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Mechanical Performance of Graphite Particulate & Al₂O₃ Reinforced Aluminium 6061 Alloy Hybrid Metal Matrix Composites

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ABSTRACT: Metal matrix composites (MMCs) made of aluminum has become more significant in a variety of industries due to their excellent mechanical qualities, which include exceptional structural stiffness, low density, high strength, and resistance to wear. Aerospace, military, automotive, marine, and numerous other domestic uses choose aluminum MMCs. The goal of this research is to create and investigate the mechanical properties of hybrid aluminum metal matrix composites reinforced with graphite and Al6061/ Al₂O₃. The Liquid Metallurgy Route (Stir Casting Technique) is used to prepare the composite. Powder metallurgy yields MMCs with better mechanical properties, but liquid metallurgy has some significant advantages of its own, including better matrix particle bonding, easier control over matrix structure, simplicity, low processing costs, closer adherence to net shape, and a larger variety of materials. The base matrix employed is Al6061 alloy, to which graphite and Al₂O₃ particles are added as reinforcements. While the graphite content in the base matrix is changed between 1, 2 and 4wt%, 5wt% of Al₂O₃ is added to it. To improve wettability and distribution, reinforcement particles are pre-heated to 200°C for each composite and then disseminated in steps of three into the molten Al6061 alloy vortex. The produced composites' tensile and hardness characteristics were investigated. The addition of Al₂O₃ particles improved the mechanical characteristics of the Al6061 alloy, such as its hardness and tensile strength. The inclusion of graphite in the composite was found to reduce the Micro-Vickers hardness of the Al6061-5wt% Al₂O₃, but to have less of an impact on the composite's tensile strength.

KEYWORDS: Composites, 6061Al Alloy, Al₂O₃ and Graphite Particulates, Stir-Casting, Tensile Strength, Hardness.

I. INTRODUCTION

A composite material is a "material system" made up of two or more macro- or micro-components that are largely insoluble in one another and differ in form and chemical makeup [1]. The matrix phase is one of the constituents, and the reinforcing phase is the other. To provide the necessary characteristic, the reinforcing phase is incorporated in the matrix [2]. Advanced aerospace applications are finding metal matrix composites (MMCs) to be an increasingly appealing material due to their ability to customize their properties with the addition of specific reinforcement [3-4]. Recently, there has been significant interest in particle-reinforced MMCs due of their unique strength and stiffness at room temperature and higher temperatures [5]. It is commonly recognized that the micro-structural features of the reinforcement, such as form, size, orientation, distribution, and volume or weight percentage, have a significant impact on the elastic properties of the metal matrix composite [6]. Aluminum and its alloys are widely used in the construction of MMCs and have reached the industrial production level among the numerous matrix materials available. The development of inexpensive Al-based MMCs with different hard and soft reinforcements, such as Sic, Al₂O₃, Zircon, Graphite, and Mica, has been prioritized [7]. It has long been known that graphite, whether in the form of fibers or particles, has a high strength and low density. The pricey custom-made materials known as aluminum graphite particulate MMCs, which are manufactured using solidification processes, are used in bushes, bearings, and automobile components, among other engineering applications [8]. According to research that has been done thus far, particulate graphite improves wear resistance, and employing Al₂O₃'s hybrid performance helps to improve mechanical qualities even at high temperatures [9].

Al_2O_3 's ability to support weight, lock microcracks that frequently form in the friction direction, and effectively resist matrix deformation [10]. Graphite-filled aluminum matrix composites offer the potential to be lightweight tri-components

Composites' resistance to seizures is enhanced when graphite is used as a solid lubricating material [11]. Hard reinforcing particles such as Al_2O_3 can be included into matrix alloys to improve their mechanical and tribological behaviour; however doing so may cause rapid counter face wear and decrease machinability [12]. Hybrid composites with superior tribological characteristics that incorporate both solid and hard lubricant components have been proposed as a solution to the aforementioned issues [13]. An intriguing field of study is the examination of the mechanical behaviour of aluminum alloys reinforced with microhard particles like graphite and Al_2O_3 . Thus, this study's goal is to find out how the graphite content affects the hardness, tensile strength, and tribological behaviour of stir-cast Al6061-6wt% Al_2O_3 composites under dry wear circumstances.

II. MATERIALS AND METHODOLOGY

Aluminum 6061 (Al6061) alloy is a widely used aluminum alloy, known for its high strength, weldability, and corrosion resistance. It is a precipitation-hardened alloy, meaning it gains strength from the process of heat treatment. The main alloying elements in Al6061 include magnesium and silicon, but it also contains trace amounts of other elements to enhance its properties. The typical chemical composition of Al6061 is as follows:

Table.1 chemical composition of Al6061 alloy

SL.NO	MATERIAL	Composition Wt%
1	Magnesium (Mg)	0.8% to 1.2%
2	Silicon (Si)	0.4% to 0.8%
3	Iron (Fe)	Up to 0.7%
4	Copper (Cu)	0.15% to 0.4%
5	Manganese (Mn)	Up to 0.15%
6	Chromium (Cr)	0.04% to 0.35%
7	Zinc (Zn)	Up to 0.25%
8	Titanium (Ti)	Up to 0.15%
9	Other elements (each)	Up to 0.05%
10	Aluminum (Al)	Balance

The specific percentages can vary slightly depending on the specific version of Al6061 and the manufacturer's specifications, but the above ranges provide a general idea of the alloy's composition. The combination of these elements gives Al6061 its desirable mechanical properties, making it suitable for a wide range of applications, including aerospace components, bicycle frames, and various construction and automotive parts.

Liquid metallurgy was used to create hybrid metal matrix composites with 5Wt% of Al_2O_3 particles and a variable weight percentage of graphite. An Al6061 alloy was utilized as the matrix material and 125 μm -sized graphite and Al_2O_3 particles were used as reinforcements to create hybrid MMCs. Table.1 displays the Al6061 alloy's chemical composition.

2.1 COMPOSITE PREPARATION

The cast composites have been made using a liquid metallurgical process. The four main types of liquid metallurgical techniques are pressure infiltration, stir casting, spray deposition, and in situ processing. It is the most cost-effective method of producing metal matrix composites [11]. The wide selection of materials, improved matrix particle bonding, easier mixture structure control, low processing costs, flexibility and application to large-scale production, and exceptional productivity for near-net-shaped components are just a few of the significant benefits of the melt stirring process over alternative methods [12]. Al6061 is the alloy selected for the matrix. After solid hexachloroethane (C_2Cl_6)

was used to effectively degas the molten alloy, preheated Al_2O_3 and 125 μm -sized graphite particles of laboratory grade purity were added to the vortex. The reinforcement particles were warmed to 200°C before being added to the melt. In steps of three, the amount of Al_2O_3 and graphite particles incorporated into the matrix alloy was attained. Instead of adding the entire amount of reinforcement at once, it was calculated and is now being added to the melt three times. Using a steel impeller coated in zirconia, the molten alloy was mechanically stirred for ten minutes at each stage, both before and after the reinforcement particles were added. Prior to being submerged in the melt, the stirrer was heated to 400 rpm and placed about two thirds the height of the molten metal from the bottom. The molten composite was poured into permanent cast iron molds at a pouring temperature of 750°C. Consequently, cylinders with a diameter of 14 mm and a length of 120 mm were formed from composites that contained 5Wt% Al_2O_3 particles and 1, 2, and 4Wt% graphite. The preparation samples composites shown in the Table.2.

Table.2 compositions for preparation of samples

Sl.No	Sample name	Wt% - Al_2O_3	Wt% - graphite
1	Al 6061	-	-
2	Al + 5 Al_2O_3	5	-
3	Al + 5 Al_2O_3 + 1G	5	1
4	Al + 5 Al_2O_3 + 2G	5	2
5	Al + 5 Al_2O_3 + 4G	5	4

2.2 STIR CASTING PROCESS FOR PREPARATION COMPOSITES

Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix. The simplest and the most cost effective method of liquid state fabrication is Stir Casting. StirCasting is a liquid state method of composite materials fabrication, in which dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies.

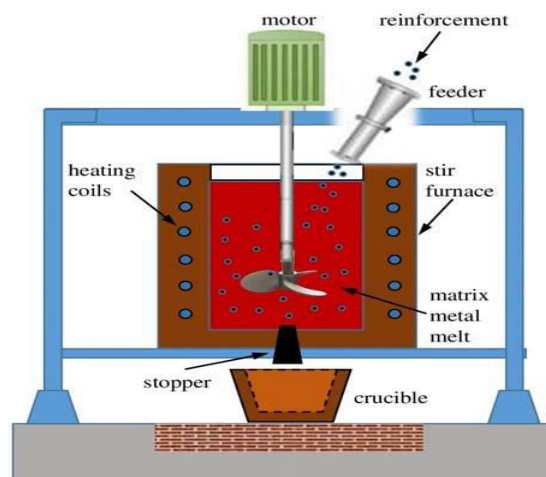


Fig. 1 Stir Casting Setup line diagram

STIR PROCESS CHARACTERISTICS

- Content of dispersed phase is limited (usually not more than 30 %).
- Distribution of dispersed phase throughout the matrix is not perfectly homogeneous.
- There are local clouds (clusters) of the dispersed particles (fibers).
- There may be gravity segregation of the dispersed phase due to a difference in the density of the dispersed and matrix phase.
- The technology is relatively simple and low cost.

2.3 TESTING OF COMPOSITES

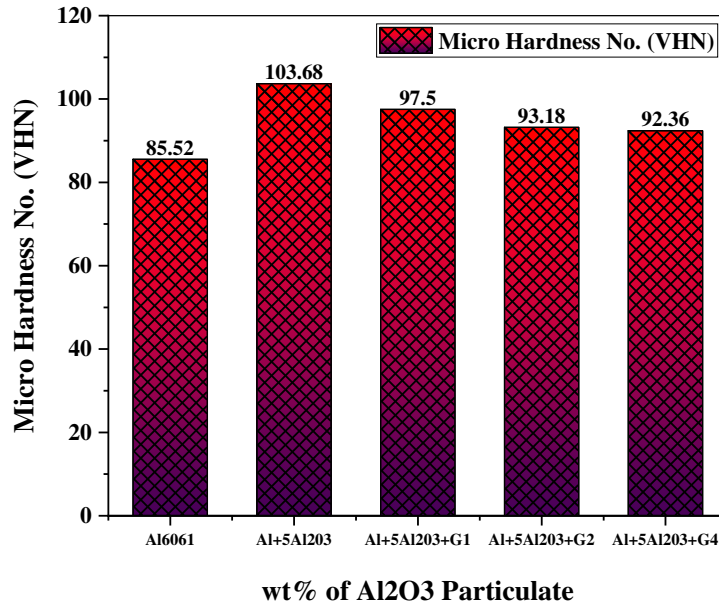
Testing of composites, especially those incorporating aluminum alloys like Al6061, is crucial for assessing their mechanical properties, durability, and application suitability in various industries, including automotive, aerospace, and construction. Al6061 alloy, known for its good mechanical properties, excellent corrosion resistance, and weldability, often serves as a matrix material in composites to enhance specific properties such as stiffness, strength, or thermal conductivity. Composite materials combine two or more distinct materials to achieve superior properties compared to the individual constituents. In the case of Al6061 composites, the matrix is Al6061 alloy, and the reinforcement can be fibers, particles, or whiskers of materials like carbon, silicon carbide, or aluminum oxide. **Mechanical Testing:** **Tensile Testing:** Measures the material's strength and ductility by pulling it to failure. **Compression Testing:** Assesses the material's behaviour under compressive loads, which is essential for applications subjected to such stresses. **Flexural Testing:** Determines the bending strength of the material, which is crucial for structural applications. **Impact Testing:** Evaluates the material's toughness and its ability to absorb energy during a sudden impact, which is vital for safety-critical applications. **Hardness Testing:** Provides information about the surface hardness of the composite, which can indicate wear resistance. **Tribological Testing:** Studies the wear resistance and friction coefficient of the composite under various conditions, which is critical for components subjected to sliding or rolling contacts.

Testing of Al6061 composites is a multifaceted approach that assesses their mechanical, thermal, and chemical properties. These tests are essential to ensure that the composites perform as expected in their specific applications, whether it is in structural components, automotive parts, aerospace components, or any other field where the unique properties of Al6061 composites can be leveraged. Each testing method provides valuable insights into the behaviour of these materials under different conditions, guiding engineers and designers in material selection and component design.

III. RESULTS AND DISCUSSIONS

3.1 HARDNESS MEASUREMENTS

The micro hardness test results for the matrix, the Al6061/5 wt% Al₂O₃ composite, and hybrid composites with different weight percentages of graphite particles 1, 2, and 4 wt% of graphite in the Al6061/6 wt% Al₂O₃ composites are displayed in Figure 1. A diamond cone indenter loaded with 100 grams was used to assess the Micro-Vickers hardness of the polished samples. The stated value is the average of 50 readings obtained at various locations. The inclusion of Al₂O₃ particles causes the alloy matrix's hardness to significantly rise. The increased composite hardness value suggests that the presence of particles in the matrix has raised the composites' overall hardness. This is because the reinforcing particle, particularly ceramic material, which is hard, positively affects the composites' hardness despite the matrix's soft nature. During the hardness test, the matrix's constraint to plastic deformation increases when stiffer and harder Al₂O₃ reinforcement is included. Therefore, the very high hardness of Al₂O₃ itself may be the cause of the increase in hardness of composites. The graph also shows that when the amount of graphite particles increased, the hardness of the Al6061/ Al₂O₃/Graphite hybrid composites declined. Pure alloy hardness 17.5 % increases with Al₂O₃, 14% increases with the G1, 8.2% increases with G2 and 7.4% increases with G4.

Fig. 2 Hardness of Al6061 and addition of different wt% of Al₂O₃+Graphene

3.2 TENSILE PROPERTIES

Tensile tests were performed utilizing a computerized, uni-axial tensile testing machine in accordance with ASTM standards in order to examine the mechanical behaviour of the composites. For every test, three specimens were utilized, and the average result is given. Figure 2 a-b-c shows the tensile parameters, which were taken from the stress-strain curves and include tensile strength, yield strength, and percentage elongation. It is evident that the tensile strength of composites with 5Wt% Al₂O₃ particles is greater than that of cast Al6061, but the composite's ductility is lower than that of an unreinforced alloy.

A primary mechanism for raising the dislocation density of the matrix and, consequently, the composite strength, is the thermal mismatch between the metallic matrix and the reinforcement. This mismatch may be the cause of the strength increase. Nevertheless, compared to unreinforced specimens, the elongation of the 5Wt% Al₂O₃ reinforced composite materials was less. It is evident that the non-deformable reinforcement and the blended soft metal matrix have harder plastic deformation than the base metal itself.

Consequently, the composite material's ductility decreases in comparison to unreinforced material. Furthermore, it was shown that the tensile characteristics of hybrid composites were not significantly affected by the amount of graphite present when graphite particles were added in increments of 1, 2, and 4 to Al6061 alloy along with 5Wt% of Al₂O₃. However, in Al6061- Al₂O₃-Graphite hybrid metal matrix composites, the percentage elongation increased as the graphite content increased. The addition of graphite particles is mostly responsible for this percentage increase in elongation since graphite has a soft nature that reduces the hardness of hybrid composites. The Tensile value 11.4% increases with Al₂O₃, 8% increases with G1, 9.16% increases with G2 and 13.43% increases with G4. Yield stress was found 8.4% increases with Al₂O₃ and 11% increases with G4. Percentage of elongation is largely increases with the increase graphite concentration it's almost 25.45% increases.

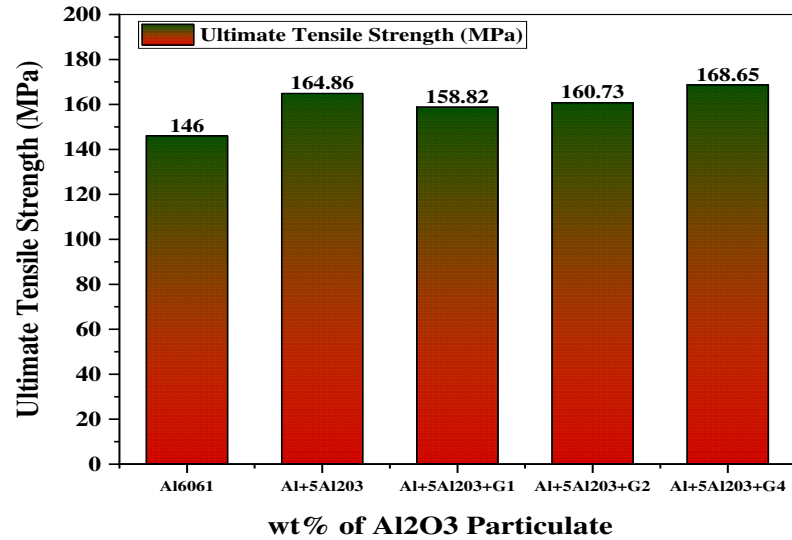


Fig. 3 Tensile strength of Al6061 and addition of different wt% of Al₂O₃+Graphene

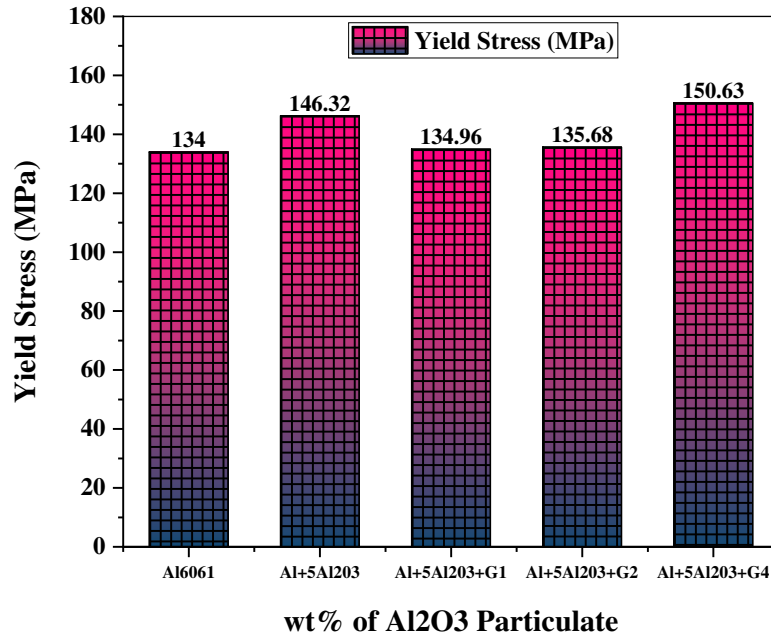
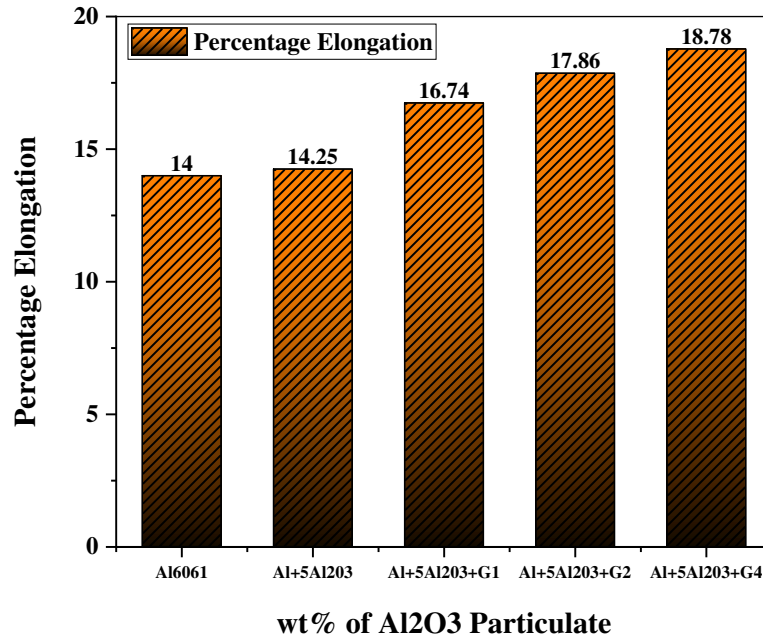


Fig. 4 Yield stress of Al6061 and addition of different wt% of Al₂O₃+Graphene

Fig. 5 Elongation of Al6061 and addition of different wt% of Al₂O₃+Graphenes

IV. CONCLUSION

By adding reinforcement in three steps and preheating the particles, melt stir technique has been successfully used to create hybrid metal matrix composites based on aluminum.

- When compared to cast Al6061, the tensile strength of produced composites is higher.
- The tensile strength is significantly increased when 5wt% Al₂O₃ is added compared to the base matrix Al6061. On the other hand, the tensile strength remains rather constant when Gr particles are added in relation to the increased Al₂O₃.
- The produced composites have a harder surface than the original AL6061 alloy.
- Hardness is significantly increased when 5wt% Al₂O₃ is added. Gr particles, on the other hand, reduce hardness while still being higher than in Al6061 alloy. Pure alloy hardness 17.5 % increases with Al₂O₃, 14% increases with the G1, 8.2% increases with G2 and 7.4% increases with G4.
- The inclusion of Al₂O₃ particles results in a loss in ductility, which lowers the percentage of elongation relative to the base alloy. In comparison to composites containing Al₂O₃ particles, the addition of graphite content improved the percentage of elongation.
- The Tensile value 11.4% increases with Al₂O₃, 8% increases with G1, 9.16% increases with G2 and 13.43% increases with G4. Yield stress was found 8.4% increases with Al₂O₃ and 11% increases with G4. Percentage of elongation is largely increases with the increase graphite concentration it's almost 25.45% increases.

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