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**Experimental Investigation of Friction and Wear Behavior at the Interface of Aluminium and Mild Steel**

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**ABSTRACT**

*The Paper incorporates the experimental studies carried out for assessing the tribological performance of Aluminium at the sliding contacts with mild steel plate, using a pin-on-disk tribometer as per ASTM-G 99. The study has been done in order to explore the friction and wear behaviors at the interface of tribo-pair. The tribological properties as coefficient of friction and specific wear rate of aluminium 6061 are investigated. The Tribological tests are carried out at 500, 1000, 1500 rpm for 1000 meters in dry condition based on Response Surface Methodology. Track diameter, rotating speed and normal load are considered as the design parameters. Using central composite design, the problem is converted into single response optimization problem and the optimum combination of design parameters are found as 50mm track diameter, 500 rpm of rotating speed and 0.5 kg of normal load. The ANOVA result shows that the rotational speed is the most significant factor, followed by load and Track diameter for co-efficient of friction. Whereas the Track diameter is the most significant factor, followed by rotating speed and normal load for specific wear rate. Finally, microscopic images are investigated to identify the wear mechanism.*

**Keywords:** *Friction; Tribological Performance; Specific Wear Rate; Aluminium; Mild Steel; Pin-On-Disk Tribometer; Analysis of Variance (ANOVA).*

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**1.0 Introduction**

The science of tribology has a long history since evolution of civilization and the basic laws of friction, such as the relation between normal force and friction force up to the limiting case of sliding are probably developed by Leonardo da Vinci in the late 15th century. Reynold concluded through conference and seminars that the hydrodynamic pressure of liquid developed between sliding surfaces is sufficient to prevent contact to form film between surfaces even at very low sliding speeds. Its practical application lead to the removal of an oil hole from axle bearings of the railway. The work of Reynold motivated other research efforts aimed at improving the interaction between two contacting surfaces that has relative motion (Gwidon W. Stachowiak and Andrew W. Batchelor). Tribology, which focuses on friction, wear and lubrication of interacting surfaces in relative motion, is a new field of science defined in 1967 by a committee of the Organization for

Economic Cooperation and Development. Aluminium is lighter metal and its alloys are used at different location and specially where the relative motion exist.

Wear is the major cause of material wastage and loss of mechanical performance and any reduction in wear can result in considerable savings. Friction is a principal cause of wear and energy dissipation.

Considerable savings can be made by improved friction control. Lubrication is an effective means of controlling wear and reducing friction. Tribology is a field of science which applies an operational analysis to problems of great economic significance, such as reliability, maintenance and wear of technical equipment ranging from household appliances to spacecraft. In simple terms, it appears that the practical objective of Tribology is to minimize the two main disadvantages of solid to solid contact: friction and wear, but this is not always the case. Several researchers [1-6] have demonstrated the

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potential benefits of modifying the topography of surfaces in the Tribological contacts. For conditions involving surface-to-surface contact, the presence of wear debris particles can be very detrimental to friction and wear behavior [22]. The mechanisms responsible for the improved performances of tribo-contacts are subject to the type of the applications and operating conditions in which surface Texturing are utilized. It was demonstrated that these particles can be removed from the contacting surfaces and trapped in surface depressions and undulations [13, 29]. The presence of certain texture features may also benefit some lubricated systems by acting as reservoirs (storing valley) and supplying the lubricant directly at the interfaces [17, 20]. Moreover, some well-designed texture features may also benefit the performance of the lubricant by boosting the hydrodynamic pressure [7, 28].

The present study focuses on the experimental studies carried out using a pin-on-disc tribometer as per ASTM-G 99 for assessing the tribological performance of Aluminium at the sliding contacts with mild steel plate. The study has been done in order to explore the friction and wear behaviors at the interface of Tribo-pair [23, 26]. The tribological properties as coefficient of friction and specific wear rate of aluminum 6061 are investigated. The track diameter (A), rotating speed (B) and normal load (C) are selected as design factors with three levels for each design parameter. The responses selected are coefficient of friction and specific wear rate. The optimum combination of design parameters were found using central composite design with Response surface methodology [24, 25]. Analysis of variance (ANOVA) is also used to find out the most significant factor which affects the responses. An effort is also made to study the morphology of wear tracks of composites after the friction tests using microscopy images.

## 2.0 Experimental Setup

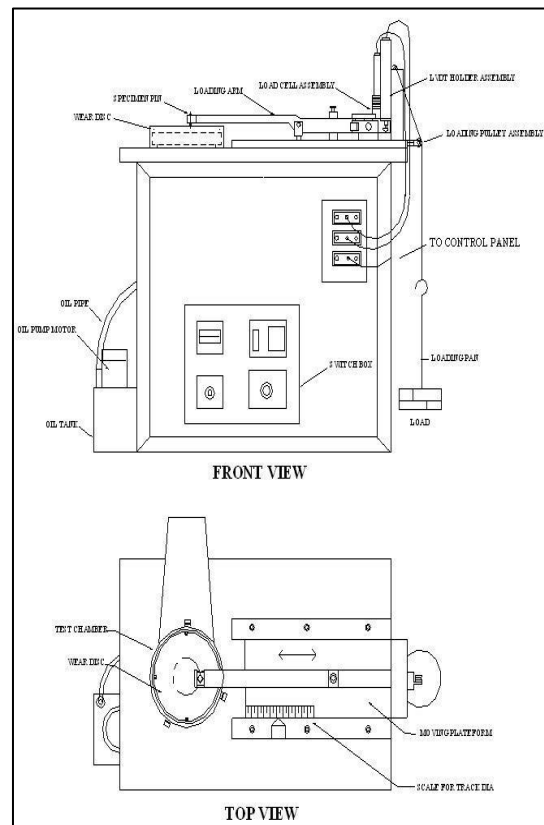
Cylindrical Aluminium pin (Al-6061) of diameter 10 mm and the mild steel disc of 165 mm diameter and 8 mm thickness has been chosen for conducting the experiments using a pin-on-disc tribometer. The ranges of parameters specified for the tribometer are provided in Table 1.

Experiments have been carried out on a pin-on-disc tribometer (Fig.1) as per ASTM-G99 at room

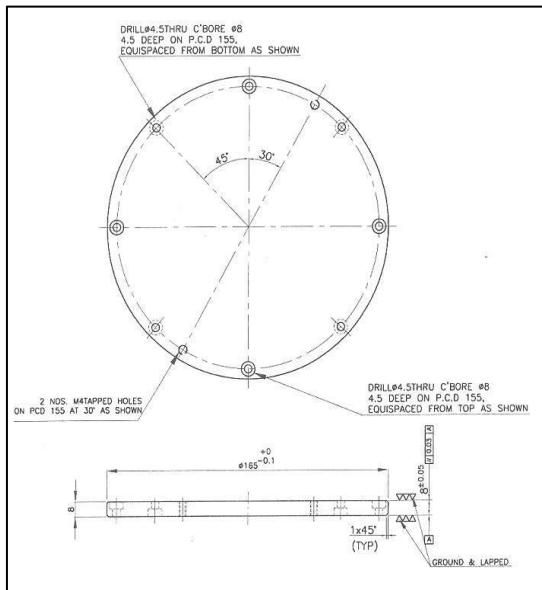
temperature. Photographic view of a disc plate is shown in Fig. 2.

The selected levels and parametric values are listed in Table 2. The specimens are cleaned and dried to remove all dirt and foreign matter. A mild steel disc of surface roughness 2 to 2.5  $\mu\text{m}$  was inserted securely in the holding device so that the disc plane remains horizontal and perpendicular to the axis. The cylindrical pin of 10 mm diameter and 32 mm height of Aluminium was inserted securely in the holder so that it remains perpendicular to the disc surface in order to maintain the necessary contact conditions. The proper mass was loaded to the system as shown in Fig.1 with leverage 1:1 to develop the selected force pressing the pin against the disc. The desired speed in RPM and time in seconds was used to run the motor, which is attached to the disc. The tests were performed as per Design of Experiments Table 2. The tribological studies (friction and wear measurements) have been carried out for the loads characterized by the contact pressure varying in the range of 6.3 – 19.1 kPa at sliding speeds 1.25 – 7.54 m/s.

**Fig 1: Schematic Diagram of Pin-On Disc Tribometer**



**Fig 2: Schematic Diagrams of the Disc**



**Table 1: Specific Parameters for Tribometer**

S. No.	Parameter	Numerical Values
1	Pin diameter, mm	3, 4, 6, 8, 10 & 12
2.	Disc diameter, mm	165
3.	Thickness of disc, mm	8
4.	Speed, RPM	200 – 2000
5.	Friction force (tangential force), N	up to 200
6.	Applied normal load at the contact, N	up to 300

**Table 2: Levels and Parametric Values**

Parameter	Units	Level 1	Level 2	Level 3
Track Diameter	mm	50	75	100
Rotating Speed	rpm	500	1000	1500
Normal Load	N	0.5	1	1.5

**3.0 Results and Discussions**

Figures 3 to 8 present the results of friction and wear variations. The experiments have been carried out at 500, 1000, 1500 RPM in dry condition based on Response Surface Methodology. The design

table has been shown in Table 3. It has been observed from main effects plot that the coefficient of friction increases as the rotational speed increases. Whereas specific wear rate increases with the increase in track diameter and decreases with increase in normal load.

**Table 3: Design Table (Randomized)**

Run	Blk	A	B	C	Run	Blk	A	B	C
1	1	1	1	-1	11	2	0	0	0
2	1	0	0	0	12	2	0	0	0
3	1	1	-1	1	13	3	0	0	-1
4	1	0	0	0	14	3	0	0	0
5	1	-1	1	1	15	3	1	0	0
6	1	-1	-1	-1	16	3	-1	0	0
7	2	-1	-1	1	17	3	0	0	1
8	2	1	1	1	18	3	0	-1	0
9	2	-1	1	-1	19	3	0	1	0
10	2	1	-1	-1	20	3	0	0	0

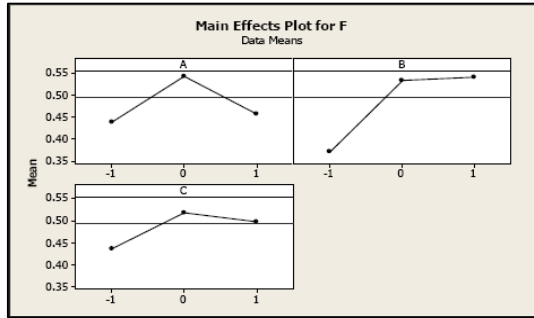
Central Composite Design has been done with three factors, one replicates, 20 base runs and three base blocks. Factorial part includes eight cube points, four Center points in a cube, six Axial points two center points in axial and alpha as 1.

**Table 4: Data Matrix**

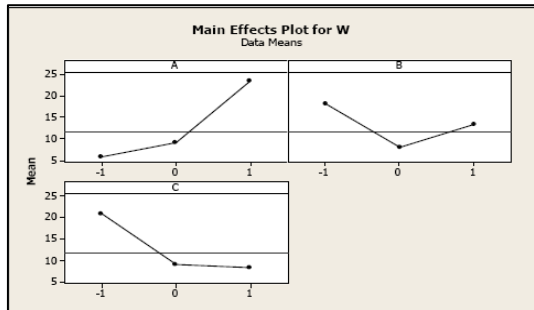
Run	A	B	C
3	1.000	-1.000	1.000
5	-1.000	1.000	1.000
6	-1.000	-1.000	-1.000
7	-1.000	-1.000	1.000
8	1.000	1.000	1.000
9	-1.000	1.000	-1.000
13	0.000	0.000	-1.000
15	1.000	0.000	0.000
18	0.000	-1.000	0.000
10	1.000	-1.000	-1.000

Optimal Design for A, B, C parameters have been done using Response surface design selected according to D-optimality. Number of candidates in design points are 20 and the number of selected design points in optimal design are 10. The selected 10 model terms are A, B, C, AA, BB, CC, AB, AC, and BC. Initial design is generated by Sequential method and Initial design is improved by Exchange method where number of design points exchanged are 1. For Optimal Design Row numbers of selected design points are 3, 5, 6, 7, 8, 9, 13, 15, 18, and 10 as shown in Table 4.

**Fig 3: Main Effects Plot for F**

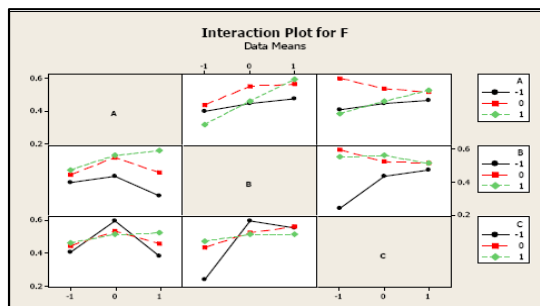


**Fig 4: Main Effects Plot for W**

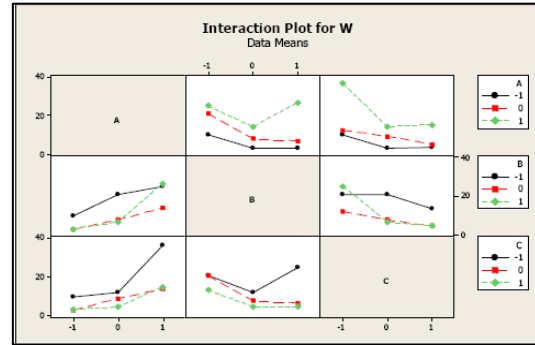


Main effects plot for coefficient of friction (F) and Specific Wear ratio (W) displays that: The coefficient of friction increase with increase in track diameter (A) 50 mm to 75 mm and decrease with increase in track diameter 75 mm to 100 mm. The coefficient of friction increase with increase in rotational Speed (B). The coefficient of friction increase with increase in Load (C) 0.5 kg to 1 kg and decrease with increase in Load 1 kg to 1.5 kg. The Specific Wear ratio increase with increase in track diameter (A). The Specific Wear ratio decreases with increase in rotational Speed (B) 500 RPM to 1000 RPM and increase with increase in Rotational Speed 1000 RPM to 1500 RPM. The Specific Wear ratio decrease with increase in Load (C).

**Fig 5: Interaction Plot for F**



**Fig 6: Interaction Plot for W**



Response Surface Regression: F versus A, B, C, The analysis was done using coded units.  $S = 0.0514892$ ,  $PRESS = 0.379496$ ,  $R-Sq = 87.63\%$ ,  $R-Sq (pred) = 0.00\%$ ,  $R-Sq (adj) = 76.49\%$

**Table 5: Analysis of Variance for F**

Source	D F	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.187759	0.187759	0.020862	7.87	0.002
Linear	3	0.080103	0.080103	0.026701	10.07	0.002
Square	3	0.047832	0.047832	0.015944	6.01	0.013
Interaction	3	0.059824	0.059824	0.019941	7.52	0.006
Residual Error	10	0.026511	0.026511	0.002651		
Lack-of-Fit	5	0.0265	0.0265	0.0053	*	*
Fit		11	11	02		
Pure Error	5	0.000000	0.000000	0.000000		
Total	19	0.214270				

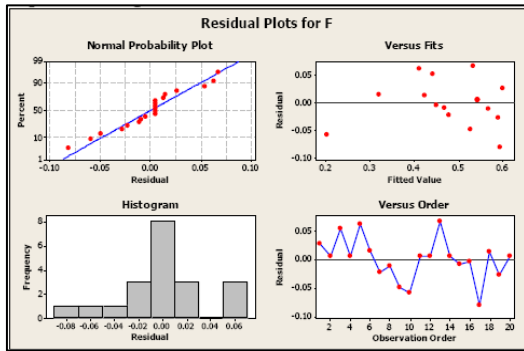
Response Surface Regression: W versus A, B, C, The analysis was done using coded units.  $S = 6.10141$ ,  $PRESS = 7146.89$ ,  $R-Sq = 82.57\%$ ,  $R-Sq (pred) = 0.00\%$ ,  $R-Sq (adj) = 66.87\%$ .

**Table 6: Analysis of Variance for W**

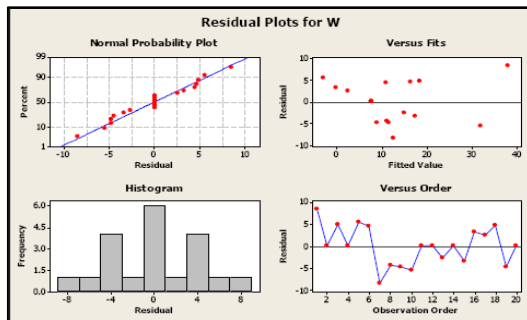
Source	D F	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1763.00	1763.00	195.889	5.26	0.008
Linear	3	1226.22	1226.22	408.741	10.98	0.002
Square	3	303.57	303.57	101.191	2.72	0.101
Interaction	3	233.20	233.20	77.734	2.09	0.165
Residual Error	10	372.27	372.27	37.227		
Lack-of-Fit	5	372.27	372.27	74.454	*	*
Pure Error	5	0.00	0.00	0.000		
Total	19	2135.27				

Table 5 and 6 shows the Analysis of Variance (ANOVA) for F and W respectively. In both cases the value of P explains the significance of the work.

**Fig 7: Residual Plots for F**



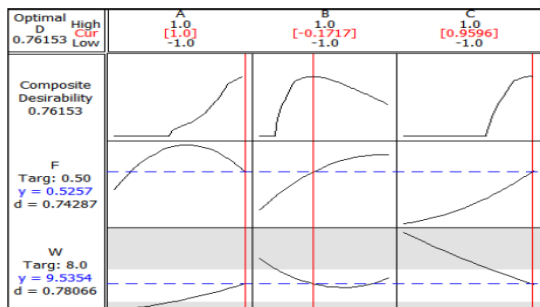
**Fig 8: Residual Plots for W**



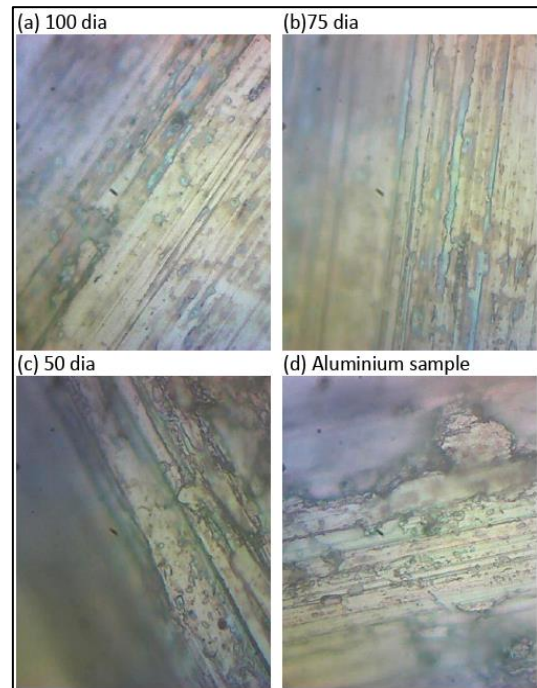
Response Optimization results with Global Solution values  $A = 1$ ,  $B = -0.171717$  and  $C = 0.959596$ . Predicted Responses, F is 0.52571 with desirability 0.742868 and W is 9.53539 with desirability 0.780658. Composite Desirability is 0.761529. Figure 9 shows the optimization plot. The

microscopic images for the values of 50, 75,100 diameter, and Al pin is as shown in figure 10 below.

**Fig 9: Optimization Plot**



**Fig 10: Microscopic Image of (a) MS disc at 100 Diameter (b) MS Disc at 75mm Diameter (c) MS Disc at 50 mm Diameter (d) Aluminium Pin**



**4.0 Conclusions**

The coefficient of friction increases as the rotational speed increases. Specific wear rate increases with increase in track diameter and decreases with the increase in normal load. The optimum combination of design parameters for coefficient of friction are as 50 track diameter, 0.5 kg of load and 500 RPM of rotational speed.

The rotational speed is the most significant factor, followed by load and Track diameter for coefficient of friction. Whereas the Track diameter is the most significant factor, followed by rotating speed and normal load for specific wear rate. The optimum combination of design parameters for specific wear rate are as 50 track diameter, 1000 RPM and 1.5 kg of load of rotational speed.

Moreover, the ANOVA showed that the quadratic effects were significant on the coefficient of friction as well as specific wear rate and interactions were statistically significant. Microscopic images have been studied to identify the wear mechanism. It can be concluded from the study that with controlling the rotating speed and track diameter at the right combination of factors, the Tribological properties may be improved.

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