Prediction of CTE of Al/TiB_2 Metal Matrix Composites

A. Chennakesava Reddy

Associate Professor, Department of Mechanical Engineering, Vasavi College of Engineering, Hyderabad, India
dr_acreddy@yahoo.com

Abstract: *The thermal expansion behavior of aluminum matrix composites reinforced with titanium boride nanoparticles was measured between 30 and 300°C and compared to theoretical models. The results revealed that the nanoparticle volume fraction had significant effect on the thermal expansion behavior of the composites. The thermal expansion of the composites has the closer values to the Turner model.*

Keywords: *Metal matrix composites, thermal expansion, titanium boride.*

1. INTRODUCTION

It is essential to study the composite materials they are used for high temperature applications where high strength / stiffness to-weight ratio is required [1]. Composite Technology combines the most important properties of the components together in order to obtain a material with overall properties suitable for the design of the engineering part required [2-10]. Most of the studies on metal matrix composites (MMC) have focused on aluminum (Al) as the matrix metal [11-17]. The combination of lightweight, environmental resistance and adequate mechanical properties has made Al and its alloys composites very popular. Titanium diboride (TiB_2) is well known as a ceramic material with relatively high strength and durability as characterized by the relatively high values of its melting point, hardness, strength to density ratio, and wear resistance [18]. Current use of this material, however, appears to be limited to specialized applications in such areas as impact resistant armor, cutting tools, crucibles, and wear resistant coatings. An important evolving application is the use of TiB_2 composites in the wear reduction of aluminum metal.

The aim of this paper was to predict the thermal expansion behavior of aluminum metal matrix composites reinforced with nanoscale titanium boride (TiB_2) particles. The effect of volume fraction of TiB_2 nanoparticles was also examined.

2. MATERIALS METHODS

Pure Al powder of 100 μm with 99.9% purity and TiB_2 powders of 100 nm were used as the starting materials. Pure powders of Al and TiB_2, in the desired volume fractions, were mixed together by high-energy ball milling for 20 h to ensure the uniform mixing. The mixing was carried out in argon atmosphere to minimize the contamination. The obtained powder mixtures were then sintered to bulk specimens by hot pressing at 800 °C with a pressure of 50 MPa in vacuum, followed by quickly cooling to room temperature in 30 min. In this study, four different composites were prepared (Table 1).

Table 1: Composition of metal matrix composites

Composite	Composition, vol.%	
	Al	TiB_2
AL-TB-1	90	10
AL-TB-2	85	15
AL-TB-3	80	20
AL-TB-4	75	25

The thermal expansion was then measured with a dilatometer (DIL 802) between 100 and 300°C at heating and cooling rates of 5°C/min in argon. With this instrument the difference in length between the specimen to be investigated and a reference sample is measured, which results in a resolution of ± 0.01 μm. The sample holder (pushrod) is made of sapphire (figure 1). Specimens with a diameter of 5 mm and length of 10 mm were used for CTE measurement. The instantaneous CTE at a given temperature was calculated using the following equation:

$$\text{CTE} = \frac{\partial}{\partial T}\left(\frac{\Delta L}{L}\right) \tag{1}$$

where L is the length of the specimen and T the temperature.

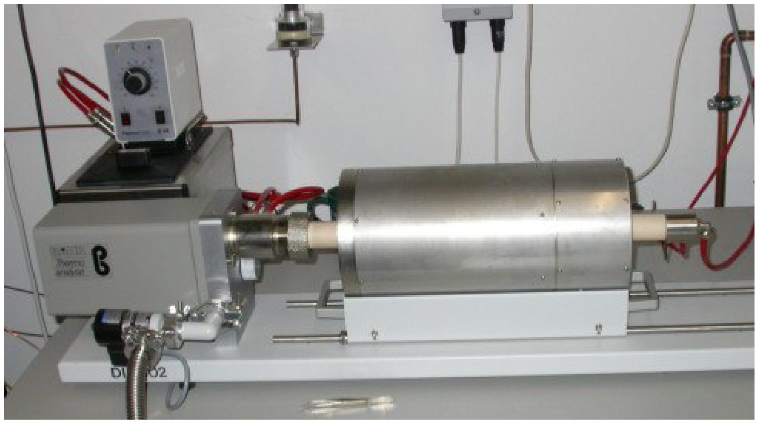

Figure 1: The differential dilatometer.

3. RESULTS AND DISCUSSION

Single crystal TiB_2 exhibits hexagonal symmetry as shown in figure 2. The lattice parameters [4-7], figure 3, have a slight quadratic dependence on the temperature which accounts for the linear temperature dependence of the coefficient of thermal expansion. The ratio c/a ranges from (1.066±0.001) at 25°C to (1.070±0.001) at 1500°C.

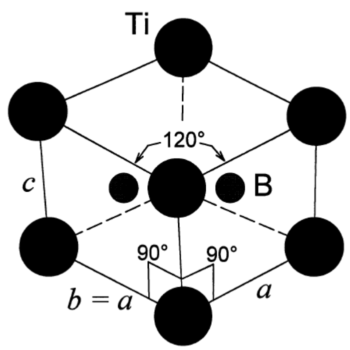

Figure 2: The hexagonal unit cell of single crystal TiB_2, $a = b \# c$, $\alpha = \beta = 90^o$, $\gamma = 120^o$, 1 formula unit per cell, Ti at (0,0,0), B at (1/3,2/3,1/2) and (2/3,1/3,1/2).

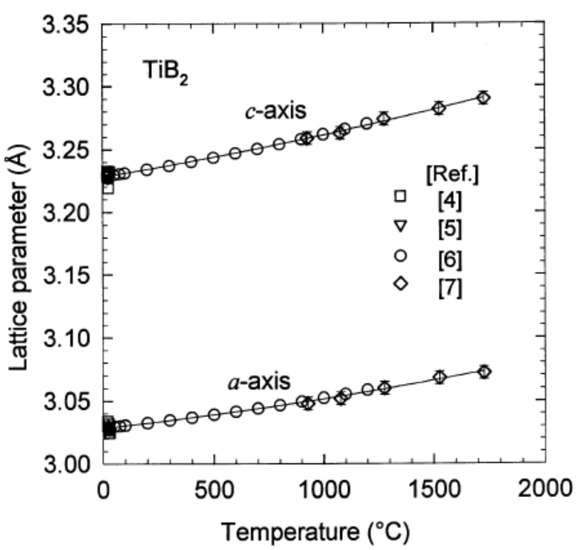

Figure 3: Lattice parameters *a* and *c* of single crystal TiB_2 as a function of temperature.

The CTE obtained from the heating and cooling as a function of temperature is plotted in figure 4 for all materials. The CTE measured during the heating cycle increases nonlinearly for the composites AL-TB-1 and AL-TB-2 with increasing temperature between 30 and 300^{o}C as shown in figure 4a and 4b. The CTE increases linearly with temperature for the composites AL-TB-3 and AL-TB-4 (figure 4c and 4d). The CTE measured during the cooling cycle decreases continuously with decreasing temperature in the same trend of heating cycle. The difference in CTE during heating and cooling is due difference in CTE along a-axis and c-axis of TiB_2 nanoparticles. For the CTE of the composites containing lower volume fraction nanoparticles (AL-TB-1 and AL-TB-2), the rate of increase is higher than that of composites containing higher volume fraction nanoparticles (AL-TB-3 and AL-TB-4).

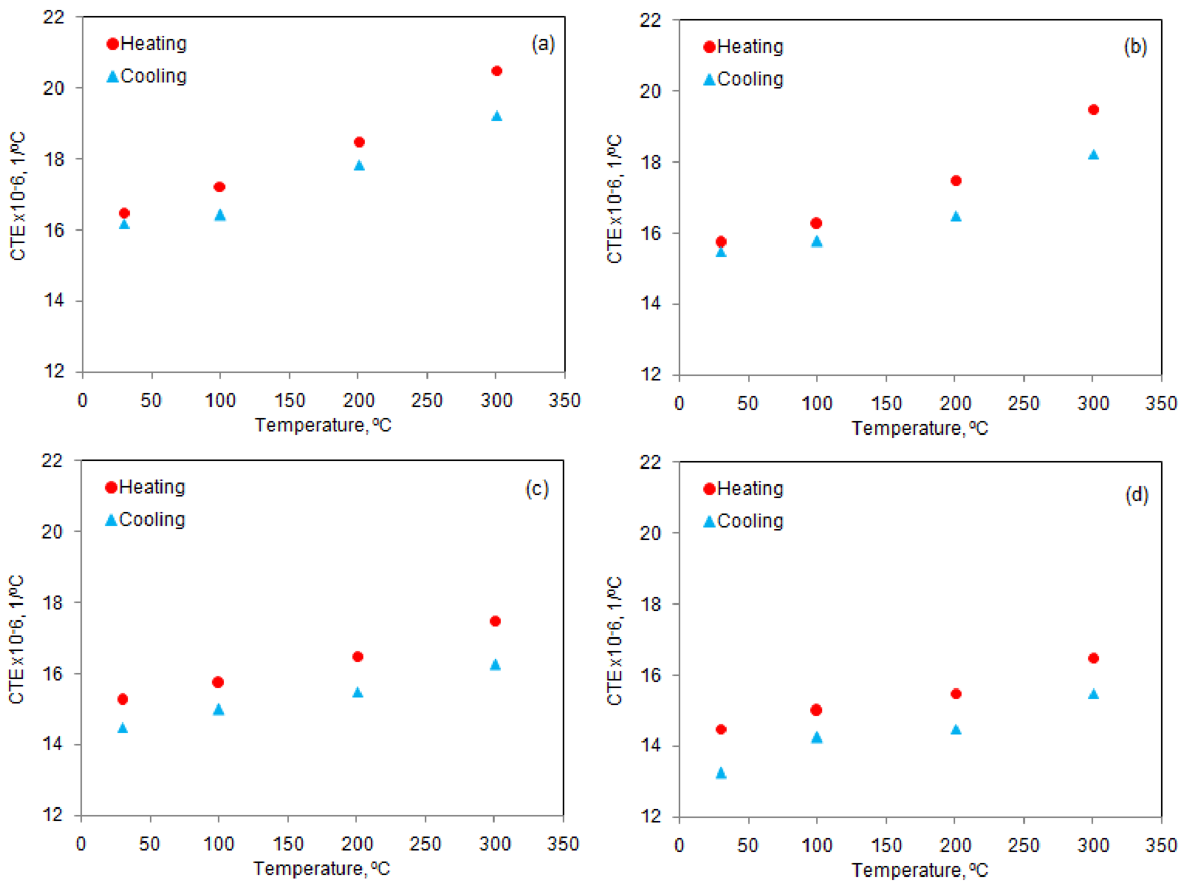

Figure 4: Coefficient of thermal expansion as a function of temperature for: (a) AL-TB-1, (b) AL-TB-2, (c) AL-TB-3 and (d) AL-TB-4.

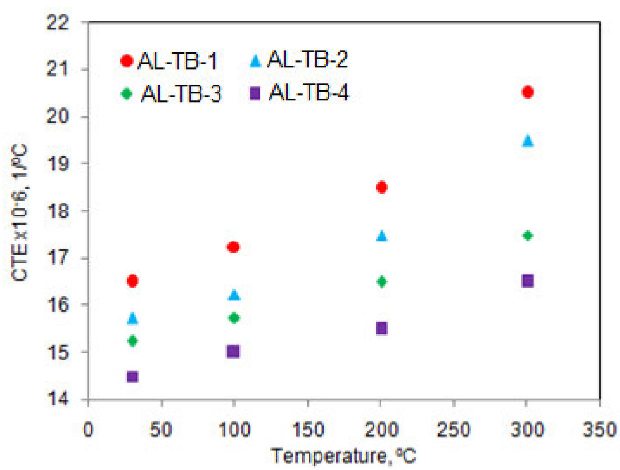

Figure 5: Compare the CTE of different composites.

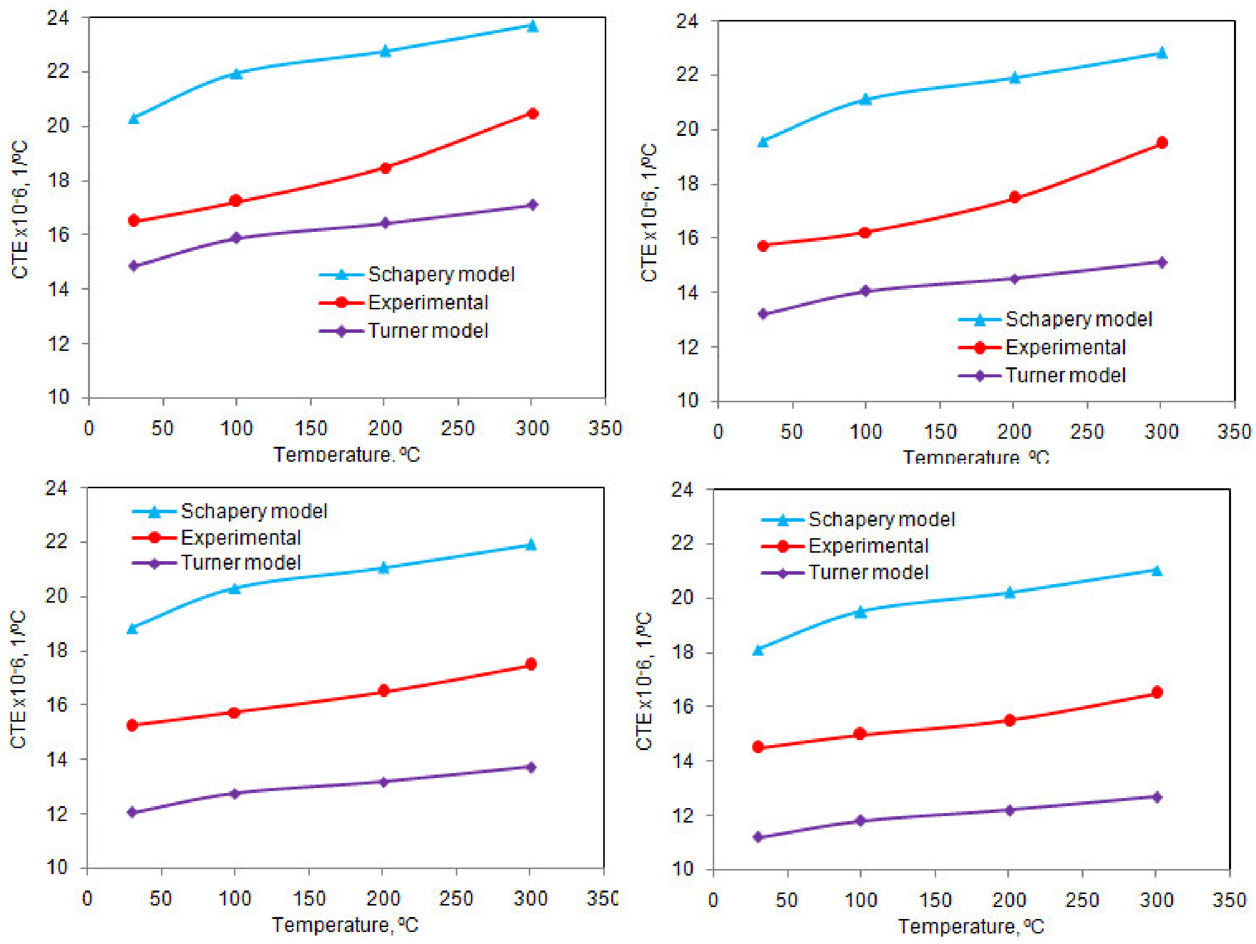

Figure 6: Coefficient of thermal expansion as a function of temperature compared with Schapery and Turner models for: (a) AL-TB-1, (b) AL-TB-2, (c) AL-TB-3 and (d) AL-TB-4.

Figure 5 compares the thermal expansion behavior of the four samples obtained from the heating cycle. It can be seen that the CTE value decreases with increase in volume fraction of TB_2 nanoparticles. The bond energy is low for the composites having high volume fraction of TB_2 nanoparticles. For the composite materials, residual stresses resulted from thermal mismatch between the matrix and the reinforcement influences the thermal expansion behavior.

Additional analysis of the thermal expansion behavior of the composites was done by comparing the experimental results with theoretical models. Several models have been proposed for estimating the CTE of the metal-matrix composite [21-22]. By assuming that only uniform hydrostatic stresses exist in the phases, Turner [21] proposed that the CTE of a particular composite can be described by

$$\alpha_c = \frac{\alpha_m V_m K_m + \alpha_r V_r K_r}{V_m K_m + V_r K_r} \quad (2)$$

where α is CTE, V the volume fraction, K the bulk modulus, and the subscripts c, m, and r refer to the composite, matrix and reinforcement, respectively. On the other hand, by considering both hydrostatic and shear stresses, Schapery [22] is expressed as

$$\alpha_c = V_r \alpha_r + V_m \alpha_m + \left(\frac{4G_m}{K_c}\right)\left[\frac{(K_c - K_r)(\alpha_c - \alpha_r)V_r}{4G_m + 3K_r}\right] \quad (3)$$

where G is shear modulus and K_c the bulk modulus of the composite given by:

$$K_c = \frac{\frac{V_r K_r}{4G_m+3K_r} + \frac{V_m K_m}{4G_m+3K_r}}{\frac{V_r}{4G_m+3K_r} + \frac{V_m}{4G_m+3K_r}} \qquad (4)$$

Figure 6 compares the experimental results with the theoretical models for all four composites. It is observed that the experimental CTE results lower than the results predicted by the Schapery model. Also, the experimental CTE results higher than the results predicted by the Turner model. This difference caused by the nanoparticle volume fraction owing to residual stresses developed in the composites.

4. CONCLUSION

In this research, the thermal expansion behavior of Al-based composites reinforced with titanium boride nanoparticles has been investigated. The results disclose that the volume fraction of nanoparticle can have significant effect on thermal expansion behavior of the composites. The thermal expansion of the composites has the closer values to the Turner model.

REFERENCES

1. K. K. Chawla, Composite Materials: Science and Engineering,Springer-Verlag, New York, 1987.
2. A. Chennakesava Reddy, Effect of Particle Loading on Microealstic Behavior and interfacial Tractions of Boron Carbide/AA4015 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 176-179.
3. A. Chennakesava Reddy, Reckoning of Micro-stresses and interfacial Tractions in Titanium Boride/AA2024 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, March 1997, pp. 195-197.
4. A. Chennakesava Reddy, Evaluation of Debonding and Dislocation Occurrences in Rhombus Silicon Nitride Particulate/AA4015 Alloy Metal Matrix Composites, 1st National Conference on Modern Materials and Manufacturing, Pune, India, 19-20 December 1997, pp. 278-282,.
5. A. Chennakesava Reddy, Interfacial Debonding Analysis in Terms of Interfacial Tractions for Titanium Boride/AA3003 Alloy Metal Matrix Composites, 1st National Conference on Modern Materials and Manufacturing , Pune, 19-20 December, 1997.
6. A. Chennakesava Reddy, Assessment of Debonding and Particulate Fracture Occurrences in Circular Silicon Nitride Particulate/AA5050 Alloy Metal Matrix Composites , National Conference on Materials and Manufacturing Processes, Hyderabad, India, 27-28 February 1998, pp. 104-109.
7. A. Chennakesava Reddy, Local Stress Differential for Particulate Fracture in AA2024/Titanium Carbide Nanoparticulate Metal Matrix Composites, National Conference on Materials and Manufacturing Processes, Hyderabad, India, 27-28 February 1998, pp. 127-131.
8. A. Chennakesava Reddy, Micromechanical Modelling of Interfacial Debonding in AA1100/Graphite Nanoparticulate Reinforced Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, India, 9-10 April 1999, pp. 249-253.
9. A. Chennakesava Reddy, Cohesive Zone Finite Element Analysis to Envisage Interface Debonding in AA7020/Titanium Oxide Nanoparticulate Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, India, 9-10 April 1999, pp. 204-209.
10. B. Kotiveera Chari, A. Chennakesava Reddy, Debonding Microprocess and interfacial strength in ZrC Nanoparticle-Filled AA1100 Alloy Matrix Composites using RVE approach, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 104-109.
11. A. Chennakesava Reddy, Micromechanical and fracture behaviors of Ellipsoidal Graphite Reinforced AA2024 Alloy Matrix Composites, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 96-103.
12. S. Sundara Rajan, A. Chennakesava Reddy, Micromechanical Modeling of Interfacial Debonding in Silicon Dioxide/AA3003 Alloy Particle-Reinforced Metal Matrix Composites, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 110-115.
13. S. Sundara Rajan, A. Chennakesava Reddy, Role of Volume Fraction of Reinforcement on Interfacial Debonding and Matrix Fracture in Titanium Carbide/AA4015 Alloy Particle-Reinforced Metal Matrix Composites, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, 116-120.
14. A. Chennakesava Reddy, Constitutive Behavior of AA5050/MgO Metal Matrix Composites with Interface Debonding: the Finite Element Method for Uniaxial Tension, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 121-127.

15. B. Kotiveera Chari, A. Chennakesava Reddy, Interfacial Debonding of Boron Nitride Nanoparticle Reinforced 6061 Aluminum Alloy Matrix Composites, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 128-133.
16. P. M. Jebaraj, A. Chennakesava Reddy, Simulation and Microstructural Characterization of Zirconia/AA7020 Alloy Particle-Reinforced Metal Matrix Composites, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 134-140.
17. P. M. Jebaraj, A. Chennakesava Reddy, Continuum Micromechanical modeling for Interfacial Debonding of TiN/AA8090 Alloy Particulate Composites, 2nd National Conference on Materials and Manufacturing Processes, Hyderabad, India, 10-11 March 2000, pp. 141-145.
18. V. I. Matkovich, Boron and Refractory Borides, Springer Verlag, New York, 1977.
19. J. D. H. Donnay and H. M. Ondik, editors, Crystal Data Determinative Tables, II: Inorganic Compounds, Third Edition, Joint Committee on Powder Diffraction Standards, 1973, pp. H-116 and H-117.
20. I. Higashi, Y. Takahashi, and T. Atoda, Crystal Growth of Borides and Carbides of Transition Metals from Molten Aluminum Solutions, Journal of Crystal Growth, 33, 1976, pp. 207-211.
21. B. Lonnberg, Thermal Expansion Studies on the Group IV-VII Transition Metal Diborides, Journal of the Less Common Metals, 141, 1988, pp. 145-156.
22. E. Fendler, O. Babushkin, T. Lindback, R. Telle, and G. Petzow, Thermal Expansion of Diboride Solid Solutions, in Fourth International Symposium on Ceramic Materials and Components for Engines, R. Carlsson, T. Johansson, and L. Kahlman, eds., Elsevier Applied Science, London and New York, 1991, pp. 204-212.
23. E.H. Kerner, Proceedings of the Physical Society, 69, 1956, pp. 808-813.
24. R.A. Schapery, Journal of Composite materials, 4, 1968, pp. 380-404.