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Analysis of Thermal Conductivity of Aluminium 6061 Reinforced with Varying Percentage of Graphene

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Abstract: ***The application of aluminium alloys holds significant importance in the aviation industry due to their low density, excellent strength, toughness, and corrosion resistance. Graphene, an allotropic form of carbon abundantly available in nature, possesses high tensile strength and low density, making it an ideal reinforcement material for aluminium alloys like Al-6061. Incorporating graphene as reinforcement enhances the thermal properties of the metal, leading to composite materials with superior attributes compared to their parent materials. This study investigates the distinctive effects of utilizing graphene as reinforcement in Al-6061 to improve its thermal conductivity. Aluminium alloy serves as the matrix material, with graphene added in varying weight percentages: 0% (as-cast), 0.25%, 0.5%, 0.75%, and 1%. The metal matrix composite was fabricated using the stir casting technique, ensuring uniform distribution of reinforcement particulates. Specimens were then machined to the required geometry following approximate ASTM standards for testing and evaluation.***

Keywords: Metal matrix composite, Graphene, Thermal conductivity

1. Introduction

In recent years, the growing demand for lightweight materials with enhanced specific strength in the automotive and aerospace industries has driven the development and adoption of aluminium alloy-based composites. Aluminium metal matrix composites (MMCs) are emerging as a class of advanced materials due to their lightweight, high strength, superior specific modulus, low coefficient of thermal expansion, and excellent wear resistance.

Despite their advantages, the use of aluminium MMCs has traditionally been limited to specific applications, such as aerospace and military weapons, due to high processing costs. However, recent advancements have expanded their application to automotive components, including engine pistons, cylinder liners, and brake discs/drums.

The processing techniques for Aluminium MMCs can be broadly categorized into three types: Liquid state processing, Semisolid processing and Powder metallurgy. Particulate reinforce Al composite can be produced easily by liquid state, i.e., stir-casting process. Melt-stir casting is an attractive processing method as it is relatively in expensive and often a wide selection of material and processing condition. The metal matrix composites (MMCs) are gradually replacing the general light metal alloys like aluminium alloy in different industrial applications where strength, low mass and energy savings are the most important factors.

Aluminium 6061 is an aluminium alloy, with magnesium and silicon as the primary alloying elements. It is used in applications where high strength to weight ratio is required. It is popular for medium to high strength requirements and has good toughness characteristics. Alloy 6061 has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to sea water. This alloy also offers good finishing characteristics and responds well to anodizing.

Graphene is a two-dimensional, crystalline allotrope of carbon atoms that form a hexagonal lattice structure with sp2 hybridization. This 96.6% optically transparent material is the strongest known to mankind per unit size with incredible electrical properties and the best heat conductor at room temperature which can lead to many applicable uses in the research and technical industries. Beyond this, graphene is an excellent conductor of heat and electricity and has interesting light absorption abilities. It is truly a material that could change the world, with unlimited potential for integration in almost any industry. Graphene is much softer than diamond, the other well-known, naturally-occurring form of carbon.

2. Material Synthesis

Aluminium 6061 alloy uses as Matrix. The research grade graphene with thickness and average diameter of 15-20 nm and 5-10 µm respectively. Supplied from Btcorp Gerenrique Nano private limited (Pillagumpe industrial area, Hoskote) were used as reinforcement particles.

The test specimen is fabricated by stir casting technique. In preparing metal matrix composed by stir casting methods some of factor of that need considerable attention are as follows;

1. To achieve uniform distribution of the reinforcement material.
2. To achieve wettability between the two main substances
3. To minimize porosity in the cast metal matrix composite

The process begins by breaking the aluminium rod into small pieces, followed by melting approximately 12 kg of Aluminium 6061 at a temperature of 600-700°C in a furnace. Next, graphene powder is added to the molten Aluminium 6061 slurry, and the mixture is stirred for 3-4 minutes.

The stirred mixture is then reheated to 700°C and maintained at this temperature for 10 minutes. Subsequently, the composite mixture is poured into a preheated sand mold and allowed to solidify naturally. Once solidified, the cast rod is machined to achieve a final size of 500 mm in length and 20 mm in diameter.

Figure 1: Mould preparation

Figure 2: Pouring of molten metal

Figure 3: Specimen rods

The cast specimen was machined for testing purpose using CNC and Lathe to get the required ASTM standard dimension for conductivity test.

3. Experimentation

The experimentation is conducted to analyze the thermal conductivity of the composites fabricated by reinforcing graphene hydroxyl with aluminium 6061. Graphene, having carbon purity >99.5%, was reinforced into the Aluminium, which was added at a temperature of 700 °C with stirring time of 3-4 min. The Amount of Graphene was varied from 0.0 Wt.% (as-cast) to 1.0 Wt% by weight. Fig.4 shows the schematic representation of experimental set up. It consists of Aluminium composite rod, one end of which is heated by electric heater and the other end projects inside the cooling water jacket. The mid portion of the rod is thermally insulated from the surroundings using glass fibre. The temperature of the rod is measured at five different locations, T_1 to T_5 along its length. When the temperature gradient exists in a composite rod, experiences have shown that there is a transfer of heat from high temperature region to low temperature region. Constant water flows is maintained and adjust the power input to the heater using the heat controller. Wait until the temperature T_1 become constant over time, indicating steady state. Use the channel selector and digital temperature indicator and read the temperature T_1-T_5 on the metal rod and read the inlet and outlet water temperature of the cooling water, then measure the water flow rate. Based on the measured temperature gradient along the length of the composite rod and the thermal conductivity of composite rod are calculated.

Figure 4: Experimental set up

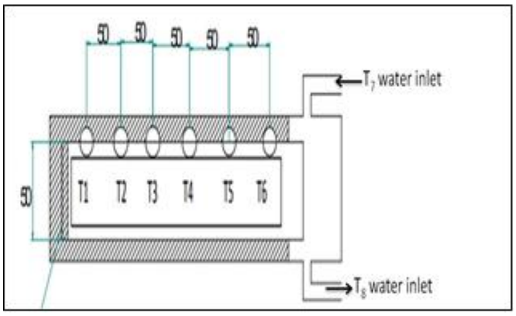

Figure 5: Schematic representation of experimental set up

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Determination of temperature gradient (△t/△x) along the length of composite rod:

From the measured temperature T_1, T_2, T_3, T_4, and T_5, surface temperature distribution along the length of composite rod can be determined by plotting a graph of distance along the rod on the x axis and temperature on the y axis as shown in Figure 6.

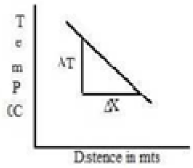

Figure 6: Distance V/s temperature

Determination of thermal conductivity of composite specimen:

Heat conduction equation is given by

Q = - kA (△t/△x)

Where,

Q = Heat flow rate through Aluminium composite rod in watts
K = Co-efficient of thermal conductivity of Aluminium, W/m K
$A = \pi d^2/4$ = Area of heat transfer in m^2
D = Diameter of the Aluminium rod = 20mm
Cp = Specific heat of water, 4.187 kJ/kg K.

Therefore, $k = \dfrac{mCp\,\Delta Tw}{A\left(\frac{\Delta t}{\Delta x}\right)}$

Calculations:

Specimen calculations for 0.25 Wt.% specimen:

$$k = \frac{2.416\times10^{-3}\times4.187\times10^{3}\times2}{\pi\frac{(20\times10^{-3})^{2}}{4}\times0.36\times10^{3}}$$

k = 178.88 W/ m K.

Similarly, calculations are carried out for other compositions and the concerned results are as shown in Table 1:

Table 1: Thermal conductivity of Aluminium with varying percentage of graphene

S.No.	Percentage variation of Graphene	Thermal conductivity (W/ m K)
1	As-cast	152
2	0.25	179
3	0.50	200
4	0.75	237
5	1.00	269

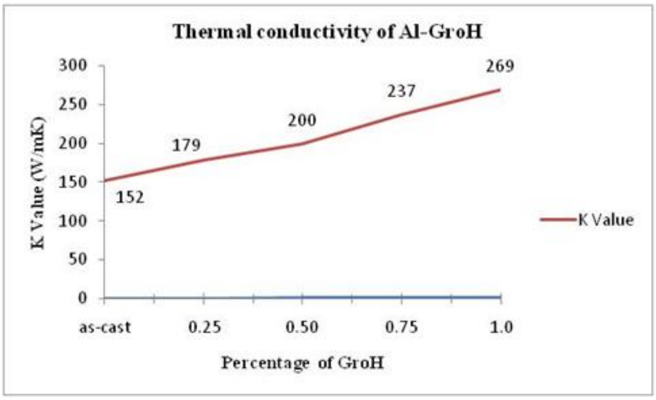

Figure 7: Graphical representation of Thermal conductivity test for varying % of Graphene

4. Conclusion

In this study, an aluminium 6061-graphene composite material was synthesized using the stir-casting technique. The thermal conductivity of the composite metal matrix showed a gradual increase with the addition of graphene hydroxyl reinforcement, ranging from 0.00% to 1.0%.

The as-cast material specimen exhibited a thermal conductivity of 152 W/m·K, which increased to 269 W/m·K for the specimen with 1.0 wt% graphene hydroxyl reinforcement, representing a 77% enhancement. This improvement demonstrates that the addition of graphene hydroxyl significantly enhances the thermal conductivity of the composite material.

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