SURFACE FRICTION & WEAR ESTIMATION

ME794 - Statistical Design of Experiments
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TEAM STRATO
Shiv Modi [19D100011]
Balbir Yadav [200100042]
Avichal Jain [200020035]
Aditi Gupta [200100009]
Ved Khandekar [20D170019]

under the guidance of
Prof. Soham Mujumdar

Department of Mechanical Engineering
INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

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ABSTRACT

The interplay between wear and friction is a critical consideration in countless engineering applications. This study delves into this intricate relationship, investigating the tribological behavior of two prevalent materials, brass and aluminum, subjected to variations in lubrication and speed. By quantifying wear and friction under controlled conditions, this research aims to elucidate the key factors governing these tribological phenomena.

The experiment meticulously examines the response of both brass and aluminum to three distinct lubrication states: unlubricated (dry), half and fully lubricated. Furthermore, the investigation incorporates four different rotational speeds (RPMs) to assess the influence of sliding velocity on the tribological properties. This comprehensive approach, encompassing diverse lubrication conditions and speeds, offers a nuanced perspective on the wear and friction mechanisms at play.

To systematically analyze the collected data and pinpoint the factors exerting the most substantial influence on wear and friction, a robust statistical technique known as Analysis of Variance (ANOVA) is employed. ANOVA decomposes the total variation observed in the wear and friction measurements into contributions from individual factors (lubrication state, RPM) and their potential interactions. By statistically evaluating these contributions, ANOVA enables researchers to isolate the factors with the most significant impact on the tribological response.

A thorough understanding of how lubrication and speed modulate wear and friction of brass and aluminum is instrumental in optimizing material selection and design for tribological systems. This knowledge can pave the way for the development of more wear-resistant and friction-reducing solutions across a wide range of applications, from bearings and gears to machine components and sliding contacts.

In essence, this research sheds light on the intricate tribological dance between brass and aluminum under varying lubrication and speed regimes. By leveraging ANOVA, the study identifies the principal factors dictating wear and friction, empowering engineers to make informed decisions for enhanced tribological performance in their designs. The knowledge generated from this investigation has the potential to revolutionize how we approach wear and friction management in brass and aluminum components, ultimately leading to more efficient and durable engineering systems.

KEYWORDS: Tribology, Friction, Lubrication, Wear, ANOVA

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Chapter 1

INTRODUCTION

Manufacturing, surface technology, and mobility are the three most critical industrial functions in contemporary industrialized civilizations. Diverse industries require various resources, which must be operated by a combination of machinery and mechanical or electrical systems, each containing many significant moving parts and interacting surfaces. Frictional forces are generated due to the relative motion, resulting in the development of the wear phenomenon. As a result, friction and wear management are critical in determining the surface characteristics and life of the component.

1.1 Motivation

It was reported that British businesses could save £500 million per year by improving their machinery's tribological performance. Another study indicated that advances in lubrication and tribology could result in annual energy savings of up to 11% across multiple sectors in the United States [3]. Five decades after the invention of tribology, frictional losses are estimated to account for more than 1% of GDP in China [7]. Holmberg and Erdemir [4] indicate that approximately 23% of today's global energy consumption is attributed to tribological difficulties, with about 20% consumed to overcome friction and around 3% required to repair or reprocess worn parts. With the growing demand for higher power densities, depleting resources, growing environmental consciousness, and more stringent regulatory requirements, energy losses can still be significantly reduced through wear, friction, and lubrication technologies.

In engineering's quest for efficiency and sustainability, predicting parameters such as surface friction is pivotal. Friction is a fundamental aspect of mechanical systems, significantly influencing efficiency and wear. The pin-on-disc setup provides a controlled environment to investigate frictional forces under varying conditions. This experiment aims to systematically explore the impact of load, disc speed, lubrication, and pin material on friction. The motivation lies in optimizing mechanical systems for enhanced efficiency, guiding material selection for reduced wear, developing effective lubrication strategies, and promoting energy-efficient operation. By employing statistical analysis, the study seeks to identify conditions that lead to improved processes and decision-making in industries relying on friction management, such as automotive, aerospace, and manufacturing.

Chapter 2

LITERATURE REVIEW

Friction occurs everywhere in nature and industry; it is necessary for daily life and is beneficial for energy conservation, but it is also alleged to be the primary source of wear failures and energy consumption. As a result, scientists have long sought to understand the origins of friction, in some cases attempting to demonstrate the possibility of creating an entirely frictionless state, with notable progress made in recent years. Kronberger et al. [5] forecasted the friction factor using fuzzy modelling, indicating an excellent performance at a significance level of 0.05. Aleksendric et al. [1] used artificial neural networks to forecast the friction coefficient of an automobile brake system. The author accurately modelled the process and predicted the friction of the material by incorporating inputs such as moulding specific pressure, moulding temperature, moulding time, heat treatment temperature, and heat treatment time. Boidi et al. [2] predicted the lubrication effect in terms of friction coefficient using the radial basis function (RBF) algorithm and discovered a reasonable correlation between experimental and predicted values.

In study [6],Aluminium surface composite with ceramic reinforcement underwent successful fabrication through friction stir processing, employing various tool RPMs. Following fabrication, pin-on-disc tests were executed, varying sliding distances (300 m, 600 m, 900 m), and applied loads (20 N, 30 N, 40 N) to assess wear behavior. Response Surface Methodology (RSM) was used to model the wear behavior Furthermore, RSM facilitated process parameter optimization, with the model identifying an optimal condition: 1200 RPM tool rotational speed, 20 N load, and 300 m sliding distance.

Chapter 3

OBJECTIVES

Investigate the influence of load, disc speed, lubrication, and pin material on friction in a pin-on-disc setup, aiming to optimize mechanical systems for enhanced efficiency and reliability in diverse industrial applications.

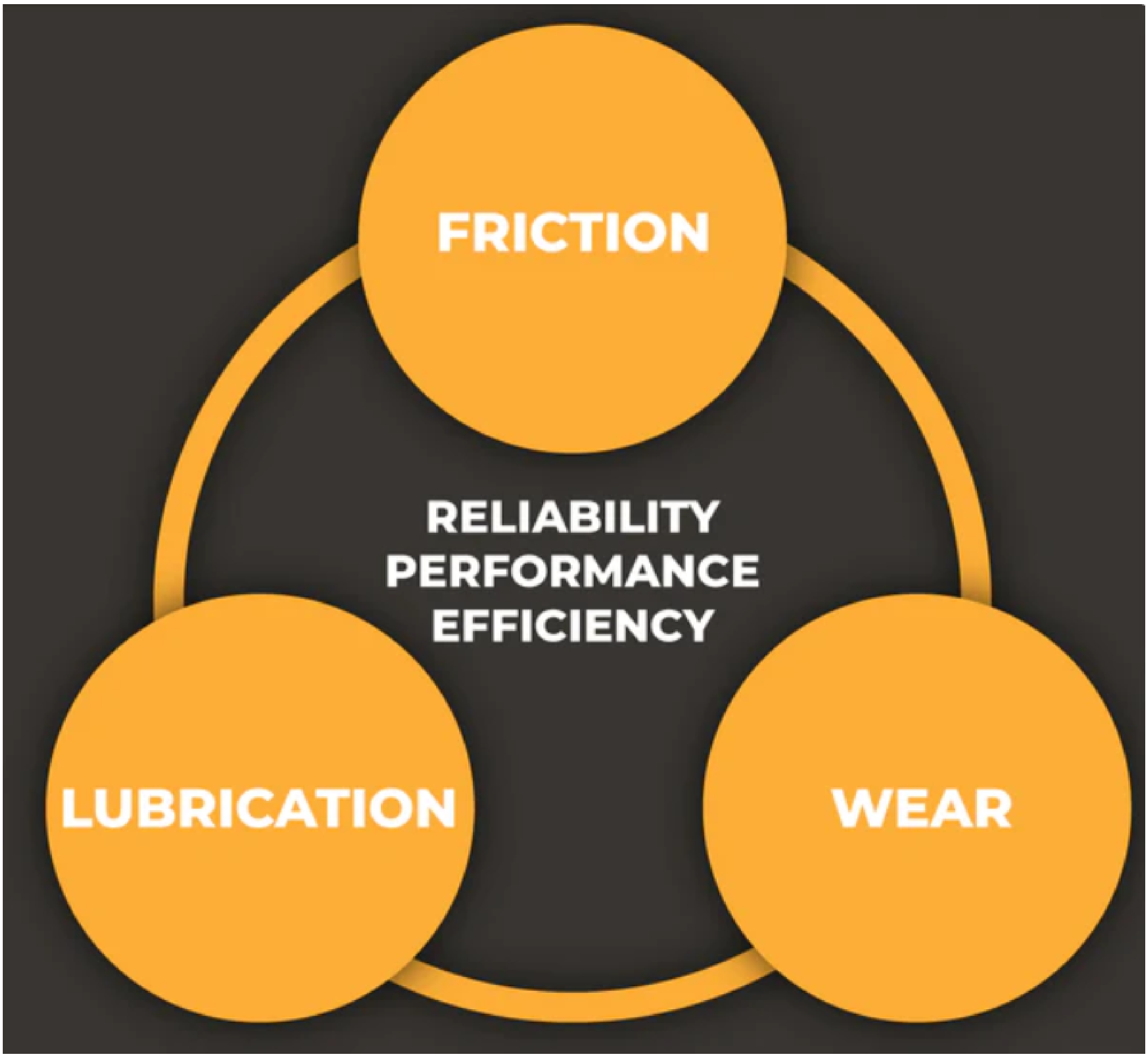


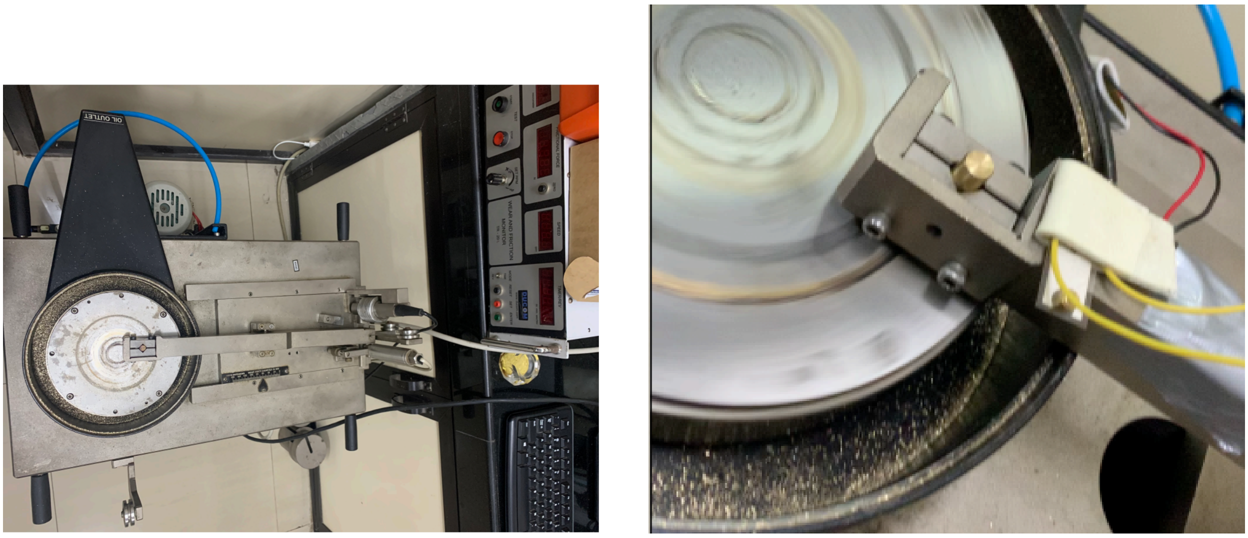
Figure 3.1: Elements of Tribology ref: Totallyseals.com

Chapter 4

METHODOLOGY

4.1 Experimental Setup

The pin-on-disc setup has a rotating steel disc that is in contact with a pin held by two vices (shown in fig. 4.1). Due to the contact between the pin and the disc, the friction between them wears out the pin. The parameters that can be changed in the machine are the weight, rpm, pin material (Brass/Aluminium), radial location of the pin on the disc and the lubrication condition. The machine has an inbuilt wear and friction force sensor, which can be collected from a software called Winducom. The values of weight, rpm and radial location of the pin should be entered in the Winducom software before collecting data.



(a) Pin on disk setup

(b) Pin held by 2 vices

Figure 4.1: Experimental setup

4.2 Preliminary Experiments

The preliminary experiment was conducted to investigate the effects of various factors on friction and wear, crucial parameters in mechanical systems. The experiment aimed to discern the impact of lubrication conditions, RPM (Revolutions Per Minute), weight, and materials on friction and wear characteristics.

Table 4.1: Preliminary Experiment Parameters Values for Aluminium (6 samples)

Variable	**Values**
Pin Material	Aluminium
RPM, Weight (kg)	(175, 2kg), (225, 5kg), (300, 8kg)
Lubrication Condition	No and Full Lubrication

Table 4.2: Preliminary Experiment Parameters Values for Brass (6 samples)

Variable	**Values**
Pin Material	Brass
RPM, Weight (kg)	(175, 5kg), (225, 8kg), (300, 11kg)
Lubrication Condition	No and Full Lubrication

The experiment involved the utilization of two distinct materials: Brass and Aluminium, which are commonly employed in engineering applications due to their differing mechanical properties. For each material, three levels of weight and RPM were selected to ensure a comprehensive examination of the variables. The weight sets for Aluminium were (175, 2kg), (225, 5kg), and (300, 8kg), while for Brass, they were (175, 5kg), (225, 8kg), and (300, 11kg).

Two lubrication conditions were established: No lubrication and Full lubrication, representing a range of real-world scenarios encountered in mechanical systems. Friction and wear measurements were recorded under each combination of material, lubrication, weight, and RPM settings.

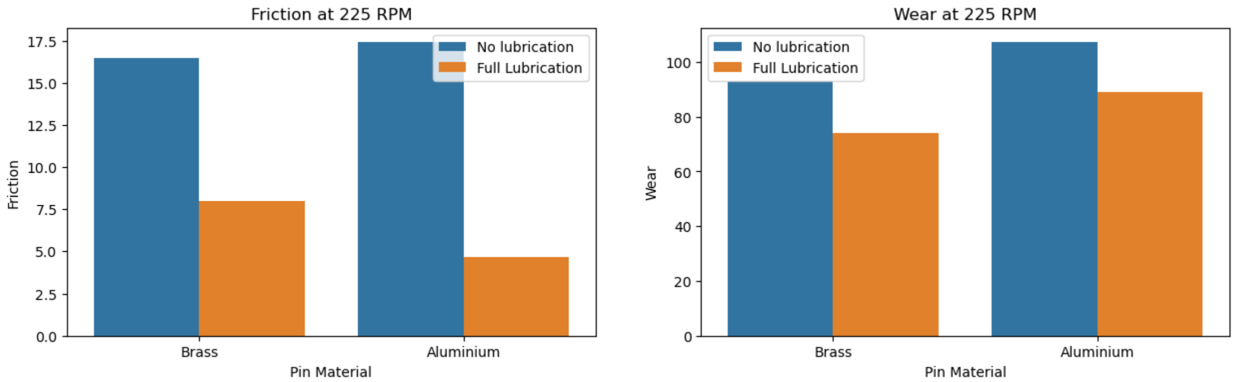
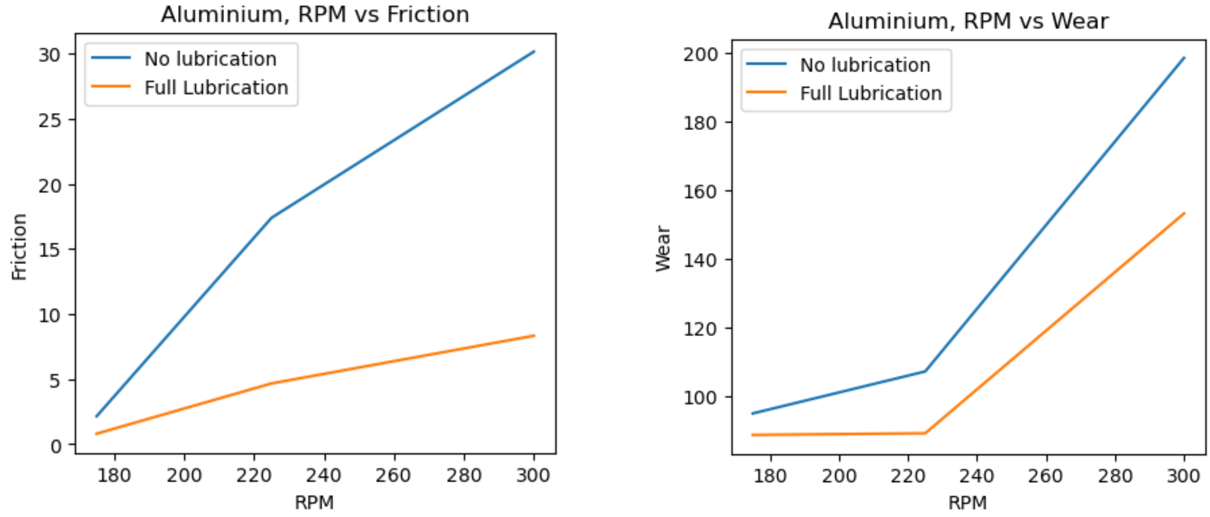


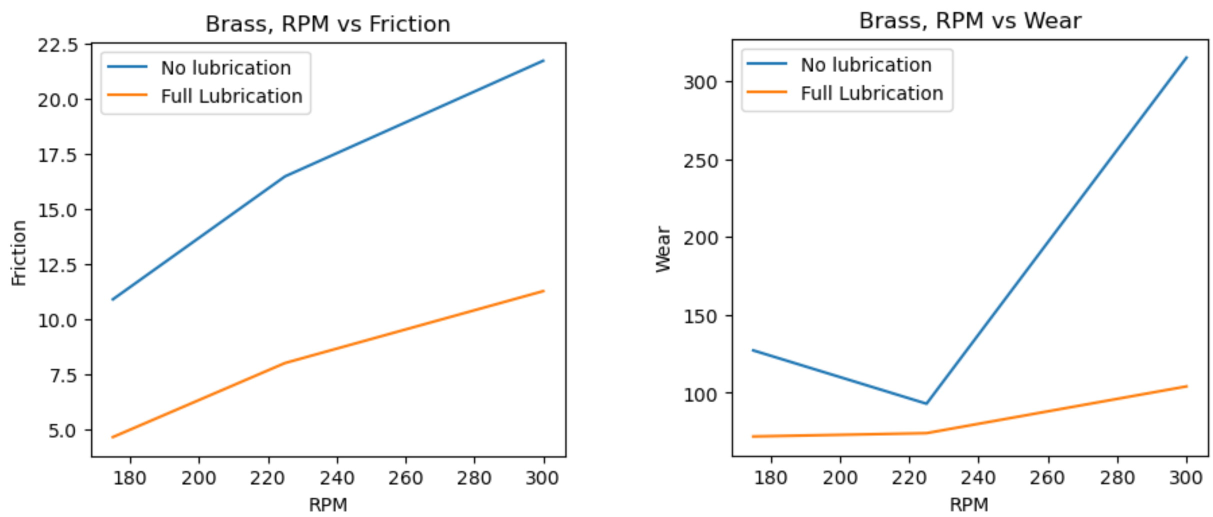
Figure 4.2: Friction and Wear for different conditions

Preliminary analysis of the data revealed intriguing trends. Initial observations suggested that lubrication conditions exerted a substantial influence on both friction and wear, with full lubrication demonstrating the most favorable outcomes. Additionally, variations in RPM and pin material showcased discernible effects on friction and wear characteristics, albeit to differing extents across materials.



(a) Friction vs RPM (b) Wear vs RPM

Figure 4.3: Friction and Wear relations with RPM for Aluminum



(a) Friction vs RPM (b) Wear vs RPM

Figure 4.4: Friction and Wear relations with RPM for Brass

The preliminary experiment provided valuable insights into the factors influencing friction and wear in mechanical systems. The identified trends lay the groundwork for further experimentation, guiding the optimization of parameters to enhance mechanical performance and durability. Subsequent analyses will delve deeper into the interactions between variables, facilitating the development of robust predictive models for friction and wear behavior.

4.3 Optimization

- **Increased Sensitivity:** To enhance the comprehensiveness and accuracy of the experimental design, an additional level of lubrication condition, namely "Half Lubrication," was introduced. This adjustment aimed to bridge the gap between the extremes of "No Lubrication" and "Full Lubrication," providing a more nuanced understanding of friction and wear behaviors under realistic operating conditions.
- **Parameter Refinement:** Fine-tuning the levels of weight and RPM to cover a wider range of operating conditions can provide a more comprehensive understanding of their effects on friction and wear. This optimization can involve exploring additional weight and RPM combinations or adjusting existing levels to capture critical thresholds more accurately.
- **Replication and Randomization:** Increasing the number of replicates for each experimental condition and implementing randomization techniques can enhance the statistical power of the analysis. By reducing the influence of random variation and confounding factors, these optimizations bolster the reliability and robustness of the experimental findings. The repeating of experiment has done to ensure

This enhancement enables the detection of potential effects that may have been overlooked in the preliminary experiment.

4.4 Experiment Design

The experiment investigates the impact of varied parameters on friction force (N) and wear (μm) in mechanical systems. The changed variables include weight, RPM, pin material, and lubrication condition, serving as input variables, while friction force and wear are the response variables. The radial location of the pin remains constant at 102 mm throughout the experiment to ensure consistency. A total of 96 samples are collected, each spanning one minute. The level values for individual parameters for each sample are shown in table 4.3. Potential sources of variability are temperature changes, inconsistent load application, measurement error, external vibrations and the uneven surface of disc.

As described in Section 4.3, to enhance replicability, each sample is further subdivided into three 15-second intervals. To accommodate samples with duration less than 60 seconds, the initial 5 seconds and the final 10 seconds are discarded. This approach effectively increases the number of replicates, similar to performing the experiment three times, thereby enhancing reliability and mitigating potential sources of error. The "Half Lubrication" condition is achieved by activating the lubricant switch for precisely 2 seconds before deactivation, initiating data collection. Experimental data are captured using Winducom software, generating two distinct files for each sample. The DUF file encompasses all parameter values, including weight, RPM, and radial pin location, while the DWF file contains temporal data such as time, wear, and friction force.

This methodical experimental design ensures systematic exploration of parameter effects on friction and wear characteristics. The increased number of replicates enhances the reliability of the findings, while meticulous data collection procedures minimize potential errors. Appendix A provides a sample of DUF and DWF files for reference.

Table 4.3: Experimental Parameters Values (96 samples)

Variable	**Values**
Pin Material	Aluminium, Brass
RPM	100, 150, 200, 250
Weight (kg)	2, 3, 4, 5 (Aluminium) | 8, 9, 10, 11 (Brass)
Lubrication Condition	No, Half and Full Lubrication

The hypotheses we seek to test are formulated as follows:
Hypothesis for Lubrication:
Null Hypothesis (H_0): There is no difference among group mean of lubrication conditions for wear and friction
Alternate Hypothesis (H_1): At least one group differs significantly from the overall mean of the lubrication conditions for wear and friction

Hypothesis for RPM and Weight:
Null Hypothesis (H_0):

- There is no difference in average weight for given material and lubrication conditions
- There is no difference in average RPM for given material and lubrication conditions
- The effect of average weight doesn't depend on the effect of the average RPM

Alternate Hypothesis (H_1):

- There is a difference in average weight for given material and lubrication conditions
- There is a difference in average RPM for given material and lubrication conditions
- There is an interaction effect between average weight and average RPM

Chapter 5

RESULTS AND DISCUSSION

5.1 Analysis of Variance - ANOVA

A one-factor ANOVA is performed to find the effect of different lubrication conditions: No Lubrication, Half Lubrication and Full Lubrication for Aluminium and Brass on wear and friction. The tables (tables 5.1, 5.5, 5.9, 5.13) of ANOVA for studying the effect of Lubrication on Wear and Friction are added and hypothesis were stated in chapter 4.

After that we conducted a two-factor ANOVA with an interaction effect test, analyzing wear and friction with Aluminium and Brass across varying levels of lubrication: no lubrication, half lubrication, and full lubrication. Tables of ANOVA for Aluminium and Brass have been added and hypothesis were stated in chapter 4.

5.1.1 Aluminium

Table 5.1: Friction analysis for Lubrication treatment for Aluminium

Source	**SSQ**	**DoF**	**MS**	**F**
Between Treatments	637.3575829	2	318.6788	41.72763
Error	343.6702722	45	7.637117	
Mean	1595.858307	1		
Total	2576.886162	48		

Table 5.2: Friction Analysis for Aluminium in No Lubrication condition

Source	**SSQ**	**DoF**	**MS**	**F**
Weight	839.9723	3	279.9908	835.9941
RPM	5.9856	3	1.9952	5.9572952
Interaction	8.058528	9	0.895392	2.673454
Pure Error	10.71743	32	0.33492	
Grand Mean	5702.636	1		
Total	6567.37	48		

Table 5.3: Friction Analysis for Aluminium in Half Lubrication condition

Source	SSQ	DoF	MS	F
Weight	103.6963	3	34.56546	22385.14
RPM	4.049932	3	1.349977	874.2669
Interaction	0.048442	9	0.005382	3.48775
Pure Error	0.049412	32	0.001544	
Grand Mean	617.8266	1		
Total	725.6707	48		

Table 5.4: Friction Analysis for Aluminium in Full Lubrication condition

Source	SSQ	DoF	MS	F
Weight	65.38255	3	21.79418	147968.3
RPM	3.547422	3	1.182474	8028.231
Interaction	0.269629	9	0.029959	203.4005
Pure Error	0.004713	32	0.000147	
Grand Mean	379.1847	1		
Total	448.389	48		

Table 5.5: Wear analysis for Lubrication treatment for Aluminium

Source	SSQ	DoF	MS	F
Between Treatments	21676.30263	2	10838.15	2.8317
Error	172234.6087	45	3827.436	
Mean	397183.5473	1		
Total	591094.4587	48		

Table 5.6: Wear Analysis for Aluminium in No Lubrication condition

Source	SSQ	DoF	MS	F
Weight	178128.3	3	59376.11	35047.15
RPM	133070.5	3	44356.85	26181.94
Interaction	68169.15	9	7574.35	4470.812
Pure Error	54.21368	32	1.694178	
Grand Mean	583945.1	1		
Total	963367.3	48		

Table 5.7: Wear Analysis for Aluminium in Half Lubrication condition

Source	SSQ	DoF	MS	F
Weight	7309.7	3	2436.567	202.9748
RPM	754.1656	3	251.3885	20.94157
Interaction	18680.27	9	2075.586	172.9038
Pure Error	384.137	32	12.00428	
Grand Mean	491840.8	1	4	
Total	518969.1	48		

Table 5.8: Wear Analysis for Aluminium in Full Lubrication condition

Source	**SSQ**	**DoF**	**MS**	**F**
Weight	71328.95	3	23776.32	191.8306
RPM	3510.733	3	1170.244	9.44169
Interaction	35751.99	9	3972.443	32.05021
Pure Error	3966.22	32	123.9444	
Grand Mean	180793.6	1		
Total	295351.5	48		

95% confidence interval
F(2,45) = 3.20

We have found that for wear, the computed F-values are less than critical F-values threshold that leads us to accept the null hypothesis and shows that there is insignificant difference in mean square of lubrication conditions for Wear for Aluminium. The story is different for friction, here the computed F-values are exceeding the critical F-values threshold, leading us to reject the null hypothesis and hence implies that there is significant difference in mean square of lubrication conditions for Friction for Aluminium.

95% confidence interval
F(3,32) = 2.901   F(9,32) = 2.189

In each scenario of 2 way ANOVA, spanning from instances of no lubrication to half and full lubrication, and across both wear and friction analyses, the computed F-values consistently surpass the critical F-value threshold. This compellingly leads us to reject the null hypothesis, signifying a substantial disparity between weight and RPM across the observed conditions. Also, there is a significant interaction effect.

Linear Regression Model for Aluminium

For Aluminium, the best fit linear regression model for wear and friction is given by these two equations.

Wear $= 90.9651 - 24.4627X_1 + 69.6204X_2 + 57.0253X_3 + 18.1843X_1X_2 + 152.244X_2X_3 - 54.604X_1X_3 + 38.4689X_1X_2X_3$

Friction $= 5.76603 - 4.04456X_1 + 6.70685X_2 - 0.75524X_3 - 4.11994X_1X_2 - 0.3718X_2X_3 - 0.16569X_1X_3 - 0.16868X_1X_2X_3$

where X_1 = Lubrication, X_2 = Weight, X_3 = RPM

5.1.2 Brass

Table 5.9: Friction analysis for Lubrication treatment for Brass

Source	**SSQ**	**DoF**	**MS**	**F**
Between Treatments	538.624249	2	269.3121	21.91808
Error	552.9246714	45	12.28721	
Mean	7775.534212	1		
Total	8867.083132	48		

Table 5.10: Friction Analysis for Brass in No Lubrication condition

Source	**SSQ**	**DoF**	**MS**	**F**
Weight	1006.468	3	335.4894	3231.666
RPM	327.8307	3	109.2769	1052.631
Interaction	119.6547	9	13.29496	128.0663
Pure Error	3.322021	32	0.103813	
Grand Mean	14640.99	1		
Total	16098.27	48		

Table 5.11: Friction Analysis for Brass in Half Lubrication condition

Source	**SSQ**	**DoF**	**MS**	**F**
Weight	74.00201	3	24.66734	765.2593
RPM	22.30093	3	7.433644	230.6153
Interaction	1.153873	9	0.128208	3.977424
Pure Error	1.031487	32	0.0322345	
Grand Mean	5128.495	1		
Total	5226.983	48		

Table 5.12: Friction Analysis for Brass in Full Lubrication condition

Source	SSQ	DoF	MS	F
Weight	85.98362	3	28.66121	31934.29
RPM	21.16759	3	7.055863	7861.635
Interaction	0.212388	9	0.023599	26.29363
Pure Error	0.02872	32	0.000898	
Grand Mean	5172.989	1		
Total	5280.381	48		

Table 5.13: Wear analysis for Lubrication treatment for Brass

Source	SSQ	DoF	MS	F
Between Treatments	443.047771	2	221.5239	0.068527
Error	145468.7773	45	3232.639	
Mean	810090.027	1		
Total	956001.8521	48		

Table 5.14: Wear Analysis for Brass in No Lubrication condition

Source	SSQ	DoF	MS	F
Weight	64116.48	3	21372.16	93.49637
RPM	33871.84	3	11290.61	49.39283
Interaction	152125.9	9	16902.88	73.94468
Pure Error	7314.82	32	228.5881	
Grand Mean	811510	1		
Total	1068939	48		

Table 5.15: Wear Analysis for Brass in Half Lubrication condition

Source	SSQ	DoF	MS	F
Weight	122552.9	3	40850.97	3062.964
RPM	5442.366	3	1814.122	136.021
Interaction	10867.31	9	1207.479	90.53554
Pure Error	426.7863	32	13.33707	
Grand Mean	856413.3	1		
Total	995702.6	48		

Table 5.16: Wear Analysis for Brass in Full Lubrication condition

Source	SSQ	DoF	MS	F
Weight	31304.74	3	10434.91	1277.056
RPM	7677.436	3	2559.145	313.1959
Interaction	8447.365	9	938.5961	114.8682
Pure Error	261.4742	32	8.171068	
Grand Mean	763675.9	1		
Total	811366.9	48		

95% confidence interval
F(2,45) = 3.20

We have found that for wear, the computed F-values are less than critical F-values threshold that leads us to accept the null hypothesis and shows that there is insignificant difference in mean square of lubrication conditions for Wear for Brass. The story is different for friction, here the computed F-values are exceeding the critical F-values threshold, leading us to reject the null hypothesis and hence implies that there is significant difference in mean square of lubrication conditions for Friction for Brass.

95% confidence interval
F(3,32) = 2.901 F(9,32) = 2.189

In each scenario, spanning from instances of no lubrication to half and full lubrication, and across both wear and friction analyses, the computed F-values consistently surpass the critical F-value threshold. This compellingly leads us to reject the null hypothesis, signifying a substantial disparity between weight and RPM across the observed conditions. Also, there is a significant interaction effect.

Linear Regression Model for Brass

For Brass, the best fit linear regression model for wear and friction is given by these two equations.

Wear $= 129.911 - 1.94517X_1 + 36.90778X_2 + 35.65505X_3 - 75.8852X_1X_2 + 113.5643X_2X_3 - 38.791X_1X_3 - 388.14X_1X_2X_3$

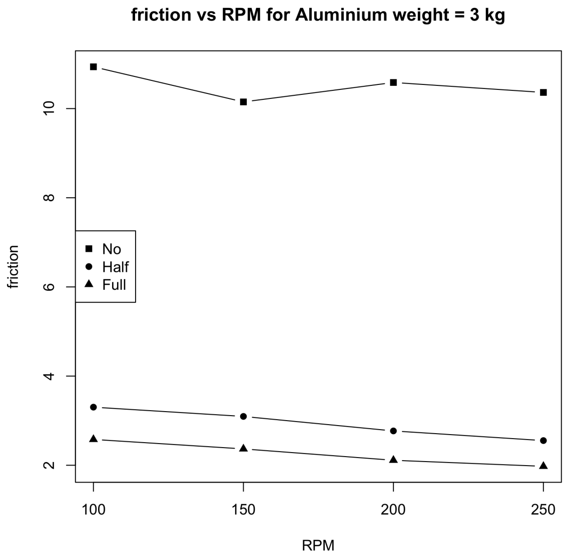
Friction $= 12.7275 - 3.5418X_1 + 20.1995X_2 - 2.8818X_3 - 13.703X_1X_2 - 0.2449X_2X_3 + 1.1953X_1X_3 + 0.18046X_1X_2X_3$

where X_1 = Lubrication, X_2 = Weight, X_3 = RPM

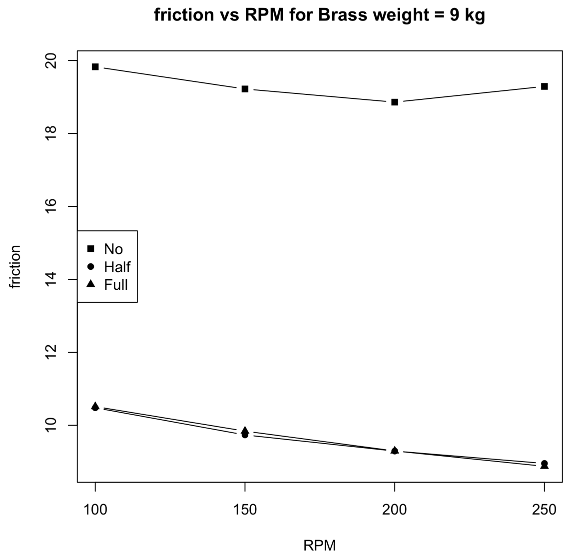
5.2 Data Visualization

5.2.1 Dependency on RPM

Figure 5.1 depicts the relationship between friction and revolutions per minute (RPM) for lubricated and non-lubricated surfaces. A fascinating observation emerges: in the presence of lubrication, friction exhibits a decreasing trend with increasing RPM. This phenomenon can be attributed to the hydrodynamic lubrication regime, where the lubricant film separates the contacting surfaces, minimizing direct asperity contact and consequently reducing friction.



(a) Friction vs. RPM for Al at 3 kg weight



(b) Friction vs. RPM for Brass at 9 kg weight

Figure 5.1: Friction relations with RPM for different Pin Materials

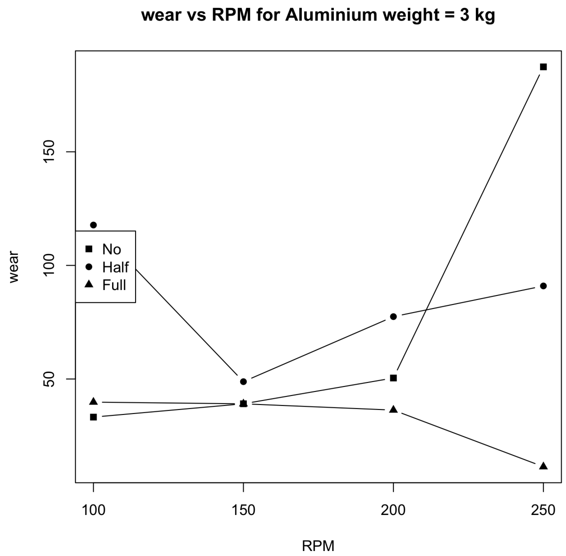
Conversely, the behavior of non-lubricated surfaces (dry contact) remains unclear based on the data presented. Friction in this scenario may exhibit various trends with increasing RPM, including remaining constant, increasing, or even decreasing. This variability can be ascribed to the complex interplay of factors such as surface roughness, material properties, and the dominance of different friction mechanisms (adhesive, ploughing, etc.) at varying contact pressures and sliding velocities associated with different RPMs.

In conclusion, lubrication plays a crucial role in reducing friction, particularly at high speeds. For non-lubricated surfaces, the relationship between friction and RPM becomes more intricate and requires further investigation.

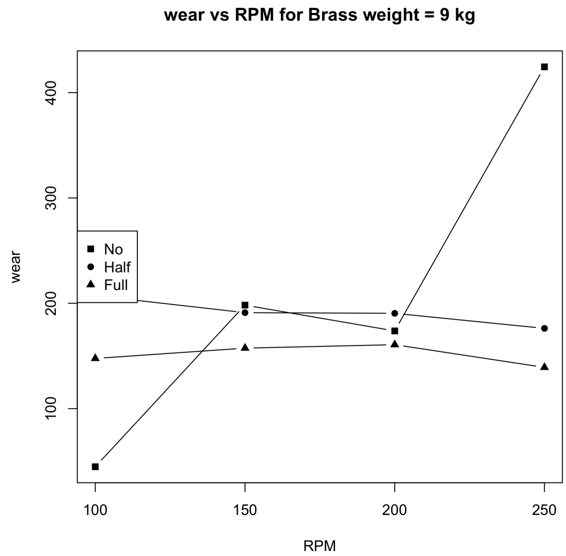
The influence of lubrication and rotational speed (RPM) on wear is investigated for both aluminum and brass. The results, as depicted in figure 5.2, reveal distinct wear behaviors under varying lubrication conditions.

Under full lubrication, aluminum exhibits a decreasing wear trend with increasing RPM. This suggests the formation of a robust hydrodynamic film that effectively separates the contacting surfaces, minimizing direct asperity contact and subsequent wear. Conversely, brass under full lubrication displays a relatively constant wear profile across the RPM range. This could be attributed to the inherent material properties of brass, which might lead to a more stable wear mechanism despite changing contact pressures associated with different RPMs.

Half lubrication presents a more complex picture. Aluminum under half lubrication demonstrates no clear trend with increasing RPM. This ambiguity suggests a potential transition zone between boundary and mixed lubrication regimes, where the effectiveness



(a) Wear vs. RPM for Aluminium at 3 kg weight



(b) Wear vs. RPM for Brass at 9 kg weight

Figure 5.2: Wear relations with RPM for different Pin Materials

of the lubricant film fluctuates, leading to inconsistent wear behavior. In contrast, brass under half lubrication exhibits constant wear, implying that even with a partial lubricant film, the dominant wear mechanism might be independent of the changing contact pressures at different RPMs.

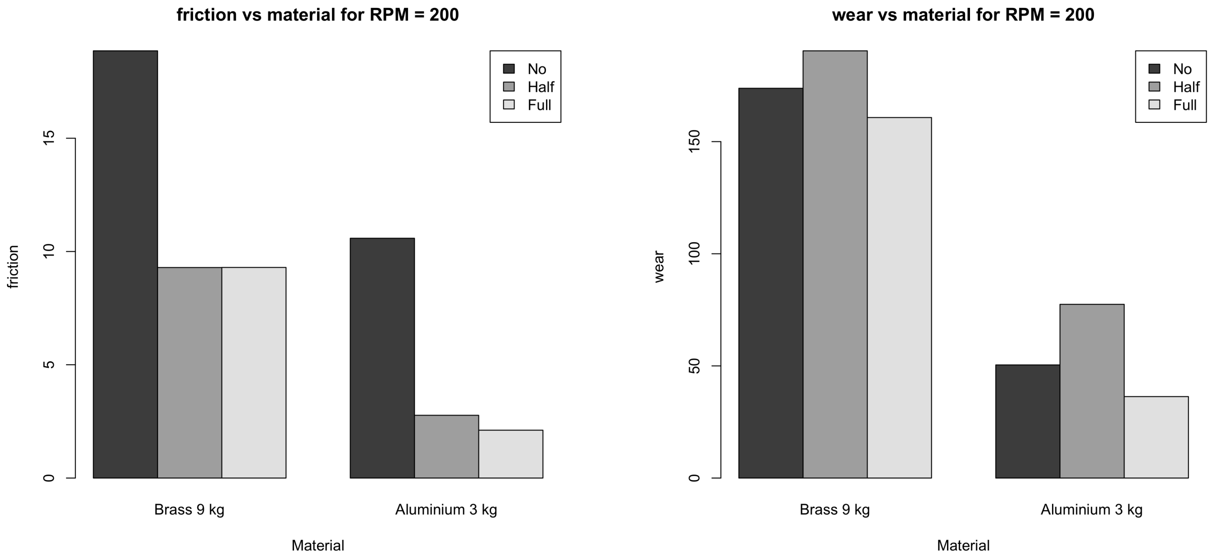
Finally, the absence of lubrication for both aluminum and brass leads to a consistent trend of increasing wear with rising RPM. This is likely due to direct asperity contact between the surfaces, resulting in increased adhesive wear and ploughing effects at higher sliding velocities associated with higher RPMs.

In conclusion, lubrication plays a critical role in mitigating wear, particularly for aluminum at high RPMs. Material properties and the interplay between lubrication regimes significantly influence wear behavior across different RPMs for both aluminum and brass.

5.2.2 Dependency on material

Figure 5.3a reveals an inverse relationship between lubrication and friction for both aluminum and brass. Friction progressively decreases with increasing lubrication levels. Interestingly, for brass, the transition from half lubrication to full lubrication resulted in minimal change in friction. This suggests that a partial lubricant film might be sufficient to achieve optimal friction reduction for brass under the tested conditions.

Figure 5.3b indicates a higher wear rate for brass compared to aluminum at 200 RPM. However, caution is necessary when interpreting this result. Since wear is often dependent on factors like material properties and contact pressure, the observed difference could po-



(a) Friction vs. Pin Material at 200 RPM

(b) Wear vs. Pin Material at 200 RPM

Figure 5.3: Friction and Wear relations with Pin Materials

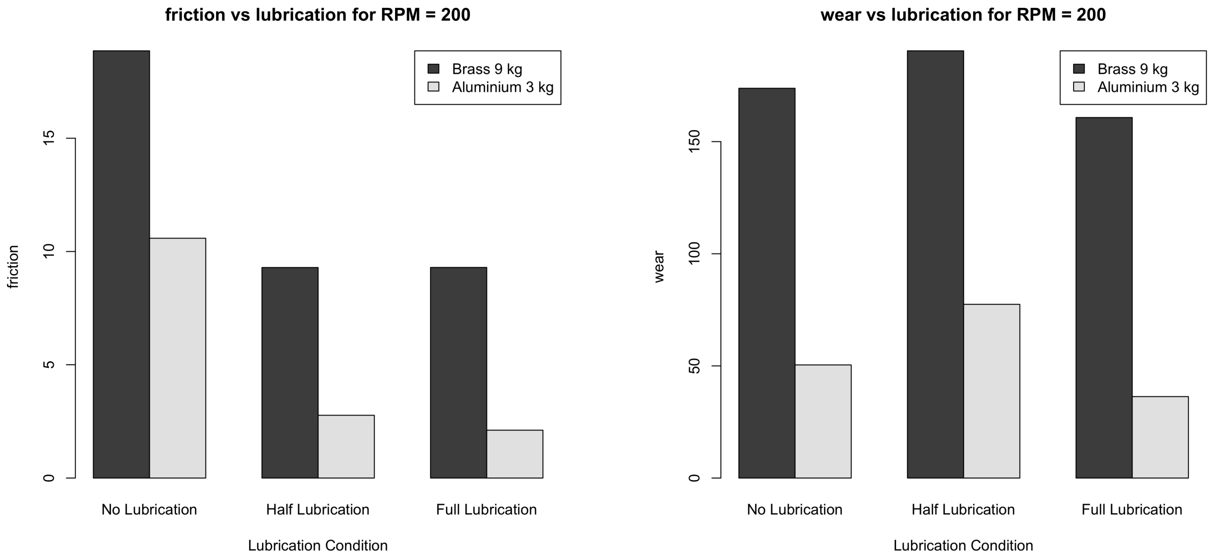
tentially be influenced by the weight of the brass sample used in the experiment. Further tests with controlled contact pressures or normalized wear data would be necessary for a definitive conclusion.

5.2.3 Dependency on lubrication condition

Refer to figure 5.4a. The analysis of friction behavior at 200 RPM reveals a clear trend: brass exhibits consistently higher friction compared to aluminum, regardless of the lubrication level. This observation suggests that the inherent material properties of brass, such as surface roughness or hardness, may contribute to a greater resistance to sliding motion. Interestingly, even under the most favorable conditions (full lubrication for brass), the friction value only marginally approaches that of unlubricated aluminum. This further strengthens the notion that material properties play a significant role in friction behavior.

However, it is essential to acknowledge a potential confounding factor in the interpretation of these results. The experiment utilized brass samples with a higher weight compared to aluminum. Since contact pressure can influence friction, the observed difference could be partially attributed to the varied weight of the test materials. Future investigations with controlled contact pressures or normalized friction data would be necessary to isolate the sole effect of material properties on friction.

In conclusion, brass exhibits a propensity for higher friction compared to aluminum at 200 RPM, potentially due to inherent material characteristics. However, the influence of the brass samples' weight necessitates further exploration to definitively isolate the material



(a) Friction vs. Lubrication at 200 RPM (b) Wear vs. Lubrication at 200 RPM

Figure 5.4: Friction and Wear relations with Lubrication Conditions

property effect.

Figure 5.4b unveils a striking parallel between wear and friction behavior. Similar to the friction data, brass exhibits consistently higher wear compared to aluminum across all lubrication conditions. This observation suggests that the inherent material properties of brass, potentially including a softer surface or a greater propensity for adhesion, may lead to more pronounced wear during sliding contact. Notably, even under the most favorable lubrication scenario (full lubrication for brass), its wear rate surpasses that of unlubricated aluminum. This further underscores the influence of material properties on wear behavior.

However, it's crucial to acknowledge a potential limitation. The experimental setup might have utilized brass samples with a higher weight compared to aluminum. Since wear can be influenced by contact pressure, the observed difference could be partially attributed to the varied weight of the test materials. Future investigations with controlled contact pressures or normalized wear data would be necessary to definitively isolate the role of material properties in wear.

Chapter 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

- There is insignificant effect of lubrication conditions on the wear and significant effect of lubrication conditions on the friction for Aluminium and Brass
- For both the materials - Aluminium and Brass and all lubrication conditions - No, Half and Full, there is significant effect of weight and rpm on wear and friction
- Lubrication demonstrates a crucial role in reducing friction, particularly evident at high speeds, attributed to the formation of a hydrodynamic film that minimizes direct asperity contact
- Wear behavior varies significantly under different lubrication conditions and RPMs, with lubrication playing a critical role in mitigating wear, especially for aluminum at high speeds
- Brass consistently exhibits higher friction than aluminum at 200 RPM, regardless of lubrication level, likely due to inherent material properties. However, the observed difference may also be influenced by the varied weight of the test materials, requiring further investigations with controlled parameters to isolate material effects
- Similarly, brass consistently shows higher wear than aluminum across all lubrication conditions, potentially due to material properties such as a softer surface or a greater propensity for adhesion. Even under the most favorable lubrication scenario for brass, its wear rate surpasses that of unlubricated aluminum, emphasizing the significant influence of material properties on wear behavior

6.2 Limitations

- Due to differences in hardness between brass and aluminum, loading them with the same weight intervals may cause damage to the pins
- Absence of a dedicated measuring device for quantifying the amount of lubricant applied limits precise control and measurement of lubrication quantity
- Effect of all possible interactions were not studied in that detail due to unavailability of method of performing four-factor ANOVA in the literature

6.3 Future Scope

The current study establishes a strong foundation for understanding the wear and friction behavior of brass and aluminum under varying lubrication and speed conditions. However, the quest for comprehensive tribological knowledge necessitates further exploration. This section outlines several exciting avenues for future research that build upon the present investigation.

- Exploring additional lubrication conditions beyond none, half, and full, such as varying viscosities and solid lubricants like molybdenum disulfide.
- Investigating the effect of lubricant degradation over time for real-world applications.
- Employing samples with similar masses to isolate the effects of RPM and lubrication state on wear and friction.
- Broadening the scope to include a wider array of engineering materials such as steel, titanium, and polymers to understand material-lubrication-speed interactions.

These extensions aim to provide a more comprehensive understanding of the interplay between lubrication, speed, and material properties, crucial for material selection, design optimization, and the development of advanced tribological solutions.

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Appendix A

SAMPLE DWF AND DUF FILES

Data Link (Use LDAP): Data
DUF File:

```
@WINDUCOM  : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
  Load :- 49.05 N,  Sample ID :- ,  RPM :- 250.00,
  Track diameter :- 102mm,  Samples/ Min :- 60
```

DWF File:

```
         0.9060;    80.36;     4.54;   102.53;
         1.8130;    77.38;     4.56;   102.53;
         2.7190;    78.71;     4.61;   102.54;
         3.6410;    77.16;     4.60;   102.54;
         4.5470;    79.49;     4.64;   102.53;
         5.4530;    77.05;     4.59;   102.53;
         6.3590;    82.73;     4.66;   102.54;
         7.2810;    79.38;     4.66;   102.53;
         8.1880;    79.65;     4.72;   102.54;
         9.0940;    77.81;     4.66;   102.54;
        10.0000;    81.38;     4.73;   102.53;
        10.9060;    77.42;     4.66;   102.53;
        11.8280;    82.88;     4.72;   102.53;
        12.7340;    79.58;     4.64;   102.54;
        13.6410;    87.70;     4.71;   102.53;
        14.5470;    81.30;     4.64;   102.54;
        15.4690;    79.56;     4.71;   102.54;
        16.3750;    81.81;     4.68;   102.54;
        17.2810;    79.60;     4.73;   102.54;
        18.1880;    83.48;     4.66;   102.54;
        19.0940;    78.92;     4.66;   102.53;
        20.0160;    85.13;     4.64;   102.53;

        ......
```