Experimental study of friction and wear behaviour of Ni based superalloy material.

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Abstract—Nickel based superalloy material is used for the design of dampers in steam and gas turbine. Parametric study of rubbing velocity, contact pressure and contact temperature influence on Nickel based superalloy material coefficient of friction and wear analysis. Friction is not desirable in machines, but it is desirable in design parameter for brakes and clutches. In the present paper, an experimental investigation is carried to find out the coefficient of friction and wear rate of Nickel based superalloy material. Experiments are carried by using a pin on disk apparatus on different diameter pins and disks of the same material. The experiments are carried on normal load ranging from 10 to 200N, speed varies from 200 to 2000 rpm and, wear track diameter ranging from 5 to 160 mm. Thus, the coefficient of friction and wear rate were studied with varying normal load at a constant rubbing velocity for different diameter pins. Thereafter the coefficient of friction and wear rate studied at a constant normal load with varying rubbing velocities for different diameter pins. By varying normal load at constant rubbing velocity it is observed that coefficient of friction decreases and wear rate increases for all diameter pins.

Keywords— Friction coefficient, Tribological wear, Nickel based superalloys, Wear track diameter, Regression equation.

I. INTRODUCTION

Nickel based super alloys have attracted a lot of attention during the last 20 years, since they possess desirable technological properties such as good corrosion and oxidation resistance, high toughness and ductility, excellent cryogenic temperature and high strength and heat resistance at high temperature (760-980^{o}C)[1]. These properties come in very handy while meeting the specific demands of a vast variety of applications like automobile, aerospace, space vehicle, rocket engines, power generation turbines, nuclear reactors, submarines, aerospace gas turbine engines, high-temperature fasteners and combustion engine exhaust valves, to name a few. In general, various failure modes related to several mechanical components, wear present a unique challenge to the design and developer of mechanical components [2]. Tribological wear resistance characteristics like coefficient of friction and wear resistance are not actual material properties, but depend on the system in which these materials have to function [3]. In many design applications wear and tear is inevitable because of relative motion between contacting parts. Friction is the resistance to movement between any two surfaces in contact with each other. Friction is not desirable in machines because it destroys the effectiveness of the machines through wear and shortens their life [4-6]. Wear is undesirable removal of material due to mechanical action. Though wear cannot be eliminated completely, it can be minimized. In most cases, a primary concern is to develop materials that possess low friction and low wear properties under dry sliding conditions against smooth metallic counterparts.

Experiments are carried on a group of specimens for duration of 10 minutes in the following ranges: loads of 30, 40, 60 and 90N; wear track diameters of 60, 80, 90 and 100mm; speeds of 400, 500, and 800 rpm [7-10]. The experimental set-up is connected to a data acquisition system which computes friction force and coefficient of friction. Experiments are performed by varying normal loads at a constant rubbing velocity to obtain coefficient of friction and wear. Graphical representation of wear rate along with friction force and coefficient of friction is given by software called WINDUCOM2010 [11-12].

II. PIN ON DISK APPARATUS

A pin on disk apparatus consist of a cylindrical pin and rotating a circular disk which is placed on pin on disk apparatus with the help of Alan key to fasten it [13-14]. The cylindrical pin surface which is placed perpendiculary with respect to the rotating circular disk as shown in Fig. 1. The pin on disk apparatus consists of a rotating circular disk, which is held in horizontaly plan, and a calibrated dead weight placed on the load pan, which acts on the pin with the help of pivot arm lever mechanisms. The pin on disk apparatus has two sensors namely a load cell and a linear variable differential transformer (LVDT) [15]. These sensors are used to find frictional force and vertical displacement (wear) of a pin automatically. A rotating circular disk is directly connected to a variable speed motor. The stationary pin, which is held to place on a holder, is attached to a pivot arm lever. Additional weights produce a test force proportional to the Fig.1 pin on disk apparatus line diagram mass of applied weight [16-18]. The pin is in cylindrical shape and it is shown in Fig. 1. The pin specimen is grounded to a surface roughness of 0.8 µm. The disk is made of hardened nickel based super alloy on which the pin is held with a jaw in the apparatus. The pin is pressed against the surface of the disk with a load being applied to the arm attachment provided to the apparatus [19-20]. The machine is attached to a controller and data acquisition by the system WINDUCOM2010 software which gives the required result. Table 1 shows the pin on disk apparatus technical specifications. In this table loads varying from 5to 200N, wear track diameter varying from 5 to 160 mm, and speed varying from 200 to 2000 rpm [21-23].

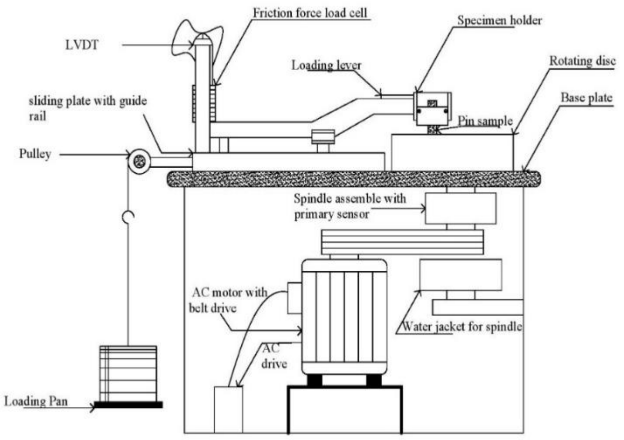

Fig. 1. Pin on disk line diagram.

S.No	Test parameters	Values
1	Specimen dimensions	Diameter of pin 12 mm and length of pin 32 mm
2	Pin/Ball diameters	2,3,4,5,6,8 and10 mm
3	Wear disk size	Diameter165 mm and thickness 8 mm
4	Normal load	Min: 5 N to Max: 200 N
6	Friction force	Min: 0 N to Max: 200 N
7	Wear measurement	Min:0 µm to Max: 2000µm
8	Wear track diameter	Min:5mm to Max:160mm
9	Lubrication module	With recirculation system
10	Loading system	Using dead weights

Table 1. Pin on disk apparatus technical specifications.

A disk is made of nickel based super alloy, which is hardened to 274 BHN and finished to get surface roughness of 1.6 Ra is used in the present experimentation. Wear track diameter is adjusted between 5 and 160 mm while the disk rotational speed is adjusted between 200 to 2000 rpm [24-25]. The diameter of disk is 165 mm and thickness of disk is 8 mm. Length of pin is 32 mm, and step length is 4 mm. All pins are made up of nickel based super alloy material [26-27]. The pin on disk controller and K-type thermocouple are also part of the instrumentation [28-29].

III. Experimental Investigation

The different diameter of pins are tested on a pin on disc experimental setup as shown in Fig.2. Initially, test specimen is inserted into the pin holder. The load, speed and time can be adjusted in the test rig as per test conditions. Table 2 shows that test conditions of 3 mm, 5 mm and 8 mm diameter pins at constant speed and wear track diameter. The speed and wear track diameter is kept constant at 500 rpm and 60mm respectively and vary loads as 30, 60, and 90N. Table 3 shows that the test conditions of 3mm, 5mm and 8mm diameter pins at constant normal load and wear track diameter. The load and wear track diameter is kept constant at 40 N and 60 mm respectively and vary speeds as 400, 600, and 800 rpm.

Fig. 2 Pin on disk experimental setup.

Normal Load (N)	Speed (rpm)	Wear track diameter (mm)
30	500	60
60	500	60
90	500	60

Table 2. Test conditions of 3 mm,5 mm and 8 mm diameter pins at constant speed and wear track diameter.

Normal Load (N)	Speed (rpm)	Wear track diameter (mm)
40	400	60
40	600	60
40	800	60

Table 3. Test conditions of 3mm, 5mm and 8mm diameter pins at constant normal load and wear track diameter.

IV. Results and Discussion

First set of normal dry sliding test investigations are carried out at loads differing from 30, 60, and 90N and at a constant rubbing velocity of 1570.796 mm/s to know the effect of coefficient friction and wear on 3 mm diameter pin made up of nickel based super alloy. Table 4 shows that coefficient of friction at constant rubbing velocity on 3 mm diameter pin. Fig. 3 shows that coefficient of friction of 3mm diameter pin at a constant rubbing velocity. From Fig.3, it is observed that the coefficient of friction decreases as load increases. The increase of contact temperature with increase of load may be the possible reason for decrease of coefficient of friction. Table 5 shows that the wear on 3 mm diameter pin at constant rubbing velocity. Fig. 4 shows that wear of 3 mm diameter pin at constant rubbing velocity. From Fig. 4. it is observed that the wear increases with load increases. The wear increases due to the effect of increasing contact temperature with increase of load.

Second set of investigations are carried out to know the behavior of coefficient of friction and wear at different rubbing velocities of 1256.637, 1884.955, and 2513.274mm/s and at a constant contact pressure of 5.6589 MPa of 3 mm diameter pin made up of nickel based super alloy. Table 6 shows the coefficient of friction at constant normal load on 3mm diameter pin. Fig. 5 shows that coefficient of friction at constant normal load and it is clearly shows that the coefficient of friction decreases as rubbing velocity increases. The increase of contact temperature with increase of rubbing velocity may be the possible reason for decrease of coefficient of friction. Coefficient of friction is a measure of the surface interactions between two bodies in contact. When the two bodies in contact slide at higher rubbing velocities, the surface undulations do not get sufficient time to lock into each other and thus there is decrease in the coefficient of friction. Table 7 and Fig 6 show the wear on 3mm diameter pin at constant normal load. From Fig. 6 it is observed that the wear increases as rubbing velocity increases. The increase of contact temperature with increase of rubbing velocity may be the possible reason for increase of wear. The above two sets of experiments are repeated for 5 mm an 8 mm diameter pins made of nickel based super alloy to know the effect of dimeter of pin on coefficient of friction and wear. From the results it is observed that the same trend of coefficient friction and wear at constant rubbing velocity and normal load for 3 mm diameter pin is also same for 5 mm an 8 mm diameter pins made of nickel based super alloy.

Contact Pressure (MPa)	Rubbing velocity (mm/s)	Contact Temperature (^0C)	Coefficient of friction (μ)
4.24	1570.78	76.6	0.484
8.49	1570.78	90.3	0.436
12.73	1570.78	97.7	0.407

Table 4. Coefficient of friction at constant rubbing velocity on 3mm diameter pin

Contact Pressure (MPa)	Rubbing velocity (mm/s)	Contact Temperature (^0C)	Wear (μm)
4.24	1570.78	76.6	731
8.49	1570.78	90.3	1564.5
12.73	1570.78	97.7	1941.5

Table 5. Wear at constant rubbing velocity on 3mm diameter pin.

Contact Pressure (MPa)	Rubbing velocity (mm/s)	Contact Temperature (^0C)	Coefficient of friction (μ)
5.66	1256.64	113.7	0.474
5.66	1884.955	123.6	0.461
5.66	25130.27	133.5	0.456

Table 6. Coefficient of friction at constant normal load on 3mm diameter pin.

Contact Pressure (MPa)	Rubbing velocity (mm/s)	Contact Temperature (^0C)	Wear (μm)
5.66	1256.64	113.7	359.5
5.66	1884.955	123.6	385.5
5.66	25130.27	133.5	493.5

Table 7. Wear at constant normal load on 3mm diameter pin.

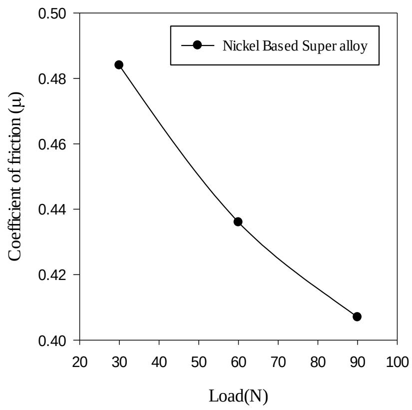

Fig.3.Coefficient of friction at constant rubbing velocity for 3mm diameter pin.

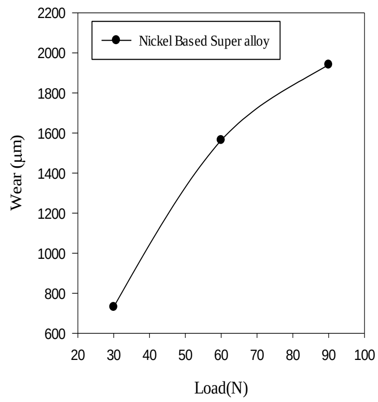

Fig. 4. Wear at constant rubbing velocity for 3mm diameter pin.

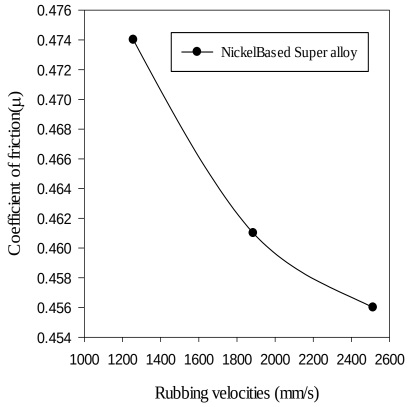

Fig. 5. Coefficient of friction at constant normal load for 3mm diameter pin.

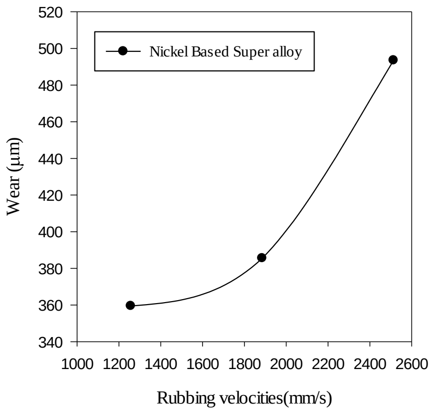

Fig. 6. Wear at constant normal load for 3mm diameter pin.

Table 8 and Fig 7 show the coefficient of friction at constant rubbing velocity on 5mm diameter pin. From Fig. 7, it is observed that the coefficient of friction decreases with increase of load. Table 9 and Fig 8 show the wear on 5mm diameter pin at constant rubbing velocity. Fig. 8 clearly shows the increase of load with increase of wear. Table 10 and Fig 9 show of coefficient of friction at constant normal load. From Fig. 9, it is observed that the coefficient of friction decreases with rubbing velocity increases. Table 11 and Fig. 10 shows that wear of 5mm diameter pin at a constant normal load. From Fig. 10, clearly shows that the wear increases with rubbing velocity. The increase of contact temperature with increase of rubbing velocity may be the possible reason for decrease of coefficient of friction.

Contact Pressure (MPa)	Rubbing Velocity (mm/s)	Contact Temperature (ºC)	friction Coefficient (μ)
1.5278	1570.796	54.9	0.385
3.0557	1570.796	70.1	0.338
4.5836	1570.796	84.4	0.307

Table 8. Coefficient of friction at constant rubbing velocity on 5mm diameter pin.

Contact Pressure	Rubbing Velocity	Contact Temperature(ºC)	Wear (μm)
1.5278	1570.796	54.9	91.5
3.0557	1570.796	70.1	273.5
4.5836	1570.796	84.4	410.5

Table 9. Wear at constant rubbing velocity on 5mm diameter pin.

Contact Pressure (MPa)	Rubbing Velocity (mm/s)	Contact Temperature (ºC)	friction Coefficient (μ)
1.5278	1570.796	54.9	0.385
3.0557	1570.796	70.1	0.338
4.5836	1570.796	84.4	0.307

Table 10. Coefficient of friction at constant normal load on 5m.

Contact Pressure	Rubbing Velocity	Contact Temperature(ºC)	Wear (μm)
2.0371	1256.637	58.9	95
2.0371	1884.955	70.5	53.5
2.0371	2513.274	84.5	182.5

Table 11. Wear at constant normal load on 5mm diameter pin.

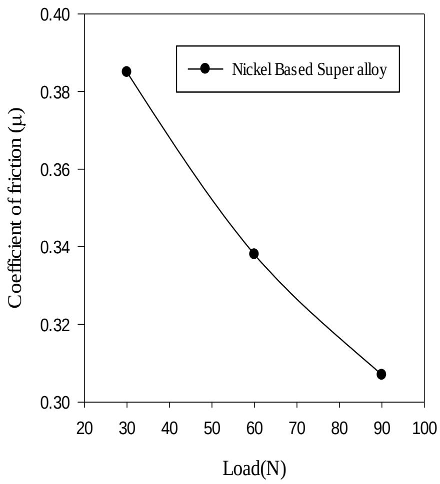

Fig.7.Coefficient of friction at constant rubbing velocity for 5mm diameter pin.

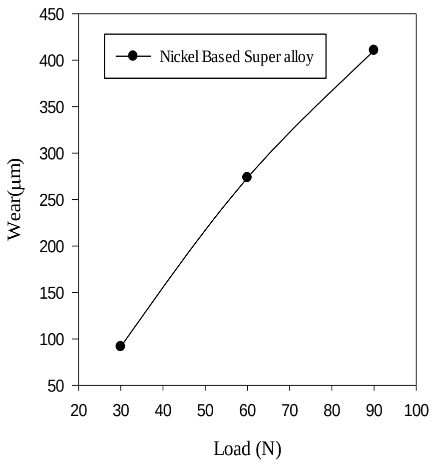

Fig. 8. Wear at constant rubbing velocity for 5mm dimeter pin.

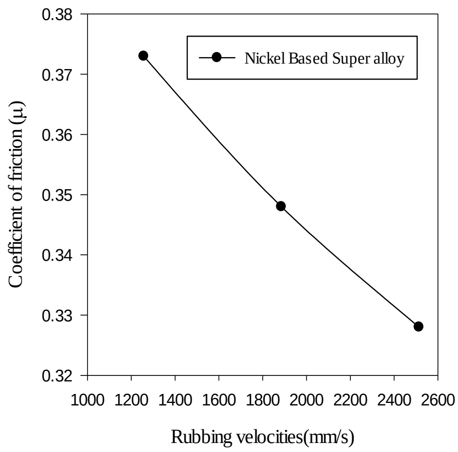

Fig. 9. Coefficient of friction at constant normal load for 5mm diameter pin.

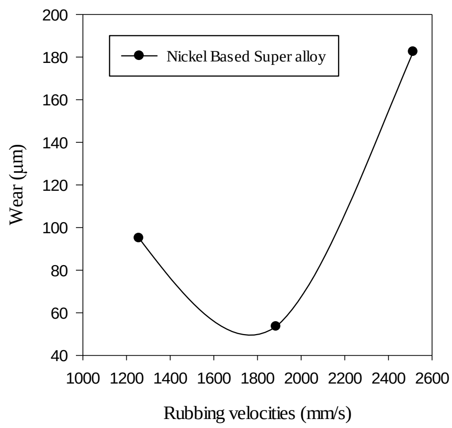

Fig. 10. Wear at constant normal load for 5mm Diameter.

Table 12 and Fig. 11 show the coefficient of friction at constant rubbing velocity on 8mm diameter pin. From Fig. 11, it is concluded that the coefficient of friction decreases with load increases. Table 13 and Fig. 12 show the the wear on 8mm diameter pin at constant rubbing velocity. Form Fig. 12, it is observed that the wear increases with increase of load. Table 14 and fig. 13 show the coefficient of friction at constant normal load on 8mm diameter pin. Fig. 13 clearly shows the decrease of coefficient of friction with increase of rubbing velocity. Table 15 and Fig. 14 show the wear on 8mm diameter pin at constant normal load. From Fig. 14, it is observed that the wear rate increases with increase of rubbing velocity.

Contact Pressure (MPa)	Rubbing Velocity(mm/s)	Contact Temperature (°C)	Coefficient of friction(μ)
0.5968	1570.796	51.6	0.445
1.1936	1570.796	61.4	0.431
1.7904	1570.796	66.8	0.417

Table 12. Coefficient of friction at constant rubbing velocity on 8mm diameter pin.

Contact Pressure (MPa)	Rubbing Velocity (mm/s)	Contact Temperature (°C)	Wear(μm)
0.5968	1570.796	51.6	30.5
1.1936	1570.796	61.4	249.5
1.7904	1570.796	66.8	553

Table 13. Wear at constant rubbing velocity on 8mm diameter pin.

Contact Pressure (MPa)	Rubbing Velocity (mm/s)	Contact Temperature (°C)	Coefficient of friction (μ)
0.7957	1256.637	53.5	0.478
0.7957	1884.955	54.3	0.436
0.7957	2513.274	170.5	0.401

Table 14. Coefficient of friction at constant normal load on 8mm diameter pin.

Contact Pressure (MPa)	Rubbing Velocity (mm/s)	Contact Temperature (°C)	Wear (μm)
0.7957	1256.637	53.5	65.5
0.7957	1884.955	54.3	55
0.7957	2513.274	170.5	170.5

Table 15. Wear at constant normal load on 8mm diameter pin.

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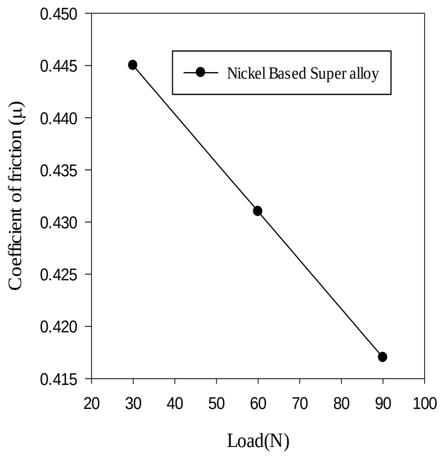

Fig. 11. Coefficient of friction at constant rubbing velocity for 8mm diameter pin.

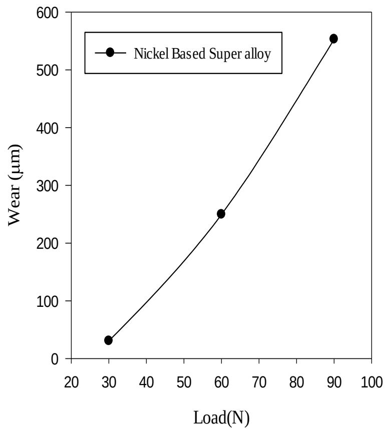

Fig. 12. Wear rate at constant rubbing velocity for 8mm diameter pin.

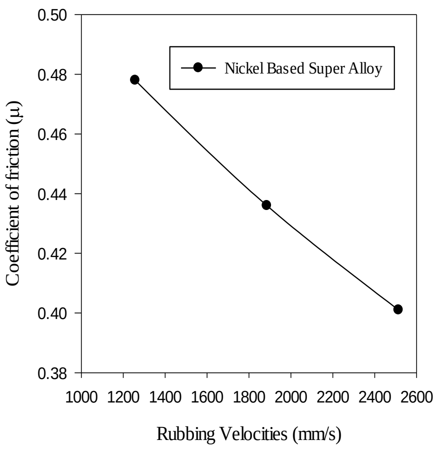

Fig. 13. Coefficient of friction at constant normal load for 8mm diameter pin.

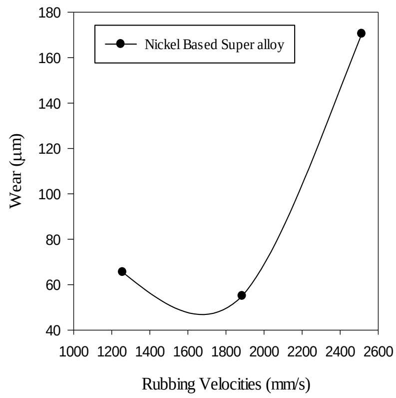

Fig. 14. Wear at constant normal load for 8mm diameter pin.

V. Regression Equations

A. Regression equation for 3mm diameter pin

Regression equation is developed for 3mm diameter pin with input parameters as contact pressure and rubbing velocity while output parameter is coefficient of friction. The regression equation of 3mm diameter pin shown in equation (1.1). Proportion of variance value is 99.99%.

$$\mathrm{Y} = 1.953 - 0.018 \times \mathrm{X}_1 + 5.26 \times 10^{-4} \times \mathrm{X}_1{}^2 - 0.349 \times \ln(\mathrm{X}_2) + 0.0216 \times \ln(\mathrm{X}_2)^2 \qquad (1.1)$$

B. 3mm diameter pin regression equation result validation

Regression equation results for 3mm diameter of nickel based super alloy pinare validated from the test conditions at contact pressure 7MPa and rubbing velocity 1600 mm/s. Fig. 15 shows the regression equation output for 3mm dimeter pin. The coefficient of friction from regression equation corresponding above test condition is 0.4501. It is close to the experimental result of 0.45. Hence regression equation is validated.

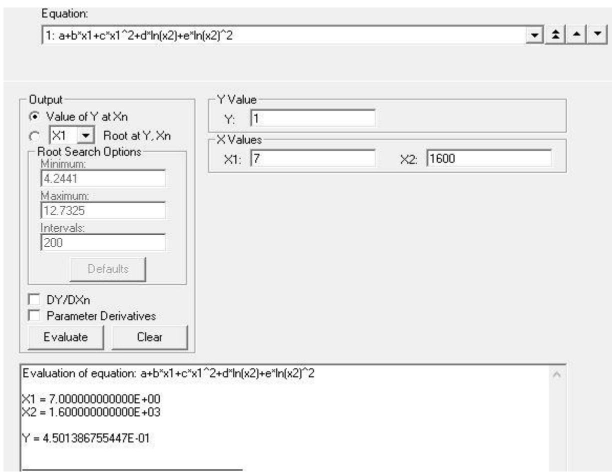

Fig. 15. Regression equation output for 3mm dimeter pin.

C. Regression equation for 5mm diameter pin

Regression equation is developed for 5mm diameter pin with input parameters as contact pressure and rubbing velocity while output parameter is coefficient of friction. The regression equation of 5mm diameter pin shown in equation (2.1). Proportion of variance value is 99.97%.

$$y = 1.064 - 0.214 \times X_1 - 0.0633 \times {X_1}^2 - 6.53 \times 10^{-3} \times {X_1}^3 - 0.0647 \times \ln(X_2) \qquad (2.1)$$

D. 5mm diameter pin regression equation result validation

Regression equation results for 5mm diameter of nickel based super alloy pin are validated from the test conditions at contact pressure 2.5MPa and rubbing velocity 1600 mm/s. Fig. 16 shows the regression equation ouput for 5mm dimeter pin. The coefficient of friction from regression equation corresponding above test condition is 0.3446. It is close to the experimental result of 0.34. Hence regression equation is validated.

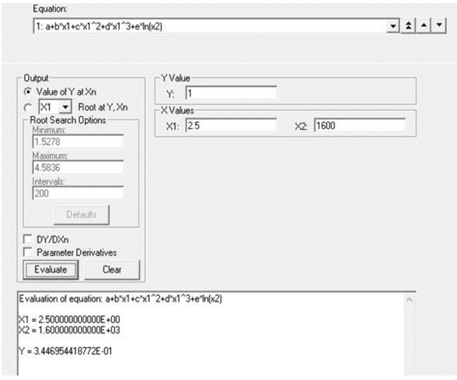

Fig. 16. Regression equation output for 5mm dimeter pin.

E. Regression equation for 8mm diameter pin

Regression equation is developed for 3mm diameter pin with input parameters as contact pressure and rubbing velocity while output parameter is coefficient of friction. The regression equation of 8mm diameter pin shown in equation (3.1). Proportion of variance value is 99.82%.

$$y = 1.0489 + 0.6643 \times X_1 - 0.6287 \times {X_1}^2 + 0.1755 \times {X_1}^3 - 0.1106 \times \ln(X_2) \qquad (3.1)$$

F. 8mm diameter pin regression equation result validation

Regression equation results for 8mm diameter of nickel based super alloy pinare validated from the test conditions at Contact Pressure 1.5MPa and Rubbing velocity 1600 mm/s. Fig.17 shows the regression equation ouput for 8mm dimeter pin. The Coefficient of friction from regression equation corresponding above test condition is 0.4076. It is close to the experimental result of 0.40. Hence regression equation is validated.

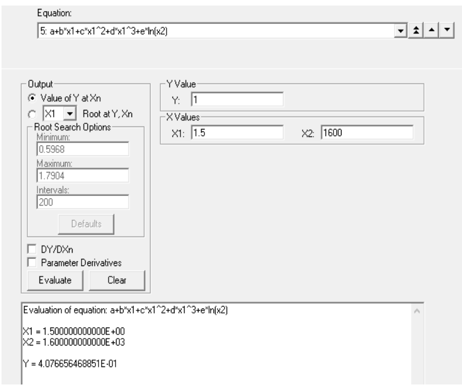

Fig.17 . Regression equation output for 8mm dimeter pin.

For all calculations: Y= Friction coefficient, X_1= Pressure contact, X_2=Rubbing velocities.

VI. Conclusion

Coefficient of friction and wear of nickel based super alloy was investigated at different conditions of normal loads and rubbing velocity. From the experimental investigation it is observed that coefficient of friction decreases when the normal load increases at constant rubbing velocity. But wear increases when the normal load increases at constant rubbing velocity. From all the experimental conditions, it is observed that the coefficient friction decreases with increase of contact temperature. Regression equations were developed to estimate coefficient of friction at any desired test conditions of load 30N to 90N and rubbing velocity 0.5m/s to 2.5m/s. The results of coefficient of friction obtained from regression equation are close to the experimental results.

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Authors' Contributions

L.Amer and M.Hamouda were in charge of the whole trial. L.AMER wrote the manuscript. M.Hamouda gave the methodology of this manuscript. Both L.Amer and M.Hamouda assisted with sampling and laboratory analyses. Both authors read and approved the fnal manuscript.

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