# INVESTIGATION ON TRIBOLOGICAL PROPERTIES OF AA7075 ALUMINUM ALLOY METAL MATRIX REINFORCED WITH TITANIUM DIBORIDE, SILICON NITRIDE & COCONUT SHELL ASH USING STIR CASTING

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## ABSTRACT

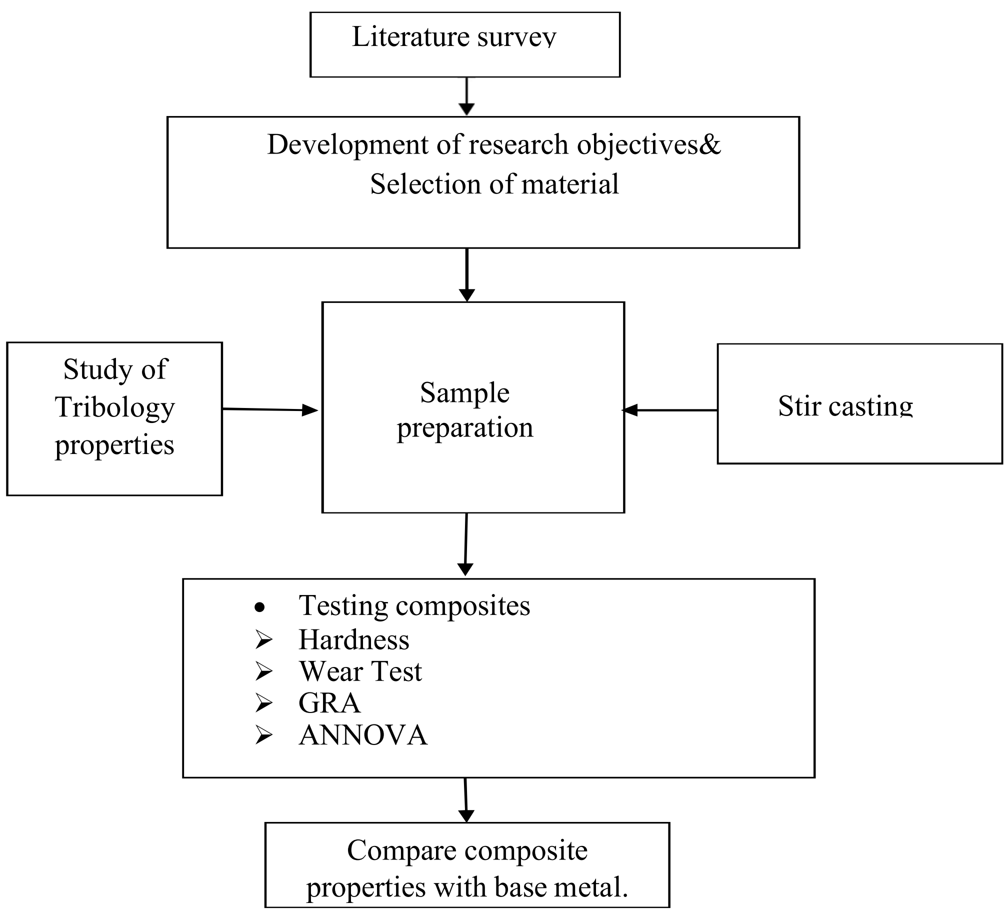
A new class of materials called metal matrix composites are emerging materials replacing conventional hard materials in many applications such as aerospace, automobiles and defense sectors etc., owing to their unique high strength to weight ratios, wear and corrosion resistant properties. For last two decades Metal Matrix Composites (MMCs) are an attractive and dynamic area for scientific analysis and research, foremost MMCs have become practical engineering materials. Aluminum (AA7075) are lightweight metals widely used in industrial and commercial applications. Aluminum alloys incorporated with hard ceramic particles increase the Hardness of these lightweight alloys in applications where wear is the predominant factor due to better stiffness and enhanced strength with improved wear and corrosion resistance. This study focuses on AA7075 as base material and Titanium Diboride, Silicon Nitride & Coconut shell ash are the Reinforcement Materials. By this composite, fabrication was done by stir casting method and make preparation of composite specimens and Analysis of Tribological Properties of Aluminum Metal Matrix Composites (AA7075) and Reinforcement Materials And optimize the Process Parameters. hybrid metal matrix composite was fabricated using the stir casting method. Four compositions were developed: (i) pure AA7075, (ii) AA7075+ 2% $TiB_2$+2%CSA (iii) AA7075 + 2% $Si_3N_4$ + 2% CSA, and (iv) AA7075 +4% $TiB_2$+ 4% $Si_3N_4$ +2%CSA.The composites were subjected to tribological evaluation using a pin-on-disc test (ASTM G99) at varying loads (0.5–2.0 kg) and sliding speeds (300–600 rpm). Wear rate and coefficient of friction (COF) were recorded and analyzed using statistical tools including Taguchi design, Grey Relational Analysis (GRA), and Analysis of Variance (ANOVA). Results reveal significant improvement in wear resistance and reduction in COF for reinforced samples compared to pure AA7075. The optimal composition (AA7075 + 4% $TiB_2$ +4% $Si_3N_4$ +2%CSA exhibited balanced performance.

**Keywords**: Tribological properties, AA7075 , Silicon Nitride , Titanium Di Boride, Pin-on-Disc Test.

## 1.INTRODUCTION

Tribology is a 'study of friction, wear and lubrication and design of bearings', science of interacting surfaces in relative motion. In recent years, metal matrix composites have drawn attention in engineering materials due to their superior mechanical properties than the conventional materials. The selection of material for specific demand necessitates the development of composites. In general, metal matrix composites possess high strength, low weight and improved wear resistance than monolithic materials. Increased research in lightweight materials arises as they can lead to reduced energy consumption in an environment increasingly trying to control climate change. Huge friction, leading to huge amounts of energy loss, within systems started acting as a concern.
These reinforcing materials offer high hardness and wear resistance. which minimizes wear. Borides such as $TiB_2$ enhance thermal conductivity, therefore, these are applied for the purpose of heat exchangers. The aluminum matrix composites have been a general devotion for researchers owing to their superior characteristics. Particulate reinforced aluminum matrix composites have recently become a major focus of attention in the automotive industry, defense, aerospace and many other engineering fields. In this research, an effort has been made to prepare aluminum (7075) Metal Matrix composites reinforced with various composition of $TiB_2$, $Si_3N_4$ & Coconut shell ash, particulates using stir casting method. The CSA particles enhance the mechanical and wear properties of the aluminum matrix composites.

## 2.METHODOLOGY




## 3.MATERIALS

## AA7075 Alloy

The AA7075 aluminum alloy is a high-strength, heat-treatable alloy that belongs to the 7xxx series of aluminum alloys, primarily composed of zinc as the major alloying element along with magnesium, copper, and chromium. It is widely recognized for its exceptional strength-to-weight ratio, making it one of the strongest aluminum alloys available. The alloy exhibits excellent fatigue resistance and good machinability, which makes it highly suitable for aerospace, defense, automotive, and sporting applications where high performance is required. However, a notable limitation of AA7075 is its relatively low corrosion resistance compared to other aluminum alloys like AA6061 or AA5052, which means protective coating or cladding are often applied when it is used in harsh or marine environments. The mechanical properties of AA7075 vary depending on its temper; for instance, in the T6 condition it offers very high tensile and yield strength but lower fracture toughness, whereas in the T73 condition it sacrifices some strength in exchange for improved resistance to stress-corrosion cracking. With a density of about 2.81 g/cm$^3$, a tensile strength in the range of 510–600 MPa, and a yield strength of 430–540 MPa, AA7075 is a preferred material for critical structural components such as aircraft frames, automotive racing parts, and military equipment. Its limitations in welding and corrosion resistance are balanced by its superior strength, making it one of the most important aluminum alloys in high-performance engineering applications.

## TiB2 (Titanium Di Boride)

It is a ceramic material well known for its exceptional combination of mechanical and physical properties. It is a hard, covalently bonded compound with a very high melting point of about 3225 °C, excellent hardness (around 25–30 GPa), and high strength even at elevated temperatures. $TiB_2$ also exhibits excellent wear resistance, good thermal conductivity, and remarkable chemical stability, making it suitable for extreme environments. Another key property is its relatively high electrical conductivity compared to most ceramics, which enables its use in applications like cathodes in aluminum electrolysis cells. However, $TiB_2$ has limitations such as poor oxidation resistance above 1000 °C and inherent brittleness, which restrict its structural applications. It is often used in composite form, especially as a reinforcement in metal matrix composites, to improve hardness, stiffness, and wear resistance of materials such as aluminum and magnesium alloys. Because of this balance of unique properties, $TiB_2$ finds applications in aerospace, defense, cutting tools, armor, and wear-resistant components.

## $Si_3N_4$ (Silicon Nitride)

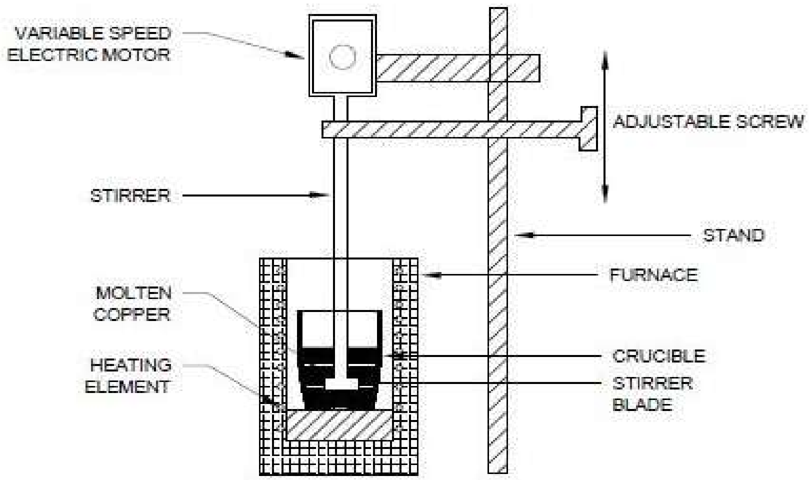
It is a high-performance ceramic material valued for its exceptional combination of mechanical, thermal, and chemical properties. It possesses high strength and toughness, even at elevated temperatures, along with excellent wear resistance and low density, making it suitable for lightweight and durable applications. $Si_3N_4$ has outstanding thermal shock resistance and maintains stability up to about 1200 °C in oxidizing atmospheres, which is significantly better than many other ceramics. It also exhibits low thermal expansion, high hardness, and good resistance to creep, oxidation, and chemical attack. However, like most ceramics, it is inherently brittle and requires advanced processing methods for manufacturing. Due to these unique properties, $Si_3N_4$ is widely used in demanding applications such as bearings, cutting tools, turbine blades, engine components, biomedical implants, and aerospace parts where high strength, heat resistance, and reliability are critical.

**CSA (Coconut Shell Ash)**

It is agricultural waste byproduct obtained by burning coconut shells, which are abundantly available in tropical regions. It is rich in silica, along with other oxides such as alumina, calcium oxide, potassium oxide, and iron oxide, making it a potential low-cost reinforcement material for composites. The presence of silica and other ceramic phases in CSA contributes to its hardness, wear resistance, and thermal stability. When used as a reinforcement in metal matrix composites, CSA can enhance properties such as hardness, wear resistance, and strength while also reducing overall material cost, since it is an inexpensive and eco-friendly alternative to conventional ceramic reinforcements. Additionally, the utilization of CSA helps in effective waste management by converting agricultural waste into a value-added engineering material.

## 4. STIR CASTING

It is one of the most widely used and cost-effective techniques for fabricating metal matrix composites (MMCs). In this process, the base metal, commonly aluminum or its alloys—is first heated in a furnace until it reaches a molten or semi-solid state. Once the alloy is melted, ceramic or other reinforcing particles (such as $TiB_2$,$Si_3N_4$, and coconut shell ash) are introduced into the melt. To ensure uniform distribution of these reinforcements, a mechanical stirrer is used to agitate the molten mixture at a controlled speed, temperature, and duration. The stirring action helps to overcome particle clustering, enhances wetting between the molten metal and reinforcement, and promotes homogeneous dispersion. After sufficient stirring, the composite melt is poured into molds and allowed to solidify, forming a solid metal matrix composite. Stir casting is particularly attractive because of its simplicity, scalability, and relatively low production cost compared to other advanced composite manufacturing methods such as powder metallurgy or squeeze casting. However, achieving uniform particle distribution, minimizing porosity, and preventing particle settling are some of the main challenges in this method. With proper process control, stir casting produces composites with improved mechanical, wear, and thermal properties, making it a popular choice in automotive, aerospace, and structural applications.




## 5. PIN-ON-DISC TESTING

The main goal of the test is to investigate how different load conditions, disc speeds, and reinforcement levels influence the material's wear resistance and frictional response. These tests aim to reveal how the addition of reinforcements affects tribological performance across various operating conditions, helping identify the optimal composition and processing parameters for enhanced wear resistance.

Standard (ASTM G99)
Pin size: Diameter: 3, 4, 6, 8, 10 & 12 mm.
25 to 30 mm load
Disc size: Diameter: 165 mm, 8 mm thick
Wear track: Diameter: 50 to 100 mm
Disc rotation: 200 – 2000 rpm
Sliding speed: 0.5 to 10 m/s
Normal load: 5 to 200N
Temperature: Ambient 36°C

The use of the L16 array allows the experimental design to effectively incorporate all combinations of load (0.5, 1, 1.5, and 2 kg), disc speed (300,400,500 and 600 rpm), and reinforcement percentage (0%+0%, 2%+0% 2%+2%, and 4%+4%). This comprehensive coverage enables a clear analysis of the individual and combined effects of these parameters on the material's wear performance. The approach ensures that the results are statistically sound, repeatable, and reliable, leading to more precise conclusions about the optimal conditions for enhancing wear resistance.

# 6.ANALYSIS OF VARIANCE

It is a statistical technique used to determine whether there are any statistically significant differences between the means of three or more independent (unrelated) groups. It helps to test hypotheses about the impact of one or more factors by comparing the means of different samples. Essentially, ANOVA analyses the total variation in a dataset and partitions it into variation between groups and variation within groups The core idea behind ANOVA is to assess whether the observed differences in group means are larger than what could be expected due to random chance. It significance of three independent factors % reinforcement, load, and speed on a dependent response variable, likely wear rate or coefficient of friction. The ANOVA table includes degrees of freedom (DF), adjusted sum of squares (Adj SS), adjusted mean squares (Adj MS), F-values, and P-values for each source of variation. The percentage of reinforcement has 3 degrees of freedom and an adjusted sum of squares of 0.012092, leading to an adjusted mean square of 0.004031. The F-value is 20.74, with a corresponding P-value of 0.001, indicating that reinforcement percentage has a statistically significant effect on the response variable. The load factor also has 3 degrees of freedom but a much larger adjusted sum of squares of 0.090198, resulting in an adjusted mean square of 0.030066. The F-value of 154.71 and a P-value of 0.000 strongly confirm that load is the most influential factor among the three, significantly affecting the outcome. In contrast, speed has a minimal adjusted sum of squares (0.000890) and a low mean square value (0.000297). The F-value is just 1.53, and the P-value is 0.301, indicating that speed does not have a statistically significant effect on the response variable under the tested conditions.

The error term accounts for the unexplained variation in the model, with 6 degrees of freedom and an adjusted mean square of 0.000194. The total variation in the dataset (Total SS) is 0.104345 across all 15 degrees of freedom. In conclusion, the ANOVA results demonstrate that both reinforcement percentage and load have a significant influence on the response, with load having the strongest effect, while speed does not contribute significantly to the variation in the response variable.

The reinforcement percentage, load, and speed on the coefficient (likely of wear or friction) in a composite material testing scenario. The analysis includes key regression outputs such as the coefficient value, standard error (SE Coeff), t-value, p-value, and variance inflation factor (VIF) for four distinct experimental conditions. At 0% reinforcement, 4.90 N load, and 300 RPM speed, the coefficient is 0.04250 with a standard error of 0.00604. The high T-value of 7.04 and a p-value of 0.000 indicate that this result is statistically significant, strongly affecting the response variable. As reinforcement increases to 4%, with a corresponding load of 9.80 N and speed of 400 RPM, the coefficient drops drastically to 0.00775. However, the t-value of -1.28 and p-value of -247 suggest that this result is not statistically significant. At 6% reinforcement, 14.75 N load, and 500 RPM speed, the coefficient rises to 0.03400. The negative t-value of -5.63 and a low p-value of 0.001 indicate a strong and statistically significant negative effect. Similarly, at 10% reinforcement, 19.6 N load, and 600 RPM speed, the coefficient further increases to 0.042500, with a t-value of -4.61 and a p-value of 0.007, confirming statistical significance as well. The VIF value remains constant at 1.50 for all cases, indicating low multicollinearity among the independent variables, and confirming the reliability of the regression estimates. In summary, the table reveals that both reinforcement and operating conditions influence the coefficient values, with certain configurations showing statistically significant effects, particularly at lower and higher reinforcement levels.

# 7. GRA OPTIMIZATION

1) Data Pre-processing
2) Normalization
3) Deviation Sequence Calculation
4) Grey Relational Coefficient Determination
5) Grey Relational Grade Calculation

## 7.1GRA Optimization table

| Original Values | | | Normalizing Values | | Deviation Sequences | | GRC | | GRG | Ra nk |
|---|---|---|---|---|---|---|---|---|---|---|
| Sl. No | COF | ROW | COF | ROW | COF | ROW | COF | ROW | --- | --- |
| 1 | 0.441 | 0.046 | 0.4626 | 0.523809 | 0.537346 | 0.476190 | 0.481999 | 0.512195 | 0.497097 | 16 |
| 2 | 0.306 | 0.031 | 0.7313 | 0.761904 | 0.268673 | 0.238095 | 0.650471 | 0.677419 | 0.663945 | 12 |
| 3 | 0.236 | 0.024 | 0.8706 | 0.873015 | 0.129361 | 0.126984 | 0.794456 | 0.797468 | 0.795962 | 9 |
| 4 | 0.216 | 0.022 | 0.9104 | 0.904761 | 0.089557 | 0.095238 | 0.848093 | 0.842541 | 0.844046 | 7 |
| 5 | 0.375 | 0.039 | 0.5940 | 0.634920 | 0.405994 | 0.365079 | 0.551879 | 0.577981 | 0.564930 | 15 |
| 6 | 0.251 | 0.026 | 0.8407 | 0.841269 | 0.159213 | 0.158730 | 0.758479 | 0.759036 | 0.758757 | 10 |
| 7 | 0.201 | 0.021 | 0.9402 | 0.920634 | 0.059704 | 0.079365 | 0.893327 | 0.863013 | 0.878170 | 5 |
| 8 | 0.171 | 0.017 | 1 | 0.984126 | 0 | 0.015873 | 1 | 0.969230 | 0.984615 | 2 |
| 9 | 0.319 | 0.034 | 0.7054 | 0.714285 | 0.294545 | 0.285714 | 0.629290 | 0.636363 | 0.632827 | 13 |
| 10 | 0.221 | 0.022 | 0.9004 | 0.904761 | 0.099508 | 0.095238 | 0.834016 | 0.84 | 0.837008 | 8 |
| 11 | 0.181 | 0.019 | 0.9800 | 0.952380 | 0.019901 | 0.047619 | 0.961720 | 0.913043 | 0.937381 | 4 |
| 12 | 0.172 | 0.016 | 0.9980 | 1 | 0.001990 | 0 | 0.996035 | 1 | 0.998017 | 1 |
| 13 | 0.378 | 0.04 | 0.5881 | 0.619047 | 0.411965 | 0.380952 | 0.548266 | 0.56756 | 0.557916 | 14 |
| 14 | 0.261 | 0.027 | 0.8208 | 0.825396 | 0.179115 | 0.174603 | 0.736251 | 0.741176 | 0.738714 | 11 |
| 15 | 0.211 | 0.021 | 0.9203 | 0.920634 | 0.079606 | 0.079365 | 0.862653 | 0.863013 | 0.862833 | 6 |
| 16 | 0.176 | 0.018 | 0.9900 | 0.968253 | 0.009950 | 0.031746 | 0.980486 | 0.940298 | 0.960392 | 3 |
| | | | | | | | | | | |
| ma x | 0.632 | 0.071 | 1 | 1 | 1 | 1 | 1 | 1 | 0.723389 | 16 |
| mi | 0.265 | 0.03 | 0 | 0 | 0 | 0 | 0.333333 | 0.333333 | 0.512638 | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| n | | | | | | | | | | |

### 7.2 Taguchi Design using $L_{16}$ Orthogonal array:

1.Reinforcement Effect
2.Load Effect
3.Speed Effect

| Level | %reinforcement | load | speed |
|---|---|---|---|
| 1 | 0.7003 | 0.5632 | 0.7884 |
| 2 | 0.7966 | 0.7496 | 0.7724 |
| 3 | 0.8513 | 0.8686 | 0.7880 |
| 4 | 0.7800 | 0.9468 | 0.7793 |
| Delta | 0.1510 | 0.3836 | 0.0160 |
| Rank | 2 | 1 | 3 |

## 8. RESULTS & DISCUSSION

| Levels | Initial parameters | Optimal parameters | |
|---|---|---|---|
| | | Predicted | Experimental |
| Setting Level | R1 L1 S1 | | R3 L4 S4 |
| Coefficient of Friction | 0.441 | | 0.172 |
| Wear rate | 0.046 | | 0.016 |
| Grey Relation Grade | 0.497 | 0.8147 | 0.948 |
| Improvement in GRG | | 18 | |

It presents a comparative summary of initial and optimal parameters for a process evaluated using Grey Relational Analysis (GRA). The focus is on optimizing two critical output responses: Coefficient of Friction (COF) and Wear Rate, with the performance evaluated via the Grey Relational Grade (GRG). Initially, the process was conducted at the parameter setting R1 L1 S1, which resulted in a COF of 0.441, a wear rate of 0.046, and a corresponding GRG of 0.497. Through GRA-based optimization, the predicted optimal setting R3 L4 S4 showed a significant improvement, with the predicted GRG at 0.8147 and the experimentally validated GRG at 0.948, demonstrating even better performance than predicted. This improvement is primarily attributed to the considerable reductions in both the coefficient of friction (down to 0.172) and wear rate (down to 0.016). Overall, the experimental optimization led to an 18% improvement in GRG, confirming the effectiveness of the selected parameter combination in enhancing tribological performance.

## 9. CONCLUSION

1. The percentage reinforcement (%w) and Load are the statistically significant factors affecting the wear rate of the AA7075 Aluminum composite.
2. The regression model explains 99.20 % of the variation in wear rate, indicating a good fit to the experimental data, though its predictive power is limited. One data point showed a large residual and may require further investigation.
3. The percentage of reinforcement ($TIB_2$+ $SI_3N_4$+CSA) is the dominant factor influencing the tribological performance of the AA7075 Aluminum alloy.
4. Higher reinforcement levels significantly reduce the wear rate, demonstrating improved material resistance. In contrast, variations in load and speed show minimal or statistically insignificant effects within the tested range. These findings are supported both statistically (ANOVA) and visually.

## 10. REFERENCES

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