Experimental Investigation of EN24 Steel Against OHNS Under Wet Sliding Conditions by Using Pin-On-Disc.

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Abstract

In this study, the tribological behavior of EN24 steel and oil hardened non-shrinking steel (OHNS) is investigated. Experimentation is performed using a pin-on-disc wear test setup. EN24 is used as pin material and OHNS as disc. Samples of pin are performed under wet sliding conditions at ambient temperatures. Sliding speed, load, and time are input parameters, while frictional force, friction coefficient and wear are the output parameters. Wear losses and worn-out surfaces are measured using an electronic balance and an optical microscope. By introducing oils between the pin and disc, lubricant enhances the system performance which is measured. Ferrography is used for figuring out how many and what kind of wear particles are in lubricating oil. Surface investigations were carried out using SEM and EDS to understand the friction and wear behavior. Taguchi L9 is used for the design of experiments, and ANOVA is used for optimization. Most significant parameter observed is load as compared to sliding velocity and time in terms of frictional force and friction coefficient. For wear, load and sliding speed are significant factors.

Keywords
EN24, OHNS, SEM, Pin-on-disc, and ANOVA.

1. Introduction

Wear is the main factor in the failure of components, which are widely used in the industries. Steels and alloys are used as the connecting rods, gear shafts, large cross section for aircrafts, crankshafts, gear shafts and landing gear components and some heavy forgings, like rotor shafts and discs. For performing the experimental study EN 24 alloy steel is used as pin as it has application in various industries. It is a medium carbon low alloy steel that includes several alloying elements including chromium, nickel, and molybdenum. This alloy steels major components, Mn, and Cr, provide it excellent strength and hardness. The qualities such as strength, toughness, and hardenability are all enhanced by nickel, which also raises the hot hardness value and increases corrosion and wear resistance. Now, it is necessary to increase power, reduce maintenance, and better replacement method while also reducing the size of machine components. These demands put a lot of pressure on demand and design for other solutions. It would be extremely costly and time-consuming to test solutions on an entire machine. Therefore, prior to full-scale tests, tribological research is widely performed using the universal experimental set-ups (Baig et.al. 2021).

The major source of energy loss, which lower the performance of mechanical systems, is the wear on sliding pairs. To determine the impact on EN24 steel, a pin-on-disc wear test is conducted. A fixed pin with an applied load in contact with a rotating disc which makes up a pin-on-disc wear test device. The sliding wear and friction characteristics of lubricated or dry surfaces made of a range of materials are measured by the pin-on-disc setup. On the pin-on-disc test setup, the standard load, rotational speed, sliding distance, and temperature all these parameters are available. Specimen with a 50 mm length and Conical heads are used with such pins because they are simple to position and provide the ideal region of contact with rotating discs.

Table.1 Composition of material EN24.

Element	C	Si	Mn	P	S	Mo	Cr	Ni	Fe
EN24 (Min-Max)	0.36 - 0.44	0.10-0.35	0.45-0.70	0.035	0.04	0.20-0.35	0.80-1.20	1.30-1.70	Balanced

The disc being tested for wear has a hardness with 62 HRC. The rotating disc and the pin are in contact with one another perpendicularly, and the experiment was conducted using this. The disc is made of oil hardened non-shrinking steel (OHNS).

Table 2. Composition of material OHNS.

Element	C	Si	Mn	P	S	Cr	V	Fe
OHNS (Min-Max)	0.85 - 1.00	0.15-0.35	1.00-1.20	0.030	0.030	0.50-0.70	0.15	Balanced

Effects on EN24 steel in different sliding conditions and surface wear induced by sliding of EN24 steel against Oil Hardened Non-Shrinking steel (OHNS) at lubricating conditions. Also, interactions of applied parameters and wear characteristics of pin and disc and analysis of wear debris, types of wear occurred during the experimentation is carried out.

2. Literature Review

The study of literature provides in-depth analysis of predictions of friction and wear using different materials. Due to their mechanical characteristics, alloy steels are commonly utilized as machine parts and other applications in industries. Many tribology investigations focus on different alloy steels. Only a few tests are carried out using EN24 material under certain circumstances using various lubricants.

Singh et al. (2021) studied the tribological characteristics of AISI 4140 were optimized under lubricated conditions. To determine the impact of load, sliding speed and distance on the characteristics of AISI 4140 steel, Pin-on-disc wear test is conducted. To compare, the wear research was conducted for various loads. In this experimental study, ANOVA is used. The combination of outcomes, i.e., coefficient of friction and wear, is most significantly influenced by sliding distance and sliding speed parameters.

Shaogang et al. (2021) studied the tribological behavior of various tool against mild steel and high-chromium steel, in which Si3N4, SiC, and commercial high speed steels were studied. The study of interfacial tribological properties when various tools are utilized on mild steel and ST is enhanced through this work. Studies are done on how the counterface impacts the tribo oxide layers mechanical characteristics, surface transformation, and how layer interacts to wear and friction.

Singh et al. (2017) examined the wear and loss of AISI D3 die steel as it passed through mild steel under dry circumstances. Sliding parameters including sliding time, sliding speed, and normal load were taken. The rate of weight loss increases as the speed increases. This is because high temperatures lead to the development of significant frictional heats. The three main types of wear processes that were identified by SEM investigations in the study are abrasion, adhesion, and surface ploughing.

Elhadia et al. (2021) studied the how varying hardnesses and applied loads affected the surface wear caused by dry sliding of hard carbon steel disc (AISI 1055) against tempered low alloy steel pin (AISI 4140). The study demonstrated that the complicated thermo mechanical behavior of worn surfaces is an outcome of the interaction between the applied load and pin hardness. Adhesion, oxidation, and abrasion were the primary wear causes seen on the discs when a pin of lower hardness was used. High applied loads cause third-body wear, which causes high hardness pins to wear out more quickly than low hardness pins.

Chowdhurya et al. (2013) Studied several steel materials are investigated and evaluated, and a pin-on-disc apparatus is designed and manufactured. When different disc materials, including SS 314, SS 202, and mild steel, slide against stainless steel 314 pins, experiments were conducted. The conditions for the experiments include a normal load, sliding speed, and relative humidity. The obtained analysis shows that for all the investigated materials, friction coefficient decreases as load increases. For all the materials tested, it is also observed that friction coefficient rises as sliding velocity increases. For SS 314, SS 202, and mild steel, wear rates increase with both an increase sliding velocity and normal load.

Chen et al. (2018) Studied when MoS2, Fe2O3, and their combinations were applied to the sliding contact, the tribo layers and tribological behavior of AISI 1045 steel sliding against steel 52100 were examined. For sliding wear tests, a pin-on-disc wear and friction setup was used. The pin and disc sliding components were chosen from AISI 1045 and 52100 steel. Also investigated that, artificial tribo layers developed on the worn surfaces when nanoparticles were added. The properties of the tribo layers, which determined by different nanoparticles, affected the tribological behavior of sliding pairs.

Kumar et al. (2010) studied the medium carbon steel dry sliding wear behavior with an alumina disc. The heat-treated specimens conducted in a pin-on-disc wear setup at dry sliding conditions. Under typical loads, a pin specimen was held against disc while rotating. In secondary electron image mode, a scanning electron microscope was used to examine at the debris and worn surfaces of wear test specimens.

Davim et al. (2000) Studied how the brass/steel combination reacted to wear and friction. On a pin-on-disc test setup, a set of experiments based with Taguchi's methods were carried out and investigated that, the temperature factor, load/velocity, and temperature/load interactions all have a significant impact on the friction coefficient. The load factor has a significant impact on wear, but to a lesser extent than the temperature.

Li et.al. (2022) studied during contact sliding, the surfaces of the opposing materials wear and damage. The wear behaviors of the contact pair are examined using a cylinder-on-flat testing arrangement. To clear the debris in sliding zones compressed air is used. The comparison investigation shows that the surface characteristics of contact pairs have an impact on the influence of debris removal. Debris removal may significantly modify the development of surface damage. When significant wear debris builds up on the surface of tool, leading for various rates of material removal, friction transitions, and surface morphologies for the contact pair. Debris properties and debris effects relations are also studied.

3. Methods

3.1 Experimental Setup

The experiments are carried out on a pin on disc wear test setup consists of a fixed pin made up of EN24 under an applied load against with a rotating disc made up of OHNS. The pin on disc tester measures the sliding wear and friction properties of lubricated or dry surfaces of a variety of materials. The pin-on-disc is instrumented with LVDT to measure frictional force and disc can rotate upto 3000 rpm with rpm controller. Timer, temperature controller, heater, frictional force indicator, rpm indicator, temperature indicator, heater indicator, mains indicator, mains switches, heater switches, dimmer, amp meter, voltmeter also instrumented. As setup is shown in Figure 1 Weight before test and weight after test is taken for wear calculation electronic balance is used.

3.2 Experimental Procedure

Using the Taguchi L9 orthogonal array experiment is carried out. The selection of the control factors and the values assigned to them are based on a literature review. The Taguchi model gives the minimal number of experiments If there were three factors and three levels, it would require nine runs. Three factors are taken as input process parameters. i.e. Speed (Rpm), Pressure(N/mm2), Time (Hr). Experimental steps followed ASTM G99 Using a pin-on-disc, a standard test procedure for testing is used. Separate pins are used for each experimental run, conical shaped pin specimen of 50 mm length and 10 mm pin diameter with 3mm conical surface diameter for contact with counter-face disc of OHNS (Oil Hardened Non-Shrinking Steel) having higher hardness than that of pin. Levels and parameters used for experimentation are as following Table 3, Figure 2 and Figure 3.

Table 3. Levels and Parameters

Sr No.	Parameters	Level 1	Level 2	Level 3
1	Speed (rpm)	500	1000	1500
2	Pressure (N/mm2)	2	3	4
3	Time (Hr)	8	16	24

Figure 1. Pin on disc setup

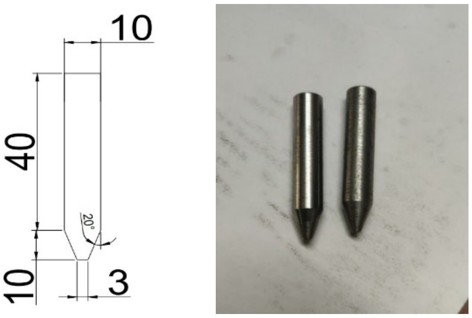


Figure 2. Pins

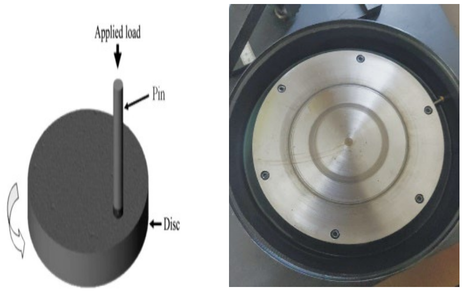


Figure 3. Disc

4. Data Collection

The observed data is recorded which is shown in table 4. The observed data table gives the output of Frictional force, COF, and wear by initial and final weight difference along with GRG. Input parameters speed (rpm), pressure(N/mm$^{2)}$, and time (Hr) are used at ambient temperature.

Table 4. Input and Output parameters with GRG

	Input Parameters			**Output Parameters**			
Pin. No	**Speed (rpm)**	**Pressure (N/mm2)**	**Time (Hr)**	**Frictional Force (N)**	**Coefficient of friction**	**Wear(gm)**	**GRG**
1	500	2	8	2.1	0.148545317	0.0012	0.756770703
2	500	3	16	2.3	0.108461404	0.0013	0.518167048
3	500	4	24	2.5	0.088419519	0.0021	0.359477124
4	1000	2	16	2	0.14147173	0.0014	0.749672791
5	1000	3	24	2.3	0.108461404	0.0014	0.499985229
6	1000	4	8	2.6	0.0919563	0.0019	0.362957744
7	1500	2	24	2.2	0.155631013	0.0009	0.878787879
8	1500	3	8	2.3	0.108461404	0.001	0.603881333
9	1500	4	16	2.7	0.09549308	0.0017	0.373463411

Figure 4. Direct Reading Ferrography

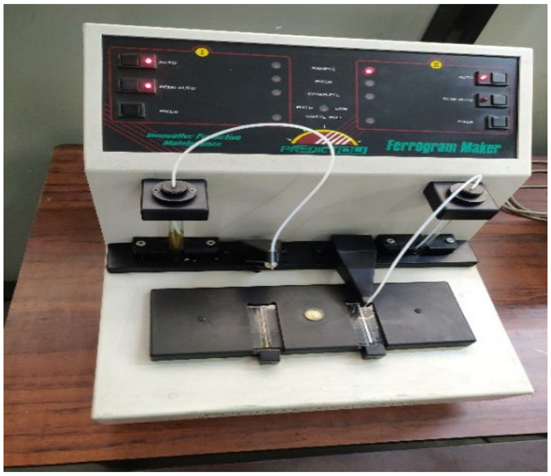


Figure 5. Dual Slide Ferrogram Maker

4.1 Direct Reading Ferrography

To measure the number and quality of wear particles immersed in lubricating oil, ferrography is a significant approach. The data obtained using this method is used to classify the level of wear and to perform condition monitoring on a variety of machine components, including the engine, bearings, and gearbox. Additionally, it allows for the early identification of abnormal wear of lubricated components. Using direct reading ferrography, as shown in Figure 4 wear particles were quantitatively analyzed. The concentration of small and large size particles gives the wear severity index and percentage of large size particles. small size particles are those less than 5 microns in diameter while big size particles are those more than 5 microns in diameter.

4.2 Dual Slide Ferrogram Maker

Dual Slide Ferrogram Maker, the oil sample that was collected was used to prepare a ferrogram slide. After sample collection, the mixture was produced by adding 3ml lubricating oil and 1ml fixture oil and thoroughly mixing it. We always should bring a fresh set of glass slides and test tubes for the lab. Fix the glass tube correctly and place the glass slides. When the glass tube is closed with the knob, a vacuum is formed inside the glass tube. Due to the pressure difference created, oil from the mixture will flow from the glass tube to the glass slide. Wear particles will become magnetized to the glass slide when mixture oil passes over it, sticking to the slide. Fixture oil will pass through the slide at the conclusion of the procedure to clear the glass slide of any extra lubricating oil. The slide is created in this way, as shown in Figure 5, Figure 6 and Figure 7. Experimental and calculated results are shown in Table 5.

Table 5. Direct reading ferrography

				Wear Particle Concentration	**Severity Of Wear**	**Percentage Of Large Particle**	**Wear Severity Index**
				WPC	**SOW**	**PLP**	**WSI**
SR.NO	**PIN**	**DL**	**DS**	**(DL+DS)**	**(DL-DS)**	**{(DL-DS)/(DL+DS)} *100**	**(DL+DS) (DL-DS)**
1	1	154.2	79.2	233.4	75	32.13367609	17505
2	2	93.6	47	140.6	46.6	33.14366999	6551.96
3	3	108.3	42.3	150.6	66	43.8247012	9939.6
4	4	98.1	45.8	143.9	52.3	36.34468381	7525.97
5	5	120.4	48.3	168.7	72.1	42.73858921	12163.27
6	6	115.1	44.8	159.9	70.3	43.96497811	11240.97
7	7	153.2	60.2	213.4	93	43.58013121	19846.2
8	8	150.1	59.3	209.4	90.8	43.36198663	19013.52
9	9	120.9	36.8	157.7	84.1	53.3291059	13262.57

5. Results and Discussion

5.1 Numerical Results

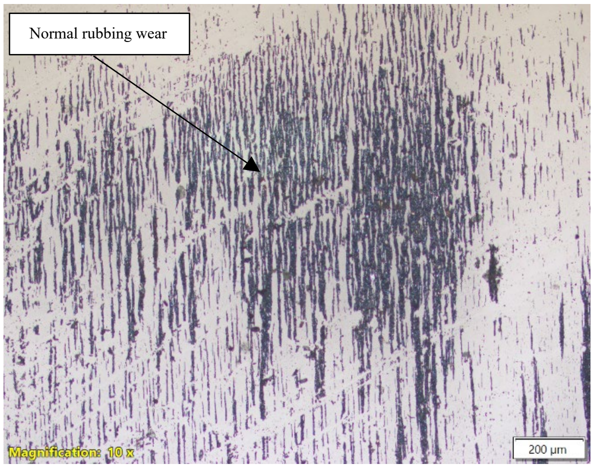


Figure 6. Normal rubbing wear (10X)

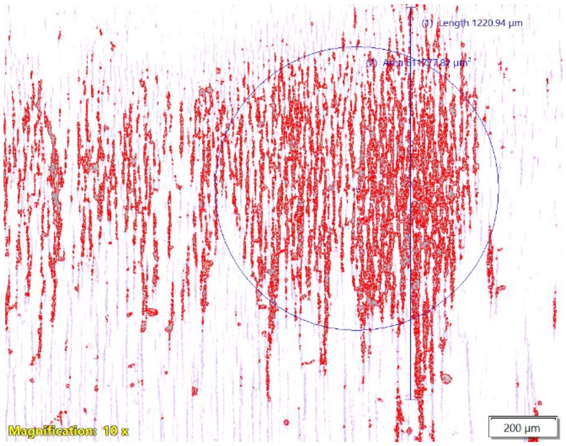


Figure 7. Thresholding of wear particles

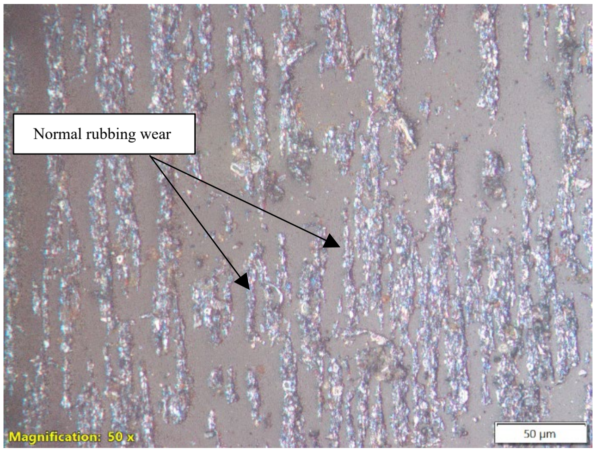


Figure 8. Normal rubbing wear (50X)

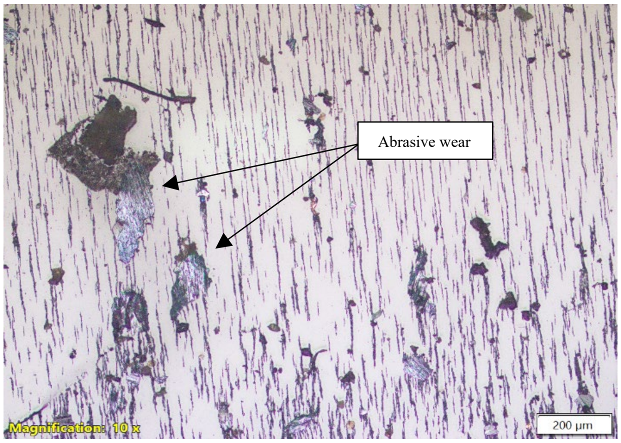


Figure 9. Severe sliding wear (10X)

Normal rubbing wear particles are observed in optical microscope at lowest load and speed normal rubbing wear particles in smaller range observed. After increasing in load and speed abrasive wear and severe wear particles observed this is because of the large number of wear particles and lubricants acted as third body. If a contamination in a form of dust particles, present in lubricating oil rubbing wear increases. Wear particles are captured at 10X, 50X and 100X magnification by using Bi-Chromatic optical microscope and Olympus software. Figure 6 shows the 10X magnification of wear. Normal rubbing wear is observed. Figure 7 shows the thresholding of wear particles on the slide. Figure 8 shows the 50X magnification of slide. In which normal rubbing wear particles are observed. Figure 9 shows the 10X magnification of slide. It shows abrasive wear particles. The ferrogram slide was heated up before being examined under a microscope. Ferrous wear particles partially oxidized during the heating of the ferrogram slide, changing the colour of the wear debris. Thresholding of wear particles gives the colour to wear particles which helps to count and measure of wear particles.

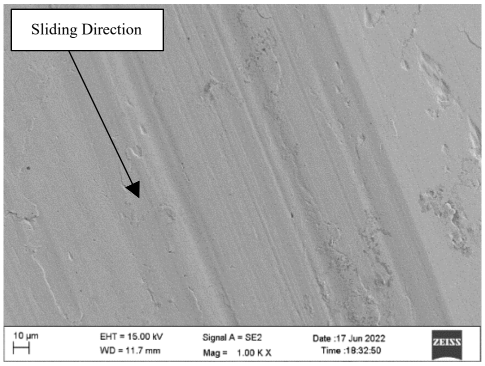


Figure 10. SEM of EN24 after test (10µm)

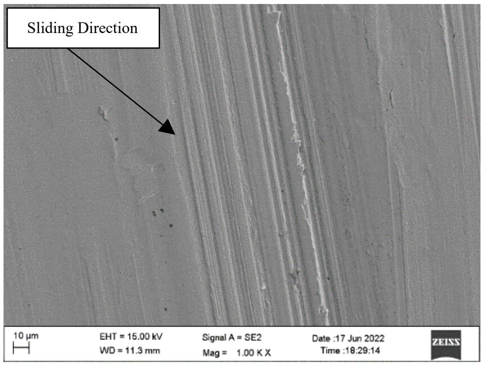


Figure 11. SEM of EN24 after test (10µm)

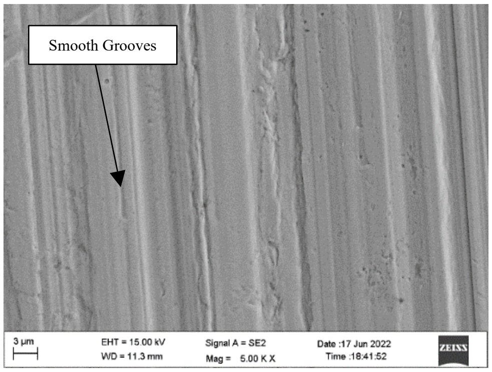


Figure 12. SEM of EN24 after test (3µm)

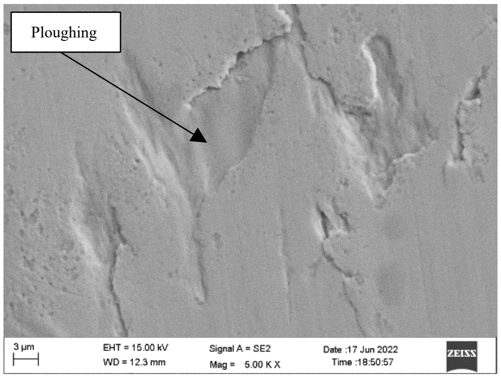


Figure 13. SEM of EN24 after test (3µm)

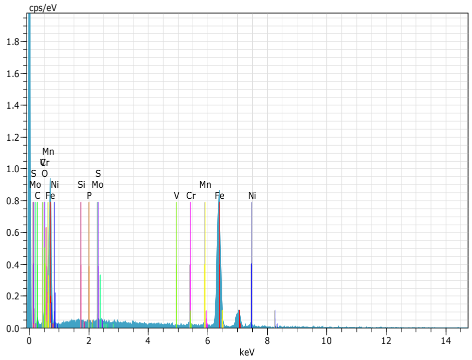
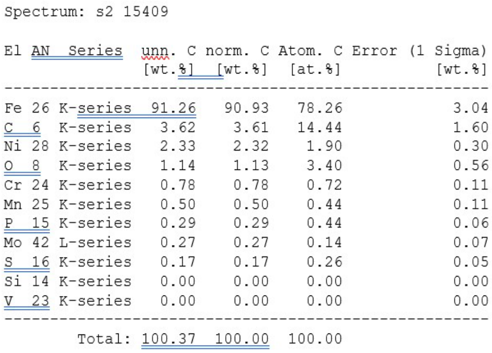


Figure 14. EDS analysis graph



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Spectrum: s2 15409

El AN  Series  unn. C norm. C Atom. C Error (1 Sigma)
               [wt.%]  [wt.%]  [at.%]           [wt.%]
-----------------------------------------------------
Fe 26 K-series  91.26    90.93   78.26             3.04
C   6 K-series   3.62     3.61   14.44             1.60
Ni 28 K-series   2.33     2.32    1.90             0.30
O   8 K-series   1.14     1.13    3.40             0.56
Cr 24 K-series   0.78     0.78    0.72             0.11
Mn 25 K-series   0.50     0.50    0.44             0.11
P  15 K-series   0.29     0.29    0.44             0.06
Mo 42 L-series   0.27     0.27    0.14             0.07
S  16 K-series   0.17     0.17    0.26             0.05
Si 14 K-series   0.00     0.00    0.00             0.00
V  23 K-series   0.00     0.00    0.00             0.00
-----------------------------------------------------
        Total: 100.37  100.00  100.00
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Figure 15. EDS results

The energy dispersive spectroscopy i.e., EDS method is used for qualitative analysis of materials. Generally, an EDS system is included with SEM apparatus to enable chemical analysis of features being seen in the SEM display. For morphological analysis image formation is created by backscattered electrons and secondary electrons. To identify compounds of certain element X-rays are used. These signals are created by a SEM/EDS system. The worn surfaces of tracks on pin have been studied using optical microscope and SEM methods to determine the wear processes. Figures 10 and 11 shows SEM images of worn pins. For the high load, the worn surface on the pin is larger as compared to the low load. At high load normal rubbing wear pattern as well as third body abrasion wear is observed in Figure 12. From Figure 13 shows SEM images of pin at high load and high speed third body abrasive wear is observed. Figures 14 and Figure 15 show EDS analysis graph and EDS results of EN24 after test.

5.2 Graphical Results

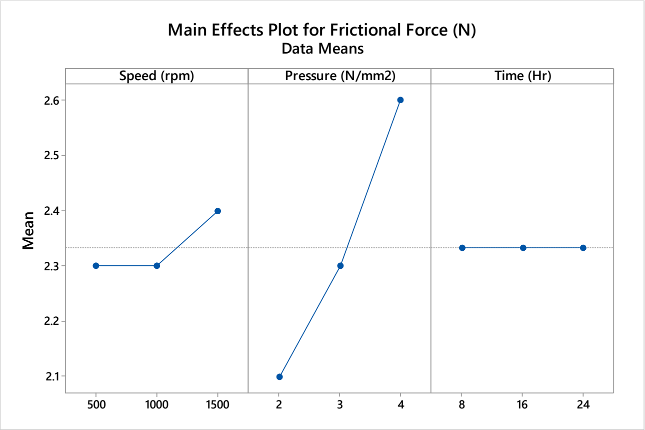

Figure 16. Main effect plot for Frictional force

Table 6. Analysis of Variance for Frictional force

Source	DF	Adj-ss	Adj-ms	P- Value	F- Value
Speed(rpm)	2	0.020000	0.010000	0.500	1.00
Pressure(N/mm2)	2	0.380000	0.190000	0.050	19.00
Time (Hr)	2	0.000000	0.000000	1.000	0.00
Error	2	0.020000	0.010000		
Total	8	0.420000			

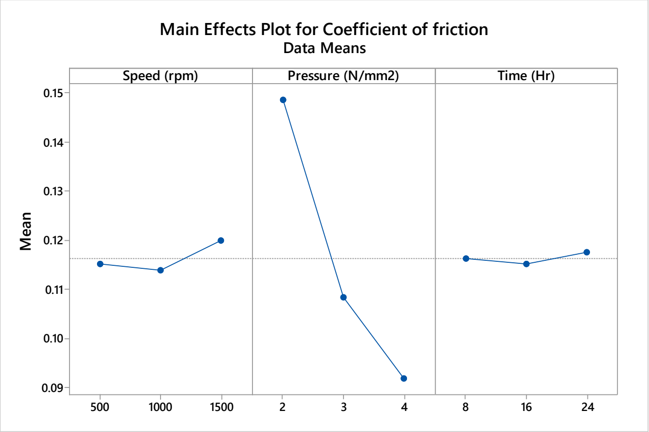

Figure 17. Main effect plot for coefficiet of friction

Table 7. Analysis of Variance for Frictional force

Source	DF	Adj-ss	Adj-ms	P- Value	F- Value
Speed(rpm)	2	0.000058	0.000029	0.500	1.00
Pressure(N/mm2)	2	0.005082	0.002541	0.011	86.98
Time (Hr)	2	0.000008	0.000004	0.875	0.14
Error	2	0.000058	0.000029		
Total	8	0.005207			

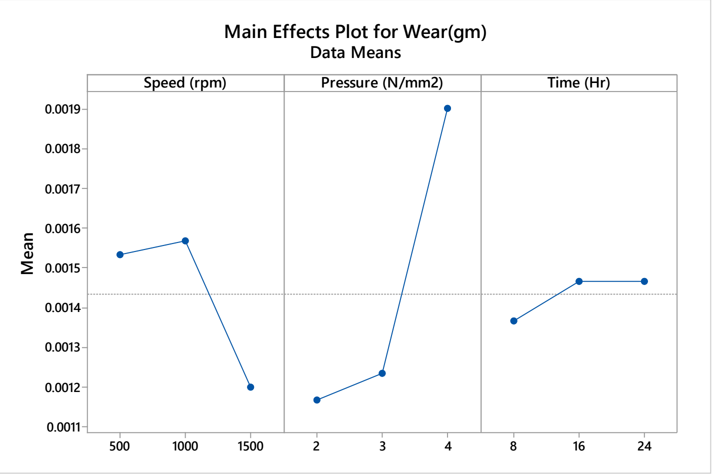

Figure 18. Main effect plot for Frictional force

Table 8. Analysis of Variance for Wear

Source	DF	Adj-ss	Adj-ms	P- Value	F- Value
Speed(rpm)	2	0.000000	0.000000	0.098	9.25
Pressure(N/mm2)	2	0.000001	0.000000	0.026	37
Time (Hr)	2	0.000000	0.000000	0.571	0.75
Error	2	0.000000	0.000000		
Total	8	0.000001			

In Figure 16 It was observed that when the speed increases frictional force is in between mean upto certain speed, after that it increases in certain amount. Frictional force continuously increased when load increased. Load is significant factor in terms of frictional force. Table 6 shows ANOVA for frictional force, and it has found that load is more significant as compared to speed and time.

In Figure 17 It was observed that when the load increased, the coefficient of friction continuously decreased. This occurs because of a large accumulation of wear debris and lubricant in the contact zone that acted as a third body as the load increased. Therefore, three body abrasive wear processes were responsible for the decrease in friction coefficient. Table 7 shows ANOVA for coefficient of friction, in which pressure has significant effect.

In Figure 18 As the load increased continuously wear also increased, for wear load is significant factor. As the speed increases at certain speed wear also increases after increases in higher speed wear is decreased in minor, this is because of the at higher speed it gets constant boundary condition of lubricating oil between pin and disc. From analysis of variance of wear load shows significant result as shown in table 8.

6. Conclusion

The main conclusions that are observed during the experiments are as follows.

- Most significant parameter observed are load compared to speed and time in terms of frictional force and coefficient of friction. Load and speed are significant factors in terms of wear.
- It is found that the coefficient of friction continuously reduced as the load increased. This is because when the load increased, a lot of wear debris gathered in the contact zone and mixed with lubricant, acting as a third body. Therefore, the decrease in friction coefficient was caused by three body abrasive wear mechanisms.

- The slide prepared from lubricating oil was obtained using analytical ferrography. Images from a bi-chromatic microscope confirmed types of wear.
- EN24 pin material showed best results for wear resistance at highest speed and lowest load. Wear is more at highest load and lowest speed.

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