Journal of Manufacturing Engineering, June 2018, Vol. 13, Issue. 2, pp 063-068

STUDY OF DRY SLIDING WEAR AND CONTACT MECHANISM OF INCONEL 718 AT HIGH TEMPERATURE

***Bibin Jose[1], Parthasarathi N. L[2], Arivazhagan N[3], Arvinth Davinci M[2] and Utpal Borah[2]**

[1]PG Scholar, Dept. of Manufacturing Engineering, Vellore Institute of Technology, Vellore, India
[2]Scientific Officer, MFTS, MDTD, Indira Gandhi Center for Atomic Research, Kalpakkam, India
[3]Professor, Dept. of Manufacturing Engineering, Vellore Institute of Technology, Vellore, India

ABSTRACT

In this work, dry sliding wear tests were carried out using a pin-on-disc test rig with a constant load (40 N) and sliding speed (0.8 m/s). The pins were made of austenitic 316LN stainless with three different nitrogen concentrations of 0.07, 0.11 and 0.22 wt. % and disc was made from Inconel 718. The tests were conducted at four different temperature domain ie, room temperature, 200°C, 400°Cand 550°C. In order to prevent the surface oxidation of the samples, the tests were carried out in a vacuum of 10-6 torr. It is attempted to investigate the wear mechanism of Inconel 718 by surface morphology studies and also mathematically evaluating the radius of the circular contact area, maximum contact pressure and maximum shear stress. The wear mechanism was characterized using OLYMPUS LEXT 3D laser con-focal microscope.

Keywords: *Inconel 718, 316LN Stainless steel, sliding wear, Pin-on-disc test, laser con-focal microscope.*

1. Introduction

Inconel 718 is a nickel-based super alloy which is appropriate for applications requiring high strength and working temperature ranges from cryogenic to 1400°F. Inconel 718 also shows excellent tensile and impact strength. Friction and wear fundamentally impacts tribological properties of the material. In the case of pin-on-disc test, it establishes a point contact with the pin and the disc and can be mathematically estimated by hertz contact mechanism. Hertz was the first scientist to investigate and provide a valuable theory of contact mechanics [1]. In 1980, K.L. Johnson of Cambridge University focused on linking the science of contact mechanics to the many engineering domains, including sliding of surfaces with frictional considerations. The deviations of a surface from its principle shape are commonly defined as surface roughness [2]. Surface roughness influence noise, vibration and dimensional tolerances of parts in mechanical assemblies. In many a case, appropriate and precise quantification of surface roughness is yet another problem because of its repeatability and consistency issues. The estimations of different surface roughness parameters are prone to vary due to factors like type of technology, viz. contact or non-contact type, type of filters, reflectivity, resolution and scanning speed and so on. Surface finish is one of the most common measure to quantify the surface quality of metal parts and a wide variety of methods and parameters are been developed for its measurement. Mignot [3] have compared the optical surface roughness measurements and classical contact stylus techniques and found that optical method have an edge over the classical method. It was also found that optical surface roughness machines works well, especially in low roughness. Peter J have observed significant variation in arithmetic average roughness, root mean square roughness and peak to valley roughness while comparing the data obtained from various topographic measuring instruments [4]. David Collins has introduced a latest method by using laser sensor based system with a scanning area of 200 by 120 mm. The testing of the system was also discussed, including the limitations of the profilometer and possible improvements to the system [5]. In the literature, there are different studies which observe the wear characteristics of both treated and untreated Inconel 718 [6, 7, 8]. The friction and un-lubricated wear of 316L austenitic stainless steel was studied by Smith. A detailed model of the wear process was established, in terms of asperities contact to form adhesive transfer platelets, which agglomerate in to

**Corresponding Author - E- mail: bibinjose96@gmail.com*

prow layers [9]. The motivation of this work was to observe the surface roughness of the wear track at different temperatures and also to find the difference of wear track with varying nitrogen concentration of the pins. It also mathematically finds the maximum contact pressure, maximum shear stress and also the depth of maximum shear stress. This work also attempts to characterize and quantify the wear mechanism by incorporating 3D-profilometery.

2. Experimental Procedure

2.1 Material

In this experiment, the test specimen is the disc of Inconel 718 (525 HV) and the counter body which is the pins of 316LN (155 HV) with three nitrogen levels of 0.07, 0.11 and 0.22 wt. %. Inconel 718 alloy chemical composition is tabulated in Table 1 [10]. Since disc is harder material compared to pin, the disc will act as a rigid body and the material gets eroded from the pin surface.

Table 1: Chemical composition of Inconel 718

Elements	*Composition*
C	0.08
Mn	0.35
Si	0.35
Cr	21.0
Co	1.00
Mo	3.30
Nb+Ta	5.50
Ti	1.15
Al	0.80
Fe	Balance
Cu	0.30
Ni	55.00

2.2 Wear testing procedure

The dry sliding wear test was carried out in DUCOM make TR-20-M12EV high temperature, high vacuum pin on disc tribometer according to ASTM: G99-05 standard test technique for wear testing. Inconel 718 disc of 130 mm diameter and 10 mm thick, were machined out from a block. AISI 316 LN pins with hemispherical contact, which is capable of establishing point contact, were also machined in required quantity. The nose radius of the pin was 5 mm. A constant load of 40 N was applied and the tests were carried out for 1250 seconds, each at constant sliding velocity of 0.8 m/s resulting in total sliding distance of 1000 m in each test. The wear tests were conducted at room temperature, 200°C, 400^{o}C and 550^{o}C. After the experiment surface roughness, macrograph and 3D-plots were taken by OLYMPUS LEXT 3D laser con-focal microscope. Fig.1 Laser con-focal microscope.

Fig. 1. Laser Con-focal Microscope

3. Results and Discussion

3.1 Characterization of Wear

The graph shows a steady increase in wear with sliding distance. It also shows a slight increase in wear with increase in nitrogen concentration. With increase in temperature severity of wear also increased. As temperature increases the material becomes softer which leads to the highly pronounced wear. Fig.2. Shows, consolidated variation of wear with respect to distance and temperature. The wear is measured in micron whereas distance is measured in meters.

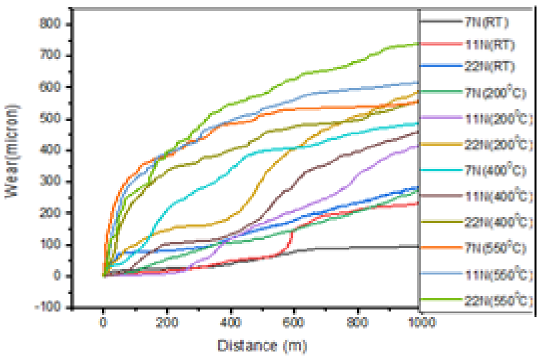


Fig. 2. Consolidated wear graph

3.2 Hertz contact

At the point when two surfaces come into contact, elastic and plastic deformation happens at their interface. When a perfectly elastic, perfectly smooth sphere comes in contact with a perfectly elastic, perfectly smooth flat plane, a circular contact area results at the maximum compressive stress is located at the centre of the circular interface, and the perimeter is in a state of pure shear, due to the hoop stress and radial stress being of equal and opposite in magnitude. Table 2 shows the hertz contact parameter.

Table 2: Hertz contact parameter

Material	316LN	Inconel 718
Object shape	Sphere	Plane
Poisson's ratio	0.25	0.29
Elastic Modulus	193GPa	200GPa
Dia. of object	10 mm	-
Force	40N	

The maximum hertzian contact stress, maximum shear stress, and depth of the max shear stress can be calculated using Equations 1-4; here E is the elastic modulus, v is Poison's ratio, P_0 is the maximum contact pressure, a is the radius of the circular contact area, F is the applied load, τ is the maximum shear stress and z is the depth of maximum shear stress. Table 3 provides the solutions. Fig.3: shows the hertz contact.

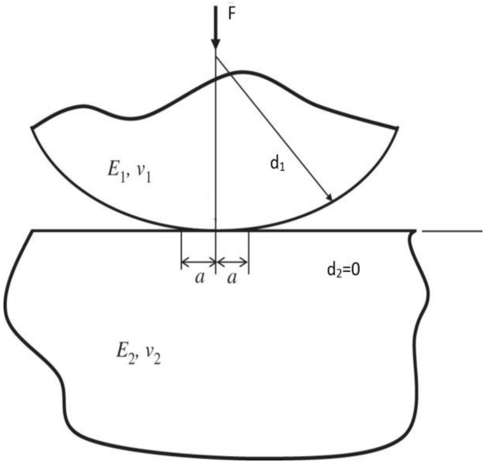


Fig. 3. Hertz contact

$$a = \sqrt[3]{\frac{3F}{8}\frac{(1-v_1^2)/E_1+(1-v_2^2)/E_2}{1/d_1+1/d_2}} \tag{1}$$

$$p_0 = \frac{3F}{2\pi a^2} \tag{2}$$

$$\tau = 0.31 p_0 \tag{3}$$

$$z = 0.48a \tag{4}$$

Table 3: Solution of contact parameter

Parameters	Values
Radius of Contact (a)	0.112 mm
Max. Contact Pressure (p_0)	1.51 GPa
Max. Shear stress (τ)	0.48 GPa
Depth of Max. Shear stress (z)	0.052 mm

3.3 Surface Roughness

Surface roughness is a component of surface texture. It is quantified by the deviation in the direction of the normal vector of a real surface from its ideal form. If this deviation is large then the surface is rough and if the deviation is small then the surface is smooth. Surface roughness was measured by using OLYMPUS LEXT 3D measuring laser microscope. Fig.4. Shows surface roughness plot of the disc after the wear test. S_a is one of the most important factor as far as surface roughness is concerned. The amplitude parameter, namely the arithmetic mean deviation of surface (Sa) was found to increase with increase of nitrogen concentration. Surface roughness values also show an increase with increasing temperature. Fig.5. (a), (b), (c) and (d) shows the 3D plot of Sa at 0.07wt % of nitrogen at four different temperatures ie, at room temperature, 200°C, 400°C and 550°C.

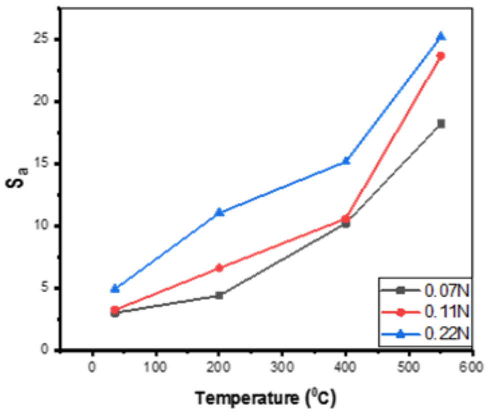
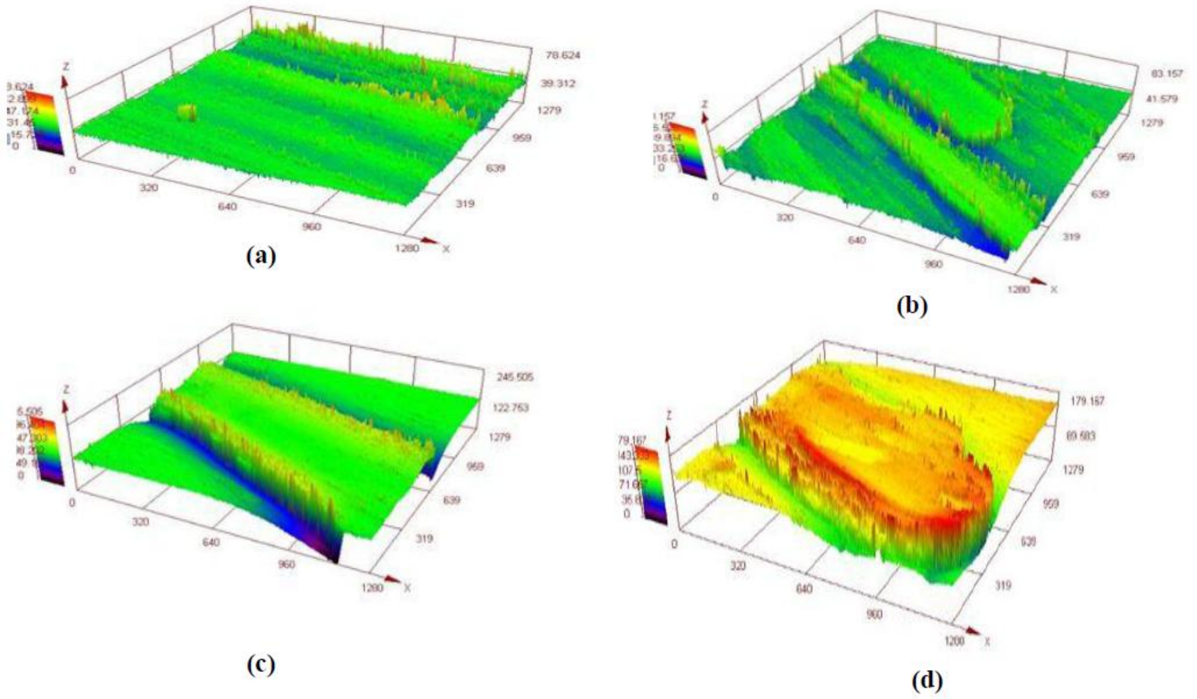


Fig. 4. Surface roughness plot of the disc

3.4 Profilometer study of the Disc

Profilometry is a technique used to extract topographical data from a surface. This can be a single point, a line scan or a full three dimensional scan. The purpose of profilometry is to get surface morphology, step height and surface roughness. This can be done by physical probe or by light. In order to find the wear mechanism involved in the experiment a rectangular section is taken for investigation from the circular disc.



(a)

(b)

(c)

(d)

Fig. 5. (a), (b), (c) and (d) shows the 3D plot of Sa at 0.07wt % of nitrogen at four different temperatures ie, at room temperature, 200°C, 400°C and 550°C.

Fig. 6. Macrograph of the disc taken with 2.5X magnification.

The macrograph of the disc taken with 2.5X magnification is shown below. From Fig.6: it is also evident that the track width also increases with increase in both nitrogen concentration and also temperature. Fig.7. 2D- surface plot is taken, in that blue colour indicates the disc surface and the green colour patches indicates the adhesion of 316LN to the surface of the Inconel 718 disc. Fig.8 shows 3D surface plot of the disc which provides us the extent of adhesion to the surface.

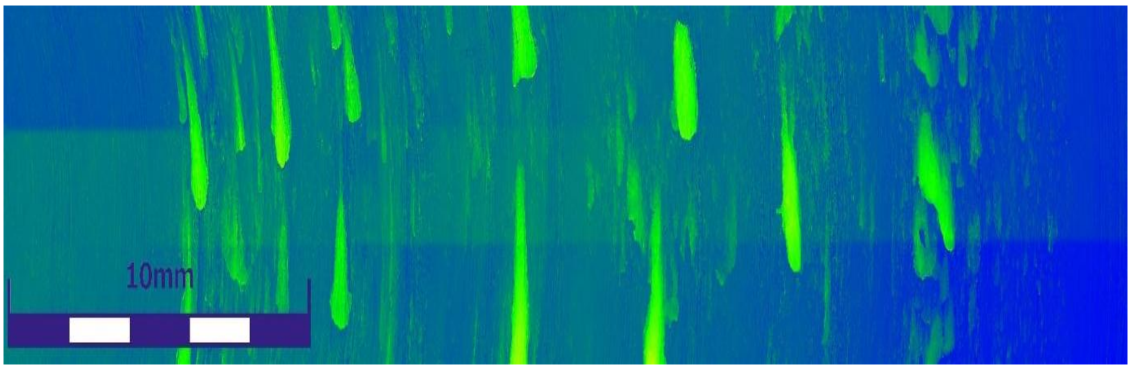


Fig. 7. Two Dimensional surface plot of disc

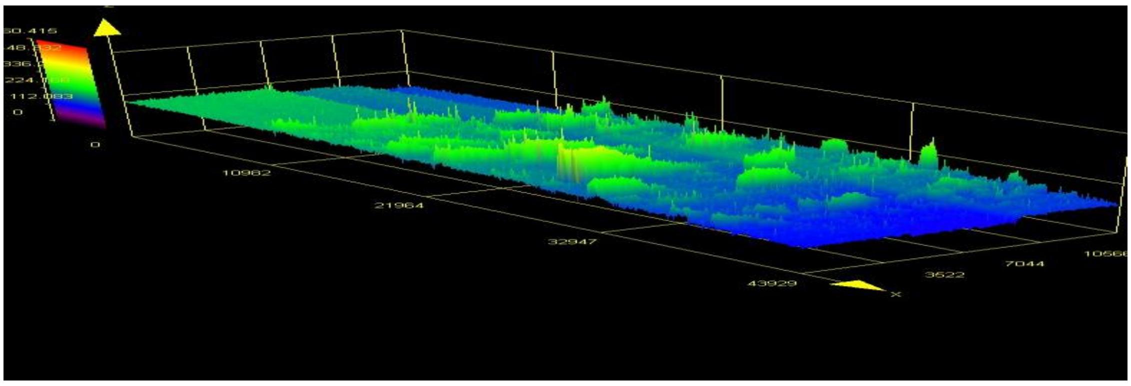


Fig. 8. Three dimensional surface plot of disc

4. Conclusions

Surface roughness was found to increase with increase of nitrogen concentration as well as with increasing temperature.

- The wear mechanism involved in the experiment was found out to be adhesive wear.
- Profilometer proves to be a best tool for wear mechanism estimation.
- The radius of the circular contact area ‘a’ was found to be 0.112 mm.
- Maximum shear stress at the interface of the two materials was found to be 0.48GPa.
- Maximum contact pressure was found to be and 1.51GPa.

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