Thermal analysis on Al7075/Al₂O₃ metal matrix composites fabricated by stir casting process

S Jacob¹, S Shajin² and C Gnanavel³

¹Assistant professor, Department of Automobile Engineering, Vels University
Chennai, Tamilnadu, India
²Assistant professor, Department of Mechanical Engineering, Narayanaguru Siddhartha College of Engineering, Athencode, Tamilnadu, India
³Assistant professor, Department of Mechanical Engineering, Vels University, Chennai, Tamilnadu, India

E-mail: jacobthermal@gmail.com

Abstract. Metal matrix Composites (MMC’s) have evoked a keen interest in recent times for various applications in aerospace, renewable energy and automotive industries due to their superior strength, low cost, easy availability and high temperature resistance [1]. The crack and propagation occurs in conventional materials without any appreciable indication in a short span. Hence composite materials are preferred nowadays to overcome this problem [2]. The process of metal matrix composites (MMC’s) is to unite the enviable attributes of metals and ceramics. The Stir casting method is used for producing aluminium metal matrix composites (AMC’s). A key challenge of the process is to spread the ceramic particles to achieve a defect free microstructure [2]. By carefully selecting stir casting processing specification, such as stirring time, temperature of the melt and blade angle, the desired microstructure can be obtained. The focus of this work is to develop a high strength particulate strengthen aluminium metal matrix composites, and Al7075 was selected which can offer high strength without much disturbing ductility of metal matrix [4]. The composites will be examined using standard metallurgical and mechanical tests. The cast composites are analysed to Laser flash analysis (LFA) to determine Thermal conductivity [5]. Also changes in microstructure are determined by using SEM analysis.

1. Introduction
A composite material is a combination of two or more definite materials, having a identifiable by the interface between them. Composites are used in modern world due to its high strength to weight ratio, less weight and low cost. Modern composite materials are most effectively used to achieve a equivalence of properties for a given applications. Most of the composites are made of just two materials [7]. One is the matrix and it surrounds and binds together fragments of the other material, which is called the reinforcement. The biggest advantage of modern composite materials is that they are light and strong. Composite has the ability to be easily modified because many of them can be molded into different shapes. The mostly preferred matrix material for making a composite is Aluminium because of its cheapest and reduced weight. Aluminium 7075 alloy has higher toughness and are preferred in aircraft and automotive sector [9]. Composites able to meet the design requirements with weight as well as high strength as compared to conventional materials. Composite
materials used in aerospace, automotive, trucking, and mass movement will all have fuel consumption. The products manufactured with composites that need less energy to transport or ship than traditional materials [10]. While composites have their worth as weight-saving materials, the current scenario is to make them cost effective. The efforts to produce composite components have several manufacturing methods now used in the composites industry. The various feature of materials to be noted when making sport equipment are strength, ability to deform under tensile stress, modulus (damping), and cost [12].

2. Methodology
The preparation of composite is by the Stir casting process. The various aspects of the Stir casting process on the microstructure are the dissemination of the reinforcing particles. It depends on the processing steps involved. During pouring of the melt composite, the content may vary from one form to another or even it can vary in the same process from one region to another. Therefore the spreading of the particles in the melt is a necessary condition for homogeneity in the castings. Hence the study of the distribution of the particles in the laminate is of great significance. Aluminium 7075 Alloy is melted in a crucible by heating it in a muffle furnace up to 950°C for one hour. The grain size of the Aluminium oxide particles used is 150 µm. The Aluminium oxide particles are preheated at 700°C for one to three hours to make their surfaces oxidized. A pink coloured powder (Scum powder) Hectochloroethane is added to the melted Aluminium to remove the Slag from the melt. A blue tablet (Degassing flux) is mixed to remove the bubbles from the melt. Then the melted Aluminium is cooled below the liquid state to keep the slurry in Semi solid state. Automatic stirring was carried out with the help of radial stirrer operated by an electric DC motor for about 3 to 4 minutes at stirring rate of 280 RPM. In order to minimize gas trapping in the molten matrix during stirring, the mixing speed and the stirrer location was placed at a particular location. At this stage, the preheated Aluminium oxide particles were added manually to the vortex. In the final mixing processes the temperature was controlled within 700 ± 10°C. After the process the melt was settled in the sand mould to get desired shape of specimen. The preparation of particle-reinforced MMC was quite a challenge, as the particles are very hard and fragile compare to the matrix materials. This composition of hard and soft materials makes it complex to avoid damages like cracks and broken reinforcement particles, and relief the particle and soft matrix during preparation. The process used is similar for specimens with different compositions (5%, 10% & 15%) of Aluminium oxide.

3. Results and Discussion
3.1 Hardness Analysis Of Specimens

The micro hardness of the three specimens are shown in graph.

![Graph](image)

**Figure 1.** Micro hardness

The hardness values of the specimens were tested by Vickers micro hardness test. From the above graph it reveals that up to a 10 % of reinforcement of the aluminium oxide particles, the micro
hardness of the specimen is higher and on further addition of aluminium oxide particles it decreases. The maximum hardness value thus obtained at 10% reinforcement is 148.09 VHN.

3.2 SEM Analysis
The microstructures of the specimens with various wt. % reinforcements of Aluminium oxide with Al7075 are shown in figure

![Figure 2(a)](image)
![Figure 2(b)](image)
![Figure 2(c)](image)

Figure 2. SEM analysis of specimens

The microstructures of Al7075 reinforced with Al₂O₃ particles of various weight percentages obtained are as in Fig. 4.2. The SEM images are obtained at 1500X magnification range. Here dark grey colored particles are Aluminium particles and light white particles are Aluminium oxide particles. The specimen with 10% reinforcement (Fig. 2(b)) is found to have more acquisition of aluminium oxide particles. On the other hand, with the increase of the weight composition of Aluminium oxide particles the uniformity and homogeneity tends to decrease.

3.3. EDAX Analysis

![Figure 3(a)](image)
![Figure 3(b)](image)
The above charts show the different material composition of the three specimens. For all the three specimens Aluminium is the superior material. The dominant material next to aluminium is Zinc. The other materials like Fe and O are fewer in composition.

3.4. Tensile Testing

The dimensions for the preparation of specimens is shown in the

![Figure 4. Tensile test specimen](image)

From the above graph it can be seen that the Tensile strength of the material is maximum at 10% reinforcement. The maximum tensile strength at 10% reinforcement is 69.5 N/mm² and is obtained at a peak load of 5.46kN. The graph (figure. 6) shows the Yield strength of the specimen with various reinforcement percentages of Aluminium oxide (Al₂O₃). The maximum yield strength is obtained at 5% reinforcement at a peak load of 4.6kN. The higher value of yield strength is 17.825N/mm².
3.5. Thermal Conductivity

![Thermal Conductivity Graph](image)

**Figure 7.** Thermal conductivity

The above figure 7 shows the thermal conductivity of the composite specimens. The heat conductivity of the cast specimens obtained is maximum at 10% reinforcement and is 129.927 W/mK and the lowest value obtained at 15% reinforcement is 125.01 W/mK. So with the further addition of Al₂O₃ the value of thermal conductivity decreases.

3.6. Temperature Distribution

Figure. 8(a) shows the temperature distribution of Al7075/Al₂O₃ (5%) composite. From the figure it can be noted that the temperature transfers from the high temperature end to the lower temperature end. The least temperature thus obtained is 606.42 K. Figure. 8(b) shows the temperature distribution of Al7075/Al₂O₃ (10%) composite. Here the lower temperature obtained is 613.407 K. Here the heat transfer increases when compared to Al7075/Al₂O₃ (5%) composite. Figure. 8(c) shows the temperature distribution of Al7075/Al₂O₃ (15%) composite. The heat transferred from one end to the other decreases and the least temperature obtained is 602.623 K. From all the three composites, the heat transfer is maximum at 10% reinforcement of Al₂O₃. The transfer of heat to the lower temperature end as obtained is 613.407 K.

![Temperature Distribution Images](image)

**Figure 8 (a)**

**Figure 8 (b)**

**Figure 8 (C).** Temperature distribution of specimens
3.7. Thermal Flux Distribution

Figure 9 (a) Thermal flux of specimens

Figure 9 (b) Thermal flux of specimens

Figure 9 (c) Thermal flux of specimens

Figure 9(a) shows the thermal flux distribution of Al7075/Al₂O₃ (5%) composite. The maximum thermal flux is at the initial end and is $0.119 \times 10^7$ W/m². In the end the thermal flux is minimum and is 62194.9 W/m². Figure 9(b) shows the thermal flux distribution of Al7075/Al₂O₃ (10%) composite. Here the maximum and minimum thermal fluxes obtained are $0.119 \times 10^7$ W/m² and 62194.9 W/m². Figure 9(c) shows the thermal flux distribution of Al7075/Al₂O₃ (15%) composite. The maximum and minimum thermal fluxes obtained are $0.118 \times 10^7$ W/m² and 61137 W/m² respectively. From the thermal flux distribution of the composites, the composite with 10% reinforcement of Al₂O₃ is more effective when compared to other composites. The maximum and minimum values obtained for composites of different percentages of reinforcement are tabulated below in Table.

| Al7075 + %Al₂O₃ | Minimum Thermal flux (W/m²) | Maximum Thermal flux (W/m²) |
|------------------|-----------------------------|-----------------------------|
| 5%               | 61507.8                     | $0.118 \times 10^7$         |
| 10%              | 62194.9                     | $0.119 \times 10^7$         |
| 15%              | 61137                       | $0.118 \times 10^7$         |
3.8. Thermal Gradient

Figure 10 (a) shows the thermal gradient of Al7075/Al₂O₃ (5%) composite. The thermal gradient decreases with the increase in the length of the composite material. Minimum and maximum thermal slope obtained are 466.152 W/m and 8979.72 W/m.

Figure 10 (b) shows the thermal flux of the Al7075/Al₂O₃ (10%) composite. Here the heat gradient occurs a maximum value at initial end and the value is 8793.68 W/m. The lowest value of thermal gradient is 458.854 W/m. Figure 10 (c) shows the thermal gradient of the Al7075/Al₂O₃ (15%) composite. Here the thermal gradient occurs a maximum value at initial end and the value is 9080.68 W/m. The minimum value of thermal gradient is 470.068 W/m. From the results of the thermal gradient obtained, the composite with 10% reinforcement of Al₂O₃ is the material with less thermal gradient and the material with 15% reinforcement of Al₂O₃ occurs higher.

| Table 2. Thermal gradient of specimens |
|----------------------------------------|
| Al7075 + %Al₂O₃ | Minimum Thermal gradient (K/m) | Maximum thermal gradient (K/m) |
|--------------|-------------------------------|-------------------------------|
| 5%           | 466.152                       | 8979.72                       |
| 10%          | 458.854                       | 8793.68                       |
| 15%          | 470.068                       | 9080.68                       |
4. Conclusion
The following are concluded from the above analysis
- The higher ultimate tensile strength (69.519N/mm$^2$) is obtained at 10% reinforcement of Aluminum oxide.
- The maximum Micro hardness value (148.09 VHN) is obtained at 10% reinforcement of Aluminum oxide.
- Thermal conductivity is also maximum at 10% reinforcement with 129.927 W/mK.
- The Temperature distribution and Thermal flux are superior at 10% reinforcement of Al$_2$O$_3$ in the Al7075 matrix.

So by all the tests carried out, the specimen with 10% reinforcement is having superior properties.

5. References
[1] AlptekinKisasoz, Kerem AltugGuler and AhmetKaraaslan, 2012 Infiltration of A6063 aluminium alloy into SiC–B4C hybrid performs using vacuum assisted block mould investment casting technique Transactions of nonferrous metals society of china 22 563-1567.
[2] Bayraktar. E, Katundi. D, 2010 Development of a new aluminium matrix composite reinforced with iron oxide (Fe3O4) Journal of achievements in materials and manufacturing engineering 38 7-14.
[3] Krupiński M, Labisz K, Dobrzański. L. A, and Rdzawski A, 2010 Image analysis used for aluminium alloy microstructure investigation Journal of achievements in materials and manufacturing engineering 42 58-65.
[4] Loizaga A, Niklas, Fernandez-Calvo A I and Lacaze J 2009 Thermal analysis applied to estimation of solidification kinetics of Al-Si aluminium alloys International Journal of Cast Metals Research 22 345-352.
[5] MadevaNagaral, Auradi V and Ravishankar M K 2013 Mechanical Behaviour Of Aluminium 6061 Alloy Reinforced With Al$_2$O$_3$ and Graphite Particulate Hybrid Metal Matrix Composites International Journal Of Research In Engineering & Technology 1 193-198.
[6] Muhammad Hayat Jokhio, Muhammad Ibrahim Panhwar and Mukhtiar Ali Unar, 2010 Manufacturing of Aluminum Composite Material Using Stir Casting Process Mehran University Research Journal Of Engineering & Technology 30 53-64.
[7] Naher S, Brabazon D and Looney L 2003 Simulation of the stir casting process Journal of Materials Processing Technology 24 567-571.
[8] Narasimalu Srikanth, KhineKhine TUN and Manoj Gupta , 2003 Finite Element Based Energy Dissipation Studies of Al-SiC Composites Journals of composite materials 35 1385-1410.
[9] Neelima Devi, Mahesh V, Selvaraj N 2011 Mechanical Characterization Of Aluminium Silicon Carbide Composite International Journal Of Applied Engineering Research 1 793-799.
[10] Pardeepsharma, Gulshanchauhan, Neerajsharma 2003 Production of AMC by stir casting International journal of contemporary practices 2 23-46.
[11] Phool Kumar, Azada A M, Vinod Kumar 2013 Frictional and Wear Characteristics of Stir-Cast Hybrid Composite Aluminium Al6061Reinforced with SiC Particulates International Journal of Engineering Research & Technology 2 403-410.
[12] Sudindra S and Anil Kumar C 2013 Studies on Al6061/Al$_2$O$_3$ and graphite hybrid metal matrix composites International journal of metallurgical & materials science and engineering 3 35-42.