International Journal of Computational and Experimental Science and ENgineering
(IJCESEN)
Vol. 11-No.3 (2025) pp. 6940-6947
http://www.ijcesen.com
ISSN: 2149-9144

Research Article

Investigation of Mechanical Properties of LM6 Aluminium Alloy Embedded with Nanographene

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Article Info:

DOI: 10.22399/ijcesen.3880
Received : 08 July 2025
Accepted : 11 September 2025

Keywords

LM6 Aluminium
Nano Graphene Casting
Hardness
Wear
Wear Rate

Abstract:

Aluminum alloys are widely utilized in the automotive, aerospace, and marine industries due to their lightweight structure, excellent corrosion resistance, and superior castability. Among these, Aluminium LM6, a hypoeutectic alloy with a high silicon content, is particularly favored for applications requiring smooth flow during casting and long-term durability in corrosive environments. While LM6 offers notable advantages in terms of manufacturability and ductility, its mechanical properties—such as tensile strength and hardness—are relatively limited compared to other structural alloys. This restricts its use in load-bearing or high-stress components.To address these limitations, Metal Matrix Composites (MMCs) have emerged as a promising solution. By reinforcing base metals with solid secondary materials, MMCs significantly enhance mechanical performance, wear resistance, and thermal stability. In recent years, nano-reinforcements, especially nano-graphene, have gained considerable attention due to their exceptional mechanical, thermal, and electrical properties. Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, exhibits extraordinary tensile strength, a high surface area, and a large Young's modulus. These attributes make it an ideal candidate for strengthening metal matrices, offering a pathway to develop lightweight, high-performance composites suitable for advanced engineering applications.

1. Introduction

The main goal of this study is to manufacture and test aluminum alloy LM6 reinforced using different mass percentages of nano graphene. Aluminium alloys are widely favoured in transportation sectors such as automotive, aerospace, and marine engineering due to their lightweight nature, excellent corrosion resistance, and superior casting characteristics. Among these, Aluminium LM6 stands out as a particularly versatile choice. LM6 is a hypoeutectic Aluminium-silicon alloy, typically containing 10–13% silicon, which imparts exceptional fluidity during casting and enhances its resistance to corrosion — especially in marine environments.

Its popularity stems from its ability to produce intricate and thin-walled castings with minimal hot tearing, making it ideal for components that require

leak-tightness and dimensional precision. LM6 is also highly ductile, allowing castings to be modified post-production, such as bending or reshaping for specific contours.
However, LM6's mechanical limitations temper its broader structural applications. While it offers moderate tensile strength (130–160 MPa) and Brinell hardness around 50–60 HB, these values are lower compared to other Aluminium alloys designed for high-load or high-impact scenarios. Its non-heat-treatable nature means that mechanical properties cannot be significantly enhanced through conventional thermal processes. As a result, LM6 is often confined to non-load-bearing or secondary support roles, where corrosion resistance and castability are prioritized over strength and wear resistance. In essence, LM6 is a material of trade-offs: it excels in environments demanding corrosion protection and casting precision, but its structural limitations restrict its use in high-stress applications. Engineers must carefully balance these attributes when selecting LM6 for design, often reinforcing or combining it with other materials when mechanical performance is critical[1][2].

2. Materials and Methods/Methodology

2.1 Materials Used

This research is to examine how well nano graphene might be used as material used to strengthen the mechanical qualities of Aluminum LM6, paving how to use it in more complex situations within engineering. This work aims to measure the mechanical characteristics of Aluminum LM6 reinforced with nano particles. We particularly study graphene particles to explore how their number and distribution shapes the structure. mechanical behavior of the composite is shaped by the various techniques and methods used during manufacturing. The research is related to the manufacture of nano-graphene-reinforced LM6 composites through casting. Subsequent to powder metallurgy techniques, the samples are completely characterized. testing a material by doing tension, hardness and effects-of-impact tests [4][5]. The raw material LM6 was chosen due to the following Properties:

- Corrosion resistance: LM6 exhibits excellent resistance to corrosion in both atmospheric and marine conditions, making it suitable for applications like marine components.
- Ductility: It has high ductility; means it can easily be bent or reshaped.
- Castability: LM6 has good castability, allowing for the creation of intricate castings with thin sections.
- Strength: While not high-strength, LM6 is considered medium strength and its not heat treated.
- Because LM6 has a high silicon content, it is not very easy to machine..

Fluidity and strong resistance to hot tearing during the casting process are two further ways the metal is recognized. process.
The material for the composite was prepared using the stir method. Because it is easy and inexpensive, casting continues to be used by many industries. Reinforcements are uniformly spread out through the molten metal. Tests under tension are considered mechanical tests. Nano result was evaluated by measuring strength, hardness and impact resistance. Graphene has been applied to the base alloy. Also, optical and scanning microscopy methods are used to study the structure of these materials. The electron microscope was used to investigate the pattern and chemical linkages between the layer and substrate. Alternatively, nano particles are added directly into aluminum [5].

3.Blending Process

LM6 is often selected as the matrix material in metal matrix composites due to its excellent casting characteristics and superior corrosion resistance. Nano graphene has improved mechanical and tribological properties there its influence can explore the reinforcement. fly ash, a low-cost by-product of coal combustion, is increasingly utilized to enhance the hardness and wear resistance of steel surfaces. Aluminium LM6 composites reinforced with varying proportions of nano-graphene can be effectively fabricated using the stir casting process, a method known for its simplicity and cost-efficiency. The procedure begins by melting LM6 alloy in a furnace until it reaches a fully liquid state. Meanwhile, nano-graphene and fly ash particles are preheated to eliminate moisture and enhance their wettability and bonding with the molten metal. Once preheated, the reinforcements such as the graphene are gradually introduced into the liquid Aluminium using unbroken guide wires, ensuring uniform dispersion through continuous stirring. The homogenized mixture is then poured into preheated metal moulds and allowed to solidify under controlled cooling conditions, forming a composite with improved mechanical and tribological properties.
[11][12]. The material composition is shown below in the Table 1.

Table 1. *Material composition*

SL No	Material	Base material	Nano Additive graphine in %
1	Sample 1	Al Lm6	2%graphene
2	Sample 2	Al Lm6	3%graphene
3	Sample 3	Al Lm6	5%graphene

An electric furnace is a heating system that uses electricity instead of combustion fuels (like gas or oil) to generate heat. It's commonly used for both residential heating and in industrial applications (such as metal smelting or glass production). An electric furnace is a heating device that uses electricity as its energy source to produce high temperatures for various purposes, such as space heating, metal melting, or industrial processing. [2].

Figure 1. *Aluminium Lm6.*

Figure 2. *Graphene.*

4. Mechanical Testing

To evaluate the mechanical performance of the developed composites, the following tests we are conducted: such as

Figure 3. *Casting.*

1. Impact Test: The material's toughness and energy absorption capacity was measured using a Charpy impact testing machine. An impact testing machine is a mechanical instrument intended for testing the toughness or impact strength of materials. It shows how the material will respond to unexpected, harsh forces. This test helps determine a material's ability to transfer energy during a crack and is especially useful in assessing how objects respond to bending, breakage and continued use. Both automotive and aerospace fields rely on impact testing for quality control and getting the right material. There are also construction and manufacturing, where materials quickly face the risk of impacts during use.

2. Hardness Test: Brinell or Vickers hardness tests were conducted to determine surface hardness. A wear testing machine is employed to measure the level of resistance of various materials to wear. In special facilities that help control all the factors. By estimating contact with real-world surfaces, it shows how Everything responds to friction, pressure and the motion caused by having different objects move relative to each other. The aim is to track how much material is lost. Hardness refers to a material's ability to withstand surface indentation, scratching, or abrasion. It's not a fundamental property like strength but provides useful comparative information.[6].

3. Compression Test: The compression test is a fundamental mechanical evaluation used to determine a material's ability to withstand axial compressive loads without failure. It provides critical insights into the compressive strength, deformation behavior, and failure mechanisms of materials — especially important for structural applications where materials are subjected to squeezing or crushing forces. In this test, specimens (typically cylindrical or cuboidal) are placed between two compression platens of a Universal Testing Machine (UTM). The UTM applies a gradually increasing load along the longitudinal axis of the specimen. As the load intensifies, the material begins to deform, and the machine records both the applied force and the resulting displacement. The test continues until the specimen either fractures or reaches a predetermined strain limit. For materials like Aluminium LM6 composites, this test is particularly useful in assessing how reinforcements (e.g., nano-graphene, fly ash) influence load-bearing capacity and deformation resistance. The UTM setup ensures uniform load distribution, often using a hemispherical bearing to avoid eccentric loading. Specimen preparation is crucial — surfaces must be flat and parallel to prevent uneven stress concentrations.

4. Wear Test: The wear resistance of materials under dry sliding conditions can be effectively evaluated using a pin-on-disc apparatus, a widely recognized method in tribological testing. In this setup, a stationary pin is pressed against a rotating disc under a controlled normal load, simulating real-world contact scenarios. The test is conducted without lubrication, allowing direct observation of material behaviour during sliding. Parameters such as sliding speed, load, and distance are carefully regulated to ensure consistency. Throughout the test, the apparatus records the coefficient of friction and wear rate, typically measured through weight or dimensional loss of the pin. This method is particularly useful for assessing the performance of reinforced LM6 Aluminium composites, as it reveals how additives like nano-graphene or fly ash influence surface durability, frictional stability, and wear mechanisms. Post-test analysis often includes microscopic examination to identify dominant wear modes such as abrasion or adhesion, offering valuable insights into the material's suitability for high-contact applications [3][8][9].

Figure 4. *Samples for Impact, Hardness and compression*

5. Results and Discussion

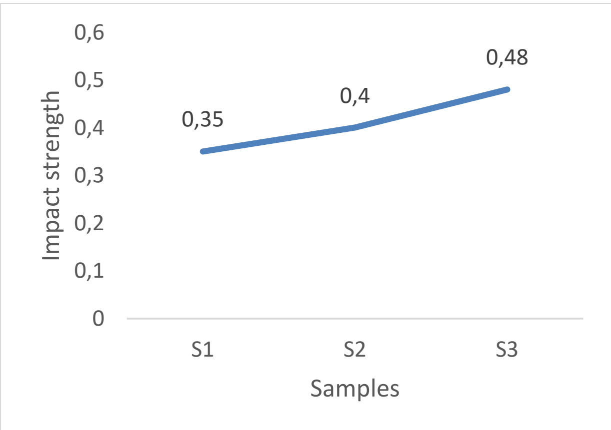
Mechanical Testing of Aluminium LM6 and Nano Graphene with 2%, 3%, and 5% additives

5.1. Impact Test

This test evaluates the toughness of the composite materials by measuring the energy absorbed during fracture. The Charpy impact test was used to determine the fracture energy and impact strength of Aluminum LM6 composites reinforced with 2%,3%,and 5% nanographene[7][8].

Table 2. *Impact Test Results*

Sl No	Material	Angle of Raise	Fracture energy in J	Impact Strength in J
1	Sample 1	140deg	3.5J	0.35
2	Sample 2	135deg	4.0J	0.4
3	Sample 3	130deg	4.8J	0.48



The data indicates a clear improvement in impact strength as the graphene content increases that is as Al LM6 and 2% Graphene shows a moderate impact resistance with a fracture energy of 3.5 J. With 3% graphene, both fracture energy and impact strength increase, suggesting improved toughness. At 5% graphene, the composite exhibits the highest fracture energy (4.8 J) and impact strength (0.48 kJ/m²), indicating that nanographene effectively enhances the ability of the material to absorb energy during sudden impacts.

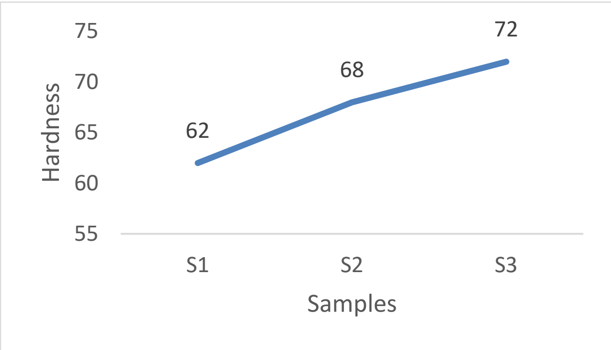
5.2 Hardness Test

The hardness of the composite specimens was measured using the Rockwell Hardness Test (HRB scale), which involves pressing a steel ball indenter into the surface of the material under a fixed load.

The resulting indentation depth determines the material's hardness.

Table 3. *Hardness Test Results*

Sl No	Material tested	Indentor	Load (kgf)	Harness Scale	Hardness Number
1	Sample 1	Steel bar	100	HRB	62
2	Sample 2	Steel bar	100	HRB	68
3	Sample 3	Steel bar	100	HRB	72



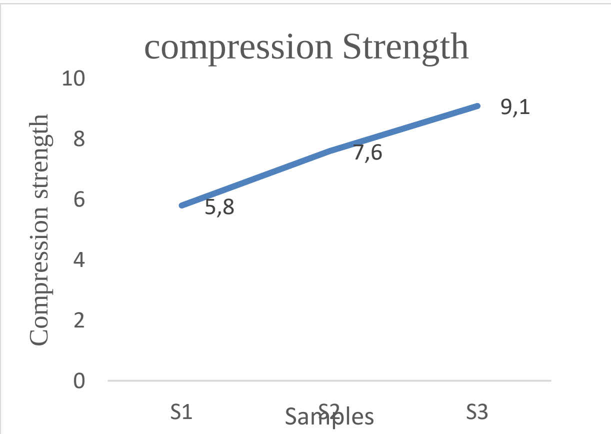
The results show a progressive increase in hardness with higher nanographene content 2% graphene yields a hardness of 62 HRB, showing moderate surface resistance, at 3% graphene, the hardness increases to 68 HRB, indicating improved reinforcement distribution and matrix strengthening and at 5% graphene provides the highest hardness value of 72 HRB, demonstrating that nanographene effectively enhances the composite's resistance to surface deformation.

5.3 Compression Test

The compression test evaluates a material's ability to withstand axial loads without failure. It helps determine the compressive strength, stress, and strain behavior of composite specimens.

Table 4. *Compression Test Results*

Sl.No	**Material tested**	**Load (F) (KN)**	**Deformation(mm)**	**Stress(N/mm2)**	**Strain**
1	Sample 1	35	1.2	350	0.060
2	Sample 2	38	1.0	380	0.050
3	Sample 3	41	0.9	410	0.045



The results indicate a significant improvement in compressive strength with increasing graphene content the composite with 2% graphene supports a load of 35 kN and has a stress value of 350 N/mm²,Increasing graphene to 3% results in higher strength (380 N/mm²) and slightly lower deformation and At 5% graphene, the material exhibits the highest compressive stress of 410 N/mm², with the least deformation and strain, indicating superior resistance to compressive loads.

5.4 Wear Test

5.4.1 Sample 1

The pin-on-disc wear test was conducted to evaluate the wear resistance of the composite material. The test measures material loss after sliding the specimen against a rotating disc under different loads and sliding distances at a constant RPM (750) at 10N load, 20N Load and 30N load.

Table 5A. *Wear Test Results at 10N Load*

%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
2%	10N	1000	10.34	10.1389	0.2011	750
2%	10N	2000	10.34	10.138198	0.201802	750
2%	10N	3000	10.34	10.130	0.210	750

Table 5B. *Wear Test Results at 20N Load*

%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
2%	20N	1000	10.1289	10.118	0.0109	750
2%	20N	2000	10.1289	10.113	0.0159	750
2%	20N	3000	10.1289	10.113	0.0159	750

Table 5C. *Wear Test Results at 30N Load*

%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
2%	30N	1000	10.1889	10.0787	0.1102	750
2%	30N	2000	10.1889	10.0787	0.1102	750
2%	30N	3000	10.1889	10.0787	0.1102	750

At 10N, wear loss increased slightly with sliding distance, indicating gradual surface degradation over time. At 20N, wear loss was surprisingly lower and consistent (0.0159g max), suggesting better wear performance at moderate loads—possibly due to optimal surface-film formation or improved load-sharing by the nanographene. At 30N, wear loss remained constant at 0.1102g, showing that the material reaches a wear plateau where further sliding doesn't significantly increase wear, but this value is higher than at 20N, indicating that excessive load reduces efficiency of reinforcement.

5.4.2 Sample 2

Table 6A. *Wear Test Results at 10N Load*

%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
3%	10N	1000	10.0787	10.0747	0.004	750
3%	10N	2000	10.0787	10.0727	0.006	750
3%	10N	3000	10.0787	10.0687	0.010	750

Table 6B. *Wear Test Results at 20N Load*

%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
3%	20N	1000	10.1289	10.118	0.0109	750
3%	20N	2000	10.1289	10.113	0.0159	750
3%	20N	3000	10.1289	10.113	0.0159	750

Table 6C. *Wear Test Results at 30N Load*

%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
3%	30N	1000	10.1889	10.0787	0.1102	750
3%	30N	2000	10.1189	10.0751	0.01138	750
3%	30N	3000	10.1189	10.0712	0.1177	750

At 10N, the wear loss is very low (0.004g to 0.010g), and increases gradually with distance, showing excellent wear resistance at lower loads. At 20N, the wear behavior is consistent with 2% GNP results, peaking at 0.0159g and remaining stable after 2000m. At 30N, wear increases substantially at 1000m (0.1102g) but decreases at longer distances, possibly due to inconsistent starting weights or initial material surface effects like debris formation or work-hardening. Overall, 3% nanographene reinforcement offers superior wear resistance at low and moderate loads, with performance slightly decreasing under high-stress conditions (30N), but still better than 2% in lower-load scenarios.

5.4.3 Sample 3

%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
5%	10N	1000	10.1125	10.1085	0.004	750
5%	10N	2000	10.1125	10.1065	0.006	750

5%	10N	3000	10.1125	10.1025	0.010	750

Table 7A. *Tabulated of Wear Loss 10N Load*

Table 7B. *Tabulated of Wear Loss 10N Load*

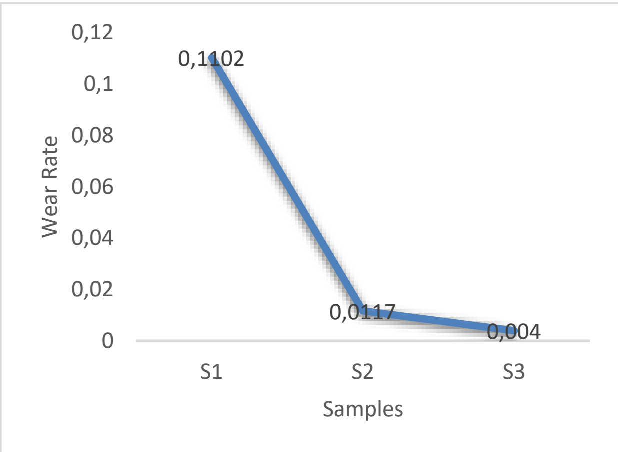
%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
5%	20N	1000	10.1129	10.1069	0.006	750
5%	20N	2000	10.1129	10.1009	0.012	750
5%	20N	3000	10.1129	10.0979	0.015	750

Table 7C. *Tabulated of Wear Loss 10N Load*

%GNP	Load(N)	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)	RPM
5%	30N	1000	10.0979	10.1080	0.0112	750
5%	30N	2000	10.0979	10.1000	0.016	750
5%	30N	3000	10.0979	10.09880	0.004	750

Table 8. *Final summary of wear test results*

Sl.no	%GNP	Load(N)	RPM	Sliding Distance(m)	Initial weight(g)	Final weight(g)	Wear loss (g)
1	2%	30N	750	3000	10.1889	10.0787	0.1102
2	3%	10N	750	3000	10.1189	10.0712	0.0117
3	5%	10N	750	3000	10.0979	10.09880	0.004



A. Effect of Sliding Distance:

- At each load level, wear loss increases with sliding distance.
- This is expected due to more prolonged contact and friction between the surfaces.

B. Effect of Load:

- For a given distance, wear increases as load increases.
- For example, at 1000m: 10N: 0.004g, 20N: 0.006g and 30N: 0.0112g hence this demonstrates that higher pressure accelerates material removal due to higher contact stress.

C. Anomaly at 30N / 3000m:

- Wear loss at 3000m (0.004g) is lower than at 2000m (0.016g), which is unexpected.
- Possible reasons: Measurement in consistency, Surface smoothing effect after prolonged sliding and Debris compaction reducing wear.

6. Conclusion

The mechanical properties of aluminum LM6 fortified with nanographene were assessed in laboratory experiments. investigated to determine the effects of adding a nanomaterial on a common casting alloy for engineering use. According to the study, the LM6 engine's performance under mechanical testing conditions was significantly improved by the addition of nanographene. It became evident that there had been a specific increase in tensile strength, hardness, and wear resistance. Graphene's exceptional strength and stiffness contribute to improvements in membrane performance. its ability to more evenly distribute the stress load throughout the composite. The presence of nanographene Furthermore, the alloy's microstructure was enhanced by the treatment, which enhanced its mechanical qualities.
Hence Use nanographene to improve LM6, a common alloy for aluminum casting because it has Increased hardness that is a material's increased ability to withstand localized plastic deformation, including abrasion, scratching, and indentation. This characteristic directly affects the durability and performance of materials that are subjected to wear and mechanical stress, making it essential and Improved wear resistance: this refers to a material's capacity to tolerate the progressive loss of its

surface as a result of mechanical processes like erosion, abrasion, or friction.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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