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# An Investigative Review on Thermal Characterization of Hybrid Metal Matrix Composites

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***Abstract:*** *Composite materials have become cynosure among all materials that have applications in profusion. The applications of these materials are absolutely appreciative and applicable in almost all areas of mechanical engineering. The mechanical characterization of these materials has become common nowadays. But the thermal characterization of hybrid metal matrix composites is increasingly important in a wide range of applications. Aluminium Silicon alloys in particular finds extensive and increased applications in industries due to their properties viz., high fluidity, low melting point, high strength, corrosion resistance, good casting characteristics and lower coefficient of thermal expansion. In the present scenario, research work is accomplished on hybrid composites based on mechanical properties but very limited research has been carried out on hybrid composite based on thermal properties and characterization. The thermal analysis of hybrid metal matrix composites is required to clearly examine the thermal properties viz., Thermal Conductivity, Temperature Difference, Thermal Capacity or Heat Difference, Coefficient of Thermal Expansion and Rate of Heat Transfer. Thermal Analysis is also often used as a term for the study of Heat Transfer to measure Heat capacity and Thermal Conductivity. The behaviour of hybrid composite materials is often sensitive to changes in temperature. This is mainly because, the response of the matrix to an applied load is temperature-dependent and changes in temperature can cause internal stresses to be set up as a result of differential thermal contraction and expansion of the constituents. The flash method is a well-established unsteady-state measurement technique for measuring the thermal diffusivity, α, of solid homogeneous isotropic opaque materials. This technique is regarded to be the most polished and sophisticated technique for the determination of thermal parameters of composites. On the basis of the present review, it is obvious and pragmatic that the thermal properties on hybrid composites have not been adequately experimented and investigated. The thermal analysis of hybrid composites is beneficial in automotive, aeronautical and many other engineering applications. This review summarizes illustratively about the experimental and analytical investigations and corroborations about the thermal analysis of hybrid metal matrix composites also provide convincing and conclusive recommendations for emerging trends in composite materials.*

***Key words:*** *Metal Matrix Composites, Thermal Analysis, Thermal Conductivity, Heat Capacity, Temperature Potential, Heat Capacity.*

## I. Introduction

A composite material is a macroscopic combination of two or more distinct materials having a recognizable interface between them. Composites are used not only for their structural properties, but also for electrical, thermal, tribological and environmental applications [1]. The term Metal Matrix Composites (MMCs) covers a very wide range of materials to simple reinforcements of castings with low cost refractory wool, to complex continuous fires lay-ups in foreign alloys. The properties of MMCs are controlled by the matrix, the reinforcement and the interface. In particular many of the considerations arising due to fabrication, processing and service performance of composites are related of processes that take place in the interfacial region between matrix and reinforcement.

Among modern composite materials, particle reinforced Aluminium Matrix Composites (AMCs) are finding increased application due to their favorable mechanical properties and good wear resistance [2]. Aluminium-Silicon Carbide and Aluminium-Graphite are used as reinforced composites to study its unique characteristics and behaviour. Aluminium Matrix Composites (AMC) consists of Aluminium or its alloys as the continuous matrix and a reinforcement that can be particle, short fiber or whisker or continuous fiber. Research and development activities of the last decade have resulted in the evolution of a class of MMCs termed as Discontinuously Reinforced Aluminium (DRA) composites. Particle or discontinuously reinforced AMCs have become very important because they are economical when compared to continuous fiber reinforced composites and they have relatively good isotropic properties compared to fiber-reinforced composites. These materials have captivated the attention of producers and researchers all over the world because of their outstanding properties such as high-strength-to-weight ratio, improved wear and elevated temperature resistance and low density. In addition these materials are comparatively easier to manufacture than the continuously reinforced composites and have a great potential to be available at low cost [3]. Though initially aimed only at aerospace and defense products, AMCs have progressively moved into higher volume applications. These materials employ a metallic matrix such as Aluminium to which is added reinforcement materials such as Alumina or Silicon Carbide (SiC). The net result is a composite material with enhanced mechanical properties particularly with regard to density and stiffness.

The development of metal matrix composites has been catalyzed by the need for structural materials with high specific strength and stiffness. The composites mainly with Aluminium matrix are fabricated either by molten metal infiltration or by powder metallurgical routes. The mechanical and fracture properties of Al-SiC composites are of primary importance in design and thermal considerations when they are to be used as structural materials. Metal Matrix Composites are a diverse class of materials that consist of a metallic alloy matrix typically reinforced with a ceramic phase in the form of particles, platelets, whiskers, short fibers and continuously aligned fibers. These composites are used in structural applications, and in applications requiring wear resistance, thermal management and weight savings. By far the most common commercial metal matrix composites are based on aluminium, magnesium and titanium alloys reinforced with either Silicon Carbide, Alumina, Carbon or Graphite [4].

## II. Thermo physical Properties of Metal Matrix Composites

The thermophysical properties of metal matrix composites are required to characterize the composites comfortably. Some of the important thermophysical properties considered are Density, Coefficient of Thermal Expansion, Thermal Conductivity and Diffusivity, Specific Heat and Thermal Stresses. The measurement and characterisation of thermophysical properties such as density, CTE (Coefficient of Thermal Expansion), Specific Heat and Thermal conductivity or resistivity plays an important role. Additionally requirements to this material class are given through their use under varying temperature conditions. So investigations and observations of thermophysical properties are not only performed at room temperature but also at higher temperatures or under cycling conditions.

The determination of Thermal Conductivity and Diffusivity can be accomplished by Laser Flash Technique. On the contrary, the evaluation of Specific Heat can be carried out using Differential Scanning Calorimetry or using Thermal Conductivity tester. Measurement of thermal cycling is necessary in order to simulate the behaviour and the performance of a material during its operation. Therefore the measurement of CTE or thermal conductivity of a material during several temperature cycles can be useful. Temperature ranges can be between room temperature and the proposed temperature of operation. Measuring of CTE during several cycling leads to the information about the deformation per cycle or the total resulting deformation during all cycles. The behaviour of CTE and Thermal conductivity during thermal cycling also allows a practical approach to understand about the interface properties in the material [5].

## III. Thermal Analysis of Composites

The need for the thermal analysis of hybrid metal matrix composites must be comprehensively discussed. The behaviour of composite materials is often sensitive to changes in temperature. This is mainly because, the response of the matrix to an applied load is temperature-dependent and changes in temperature can cause internal stresses to be set up as a result of differential thermal contraction and expansion of the constituents. Thermal analysis of hybrid composites is a pragmatic approach to clearly study its thermal characteristics. Most of the thermal studies are mainly concerned with AMCs but less information is available on hybrid composites [6].

The development, specification, and quality control of materials often require the measurement of thermo physical properties. This data can be critical to a successful design, especially with the rapidly increasing cooling requirements that result from the packaging of higher performance devices. A variety of methods, involving both steady state and transient techniques, are available for measuring thermal diffusivity, specific heat, thermal conductivity and thermal resistance. Information of the thermo physical properties of materials and heat transfer optimization of final products is becoming more and more vital for industrial applications. Over the past few decades, the flash method has developed into the most commonly used technique for the measurement of the thermal diffusivity and thermal conductivity of various kinds of solids, powders and liquids. Application areas are electronic packaging, heat sinks, brackets, reactor cooling, heat exchangers, thermal insulators and many others. Trouble-free sample preparation, small required sample dimensions, fast measurement times and high accuracy are only a few of the advantages of this non-contact and non-destructive measurement technique.

Metal matrix composites with high thermal conductivity and coefficient of thermal expansion are found widespread applications in electronic package and thermal management. The increasing requirement imposed on thermal management materials in microelectronics and semiconductors drives the development of advanced metal matrix composites (MMC) with high thermal conductivity (TC) to effectively dissipate heat and coefficient of thermal expansion (CTE) to minimize thermal stresses. This is of vital importance to enhance the performance, life cycle and reliability of electronic devices. Metal matrix composites with high volume fraction of reinforcement are attractive in view of the possibility to further enhance TC by the use of high TC components and the flexibility to adjust the CTE by controlling the content of reinforcement. Al and Cu were usually used as metal matrix due to their high TCs, and the reinforcements involved SiC, carbon and diamond. On the consideration that the composites produced from the same reinforcement have similar difficulties during fabrication, the composites with high TC were divided into three main categories: SiC/metal, C/metal and diamond/metal composites. Owing to the fact that specific thermal conductivity (thermal conductivity divided by density) of Al-based composites was higher than that of Cu-based composites, Al-based composites are more desirable in avionic applications where light weight is demanded [7].

Thermal studies on composite materials are getting greater importance in the present scenario. Thermal analysis will help to understand the properties of materials as they change with temperature. It is often used as a term for the study of heat transfer through structures. The assessment of thermal parameters of composites will benefit to analyze heat capacity, variation in the intensity of heat, heat diffusion and heat release rate. The main parameter considered in thermal analysis of composites is thermal conductivity. The increase in thermal conductivity of composites will depend on strength and porosity, which finds this property in aerospace and automobile applications extensively. Thermal diffusivity is an important property for materials being used to determine the optimal work temperature in design applications referred under transient heat flow. It is the thermophysical property that determines the speed of heat propagation by conduction during changes in temperature with time. The heat propagation is faster is faster for materials with high thermal diffusivity. Metal Matrix Composites can be customized to provide good CTE matching for thermal management and thermal conductivity applications. It is essential to evaluate new materials for the thermal stability and to measure properties including CTE and thermal conductivity for specialty products [16].

## IV. Measurement Techniques

Laser Flash technique is highly resourceful for the evaluation of Thermal Conductivity and Diffusivity The sample is positioned on an electronically controlled and programmable robot located in a furnace. The furnace is then held at a predetermined temperature. At this temperature the sample surface is then irradiated with a programmed energy pulse (laser or xenon flash). This energy pulse results in a homogeneous temperature rise at the sample surface. The resulting temperature rise of the rear surface of the sample is measured by a high speed infrared detector and thermal diffusivity values are computed from the temperature rise versus time data. The resulting measuring signal computes the thermal diffusivity, and in most cases the specific heat ($C_p$) data. The Laser Flash technique covers the widest measuring range of all techniques, 0.1 up to 2000 W/mK for Thermal Conductivity and 0.01 up to 1000 $mm^2/s$ for Thermal Diffusivity. The used Nd: YAG Laser will have a power output of 25 J/pulse. Both the power and the pulse length can be easily adjusted by the Software. Application areas are electronic packaging, heat sinks, brackets, reactor cooling, heat exchangers, thermal insulators and many others. Trouble-free sample preparation, small required sample dimensions, fast measurement times and high accuracy are only a few of the advantages of this non-contact and non-destructive measurement technique.

The thermal conductivity of metals, alloys or composites with 0,2 ... 100 W/mK can be measured by comparative method with steady state longitudinal heat flow in a temperature range room temperature up to about 1000°C. The comparative instrument measures heat flow based upon the known thermal properties of standard reference materials. The test specimen is sandwiched between two identical reference samples. This stack is placed between two heating elements controlled at different temperatures. A guard heater is placed around the test stack to ensure a constant heat flux through the stack and no lateral heat flow losses. As heat flows from the hot element to the cold element the temperature gradient across the stack is measured with thermocouples. In a laser flash method, laser fires a pulse at the sample's front surface and the infrared detector measures the temperature rise of the sample's back surface. The software uses literature-based analysis routines to match a theoretical curve to the experimental temperature rise curve. The thermal diffusivity value is the diffusivity value associated with the selected theoretical curve. To determine specific heat, the infrared detector measures the actual temperature rise of the sample. The response of the infrared detector is calibrated with a reference sample of known specific heat.

Coefficient of Thermal Expansion is one of the most important properties of MMCs. Since nearly all Metal Matrix Composites are used in various temperature ranges, measurement of CTE as a function of temperature is necessary in order to know the behaviour of the material. Several different systems for measurement of CTE can be used depending on the temperature conditions. One of the most common used system is a dilatometer. A dilatometer measures the length or the volume changes of the sample, when the sample follows a temperature program and submits a small force. In a push rod dilatometer the change in length of the sample is detected by an inductive displacement transducer. Calibration and corrections of measurements are done by using various standards and comparison with materials of known expansion. The measurement of the coefficient of thermal expansion (CTE) can be carried out in the temperature range from approximately –150°C to 1500°C.

## V. Investigative Review on Hybrid MMC

The investigations of thermal characterization of hybrid metal matrix composites have become a challenging task for the researchers. The thermal characterization on few hybrid composites have been carried out with convincing experimentations and evidences, but unable to emphasize on mainly Al-Gr-SiC composites. Some of the important research works carried out in MMC are mentioned:

L Z Zhao, M J Zhao, X M Cao et al [8] in their research on thermal expansion of hybrid SiC foam-SiC and Al composites have focussed on a new type of hybrid SiC foam–SiC particles–Al composites to be used as an electronic packaging substrate material were fabricated by squeeze casting technique, and their thermal expansion behaviour was evaluated. It was investigated that the measured CTEs are much lower than those of SiC particle-reinforced aluminium (SiC-Al) composites with the same content of SiC because of the characteristic interpenetrating structure of the hybrid composites. A material of such a low CTE is ideal for electronic packaging because of the low thermal mismatch and therefore low thermal stresses between the electronic component and the substrate

S Cem Okumus, Sardar Aslam et al [9] carried out an investigative study on Thermal Expansion and Thermal Conductivity behaviours of Al/Si/SiC hybrid composites clearly highlights that Aluminium-silicon based hybrid composites reinforced with silicon carbide and graphite particles were prepared by liquid phase particle mixing and squeeze casting. The thermal expansion and thermal conductivity behaviours of hybrid composites with various graphite contents (5.0; 7.5; 10 wt.%) and different silicon carbide particle sizes (45 μm and 53 μm) were investigated. Results indicated that increasing the graphite content improved the dimensional stability, and there was no obvious variation between the thermal expansion behaviours of the 45 μm and the 53 μm silicon carbide reinforced composites. The thermal conductivity of hybrid composites was reduced due to the enrichment of the graphite component Figures 1,2and 3 below depict CTE V/s Temperature which are based on the above observations.

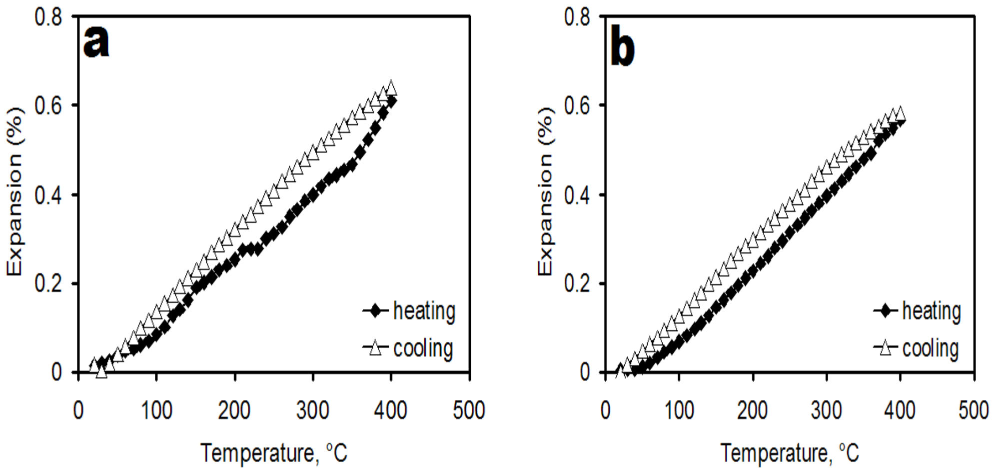


Fig. 1. Thermal strain response curves recorded during the heating and cooling between 20°C and 400 °C for (a) the hybrid Al-Si-20 vol.% SiC (53 μm)/graphite composites, (b)7.5 wt.% graphite and 10 wt.% graphite

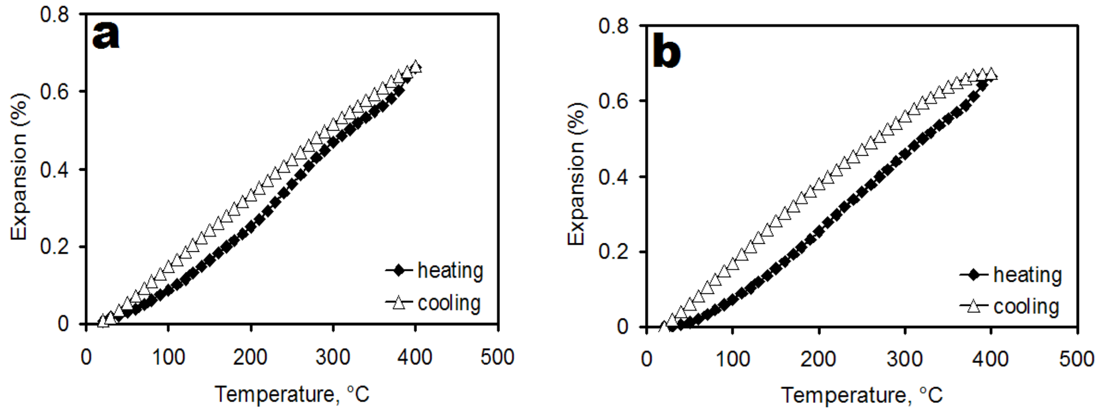


Fig. 2 Thermal strain response curves recorded during the heating and cooling between 20 °C and 400 °C for (a) the hybrid Al-Si-20 vol.% SiC (45 μm)/graphite composites (b)7.5 wt.% graphite and 10 wt.% graphite

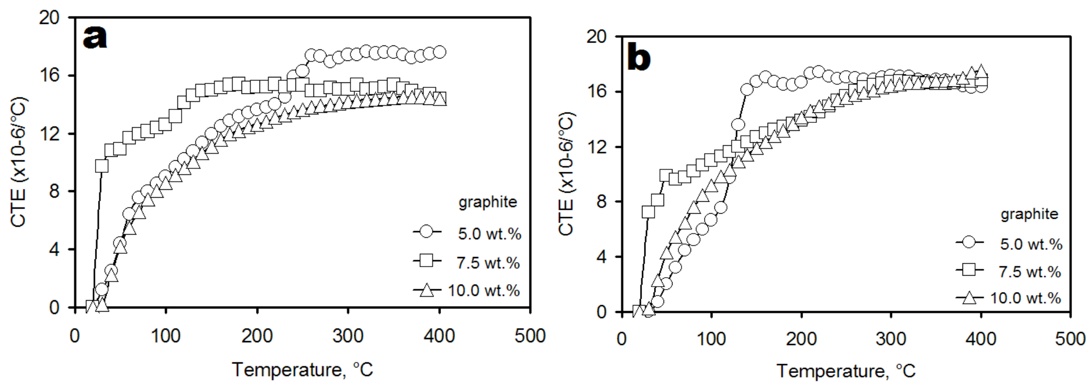


Fig. 3 Coefficient of Thermal Expansion as a function of temperature for (a) Al-Si-20 Vol % SiC (53 μm)/graphite composites (b) Al-Si-20 Vol % SiC (45 μm)/graphite composites

The table 1 shows the thermal conductivity results obtained at different temperatures for SiC reinforced Al-Si based hybrid MMC with various graphite contents. Thermal Conductivity decreases with increasing graphite content. The percentage volume fraction is maintained constant at 20% with variation in weight by considering grain size to be 45 μm and 53 μm.

Table I: Thermal Conductivity values (W/mK) of the Al-Si hybrid composites between 50 °C and 300 °C

| Composite | 50 °C | 100 °C | 150 °C | 200 °C | 250 °C | 300 °C |
|---|---|---|---|---|---|---|
| Al-Si 20 vol.% SiC at 5.0 wt.% graphite (45 μm) | 186.4 | 178.8 | 171.1 | 165.4 | 161.2 | 158.1 |
| Al-Si 20 vol.% SiC at 7.5 wt.% graphite (45 μm) | 181.2 | 173.5` | 157.6 | 148.2` | 138.8 | 130.5 |
| Al-Si 20 vol.% SiC at 10 wt.% graphite (45 μm) | 176.4 | 165.5 | 152.4 | 136.3 | 128.8 | 118.4 |
| Al-Si 20 vol.% SiC at 5.0 wt.% graphite (53 μm) | 202.2 | 195.5 | 188.4 | 171.5 | 168.3 | 158.6 |
| Al-Si 20 vol.% SiC at 7.5 wt.% graphite (53 μm) | 194.8 | 190.4 | 181.1 | 170.5 | 162.1 | 150.8 |
| Al-Si 20 vol.% SiC at 10 wt.% graphite (53 μm) | 185.6 | 175.5 | 166.2 | 155.3 | 146.21 | 136.7 |

Davis L C [10] described that thermal conductivity of metal matrix composites describes the thermal conductivity of metal-matrix composites, which are potential electronic packaging materials, is calculated using effective medium theory and finite-element techniques. The thermal boundary resistance, which occurs at the interface between the metal and the included phase (typically ceramic particles), has a large effect for small particle sizes. It is found that SiC particles in Al must have radii in excess of 10 μm to obtain the full benefit of the ceramic phase on the thermal conductivity. Bimodal distributions of particle size are considered, since these are often used to fabricate high-volume fraction composites. It is found that if the small particles (in a bimodal distribution) have a radius less than 2.5 μm in SiC/Al their addition reduces the thermal conductivity of the composite.

J M Molina, J Narciso, E Louis et al [11] studied on thermal conductivity of Al-SiC composites demonstrates that the thermal conductivity of aluminium matrix composites having a high volume fraction of SiC particles is investigated by comparing data for composites fabricated by infiltrating liquid aluminium into preforms made either from a single particle size, or by mixing and packing SiC particles of two largely different average sizes (170 and 16 μm). For composites based on powders with a monomodal size distribution, the thermal conductivity increases steadily from 151 W/m K for particles of average diameter 8 μm to 216 W/m K for 170 μm particles. For the bimodal particle mixtures the thermal conductivity increases with increasing volume fraction of coarse particles and reaches a roughly constant value of 220 W/m K for mixtures with 40 or more percentage volume of coarse particles. It is shown that all present data can be accounted for by the differential effective medium (DEM) scheme taking into account a finite interfacial thermal resistance.

J M Molina, M Rheme et al [12] reviewed on thermal conductivity of aluminium matrix composites reinforced with mixtures of diamond and SiC particles is carried out that illustrates that aluminium matrix composites reinforced with mixtures of diamond and SiC particles of equal size were produced by gas pressure-assisted liquid metal infiltration. Replacing SiC gradually by diamond particles results in a steady increase of thermal conductivity from 220 to 580 W m K. Electrical conductivity measurements indicate that the silicon content in the matrix decreases with increasing diamond volume fraction. Predictions of the differential effective medium scheme generalized for multiple types of inclusions agree well with experimental results.

R Arpon, E Louis et al [13] carried out a detailed analysis is also carried out on thermal expansion behaviour of aluminium/SiC composites with bimodal particle distributions where it summarizes that The thermal response and the coefficient of thermal expansion (CTE) of aluminium matrix composites having high volume fractions of SiC particulate have been investigated. The composites were produced by infiltrating liquid aluminium into preforms made either from a single particle size, or by mixing and packing SiC particulate of two largely different average diameters (170 and 16 μm, respectively). The experimental results for composites with a single particle size indicate that the hysteresis in the thermal strain response curves is proportional to the square root of the particle surface area per unit volume of metal matrix, in agreement with current theories. Instead, no simple relationship is found between the hysteresis and any of the system parameters for composites with bimodal particle distributions. On the other hand, the overall CTE is shown to be mainly determined by the composite compactness or total particle volume fraction; neither the particle average size nor the particle size distribution seems to affect the overall CTE. This result is in full agreement with published numerical results obtained from finite element analyses of the effective CTE of aluminium matrix composites. The results also indicate that the CTE varies with particle volume fraction at a pace higher than predicted by theory.

R A Saravanan, J Narciso et al [14] in their investigative approach on thermal expansion behaviour of particulate metal matrix composites explains that Aluminium-matrix composites containing thermally oxidized SiC particles of controlled diameter ranging from 3 to 40 μm have been produced successfully by vacuum assisted high-pressure infiltration. Their thermal-expansion coefficients (CTEs) were measured between 25°C and 500°C with a high-precision thermal mechanical analyser (TMA), and compared with the predictions of various theoretical models. The thermal-expansion behavior of the three-phase Al/SiC/SiO2 composite shows no significant deviation from the predictions of elastic analysis, since the measured CTEs lie within the elastic bounds derived by Schapery's analysis. The effect of particle size is quite evident in the pressure-infiltrated composites: the larger the particles, the greater the thermal expansion of the composite. The observed behavior of these composites is discussed in terms of particle size, silica layer formed during oxidation, and thermal stresses developed as a result of the CTE mismatch between the reinforcement and the matrix.

Parker W J, Jenkins R J, Abbott G L et al [15] carried out a comprehensive study on Flash method of determining Thermal Diffusivity, Heat Capacity and Thermal Conductivity is carried out that lucidly narrates that a flash method of measuring the thermal diffusivity, heat capacity and thermal conductivity is described for the first time. A high-intensity short-duration light pulse is absorbed in the front surface of a thermally insulated specimen a few millimeters thick coated with camphor black, and the resulting temperature history of the rear surface is measured by a thermocouple and recorded with an oscilloscope and camera. The thermal diffusivity is determined by the shape of the temperature versus time curve at the rear surface, the heat capacity by the maximum temperature indicated by the thermocouple, and the thermal conductivity by the product of the heat capacity, thermal diffusivity and the density. These three thermal properties are determined for copper, silver, iron, nickel, aluminium, tin, zinc, and some alloys at 22°C and 135°C and compared with previously reported values. In another review on metal matrix composites with high thermal conductivity for thermal management applications, it emphasizes that the latest advances in manufacturing process, thermal properties and brazing technology of SiC/metal, carbon/metal and diamond/metal composites were presented. Key factors controlling the thermo-physical properties were discussed in detail. The problems involved in the fabrication and the brazing of these composites were elucidated and the main focus was put on the discussion of the methods to overcome these difficulties. This review shows that the combination of pressure-less infiltration and powder injection molding offers the benefits to produce near-net shape composites [7]

Na Chen, Zhang et al [16] examined the effect of thermal cycling on the expansion behaviour Al/SiC composites is carried out where the coefficient of thermal expansion (CTE) and accumulated plastic strain of the pure aluminium matrix composite containing 50% SiC particles (Al/SiCp) during thermal cycling (within temperature range 298–573 K) were investigated. The composite was produced by infiltrating liquid aluminum into a preform made by SiC particles with an average diameter of 14 microns. Experiment results showed that the relationship between the CTE of Al/SiCp and temperature is nonlinear; CTE could reach a maximum value at about 530 K. The theoretical accumulated plastic strain of Al/SiC composites during thermal cycling has also been calculated and compared with the experimental results.

Tran Nam, Requena et al [17] have emphasized on thermal expansion behaviour of aluminium matrix composites with densely packed SiC particles where The coefficient of thermal expansion (CTE) of Al-based metal matrix composites containing 70 vol.% SiC particles (Al/SiC) has been measured based on the length change from room temperature to 500 °C. In the present work, the instantaneous CTE of Al/SiC is studied by thermo-elastic models and micromechanical simulation using finite element analysis in order to explain abnormalities observed experimentally. The CTE is predicted according to analytical thermo-elastic models of Kerner, Schapery and Turner. The CTE is modelled for heating and cooling cycles from 20 deg C to 500 deg C considering the effects of microscopic voids and phase connectivity. The finite element analysis is based on a two-dimensional unit cell model comparing between generalized plane strain and plane stress formulations. The thermal expansion behaviour is strongly influenced by the presence of voids and confirms qualitatively that they cause the experimentally observed decrease of the Coefficeint of Thermal Expansion above 250 deg C.

The graphical analysis on CTE versus temperature is shown below. The CTE results using GPE formulation during the 2nd heating shows good agreement with the experimental results for the whole temperature range for C1 and up to about 350°C for C2, respectively. The CTE curves of both unit cell models with voids using genaralized plane strain during cooling fall between lower and upper Schapery bound in the whole temperature range and fit to the experiment below 250°C.

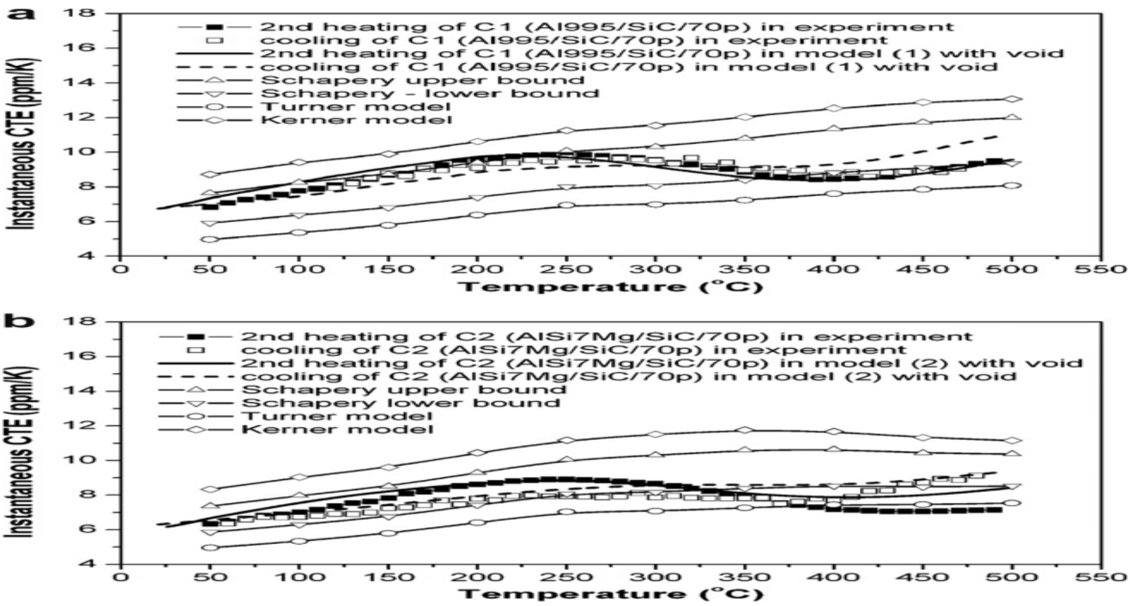


Fig 4: CTE results obtained from thermo-elastic models and unit cell models with voids during heating compared with experimental results of composite C1 and composite C2.

N Chawla, X Deng et al [18] has carried out research on thermal expansion anisotropy in extruded SiC particle reinforced 2080 aluminium alloy matrix composites where Thermal expansion behavior is an important physical property of metal matrix composites (MMCs). For extruded Al/SiC composites, both the particle volume percent and the orientation relative to the extrusion direction have significant effects on the coefficient of thermal expansion (CTE) of a composite. In this study, the coefficient of thermal expansion of extruded, SiC particle reinforced 2080 Al composites were measured using a thermal mechanical analyzer (TMA). It was found that the anisotropic distribution of SiC particles determines the anisotropic thermal behaviour of Al/SiCp composites. For the same SiC content, the CTE in the short transverse direction (normal to the extrusion axis) is higher than that in the transverse direction, with the longitudinal direction (parallel to the extrusion axis) having the lowest CTE. Finite element modeling (FEM), based on the actual microstructure of Al/SiCp composites, was employed to simulate the thermal behavior. The experimental results for the CTE of the composite correlated very well with those predicted by two-dimensional (2D) numerical models. The FEM results showed that orientation of SiC particles changes the internal stress in the composite, which yields anisotropic thermal behavior. A comparison was made between the experimental results and the FEM model, and these were related to several analytical models.

The graphical analyses are shown that emphasises CTE comparison between experimental results and microstructure based FEM simulation for longitudinal, transverse and short transverse orientations. The FEM results of the current study, as shown in Fig. 5, show the anisotropy of CTE, which is quite similar to the experimental data. At a particular SiC content, the short transverse direction has the largest CTE followed by transverse and then the longitudinal direction.

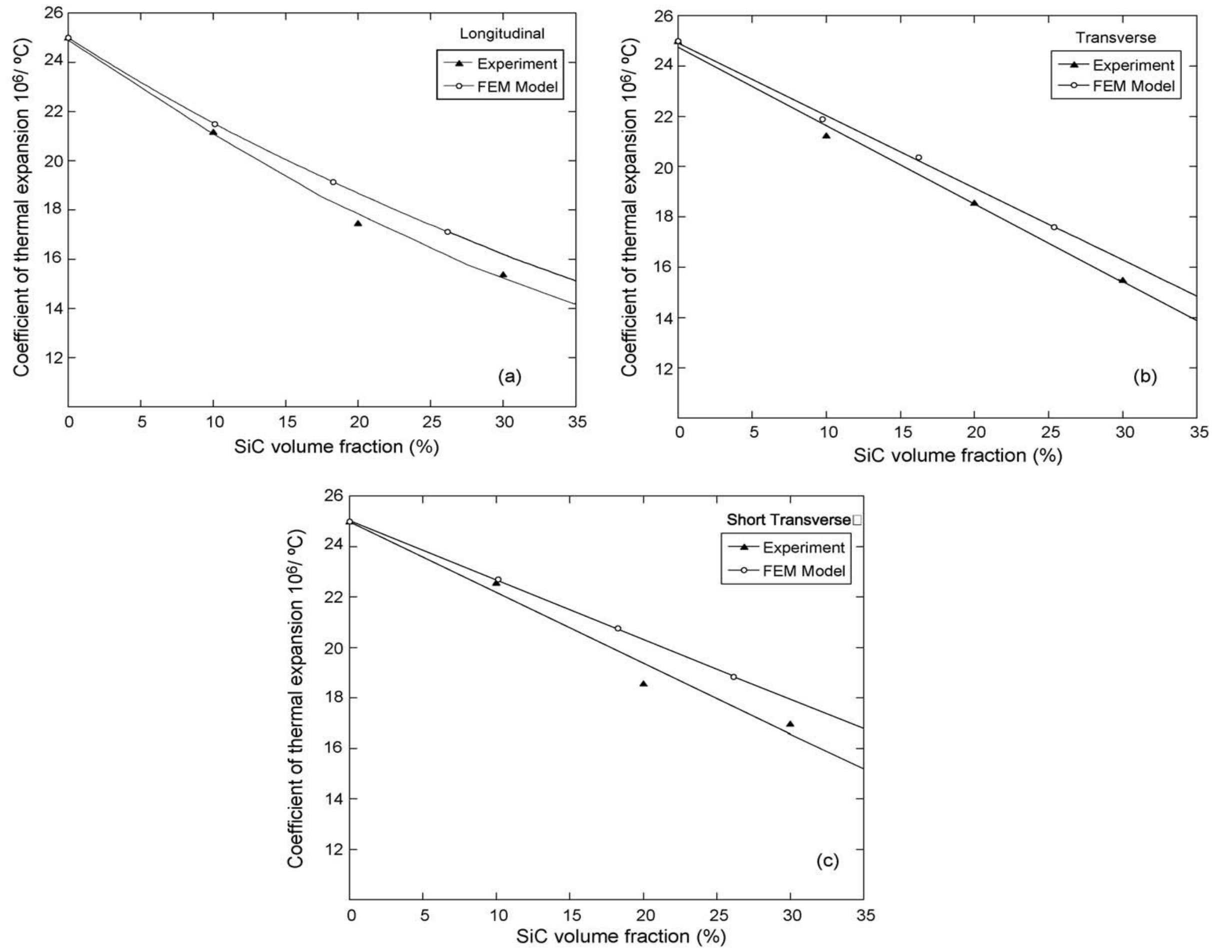


Fig 5: CTE comparison between experimental results and microstructure-based FEM simulation for: (a) longitudinal, (b) transverse, and (c) short transverse orientation. The FEM results are consistent with the experiment, although the predictions are slightly higher.

Zhang, Wu et al [19] scrutinized a study on microstructure and thermal conduction properties of an Al-12 Si matrix composite reinforced with dual sized SiC particles is carried out where it deal with the microstructural characterization and thermal conduction properties of an Al-12Si matrix composite reinforced with 70 vol% SiC particles of two sizes, with an emphasis on the effect of dual sized particles on thermal conductivity. In this work, the SiC particles were a mixture of 20 μm and 60 μm with a weight ratio of 4:1. This gives a particle size of 23 µm. The SiC particles had a thermal conductivity of 160–180 W/(m·K). The calculated value agrees well with the experimental value, suggesting that the modified EMA with an equivalent particle size was valid in the case of a dual sized particle reinforced composite.

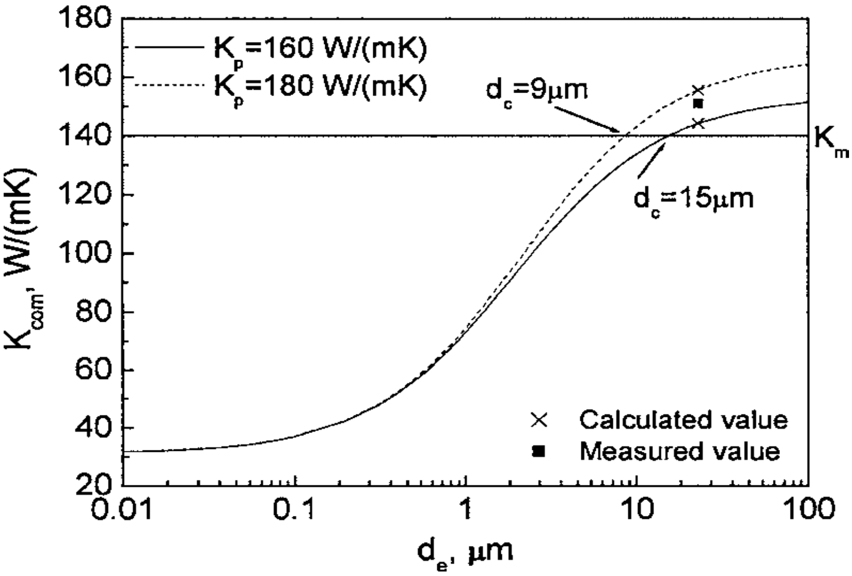


Fig 6: Variation of K of SiC/Al composite with particle size

Weidenfeller, Hofer et al [20] summarized an analysis on thermal conductivity, thermal diffusivity and specific heat capacity of particle filled polypropylene is carried out where Composites samples of polypropylene (PP) with various fillers in different fractions (up to 50 vol%) were prepared with an injection moulding process to study the evolution of the properties as a function of filler content. Standard filler materials like magnetite, barite, talc, copper, strontium ferrite and glass fibres were used. Thermal diffusivities, specific heat capacities and densities of the prepared composite samples were measured, and thermal conductivities were derived. Thermal conductivity of the polypropylene is increased from 0.27 up to 2.5 W/(m K) with 30 vol% talc in the polypropylene matrix. Thermal conductivities of the filled polypropylene samples are compared with the modelled values according to Hashin and Shtrikman. The interconnectivity of the particles in the polypropylene matrix is derived from a comparison between modelled and measured thermal conductivity values.

Hohenauer et al [21] studied on flash methods to examine diffusivity and thermal conductivity of metal foams is conducted where The analysis of the standard uncertainty of thermal conductivity results obtained by a comparative set-up motivated the use of a laser flash device to determine the thermal conductivity of metallic foam materials. In particular a Magnesium alloy is investigated. To meet the requirements of flash techniques coplanar samples are prepared. Therefore the surface near open porosity is filled with a ceramic paste (e.g. SiC). A finite element model is generated to study the influences of the preparation method to the measurement results. This enables to separate the conductivity behaviour of the foam structure from the inhomogeneity effects of the prepared sample.

## VI. Summary

From the above research reviews, it can be noticed that the thermal characterization on hybrid MMC is carried out to limited extent. Expansive studies are to be carried out on different hybrid composites with proper experimentation and validation. In the future investigation, it is proposed to use Aluminium-Silicon Carbide-Graphite Hybrid Composite standard test specimens using thermal analyzer namely Dilatometer, Thermal Conductivity tester or Laser Flash apparatus, Differential Scanning Calorimeter, Modulated Differential Scanning Calorimeter. These specimens have different proportions of reinforcements and while conducting the experiments the parameters are varied to analyze their thermal characterization. The results obtained can be analyzed using Analysis of Variance. Then the significant factors affecting thermal parameters are determined and the thermal parameters are optimized. A mathematical model could be developed involving thermal parameters and the response. The theoretical results can be compared with the experimental results to establish an effective transient thermal analysis. Maximum emphasis is given to the experimentation to carry out thermal analysis for the metal matrix composites. A CFD tool can also be used to carry out the thermal analysis.

In the present scenario, it is pertinent to carry out research work on hybrid composites for their mechanical and thermal characteristics. Limited research has been carried out on Aluminium-Silicon Carbide-

Graphite hybrid composite based on its thermal properties. The Aluminium-Silicon Carbide-Graphite hybrid composites are expected to have excellent thermal property and possess unique behaviour. Thermal analysis of Aluminium-Silicon Carbide-Graphite hybrid composites may help to know its hidden properties and also benefits to clearly comprehend its applications in the fields of Manufacturing, Automotive applications and Thermal Engineering. The investigation may be beneficial for the industries to know about the developments and advanced techniques in the field of composite materials.

The structured reinforced metal matrix composites selected are Silicon Carbide (SiC) and Graphite (Gr) with aluminum as matrix material. This combination is unique and is capable of exhibiting substantial transient characterization behaviour. These reinforced composites possess unique thermal properties and help in exhibiting transient characterization behaviour. The effect of Silicon Carbide and Graphite particulates on the resultant thermal behavior can be expansively investigated and studied The Aluminium-Silicon Carbide-Graphite hybrid composites are expected to have excellent thermal property and possess unique behaviour. Thermal analysis of Aluminium-Silicon Carbide-Graphite hybrid composites may help to know its hidden properties and also benefits to clearly comprehend its applications in the fields of Manufacturing and Thermal Engineering. The present investigation may be beneficial for the industries to know about the developments and advanced techniques in the field of composite materials. They can also acquire complete information about the thermal characterization of hybrid metal matrix composites. The evaluation of thermal parameters requires extensive experimentation, which is both expensive and time consuming. Experimentation should be carried out in a systematic way so as to get reliable results with minimum, cost and time.

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