INFLUENCE OF CERAMIC PARTICLES ON THE COEFFICIENT OF THERMAL EXPANSION OF ALUMINIUM ALLOY MATRIX COMPOSITE

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Abstract

The increased role of advanced materials in mechanical design optimization has purred the development of new material types and combinations previously unavailable to the designer. These new materials give the designer the ability to design higher density systems by matching the material characteristics of all parts within the system. Certain metal matrix composites now allow the designer to select needed material properties over a fairly large range for example (thermal expansion, conductivity and material strength).The current work has been made for the evaluation of coefficient of thermal expansions (CTE) of Aluminum based cast composites reinforced with mixture of (Al_2O_3) and (SiC) particles with different volume fraction. The cast composites have been prepared by liquid metallurgical route. The results show that (CTE) significantly increased with increasing temperature up to 400 °C. But it has been observed that (CTE) decreases with increasing volume fraction of reinforcing particles. The (CTE) values were found to be comparable with theoretical results. Turner model showed good agreement with the current experimental results.

Key words: Coefficient of thermal expansion(CTE); Aluminium metal matrix composites ;AL_2O_3 and SiC particles.

دراسة تأثير دقائق السيراميك على معامل التمدد الحراري في المواد المتراكبة التي أساسها الألمنيوم

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الخلاصة

إن الدور المتزايد للمواد المتقدمة في التصميم الميكانيكي الأمثل يستنهض أنواع من المواد الجديدة ومجموعاتها غير المتيسرة سابقا للمصمم. إن هذه المواد الجديدة تعطي للمصمم القابلية لتصميم مجموعات ذات كثافة عاليه وذلك من خلال التوافق بين خواص المواد لكل الأجزاء ضمن المجموعة . هناك الآن مواد مركبه تسمح للمصمم لاختيار مواصفات المواد المطلوبة بالاضافه إلى مدى كبير من (التمدد الحراري التوصيل الحراري ومقاومة المواد على سبيل المثال) . إن العمل الحالي أنجز من اجل تقدير معامل التمدد الحراري لمركبات الألمنيوم المقوى بخليط من دقائق اوكسيد الألمنيوم وكربيد السليكون وبأجزاء ذات أحجام مختلفة إن المواد المتراكبة الحالية تم تحضيرها بطريقه السباكة التقليدية ألمعروفه.أظهرت النتائج بان هناك زيادة واضحة في معامل التمدد الحراري بزيادة درجة الحرارة لغاية 400 درجة مئوية إلا انه لوحظ بان معامل التمدد الحراري يقل بزيادة حجم الأجزاء للجزيئات المقوى. إن قيم معامل التمدد الحراري وجدت من اجل مقارنتها مع النتائج النظرية ولقد اظهر نموذج **Turner** التوافق الجيد مع نتائج التجربة الحالية.

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1. Introduction:

In the continuing quest for improved performance, which may be specified by various criteria including light weight, high strength, controlled thermal expansion coefficient, and lower cost, currently-used materials (monolithic materials) frequently reach the limit of their usefulness. Thus, materials scientists and engineers are always striving to produce either improved traditional materials or completely new materials. Composite materials are an example of the latter category. Many applications of metal matrix composites (MMCs) require controlled thermal expansion characteristics in order to match those of other components [1]. The higher elastic modulus and reduced coefficient of thermal expansion (CTE) is due to the incorporation of ceramic particles or fiber in to the matrix [2].

Aluminuim MMCs find potential applications in several thermal environments. Automobile engine parts, space applications such as drive shafts cylinders, pistons and brake rotors [3]. For example an investigation relating to the temperature profiles of the piston area in a diesel engine has shown that the temperature can reach as high as 400 °C in certain regions of the piston [4]. As the piston and cylinder areas are exposed to high temperature, the materials used should have sufficient stability. The stability can be described in two ways change in geometrical form and change in mechanical properties. In the former case the coefficient of thermal expansion (CTE) of composite material plays a key role, while in the latter case the mismatch of CTEs between the metal matrix and the reinforcement has a dominant effect [5,6].However, the candidate composite material for thermal applications must posses high elastic modulus and lower CTE.

In open literature, some studies have been focused on CTE of MMCs. Skirl et al., [7] have examined the effect of other material parameters, such as elastic properties of matrix and reinforcement, size and shape of the reinforcement on the CTE and internal residual strain of Al_2O_3 reinforced aluminium base metal matrix composite. Balch and et al., [8], reported that the variation of thermal strain with respect to temperature for sic foam reinforced with aluminium MMCs where they attempted a comparison between the experimental and analytical results obtained reasonably good agreement for thermal cycle with temperature difference.

The current investigation is a focused on the thermal behaviour of aluminium metal matrix composites (Al – MMCs) reinforced with a mixture of alumina (Al_2O_3) and silicon carbide (SiC) particles. The CTE of the Al-MMCs has been measured between 25 °C and 450 °C by high-precision thermal mechanical analyzer (TMA) and the results are compared with the predictions of theoretical models.

2. Experimental Procedure:

Aluminium metal matrix composite reinforced with a mixture of Al_2O_3 and SiC particles, have been fabricated by stirring these particles into molten aluminium alloy at a temperature of 750 °C. The chemical composition of the aluminium alloy (Al -7075) used in the current investigation is given in Table 1.

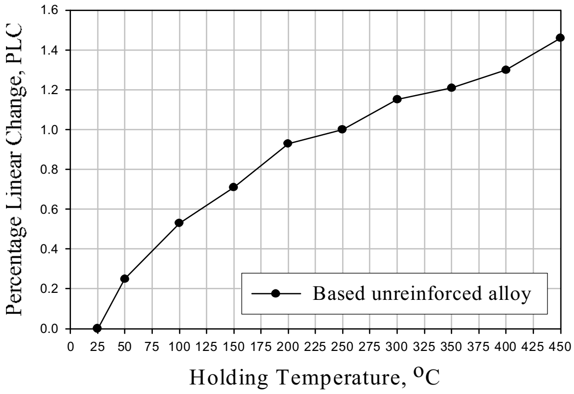
Table 1: Main chemical composition of Al-7075.

Zinc (wt .%)	Cupper (wt .%)	Magnesium (wt .%)	Aluminium (wt .%)
15.7	1.7	2.4	Balance

The average sizes of the reinforcing particles used in the current investigation are about 35 μm and 23 μm for Al_2O_3 and SiC respectively.

Specimens for CTE tests have been prepared using traditional casting route, with the variation of the reinforcing particles in steps of 3,5,7 and 10 wt .%. after that these specimens are machined out to get the standard test specimens for CTE tests (10 x 5 x 2 mm in size). The specimen surfaces have been polished with 1 μm diamond paste. Five samples of each composite have been tested under same conditions to verify the reproducibility of the data tests.

CTE measurements have been performed in the range of 25 °C to 450 °C at a rate of heating of 5 °C /min, using commercially available Thermal Mechanical Analyzer (TMA). Standard TMA data analysis software has been used to evaluate the CTE of the composite materials.



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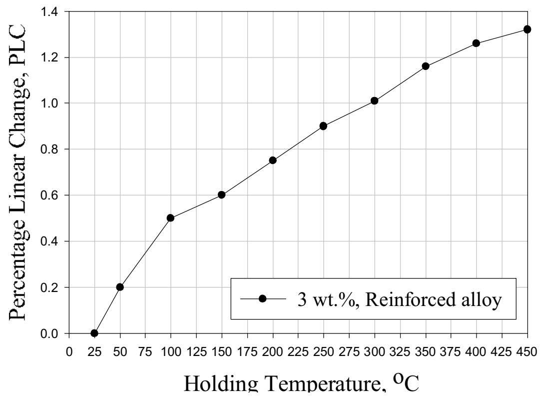

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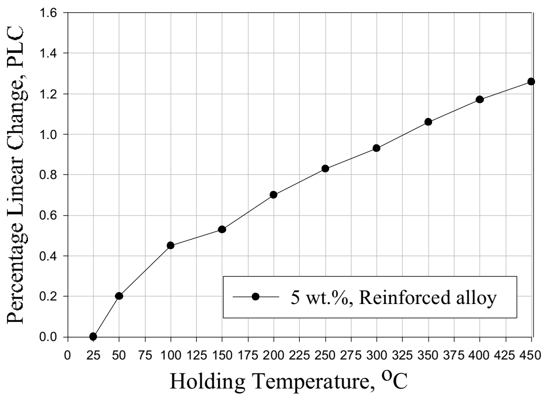

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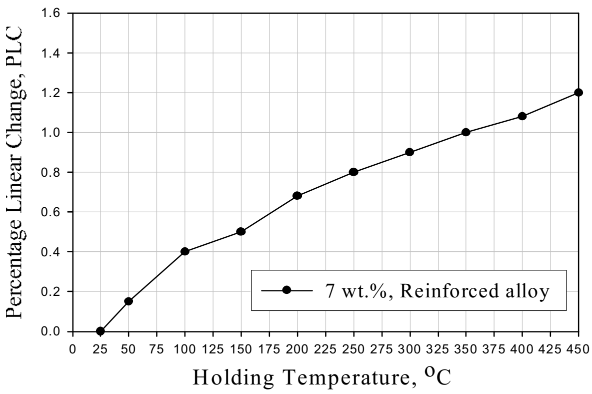

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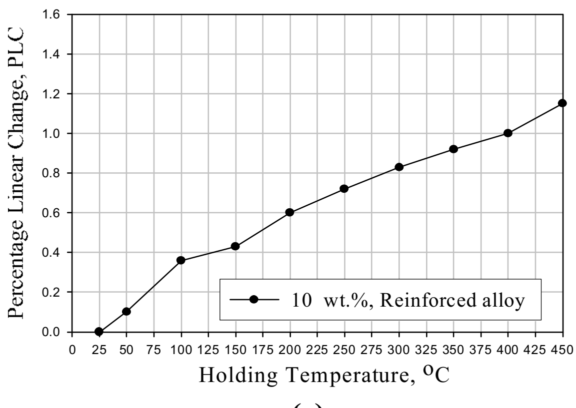

(e)

Figure 1: Show the variation of percentage linear change (PLC) with temperature; (a) 0 wt.%, (b) 3 wt.%, (c) 5 wt.%, (d) 7 wt.% and (e) 10 wt.%

3. Results and Discussion:

Figure 1, shows the experimental results of the variation of percentage linear change (PLC) of aluminium based alloy particulate composites with different weight percentages of reinforcements as functions of temperature. It is observed that there is no significant differences between these curves, i.e. nearly similar characteristics as demonstrated in Fig. 1.

But the increase in weight percentage of the reinforcing particles showed a relatively larger contraction as shown in Fig. 2, where all curves are plotted together. It is also, observed that the differences in contractions increases with increasing temperature.

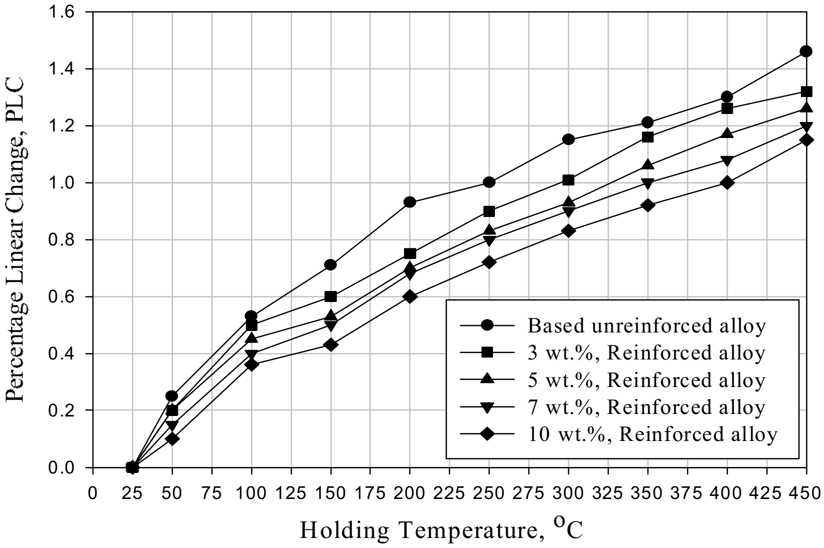

Figure 2: Variation of PLC with holding temperatures for different composition of the tested composite materials.

These significant increases in constructions are attributed mainly to the present of ceramic reinforcing particles. The results of the CTE of unreinforced aluminium based alloy and different weight percentage of particles reinforced composite are shown in Table 2. One observes a dramatic reduction in the CTE of the composite in comparison with that of the based unreinforced alloy, which explain that in these composite material, there is good interfacial bonding, due to existence of macroscopic strain.

Table 2. Results of coefficient of thermal expansion (CTE, x10^{-6}/k) of based unreinforced alloy and composites

Temp. °C	Based unreinforced alloy	3 wt .%	5 wt .%	7 wt .%	10 wt .%
	coefficient of thermal expansion (CTE, x10^{-6}/k)				
25	21.32	16.37	15.31	13.82	13.03
50	22.41	18.80	17.01	16.3	15.05
100	23.54	20.99	18.06	16.91	15.88
150	24.43	21.89	19.66	17.71	16.55
200	25.09	23.13	21.54	19.81	18.03
250	26.11	24.32	22.31	21.02	19.12
300	27.21	25.43	24.06	22.6	21.03
350	27.92	26.21	25.2	23.6	22.61
400	28.42	27.06	26.31	24.7	23.43
450	29.03	28.11	27.08	25.81	24.02

The variations CTE of the based unreinfoced alloy and particulate composites with holding temperature are shown in the Fig. 3. The CTE of based unreinforced alloy and particulate composites were found to increase with increasing temperature.

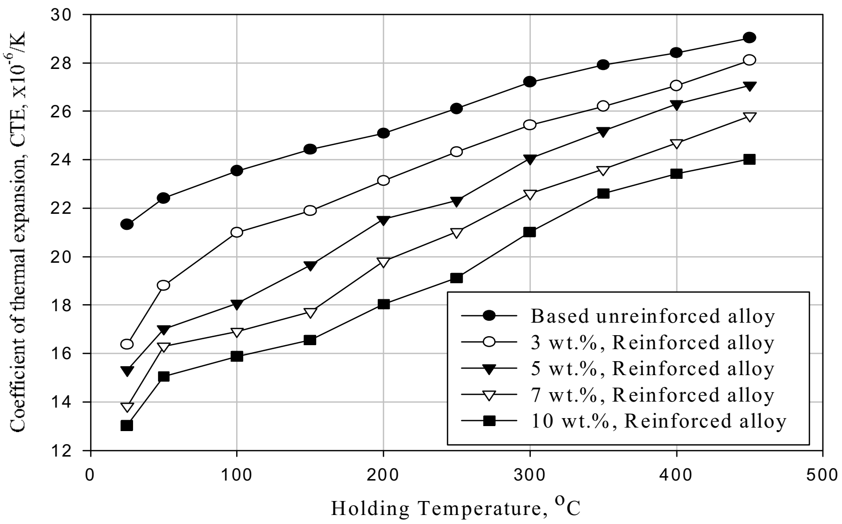

Figure 3: The variation of CTE with increasing temperature for base unreinforced alloy and particulate composites with different amount of reinforcing particles .

Experimental results of CTE measurements conducted on the particulate composites are compared with the predicted values obtained from Turner model [9]. This model is based on the uniform hydrostatic stresses existing in the phase. In this model the CTE of the composite material is given by,

$$\alpha_c = \frac{\alpha_m V_m K_m + \alpha_p V_p K_p}{V_m K_m + V_p K_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where α is the coefficient of thermal expansion, V is the volume fraction of reinforcing particles and K is the bulk modulus. The subscripts c, m, and p refer to the composite, matrix and reinforcing particles respectively.

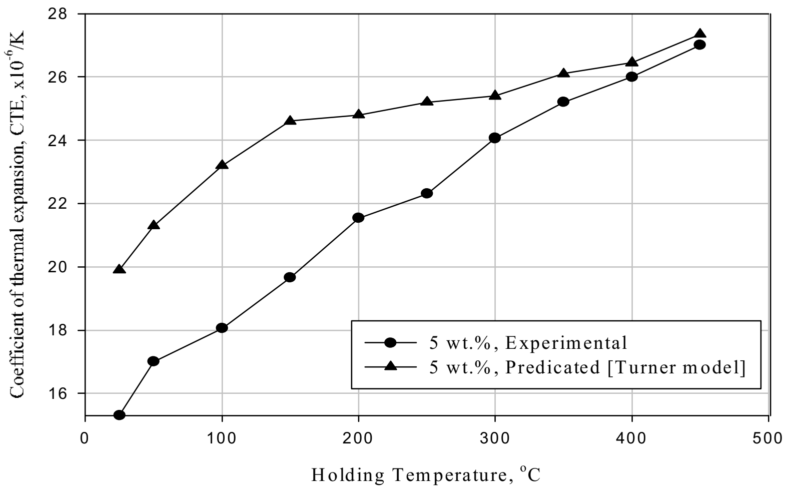

Figure 4: Comparison between results of CTE measured of composite with 5 wt% reinforcing particles and predicted values obtained from Turner model.

The measured CTEs of the different particulate composites are agree fairly well with those predicted by the Turner model, particularly at higher temperature region, as demonstrated in Fig. 4.

4. Conclusions:

The coefficient of thermal expansion CTE of cast unreinforced alloy and particulate composites were evaluated experimentally and compared with those predicted by Turner model. The main conclusions may drawn from the current work are:

1- Aluminium alloy based cast particulate composites could be successfully produced by casting technique.

2- The coefficient of thermal expansion of both based unreinforced alloy and particulate composites increases with increasing temperature from 25 °C to 450 °C for base unreinforced alloy the increases in CTE near about 36% but, for example ; in the case of composite containing (5 wt.%) reinforcing particle , the increases near about 76.8 % .

3- The coefficient of thermal expansion of particulate composite decreases with increasing weight percentage of reinforcing particles. For example , at a given holding temperature , say 50 °C , the CTE of composite containing (5 wt.%) decreases about 24 % .

4- In the theoretical model used to predict the coefficient of thermal expansion of the particulate composite, Turner model appears to reasonably predict the CTE, particularly at higher temperatures.

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