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Experimental Investigation of Fabricated SiC Reinforced Aluminium (4032) Based Metal Matrix Composite

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Abstract: ***Aluminium 4032 alloy is widely used in engineering sectors owing to its low density, machinability, and high thermal conductivity. However, its mechanical and tribological limitations restrict its application under high wear and load-bearing conditions. Metal matrix composites (MMCs) reinforced with ceramic particulates have emerged as a promising solution to enhance the mechanical properties of engineering alloys. In the present work, Silicon Carbide (SiC) was used as reinforcement material in Aluminium 4032 alloy, with weight fractions ranging between 6 wt.% and 26 wt.% to evaluate its influence on mechanical, physical, and tribological behaviour. Stir casting was adopted as a cost-effective manufacturing method due to its simplicity, scalability, and suitability for particulate reinforcement. Magnesium was added as a wetting agent to improve matrix-particle interfacial bonding. The fabricated composites were analyzed for density, porosity, hardness, tensile strength, wear resistance, and microstructural characteristics. Results confirmed that mechanical and wear properties improved significantly with reinforcement, showing peak performance at 21 wt.% SiC. Beyond this percentage, clustering and formation of brittle phases reduced ductility and strength. The study concludes that 21 wt.% SiC reinforced Aluminium 4032 MMC provides an optimal balance of performance and cost, making it suitable for automotive and wear-intensive industrial applications.***

Keywords: MMC, Stir Casting, Aluminium 4032, Silicon Carbide, Wear, Hardness, Mechanical Properties

1. Introduction

The rapid growth of aerospace, automotive, and defense industries has increased the demand for lightweight, high-strength, and wear-resistant materials. Conventional monolithic metals such as aluminium alloys exhibit desirable density and machinability but suffer from inferior hardness, limited wear resistance, and moderate strength under severe operating conditions. To overcome these limitations, reinforcement of metallic materials with ceramic phases has emerged as a viable approach, resulting in Metal Matrix Composites (MMCs).

Aluminium 4032, categorized as a hypereutectic alloy due to its silicon-rich chemical composition, is commonly used in piston manufacturing, engine cylinders, compressors, and high-temperature precision components. Its superior thermal stability and fatigue resistance make it ideal for dynamic load applications. However, the alloy lacks sufficient surface hardness and abrasion resistance under dry sliding and abrasive wear conditions.

Silicon Carbide is a hard ceramic particle known for excellent hardness, thermal stability, low density, and chemical inertness. When added to aluminium matrix, SiC particles act as load-bearing constituents, reduce material removal, improve wear resistance, and restrict plastic deformation. Furthermore, mechanisms such as grain refinement, thermal mismatch strengthening, and Orowan strengthening promote improved mechanical strength.

Stir casting is one of the most economical and commercially adopted methods for fabricating particulate MMCs. It enables uniform distribution of reinforcements if processed correctly and allows direct scaling to industrial production. However, particle agglomeration, weak wettability, and interfacial porosity remain challenges. The addition of magnesium reduces surface tension, improves wetting, and enhances bonding between SiC and aluminium matrix.

This research addresses the limited literature available on Aluminium 4032 based MMCs compared to extensively studied aluminium 6061, 7075, and A356 systems.

2. Literature Review

Alpas and Zhang (1992) reported that the reinforcement of ceramic particles within aluminium matrices significantly improves wear resistance due to their ability to bear load and prevent surface deformation. Ravikiran and Surappa (1997) observed that increasing reinforcement reduced wear, particularly at higher sliding speeds, as a mechanically mixed tribofilm forms between the mating surfaces.

Singh et al. (2002) investigated abrasive wear mechanisms in aluminium composites and attributed improvements to the presence of hard particles that oppose penetration of abrasive ridges. Krishna and Xavior (2014) demonstrated that mechanical properties improve progressively until an optimum reinforcement level is reached, beyond which clustering reduces ductility.

Rahman et al. (2014) conducted tensile testing of Al-SiC composites and confirmed that reinforcement results in dislocation generation due to mismatch in thermal expansion coefficients. This increases strain hardening but reduces elongation. Similar observations were made by Singh & Garg (2015), where excessive ceramic loading induced brittle fracture.

Despite extensive research on Aluminium 6061 and 7075 composites, limited studies exist on 4032-based MMCs. The presence of high silicon content results in different solidification behaviour, particle interactions, and carbide formation trends.

3. Materials and Methods

3.1 Materials Used

- **Matrix material:** Aluminium 4032 alloy
- **Reinforcement:** Silicon Carbide powder (50–80 µm mesh)
- **Wetting agent:** Magnesium (1 wt.%)
- **Reinforcement levels:** 0%, 6%, 11%, 16%, 21%, 26 wt.% SiC

3.2 Casting Procedure

The Aluminium 4032 alloy was melted in a graphite crucible at 760 °C using an electric resistance furnace. SiC reinforcement was preheated to 300 °C to eliminate moisture. A mechanical stirrer running at 270 rpm generated a vortex, and particles were gradually introduced to avoid flotation. The molten composite was poured into preheated permanent moulds.

3.3 Sample Preparation

Specimens for tensile testing, hardness, density, and wear tests were prepared as per ASTM standard dimensions and machining tolerances.

3.4 Testing Standards

Test	Standard
Tensile Strength	ASTM E8
Hardness	Rockwell B
Wear (pin-on-disc)	ASTM G99
Abrasion	ASTM G65
Density	Archimedes method

4. Results and Discussion

4.1 Tensile Strength

Tensile strength increased from 95 MPa for base alloy to 185 MPa at 21 wt.% SiC. This improvement is attributed to load-sharing and restricted matrix deformation. Beyond 21 wt.%, brittleness increased due to clustering.

4.2 Hardness

Surface hardness increased steadily with reinforcement due to the presence of ceramic particles. Hardness improved from 42 HRB (unreinforced) to 66 HRB (26 wt.% SiC).

4.3 Density and Porosity

Theoretical and experimental densities remained close. Porosity increased slightly with reinforcement due to gas entrapment and solidification shrinkage.

4.4 Wear Resistance

Wear resistance improved significantly with reinforcement as SiC particles acted as barriers against plastic flow and asperity penetration. Minimum wear occurred at 21 wt.% SiC reinforcement.

4.5 Ductility

Elongation values reduced gradually as brittle particle addition hindered uniform plastic deformation. Fractography studies in literature confirm similar patterns.

5. Conclusion

- SiC reinforced Aluminium 4032 MMCs were successfully fabricated using stir casting.
- Mechanical, tribological, and physical properties improved continuously up to 21 wt.% reinforcement.
- Beyond optimum loading, particle clustering and formation of brittle Al_4C_3 phases reduced toughness.
- The MMC developed is suitable for applications that require high wear resistance, such as engine components and sliding assemblies.

6. Future Scope

- Heat treatment optimization for further strength improvement
- Nano-SiC reinforcement for grain refinement
- Hybrid MMCs such as SiC + graphite for self-lubrication
- Corrosion and fatigue studies under cyclic loading
- Squeeze or ultrasonic casting to reduce porosity

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