Thermal Expansion Coefficient Investigation of Al 2024/Cu-Al-Ni Adaptive Composites

Kotresh M[1], Dr. M M Benal[2], Dr. N H Siddalingaswamy[3]

[1] *Research Scholar, Visvesvaraya Technological University Research Resource Center, Belagavi, Karnataka, India*
[2]*Professor & Head, Department of Mechanical Engineering, Government Engineering College, Kushalnagar, Madikeri, Karnataka, India*
[3]*Director, All India Council for Technical Education, M.H.R.D, Govt. of India, New Delhi, India*

ABSTRACT

In last few decades, smart materials have been developed extensively and have become an important topic for researchers in microelectronics and micro electro mechanical systems (MEMS). The shape memory alloy is a good candidate material for active control of the smart systems. The coefficient of thermal expansion is an important mechanical property for shape memory particulate reinforced composites. There are several problems that arise from the thermal expansion effect; for example, the mismatch of thermal expansion between particulates and host matrix which may lead to residual stresses in the composites. Shape memory alloys experience shape memory effect at their service temperature. This shape memory effect can vary the expansion properties of adaptive composites by changing residual stress field. In this investigation, the expansion coefficient with particulate volume fractions was investigated using thermo mechanical analyser (TMA). The stir casting technique is used to prepare the castings and machined accordance to ASTM standards followed by heating to bring shape memory effect in the pre strained particles. The expansion coefficient was calculated by subjecting the as-cast and SME specimens, and then the experimental results were recorded. The expansion coefficient is found to be decreased with increase of SMA volume fraction and increased with increase in temperature of shape memory effect.

Keyword: *Composite materials, Al 2024, Cu-Al-Ni, shape memory effect, expansion coefficient, residual stress;*

1. INTRODUCTION

Thermal expansion is an important mechanical behavior in the areas of microelectronics and micro electro mechanical systems (MEMS). There are several problems that arose from the thermal expansion effect, for instance, the mismatch of thermal expansion between particulates and host matrix which may lead to residual stresses in the composites [1]. The shape memory effect can vary the expansion coefficient of the adaptive composite by changing residual stress field. Copper based shape memory particles (Cu-Al-Ni) seem to be good candidate for the reinforcement of aluminium alloy metal matrix composite known as adaptive composite. Cu-Al-Ni shape memory particles are chemically stable in aluminium alloys and exhibits good mechanical properties at relatively low cost [2]. On the other hand, metal matrix composites reinforced with discontinuous reinforcement (short fibre, whisker or particle) is attractive for applications requiring higher thermal stiffness and strength than monolithic alloys.

The thermal expansion effect can be exploited to drive micro actuators [3-4]. In order to design micro machined components as well as microelectronics devices properly, it is necessary to characterize the coefficient of thermal expansion (CTE). Adaptive composites have microscopic scale of thermal residual stress that is generated after cooling from high temperature because of the difference of thermal expansion coefficient between the matrix and reinforcement. So, that residual stress is one of the inherent properties of composites and cannot be removed by heat treatment [5]. The development of such stresses and the mechanical behaviour of MMC in the presence of these stresses have been thoroughly studied by several authors using analytical, numerical and/or experimental methods [6-10] The results of these studies indicate that the mechanical properties such as hardness, tensile stress and wear properties of MMC largely depend on the residual stress due to difference in thermal expansion coefficient between host matrix and reinforcement. So that it is necessary to characterize the CTE. In this experimental investigation is carried out to determine the CTE of adaptive composites for varying SMA volume fractions and temperatures of shape memory effect.

2. EXPERIMENTAL

2.1 Preparation of composites

The matrix material used in this study for producing an adaptive composite is Aluminium 2024. This alloy is best suited for mass production of light weight castings. Table 1 depicts the chemical composition of Al 2024 alloys. Table 2 shows the mechanical properties of the Cu-Al-Ni shape memory particulates. The Cu-Al-Ni of 100 µm size is reinforced randomly in the matrix material. Three reinforcement volume fractions 5, 10 and 15 vol. % were introduced by the liquid route technique known as stir-casting.

Table 1 Chemical composition of Al 2024 alloy

Element	ASTM Standard	As Supplied by Supplier
Aluminium	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 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

Using stir-casting 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 stirrer. 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 pre-heated reinforcement particles were 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 pre-heated permanent metallic mold.

2.2 Specimen preparation

After casting the adaptive composites by the stir-casting method, test specimens were prepared by machining in accordance with the ASTM standards from cylindrical bar castings, each specimen of 10 mm diameter and 10 mm height. The specimen surfaces were polished with 1 µm diamond paste. The result presented is an average of four samples. The specimens are tested under identical conditions (11) for as-cast composites and varying temperature conditions for SME composites.

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

The shape memory effect in SMA particles has been obtained by heating the composite to pre-heated temperature of the particles. The best shape memory results were obtained at the temperature less than 120°C. This investigation is based on the experiments of Jonnalagadda et al (12) who measured the stress distribution during the SMA transformation by using the Photo-elastic technique.

2.4 Measurement of CTE

Coefficient of thermal expansion is a material property that is indicative of the extent to which a material expands upon heating. Coefficient of thermal expansion tests was carried out with Thermo mechanical analyzer TMA Q400 shown in the figure 1. Specimens were subjected to a constant load of 0.5 N and measurements were taken from temperature 30 °C to 500 °C for the heating part of the cycle and from 500 °C to 30 °C for cooling part of the cycle at a sweep rate of 5 °C.

Figure 1 Thermo Mechanical Analyzer

3. RESULTS AND DISCUSSIONS

The variation of CTE with SMA volume fraction of as-cast and shape memory effect adaptive composite is shown in figure 2. It is seen that the respective CTE of as-cast and SME adaptive composites increases with increasing temperature. Moreover increase in temperature of shape memory effect monotonically increasing its CTE. It can be inferred from this effect that in these composites there is a shape recovery of Cu-Al-Ni shape memory particles, due to this good interfacial bonding between matrix and reinforcement. It is found that as the temperature of shape memory effect increases the respective CTEs of as-cast and SME composites as shown in table 3.

Table 3 CTE values obtained from experimental method for 0%, 5%, 10% and 15% SMA volume fractions for both as-cast and SME adaptive composites

Sl. No.	SMA Volume fraction (%)	Coefficient of Thermal Expansion (μm/m °C)	As-Cast	SME	SME	SME
				110 °C	115 °C	120 °C
1	0%	Ambient to 500 °C	25.46	27.035	28.339	29.607
2	5%	Ambient to 500 °C	25.36	26.625	27.871	29.117
3	10%	Ambient to 500 °C	24.71	26.143	27.367	28.592
4	15%	Ambient to 500 °C	24.21	25.765	26.971	28.177

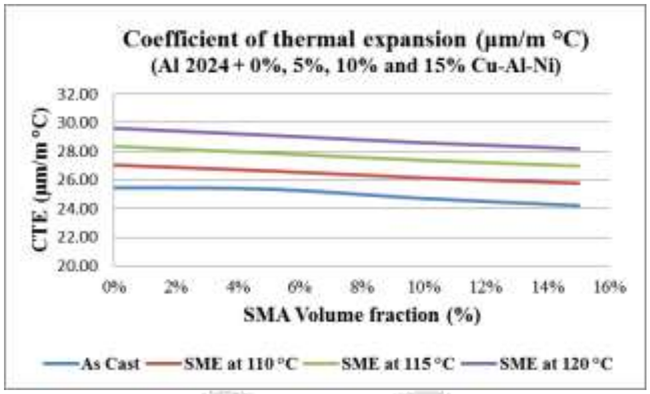

Figure 2 Variation of CTE with 0%, 5%, 10% and 15% SMA Particulate volume fraction for as-cast and SME adaptive composites.

4. CONCLUSIONS

An experimental CTE value of Al 2024/Cu-Al-Ni adaptive composites have been found. The method of TMA Q400 test was employed to extract CTEs for different temperatures in the SMA embedded composites. The recorded CTE values showed lower values as the SMA volume fraction increases and showed higher values as the temperature of shape memory effect increases. Both CTE and SMA volume fraction exhibited strong scatter, which attributes microscopic response of external stimulation temperature of shape memory effect. These results are in close agreement with the work of Weiland et al.

5. ACKNOWLEDGEMENT

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