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Comprehensive Investigation of Aluminium Matrix Composites

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Abstract

Aluminium Matrix Composites (AMCs) have gained significant attention due to their excellent combination of lightweight properties, high strength, and superior wear resistance. This study focuses on the development and characterization of Aluminium 7075-T6 reinforced with Silicon Carbide (SiC) particles, fabricated using the stir casting method. The research evaluates key mechanical properties such as tensile strength, hardness, and impact resistance, along with wear performance. Experimental results demonstrate substantial enhancements in mechanical and wear properties compared to conventional aluminium alloys. The findings highlight the potential of AMCs for high-performance applications in the automotive and aerospace sectors, where weight reduction and improved durability are critical.

Introduction

Aluminium matrix composites (AMCs) are a class of advanced materials that combine the lightweight nature of aluminium with the superior mechanical properties imparted by reinforcements such as ceramics, carbides, and oxides. The increasing demand for innovative materials in the automotive and aerospace industries has led to extensive research into AMCs, particularly those reinforced with Silicon Carbide (SiC), Titanium Carbide (TiC), and Aluminium Oxide (Al_2O_3). These reinforcements enhance strength, wear resistance, and thermal stability, making AMCs ideal for structural and functional applications in high-stress environments.

Among aluminium alloys, the 7-series (Al 7075-T6) is known for its high strength-to-weight ratio and fatigue resistance. The addition of SiC as a reinforcement further enhances these properties, making the composite suitable for demanding applications such as engine components, braking systems, and aerospace structures.

Types and Classifications of Aluminium Matrix Composites

Aluminium matrix composites can be classified based on the type of reinforcement used. Particle-reinforced composites utilize materials like SiC, TiC, and Al_2O_3, offering isotropic properties and good wear resistance. Fiber-reinforced composites use reinforcements such as carbon fibers and glass fibers, which provide high tensile strength and directional properties. Whisker-reinforced composites, with reinforcements like SiC whiskers, exhibit excellent toughness and strength. Current trends in AMCs include the incorporation of nano-reinforcements for enhanced mechanical properties, the development of hybrid composites combining multiple reinforcements, the use of sustainable and eco-friendly fabrication methods, and the optimization of composites through simulation and computational modelling.

Comparison of Aluminium 6 Series and 7 Series

Aluminium 6 series alloys, such as 6061, offer moderate strength, excellent corrosion resistance, and good machinability at a lower cost, making them suitable for structural components. In contrast, Aluminium 7 series alloys, such as 7075, provide high strength and good machinability but exhibit moderate corrosion resistance and higher costs. Aluminium 7075-T6, with its superior mechanical properties, is chosen as the matrix material for this study due to its mechanical, thermal and wear properties which is critical for automotive applications.

Table -1: Comparison of Aluminium 6 vs 7 series

Property	7 Series Aluminium Alloy	6 Series Aluminium Alloy
Ultimate Tensile Strength	572 MPa	398 MPa
Yield strength	503 MPa	276 MPa
Thermal Conductivity	130 W/mK	167 W/mk
Hardness (Brinell)	150 kg/mm^2	95 kg/mm^2

The Aluminium 7-series material was procured from aluminium manufacturers and subjected to chemical composition testing at Omega Testing Laboratory, Chennai to ensure compliance with required specifications. The testing followed the ASTM B221 standard, which defines the requirements for aluminum and aluminum-alloy extruded products, including bars, rods, wires, profiles, and tubes. This standard specifies the chemical composition requirements, along with guidelines for dimensions, tolerances, and heat treatment processes, ensuring the material's quality and suitability for high-strength applications. The specifications and observed values of tested specimen are tabulated.

Table -2: Chemical composition of tested specimen

Element	Composition range in %	Observed values in %
Zinc	5.10 - 6.10	6.042
Magnesium	2.10 - 2.90	2.429
Copper	1.20 - 2.00	1.721
Iron	< 0.50	0.144
Chromium	0.18 - 0.28	0.208
Silicon	< 0.40	0.150
Manganese	< 0.30	0.099
Titanium	< 0.20	0.025

Comparison of Reinforcements

Different reinforcements provide unique properties to AMCs, making them suitable for various applications. Silicon Carbide (SiC) offers high hardness, wear resistance, and thermal stability, making it ideal for automotive applications. Aluminium Oxide (Al_2O_3) provides high corrosion resistance and thermal stability, making it suitable for structural parts and heat exchangers. Titanium Carbide (TiC) delivers excellent strength and moderate density, making it valuable for cutting tools and aerospace parts. Boron Carbide (B_4C), with its extreme hardness and lightweight properties, is used in armor plating and brake pads.

Fabrication of Aluminium Matrix Composite Using Stir Casting

The fabrication process begins with the preparation of materials. Aluminium 7075-T6 is chosen for its superior mechanical properties, while Silicon Carbide (SiC) powder of 180 grit size is selected for its high surface area and excellent wear resistance. The Aluminium 7075-T6 billets are cleaned using isopropyl alcohol and a soft brush to remove contaminants. These billets are then preheated to 600°C for a few minutes to eliminate moisture and reduce thermal shock during melting. Similarly, the SiC powder is preheated to 200–300°C for a few minutes to improve its wettability.

The melting process involves transferring the preheated aluminium billets to a crucible and heating it in a furnace to 850°C. The temperature is maintained for 60–65 minutes to ensure the aluminium reaches a fully molten state. The preheated SiC powder is gradually added to the molten aluminium. Using a mechanical stirrer, the mixture is stirred at 450 rpm for 5–10 minutes to achieve uniform dispersion of SiC particles. Constant stirring speed and temperature are maintained to ensure homogeneity.

The molten composite is then poured into a preheated cast iron die, where it is allowed to cool and solidify under ambient conditions. This stir casting method offers a cost-effective and efficient way to fabricate high-quality AMCs with uniform reinforcement distribution.

Fig -1: Stir casting process

Mechanical test

After the casting process, the specimen was allowed to cool to room temperature before being subjected to mechanical testing. Machining was performed in accordance with ASTM E8/E8M-22 standards at a certified testing laboratory. The mechanical tests were conducted using a Universal Testing Machine (UTM) under controlled conditions at a room temperature of 27°C, and the obtained results are presented in the following table.

Table -3: Mechanical properties

Property	Inferred values
Tensile Strength in Mpa	224.55
Yield Stress in Mpa	110.45
Elongation in GL of 50 mm	4.44 %
Compression load in KN	185
Impact values in Joules	2
Hardness in HV @1 Kg load	153,155,152

Fig -1: Impact specimen

Fig-2: Hardness specimen

Fig -3: Compression specimen

Fig -4: Tensile Specimen

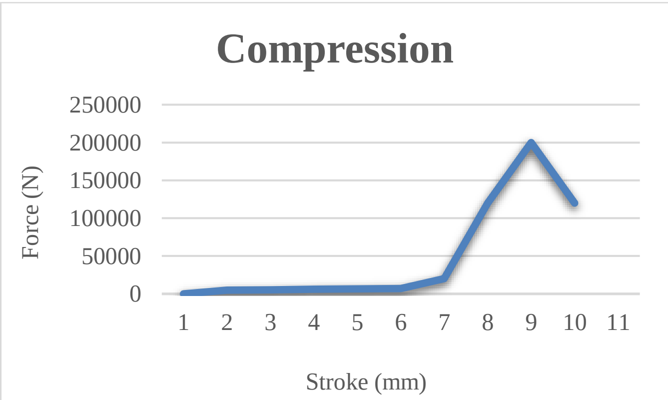

Fig -5: Compression test data

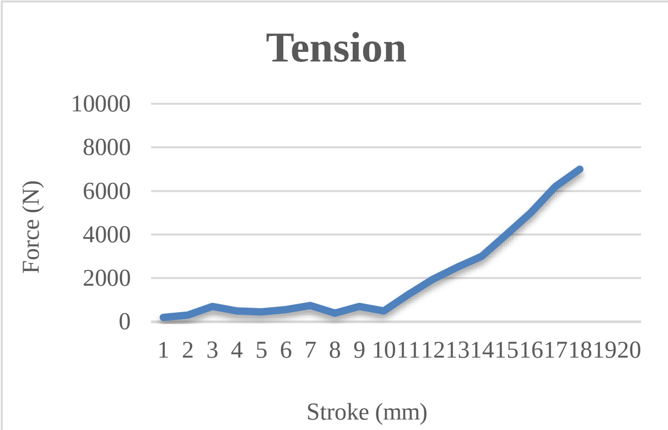

Fig -6: Tensile test data

Wear test

The wear test was conducted using a cylindrical specimen with a diameter of 15 mm and a length of 500 mm. The test was performed on a coarser abrasive sheet of 60-grade, with an equivalent revolution count of 84 cycles. The specimen was subjected to a rotational frequency of 40 ± 1 rpm under a 1 kg load. Based on these input parameters, the wear test results have been compiled in the following table.

Table -4: Wear test results

Initial weight (g)	Final weight (g)	Abrassion loss (g)	Percentage
6.3239	6.2811	0.0428	0.68

Conclusion

This study comprehensively investigated the mechanical and wear properties of Aluminium 7075-T6 reinforced with Silicon Carbide (SiC), fabricated using the stir casting method. The result demonstrate that the composite exhibits significant improvements in tensile strength, hardness, and wear resistance compared to conventional aluminium alloys. These enhanced properties make it a viable material for high-performance automotive applications, particularly in components requiring superior strength-to-weight ratio, wear resistance, and thermal stability. The wear test results indicate minimal material loss, validating the composite's durability under abrasive conditions. The mechanical tests further confirm its suitability for structural and load-bearing applications. The findings highlight the potential of Aluminium Matrix Composites (AMCs) in advancing lightweight and efficient automotive designs.

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