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THERMAL EXPANSION COEFFICIENT INVESTIGATION IN AL 2024/ CU-AL-NI ADAPTIVE COMPOSITES BY FINITE ELEMENT TECHNIQUE

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Abstract
In last few decades, smart materials have been developed extensively and have become an important topic for researchers in various areas. The shape memory alloy is a good candidate material for active control microelectronics and micro electro mechanical systems (MEMS). A Successful application of smart materials in engineering design requires a detailed characterization of thermal property such as coefficient of thermal expansion (CTE).The CTE is a strong function of volume fraction, shape memory effect of reinforcement and operating temperature levels. Finite element method offers as a quicker, reliable and cost effective tool for the computation. The method is developed to illustrate the evaluation of CTE for the Al 2024/Cu-Al-Ni composite system. The two-dimensional FEM investigation is carried out to find CTE for a shape memory particulate reinforced composite system known as adaptive composites with varying volume fraction.

Key Words: Composite Materials, Al 2024 Alloy, Cu-Al-Ni Alloy, Shape Memory Effect, Thermal Expansion, Finite Element Method.

I. 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]. Thus, the electronic devices, as well as the micromachined structures will be damaged or deformed by this effect.

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 a good candidate for the reinforcement of aluminium alloy metal matrix composite known as an adaptive composite. Cu-Al-Ni shape memory particles are chemically stable in aluminium alloys and exhibit 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 microactuators [3-4]. In order to design micromachined components as well as microelectronics devices properly, it is necessary to characterize the coefficient of thermal expansion (CTE).

Shape memory alloys (SMAs) have the ability to return to a predetermined shape when heated past the martensitic transformation, with the potential of reversible strains of several percents, generation of high recovery stresses and high power/weight ratios. The integration of thin SMA wires in fibre reinforced composite materials leads to so-called adaptive composite materials. Such SMA composites can be used to actively coefficient of thermal expansion in the case of hard matrices and change shape in the case of soft matrices [5, 6].

In this investigation is carried out to find out the coefficient of thermal expansion for shape memory particulate reinforced Al 2024/Cu-Al-Ni adaptive composite system using two-dimensional finite element analysis.

II. Experimental Procedure

1. **FEM Analysis:** Finite element analysis was carried out on different sets of particulate reinforced Al 2024/ Cu-Al-Ni composite test coupons subjected to thermal loading. The analysis was carried out with the help of front-end commercial software ANSYS (Ver.14). Two-dimensional FEM test coupons were created consisting of a composite system under thermal loading.

2. **Geometry and Dimensions of the Test Coupon:** Table 1 gives the material properties of Al 2024 matrix and Cu-Al-Ni shape memory particulates at room temperature. The dimensions of test coupons are considered on a micromechanical scale as shown in fig. The particles are assumed to be aligned parallel the global reference axis. The particles are placed in such a way that they are covered completely on either side by the matrix material. The

investigations are carried out under the assumption of plane stress condition with the thickness being 100 microns. The test coupon size is taken as 1000 microns X 1000 microns.

Table 1: Material Properties of Al 2024 Matrix and Cu-Al-Ni Shape Memory Particulates

Material	Al 2024 Matrix	Cu-Al-Ni SM Particles
Young's Modulus in (G Pa)	73.1 G Pa	85 G Pa
Poisson's Ratio	0.33	0.3
CTE	25.46 µm/m-°C	17 µm/m-°C

3. **FEM Modeling Details:** Finite element mesh was generated for the test coupons using 18 nodes plane-stress element as shown in fig. To improve the accuracy of the result a finer mesh is used, which was arrived at through convergence studies. Following is the summary of a typical FEM mesh used, which corresponds to 15% volume fraction having element edge of length equal to 100 microns.
   Number of elements: 406
   Type of elements: PLANE 182
   Number of nodes: 446
   Number of degrees of freedom: 892

4. **Loading and Displacement Boundary Conditions:** Figure 1 shows the details of geometric and load boundary conditions used to predict the CTE. The nodes lying on the Y-axis are constrained from moving in X direction, the middle node lying on y-axis is constrained from moving in both X and Y directions, the nodes lying on right edge of the model are coupled together to move in X-direction and a predefined temperature of 100 °C is applied as a thermal load for the entire test coupon.

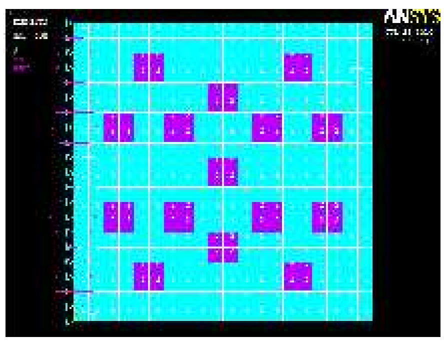

Figure 1: Geometry and Load Boundary Conditions for Composite Test Coupon

5. **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 of the applications require the transfer of load or strain from the particles to the host matrix. 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 [7] who measured the stress distribution during the SMA transformation by using the Photo-elastic technique.

The FEA simulations consisted of a sequence of transient thermal and structural analyses using ANSYS. In the former, it was assumed that the temperature in the particle was increasing at 1 °C/min. The PLANE 182, 18 node elements were selected for the thermal and structural analysis, respectively. The most difficult part of the structural analysis was to import into the ANSYS software the 1 % pre-strain that the particle had. Fig.1 presents a stress-strain graph, including the pre-straining stage. This involves an initial application of stress in the martensitic phase at room temperature, exceeding the yield stress. Upon release of the stress, some of the strain is recovered but the plastic strain, $\varepsilon o = 0.01$, remains.

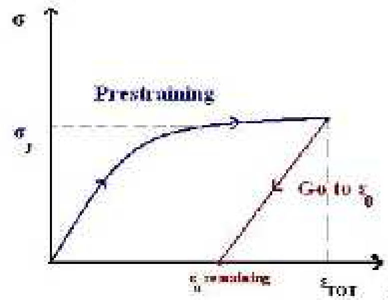

Figure 2: Stress-Strain Graph for the Pre Straining Stage

From the graph in Fig. 2 and given that ANSYS was not able to incorporate initial strain conditions; an equation for the total strain was generated:

$$\varepsilon TOT = \varepsilon ANSYS + \varepsilon 0$$

The equation for the total stress is:

$$\sigma = E\ \varepsilon ANSYS + E\ \varepsilon 0$$

If it is assumed that the initial stress is equal to zero and interpolated for ε ANSYS between the two phases (Martensite and Austenite), it yields

$$\frac{\sigma - \left(EAus\,\frac{\varepsilon 0}{EAus} - \frac{\sigma}{Emart}\right)\,X\,(T - 35)}{(Af - As)} = \varepsilon ANSYS$$

III. Results and Discussion

From FEM analysis, peak values of displacements along longitudinal directions are recorded for different volume fractions. The figure depicts typical Ux displacements contour for 15% volume fraction. By using the values of Ux displacements, CTE along longitudinal direction was computed using the following equation:

α = Ux /[1000X rise in temperature (100 °C)]

The results obtained from FEM analysis are also listed in table 2. The figures [3-7] shows the variation of longitudinal CTE values as a function of volume fraction obtained from the finite element analysis.

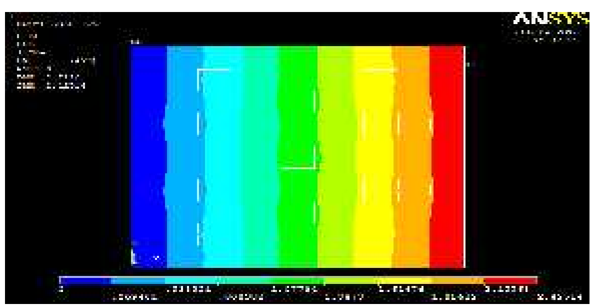

Figure 3: Ux Displacement Contour for 15% Particulate Volume Fraction

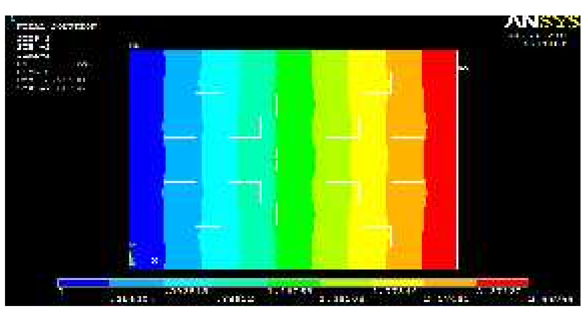

Figure 4: Ux Displacement Contour for 15% Particulate Volume Fraction when Heated to 10 °C

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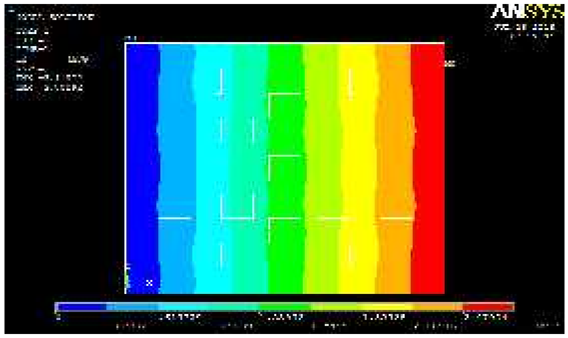

Figure 5: Ux Displacement Contour for 15% Particulate Volume Fraction when Heated to 15 °C

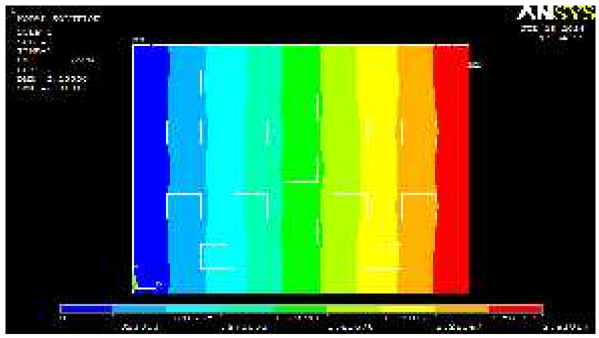

Figure 6: Ux Displacement Contour for 15% Particulate Volume Fraction when Heated to 20 °C

Table 2: Displacement and CTE Values for Different Volume Fraction

Volume fraction	Displacement in microns		CTE in µm/m-°C	
	As-Cast	SME	As-Cast	SME
0%	2.546	2.546	25.46	25.46
5%	2.504	2.755	25.04	27.55
10%	2.46	2.829	24.6	28.29
15%	2.425	2.91	24.25	29.1

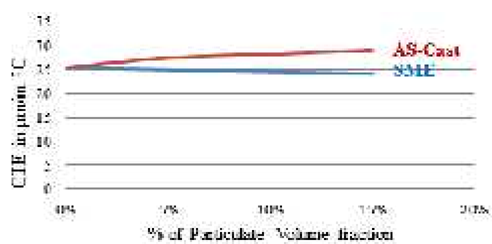

Figure 7: **CTE Values for Different Volume Fractions**

IV. Conclusion

As the reinforcement volume fraction increases, CTEs of the composite system for the model without shape memory effect in longitudinal direction decreases. But for the model with shape memory effect CTE increases in the same reflective pattern due to plastic deformation when the model is heated.

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