Thermal Property Evaluation of Heat Treated Aluminium Metal Matrix Composite Material

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***Abstract*— The quest for lighter materials with high stiffness and strength has triggered the development of metal matrix composites as an alternative to conventional engineering alloys. They possesses attractive properties like good mechanical, thermal and wear resistance properties. In this present investigation to study the thermal properties of Al metal matrix composites reinforced with SiC and Gr particles. The Al356 alloy was used as a matrix and varying the reinforcement percentage from 0% to 15% by weight in steps of 5% of SiC and fixed 5% weight of graphite. The composites are fabricated by liquid metallurgy (stir cast) method. The composites were heat treated (540^{0}C for 12 hours). Artificial ageing was carried out at 155^{0}C for 5, 10, 15 hours. The prepared composites were experimented for thermal property evaluation. The thermal property such as thermal conductivity was studied and result was compared with unreinforced material. The significant improvement of thermal conductivity was observed by increasing the weight 5% of SiC particles in the composite material.**

***IndexTerms*— Metal Matrix Composites (MMCs), Stir Casting, Heat Treatment, Thermal Conductivity.**

I. INTRODUCTION

The Composite materials signify the combination of two or more materials in physically distinct and mechanically separate form. The layout of this report includes forms of composites, mechanics of composites, preparation and application of advanced composites and conclusion of study on the development of advanced composite materials. Mankind is aware of composite materials from time immemorial.

Since then, many modern composites have been developed with new fibers such as carbon, boron, aramides etc. with matrices made of polymers, metals and ceramics. Introduced over 50 years ago, composites are fiber-reinforced plastics used in a variety of products, application and industries. They also provide good design flexibility and high dielectric strength, and usually require lower tooling costs. Because of these advantages, composites are being used in a growing number of industries, as well as recreation boating applications. Their tremendous strength-to-weight and design flexibility make them ideal in structural components for the transportation industry. High strength lightweight premium composite materials such as carbon fibers and epoxies are being used for aerospace application and in high performance sporting goods. Composites superior electrical insulating properties also make them ideal for appliances, tools and machinery, tanks and pipes constructed with corrosion-resistant composites offer extended service life over those made with metals. The composite's main advantages is how their components – glass fiber and resin matrix –complement each other, while thin glass fibers are quite strong, they are also susceptible to damage. Certain plastics are relatively weak, yet extremely versatile and tough combining these two components together, however results in a material that is more useful.

With the right fiber, resin and manufacturing process, designers today can tailor composites to meet final product requirements that could not be meet by using other materials. **Natarajan [1]** et al. has studied on wear behaviour of A356/25SiC$_p$ aluminium matrix composites sliding against automobile friction material. The wear behaviour of aluminium metal matrix composite (Al MMC) sliding against automobile friction material has compared with the conventional grey cast iron. The wear tests are carried out on pin-on-disc machine for both materials. They concluded that the lower wear of MMCs is lower than the cast iron. **Uyyuru [2]** et al. has studied on tribological behaviour of Al-Si-SiC$_p$ composites/automobile brake pad system under dry sliding conditions. Tribological behaviour of stir-cast Al-Si/SiC$_p$ composites against automobile brake pad material was studied using pin on disc tribotester. They concluded that the formation of tribo-layer have a significant role to play in wear behaviour of tribological couple made of Al-Si/SiCp MMC and brake pad during the service. **Pramila Bai [3]** et al. has studied on dry sliding wear of A356-Al-SiC$_p$ composites. The sliding wear tests have carried out for different loads using pin-on-disc machine. The results were concluded that A356-Al-SiC$_p$ composites possess improved wear resistance compared with the unreinforced alloy. The improved wear resistance due to addition of SiC particles which reduce the propensity of material flow at the surface.

Aluminium is remarkable for its ability to resist corrosion and its light weight. Structural components made from aluminium and its alloys are vital to the aerospace industry and very important in other area of transportation and building. Here in this work A356 aluminium used as matrix material, their composition and properties are shown in the table 1.1 & 1.2.

Table 1.1 Chemical composition of matrix alloy (A356) (wt. %)

Elements	Cu	Mg	Mn	Si	Fe	Zn	Ti	Al
Wt%	0.20 max	0.25 to 0.45	0.1 max	6.5 to 7.5	0.10 max	0.20 max	0.20 max	Balance

Table 1.2 Mechanical properties of A356, T6 Material

Material	Density (g/cm^3)	Yield strength (MPa)	Tensile strength (MPa)	% elongation	Hardness BHN	Thermal conductivity (W/m^0 k)
A356, T6	2.685	185	262	5.0	80	159

The sustained interest to develop engineering materials which could cope with the raised performance standards, resulted in emergence of a newer class of materials, called Metal Matrix Composites (MMCs). They constitute a family of customizable materials with customizable critical property relationships. Such materials are known for their exceptional high modulus, stiffness, wear resistance, fatigue life, strength-to-weight ratios, tailor able coefficient of thermal expansion, etc. With these enhancements in properties, they pose for strong candidature for replacing conventional structural materials. But what makes them stand apart is the ability to customize their properties to suit the service requirement. Such advantages have made this group of materials a nice pick for use in weight-sensitive and stiffness-critical components in transportation systems. MMCs can be described as a group of materials in which a continuous metallic phase (matrix) is combined with one or more reinforcement phases. The aim of such a composite material is to enhance the suitability of the end product by selectively enhancing the complimentary properties, and masking the detrimental properties of the matrix and the reinforcement.

II. EXPERIMENTAL WORK

2.1 FABRICATION METHODS OF MMCs

In recent years the potential of Metal matrix composites (MMCs) material for significant improvement in performance over conventional alloys has been recognized widely. However, their manufacturing cost is still relatively high. There are several fabrication techniques available to manufacture the MMC materials; there is no unique roué in this respect. Due to the choice of material and reinforcement and of the types of reinforcement, the fabrication technique can vary considerably. The processing methods used to manufacture particulate reinforced MMCs can be grouped as follows.

Solid- phase fabrication methods: diffusion bonding, hot rolling, extrusion, drawing, explosive welding, PM route, pneumatic impaction etc.

Liquid- phase fabrication methods: liquid- metal infiltration squeeze casting, compo casting, pressure casting, spray code position, stir casting etc.

Two phase (solid/liquid) processes: which include recasting and spray atomization.

2.2 COMPOSITE PREPARATION

1. Composite was prepared by liquid metallurgy route. To obtain the composite several combinations were tried by varying the parameters such as Ageing, change in percent by weight of Silicon carbide.

2. The matrix Al-Si-Gr was prepared by Stir casting method. The nominal composition of the alloy was 0.25 % magnesium, 0.2 %copper, 0.1 % magnese,6.5 % silicon,0.2 % iron ,0.1 % zinc, 2 % titanium and remaining aluminium.

3. The different combinations of composites were prepared in four steps:

4. Aluminium alloy (A356) used was cut into pieces from a big bar. The weighed aluminium pieces were taken in a clay graphite crucible and melted in a crucible furnace at 1073°K. Later it was chill cast into a cast iron channel having the approximate dimensions of 200×25×13.2 mm.

5. In second step aluminum alloy (A356) was melted at 1073^0 K. The reinforcement materials graphite 5% by weight and silicon carbide 5% by weight were added. Small chips of magnesium were added along with Camphor tablet. Magnesium acts as a binding material and camphor (C_2Cl_6) removes the entrapped gases. The charge was stirred well by a stirrer in the furnace at 1073°K. Later it was chill cast into a cast iron channel.

6. The base alloy was prepared similarly as in previous steps. Reinforcement materials graphite 5% by weight and silicon carbide 10% by weight was added to molten alloy. Chips of magnesium and camphor tablets were added to the molten metal alloy. The charge was stirred well by a stirrer in the furnace at 1073°K. Later it was chill cast into a cast iron channel.

7. All the operations remain the same. In the combination of reinforcement materials graphite 5% by weight and silicon carbide 15% were added.

Fig10.6: Graphite powder

Fig10.7: SiCp powder

Fig10.8: Mixture of SiC_p+Gr powder

Fig10.9: C_2Cl_6 Tablet

Fig10.10: Mg foils

2.3 CASTING PROCEDURE

Raw aluminum is fed into the furnace and heated up to a temperature of 780 °as shown in Fig.2.7. A known quantity of mixture (silicon-carbide and graphite), depending on the percentage composition required is slowly added into the furnace crucible. Simultaneously the stirrer is switched on. The stirrer is preheated before immersing it into the crucible. The flux and the magnesium ribbon are added to increase the wet ability of aluminum metal so that the mixture added to the metal is evenly dispersed. After proper stirring (i.e. formation of the vortex) for around 10 minutes the furnace is tilted and molten aluminium-silicon carbide-graphite composite is collected into a preheated ladle. The ladle is taken near the sand mould and the molten composite is slowly poured into the runner until the mould cavity is completely filled with molten metal.

Fig2.6:A356 block

Fig2.7:Stir casting technique

Fig2.8:Pouring of molten metal into mould cavity

Fig2.9:Slag removed

Fig2.10:Cast rod

Fig2.11:Final specimen after machining operation

2.4 HEAT TREATMENT

The specimens of composites and non composite materials were heat treated at 540°K for 12 hours. The heat treatment was carried out in automatic electric furnace as shown in Fig.2.12. The sample was quenched into water after the predetermined time. The temperature of the furnace was maintained within ±5 degree of the set point by means of an automatic temperature controller.

Fig2.12: Heat treatment furnace

2.5 AGEING TREATMENT

The ageing treatment of the composite materials was carried out at 428 ^{0} K for 5, 10, 15 hours for different lengths of time. For this purpose the samples were tied by nichrome wire so that samples can be made to suspend within the central zone of the vertical tubular furnace maintained, at ageing temperature. The samples were aged at the specified temperature and the samples were quenched in water at predetermined intervals. Thermal conductivity was determined after polishing the surface. Heat treatment procedure of the material as followed in Table 6.1

Table 6.1 Typical Heat Treatment for Aluminium alloy for Permanent mold casting.

Alloy	Temperature	Type of casting	Heat treatment		Ageing treatment	
			Temp(K)	Time(hr)	Temp(k)	Time(hr)
A356	T61	P	813	12	428	5-15

2.6 THERMAL CONDUCTIVITY STUDIES

The specimen geometry is shown in figure 6.1. The specimens were machined (Facing, turning) to the required dimensions in Lathe machine and polished using SiC paper. The specimens were heat treated for 12 hours and then subsequently aged for 5, 10, 15, hours. Thermal conductivity test was carried out using Thermal Conductivity Apparatus. The specimen dimension is shown in Fig.6.1

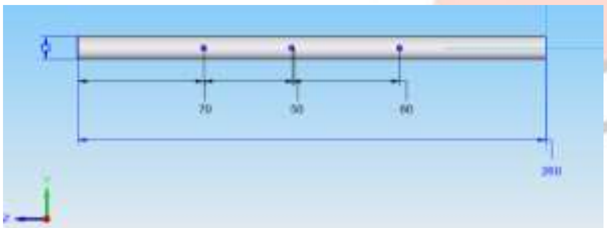

Fig6.1: Thermal conductivity specimen
(All dimensions are in mm)

Fig6.2: Thermal conductivity

2.6.1 ANALYSIS OF THERMAL CONDUCTIVITY

From Fourier's law of heat conduction;

$$Q=-KA\ dT/dx \quad (1)$$

$$-K\times A\times dT/dx=m_f\ Cp\ (T_9-T_8) \quad (2)$$

$$-K= [m_f\ C_{pw}(T_9-T_8)]/\ [A\times dT/dx] \quad (3)$$

Where, Q=Rate of heat conducted, W
A=Cross section area of heat transfer, m^2
K= Thermal conductivity of material, W/m-K
dT/dx= Temperature gradient.
'C_{pw}'=Specific heat of water = 4.187 kJ/kg-K
m_f = Mass flow rate in cc/s
T_8= Inlet temperature in °C
T_9=Outlet temperature in °C

2.6.2 SPECIFICATIONS OF THERMAL CONDUCTIVITY APPARATUS:

Specimen material	: Aluminium
Size of the specimen	: ϕ13 mm, 260mm length
Cylindrical shell	: 160mm length
Voltmeter	: Digital type, 0-300volt, AC
Ammeter	: Digital type, 0-10amp, AC
Dimmer for heating coil	: 0-230, 12amps
Heater	: band type Nichrome heater, 250 W
Thermocouple used	: 9 nos.
Temperature indicator	: Digital type, 0-400, Cr-Al

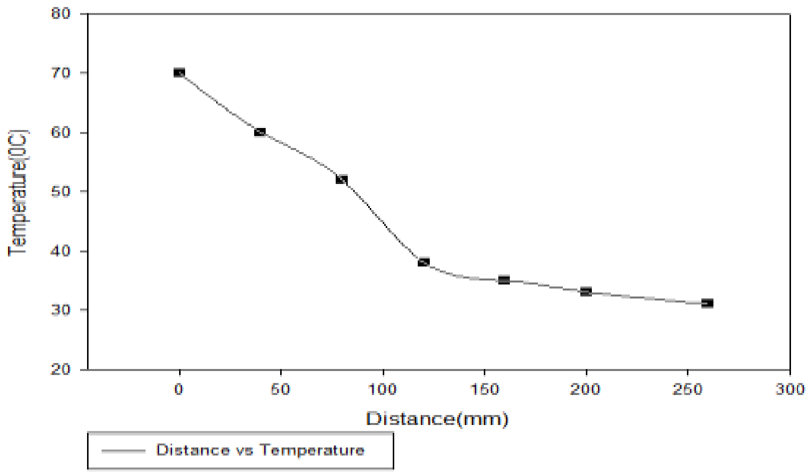

Fig.2.13: **Graph: temperature v/s distance**

By using ''Eq. 3"

K=200.64 W/m^{0}K

III. RESULTS AND DISCUSSION

3.1 THERMAL CONDUCTIVITY TEST

Thermal conductivity is increases with increasing the percentage reinforcements of SiC_p in A356-5%Gr composite material. From the figure7.1, Thermal conductivity increases for unreinforced material with increasing in ageing durations such as 5, 10, 15 hrs. In 15 hrs of ageing time material shows better thermal conductivity was obtained. When increasing the ageing durations of the material, material structures will align properly with removing dendrite arm structures. So that the material shows better thermal conductivity with increasing ageing time were observed.

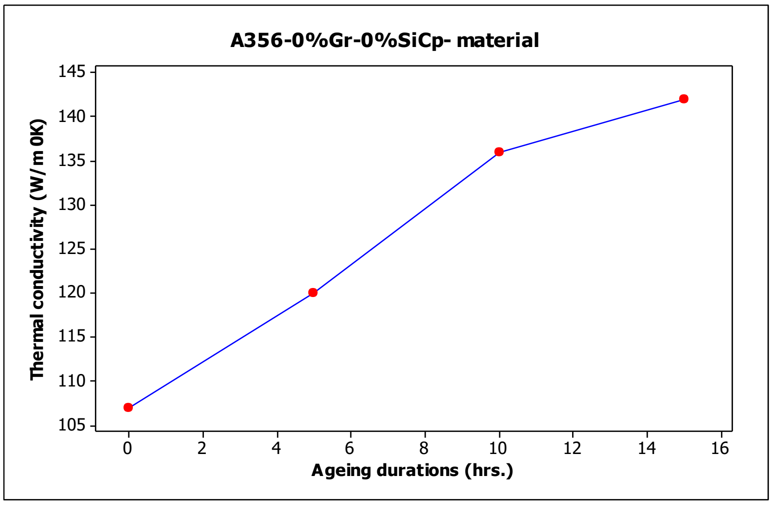

Fig 7.1: Thermal conductivity Vs Ageing duration (A356-0%Gr-0%SiCp)

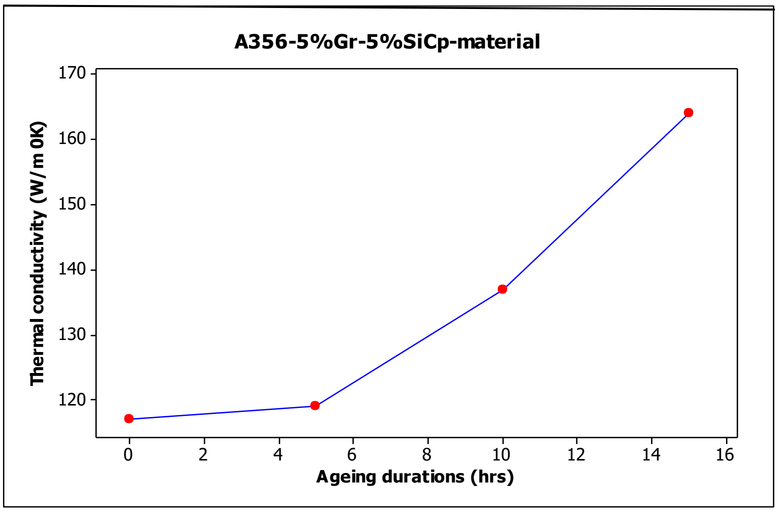

Fig 7.2: Thermal conductivity Vs Ageing duration (A356-5%Gr-5%SiCp)

From the figure 7.2, shows that increasing of thermal conductivity with increasing of ageing time were observed. From the figure 7.2, thermal conductivity value is increases with increasing the reinforcement of 5 % SiCp into A356-5%Gr composite material were observed compare with the figure1. At 15 hrs ageing period the material shows good thermal conductivity, due to mobility of the reinforcements occur during increasing the ageing time. The thick bonding between the reinforcements and matrix material it produces a good hardness to the composite material and it produces a better thermal conductivity were observed.

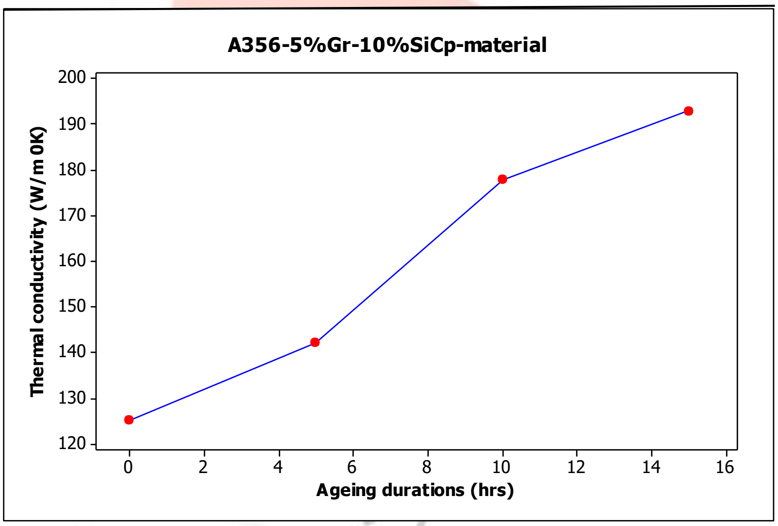

Fig 7.3: Thermal conductivity Vs Ageing duration (A356-5%Gr-10%SiCp)

Variations of thermal conductivity with respect to ageing durations The thermal conductivity of the composite material increases with increasing the reinforcement content and ageing durations were observed from the figure7.1, compare with the figure 7.2and 7.3. During the increasing in ageing time the composites produces better precipitations were obtained when higher order reinforcement content it increases. So that it produces better thermal conductivity were obtained when increasing the content of SiCp in A356-5%Gr composite material.

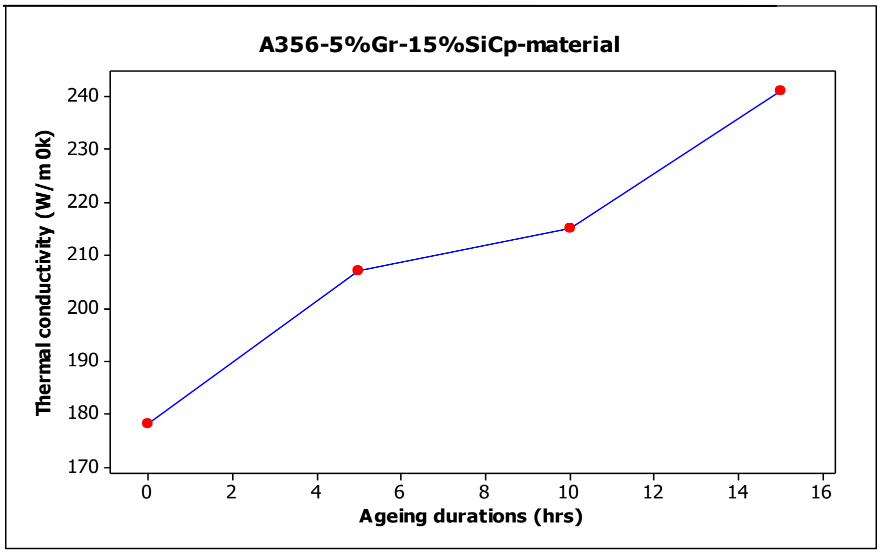

Fig 7.4: Thermal conductivity Vs Ageing duration (A356-5%Gr-15%SiCp)

The composite A356-5%Gr-15%SiCp material treated with different ageing durations, produces a better thermal conductivity was obtained. The composite contains 15 wt. % of SiCp which produces a better mobility was obtained during ageing time were increases. The higher order SiCp in 15 hrs ageing time best mobility were obtained and it produces a highest thermal conductivity were obtained when compare with all the unreinforced and reinforced material with different ageing period material.

IV. CONCLUSION AND SCOPE FOR FUTURE WORK

The thermal conductivity is very important parameter in high temperature application. In aluminium metal matrix composite material, it gives the strength to the material and it gives high thermal conductivity. The A356-5%Gr composite reinforced with varying steps of SiC_p in hybrid composite material. Thermal conductivity increases for unreinforced material with increasing in ageing durations such as 5, 10, 15 hrs. In 15 hrs of ageing time material shows better thermal conductivity was obtained. The composite contains 15 wt. % of SiCp which produces a better mobility was obtained during ageing time were increases. The higher order SiCp in 15 hrs ageing time best mobility were obtained and it produces a highest thermal conductivity were obtained when compare with all the unreinforced and reinforced material with different ageing period material.

FUTURE WORK:

- To fabricate the aluminium MMCs for a different % of reinforcement.
- To characterize the composites for fatigue test, Micro-hardness test & corrosion test can be determined.
- To perform tribological characteristic for the composites
- To determine the thermal property of the composites.
- To perform FE analysis of different composite materials could be checked for maximum operating temperature.

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BIOGRAPHY

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