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Mechanical Engineering

Elixir Mech. Engg. 48 (2012) 9517-9519

ISSN: 2229-712X

Effect of thermal ageing on the coefficient of thermal expansion of Aluminium 7075/SiC $_p$ composites

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ARTICLE INFO

Article history:
Received: 23 May 2012;
Received in revised form:
28 June 2012;
Accepted: 17 July 2012;

Keywords
Alloys,
Heat treatment,
Coefficient of thermal expansion (CTE).

ABSTRACT

This paper describes the study of coefficient of thermal expansion (CTE) of as-cast and heat treated aluminium 7075/ SiC composites. These composites were subjected to different aging durations. The stir casting technique is used to prepare the castings. Castings were machined in accordance with ASTM standards followed by heat treatment process. All the castings were aged to different periods of 1hr, 3hr, 5hr at an aging temperature of 175 ^{o}C. Coefficient of thermal expansion tests were performed in both as-cast and heat treated conditions. In each case the coefficient of thermal expansion values were found to increase with increase in aging durations. Solution heat treatment at 530 ^{o}C followed by artificial aging at 175 ^{o}C found to increase in dimension change of every specimen tested. The coefficient of thermal expansion curves exhibited some residual strains, which were decreased with the increase in aging durations.

Introduction

Aluminium based composites have received considerable attention for aerospace applications because of their low density and high stiffness [1]. Further the addition of ceramic reinforcements (e.g.SiC, E-glass fiber) has raised the performance limits of the Aluminium(6061) alloys [2]. Ceramic materials are employed for high-temperature structural applications because of their high melting point, high temperature strength, stiffness and oxidation resistance [3]. However, ceramics have limited fracture toughness. Owing to high strength, high stiffness and high resistance to wear, ceramic reinforced MMCs have attracted considerable attention in the past two and half decades [4]. Composite materials are widely used because the qualities of two or more constituents can be combined without seriously affecting their short comings [5].

The mostly used metals as matrix materials for producing MMCs are aluminium and its alloys, since their ductility, formability and low density can be combined with the stiffness and load bearing capacity of the reinforcement. Microscopically, the mechanism of failure seems to depend on many factors such as strength of the interface between the reinforcements and the surrounding matrix, the reliability of the reinforcements and the matrix material properties [6].

SiC/Al_2O_3 particulate-reinforced Al MMCs are extensively used in the aero space , automobile and srorts industries due to their light strength, light weight, low CTE, good thermal properties and excellent wear and abrasion resistance compared to monolithic counterparts [7].

The incorporation of ceramic particles in the matrix material, results in a higher elastic modulus and a reduced coefficient of thermal expansion [13]. The strengthening of particulate reinforced MMCs is associated with a high dislocation density in the matrix due to difference in CTE between the reinforcement and the matrix. Increase in the strength and decrease in the CTE of composites after the work hardening process are discussed in the present paper.

In the present work, the weight fraction of SiC particulates used for making MMCs was 3%. The present investigation is undertaken with the main objective of studying the thermal behavior of heat-treated Al MMCs reinforced with SiC after different aging durations.

Experimental procedure

Preparation of composites

The matrix material used for producing MMCs in this study is aluminium 7075. This alloy is best suited for mass production of lightweight castings. Table 1 shows the chemical composition of Al 7075 alloys and Table 2 shows the mechanical properties of the SiC particulates. The SiC of 60µm with green colour is reinforced in the matrix material. The liquid route technique is employed to fabricate the composite material. Using this technique the reinforcing material is introduced into the molten metal pool through the vortex created in the melt by the use of alumina coated stainless starrier. The coating of an alumina to the blades of the stirrer is essential to prevent the migration of ferrous ions from the stirrer into the molten metal. The stirrer was rotated at 550 rpm and the depth of immersion of the stirrer was maintained about two-thirds the depth of the molten metal. The preheated reinforcing material was introduced into the vortex of the liquid melt, which was degassed using pure nitrogen for about 3-4 minutes. The resulting mixture was tilt poured into the preheated permanent metallic moulds.

Table 1 Chemical composition of Al 7075 alloy:

Aluminium	Balance
Chromium	0.18-0.28
Copper	1.2-2
Iron	0.5 max
Magnesium	2.1-2.9
Manganese	0.3 max

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Remainder each	0.05 max
Remainder total	0.15max
Silicon	0.4 max
Titanium	0.2 max
Zinc	5.1-6.1

Table 2 Mechanical properties of Silicon Carbide:

MECHANICAL	SI/ METRIC	SI/ METRIC
Density	Gm/cc	3.1
Porosity	%	0
Colour		green
Flexural strength	MPa	550
Elastic modulus	GPa	410
Shear modulus	GPa	-
Poisons ratio		0.14
Compressive strength	MPa	3900
Hardness	Kg/mm^2	2800
Fracture toughness	MPa	4.16
Maximum use temperature	^oC	1650

Specimen preparation

After casting the Aluminium 7075 based composites by the stir cast method, CTE test specimens were prepared by machining in accordance with ASTM standard from the cylindrical bar castings. Each specimen was 10mm in diameter and 15mm in height. The specimen surfaces were polished with 1µm diamond paste. Each result presented is an average of five samples and each composite was tested under identical conditions [14].

The samples for microscopic examination were etched with keller's reagents [15]. The specimens were washed with distilled water followed by acetone and dried thoroughly.

Heat treatment

A T6 heat-treatment process called aging was carried out for the as-processed composites. The following steps were followed during the aging process. The specimens (as-cast conditions) were subjected to the following heat-treatment conditions and also the T6 heat-treatment cycle is shown in Fig.1.

1. Solution treatment for 12hr at a temperature of 530 ^oC
2. Quenching in water at a temperature of 80 ^oC
3. Stabilizing at room temperature for 3hr
4. Aging at 175 ^oC for different intervals of time ranging from 1h, 3h, 5h.

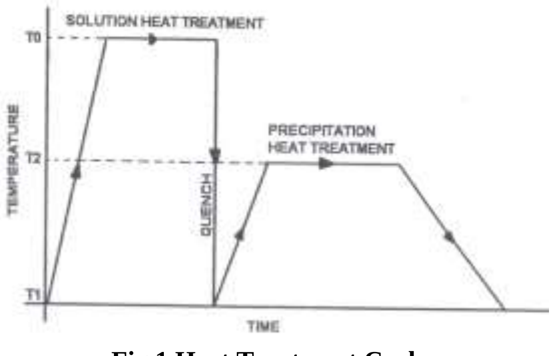

Fig.1 Heat Treatment Cycle.

CTE measurement

Coefficients of thermal expansion tests were carried out at polymer division, CPRI Bangalore using a TMA Q400 Thermo-mechanical analyzer having a resolution of 10 significant decimal digits. CTE test specimens of size diameter 10 mm and height 15 mm were prepared, by machining a cylindrical bar castings of 20mm in diameter and 300 mm in length using a centre lathe. The specimen surfaces were polished with 1µm diamond paste to obtain fine finish. Specimens were subjected to a constant load of 0.5N and measurements were taken from room temperature to 400^oC for the heating part of the cycle and from 400^oC to room temperature for the cooling part of the cycle at a sweep rate of 5 ^oC/min. the specimen was positioned on a quartz base and a standard expansion probe was used to measure the changes in length. The whole experiment was carried out in a furnace whose temperature could be controlled and monitored. The data were noted in terms of linear dimension changes with respect to temperature. Each result noted was an average of five samples and each composite was tested under identical conditions [16]. Standard TMA data analysis software was used to compute the CTE of the as-cast and heat-treated composites.

Results and discussion

Microstructure of composites

Microstructure plays an important role in the overall performance of alloy as well as a composite material. The physical property depends on the microstructure, particulate, fiber size, shape and distribution in the alloy.

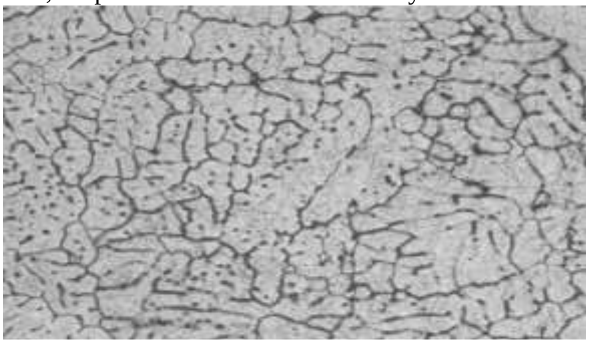

Fig.2 Microstructure of Aluminium 7075 + 3% SiC composite

Fig.2 shows typical optical microstructure of the aluminium 7075 containing 3% SiC particulates. The photograph suggests that colder particles initiated nucleation. The dendrites grow away from the particle due to the restriction caused by the particle to solute enrichment. Thus the grains grow outwards from the particle. The last remaining eutectic liquid solidifies around the particle. However, no gap is observed between the particle and the matrix. The reinforcing materials are seen well bonded with the matrix.

Dimension change

The coefficient of thermal expansion results were expressed as dimension change as a function of temperature. The dimension change as a function of temperature for as-cast and heat treated specimens are shown in Fig.3,4,5,6

It is observed that all the plots of dimension change versus temperature for MMCs with different aging times had similar characteristics and all the curves showed similar trends. During the heating part of the cycle, as the temperature increases so does the dimension change (µm). on the return (cooling) part of the cycle, there is invariably some hysteresis and dimension change and it is always more than that during heating. This hysteresis becomes less as the aging duration increases. There was invariably some residual strain at the end of each thermal (heating-cooling) cycle. An increase in aging durations plays a significant role in influencing the residual contractions seen in these MMCs upon cooling. The hysteresis is caused by the thermal stress relaxation in the matrix material. Thus stress relaxation causes plastic yielding in the matrix that causes the curves not to retrace their path on the return (cooling) part of the thermal cycle. The result is not only a hysteresis phenomenon, but also a final residual strain in each case.

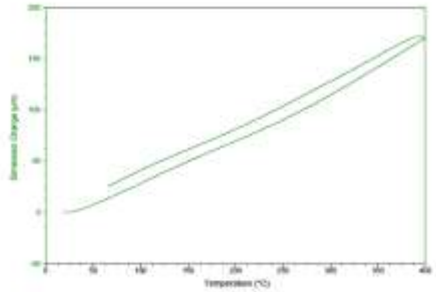

Fig 3. Dimension change as a function of temperature for as-cast condition

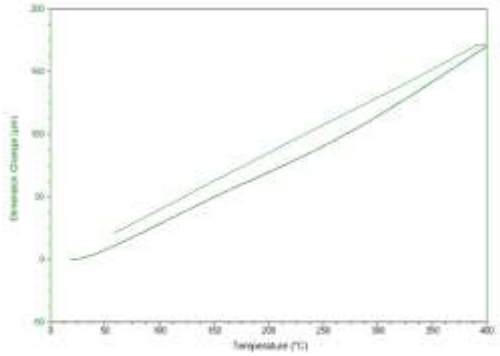

Fig 4. Dimension change as a function of temperature for heat-treated condition (1h)

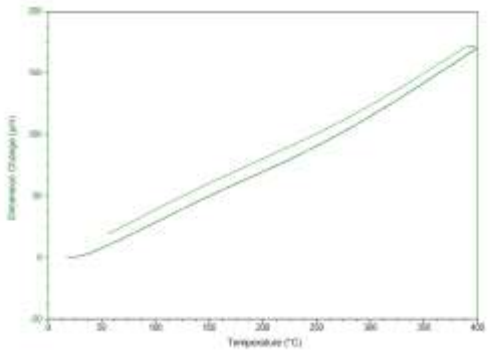

Fig 5. Dimension change as a function of temperature for heat-treated condition (3h)

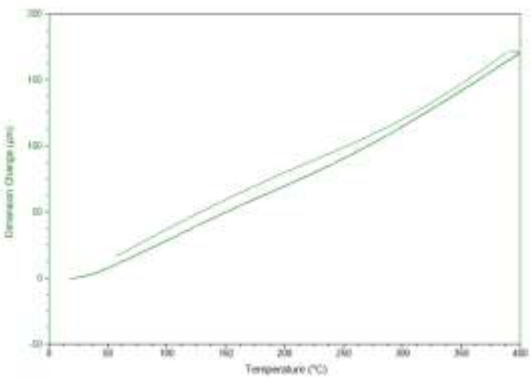

Fig 6. Dimension change as a function of temperature for heat-treated condition (5h)

The residual strain in the case of the as-cast condition is found to have a maximum value when compared to heat-treated one. The area of the hysteresis between the curves decreases with increase in the aging durations.

Authors Vaidya and Chawla [17] observed similar effects when testing MMCs consisting of Al alloy 6061 reinforcements with Al2O3 particles. Holfman et al. [18] believed that the hysteresis seen was caused by viscoplastic deformation in the metal matrix. They explained that this deformation occurs by yielding followed by cavitation and also by time-dependent creep mechanism.

Conclusions

The coefficient of thermal expansion of the as-cast and heat treated aluminium 7075 based composites has been investigated over a room temperature to 400 ^{o}C both in the heating and cooling cycles. The thermal expansion study showed hysteresis residual strains. This study revealed the presence of the residual thermal stresses generated in the composites. This is due to the difference in the CTE between the as-cast and heat-treated composites.

The study of residual strains obtained is particularly useful in high-temperature applications of composites. Residual thermal stresses at the matrix reinforcement interface are induced by the CTE mismatch between the reinforcement and matrix, which are dependent on the properties of the matrix, reinforcements and aging durations.

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