Comparative Study on Mechanical Properties of SiC/Gr & Al₂O₃/Gr reinforced AL6061 hybrid metal matrix composites

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Abstract. Silicon carbide / Graphite and Alumina / Graphite reinforced AL6061 Hybrid metal matrix composites are fabricated by stir casting (liquid metallurgy) route. Four samples A,B,C,D with varying proportions in both matrix and reinforcements by fixing graphite proportion (5%) constant for all sampled are prepared. Mechanical properties of all the samples are compared with matrix material (AL6061). Scanning electron microscope is used to examine the microstructural characteristics of the composite samples. Mechanical test results exhibit 3.5% (sample C) increase in the hardness number than the base matrix. But, yield and ultimate tensile strength are reduced with all the reinforcements. Microstructural characterisation clearly depicts the presence of cracks, Agglomeration of reinforcements, cast defects on the surface of prepared composites which leads to poor yield and ultimate tensile strength.

Key words: AL6061 Hybrid metal matrix composites, Alumina, Graphite, Silicon Carbide, Stir Casting.

1. Introduction
In recent times, the engineering world is in requisites of newer materials to meet their demands. Such newer materials are also called as composite materials, their usage in military, automobile, aviation, defence sectors, keeps on increasing owing to their less weight, high thermal resistance, high strength to weight ratio, wear resistance, high hardness, and stiffness when compared to conventional engineering materials. In this way it is witnessed that hybrid metal matrix composites have overcome the limitations of other composite materials from recent researches. A hybrid metal matrix composites consist of a minimum of two distinct phases for reinforcement with the matrix phase. Aluminium based hybrid metal matrix composites find way in recent times to replace older materials. Researchers fabricated different grades of aluminium (AL6061, AL7075, AA6351, AL6082, AL2024) based hybrid MMCs with ceramic reinforcements like Alumina (Al₂O₃), Silicon Carbide (SiC), Titanium Boride (TiB₂), Titanium Oxide (TiO₂), Boron Carbide (B₄C), etc. These reinforcements enhance the mechanical properties of composites to meet industrial demands. B Jayendra, D Sumanth, G Dinesh, Dr. M Venkateswara Rao had observed that reinforcement of B₄C and Graphite in AL7075 enhanced the hardness, impact, and tensile strength of the composites considerably [1]. M Satheesh, M Pugazhavadi found 8% reinforcement of...
coconut shell ash (CSA) in AL6061-Sic matrix phase has increased the hardness and tensile strength by 46% & 47.31% when compared to 10% CSA mixed sample [2]. V.Jaya Prasad, K.Narasimha Rao, N.Kishore Babu R reinforced ceramics (TiB2/SiC) and observed the addition of ceramics in aluminium increases the mechanical properties of the composites [3]. Abhishek Sharma, Vyas mani sharma, Jinu paul has found reinforcement of graphene and carbon nanotubes (CNT) in AL6061-SiC matrix increases the nano hardness of composites by 27% and microhardness values by 36% than alone AL6061 [4]. V. Anirudh, M.Vigneshwaran, E.Vijay, R.Pramod, GB Veeresh Kumar studied the TiB2 and graphite-reinforced AL6061 alloy and concluded increasing the proportion of reinforcements increases the hardness and UTS of composites than alone AL6061 [5]. V.Mohanavel, K.Rajan, P.V.Senthil, S.Arul in another study informed after the dispersion of Al2O3 and Graphite in AA6351 alloy increased the mechanical properties of composites than pure AA6351 [6]. B.Ramgopal Reddy, C.Srinivas has studied the reinforcement of SiC and fly ash in AL6082 matrix as a base and found a considerable enhancement in UTS, Hardness, and wear resistance in the composites [7]. Cheng-jin Hu, Hong-ge YAN, Ji-hva CHEN Bin SU reinforced Graphite and SiC in AL2024 matrix and concluded tensile strength and elongation of composites were reduced with reinforcements [8, 9]. From this literature survey it was observed that aluminium based hybrid metal matrix composites are prepared by various processes such as Squeeze casting, Vacuum hot pressing, Friction stir processing, Stir casting, and Powder metallurgy. Among the above methods stir casting is mostly preferred owing to some advantages over other methods, one of the important phenomena where stir casting stands prior to other methods is the preparation of a wide range of shapes with larger sizes is possible and this process is economically suited. There is a lack of research concentration in AL6061 based hybrid metal matrix composites. So, this work is aimed to fabricate a hybrid metal matrix composite of AL6061 reinforced with SiC/Al2O3 (varying proportions) with constant proportion (5%) of Graphite using stir casting process and to compare their mechanical properties with the base matrix (AL6061).

2. Methodology

2.1. Material Selection
AL6061 was chosen as matrix material because of its cast ability and being utilized in wide range of applications such as in aircraft wings, fuselages etc., table 1 and table 2 shows the chemical composition and mechanical properties of AL6061.

| Component | Wt % |
|-----------|------|
| Mg        | 0.9  |
| Si        | 0.62 |
| Fe        | 0.33 |
| Cu        | 0.28 |
| Cr        | 0.17 |
| Mn        | 0.06 |
| Zn        | 0.02 |
| Ti        | 0.02 |
| Al        | 97.6 |
SiC was chosen as one of the reinforcements during fabrication of composites. Silicon in SiC enhances the fluidity property of AL6061 during casting, meanwhile SiC possessing capacity to withstand in high temperatures with melting point of 2830°C. Owing to its high hardness and strength, Al2O3 was chosen as other reinforcement. Due to its high thermal resistance capability, graphite was chosen as reinforcement with a constant proportion in all samples.

2.2. Stir Casting
AL6061 aluminium hybrid metal matrix composite samples A, B, C, D were prepared by stir casting process (under argon atmosphere) by adding SiC/Graphite and Al2O3/Graphite with varying proportions as shown in table 3. Stir casting has been selected for fabrication of composites as the reinforcements having uniform distribution in the matrix phase in this process. Al6061(CP) was taken in form of ingots and melted in the graphite crucible (750°C) and then followed by mixing SiC with stirring speed 350 rpm for 15 minutes and graphite is mixed to the molten mixture to prepare samples A&B. Then above procedure is followed by replacing SiC with Al2O3 to prepare samples C&D respectively. SiC and Al2O3 were used in the form of powders with 20µm particle size. Mechanical type stirrer is used in the stir casting setup. Stir casting setup and work flow chart is shown in the figures 1 and 2 as a pictorial illustration. Molten mixture was poured into the die to get circular specimen of 225mm length and 20mm diameter.

Table 3. Proportion of Reinforcements (in %)

| Sample | Al 6061 | Sic | Al2O3 | Graphite |
|--------|---------|-----|-------|----------|
| A      | 85      | 10  | -     | 5        |
| B      | 80      | 15  | -     | 5        |
| C      | 85      | -   | 10    | 5        |
| D      | 80      | -   | 15    | 5        |

Figure 1. Stir Casting Setup
3. Results and Discussion

3.1. Hardness test
Rockwell hardness test machine (B-Scale) was used to measure hardness values in the fabricated samples. Hardness test specimens were prepared as per ASTM standards and the test results are shown in the below chart 1. Pre-treatment was given to the test specimens; its surfaces were degreased and polished to get even surface. Load of 450kgs was applied for 10 seconds. Sample “C” exhibits higher RHN value than the base matrix.

![RHN Variation with respect to Reinforcement](chart.png)

**Chart 1.** RHN Values Comparison Graph of Composite Samples
3.2. Tensile test
As per ASTM SA370 standard tensile test specimens were prepared like the design shown in the figure 3. Tests were carried on the prepared specimens in universal testing machine. The ultimate tensile strength (UTS) and yield strength values are obtained for all samples. The values are given in the below charts 2 & 3. Test results reveals that the yield strength and the ultimate tensile strength of all samples are decreased when compared with the AL6061 base matrix.

![Design of Tensile Test Specimen](image)

**Figure 3. Design of Tensile Test Specimen**

| Sample   | Yield Strength with respect to Reinforcement |
|----------|---------------------------------------------|
| Sample A | 210  (85%AL6061+ 10% SiC+5%Gr)              |
| Sample B | 220  (80%AL6061+ 15% SiC+5%Gr)              |
| Sample C | 225  (85%AL6061+ 10% AL2O3+5%Gr)            |
| Sample D | 230  (80%AL6061+ 15%AL2O3+5%Gr)             |

**Chart 2. Yield Strength Results**
3.3. Micro structural characterization

Scanning electron microscope was used to observe micro structural changes on the stir casted specimen surfaces with high magnification. Micro structural images of different samples were given in below figures 4,5,6&7. Image results show the distributed reinforcement particles in the AL6061 matrix phase with higher level of agglomeration of reinforcements and cracks in the surface of the composites. For the sake of getting good quality images pre-treatments like mirror polishing and degreasing were done on the surface each sample. The cracks and cast defect on the surface of the composites fails to improve the yield and ultimate tensile strength when compared with as cast AL6061 base matrix.

![Image 1](chart3.png)

**Chart 3. Ultimate Tensile Strength Results**

**Figure 4.** Sample A
(85% Al6061 + 10% SiC + 5% Gr)

**Figure 5.** Sample B
(80% Al6061 + 15% SiC + 5% Gr)
4. Conclusion

AL6061 based hybrid metal matrix composites reinforced with Al₂O₃/Graphite and SiC/Graphite samples with varying proportions with fixed proportion of graphite (5%) were fabricated using stir casting process. From the experimental results the following comparison statements can be drawn. There is an increase in the hardness value with increasing the proportion of the reinforcements, Sample “C” exhibits 3.5% increment in RHN number then the base matrix when compared with other samples. Micro structural characterization images of all the samples A, B, C, D clearly shows the distribution of reinforcement particulates in the matrix phase with clusters of reinforcements in some places. Also, cast defects and surface cracks are present in the samples, which reduce the mechanical properties of the composites drastically. Cast defects are the major limitations found in the study. This work will be extended by reducing the clustering of reinforcement particles in the stir casted composite by performing further heat treatment process. Secondly, optimization of process parameters could be done with optimization tools.

References

[1] Jayendra B, Sumanth D, Dinesh G, Venkateswara Rao M 2020 Mechanical Characterization of stir cast AL-7075/B4C/Graphite reinforced hybrid metal matrix composites Materials proceedings 211104-1110.
[2] Satheesh M, Pugazhvadiy M 2019 Investigation of physical & mechanical properties of Al-6061-SiC/CSA (Coconut Shell Ash) hybrid composites Physica B : Condensed Matter 572 70-75
[3] Jaya Prasad V, Narasimha Rao K, Kishore Babu RN 2020 Mechanical and tribological characterization of AL metal matrix composites reinforced with micro ceramics particles(TiB2/SiC) Materials Proceedings 23 637-641
[4] Abhishek S, Sharma V, Paul J 2019 A comparative study on microstructural evolution & surface properties of graphene/CNT reinforced AL-6061-SiC hybrid surface composites fabricated via friction stir processing Transactions of non-ferrous metals 29 2005-2026
[5] Anirudh V, Vigneshwaran M, Vijay E, Pramod R, Veeresh Kumar GB 2018 Influence of TiB2 & Graphite reinforcement on AL6061 alloy Materials Proceedings 25341-25349.

[6] Mohanavel V, Rajan K, Senthil PV, Arul S 2017 Mechanical behaviour of hybrid composites (AA6351+Al2O3+Graphite) fabricated by stir casting method Materials today 4 3093-3101

[7] Ramgopal Reddy B, Srinivas C 2018 Fabrication & characterization of Silicon carbide and fly ash reinforced aluminium maetal matrix hybrid composites Materials today proceedings 5 8374-8381

[8] Hu C, Yan H, Chen V and Bin SU 2016 Microstructures and mechanical properties of 2024AL/Gr/SiC hybrid composites fabricated by vacuum hot pressing Transactions Of Non Ferrous Metals Society Of China 26 1259-1268.

[9] Nagaraja KC, Rajanna S, Prakash GS, and Rajeshkumar G 2020 Improvement of mechanical and thermal properties of hybrid composites through addition of halloysite nanoclay for light weight structural applications Journal of Industrial Textiles 1-19