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Preparation and Testing of Aluminium 4032 Composites for Piston Applications

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ABSTRACT

The Al metal matrix composites is extensively used in aerospace, light weight, high specific stiffness, and low coefficient of thermal expansion. Now the Al metalmatrix composition of metals like Nickel, magnesium, Aluminium Copper, Zirconium Diboride, Graphene. These metals are combined by the stir casting process to increase the Impact strength and hardness. The resultant material are being tested under mechanical testing equipment like Charpy, Izod, Hardness. The objective of the Aluminium metal matrix increases the Impact strength and hardness. It is appropriate to use in applications like Aerospace, Ship building. Casting is one of the main routes for producing aluminium-alloy parts. Good castability for foundry alloys includes a relatively high fluidity, low melting point, short casting cycles, relatively low tendency for hot cracking, good as-cast surface finish and chemical stability. In hypoeutectic alloys, it is common to refine the size of the aluminium crystals by grain refinement for applications requiring good mechanical properties. In Al-Si alloys, a treatment called eutectic modification is often used to change the eutectic silicon from coarse platelike into fine fibrous morphology, which is less harmful to mechanical performance. Main shape casting processes include high-pressure die casting, lowpressure die casting, permanent mould casting and sand casting. Each process has its own strategy for filling the alloy into the mould/ die and feeding the solidification shrinkage.

INTRODUCTION

The significance of composite materials, including polymers and ceramics, has grown exponentially over the last few decades due to their diverse applications across various industries. These materials have become integral in engineering, replacing traditional metals due to their lightweight, high strength, and corrosion resistance. The use of natural fibres like abaca and coir as reinforcements in composites highlights a shift towards sustainable materials. These fibres enhance the mechanical properties of composites, making them ideal for automotive, construction, and sporting applications while reducing environmental impact. Aluminium-based composites, particularly those reinforced with materials like zirconium diboride (ZrB2), demonstrate remarkable properties suitable for high-performance applications in aerospace and automotive industries. ZrB2, an ultra-high-temperature ceramic, imparts excellent thermal and electrical conductivity, making these composites ideal for extreme conditions. Moreover, the development of innovative manufacturing techniques, including advanced casting processes, has significantly improved the cost-effectiveness and performance of these materials. The integration of traditional metals like aluminium, nickel, and magnesium with modern composites and reinforcements such as graphene and silicon further enhances the properties of engineered materials, leading to improved durability, strength, and application versatility. As research continues, the potential for composites in reducing environmental impact and advancing technology across multiple sectors becomes increasingly evident. This review underscores the importance of ongoing innovation in material processing and the development of sustainable, high-performance composites for future engineering challenges.

LITERATURE REVIEW

(1) Material Properties Data: Alumina (Aluminium Oxide) Archived 2010-04-01 at theWayback Machine.Makeitfrom.com. Retrieved on 2013-0417.Fromthis reference we have taken the Alumina is an oxide-based engineering ceramic. It can have a fairly high thermal conductivity and a moderately high heat capacity among oxide-based engineering ceramics.

(2) "Alumina (Aluminium Oxide) – The Different Types of Commercially Available Grades". The A to Z of Materials. 3 May 2002. Archived fromtheoriginal on 10 October 2007. Retrieved 27 October 2007.From this reference we have taken the Alumina (Aluminium Oxide) is the most widely used oxide ceramic material. Its applications are widespread, and include spark plugs, tap washers, abrasion resistant tiles, and cutting tools.

(3) American Elements, Aluminium Oxide, American Elements, USA, n.d., Accessed on: Oct. 28, 2019. From this reference we have taken the **Alumina**, commonly known as **aluminium oxide (Al_2O_3)**, is an inert, odourless, white amorphous material often used in industrial

ceramics. Due to its outstanding properties, alumina has contributed to a significant number of life-extending and society-enhancing applications. It is widely used in the medical field and modern warfare.

MIXING AND CASTING

In this study, ten distinct aluminum-based composite materials were developed for the fabrication of pistons using the stir casting method. The compositions include varying percentages of magnesium (Mg), graphene, and zirconium diboride (ZrB_2), systematically altering the content to investigate the influence of these reinforcements on the mechanical properties of the pistons. The use of aluminium as the base matrix was motivated by its excellent strength-to-weight ratio and widespread use in automotive and aerospace applications. Magnesium was introduced in varying proportions (1.5%, 2%, and 2.5%) to enhance the alloy's mechanical strength and hardness. Graphene, known for its exceptional mechanical properties and high thermal conductivity, was added in concentrations of 2% and 4%. The addition of ZrB_2, ranging from 2% to 6%, aimed to further improve the wear resistance, hardness, and high-temperature stability of the composite.

S.NO	COMPOSITION
1	Aluminium + 1.5% Mg + 2% Graphene + 2% ZrB2
2	Aluminium + 2% Mg + 2% Graphene + 4% ZrB2
3	Aluminium + 2% Mg + 2% Graphene + 4% ZrB2
4	Aluminium + 1.5% Mg + 4% Graphene + 4% ZrB2
5	Aluminium + 2% Mg + 4% Graphene + 6% ZrB2
6	Aluminium + 2.5% Mg + 4% Graphene + 2% ZrB2
7	Aluminium + 1.5% Mg + 6% Graphene + 6% ZrB2
8	Aluminium + 2% Mg + 6% Graphene + 2% ZrB2
9	Aluminium + 2% Mg + 6% Graphene + 4% ZrB2
10	Pure Aluminium

Table 1: Aluminium Metal Matrix Composites

Stir casting was selected as the fabrication technique due to its effectiveness in achieving uniform distribution of the reinforcement particles within the aluminium matrix. This method involves mechanical stirring of the molten aluminium to disperse the graphene and ZrB_2 particles evenly, thereby ensuring homogeneous material properties throughout the piston. The resulting composites were analysed for their mechanical performance, particularly focusing on parameters such as hardness, tensile strength, and wear resistance. The influence of the varying compositions on these properties was critically evaluated to identify the optimal material combination for high-performance pistons. The pure aluminium sample was used as a control to assess the enhancement in properties due to the introduction of Mg, graphene, and ZrB_2. The findings from this study are expected to contribute to the development of advanced piston materials that offer superior performance in demanding operational conditions.

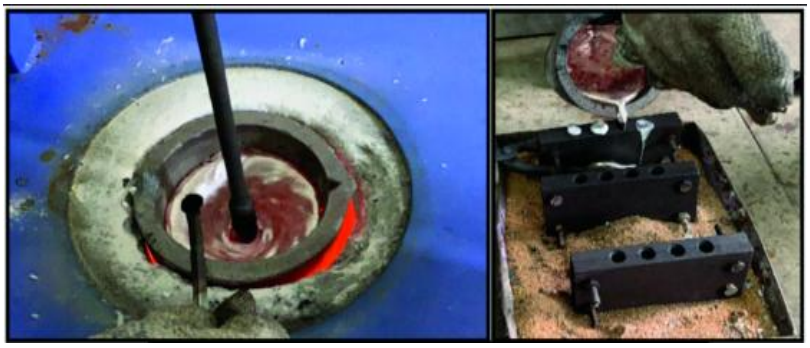

Figure 1: Image for Stir CastingProcess

EXPERIMENTAL SETUP AND EXPERIMENTATIONRESULTS

1. **Universal Testing Machine (UTM)** testing is a critical procedure in materials science and engineering used to evaluate the mechanical properties of materials, such as tensile strength, compressive strength, and shear strength. It involves applying controlled forces to materials and measuring their responses to those forces. This testing is crucial for understanding how materials behave under various loads, which is vital for designing and ensuring the safety of structures and components.

- **Preparation:** Sample preparation is critical. The sample must be of the correct dimensions and shape as per standard test specifications.
- **Mounting:** The prepared sample is mounted in the UTM's grips or fixtures. For tensile tests, the sample is typically held between two jaws that apply the pulling force.
- **Loading:** A controlled load is applied to the sample. The UTM applies forces or displacements at a constant or variable rate.
- **Measurement:** The UTM records the force applied and the corresponding deformation (elongation, compression, or shear displacement). Modern UTMs are equipped with sensors to measure these parameters precisely.
- **Data Analysis:** The data collected is used to create stress-strain curves and other graphical representations. This helps in analysing the material's properties and behaviour under load.

Figure 2: Image for UTM

	Specimen 3
Ultimate Load (KN)	42.460
Elongation %	2.12
Maximum Tensile Strength (MPa)	201.3
Specimen Diameter (mm)	12.2
Initial Diameter (mm)	50
Final Diameter(mm)	51.7
Load at Peak	27.1

Table 2: Resulted values of Tensile Test for specimen 3

Input Data	Results
Specimen Type : Round Initial Diameter (mm) : 12 Final Diameter (mm) : 14.6 Original Gauge Length (mm) : 50 Final Gauge Length (mm) : 45.9	Ultimate Load (KN) : 91.23 Compressive Strength (N/mm) : 595.65

Table 3: Resulted values of Compression Test for specimen 3

2. **Hardness testing** is a method used to determine the resistance of a material to deformation, particularly permanent deformation, indentation, or scratching. It is a key property in materials science and engineering, providing insights into a material's durability, wear resistance, and mechanical performance.

- **Material Selection:** Helps in choosing the right material for specific applications based on hardness requirements.
- **Quality Control:** Ensures that materials and products meet specified hardness standards and quality criteria.
- **Performance Evaluation:** Assesses wear resistance and durability of materials under various conditions
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Figure 3: Image for Hardness Testing Machine

Aluminium + 1.5% Mg + 2% Graphene + 2% ZrB_2	58	58.5	59	Average: 58.5
Aluminium + 2% Mg + 2% Graphene + 4% ZrB_2	61	60	61	Average: 60.6
Aluminium + 2.5% Mg + 2% Graphene + 4% ZrB_2	63	62.5	63	Average: 62.8
Aluminium + 1.5% Mg + 4% Graphene + 4% ZrB_2	60	61	60	Average: 60.3
Aluminium + 2% Mg + 4% Graphene + 6% ZrB_2	65	65	65.5	Average: 65.1
Aluminium + 2.5% Mg + 4% Graphene + 2% ZrB_2	61	59.5	61	Average: 60.5
Aluminium + 1.5% Mg + 6% Graphene + 6% ZrB_2	60	60	60.5	Average: 60.1
Aluminium + 2% Mg + 6% Graphene + 2% ZrB_2	65.5	65	66	Average: 65.5
Aluminium + 2% Mg + 6% Graphene + 4% ZrB_2	66.6	66.4	66.8	Average: 66.6
Pure Aluminium	59	57.5	58	Average: 58.1

Table 4: Resulted values of Hardness Test

3. **Impact testing** is a type of mechanical test used to evaluate the ability of a material to withstand sudden forces or impacts. This test measures the material's toughness, which is its ability to absorb energy and deform plastically before breaking. It is crucial in assessing the material's performance in real-world conditions where impacts and shocks are likely.

- **Material Toughness:** Determines how well a material can absorb and dissipate energy, which is critical for applications involving dynamic loads or impact.
- **Fracture Toughness:** Helps in evaluating the material's resistance to crack propagation under impact loading.
- **Design Considerations:** Provides insights for designing structures and components to ensure they can withstand sudden impacts and shocks.
- **Quality Control:** Ensures that materials meet the required standards and specifications for impact resistance.

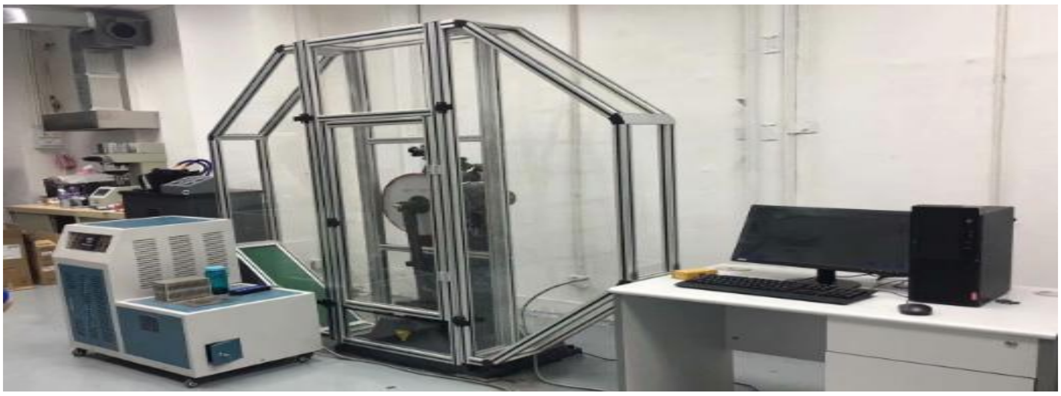

Figure 4: Image for Impact Testing Machine

SAMPLE	IMPACT 1	IMPACT 2	AVERAGE
Aluminium + 1.5% Mg + 2% Graphene + 2% ZrB_2	22	0	22
Aluminium + 2% Mg + 2% Graphene + 4% ZrB_2	21.5	0	21.5
Aluminium + 2.5% Mg + 2% Graphene + 4% ZrB_2	24	0	24
Aluminium + 1.5% Mg + 4% Graphene + 4% ZrB_2	20	0	20
Aluminium + 2% Mg + 4% Graphene + 6% ZrB_2	24	0	24
Aluminium + 2.5% Mg + 4% Graphene + 2% ZrB_2	22	0	22
Aluminium + 1.5% Mg + 6% Graphene + 6% ZrB_2	21	0	21
Aluminium + 2% Mg + 6% Graphene + 2% ZrB_2	20	0	20
Aluminium + 2% Mg + 6% Graphene + 4% ZrB_2	22.5	0	22.5
Pure Aluminium	21	0	21

Table 5: Resulted values of Impact Test

CONCLUSION

The results indicate that the optimal combination for enhancing both hardness and impact strength was found in the composition with 2% Mg, 4% graphene, and 6% ZrB_2. This composite exhibited a balanced improvement in both hardness and impact resistance, making it a promising candidate for piston applications that demand a combination of strength and toughness.the study demonstrates the potential of these novel aluminium composites in improving the mechanical properties of pistons, with specific compositions offering significant advantages. Further research could focus on optimizing the processing parameters and exploring the microstructural characteristics that contribute to the observed mechanical behaviour.By adding the amount of Graphene the Maximum Tensile Strength, Elongation of the shaft increased. Remaining measurements are differs by the amount of ZrB2 for tensile test. By adding the Percentage of Graphene the Final Diameter is going to be increased.By maintaining the Constant percentage of Graphene and Increasing the Percentage of ZrB2 will leads to increase the compressive strength of the shaft material.

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