STUDYING THE INFLUENCE OF CERAMIC PARTICLES ON THE COEFFICIENT OF THERMAL EXPANSION OF METAL 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 (thermal expansion , conductivity and material strength for example).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 400C° .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 conformance with the current experimental results.

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

دراسة تأثير ذرات السيراميك على معامل التمدد الحراري في قولب المواد المتراكبة

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الخلاصة

إن الدور المتزايد للمواد المتقدمة في التصميم الميكانيكي الأمثل يستنهض أنواع المواد الجديدة والمجموعات المسبقة غير المتيسرة 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 قوالب 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 قالب الألمنيوم المقوى بخليط من جزيئات اوكسيد الألمنيوم وكربيد السليكون وبأجزاء ذات أحجام مختلفة. إن مركبات القالب قد تم تهيئتها بواسطة قناة سائل معدنية.أظهرت النتائج بان هناك زيادة واضحة في معامل التمدد الحراري حدثت بزيادة درجة الحرارة لغاية ٤٠٠ درجة مئوية إلا انه لوحظ بان معامل التمدد الحراري يقل بزيادة حجم الأجزاء لجزيئات القالب المقوى. إن قيم معامل التمدد الحراري وجدت من اجل مقارنتها مع النتائج النظرية ولقد اظهر نموذج Turner التوافق مع نتائج التجربة الحالية.

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 (Xu, Chawala, Mitra, and Fine,1994). 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 (Elomari, Boukhili, and Lloyd 1996).

Aluminuim MMCs find potential applications in several thermal environments. Automobile engine parts, space applications such as drive shafts cylinders, pistons and brake rotors (John, Allison and Gerald 1993).

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 400C° in certain regions of the piston (Bowles, Macini, and Toaz,1990). 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 (Minoru Taya and Richard Arsenault 1989) [5] and (Everett, and Richard Arsenault 1991) [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, Hoffman, Bowman, Wiederhorn, and Rodel, 1998) 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, Fitzgerald, Michaud, Mortensen, Shen, and Suresh, 1996), 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 focus on the thermal behaviour of aluminium metal matrix composites (Al – MMCs) reinforced with a mixture of alumina (Al_2O_3) and silicon carbide (Sic). The CTE of the Al-MMCs has been measured between 25C° and 450C° by high-precision thermal mechanical analyzer (TMA) and the results are compared with the predictions of theoretical models.

Experimental Procedure:

Aluminium metal matrix composite reinforced with a mixture of Al2O3 and Sic particles, have been fabricated by stirring these particles into molten aluminium alloy at a temperature of 750C°. the chemical composition of the aluminium alloy (Al7075) is given in Table (1).

The average size of the reinforcing particles used in the current investigation are about 35 μm and 23μm for Al2O3 and Sic respectively.

Specimens for CTE tests have been prepared using compocasting route, with the variation of the reinforcing particles in steps of 3,5,7 and 10 wt%. after that these specimens are machined 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 test.

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

Results and Discussion:

Figure 1 shows the experimental results of the variation of percentage linear change (PLC) of aluminium alloy particulate composites with different weight percentages as functions of temperature. It is observed that there is no significant differences between these curves, i.e. nearly similar characteristics as demonstrated in **Figure 1**. but the increase in weight percentage of the reinforcing particles showed a relatively larger contraction as shown in **Figure 2**, where all the curves are plotted together. It is also, observed that the differences in contractions increases with increasing temperature.

These significant increases in constructions are attributed mainly to the present of reinforcing particles. The results of the CTE of base unreinforced aluminium 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.

The variations CTE of the base unreinfoced alloy and composites with holding temperature are shown in the **Figure 3**. the CTE of base unreinforced alloy and composites were found to increase with increasing temperature.

Experimental results of CTE measurements conducted on the composites are compared with the predicted values obtained from Turner model (Matthews, and Rawlings 2001). 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,

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

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.

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

Conclusions:

The main conclusions may drawn from the current work are:

- Aluminium alloy based cast particulate composites could be successfully produced by compocasting technique.
- The coefficient of thermal expansion of both base unreinforced alloy and composite increases with increasing temperature.
- The coefficient of thermal expansion of composite decreases with increasing weight percentage of reinforcing particles.
- In the theoretical model used to predict the coefficient of thermal expansion of the composite, Turner model appears to reasonably predict the CTE, particularly at higher temperatures.

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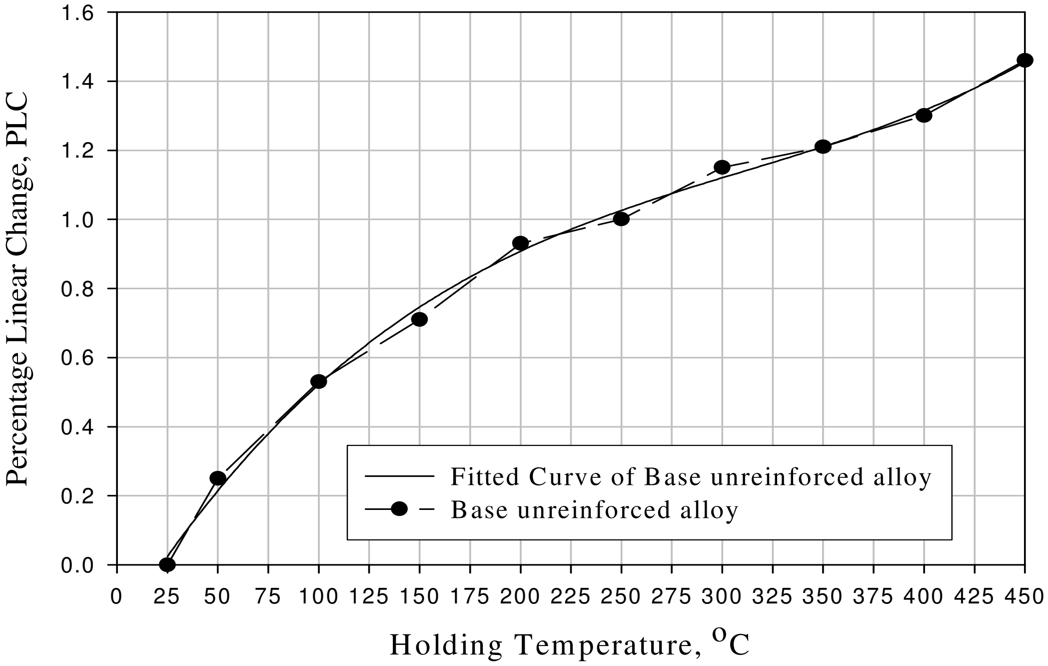
Table 1: Main chemical composition of Al-7075.

Zn (wt%)	Cu (wt%)	Mg (wt%)	Al (wt%)
15.7	1.7	2.4	Balance

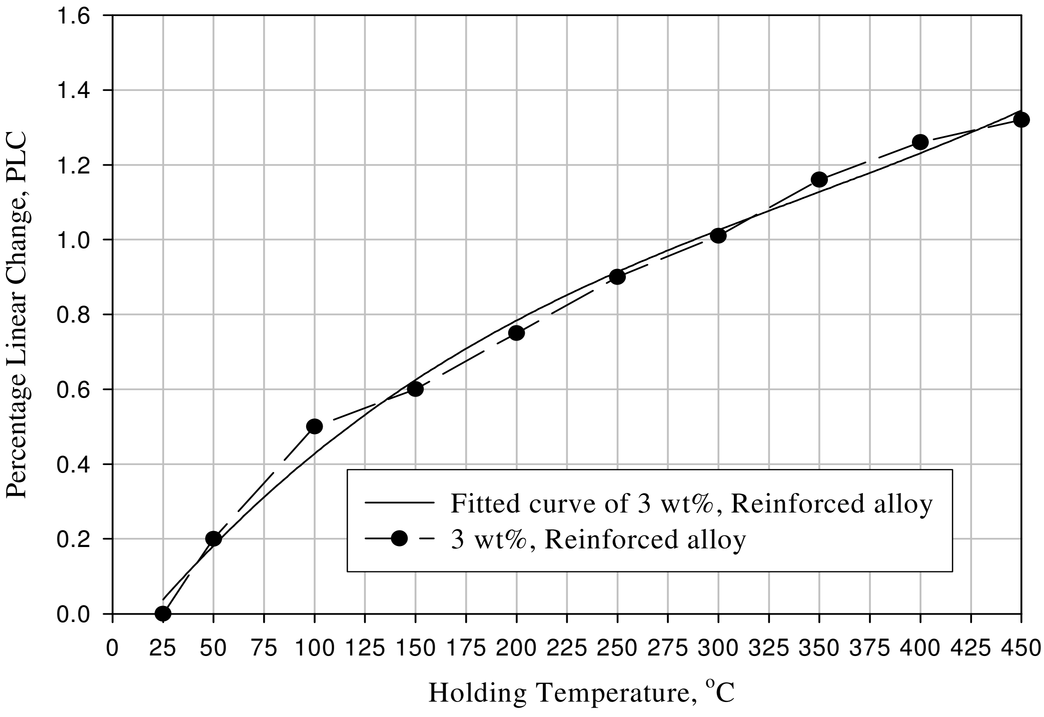
Table 2. Results of coefficient of thermal expansion (CTE) ($x10^{-6}/k$) of base alloy and composites

Temp. C°	Base unreinforced alloy	3 wt%	5 wt%	7 wt%	10 wt%
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



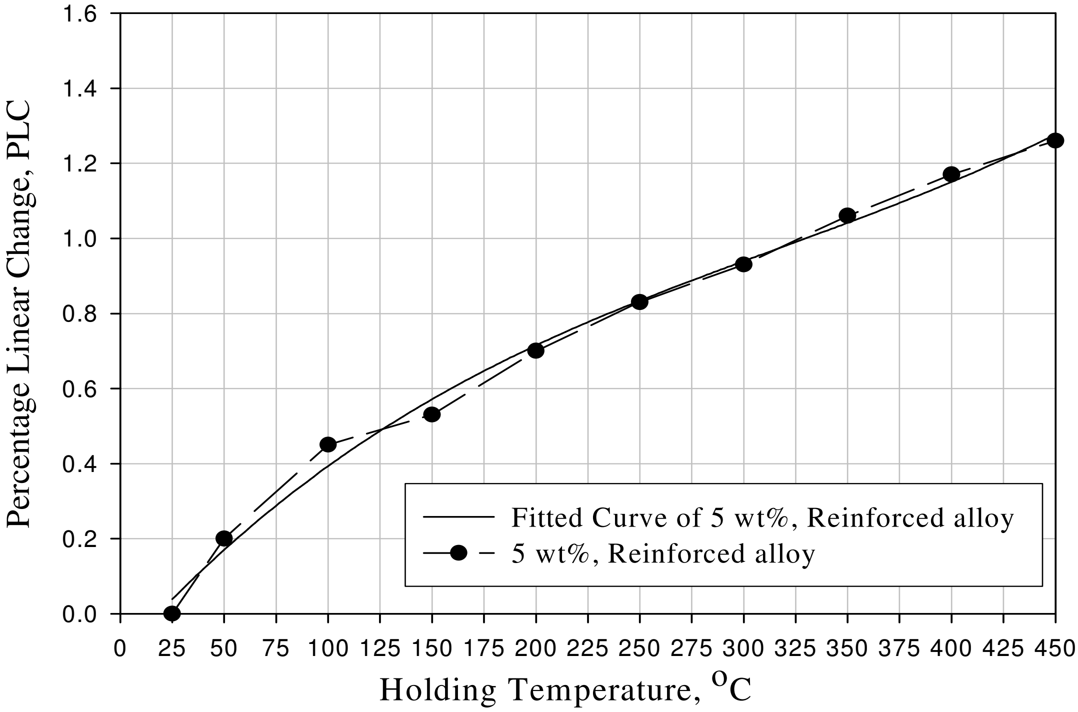
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Percentage Linear Change, PLC
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450
Holding Temperature, °C
Fitted Curve of Base unreinforced alloy
Base unreinforced alloy

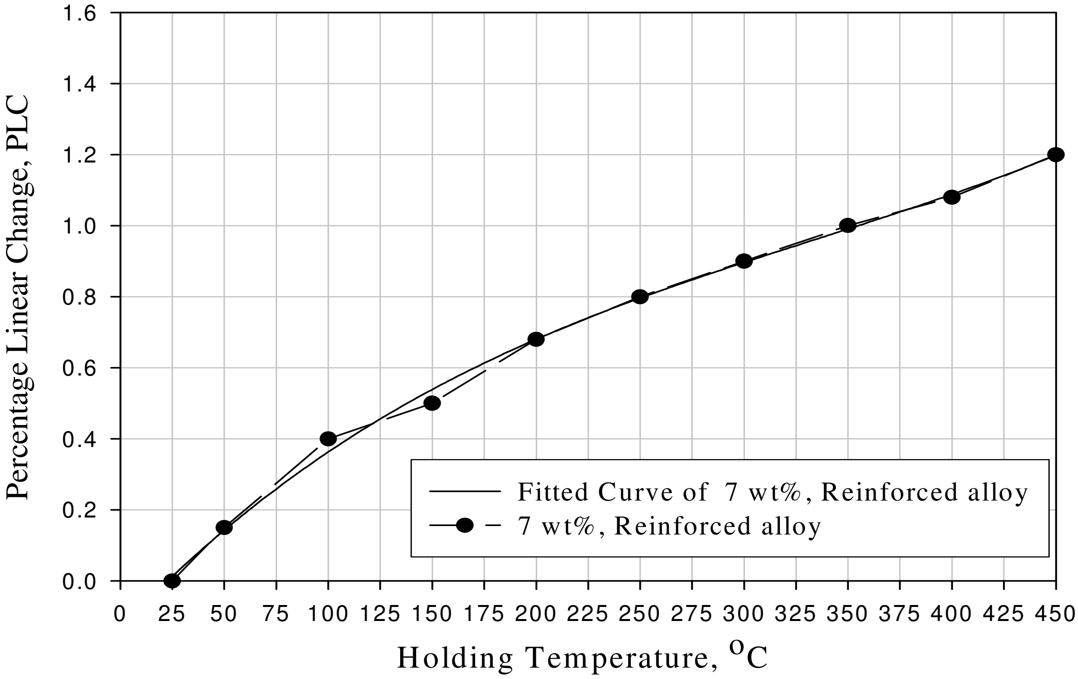
(a)



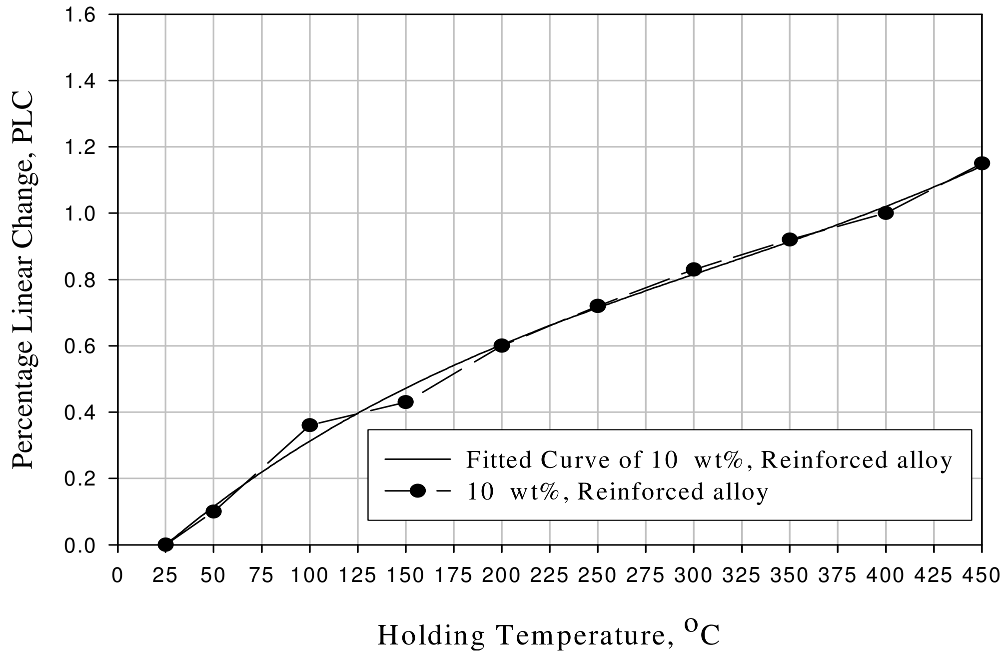
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Percentage Linear Change, PLC
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450
Holding Temperature, °C
Fitted curve of 3 wt%, Reinforced alloy
3 wt%, Reinforced alloy

(b)


Percentage Linear Change, PLC
Holding Temperature, °C
Fitted Curve of 5 wt%, Reinforced alloy
5 wt%, Reinforced alloy
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450


Percentage Linear Change, PLC
Holding Temperature, °C
Fitted Curve of 7 wt%, Reinforced alloy
7 wt%, Reinforced alloy
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450

(d)



(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) 10wt% .

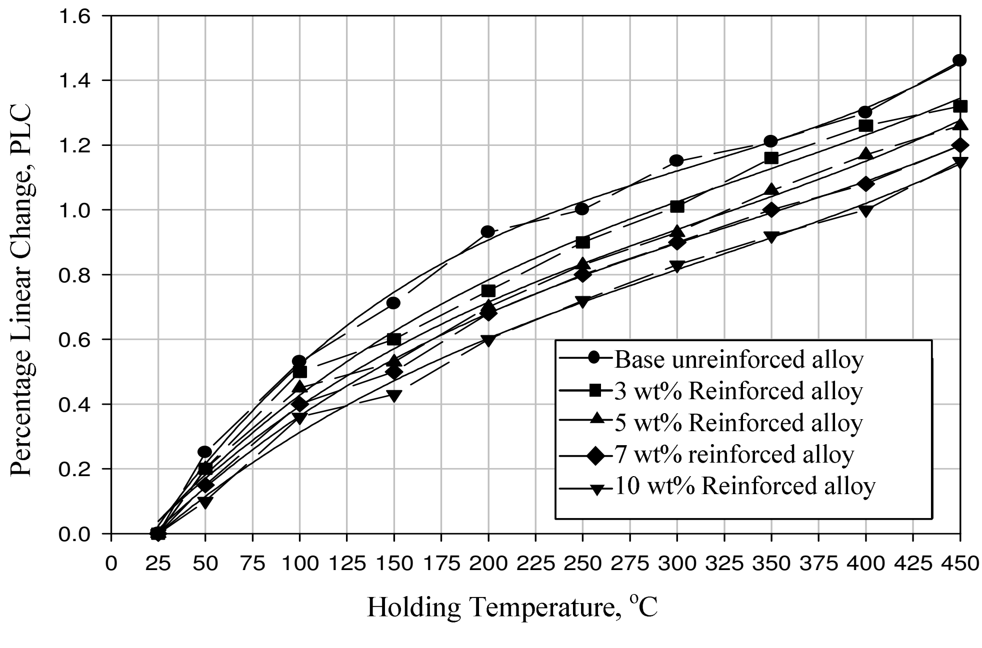


Figure 2: Variation of PLC with holding temperatures for different composition of the tested composite materials .

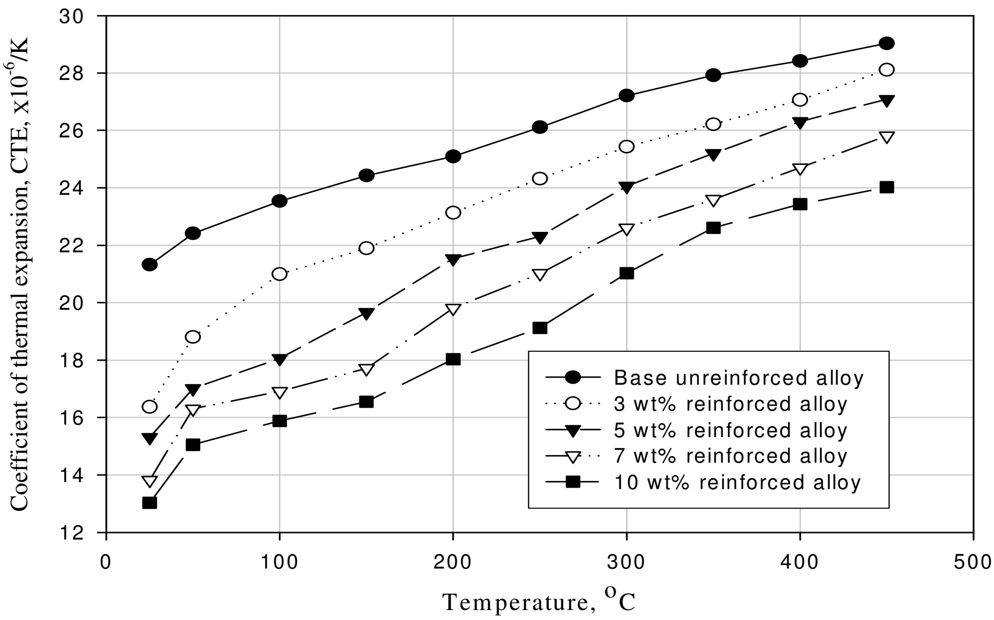


Figure 3: The variation of CTE with increasing temperature for base unreinforced alloy and composite with different amount of reinforcing particles .

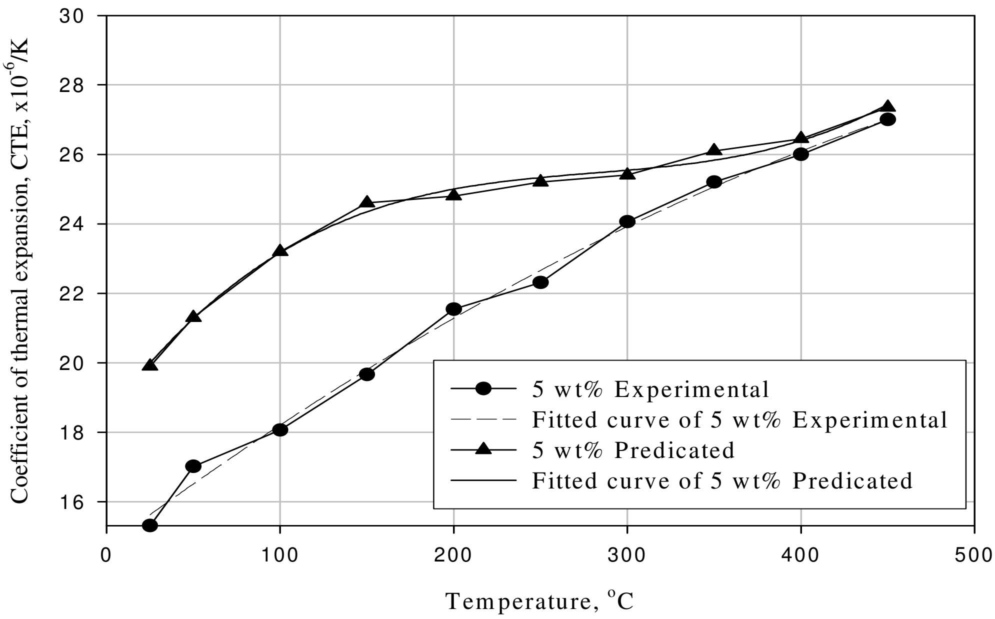


Figure 4: Comparison between results of CTE measured of composite with 5 wt% reinforcing particles and the predicted values obtained from Turner model.