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Experimental investigation of Thermal conductivity of aluminium metal matrix composites

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Abstract: **Now a days, Metal matrix composites have been regarded as one of the most proposition grouping in composite materials. There is lot of demand in the modern society from the working life in aluminum metal matrix composites. The best example for this is application of the aluminum and its alloys as substitution for steel and similar materials. Specific aluminum alloys have good mechanical properties, but poor Tribological characteristics. The thermal characterization of hybrid metal matrix composites has imperative impact in a wide range of applications. The thermal conductivity is the most important properties of Metal Matrix Composites (MMCs). Since nearly all Metal Matrix Composites are used in various temperature ranges, measurement of thermal properties of MMC's as a function of temperature is necessary in order to know the behavior of the material. Thermal conductivity is one of the primary terms commonly used in the research of materials. The thermal characterization of composite materials has received large consideration and has become governing in materials science and engineering. In this paper, the thermal conductivity investigation of Al6351, Sic and Gr. hybrid metal matrix composites by varying percentage reinforcement of Sic (0,2,4,6,8,10%) and Gr.(10,8,6,4,2,0%) have been carried out. Al based composite reinforced with Sic and Gr. particle have been prepared by squeeze casting technique. The main advantage of going for squeeze casting is the material wastage is less and the low level of porosity. The investigation of thermal conductivity behavior of hybrid composites with varying percentage reinforcement at lower division have been emphasized.**

Index Terms— **Al6351, sic, graphite, squeeze casting, thermal conductivity.**

I. INTRODUCTION

Now a days in a composite material is a macroscopic combination of two or more dissimilar materials having an identifiable interface between them, in recent day's Metal matrix composites (MMC's) are improving a lot and also found many applications in many areas hybrid Metal matrix composites has its effects of the corrosion, Mechanical and wear performance of the material The use of the metal matrix composite has been significant rise in the field of space vehicle, automobile and under water vehicle [1]. Aluminum and its alloys have attracted most absorption as base metal in metal matrix composites. Al MMC's are extensively used in aircraft, aerospace, automobiles and various other fields [2]. The reinforcements should be stable in the given working temperature and non-reactive too. Silicon Carbide (Sic), Aluminum Oxide (Al_2O_3), Boron carbide, Titanium oxide, Graphite are some of the reinforcements which are widely used for better properties. Hybrid aluminum metal matrix composites (HAMCs) are the second generation of composites that have potential to substitute single reinforced composites due to improved mechanical properties.

Squeeze casting is a relatively new and developing casting process. Squeeze casting is simple and economical, efficient in its use of raw material, and has excellent potential for automated operation at high rates of production. The process generates the highest mechanical properties attainable in a cast product. The squeeze cast products are desirable for many exacting applications. It is suitable for high strength, high ductility, lightweight structural aluminum castings needed for advanced components. The squeeze casting product is increasingly demanding lightweight components to improve fuel efficiency. Because squeeze casting is relatively new, much work needs to be done to better understand the fundamentals of the process.

In particular, the relationships between the design, the processing parameters, and the integrity of the squeeze cast parts are still to be understood well. Squeeze Casting is a combination of forging and casting process. The major advantages of squeeze casting are: (i) Parts produced are without gas porosity or shrinkage porosity; (ii) feeders or risers are not required and therefore no metal wastage occurs; (iii) alloy fluidity not critical in squeeze casting as both natural casting alloys and wrought alloys can be squeeze cast to finished shape with the aid of pressure; (iv) squeeze castings can have mechanical properties as good as wrought products of the same composition [3]. Thermal conductivity is the transfer of heat from one part to another part with which it is in contact. Thermal conductivity λ is defined as ability of material to transmit heat and it is measured in watts per square meter of surface area for a temperature gradient of 1 K per unit thickness of 1 m.

The thermal conductivity is not always constant. The main factors affected the thermal conductivity are the density, moisture of material and ambient temperature. With increasing density, moisture and temperature the thermal conductivity increases. Metals and other dense solid materials tend to have high levels of conductivity, whereas materials with very small amount of solid matter and large proportion of voids (gas or air bubbles, not large enough to carry heat by convection) have the lowest thermal conductivities.

II.LITERATURE REVIEW

S Cem Okumus et al [4] has studied on thermal expansion and thermal conductivity behavior of hybrid composite of AL/Sic/SI/Gr manufactured a composite by liquid phase particle mixing squeeze casting by taking the reinforcements of Sic, Gr

(45µm and 53µm) by changes the contents (5.0, 7.5, 10wt%).result. Results indicated that there is an extent component and there was no evident differential between thermal behavior of 45µm and 53µm by increasing the graphite content.

J M Molina et al [5] studied on thermal conductivity of the hybrid aluminum matrix composites reinforced with combination of diamond and sic particles which is produced by gas pressure support liquid metal infiltration. By replacing sic gradually with diamond results in study increasing of thermal conductivity from 220 to 580 w/Mk. Electrical conductivity measurement indicated that silicon content in the matrix decreasing with increasing diamond volume fraction. Prognostication of the differential effective medium scheme generalized for multiple types of inclusion agree well with experimental results.

Tran Nam et al [6] investigated the graphite and silicon carbide with al 6061 has no effect on the thermal conductivity of hybrid composites, which confirms that the addition of reinforcement concretely with matrix alloy has substitutional effect in the increase of thermal conductivity. It can be observed that aluminum and silicon carbide composite exhibits higher thermal conductivity but by addition of graphite aluminum matrix alloy and silicon carbide slowly decreases the thermal conductivity of hybrid composites. The thermal conductivity of graphite is (100'w\mk') very low when compared to aluminum 6061(166'w/mk') and silicon carbide (150-180'w\mk'). It has been observed that aluminum graphite composite exhibits high thermal conductivity at higher volume fraction.

Na Chen et al [7]concluded on the aluminum 6061 with reinforcement silicon carbide and graphite with weight mass fraction of 2.5%,5%,7.5%,10% from the it can be see that addition of silicon carbide and graphite with weight mass fraction, the reinforcement issue is uniform with a non-appearance of cracks and harmful pores and is reported that due to increases in volume fraction of reinforcement the distribution is more reliable with negligible porosity the variation of thermal conductivity with temperature for different composites of hybrid metal matrix composites. It has been observed that the al 6061 has higher thermal conductivity of 168w/mk and al6061+5%sic+5%gr low thermal conductivity of (163'w/mk') at 300°C it is noted that by the inclusion of reinforcement silicon carbide and graphite with al6061, there has been a gradually decreases in the thermal conductivity of hybrid composites at all temperatures.

Krishna et al [8] evaluated the heat flow administration characteristics of the metal matrix composite of Al6061 with silicon carbide and graphite using ANSYS software. The results showed the decreases of thermal conductivity due to the increases of graphite.

Ashish Srivastava et al[9] The thermal conductivity of hybrid composite depends on the grain size of silicon carbide as the result, the interfacial thermal resistance as the comprehending the effect of thermal conductivity behavior. It has been reported that, due to an increasing the silicon carbide with any aluminum matrix alloy. The change in thermal conductivity values of composite materials depicts an increasing and decreasing of the particle size. It is has been noticed that, the increasing of the silicon carbide and the thermal conductivity values are gradually increased.

Julia A. King et al. [10] presented that the interaction of the each filler on thermal conductivity composite. These composite have three different filler (carbon nanotubes, carbon black and synthetic graphite particles).These used in the single filler system, synthetic graphite used the largest thermal conductivity increases, followed by carbon nanotubes and then the carbon black. The combination of the carbon black with synthetic graphite, combination of carbon nanotubes with synthetic graphite, caused a significant increase in composite through-plane thermal conductivity. For example, when carbon nanotubes and synthetic graphite are combined into a composite, the thermal conductivity in higher than the expected from effect of each single filler. It is from thermal conductivity path ways with these carbon fillers with results is increased composite thermal conductivity. Authors found that in-plane thermal conductivity for the composite containing 75wt% (54.7vol %) and 80wt% (61.6vol %) synthetic graphite in polypropylene was 24.4and 33.6w/mk.

Xuebing Liang et al [11] presented in the aluminum and diamond composite with uncoated and TI-coated diamond particles were prepared by SPS (spark plasma sintering) technique. The effect of diamond volume fraction and temperature on the thermal conductivity and micro structure are evaluated. It is found that TI-coated improve the wetting property and interfacial bonding between the matrix and diamonds, on increases sintering temperature can effectively promote the wetting action and diffusion effect at the interface. So the higher sintering temperature is conductive for the interfacial bonding and thermal conductivity of TI-coated composites. Composite with uncoated composites, the thermal conductivity of TI-coated composite to the decline of relative density and just varies in the range from 433 to 491 w/mk.

III. MATERIALS AND METHOD

The material used as base metal is Al 6351 due to its strength, bearing capacity, ease of workability and weld ability. It is also used in building boats, column, chimney, rod, mould, pipe, tube, vehicle, bridge, crane and roof. One of the most important properties of Al alloy is that the prescription of solid solution is not so difficult. The advantages of base metal have several important performance characteristics that make them very attractive for aircraft structures, namely light weight, only one third that of steel, strength comparable to typical other aluminum alloys, excellent corrosion resistance, with negligible corrosion even in the presence of rain and other drastic conditions, high toughness and resistance to low-ductility fracture even at very low temperatures and free of any ductile-to-brittle transition that has sometimes been fatal to older structures and good fabric ability. Silicon carbide is an important non-oxide ceramic which has various industrial applications. It has different properties such as high hardness and strength, chemical and thermal stability, high melting point, oxidation resistance, high erosion resistance, etc. All of these qualities make Sic a perfect candidate for high power, high temperature electronic devices as well as abrasion and cutting applications.

The crystalline structure of graphite consists of hexagonal rings forming thin parallel plates (graphene's). Each carbon atom is covalent bonded to three other atoms in the plate. The outermost electron shell of a carbon atom has four valence electrons, three of which are used by the covalent bonds. The forth valence electron does not take part in covalent bonds and may be easily displaced from the electron shell by an electric field. These electrons provide electrical conductivity of graphite.

Squeeze casting is used as it is a combination of casting and forging that is used to improve the properties so as to get less porosity. The development of squeeze casting process can be used in tremendous possibility for manufacturing of components of aluminum alloys, which are not properly commercialized as yet. It can also be effective in for import substitution of over critical components.

IV. PREPARATION OF COMPOSITE

Al alloy, Sic and Graphite hybrid metal matrix composite have been by squeeze casting by using al alloy 6351 as the matrix material and reinforcement of sic and graphite was the difference percentage of sic (0,2,4,6,8,10%) and graphite (10,8,6,4,2,0%) was melt attained by mushy state. Stirring was continued for 5 minutes to increase sic and graphite particle into the aluminum matrix. After the temperature reach 700°C the mixing was completed. Additional the stirred was mixed in 20 seconds to sic and graphite particles it was completed mixing the liquid metal it was poured into a squeeze casting steel mould, which was pre heated at 500°C.

The reinforcement and matrix mixing under a protective argon atmosphere to avoid the oxidation of both the melt the reinforcement. The extent of pressure applied is significantly less than in forging. Parts of great details can be produced. Coring can be used in tandem with the process to form holes and recesses. The high pressure and

The close contact of molten alloy with the metal die surface results in minimum porosity and improved mechanical properties.

Fig.1: Squeeze casting diagram

Fig 2: Sample of thermal conductivity

The samples were prepared by squeeze casting and prepared sample for thermal conductivity test according to the ASTM E1530 standards of Dia. 50mm, then the samples are done with polishing with sand paper with grades of 400,600,800 for the polishing of the sample. Again for finish polishing Disc polishing machine is used to get desired finish for the samples to thermal conductivity test. The samples after polishing in disc polishing are as shown in the fig.2

V. TESTING FOR THERMAL CONDUCTIVITY

Thermal conductivity refers to the intrinsic ability of a material or conduct the heat. Thermal conductivity occurs through the molecular agitation and contact, but it does not result in the bulk movement of the solid itself heat moves along a temperature gradient, from an area of higher temperature and high molecular energy to an area with a lower temperature and lower molecular energy. This transfer will continue until thermal equilibrium state is reached. The rate at which heat is transferred is dependent upon the magnitude of the temperature gradient of the material and the specific thermal characteristics.

There are different methods to measure thermal conductivity experimentally. Laser Flash technique is highly resourceful for the evaluation of thermal conductivity. The sample has been place on an electronically controlled and programming robot located in a furnace. The furnace is then held at a fixed temperature. At this temperature, the sample surface is then irradiated with a arrange energy pulse (laser or xenon flash). This energy pulse results in a related temperature rise at the sample surface. By using NETZSCH model LFA 447 Nano flash diffusivity apparatus. The unit used in this work has been equipped with a furnace, of appropriate of operation from 25°C to 300°C.

In this paper, DTC-300 is used to measure thermal conductivity. It is a process used by change of materials, including polymers, ceramics, composites, glasses, rubbers, some metals, and other materials of low to medium thermal conductivity. Only a relatively small test specimen is needed. Non-solids, such as pastes or liquids, can be tested using particular containers. Thin films can also be tested exactly using a multi-layer technique. The samples are prepared according to the ASTM E1530 Standard.

A specimen of the material is held below a uniform compressive load between two polished surfaces, separate controlled at a different temperature. The lower surface is part of a calibrated heat flow transducer. The heat flows from the upper surface, through the specimen, to the lower surface, create an axial temperature gradient in the stack. After reaching thermal equilibrium, the temperature difference across the specimen is measured along with the output from the heat flow transducer. These values and the specimen thickness are then used to calculate the thermal conductivity.

Each DTC-300 is factory calibrated using specimens of known thermal resistance, transverse the particular range. The contact resistance is kept small by applying a reproducible, pneumatic load to the test stack, and a thermally conductive combine compound. A guard furnace surrounds the test stack to decrease the effect of heat transfer across the boundary of the specimen. For sub-ambient testing, the DTC-300 is supplied with an airtight compartment, keeping the atmosphere relatively moisture-free with dry air purge. Polymers can be tested through the melt using special condition cells. A typical test takes about 45 to 60 minutes to complete at a single temperature.

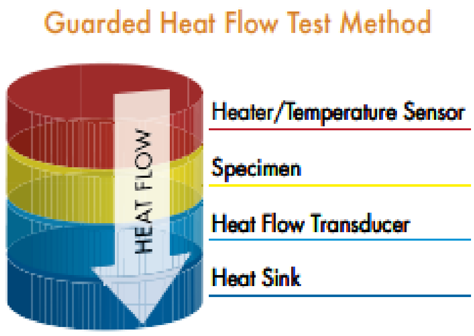

Fig. 3 DTC300 machine

VI. Theoretical Thermal Conductivity

The thermal conductivity of composite can be evaluated by using the different theoretical models 1.Series model, 2.parallel model, 3.Geometric model, 4.maxwells model, 5. Rule of mixture.
In the present research work the numerical model selected is rule of mixture and the theoretical calculations are carried out to verify the experimental results

1. Series model : $k_e = \frac{k_m k_f}{\emptyset k_m + (1-\emptyset) k_f}$ -------------------------- 1

2. Parallel model: $k_e = \emptyset k_f + (1-\emptyset) k_m$ ---------------------- 2

3. Geometric model: $k_e = k_f^{\emptyset} + k_m^{(1-\emptyset)}$ ----------------------- 3

4. Maxwell's model: $k_e = k_m \frac{k_f + 2k_m + 2\emptyset(k_f - k_m)}{k_f + 2k_m - \emptyset(k_f - k_m)}$ --------------------- 4

5. Rule of mixture: $k_c = f k_f + (1-f) k_m$ ---------------------- 5

VII. RESULTS AND DISCUSSIONS

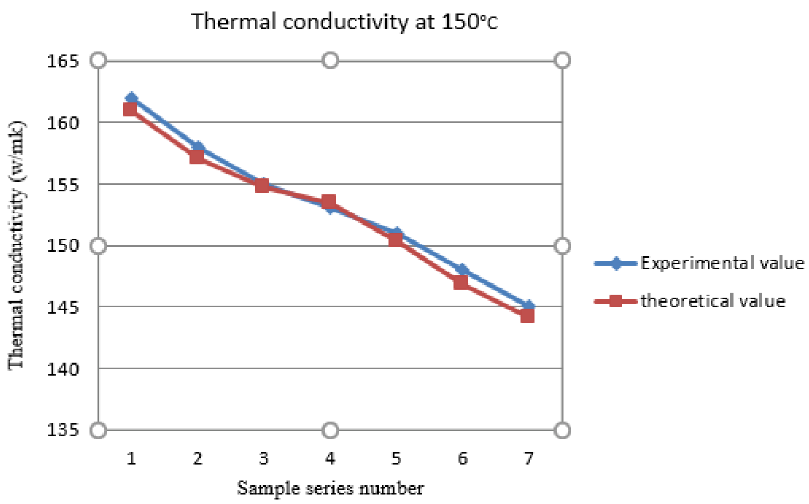

Fig. 4 Thermal conductivity

The thermal conductivity behavior of hybrid metal matrix composites has been determined with different weight fraction. The effect of Graphite on thermal behavior in Aluminum-graphite-Silicon Carbide hybrid metal matrix composites has been investigated. Fig.4 illustrates the change of thermal conductivity with temperature for different percentage compositions of hybrid metal matrix composites.

From fig 4, it has been observed that, base metal has high thermal conductivity and base metal of sample 7 reveals low thermal conductivity. It has been noticed that, with the addition of reinforcements Silicon Carbide and Graphite with base metal, there has been a gradual decrease in the thermal conductivity. For different percentage compositions of hybrid metal matrix composites. Generally, the thermal conductivity of materials single as the temperature. There has been a decline in thermal conductivity of hybrid composites. Experimentally, it has been inferred that, by the addition of Graphite with Sic and Aluminum matrix alloy with different weight fraction at lower proportions resulted in the considerable reduction in thermal conductivity of the hybrid metal matrix composites. The present experimental investigation, it can be inferred that, by the addition of Graphite with Silicon Carbide and base metal, there has been no generous change in thermal conductivity.

This confirms that, the addition of reinforcements Silicon Carbide and Graphite coincident with the matrix alloy has insignificant impact in the increase of thermal conductivity. It has been obvious that, Aluminum and Silicon Carbide composite exhibits high thermal conductivity, but by the addition of Graphite with Aluminum matrix alloy and Silicon Carbide regularly decreases the thermal conductivity of hybrid composites experimental investigation, it can be inferred that, by the addition of Graphite with Silicon Carbide and base metal, there has been no substantial change in thermal conductivity. This confirms that, the addition of reinforcements Silicon Carbide and Graphite concurrently with the matrix alloy has insignificant influence in the increase of thermal conductivity. It has been obvious that, Aluminum and Silicon Carbide composite show high thermal conductivity, but by the addition of Graphite with Aluminum matrix alloy and Silicon Carbide gradually decreases the thermal conductivity of hybrid composites.

The correct and accurate modelling for thermal conductivity of composite materials has a great value due to their excellent thermal and mechanical properties and their use in industrial applications and technological fields. The challenges in modelling complex materials come mainly from the inherent variety and randomness of their microstructures, and the coupling between the components of different phases. Several attempts have been made to develop expressions for thermal conductivity by various researchers. Numerical models have been developed over the last century to predict the thermal conductivity of phase composites for which dispersion of a second phase in a continuous medium of the first phase is assumed.

To understand the thermal Conductivity behavior of the hybrid composites, several existing theoretical models of composites are compared. When the interfaces are free to slide and the constituent phases are free to flow, the Thermal conductivity of the composites can be expressed by Rule of Mixtures.

In the present research, some of the empirical models considered in the evaluation of thermal Conductivity are Rule of Mixtures Fig.4 represents the comparison of experimental values of thermal conductivity at maximum temperature with the mathematical models. Fig.4 clearly indicates that the experimental values of thermal Conductivity with varying weight fraction of composites closely match with Rule of Mixtures It can be inferred that experimental data are in good argument with all mathematical models.

CONCLUSION

1. Base metal exhibits maximum value of thermal conductivity, whereas there is a decline in thermal conductivity at maximum temperature for the different percentage compositions of hybrid MMCs with the addition of reinforcements Sic and Gr to base metal.
2. The thermal conductivity of hybrid composites decreases due to the increases of Gr content.
3. The values of thermal conductivity decreases over the range of temperatures, variation in volume fraction of Sic and graphite of hybrid composites.
4. The inclusion of reinforcements of low volume fractions, thermal conductivity of hybrid has been detecting to be low.
5. The variation in thermal conductivity depends on porosity, temperature variation, volume fraction, internal structure of the composites.
6. It has been observed that base metal to sample 1 exhibits the maximum thermal conductivity.

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