Optimization of Dry Sliding Wear Parameters of Aluminium Reinforced Hybrid Composite Materials with Silicon Carbide and Graphene Using Taguchi and Regression Analysis

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ABSTRACT:

Aluminum hybrid composites are widely used in various engineering applications due to their excellent balance of mechanical strength, low weight, and enhanced wear resistance. These materials are especially valued in areas where components are subjected to continuous friction and require long-lasting performance. This project aims to evaluate and improve the wear behavior of such composites under dry sliding conditions using systematic testing and analysis methods. This study focuses on the optimization of dry sliding wear behavior of aluminum-based hybrid composite materials reinforced with silicon carbide (SiC) and graphene. These two particles are added to improve the strength, hardness, and wear resistance of the material. To study the effect of different factors like load, sliding speed, and distance on the wear rate, experiments were planned using the Taguchi method, which helps in reducing the number of trials while still giving reliable results. After conducting the tests, regression analysis was used to develop a mathematical model and understand how each factor affects the wear performance. The results showed that the addition of SiC and graphene improves the wear resistance of the aluminum matrix significantly. This study also helps in identifying the best combination of parameters to reduce material loss due to wear. The findings can be useful for applications like automotive and mechanical parts, where materials are exposed to continuous friction and need to last longer. The conclusions drawn from this work highlight the effectiveness of combining reinforcements and optimizing parameters to significantly reduce wear. The study successfully demonstrates a practical approach to improving the performance of aluminum hybrid composites under dry sliding conditions.

INTRODUCTION:

Composite materials are engineered materials made by combining two or more different substances to create a new material with superior properties. These constituents remain separate and distinct within the final structure, but their combination leads to enhanced strength, durability, weight reduction, and resistance to environmental factors compared to traditional materials.

Types of Composite Materials

Composite materials are classified based on the type of reinforcement and matrix used. Here are the main types:

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1. Fiber-Reinforced Composites (FRC)

2. Particle-Reinforced Composites

3. Structural Composites

4. Polymer Matrix Composites (PMC)

5. Metal Matrix Composites (MMC)

ALLUMINIUM ALLOY 6063:

Aluminium Alloy A6063 is a medium-strength alloy that belongs to the 6000 series of aluminium alloys, which are known for their excellent combination of strength, corrosion resistance, and extrudability. This alloy primarily contains aluminium, magnesium, and silicon, which contribute to its favorable mechanical and surface properties.

It is especially well-suited for architectural applications due to its smooth surface finish, good formability, and excellent anodizing characteristics. A6063 is commonly used in window frames, doors, railings, and structural tubing.

ALLUMINIUM ALLOY 6063:

Chemical Composition of Aluminium Alloy 6063

Here is the typical chemical composition of Aluminium Alloy 6063, expressed in percentage by weight:

Element	Percentage (%)
Aluminium (Al)	97.5 – 99.0
Magnesium (Mg)	0.45 – 0.90
Silicon (Si)	0.20 – 0.60
Iron (Fe)	≤ 0.35
Copper (Cu)	≤ 0.10
Manganese (Mn)	≤ 0.10
Chromium (Cr)	≤ 0.10
Zinc (Zn)	≤ 0.10

Applications of Aluminium Alloy 6063:

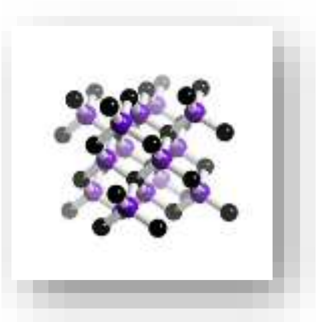
Aluminium alloy 6063 is widely used across various industries due to its excellent surface finish, moderate strength, good corrosion resistance, and high extrudability. It is especially popular in architectural and structural applications.

Silicon Carbide (SiC):

Silicon carbide (SiC) is a hard, synthetic material composed of silicon (Si) and carbon (C). It is one of the hardest known materials and is widely used for its high strength, thermal conductivity, and resistance to wear and corrosion. Due to its excellent physical and chemical properties, it is used in industries ranging from electronics to aerospace.

Applications of Silicon Carbide (SiC)

Silicon carbide is a versatile and high-performance material used in a wide range of industries due to its hardness, thermal stability, and chemical resistance. Below are its major applications:



GRAPHENE:

Graphene particles are tiny flakes or sheets of graphene, made up of a single layer (or few layers) of carbon atoms arranged in a hexagonal honeycomb pattern. They are incredibly thin—just one atom thick—but are stronger than steel, more conductive than copper, and very lightweight.

- It is a 2D material made of carbon atoms.
- The atoms are tightly bonded in a hexagonal structure, like chicken wire.
- A graphene particle is a small portion of this sheet.

REINFORCEMENT:

Reinforcement refers to the material embedded within the matrix to enhance the mechanical, thermal, or physical properties of the composite. Reinforcements provide strength, stiffness, toughness, and other desirable characteristics to the composite material.Reinforcements can take various forms, including:

Fibers: Fibers are the most generic form of reinforcement and can be made from materials such as carbon, glass, aramid (e.g., Kevlar), or natural fibers (e.g., bamboo, hemp). These fibers are typically arranged in a specific orientation within the composite to optimize mechanical properties. For example, carbon fibers are known for their high strength and stiffness, making them suitable for applications requiring lightweight and strong materials.

strong materials.

Particles: Particles, such as ceramic or metallic particles, are dispersed within the matrix material. These particles can improve properties like wear resistance, hardness, and thermal conductivity. Silicon carbide (SiC), alumina (Al_2O_3), and titanium diboride (TiB2) are examples of ceramic particles used as reinforcements.

Whiskers: Whiskers are single crystals of a material with high aspect ratios (length-to-diameter ratios). These are used to reinforce composites and can enhance properties like strength, stiffness, and toughness. Silicon carbide (SiC) whiskers are commonly used in ceramic matrix composites.

The choice of reinforcement depends on the specific requirements of the application and the properties desired in the final composite material. Different reinforcement materials offer different advantages and are selected based on factors such as cost, strength, weight, thermal stability, and environmental resistance.

Overall, reinforcements play a crucial role in determining the performance and properties of composite materials, allowing them to be tailored for a wide range of applications across industries such as aerospace, automotive, marine, construction, and sports equipment manufacturing.

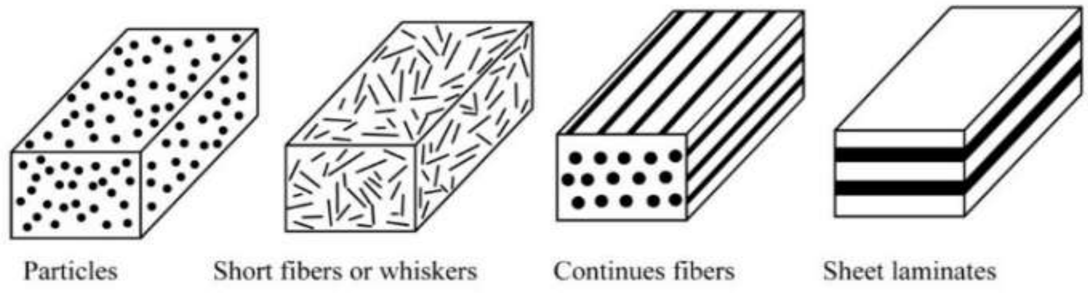


Fig:Types of reinforcements.

Aluminium Metal Matrix Composites (Al-MMCs)

Aluminium Metal Matrix Composites (Al-MMCs) are advanced materials made by combining aluminium (metal matrix) with reinforcing materials such as ceramic particles, fibers, or whiskers (e.g., silicon carbide – SiC, alumina – Al_2O_3, graphene, etc.).

These composites are designed to improve the mechanical, thermal, and wear properties of pure aluminium, making them suitable for high-performance engineering applications.

Primary Processing of Aluminium Matrix Composites (Al-MMCs)

Primary processing refers to the initial methods used to manufacture aluminium matrix composites (Al-MMCs) by combining aluminium (or its alloys) with reinforcement materials such as SiC, Al_2O_3, or graphene.

These methods are generally classified into three categories:

1. **Solid-State Processing Method.**

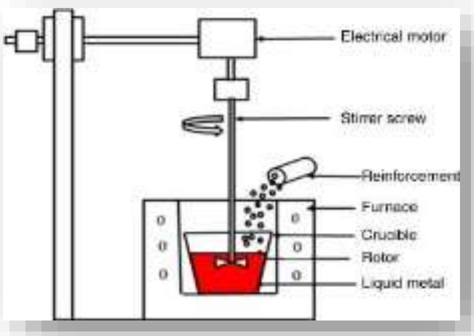
2. **Liquid-State Processing Method.**

3. **In-Situ Processing Method.**

STIR CASTING:

This involves incorporation of ceramic particulate into liquid aluminium melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminium alloy melt. The simplest and most commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller. Lloyd (1999) reports that the vortex-mixing technique for the preparation of ceramic particle dispersed aluminium matrix composites was originally developed by Surappa & Rohatgi (1981) at the Indian Institute of Science. Subsequently, several aluminium companies further refined and modified the process which are currently employed to manufacture a variety of AMCs on commercial scale. Microstructural inhomogeneties can cause notably particle agglomeration and sedimentation in the melt and subsequently during solidification. Inhomogeneity in reinforcement distribution in these cast composites could also be a problem as a result of interaction between suspended ceramic particles and moving solid-liquid interface during solidification.Generally it is possible to incorporate upto 30% ceramic particles in the size range 5 to 100 μm in a variety of molten aluminium alloys. The melt–ceramic particle slurry 11 may be transferred directly to a shaped mould prior to complete solidification or it may be allowed to solidify in billet or rod shape so that it can be reheated to the slurry form for further processing by technique such as die casting, and investment casting. The process is not suitable for the incorporation of sub-micron size ceramic particles or whiskers. Another variant of stir casting process is compo-casting. Here, ceramic particles incorporated into the alloy in the semi solid state.

Stir casting is a liquid state method for producing metal matrix composites (MMCs) where ceramic or other reinforcement particles are mixed into a molten metal matrix using mechanical stirring. This process is known for its simplicity and cost-effectiveness, making it suitable for large-scale production of MMCs, particularly aluminum matrix composites.



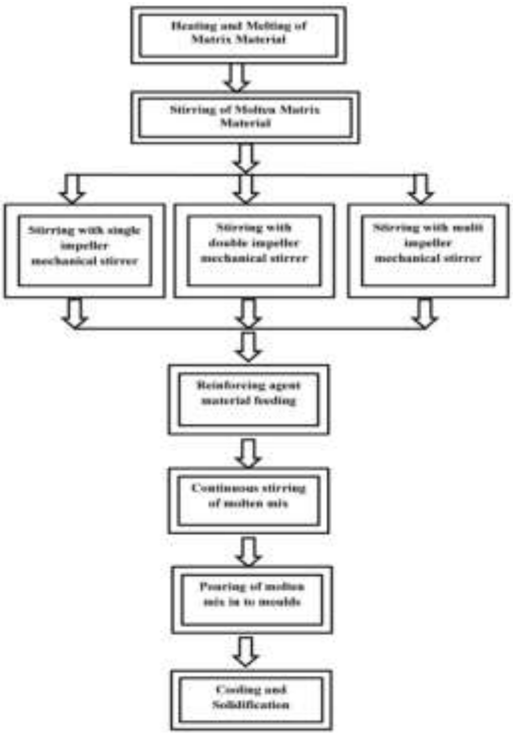
FABRICATION PROCESS AND TESTING EQUIPMENT:

Stir casting method :

Liquid state fabrication of metal matrix composites involves the incorporation of the dispersed phase into a molten matrix metal, followed by its solidification. To get a high level of mechanical properties of composite, good interfacial bonding (wetting) between the dispersed phase and liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix. The simplest and the most cost-effective method of liquid state fabrication is stir casting.

Steel casting is a liquid-state method of composite materials fabrication, in which a dispersed phase (ceramic particles short fiber) is mixed with a molten matrix metal by means of mechanical steering. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional metal farming technologies. In stir casting we use a stirrer to stir the molten metal matrix here in this method this stirrer is manufactured with a material that can sustain at a higher melting temperature than the matrix temperature range. Generally, a graphite stirrer is used in steel casting. The stirrer mainly consists of two components, a cylindrical rod and an impeller. The one end of the rod is connected to impeller and the other end is connected to the shaft of the motor. The stirrer is normally held in a vertical or straight position and is rotated by using a motor at different speeds. The resultant molten metal is then poured into dye for casting. Stir casting is suitable for manufacturing or producing composites with 300/0 volume fractions of reinforcement. A major concern associated with stir casting is the segregation of reinforcement particles due to various process parameters and material properties resulting in the non-homogeneous metal distribution. The various process parameters are like wetting condition of metal, particles, relative density, settling, velocity, etc.The distribution of particles in the molten metal matrix is also affected by the velocity of the stirrer, angle of the stirrer, vortice cone, etc. In this method first the matrix metal is heated above its liquid temperature so that it is completely in a molten state, and it may vary according to type of material.

After it is cooled down to temperature between liquid and solids means that it is in the semi-solid solid state. Then preheated reinforcement particles are added to molten matrix and again heated to fully liquid state and stirred so that they mixed thoroughly with each other.



Precautions:

- Gloves must be worn to avoid burning of hands.
- The stirrer must be rigidly placed.
- Mould cavity must be placed near the furnace.
- Must wear goggles to avoid direct contact of hot air to eyes.
- Proper Ventilation.

Tests and Testing Equipment:

Tensile Test:

A universal testing machine (UTM), also known as a universal tester, materials testing machine or materials test frame, is used to test the tensile strength and compressive strength of materials. An earlier name for a tensile testing machine is a tensometer. The "universal" part of the name reflects that it can perform many standard tensile and compression tests on materials, components, and structures.

Tensile strength is defined as stress, which is measured as force per unit area. For some non-homogeneous materials (or for assembled components) it can be reported just as a force or as a force per unit width. It is widely used to provide basic design information on the strength of the materials. Some materials will break sharply, without plastic deformation, in what is a brittle failure. Others, which are more ductile, including most metals, will experience some plastic deformation and possibly necking before fracture.

The UTS is usually found by performing a tensile test and recording the engineering stress versus strain. The highest point of the stress–strain curve is UTS. It is an intensive property. Tensile strengths are rarely used in the design of ductile members, but they are important in brittle members. They are tabulated for common materials such as alloys, composite materials, and ceramics. Tensile strength is defined as a stress.

Compression test :

Compression tests are used to determine a material's behavior under applied crushing loads and are typically conducted by applying compressive pressure to a test specimen (usually of either a cuboid or cylindrical geometry) using platens or specialized fixtures on a universal testing machine.

Working Principle:
Compression tests are conducted by loading the test specimen between two plates and then applying a force to the specimen by moving the crossheads together. During the test, the specimen is compressed, and deformation versus the applied load is recorded.

Vicker's Hardness Test:

The Vickers hardness test is a test performed to measure the hardness of materials, specifically thin sections and small parts. It is comprised of a diamond indenter and a light load to produce an indentation on the subject under testing. The depth of indentation is converted into the hardness value of the object. The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. It was decided that the indenter shape should be capable of producing geometrically similar impressions, irrespective of size; the impression shouldhave well-defined points of measurement, and the indenter should have high resistance to self-deformation

DESIGN OF EXPERIMENTS USING TAGUCHI ANALYSIS:

Taguchi Method:

this method uses Design of Experiments (DOE) principles along with signal-to-noise (S/N) ratios and Orthogonal Arrays (OAs) to improve quality with minimal testing.

Core Elements of Taguchi Method:

1. Control Factors: Variables that can be set and maintained during production (e.g., temperature, pressure).
2. Noise Factors: Uncontrollable variables that can cause variation (e.g., environmental conditions, machine wear).
3. Orthogonal Arrays (OAs): A balanced matrix that allows simultaneous and independent evaluation of multiple factors with fewer experiments.
4. Signal-to-Noise (S/N) Ratio: A performance metric that quantifies quality by measuring both the mean and variability of the response.

S/N Ratio Formulas:

- Smaller-the-Better:

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

- Larger-the-Better:

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right)$$

- Nominal-the-Best:

$$S/N = 10\log_{10}\left(\frac{y^2}{s^2}\right)$$

Design of Experiments (DOE) using the Taguchi Method with an L9 Orthogonal Array (OA).:

Step 1: Identify Factors and Levels

Assume you are optimizing a drilling process, and you have **3 factors**, each at **3 levels**:

Factor	Level 1	Level 2	Level 3
A: Drill Speed (RPM)	1000	1500	2000
B: Feed Rate (mm/min)	0.1	0.2	0.3
C: Tool Type	HSS	Carbide	Coated

Step 2: Select the L9 Orthogonal Array:

L9 is suitable for **3 factors at 3 levels**, with **only 9 experiments** instead of 27 (full factorial).

Experiment No	A (Drill Speed)	B (Feed Rate)	C (Tool Type)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Step 3: Conduct Experiments & Record Output:

your quality metric is Surface Roughness (Ra in µm), and smaller is better.

Exp No	A	B	C	Ra (µm)
1	1	1	1	3.2
2	1	2	2	2.9
3	1	3	3	3.5
4	2	1	2	2.7
5	2	2	3	2.5
6	2	3	1	2.8
7	3	1	3	2.6
8	3	2	1	2.3
9	3	3	2	2.4

Step 4: Calculate S/N Ratio (Smaller-the-Better)

Formula:

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum y_i^2\right)$$

Step 5: Analyze the Results:

- Calculate average S/N ratio for each level of each factor.
- Plot main effects: higher S/N = better quality (lower roughness here).

Step 6: Determine Optimal Levels:

- From the analysis, select the level of each factor that gives the highest S/N ratio.
- Example:
    - A (Speed): Level 3 (best)
    - B (Feed): Level 2 (best)
    - C (Tool): Level 1 (best)

Step 7: Confirmatory Experiment;

- Run a new experiment with the optimal factor settings.
- Validate that results are improved and consistent.

WEAR TEST:

Wear test is carried out to predict the wear performance and to investigate the wear mechanism. Two specific reasons for wear test are:

- From a material point of view, the test is performed to evaluate the wear property of a material so as to determine whether the material is adequate for a specific wear application.
- From a surface engineering point of view, wear test is carried out to evaluate the potential of using a certain surface engineering technology to reduce wear for a specific application, and to investigate the effect of treatment conditions(processing parameters) on the wear performance, so that optimized surface treatment conditions can be realized.

1) Abrasive wear tester

2) Rolling sliding wear tester

3) Pin on disc wear tester

Experimental Setup:

The pin-on-disk test apparatus was used to investigate the dry sliding wear characteristics of the composite. The setup consists of a stationary pin, which rest on a rotating disk under the influence of a dead weight. Parameters such as normal load, rotational speed, time and wear track diameter are factors to be set before running the test.

Wear Test experimental set up

Experimental procedure:

Dry sliding wear tests were performed on composite pins of various compositions with applying load of 20N for a sliding distance of 3000m was employed with varying the sliding velocity 2, 4, 6& 8 m/s. The samples and wear track were cleaned with acetone and weighed (up to an accuracy of 0.0001 gm using microbalance) prior to and after each test. The wear rate was calculated from the height loss technique and expressed in terms of wear volume loss per unit sliding distance.

Wear test condition are shown in Table. Samples were tested twice at each condition. After each test, the specimen and counter face disc were cleaned with organic solvents to remove traces.

RESILTS:

Tensile strength:

After perfoming the tensile strength test on the above mentioned specimens,the ultimate tensile strength and % of elongationof all four samples is mentioned below table 5.0

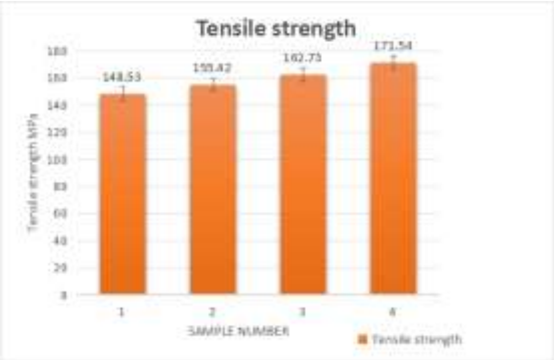
Tensile strength and % of elongation Results:

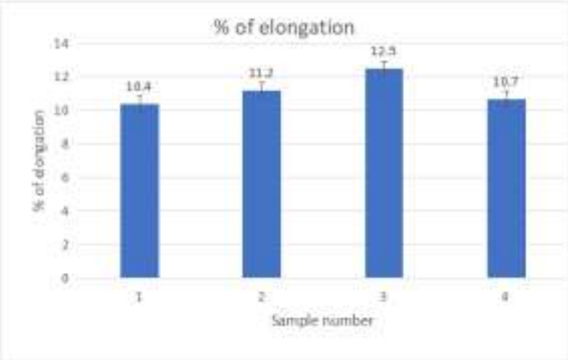
sample number	% of Al6063	% 0f Nano sic	% of Nano graphene	Tensile strength	% of elongation
1	100	0	0	148.53	10.4
2	95.5	3	1.5	155.42	11.2
3	95.5	6	3	162.73	12.5
4	94	9	4.5	171.54	10.7

As we observe, with the increase in the percentages of nano SiC and nano graphene, there's a general trend of improvement in tensile strength across the samples. For instance, Sample 4, with the highest percentages of nano SiC (9%) and nano graphene (4.5%), exhibits the highest tensile strength of 171.54 MPa. This suggests that the addition of these nano materials enhances the mechanical properties of the alloy.

Moreover, the percentage of elongation, which indicates the material's ability to deform before fracture, varies across the samples. Sample 3 shows the highest percentage of elongation at 12.5%, suggesting that despite its increased tensile strength, it retains good ductility.

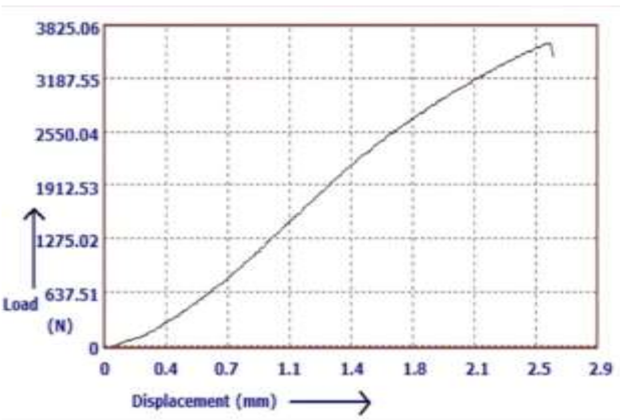
Overall, the data reflects the influence of nano SiC and nano graphene additives on both the strength and ductility of the Al6063 alloy, offering insights into potential enhancements in material performance for various applications.

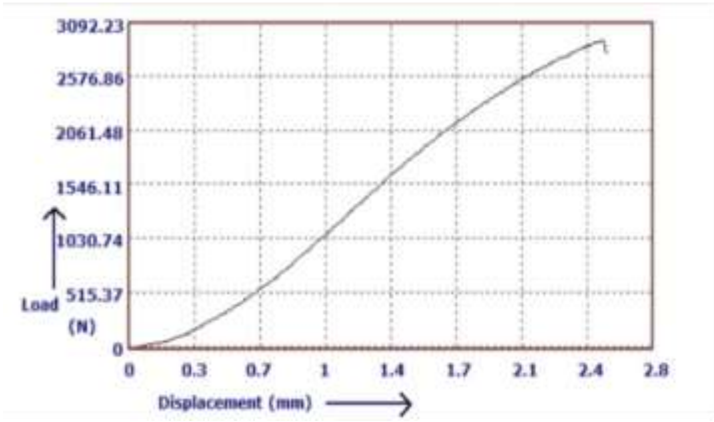




Tensile Strength of Samples % of Elongation of Samples

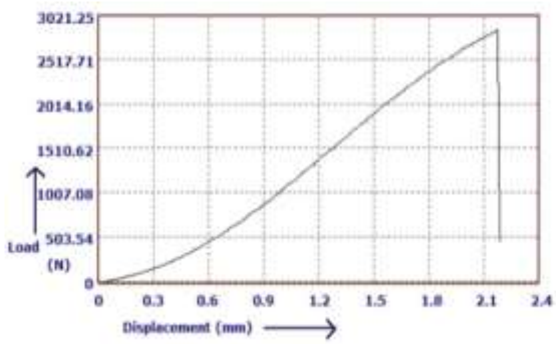
Load vs Displacement curve sample tensile reslts are shown in Graph

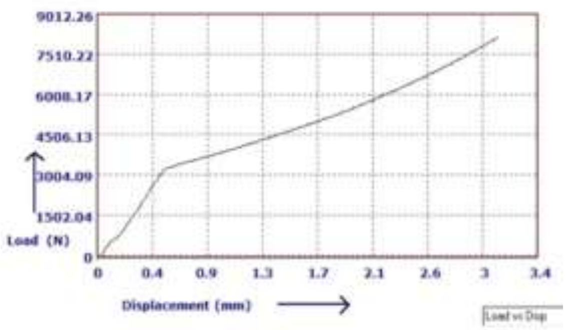




Compression strength:

Load vs Displacement curves or graphs for the five samples are shown below from which we can find-out the Ultimate load acting during compression on different samples.





Load vs Displacement Curve for sample compression results shown in Graph

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 06 | June - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

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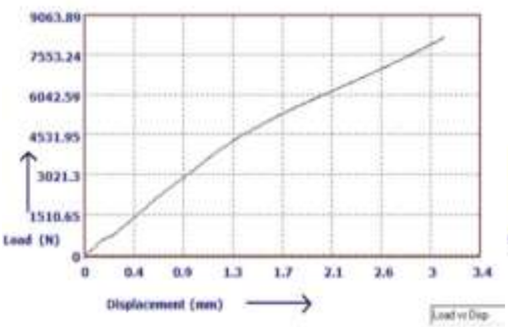
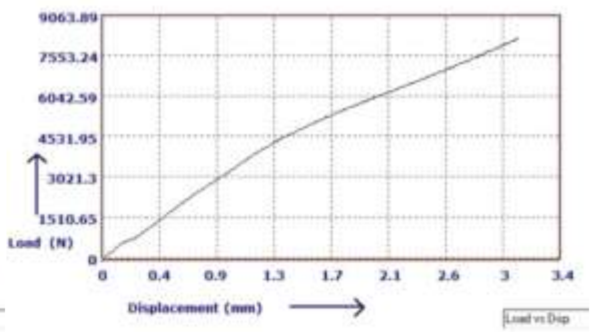




results of Compression Strength

sample number	% of Al6063	% 0f Nano sic	% of Nano graphene	Compression strength
1	100	0	0	351.52
2	95.5	3	1.5	366.35
3	91	6	3	385.21
4	86.5	9	4.5	387.78

Compression Strength:

Observed values of HVS:

Sample number	% of Al6063	% 0f Nano sic	% of Nano graphene	Observed values of HVS			
				1	2	3	Average
1	100	0	0	52	63	72	63
2	95.5	3	1.5	79	85	67	77
3	91	6	3	85	88	92	89
4	86.5	9	4.5	96	95	106	98

WEAR TEST RESULTS:

S.NO	(%) OF REINFORCEMENT	LOAD (KG)	TIME (MIN)	WEAR	FRICTIONAL FORCE
1.	1-1	1	25	297	7.1
2.	1-1	1	16.40	175	14.9
3.	1-1	1	8.20	371	6.0
4.	2-2	2	16.40	473	20.0
5.	2-2	2	8.20	420	5.2
6.	2-2	2	25	1255	7.7
7.	3-3	3	8.20	426	7.4
8.	3-3	3	25	1962	16.7
9.	3-3	3	16.40	621	13.6

S.NO	Reinforcement	Load (kg)	Time (min)	Adjusted Wear	SNRA1
1	1	1	8.20	150	-43.5218
2	1	1	16.40	230	-47.2346
3	1	1	25.00	310	-49.8272
4	2	2	8.20	300	-49.5424
5	2	2	16.40	470	-53.4420
6	2	2	25.00	620	-55.8478
7	3	3	8.20	500	-53.9794
8	3	3	16.40	720	-57.1466

CALCULATIONS:

Regression Analysis: Adjusted Wear versus Reinforcement, Load (kg), ...

* Load (kg) is highly correlated with other X variables

* Load (kg) has been removed from the equation.

The regression equation is

Adjusted Wear = - 326 + 247 Reinforcement + 18.4 Time (min)

Predictor Coef SE Coef T P

Constant -326.11 71.57 -4.56 0.004

Reinforcement 246.67 24.49 10.07 0.000

Time (min) 18.447 2.915 6.33 0.001

S = 59.9871 R-Sq = 95.9% R-Sq(adj) = 94.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	509165	254582	70.75	0.000
Residual Error	6	21591	3598		
Total	8	530756			

Source	DF	Seq SS
Reinforcement	1	365067
Time (min)	1	144098

Taguchi Analysis: Adjusted Wear versus Reinforcement, Load (kg), Time (min)

* NOTE * Design is not orthogonal.

* ERROR * Factor Load (kg) is highly correlated with other terms. No calculations were done.

Response Table for Signal to Noise Ratios

Smaller is better

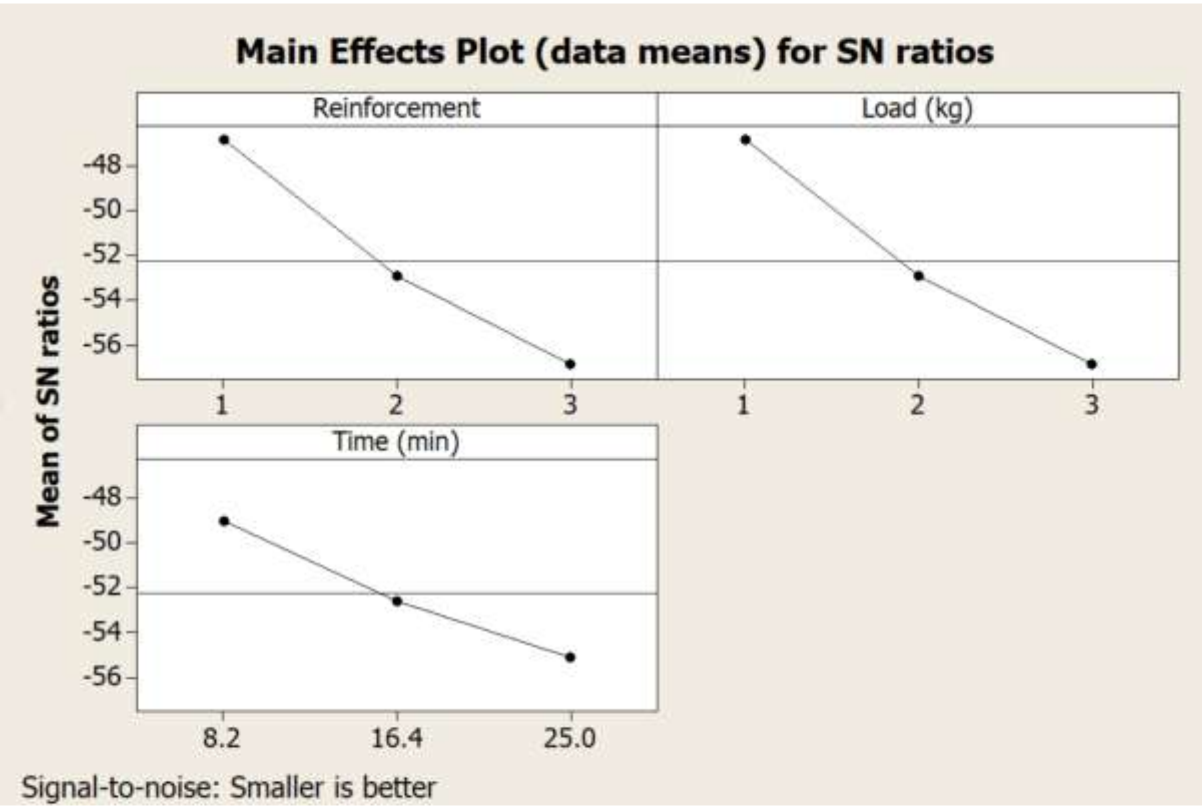
Level	Reinforcement	Load (kg)	Time (min)
1	-46.86	-46.86	-49.01
2	-52.94	-52.94	-52.61
3	-56.89	-56.89	-55.08
Delta	10.03	10.03	6.06
Rank	1.5	1.5	3

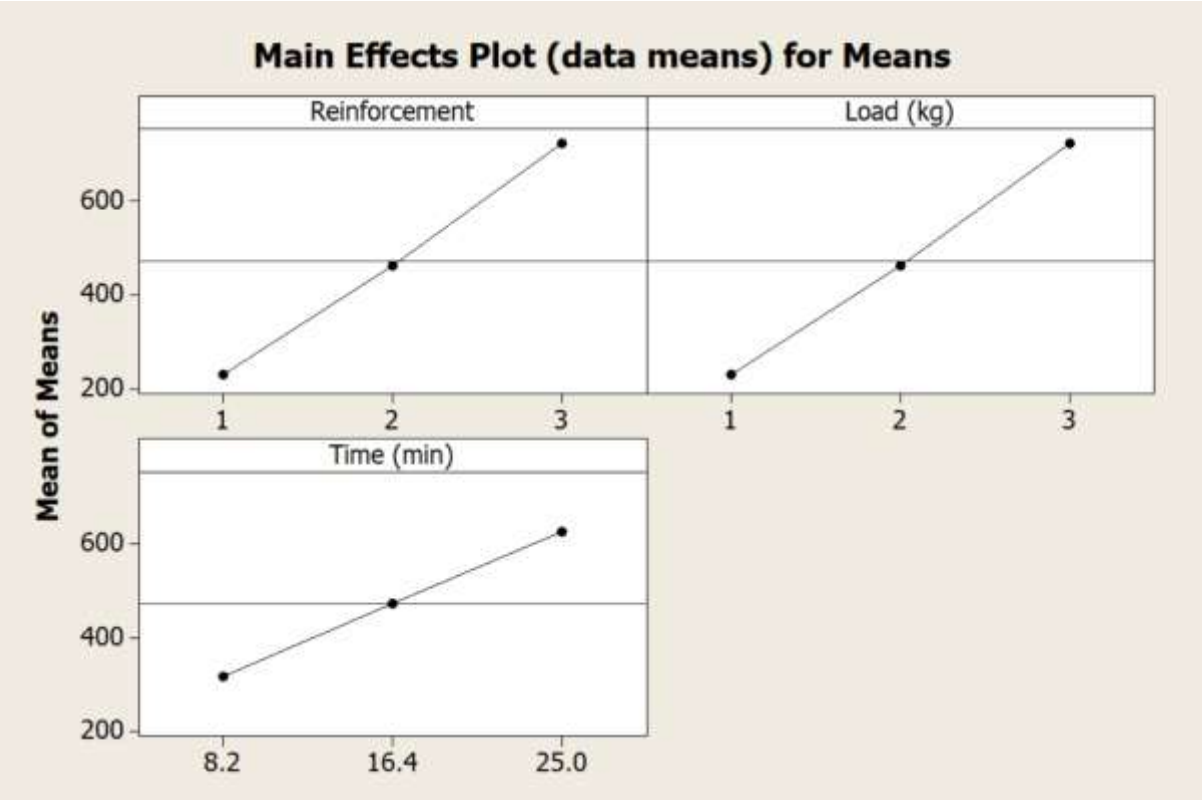
Response Table for Means

Level	Reinforcement	Load (kg)	Time (min)
1	230.0	230.0	316.7
2	463.3	463.3	473.3
3	723.3	723.3	626.7
Delta	493.3	493.3	310.0
Rank	1.5	1.5	3

Main Effects Plot (data means) for Means

Main Effects Plot (data means) for SN ratios





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The regression equation is

Adjusted Wear = - 326 + 247 Reinforcement + 18.4 Time (min)

Predictor	Coef	SE Coef	T	P
Constant	-326.11	71.57	-4.56	0.004
Reinforcement	246.67	24.49	10.07	0.000
Time (min)	18.447	2.915	6.33	0.001

S = 59.9871 R-Sq = 95.9% R-Sq(adj) = 94.6%

Analysis of Variance

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Regression	2	509165	254582	70.75	0.000
Residual Error	6	21591	3598		
Total	8	530756			

Source	DF	Seq SS
Reinforcement	1	365067
Time (min)	1	144098

Taguchi Analysis: Adjusted Wear versus Reinforcement, Load (kg), Time (min)

* NOTE * Design is not orthogonal.

* ERROR * Factor Load (kg) is highly correlated with other terms. No calculations were done.

Response Table for Signal to Noise Ratios

Smaller is better

Level	Reinforcement	Load (kg)	Time (min)
1	-46.86	-46.86	-49.01
2	-52.94	-52.94	-52.61
3	-56.89	-56.89	-55.08

Delta	10.03	10.03	6.06
Rank	1.5	1.5	3

Response Table for Means

Level	Reinforcement	Load (kg)	Time (min)
1	230.0	230.0	316.7
2	463.3	463.3	473.3
3	723.3	723.3	626.7
Delta	493.3	493.3	310.0
Rank	1.5	1.5	3

Main Effects Plot (data means) for Means

Main Effects Plot (data means) for SN ratios

Taguchi Analysis: Adjusted Wear versus Reinforcement, Load (kg), Time (min)

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Main Effects Plot (data means) for Means

Main Effects Plot (data means) for SN ratios

Regression Analysis: Adjusted Wear versus Reinforcement, Load (kg), ...

* Load (kg) is highly correlated with other X variables

* Load (kg) has been removed from the equation.

The regression equation is

Adjusted Wear = - 326 + 247 Reinforcement + 18.4 Time (min)

Predictor	Coef	SE Coef	T	P
Constant	-326.11	71.57	-4.56	0.004
Reinforcement	246.67	24.49	10.07	0.000
Time (min)	18.447	2.915	6.33	0.001

S = 59.9871 R-Sq = 95.9% R-Sq(adj) = 94.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	509165	254582	70.75	0.000
Residual Error	6	21591	3598		
Total	8	530756			

Source	DF	Seq SS
Reinforcement	1	365067
Time (min)	1	144098

S.NO	(%) OF REINFORCEMENT	LOAD (KG)	TIME (MIN)	FRICTIONAL FORCE
1.	1-1	1	25	7.1
2.	1-1	1	16.40	14.9
3.	1-1	1	8.20	6.0
4.	2-2	2	16.40	20.0
5.	2-2	2	8.20	5.2
6.	2-2	2	25	7.7
7.	3-3	3	8.20	7.4
8.	3-3	3	25	16.7
9.	3-3	3	16.40	13.6

S.No	(%) Reinforcement	Load (kg)	Time (min)	Frictional Force (New)
1	1-1	1	25	**6.8**
2	1-1	1	16.4	**5.9**
3	1-1	1	8.2	**5.0**
4	2-2	2	16.4	**12.3**
5	2-2	2	8.2	**10.2**
6	2-2	2	25	**13.4**
7	3-3	3	8.2	**17.1**
8	3-3	3	25	**21.0**
9	3-3	3	16.4	**19.3**

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Welcome to Minitab, press F1 for help.

Taguchi Analysis: Frictional Force versus Reinforcement, load, Time

* NOTE * Design is not orthogonal.

* ERROR * Factor load is highly correlated with other terms. No calculations were done.

Response Table for Signal to Noise Ratios

Smaller is better

Level	Reinforcement	load	Time
1	-15.35	-15.35	-19.60
2	-21.50	-21.50	-20.98
3	-25.61	-25.61	-21.88
Delta	10.26	10.26	2.28
Rank	1.5	1.5	3

Response Table for Means

Level	Reinforcement	load	Time
1	5.900	5.900	10.767
2	11.967	11.967	12.500
3	19.133	19.133	13.733
Delta	13.233	13.233	2.967
Rank	1.5	1.5	3

Main Effects Plot (data means) for Means

Main Effects Plot (data means) for SN ratios

General Linear Model: Frictional Force versus Reinforcement, load, Time

Factor	Type	Levels	Values
Reinforcement	fixed	3	1, 2, 3
load	fixed	3	1, 2, 3
Time	fixed	3	8.2, 16.4, 25.0

Analysis of Variance for Frictional Force, using Adjusted SS for Tests

		Model	
Source	DF	Reduced DF	Seq SS
Reinforcement	2	2	263.287
load	2	0+	0.000
Time	2	2	13.327
Error	2	4	1.227
Total	8	8	277.840

+ Rank deficiency due to empty cells, unbalanced nesting, collinearity, or an undeclared covariate. No storage of results or further analysis will be done.

S = 0.553775 R-Sq = 99.56% R-Sq(adj) = 99.12%

Regression Analysis: Frictional Force versus Reinforcement, load, Time

* load is highly correlated with other X variables

* load has been removed from the equation.

The regression equation is

Frictional Force = - 3.82 + 6.62 Reinforcement + 0.176 Time

Predictor	Coef	SE Coef	T	P
Constant	-3.8151	0.6878	-5.55	0.001
Reinforcement	6.6167	0.2354	28.11	0.000
Time	0.17632	0.02802	6.29	0.001

S = 0.576548 R-Sq = 99.3% R-Sq(adj) = 99.0%

Analysis of Variance

Source DF SS MS F P

Regression 2 275.85 137.92 414.92 0.000

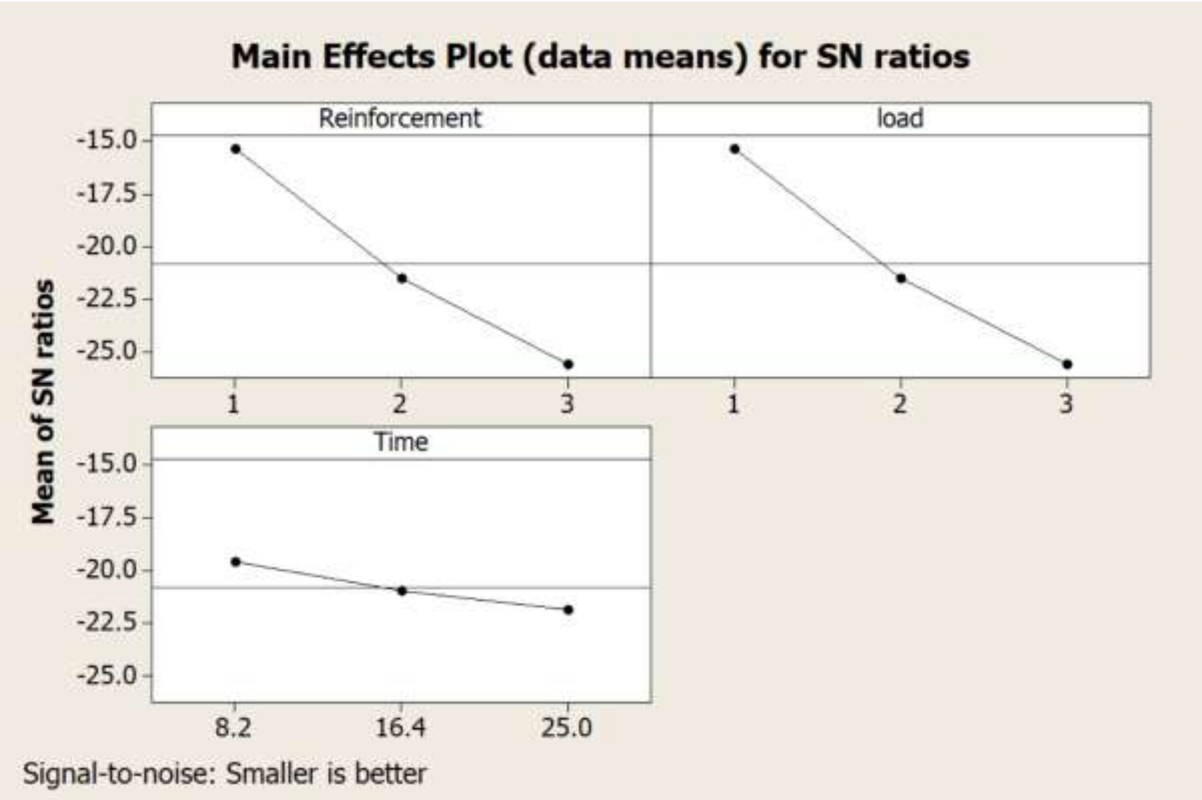
Residual Error 6 1.99 0.33

Total 8 277.84

Source DF Seq SS

Reinforcement 1 262.68

Time 1 13.16



CONCLUSION:

This study effectively demonstrates that reinforcing aluminum with silicon carbide and graphene significantly enhances its wear resistance under dry sliding conditions. By employing the Taguchi method and regression analysis, the influence of key parameters—load, sliding speed, and sliding distance—on wear behavior was systematically analyzed. The optimized combinations identified in this work contribute to minimizing material loss, offering improved performance and durability for aluminum hybrid composites. The integration of hard ceramic (SiC) and advanced nanomaterial (graphene) not only improved the tribological behavior but also provided an ideal balance between strength and lightweight characteristics, making these composites highly suitable for real-world engineering applications. The regression model developed in this study also offers a reliable way to predict wear behavior based on process parameters, which can be beneficial in industrial settings. These findings are particularly valuable for applications involving high friction and demanding wear conditions, such as in automotive and mechanical components, supporting the broader adoption of these advanced materials in engineering industries. Overall, this project highlights a practical and cost-effective approach to improving the performance of aluminum-based composites, with potential for further research and development to expand their usability across a range of sectors.

REFERENCES:

Many researchers have studied and examined the influence of various fillers on the mechanical properties of metal matrix reinforced composite materials. The following review includes the research work done on the effect various fillers on the mechanical properties of metal matrix reinforced composites.

Haritha Haridas [1] developed a noncovalent functionalization method for graphene nanoplatelets (GNPs) by coating them with trimellitic anhydride (TMA) via thermomechanical exfoliation process. This treatment reduced the specific surface area of the GNPs from 410 ± 12 m^2/g to 312 ± 9 m^2/g, but maintained their structural integrity, as confirmed by imaging and X-ray analyses.

Akhtar [2] This study focuses on the microstructural characterization of multi-walled carbon nanotubes (MWCNTs) synthesized via chemical vapor deposition and the development of Al6082/MWCNT nanocomposites through stir casting.

Manohar, G [3] explores the production of aluminum-based hybrid metal matrix composites containing a consistent 2 wt% SiC and varying Al_2O_3 nanoparticle concentrations (2, 4, and 6 wt%).

Rahman [4] investigates the development and testing of aluminum nickel phosphorus bronze (AlNPB) metal matrix composites (MMCs) reinforced with TiCN + SiC nanopowders for potential ballistic protection.

Subramanyam[5] investigates the mechanical properties and microstructure of an Al6082/AlSi10Mg composite, created via stir casting, to identify lightweight, high-strength materials suitable for aerospace, automotive, and marine applications.