International Journal of Latest Engineering Research and Applications (IJLERA)
www.ijlera.com
Volume 1 – Issue 1 pp: 09-15

SHAPE MEMORY EFFECT ON COEFFICIENT OF THERMAL EXPANSION OF Al 2024/Cu-Al-Ni SM PARTICULATE COMPOSITE

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Abstract : In last decades, smart materials have developed extensively and have become an important topic for re-searchers in various areas. SMA is a good candidate for active control of the smart composite structures. This paper reveals the investigation of coefficient of thermal expansion (CTE) of as-cast and Aluminium 2024/ Cu-Al-Ni shape memory particulate composites. These composites were subjected to shape memory effect by heating to 20° C. The stir casting technique is used to prepare the castings and machined in accordance to ASTM standards followed by heating to bring shape memory effect in the embedded particles. Coefficient of thermal expansion tests were performed in both as-cast and shape memory effect conditions. In as-cast condition the coefficient of thermal expansion values were found to decrease with increased volume fraction of Cu-Al-Ni Shape memory particles. But with shape memory effect the coefficient of thermal expansion values were found to increase with increased volume fraction of Cu-Al-Ni Shape memory particles. The coefficient of thermal expansion curves exhibited some residual strains, which were decreased with the increase volume fraction and shape memory effect of Cu-Al-Ni particles.

Keywords - Coefficient of thermal expansion, Particulate composite, Shape memory effect,ThermalHysteresis

I. INTRODUCTION

Particulate reinforced metal matrix composites (PMMCs) have attracted considerable attention because of their feasibility for mass production, promising thermal properties and potential high damping capacity. In applications not requiring extreme loading or thermal conditions, such as automotive components, the discontinuously reinforced MMCs have been shown to offer substantial improvements in mechanical properties. In particular, discontinuously reinforced Aluminium alloy MMCs provide high damping and low density and allow undesirable mechanical vibration and wave propagation to be suppressed (1). As in the fibre-reinforced composites, the strengthening of the composites is achieved through the introduction of compressive stresses by the reinforcing phases, due to the mismatch of the thermal expansion coefficient between the matrix and reinforcement.

The most frequently used reinforcement materials are SiC, Al_2O_3 and Graphite (Gr) particles. Although adding SiC and Al_2O_3 to the Aluminium matrix can provide substantial gains in specific stiffness and strength, the resulting changes in damping capacity may be either positive or negative. Graphite particles may produce a remarkable increase in damping capacity, but at the expense of elastic modulus (1). More recently, Yamada et al. (2)Proposed the concept of strengthening the Aluminium MMCs by the shape-memory effect of dispersed Ti-Ni SMA particles.

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 (3).

The strengthening mechanism is similar to that in the SMA fibre-reinforced composites: the pre-strained SMA particles will try to recover the original shape upon the reverse transformation from martensite to parent (austenite) state by heating and hence will generate compressive stresses in the matrix along the pre-strain direction, which in turn enhances the thermal expansion properties of the composite at the austenitic stage. In the light of the well-known transformation 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 variation in the CTE of composites before and after the shape memory effect are discussed in the present paper. In the present work, the weight fraction of Cu-Al-Ni particulates used for making MMCs was 5%, 10% and 15%. The present investigation is undertaken with the main objective of studying the thermal behavior of Al 2024 MMCs reinforced with Cu-Al-Ni shape memory particles after heating.

Accordingly, SMA particles may be used as stress or vibration wave absorbers in paints, joints, adhesives, polymer composites and building materials.

Table 1.1 Chemical composition of Al 2024 alloy

Elements	ASTM Standard*	As by Supplied Supplier**
Aluminum	Balance	Balance
Chromium	0.1 max	0.1 max
Copper	3.8 - 4.9	4.2
Iron	0.5 max	0.5 max
Magnesium	1.2 - 1.8	1.5
Manganese	0.3 - 0.9	0.6
Remainder Each	0.05 max	0.05 max
Remainder Total	0.15 max	0.15 max
Silicon	0.5 max	0.5 max
Zinc	0.25 max	0.25 max

Table 1.2 Thermal properties of Cu-Al-Ni shape memory particles:

Thermal Properties:	
CTE, linear 250°C	24.7 µm/m-°C
Specific Heat Capacity	0.875 J/g-°C
Thermal Conductivity	121 W/m-K
Melting Point	502 - 638 °C
Solidus	502 °C
Liquidus	638 °C

II. EXPERIMENTAL PROCEDURE

2.1 Preparation of composites:

The matrix material used for producing MMCs in this study is Aluminium 2024. This alloy is best suited for mass production of lightweight castings. Table 1.1 shows the chemical composition of Al 2024 alloys and Table 1.2 shows the mechanical properties of the Cu-Al-Ni shape memory particulates. The Cu-Al-Ni of 100µ m 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 steel 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 0-750 rpm and the depth of immersion of the stirrer was maintained about two-third 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 molds.

2.2 Specimen preparation:

After casting the Aluminium 2024 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 10 mm in diameter and 10 mm in height. The specimen surfaces were polished with 1 µm diamond paste. Each result presented is an average of four samples and each composite was tested under identical conditions (4).

The samples for microscopic examination were etched with Keller's reagents (5) . The specimens were washed with distilled water followed by acetone and dried thoroughly.

2.3 The shape memory effect of SMA particles embedded in Al 2024:

The interaction between the embedded SMA and the host material is critical since most applications require transfer of load or strain from the particles to the host. In addition, the host material may have a pronounced effect on the local stress state and consequently the transformation behavior of the embedded SMA particles. This case-study is based on the experiments of Jonnalagadda et.al (6) who measured the stress distribution during the SMA transformation by using the Photo-elastic technique.

2.4 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 10 mm were prepared, by machining a cylindrical bar castings of 20 mm in diameter and 300 mm in length using a center lathe. The specimen surfaces were polished with 1 µm diamond paste to obtain fine finish. Specimens were subjected to a constant load of 0.5 N and measurements were taken from room temperature to 500° C for the heating part of the cycle and from 400° C to room temperature for the cooling part of the cycle at a sweep rate of 5° C /min. The specimen was positioned on a quartz base and a standard expansion probe was used to measure the whole experiment was carried out in a furnace whose temperature could be controlled and monitored.

The data were noted in terms of linear dimensions with respect to temperature. Each result noted was an average of five samples and each composite was tested under identical conditions (7). Standard TMA data analysis software was used to compute the CTE of the as-cast and heat-treated composites.

III. RESULTS AND DISCUSSION

3.1 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 microstructure of particulates, size, shape and distribution in the alloy.

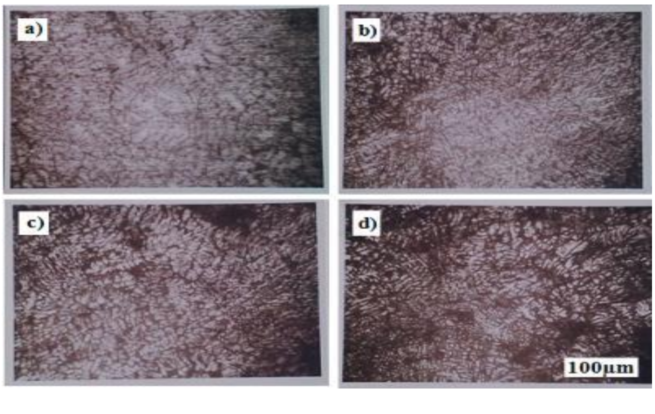

Figure 3.1Microstructure of Aluminium 2024+ a) 5% b) 10% c) 15% and d) 15% Cu-Al-Ni shape memory composite

Figure 3.1 shows typical optical microstructures of the Aluminium 2024 containing 0%, 5%, 10% and 15% Cu-Al-Ni 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.

3.2 CTE and Dimension Change:

The coefficient of thermal expansion decreases as the volume fraction of shape memory particles increases and after subjecting into shape memory effect the CTE increases with increase in volume fraction of shape memory particles as shown in Figure 3.2.

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 Figure 3.3, Figure 3.4,Figure 3.5 and Figure 3.6. It is observed that all the plots of dimension change versus temperature for MMCs with different volume fractions 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.

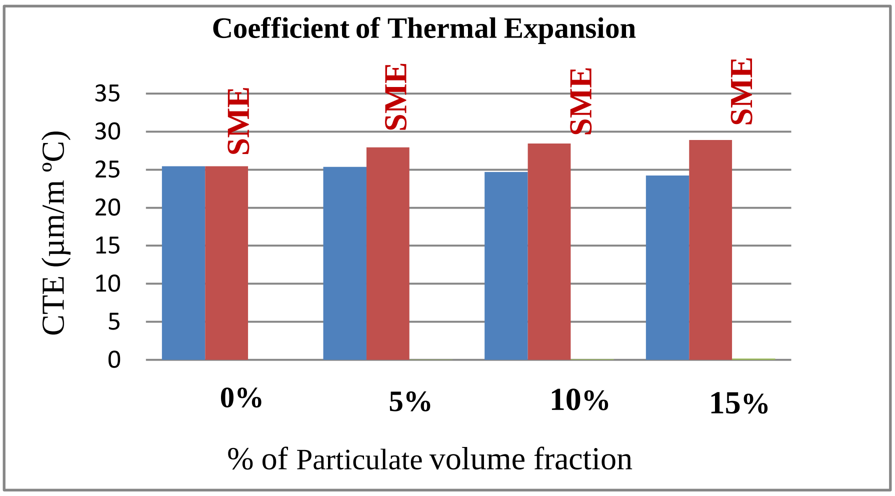

Figure 3.2 Variation of CTE for different volume fractions considering with and without shape memory effect.

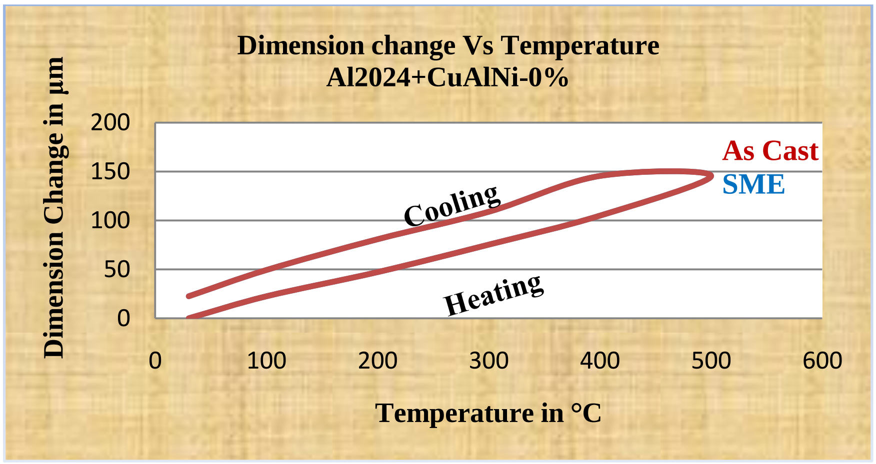

Figure 3.3 Dimension change as a function of temperature for Al 2024+CAN (0%) considering with and without shape memory effect

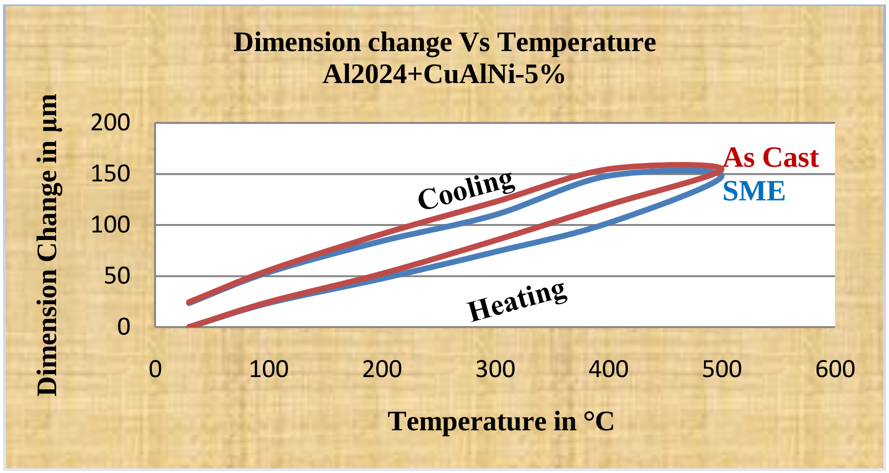

Figure 3.4 Dimension change as a function of temperature for Al 2024+CAN (5%) considering with and without shape memory effect

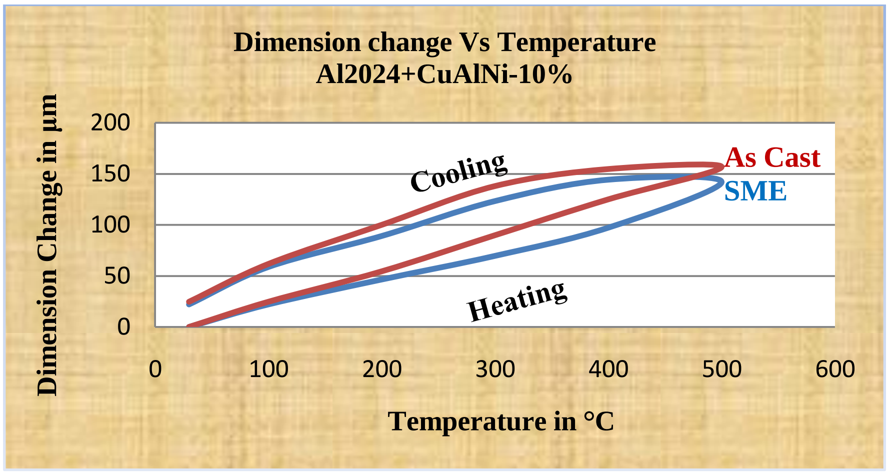

Figure 3.5 Dimension change as a function of temperature for Al 2024+CAN (10%) considering with and without shape memory effect

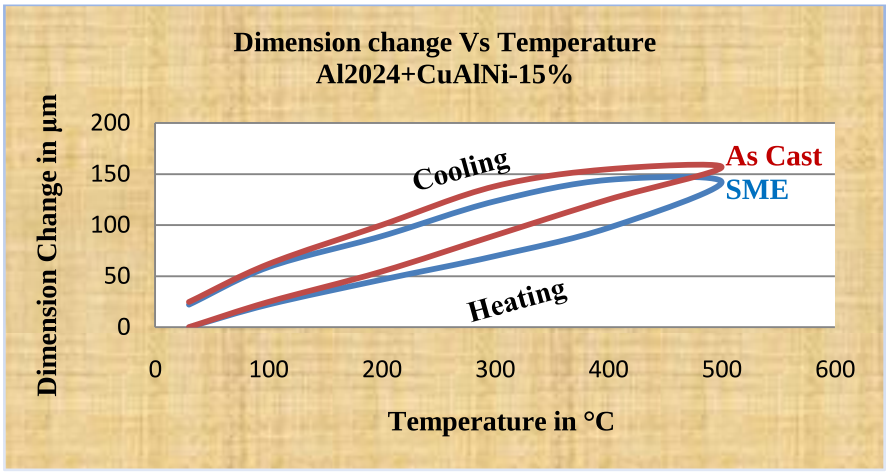

Figure 3.6 Dimension change as a function of temperature for Al 2024+CAN (15%) Considering with and without shape memory effect

The residual strain in the case of the as-cast condition is found to have a maximum value when compared to shape memory affected one. The area of the hysteresis between the curves decreases with SME. Authors Vaidya and Chawla(8) observed similar effects when testing MMCs consisting of Al alloy 6061 reinforced with Al_2O_3 particles. Holfman et al. (9) believed that 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 shape memory effect.

IV. CONCLUSIONS

The coefficient of thermal expansion of the as-cast and shape memory alloyed Aluminium 2024 based composites has been investigated over an ambient temperature to 500°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 shape memory effect composites.

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