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Research Letter

Influence of Nanosized Silicon Carbide on Dimensional Stability of Al/SiC Nanocomposite

S. M. Zebarjad,[1, 2] S. A. Sajjadi,[1] and E. Z. Vahid Karimi[1]

[1] *Department of Materials Science and Metallurgical Engineering, Engineering Faculty, Ferdowsi University of Mashhad, P.O. Box 91775-1111, Mashhad 91779-48974, Iran*
[2] *Center for Nanotechnology, Ferdowsi University of Mashhad, P.O. Box 91775-1111, Mashhad 91779-48974, Iran*

Correspondence should be addressed to S. M. Zebarjad, zebarjad@ferdowsi.um.ac.ir

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This study concentrated on the role of particle size of silicon carbide (SiC) on dimensional stability of aluminum. Three kinds of Al/SiC composite reinforced with different SiC particle sizes (25 μm, 5 μm, and 70 nm) were produced using a high-energy ball mill. The standard samples were fabricated using powder metallurgy method. The samples were heated from room temperature up to 500°C in a dilatometer at different heating rates, that is, 10, 30, 40, and 60°C/min. The results showed that for all materials, there was an increase in length change as temperature increased and the temperature sensitivity of aluminum decreased in the presence of both micro- and nanosized silicon carbide. At the same condition, dimensional stability of Al/SiC nanocomposite was better than conventional Al/SiC composites.

1. INTRODUCTION

There are many papers concentrated on Al/SiC composites. In fact, the papers can be categorized into some major groups. The studies of the first group focused on manufacturing methods. The results of their studies showed that there are some different techniques for fabrication of Al/SiC composites. The methods are squeeze casting, metal spray, metal infiltration, laser deposition technology and mechanical milling, powder metallurgy, and so on [1–9]. Among them, powder metallurgy presents one of the biggest advantages [7], although there are a lot of problems concerning the distribution of the reinforcement in the composite matrix. The second group tried to investigate the role of SiC particles on formability of aluminum matrix. Their results showed that SiC particles play like a barrier against aluminum flow [10]. The third group of researches worked on corrosion behavior of Al/SiC composites [11–14]. They demonstrated that the weight loss of the composites in corrosive media depends strongly on both volume percent and particle size of SiC [11–14]. The studies of another group concentrated on the role of SiC particles on mechanical properties and machinability of Al/SiC composites [15, 16]. They showed that both volume percent and particle size of SiC particles play an important role on mechanical behavior of Al/SiC. Finally, the last investigations concentrated on the mechanical, optical, thermal, and electrical properties of silicon carbide aluminum matrix composite [17–20]. The results illustrated that the mentioned properties vary as volume percent and particle size of SiC change.

However, in spite of the importance of dimensional stability and coefficient of thermal expansion (CTE) of aluminum matrix composite, there are few papers that concentrated on it, and the role of particle size on dimensional stability of Al/SiC composite has not been under attention. In fact, the CTE values of Al/SiC composites are important in electronic packaging industry, in which Al/SiC composite is used as the substrate for electronic chips. Thus the main goal of the current study is to clarify what happens on stability of dimension of Al/SiC composite, as SiC particle size approaches toward nanosize.

The previous result showed that the thermal expansion coefficient of aluminum depended strongly on its oxide content and decreased almost linearly with increasing oxide content. Thermal conductivity decreased by approximately 1% for every 1% of oxide present, but was higher in the direction of extrusion [21].

2. EXPERIMENTAL METHODS

2.1. Materials

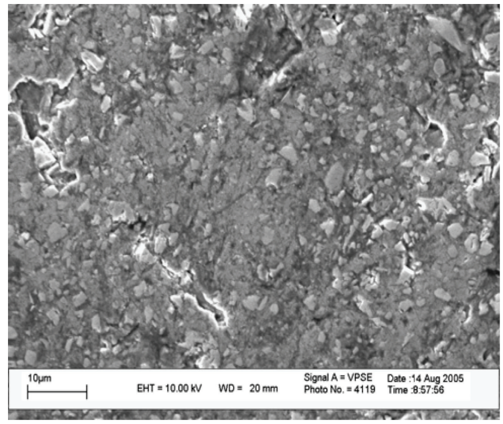
To produce Al/SiC composite, commercial aluminum powders with different sizes from 10 to 100 μm and average size of about 50 μm were obtained from Zamin Tavana Company (Tehran, Iran). Three kinds of SiC and average size of about 25 μm (size-range 5 to 50 μm), 5 μm (size-range 0.5 to 10 μm), and 70 nm (size-range 5 to 100 nm) have been provided from Banyans Sanat Company (Tehran, Iran).

2.2. Sample preparation

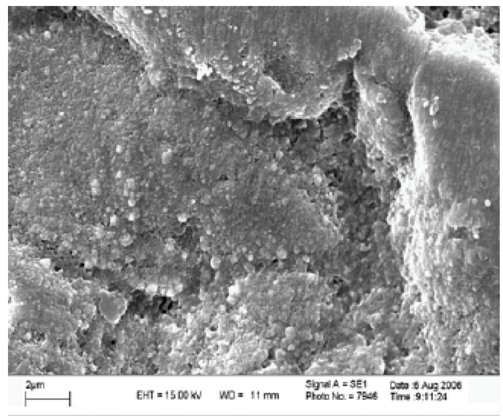
A high-energy ball mill with 70 mm in diameter and steel balls with different diameters were employed. The Al powder and SiC particles with different average sizes (25 μm, 5 μm, and 70 nm) at constant weight ratio of ball/powders (i.e., 10) were added to the ball mill and milled for 10 hours. Finally, three kinds of Al/SiC composites with different SiC content were produced using powder metallurgy method. The compacted samples were sintered at 585–6000°C for 1 hour under inert gas. The relative density of all samples was measured before and after sintering. Since the density is an effective parameter on physical properties of Al/SiC composite, particularly on its dimensional stability; therefore, the manufacturing method was designed to achieve the density of about 98% of theoretical density. For this purpose, the samples with higher SiC content were compacted at higher pressure.

2.3. Dilatometry test

To understand the effect of particle size of SiC on dimensional stability of Al matrix, dilatometry test was used. The sample sizes were 4 × 4 × 18 mm. The dilatometry apparatus was Dima_85ECO3080. The machine was equipped with cooling circulation system. To find out the role of heating rate on change in length, the samples were heated from room temperature up to 500°C at different heating rates, that is, 10, 30, 40, and 60°C/min. All samples were cooled down up to room temperature. The change in length corresponding to each temperature was measured directly. Three samples from each material were tested.



(a)



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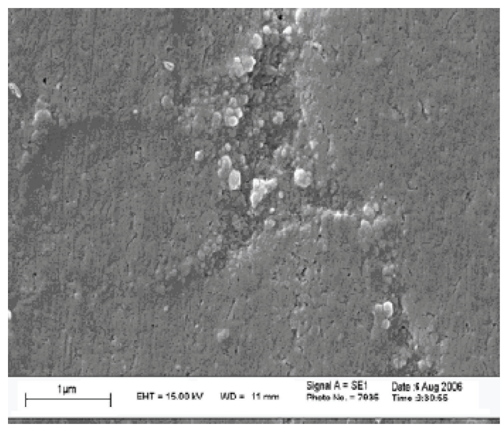

(c)

FIGURE 1: SEM micrographs of aluminum reinforced with 7.5 Vol% SiC with average particle sizes: (a) 5 μm, (b)—(c) 7 nm.

3. RESULTS AND DISCUSSIONS

Figure 1 shows the SEM micrographs taken from the fracture surfaces of Al matrix reinforced with 7.5 Vol% SiC with average particle sizes 5 μm and 70 nm, respectively. Microscopic inspection of the samples revealed that the SiC particles are dispersed in the matrix and a minor of particles agglomerated.

Figure 2 shows the variation of change in length versus temperature of Al matrix reinforced with 7.5 Vol% SiC with average particle sizes of about 25 μm, 5 μm, and 70 nm at heating rate of 10°C/min. For all materials, including composite and nanocomposite, there is an increase in length change as temperature increases. With looking, in more detail, at Figure 2, it may be concluded that the temperature sensitivity of aluminum decreases in the presence of both micro- and nanosized silicon carbide. It can be observed that the effect of nanosized silicon carbide is much higher

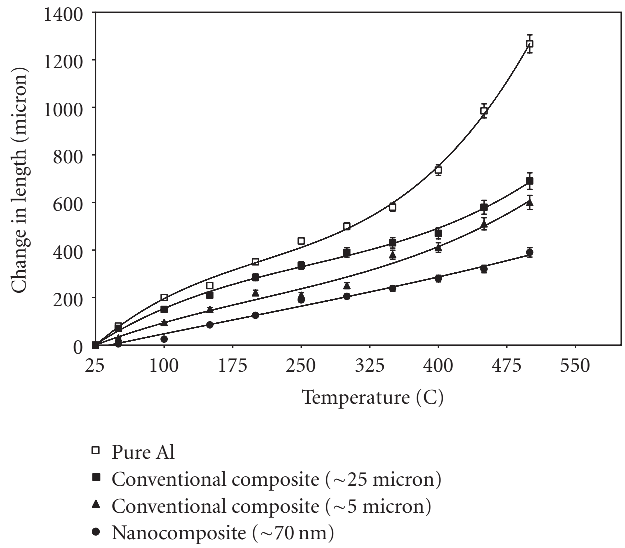

Figure 2: The variation of change in length versus temperature for aluminum and its composites at constant SiC content (7.5 Vol% SiC).

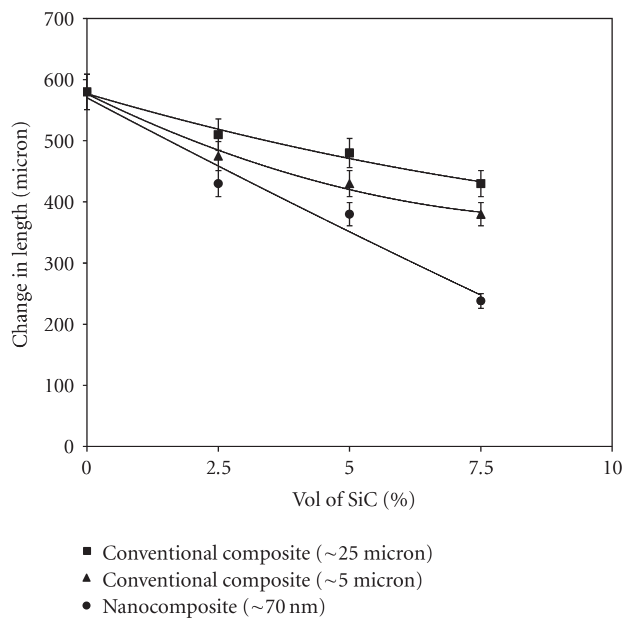

Figure 3: Comparison of the role of different particle sizes of SiC on dimensional stability of aluminum matrix at 350°C.

than that of microsized. Figure 3 compares the role of different particle sizes of SiC on dimensional stability of aluminum matrix at 350°C. As it can be seen, dimensional stability of aluminum matrix in the presence of nanosized SiC is much better than the conventional composite. For example, at 350°C the length change of pure aluminum is about 0.58 mm, while for Al matrix reinforced with 5 Vol% SiC with average particle sizes of about 25 μm, 5 μm, and 70 nm are about 0.43, 0.38, and 0.238 mm, respectively. This is because at constant volume percent, the decrease in SiC size leads to reducing the distance between them.

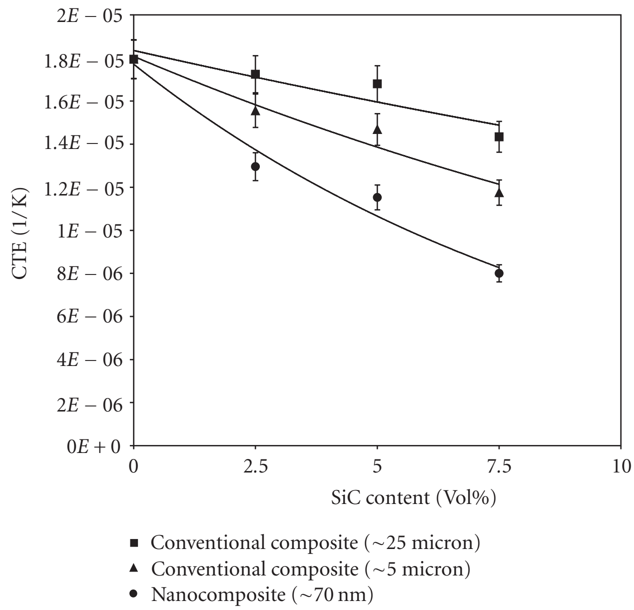

Figure 4: The variation of CTE of aluminum matrix composite versus silicon carbide content.

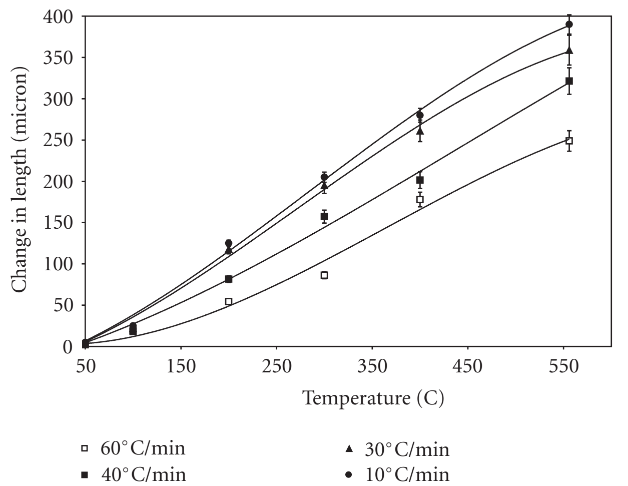

Figure 5: The dependence of change in length on heating rate of Al/5 Vol% SiC nanocomposite.

The value of linear thermal expansion coefficient, $\alpha = (1/V)(\partial V/\partial T)_p$, of Al and its composites at different reinforcements are shown in Figure 4. The results show that the influence of nanosized silicon carbide on linear thermal expansion of Al is much higher than that of microsized SiC.

Figure 5 illustrates the dependence of change in length of Al/5 Vol% SiC nanocomposite on heating rate. The results show that increasing heating rate causes to promote dimensional stability of the sample. The reason of the dependence of dimensional stability of aluminum and its nanocomposites on heating rate can be referred to the fact that heating of the whole sample needs a specific time, and by increasing heating rate the surface of sample has not enough time to transfer heat from one point to another.

These variations can be referred to the fact that dimensional stability of composite materials depends strictly on Young's modulus. According to the previous researches [16–18], at constant volume fraction, the role of nanosized silicon carbide on Young's modulus of aluminum matrix is much higher than that of microsized; therefore, change in length of aluminum should be restricted in the presence of nanosized silicon carbide. This is why Al/SiC nanocomposite provides higher-dimensional stability in comparison with Al/SiC composites.

4. CONCLUSIONS

The results of current research are remarked as below. The dimensional stability of aluminum matrix in the presence of nanosized SiC is much higher than that of conventional composite. The effect of nanosized SiC on linear thermal expansion of Al is much higher than that of microsized SiC. Increasing heating rate causes to promote dimensional stability of the aluminum matrix nanocomposites.

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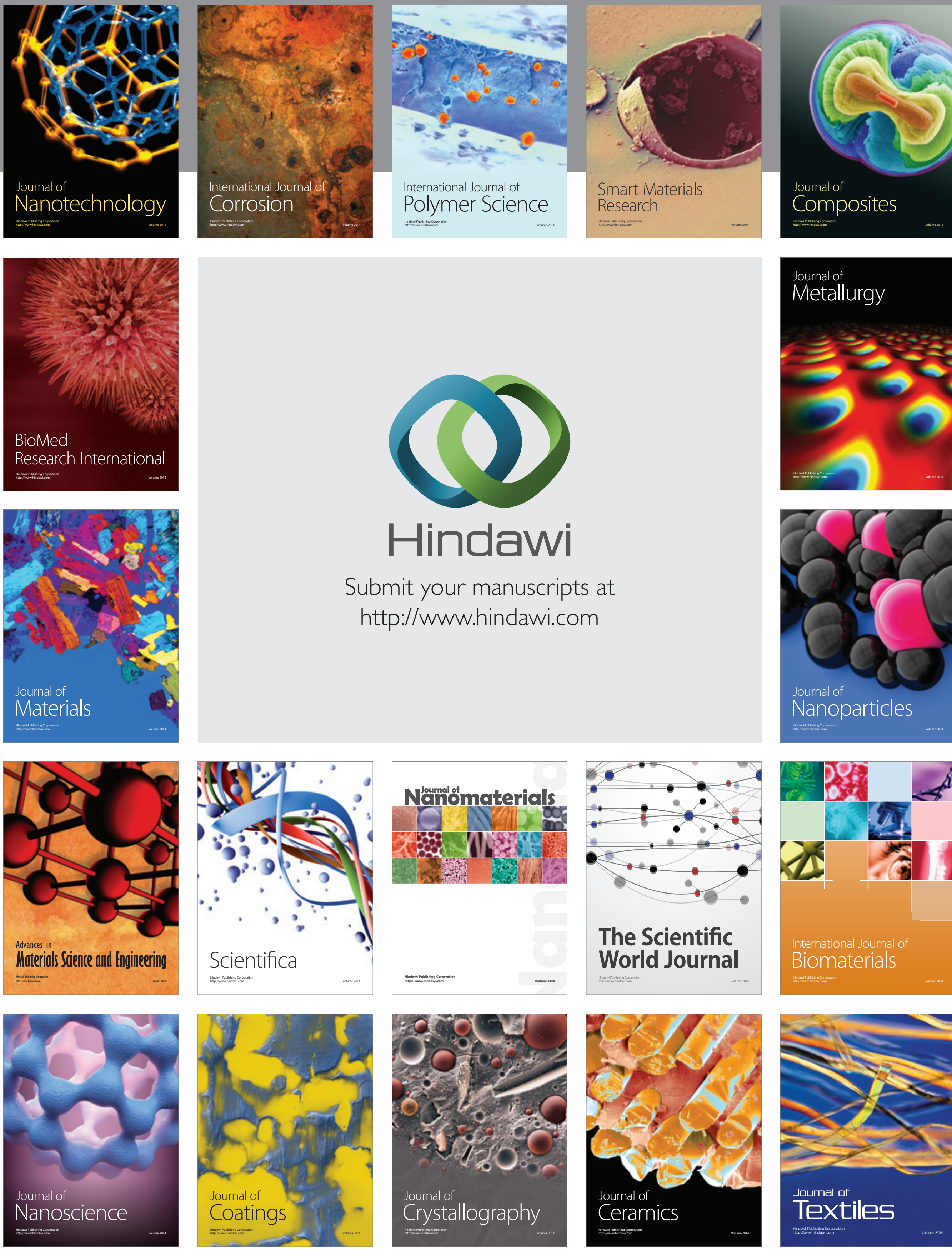

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