International Journal of Applied Engineering and Technology ISSN: 2277-212X
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2022, Vol.12, pp.307-312/Saravanan et al.
Research Article

INFLUENCE OF AGING TEMPERATURE ON MECHANICAL PROPERTIES AND THERMAL EXPANSION OF ALUMINIUM HYBRID COMPOSITE

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ABSTRACT

The mechanical and fracture properties of aluminum (Al), silicon carbide (SiC_p) composites are of primary importance in design and thermal considerations for structural applications. In this work, the weight proportion of silicon carbide (SiC_p of 220 µm particulates) 15 Wt % and graphite (Gr) 5 Wt % were reinforced in aluminum (LM 25) matrix using sand casting technique. The mechanical, thermal properties and micro structures of aluminum hybrid composite are investigated for different age hardening temperatures (350º C, 400º C and 450º C). The thermal properties test was conducted upto the maximum temperature of 550º C using dilatometer. The reinforcement result shows appreciable improvement in mechanical properties on the tensile and compressive stresses. The behavior 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 may cause the internal stresses, as a result there is a different thermal contraction and expansion of the constituents (Al) matrix. The result reveals that the silicon carbide particulate reinforcement leads to concurrent augmentation of the thermal as well as mechanical properties, when compared to base material LM25.

***Keywords:** Silicon Carbide, Graphite, Sand Casting, Dilatometer, Age Hardening, Co-efficient of Thermal Expansion*

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]. Among modern composite materials, particle reinforced aluminum matrix composites (AMCs) are found to have increased applications due to their favorable mechanical properties and good wear resistance [2]. By far the most of the common commercial metal matrix composites are based on aluminum, magnesium and titanium alloys reinforced with silicon carbide, alumina, carbon or graphite [3]. Hybrid Metal Matrix Composite (HMMC) has been playing a significant role in engineering applications particularly in light weight materials. Aluminum alloy can be an efficient and effective braking material compared to cast iron in automobile industries. But for the poor wear resistance and high thermal elongation properties of aluminum alloys make them unreliable in the selection of material. The reinforcement of SiC_p particulate will enhance the wear behavior and reduce the thermal elongation without any substantial modification of the base material properties; in fact it will improve some properties marginally when graphite particles are used for dry lubricant in state. In a practical application, high stress due to thermal environment may result in rapid crack propagation through the material interfaces. Therefore, a strong interface is highly desirable. In wear application absorption or transfer of the energy of momentum, usually by means of friction is absorbed and dissipated in the form of heat. It must have good antedate characteristics, their effectiveness should not decrease with prolonged application, and thus it should have good thermal characteristics. When the frictional heat developed results in an occasional uneven temperature distribution on the material inducing severe thermal distortion.

There were few studies on high temperature wear behavior of age hardenable MMCs, and these studies are focused on ex-situ MMCs. Martín et al. (1996) noted that heat treatment did not modify the high temperature wear resistance of either the composites (AA 2618–15 vol.% SiC_p) or unreinforced alloy (AA 2618). Muratoglu and Aksoy (2000) also found the similar results in their studies on the effect of heat treatment on the high temperature wear behavior of the Al–4Cu alloy and Al–4Cu–SiC_p composites. Okumus et al (2012) carried out an investigative study on thermal expansion and thermal conductivity behaviours of aluminium-silicon based hybrid composites reinforced with silicon carbide and graphite particles prepared by liquid phase particle mixing and squeeze casting process. They observed that, upto 20 % improvement in yield strength, a lower coefficient of thermal expansion and a higher modulus of elasticity, and they are more wear resistant than the corresponding non reinforced matrix alloy systems [6]. By varying the matrix, reinforcement and volume fractions, the MMCs can be customized to provide a good coefficient of thermal expansion (CTE) matching for thermal management and thermal conductivity (TC) applications [7, 8]. It is essential to evaluate new materials for their thermal stability and to measure their properties including CTE and TC for specialty products, such as break discs made from castings, before actual use. It is expected Al-Si/SiC_p/graphite hybrid composites can be used as load bearing material for such kind of applications. In this work, the thermal expansion and mechanical properties of an aluminum-silicon based hybrid MMC reinforced with SiC_p and graphite was investigated in terms of different age hardening temperatures.

EXPERIMENTAL PROCEDURE

Materials and Processing:

Hybrid metal matrix composite of Al-SiC_p added with graphite was the material chosen for the present study. The hybrid composite contain aluminum alloy (LM25) with 15 % of SiC_p and 5% of graphite fabricated using sand casting process. Table 1 shows the chemical composition of LM25 and Table 2 shows the details of reinforcements. The hybrid composite is sand casted and the specimens are prepared as per the dimensions in the Table 3. Prior to testing, all the samples were heated upto 300^0 C with the interval of 2 hours to maintain the homogeneous structure of composite.

2.2 Coefficient of Thermal Expansion (CTE) using Dilatometer:

CTE of the specimens were measured using horizontal push rod dilatometer (Model: DIL 402 PC, Make: NETZSCH) which was programmed to measure temperature change and with negligible sample strain. The samples were tested as per the ASTM E831. The equipment has been calibrated for high degree of reproducibility. The schematic of the dilatometer is shown in Figure 1.The horizontal design of the dilatometer with easier to be moved into furnace makes it simple to place samples into the large recess of the tube-type sample carrier. A thermocouple in direct proximity to the sample yields reproducible temperature measurement. This also allows use for calculation of endothermic and exothermic effects in the sample as well as determination of all the characteristic expansion values. The testing parameters to find thermal expansion are tabulated in Table 4. The change in length measurements due to thermal expansion is related to temperature change by a linear expansion coefficient (equation 1). It is the fractional change in length per degree of temperature change by assuming negligible effect of pressure.

$$\alpha_L = \frac{1}{L}\frac{dL}{dT} \qquad (1)$$

Where L is a particular length measurement and dL/dT is the rate of change of that linear dimension per unit change in temperature. An estimate of the amount of thermal expansion can be described by the material strain, given by $\varepsilon_{thermal}$ and defined as equation 2

$$\varepsilon_{thermal} = \frac{(L_{final} - L_{initial})}{L_{initial}} \qquad (2)$$

Where $L_{initial}$ is the length before the change of temperature and L_{final} is the length after the change of temperature.

2.3 Mechanical characteristics – Evaluation

The cast HMMC of 10 mm diameter and gauge length of 30 mm (as per ASTM B557M) were axially loaded in an universal testing machine (make: Associated Scientific Engg. Works, New Delhi) .Tensile elongation was measured using standard extensometer. The hardness test was carried out using a Micro Vickers Hardness testing machine (make: Wilson Wolpert, Germany). The compression test was carried out using universal compression testing machine.

RESULTS AND CONCLUSION

3.1 Coefficient of Thermal expansion (CTE):

The CTE was measured for the samples with different aging temperatures 350 ^{O}C, 400 ^{O}C, 450 ^{O}C. The tests were conducted as per the parameters listed in Table 3. The experiment was conducted to find the linear CTE only. The volumetric expansions were not considered. The change in length is taken into account for the present experiment. Thermal strain can be attributed to thermal stress. Higher thermal stress can lead to the generation of strain hysteresis between the heating and cooling cycles and to the retention of residual strain as the result of the plastic deformation or yielding of materials. Thermal response curves can provide valuable information for predicting the thermal stability, failure/damage and life of the structural materials that have been subjected to heating and cooling conditions [9, 10]. The total % of elongation and CTE of three different temperature hardened specimens were shown in Figure 2 and Figure 3 respectively. Typical variations of elongation at various ageing temperatures were shown in Figure 2. It is seen that the samples ageing with 450° C has resulted in enhanced thermal resistance, also aging between 350-400° C only results in marginal variation. This is also reflected to variation of coefficient of thermal expansion shown in Figure 3. It is seen that above 125° C a noticeable change with higher property of sample ageing with 400° C. Better distribution of SiC_p with the matrix graphite in the boundary of microstructure persists to 450° C contributed to enhance thermal resistance observation. It is to be noted that, despite enhance resistance of minimal expansion the co-efficient of expansion (αT) also vary with aging temperature. It is seen that composites of 350/400° C, with aging temperature of 450° C, the microstructure exhibits a relatively closer structure. This also reflects in the reduced aging of CTE (Figure 3). The decrease of the maximum temperature for CTE values for graphite reinforced composites is considered as a result of the relaxation of the compressive stress in the matrix, which was also stated by Fei et al (2006), who studied $Al/AlBO_w$ containing Fe_3O_4 particle composites produced by the squeeze casting method. The reduction in CTE values can also be attributed to the lower CTE value of graphite compared to the Al-Si matrix alloy and SiC reinforcement and the ability of the reinforcements to effectively constraint the expansion of the matrix. It is reported that, SiC_p and graphite has a CTE of about 4.5 10^{-6}/°C and 4.06 10^{-6}/°C in the temperature range of 20 °C – 400 °C, while the compared value of Al-12% Si alloy about 22.3 10^{-6}/°C in the temperature range of 50 °C – 300 °C, respectively [12, 13, 9]. The CTE of particle reinforced MMCs is affected by a variety of factors, such as interfacial reactions, plasticity due to CTE mismatch between particle and matrix during heating or cooling, and residual stresses [14]. Residual stresses cause compressive stresses on the reinforcements and tensile stress on the matrix, and their magnitude varies with the characteristics of reinforcement and matrix as well as with the processing [9, 10, 15]. Ren et al. (2007) stated that such a tensile stress is considered to be generated from the CTE mismatch between the matrix and reinforcements, progressively diminished approaching to zero during the heating stage. Due to the thermal expansion mismatch between graphite and the metal phase, residual stresses are expected to be tensile in the metal phase and compressive in the graphite, and, during heating, the residual stresses relaxed elastically or plastically [16].

3.2 ***Observation of micro structure:***

Figure 4 shows the microstructure images of hybrid composite materials after aging at different temperatures. The composite specimen (cast-preform) was prepared using standard hand polishing of 600, 800 and 1000-grit silicon carbide papers. The polished specimens were etched with keller etching solution. The etch polish procedures were used to attain good microstructure. These microstructure investigations show the uniform distribution of Al LM25, SiC_p and Gr in each hybrid composites. After preheating, in Figure 4 a) HMMC at 350^0C, the microstructure is different. The microstructure presents uniform distribution of SiC_p particulates. In aluminium solid structure, the graphite particles can be seen as spots over the grain boundary. Figure 4 b) shows the micro structure of specimen ageing at 400^0C, presents uniform distribution of SiC_p particles to aluminium matrix (solid solution) the graphite particles can be seen over the boundary. Figure 4 c) shows the micro structure of specimen ageing at 450^0C. Uniform distribution of SiC_p can be seen in aluminium solid solution. Graphite can be seen over the boundary. Although it was stated that [17] porosity can severely degrade the thermal and mechanical properties of the MMCs, the SiC_p and graphite particles were distributed uniformly in the aluminum matrix. The principal strengthening mechanisms for the composites may include the load transfer mechanism, dislocation density increment, and interaction of dislocation and particles, such as Orowan strengthening, refining grain size, and increasing plastic constraint [21-22].

3.3 Observation on micro hardness:

Figure 5 shows the evaluation of micro hardness values of specimens after aging process. It shows that at 350^0 C, it has some moderate hardness but low when compared with specimen hardness before aging (81.67 HV). After 400 ^{O}C, it becomes decreases. This prediction shows that the hardness values of specimens after 400^0 C goes on decreasing gradually. It is seen that with higher ageing temperature, the composite exhibits a reduction in hardness. It can be attributed to even distributed with SiC_p and graphite, with the occurrence of aggloramates. Cooling of SiC_p with as cast at 350 ^{0}C aged specimen. Figure 5, shows with aging temperature, the micro hardness range of the MMC 54.5HV, 55HV at 400 ^{0}C and 450 ^{0}C. It is reported [19-20, 22] that due to the different coefficient of thermal expansion (CTE) between the matrix and reinforcement during solidification, a large number of dislocations are generated around the reinforcement, leading to the formation of heterogeneous nucleation sites for precipitates.

3.4 Observation on compression test:

Figure 6, shows the graph that visualizes the compressive stress variation of specimens after aging process at three different temperatures (350 ^{0}C, 400 ^{0}C, 450 ^{0}C). The below shown graphs clearly explains the variation of compressive stresses after aging process. On evaluating after aging specimens, it decreases. After that it goes on increasing gradually.It is seen that among the specimen ageing with 350 ^{O}C results in reduced compressive resistance despite higher hardness this could be altered relatively more structure heterogonally with as cast/ lower ageing temperature also its seen that 350 ^{O}C ageing specimen exhibits a cracking/failure around 315 MPa / 0.5025 strain while 400 ^{O}C /450 ^{O}C facilitates enhanced compressive resistance with a plateau region and peak Structure (433.98 MPa/ 0. 45 strain and 437.99 MPa / 0.5 strain value for the age hardening of 400 ^{O}C and 450 ^{O}C respectively).

3.5 Observation on tensile test:

Usually, the tensile stress value is in inverse of the compressive stress value. Figure 7 shows that tensile stress graph variation of specimens after aging at three different temperatures respectively. This shows the tensile stress value of specimen before aging process was much low. Further on 350° C, the tensile stress value increases and at 400 ^{0}C, it goes on increasing. After that it becomes decreasing rate. With this bar chart, we can predict that the tensile stress value was high up to 400° C respectively. Observation on tensile loading clearly indicates superior tensile resistance of sample aged with 400° C followed by samples aged at 350° C.

CONCLUSION

From the study on influence of aging temperature (350° C, 400° C and 450° C) on mechanical properties and thermal expansion of aluminium hybrid composite(Al + 15%SiC_p+ 5%Gr), the following conclusions are drawn:

- Ageing of cast MMC results in tensile loading sensitive material responses.
- With compression loading; ageing under high temperature results in better material responses.
- The enhanced performance despite the reduced hardness could be attributed to more structural homogeneity under ageing.
- MMC aged with higher order temperature of 450^0 C exhibits enhanced thermal resistance.

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