application of force in FEA analysis of pin-on-disc wear test.

3.3. Contact pressure developed in the pin surface

The contact pressure developed in the pin surface increases with the increase in load as shown in the Table 3 for solution treated and for heat treated specimens. The contact pressure developed between the pin and disc is solely geometrical property and is dependent on applied normal force, contact area of the pin and the pressure distribution along the pin surface for a load of 10N shown in figure 5. From figure 5 it was observed that pressure distribution along the pin surface was minimum at the central portion of the pin and maximum at the edges of the pin and this trend found to be similar in all other heat treated specimens. Further the obtained contact pressure data can be used in Archard equation to determine the wear volume loss instead of analytical contact pressure calculation. It was also observed that FEM value of contact pressure is slightly on a higher side compared to analytical value of contact pressure.

Table.3 Values contact pressures

Load (N)	Analytical CP(Mpa)	C.P DSS/1050 (Mpa)	C.P DSS/50C/30	C.P DSS/50C/60	C.P DSS/50C/90 (Mpa)
			0	0	

			(Mpa)	(Mpa)	
10	0.1273	0.1404	0.1397	0.1394	0.1391
20	0.2546	0.2813	0.2801	0.2794	0.278
30	0.3820	0.4227	0.4201	0.4194	0.4184
40	0.5093	0.5526	0.5601	0.5469	0.5581
50	0.6366	0.703	0.7008	0.6994	0.6977

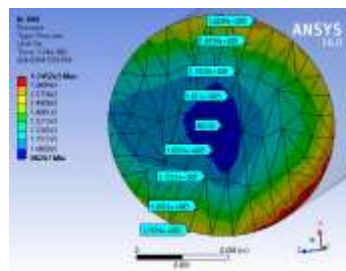


Figure 5. Contact pressure distribution along the pin surface for a load of 10N

3.4 wear coefficient (k)

The better agreement between experimental wear volume and FEA wear volume completely depends on wear coefficient k . The wear coefficient initially determined from experimental wear volume using Archard's wear law and are shown in Table 4. Further with the value of k and contact pressure obtained through FEA simulation used for determining the wear volume.

Table 4 The value of wear coefficients.

Load (N)	K for DSS/1050 (mm ³ /Nmm)	K for DSS/850/30 (mm ³ /Nmm)	K for DSS/850/60 (mm ³ /Nmm)	K for DSS/850/90 (mm ³ /Nmm)
10	6.41x10 ⁻⁸	5.608x10 ⁻⁸	3.205x10 ⁻⁸	1.762x10 ⁻⁸
20	1.522x10 ⁻⁷	1.361x10 ⁻⁷	1.041x10 ⁻⁷	7.211x10 ⁻⁷
30	2.45x10 ⁻⁷	1.816x10 ⁻⁷	1.442x10 ⁻⁷	1.281x10 ⁻⁷
40	2.724x10 ⁻⁷	2.323x10 ⁻⁷	2.083x10 ⁻⁷	1.923x10 ⁻⁷
50	2.499x10 ⁻⁷	2.339x10 ⁻⁷	2.115x10 ⁻⁷	1.858x10 ⁻⁷

3.5 Calculation of wear volume using frictional stresses developed in the pin surface

The calculation of wear volume in FEM by Archard's law

$$V = k \times F \times S$$

For wear depth $=h = k \times p \times S$

p- pressure at the pin surface

$$p = \frac{s}{\mu}$$

s-frictional stress , μ -frictional coefficient ,k-coefficient of wear ,S-sliding distance

$$\text{Wear volume} = V = h \times A$$

$$\text{Wear volume} = V = \frac{k \times S \times s \times A}{\mu}$$

3.6 Frictional stresses and wear volume for solution treated specimen's at 1050°C.

Frictional stresses developed during the FEA simulation for solution treated specimens (1050°C) are shown in figure 6-10. It was observed that frictional stresses have increased as the load increased and are at the center, it was found to minimum and maximum at the edges. The average values of frictional stresses are shown in Table 5 used for calculation of FEA wear volume and results are compared with experimental wear volume. The figure 11 indicates the experimental and FEA wear volume are in better agreement.

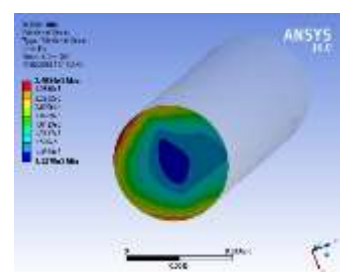
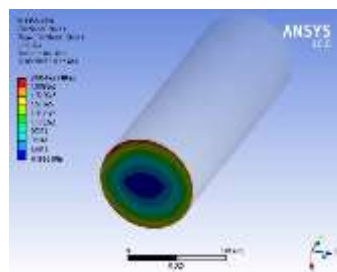
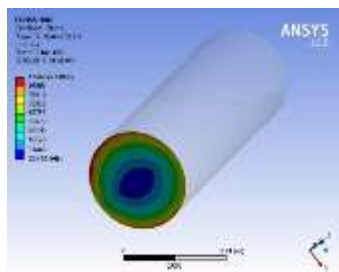


Figure 6. Frictional stress for 10N. Figure 7. Frictional stress for 20N. Figure 8. Frictional stress for 30N.

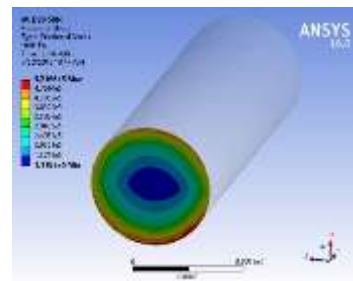
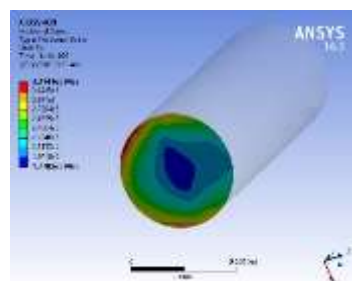


Figure 9. Frictional stress for 40N. Figure 10. Frictional stress for 50N

Table.5 The average frictional stresses and comparison of wear volume for solution treated specimens (1050°C).

LOAD(N)	Avg.frictional stress (Mpa)	FEAWear volume(mm ³)	Actual wear(mm ³)
10	0.06321	0.565572	0.5128
20	0.1266	2.688289	2.435
30	0.19066	6.388279	5.897
40	0.25421	9.667469	8.717
50	0.31681	11.01314	9.999

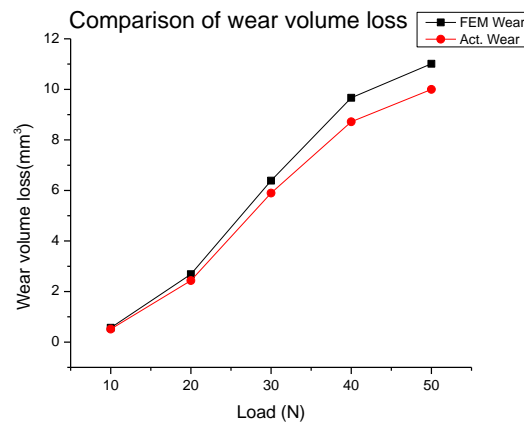


Figure 11. Comparison of wear volume loss

3.7 Frictional stresses and wear volume for solution treated specimen's 850°C 30 minutes.

Frictional stresses developed during the FEA simulation for solution treated specimens (850°C for 30 minutes) are shown in figure 12-16. It was observed that frictional stresses have increased as the load increased and are at the center, it was found to minimum and maximum at the edges. The average values of frictional stresses are shown in Table 6 used for calculation of FEA wear volume and results are compared with experimental wear volume. The figure 17 indicates the experimental and FEA wear volume are in better agreement.

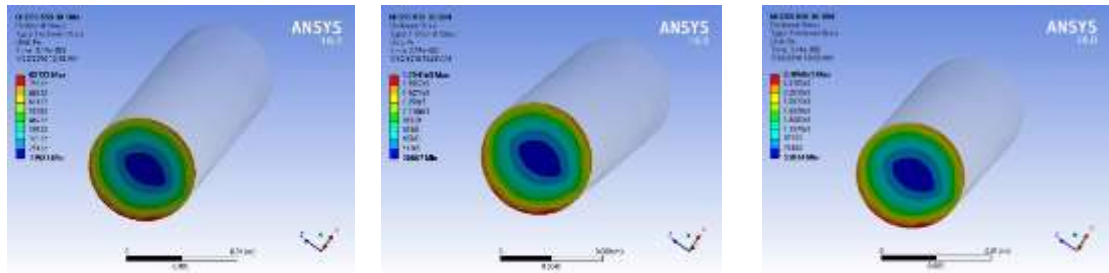


Figure 12. Frictional stress for 10N Figure13.Frictional stress for 20N Figure14.Frictional stress for 30N

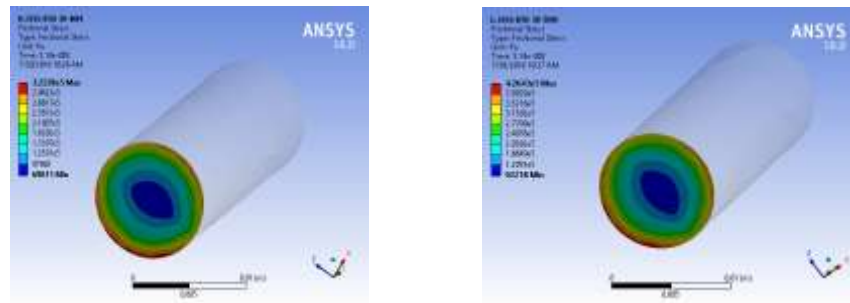


Figure 15. Frictional stress for 40N.

Figure 16. Frictional stress for 50N

Table.6 The average frictional stresses and comparison of wear volume for solution treated specimens

(850°C, 30 min).

LOAD(N)	Avg.frictional stress (Mpa)	FEAWear volume(mm ³)	Actual wear(mm ³)
10	0.05032	0.49252	0.4487
20	0.10363	2.3962	2.179
30	0.15125	4.79356	4.3588
40	0.19604	7.99134	7.435
50	0.2593	10.29809	9.3586

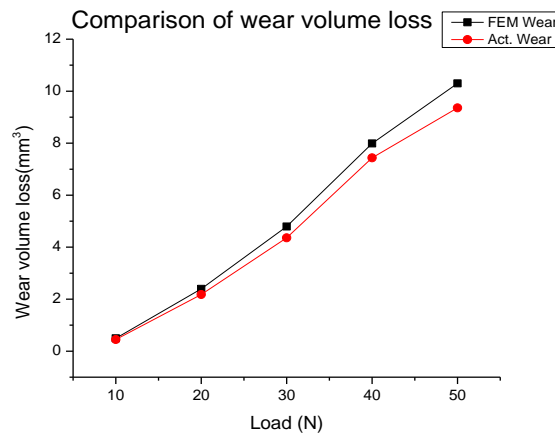


Figure.17 Comparison of wear volume loss.

Similarly wear volume was determined for other heat treated specimens (850°C with ageing time of 60 minutes, and 90 minutes as shown in figure 18 and figure 19. The wear performance is directly proportional to the frictional stress. The frictional stress shows the similar behaviour of wear volume loss in different heating condition specimens. Solution treated specimen possess higher frictional stress that also shows higher wear rate. The wear rate decreases with increase in ageing time, further the frictional stress also decreases with respect to increase in ageing time. The material property not affects directly in FEM analysis, coefficient of friction affect the stress components. The change in the von-mises stresses and the frictional stresses are due to the change in frictional coefficient during sliding motion between different materials and the disc.

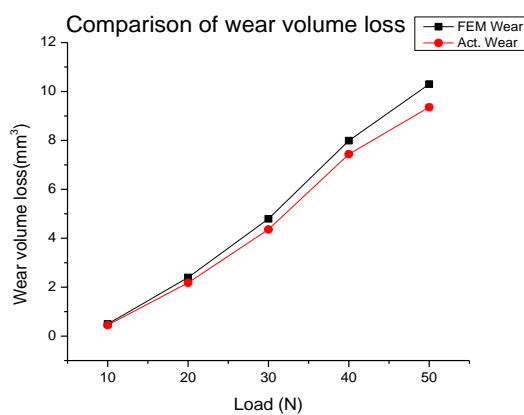


Figure18. Comparison of wear volume loss.

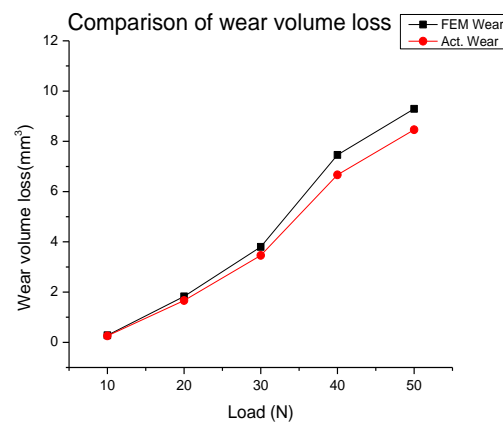


Figure19. Comparison of wear volume loss

The compared result of FEA wear volume with experimental results are shown in figure 20 and was observed that FEM analysis results are in line with experimental results.

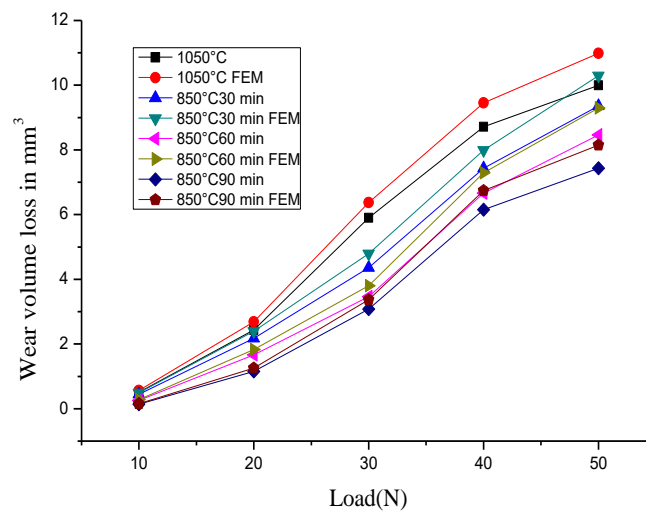


Figure 20. The compared result of FEA wear volume with experimental results

Conclusions

The following conclusions were drawn from the experimental and finite element analysis for the dry sliding wear behavior of the super duplex stainless steel AISI 2507 under different loads and different ageing time.

1. Heat treatment processs increases the hardness value with ageing time.
2. The contact pressure developed in the pin is directly related to the wear volume loss. It is a geometry related result of pin and used for the FEA validation of archard wear law for wear volume loss.
3. The pressure distribution in the pin surface is higher at the edges and lower at the centre of the pin. The contact pressure value does not depends on the hardness and coefficient of friction value but in turn depends on the geometry of the pin and the applied normal load.
4. The frictional stress obtained from the FEA analysis is used in archard wear formula for finding wear volume if k (coefficient of wear) is known. The value of frictional stress is directly related to coefficient of friction for same loads.

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