International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 12 | Dec - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Effect of Silicon Carbide and Titanium Diboride on the Mechanical Properties of Al6061 Hybrid Metal Matrix Composites

Raju M G[1], Prajwal Sandyal[1], Divya N C[1], Rijo Nelson[2], Ayush Satheesh[3], Rohan K N[4], Vedant Naik[5]

[1]Assistant Professor, Dept. of ME, Acharya Institute of Technology, Bengaluru, Karnataka, India

[2-5]Student, Dept. of ME, Acharya Institute of Technology, Bengaluru, Karnataka, India

Affiliations:

Department of Mechanical Engineering, Acharya Institute of Technology, Bengaluru, India rajumg@acharya.ac.in

Abstract

Metal Matrix Composites (MMCs) have emerged as one of the most promising classes of advanced engineering materials due to their superior mechanical, thermal, and tribological characteristics when compared with conventional monolithic metals.

Among various metal matrices, Aluminium 6061 (Al6061) has gained significant attention because of its excellent balance of mechanical strength, corrosion resistance, weldability, and relatively low density. These features make Al6061 a potential candidate for lightweight structural applications. However, its monolithic version lacks the required properties in structural applications involving high wear resistance, stiffness, and thermal stability. In such scenarios, the incorporation of reinforcement through ceramics has become one of the most evaluated approaches in materials engineering. TiB_2 and SiC are among the most efficient reinforcements used to develop advanced performance-based aluminum hybrid composites. TiB_2 has very high hardness and a high melting point, along with excellent thermal stability, which significantly improves the wear resistance and dimensional stability of the composites at elevated temperatures.

1. Introduction

This work investigates the mechanical behaviour of Al6061-based hybrid metal matrix composites reinforced with silicon carbide (SiC) and titanium diboride (TiB_2). Aluminium alloys are widely used in automotive, aerospace, and structural applications due to their low density and desirable mechanical properties. However, increasing demands for higher strength, improved wear resistance, and higher overall performance have motivated research into the development of aluminium metal matrix composites (AMMCs). The addition of ceramic particles, such as SiC and TiB_2, to aluminium matrices has been found to enhance their mechanical properties. Hybrid MMCs, characterized by the presence of more than one reinforcement phase, may exhibit better properties than singly reinforced composites. Therefore, this paper reviews the available literature on how SiC and TiB_2 reinforce the mechanical properties of Al6061 hybrid composites.

Composite materials are developed by using combinations of two or more completely different substances with unique physical or chemical properties. These are combined in such a manner that the resulting performance is better than when the respective materials act alone. In most cases, a matrix or base material binds the constituents together, while the additive phase enhances toughness, stiffness, thermal resistance, or durability. Even though the components remain as individual entities in the composite, they cooperate together to achieve superior overall performance. Because of their high strength-to-weight ratio, improved properties, and abilities to be tailored to meet particular needs, these materials find broad applications in aerospace, automotive, marine, construction, and medical devices.

2. Materials and Methods

2.1 Matrix Material

Aluminium alloy 6061 is used as the base material because it offers a good balance of low weight, adequate strength, corrosion resistance, and ease of fabrication, making it suitable for composite development.

Figure 1: Aluminium Ingots

2.2 Reinforcement Materials

Silicon carbide (SiC) is chosen as the primary reinforcement owing to its high hardness and wear resistance, which help in improving the strength and stiffness of the aluminium matrix.

Figure 2: Silicon Carbide (SiC)

Titanium diboride (TiB_2) is added as a secondary reinforcement due to its excellent thermal stability, very high hardness, and strong bonding ability with aluminium, leading to enhanced hardness and microstructural refinement.

Figure 3: Titanium diboride (TiB_2)

2.3 Fabrication methods

The hybrid composite Al6061–SiC–TiB_2 is processed based on the principle of reinforcement of the aluminium matrix by the homogeneous dispersion of hard ceramic particles. The stir casting process involves the addition of preheated silicon carbide and titanium diboride to molten Al6061 with subsequent mechanical stirring for proper distribution and interfacial bonding. After solidification, the hard reinforcement phases share part of the applied load, hinder the dislocation movement, and refine the microstructure of the resultant. As a result, the composite shows improved tensile strength, hardness value, and overall mechanical properties compared to the unreinforced aluminium.

2.4 Stir Casting Process

Stir casting is an economical method for the preparation of aluminum-based composites. In this process, Al6061 is melted in a furnace, and preheated SiC and TiB_2 particles are added gradually under continuous stirring to facilitate uniform dispersion. The mechanical stirring creates a vortex that favorably affects particle distribution and interfac9 bonding with molten aluminum. The slurry produced was then poured into a mold and allowed to solidify. This gave a hybrid composite with improved mechanical properties.

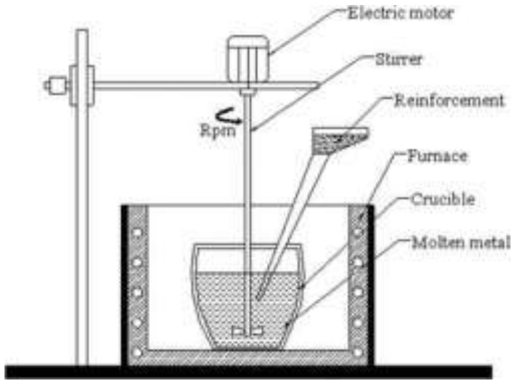

Figure 4: Stir Casting Process

3. Experiments

3.1 Hardness Test

The hardness test was performed to determine the resistance of the composite material to indentation on its surface. Specimens were prepared by grinding and polishing before testing, and hardness was measured with the Brinell hardness testing apparatus. The addition of hard SiC and TiB_2 particles results in an increased resistance to deformation, hence giving higher hardness compared to the base aluminum alloy.

3.2 Tensile Test

Uniaxial tensile tests are carried out to investigate the strength and deformation response of the composites. The properties measured include ultimate tensile strength, yield strength, and elongation. The enhanced tensile properties are attributed to efficient load transfer from the aluminum matrix to the ceramic reinforcements.

3.3 Optical Microscopy Test

The microstructure of the composite material is characterized by optical microscopy. Samples are sectioned, polished, and etched to reveal grain boundary and particle distribution. This analysis allows for the assessment of the homogeneous distribution of SiC and TiB_2 particles, grain refinement, and the quality of interfacial bonding within the aluminum matrix.

4. Results and Discussion

4.1 Hardness Test

Sample No.	Brinell Hardness (BHN)
S1	78.6
S2	83.0
S3	84.9
S4	86.8
S5	89.4

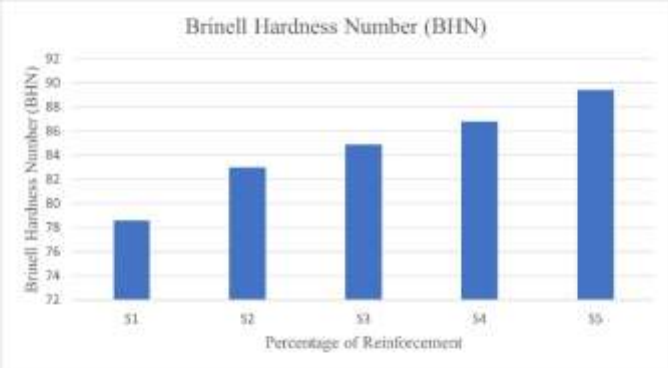

Figure 5: Variation of Brinell Hardness with increase in reinforcement

4.2 Tensile Test

Sample No.	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (mm)
S1	121.484	83.044	13.330
S2	137.274	97.879	15.140
S3	143.736	105.712	11.190
S4	156.839	118.681	15.880
S5	140.023	102.372	10.760

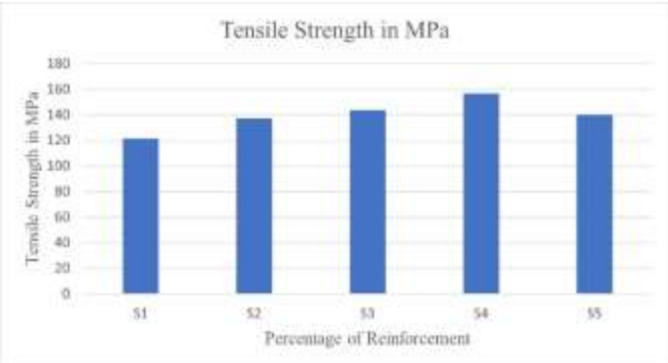

Figure 6: Variation of Tensile Strength with increase in reinforcement

The tensile strength of Al6061 reinforced with SiC and TiB_2 demonstrates progressive improvement from Sample S1 to Sample S4. This reflects an increasingly good ability of the material to bear the load, due to better reinforcement distribution and strong matrix–particle bonding. Maximum tensile strength exhibited in S4 suggests optimization in processing conditions and reinforcement efficiency. The slight drop in S5 can be ascribed to factors such as particle agglomeration, micro-porosity, or increased reinforcement content. All the results in summary justify that controlled addition of SiC and TiB_2 significantly enhances the tensile property of Al6061 composites. The yield strength values indicate a clear increase from Sample S1 to Sample S4, indicating that SiC and TiB_2 act as reinforcements within the Al6061 matrix. This is related to an improvement in the load transfer, grain refinement, and impeded dislocation motion.

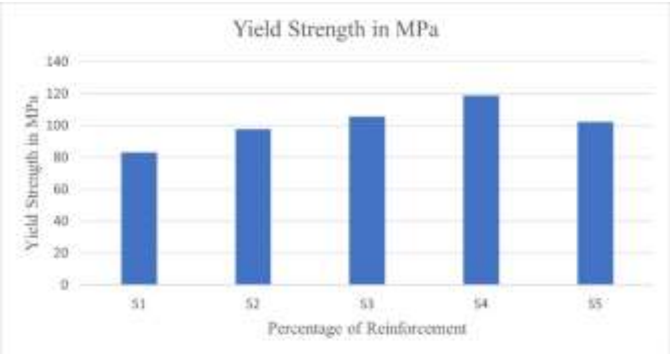

Figure 7: Variation of Yield Strength with increase in reinforcement

4.3 Microstructure Results

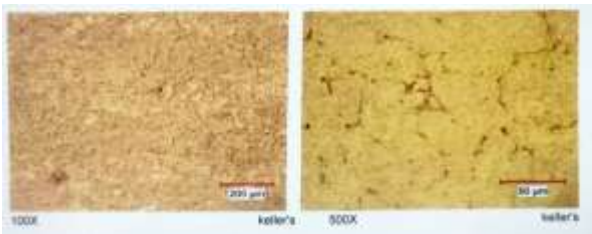

Figure 8: Microstructure of 100%Al6061+0%SiC+0% TiB_2

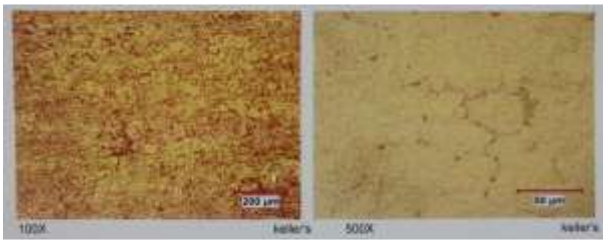

Figure 9: Microstructure of 92%Al6061+3%SiC+5% TiB_2

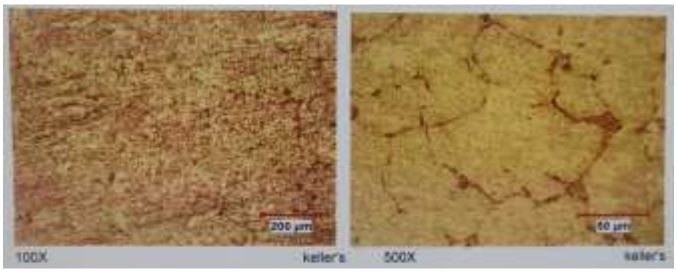

Figure 10: Microstructure of 90%Al6061+5%SiC+5% TiB_2

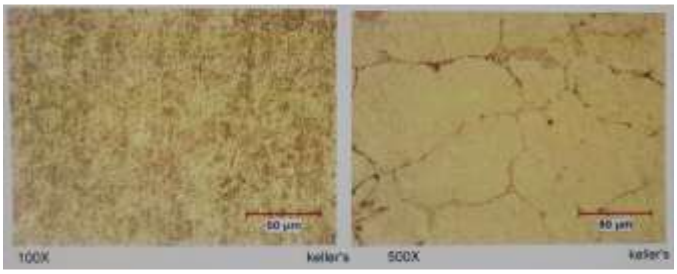

Figure 11: Microstructure of 88%Al6061+7%SiC+5% TiB_2

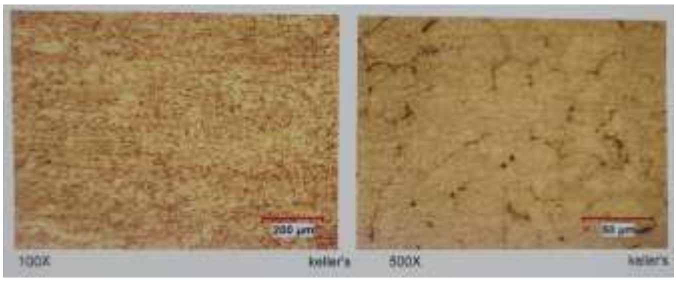

Figure 12: Microstructure of 86%Al6061+9%SiC+5% TiB_2

The obtained optical micrographs show a fairly uniform aluminium matrix with well-dispersed reinforcing particles in the Al6061-SiC-TiB_2 composite. In the high-magnification images, SiC and TiB_2 particles are clearly incorporated into the matrix, which expresses good interfacial bonding. The addition of TiB_2 favors grain refinement of the aluminium matrix. Minimal porosity is seen, most probably due to casting processes; however, no severe agglomeration has occurred. The overall microstructural examination justifies the improvement in mechanical properties of the composites.

The micrographs of Al6061 with SiC and TiB_2 reinforcement have an essentially uniform aluminium matrix with a fine dispersion of the reinforcement particles. From the microstructures at 100× magnification, it can be seen that the reinforcements are relatively well distributed without any marked agglomeration, which suggests good mixing during fabrication. In the 500× image, fairly refined aluminium grains are displayed with SiC and TiB_2 particles bonded well at grain boundaries and within the matrix. Minimal porosity and slight grain boundary networks can be seen in the image, as is common in stir-cast composites. All in all, the microstructure shows good interfacial bonding and grain refinement; hence, this improves the mechanical properties.

5. Conclusion

This study shows that reinforcing Al6061 with silicon carbide and titanium diboride improves its mechanical properties.

- Stir casting produced a reasonably uniform distribution of particles with good bonding.
- The composite exhibited higher hardness and tensile strength than the base alloy.
- Optical microscopy confirmed grain refinement and proper reinforcement dispersion.
- These results indicate that Al6061-SiC-TiB_2 hybrid composites are suitable for lightweight and high-performance engineering applications.

Acknowledgments

I would like to extend my profound appreciation to my supervisor and the department faculty for the guidance and continued support that enabled me to undertake this project. I am also grateful to my institution and to all those who, directly or indirectly, helped in the successful completion of this work.

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