Journal of Advances in Science and Technology
Vol. 12, Issue No. 25, (Special Issue) December-2016, ISSN 2230-9659

Thermal Expansion and Residual Stress Investigation in Al 2024/ Cu-Al-Ni Adaptive Composites by TMA Q400 and X-Ray Diffractometer

Kotresh M.[1]*, M. M. Benal[2]

[1]Research Student, Visvesvaraya Technological University, Research Resource Center, Belagavi, Karnataka, Belagavi, Karnataka, India

[2]Professor & Head, Department of Mechanical Engineering, Government Engineering College, Kushalnagar, Madikeri, Karnataka, India

Abstract – In last few decades, smart materials are being developed widely and become a significant topic for researchers in many areas. The active control of the smart composite structures and automobile parts shape memory alloys plays a major role. The shape memory alloy embedded composites has microscopic scale thermal residual stresses, which are generated during cooling from the high-temperature due difference in CTEs. The composites service temperature causes automobile parts and structures to experience shape memory effect and this varies residual stress field. This investigation presents the relation between residual stress and thermal expansion coefficients are investigated for varying volume fractions of shape memory particles. The thermal expansion and residual stress investigation are carried out by TMA Q400 and high-resolution X-ray Diffractometer. Thermal expansion and residual stress were calculated by subjecting specimens with and without shape memory effect and experimental results were compared.

Keywords— Composite Materials, Al 2024, Cu-Al-Ni, Shape Memory Effect, Residual Stress;

---------------------------♦-----------------------------

INTRODUCTION

Because of higher relative strength and stiffness than Fe alloys, aluminum alloys are very attractive materials for aerospace, aircraft, and automobile industries [1-4]. The metal matrix composites reinforced with discontinuous reinforcement's particles are attractive for applications needs higher thermal stiffness and strength than monolithic alloys. Cu-based shape memory particles (Cu-Al-Ni) seem to be a noble candidate for the reinforcement of metal matrix composite known as an adaptive composite. Cu-Al-Ni particles are chemically stable in aluminum alloys and exhibit good mechanical properties at relatively low cost [5].

The shape memory alloy embedded composites have microscopic scale thermal residual stresses, which are generated during cooling from the high-temperature due difference in CTEs and cannot remove by heat treatment [6]. The growth of such stresses and mechanical behavior of MMC in the occurrence of these stresses has been thoroughly studied by several authors [7-11].

The automobile parts and structures experience shape memory effect because of their service temperature. The property of adaptive composites varies by a change in the residual stress field due to SME. The current investigation presents the relation between CTE and residual stresses are investigated for varying volume fractions of reinforcement particles.

II. EXPERIMENTAL PROCEDURE

A. Composite preparation

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

Table 1 Al 2024 alloy chemical composition

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

Cu-Al-Ni 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 reinforcement material is poured into the molten metal pool during the vortex formed by alumina glazed stainless steel stirrer, alumina glazing to blades of the stirrer is essential to prevent the movement of ferrous ions from the stirrer into the molten metal. The rotation of the stirrer is 0-750 rpm and the depth of immersion is two third depth of the molten alloy. The molten alloy is degassed by pure nitrogen for about 3 to 4 minutes and the mixture is poured into the preheated metallic molds.

B. Specimen preparation:

The diffraction test specimens were prepared from the cylindrical casting of Al 2024 in accordance with the ASTM standard by machining. The diameter and height of the specimen are 10 mm and 05 mm. The polishing of specimen surfaces was made by 1 µm diamond paste. The results are taken by considering four specimen samples under identical conditions and etched by Keller's reagent [12-13]. At last washed with distilled water followed by acetone and dried.

C. Cu-Al-Ni particles shape memory effect in Al 2024 alloy:

The relation between reinforcement particles and matrix Al 2024 is critical because the application needs a transfer of load and strain from the particles to the matrix. The matrix has a pronounced effect on local stress state and transformation behavior particles. This work is based on the research of Jonnalagadda et al. [14] on stress distribution during the SMA transformation by Photoelastic technique.

D. CTE measurement:

Coefficients of thermal expansion tests were carried out with Thermomechanical analyzer TMA Q400 shown in figure 1. The specimens were subjected to a constant load of 0.5 N and readings 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.

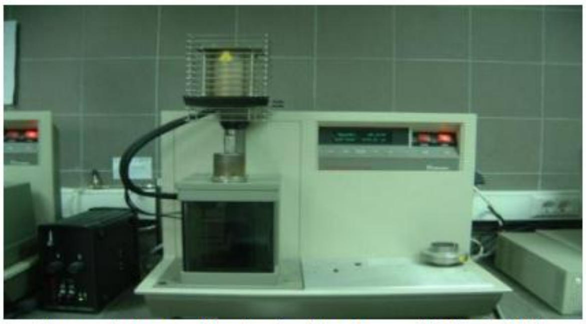

Figure 1Thermo Mechanical Analyzer (TMA Q 400)

E. Residual stress measurement:

Residual stress measurement is carried out by BRUKER D8 ADVANCE X-ray Diffractometer with specification horizontal/vertical θ/2θ or θ/θ geometry as shown in figure 1, circle diameter 435, 500, and 600 mm. Maximum usable angular Range 110° < 2θ ≤ 168°, the smallest adjustable increment of 0.0001°, anodes of Cu, Cr, and Co and application software of EVA LEPTOS & TOPAS.

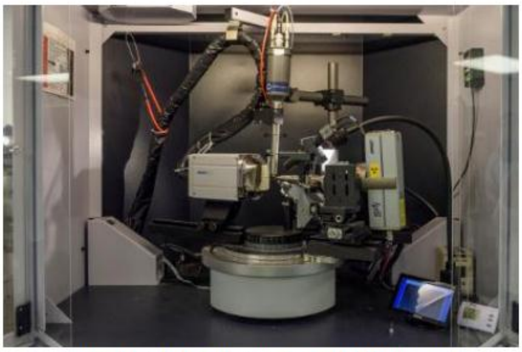

Figure 2 High-Resolution X-Ray Diffractometer

III. RESULTS AND DISCUSSION:

Figure 3 indicates that the composites obtained from stir-casting methods are good quality and sound castings. Figure 4 shows the variation of CTE measured from TMA Q400. In this, for the as-cast composites, CTE decreases as the particulate volume fraction increases due o the difference in expansion values of reinforcement and host matrix. Further, for the SME composites CTE increases as the particulate volume fraction increases due to shape memory

Kotresh M.[1]*, M. M. Benal[2]

effect and difference in CTE values of reinforcement and host matrix.

Figure 5 shows the variation of residual stress measured from high-resolution XRD machine, in this for as-cast composites residual stress decreases as the particulate volume fraction increases due to plastic flow. Further for SME composites residual stress increases as the particulate volume fraction increases due to shape memory effect and plastic flow simultaneously.

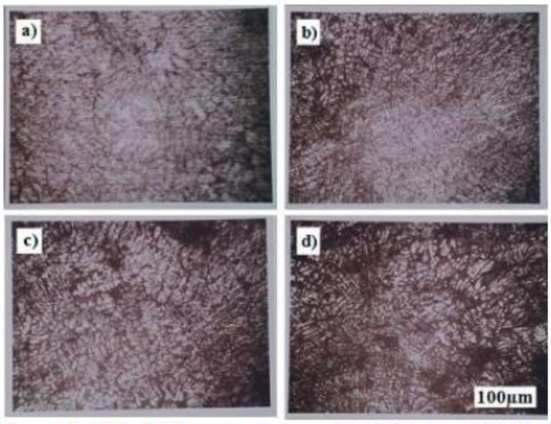

Figure 3 Optical Microstructures of Al 2024/Cu-Al-Ni SM Adaptive Composites of 0%, 5%, 10%, and 15% Vol. fractions

CONCLUSION

Thermal expansion and residual stress is a function of particulate volume fraction and the variation will be in a pronounced effect when the composites were subjected to shape memory effect.

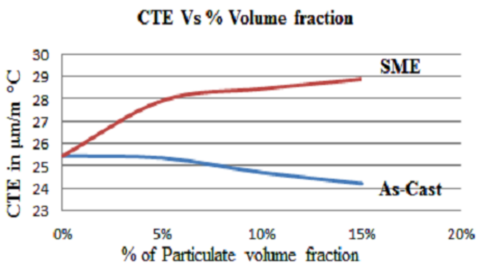

Figure 4 Coefficient of Thermal Expansion of As-cast Composites

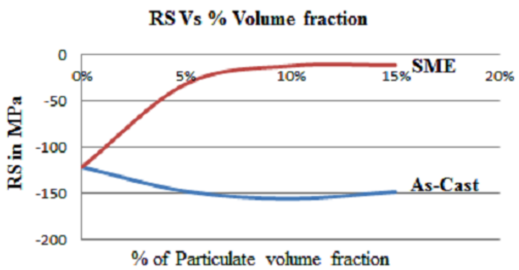

Figure 5 Residual stress of As-cast and SME Composites

From the experimental results the following conclusions can be drawn, the variation of both coefficient of thermal

ACKNOWLEDGMENT

Authors would like to thank, the Secretary, VGST, Department of Information Technology, Biotechnology and Science &Technology, Government of Karnataka for project fund of Rs.10 Lakhs /year for two years (Ref No. K- FIST (Level-1), Proposal No. L1-7 of 2012-13).

REFERENCES

D.M. Lee, B.K. Suh, B.G. Kim, J.S. Lee, C.H. Lee, Fabrication, microstructures, and tensile properties of magnesium alloy AZ91/Si Cp composites produced by powder metallurgy, Materials Science, and Technology 13 (1997) 590-595.

K.K. Ulrich, Development of Magnesium matrix composites for powertrain application, Proceedings of the 12th International Conference "Composite Materials" ICCM-12, Paris, 1999, 453-458.

C. Mayencourt, R. Schaller, Development, and characterization of high damping magnesium based composites, Proceedings of the 12th International Conference "Composite Materials" ICCM-12, Paris, 1999, 459-457.

C.O. Son, S.H. Lee, Characterization of mechanical and in-situ fracture behavior of reaction squeeze cast hybrid Al matrix composites, Proceedings of the 12th International Conference "Composite Materials" ICCM-12, Paris, 1999, 659-667.

M. Zheng, K. Wu, H. Liang, S. Kamado, Y. Kojima, Microstructure and mechanical properties of aluminum borate whisker reinforced magnesium matrix composites, Materials Letters 57 (2002) 558-564.

T.W. Clyne, P. J. Withers, an introduction to metal matrix composites. Cambridge University Press, 1993.

G.L. Povirk, A. Needleman. S.R. Nutt, An analysis of residual stress formation in whisker-reinforced Al–SiC composites, Materials Science Engineering A 129 (1990) 125-140.

G.L. Povirk, A. Needleman. S. R. Nutt, An analysis of the effect of residual stresses on deformation and damage mechanisms in

Al-SiC composites, Materials Science Engineering A 132 (1991) 31-38.

Y.L. Shen, A. Needleman, S. Suresh, Coefficients of thermal expansion of metal-matrix composites for electronic packaging, Metallurgical, and Materials Transactions A 25 (1994) 839-850.

R. Kolhe, C.Y. Hui, E. Ustundag, S.L. Sass, Residual thermal stresses and calculation of the critical metal particle size for interfacial crack extension in metal–ceramic matrix composites, Acta Materialia 44/1 (1996) 279-287.

E. Zywicz, E.M. Parks, Thermo-viscoplastic residual stresses in metal matrix composites. Composite Science and Technology 33/4 (1988) 295-315.

Elomari S., Sundarajan M.D, Richards D, (1998), Compos. Sci. Technol., 58 and 369

Sharma S.C., Kamath R., (1999), Compos. Sci. Technol. 59, 1805

Jonnalagadda K.D., Sottos N.R., Qidwai M.A. and Lagoudas D.C. Transformation of embedded shape memory alloy ribbons, J. Intel. Mater.Sys.&Struct., 1998, 9(5): 379-390.

A. Weiland, T. Johannesson, Residual stresses in fiber- and whisker-reinforced aluminum alloys during thermal cycling measured by X-ray diffraction, Materials Science Engineering A 190/1 (1995) 131-142.

Corresponding Author

Kotresh M.*

Research Student, Visvesvaraya Technological University, Research Resource Center, Belagavi, Karnataka, Belagavi, Karnataka, India

E-Mail – mkotresh@rediffmail.com