Influence of Alumina (Al2O3) Nanosized Reinforcements on Dimensional Stability of Pure Aluminum Matrix Nanocomposite

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Abstract: *The current study evaluates the influence of aluminum oxide Al2O3 particle size on the dimensional stability of pure aluminum matrix. Three composites reinforced with 2.5, 5, and 7.5 Vol.% Al2O3 and particle sizes (25 μm, 5 μm, and 70 nm) were fabricated 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 composites, 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 Al2O3. At the same condition, dimensional stability of Al/Al2O3 nanocomposite was better than conventional Al/Al2O3 composites.*

Keywords: *Aluminum Metal Matrix Composite, Al2O3 Nanosized Reinforcements, Powder Metallurgy, Ball Mill, Dimensional Stability*

1. Introduction

Powder metallurgy (PM) is a term covering a wide range of ways in which materials or components are made from metal powders.PM presents one of the biggest advantages in the manufacturing of metal matrix composites [1], although there are lots of problems concerning the distribution of the reinforcement in the composite matrix, especially with the nanosized structure. Reinforcement's particle size plays an important role in the formability of aluminum matrix. Theyact like a barrier against aluminum flow [2]. It is also reported that the weight loss of the composites in corrosive media depends strongly on both volume percent and particle size [3–6].

Investigations also reported that both volume percent and particle size play an important role on the mechanical behavior and machinability of the composite [7, 8]. In General, volume percent and particle size of reinforcements to have a strong influence on most behaviors of the new made composites [9–12]. Dimensional stability and coefficient of thermal expansion (CTE) of pure aluminum matrix and aluminum alloys composites are of great importance in many applications such as electronic packaging industry, and electronic chips as well as aerospace applications. Previous studies 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 [13].

Alumina Al2O3 brings strength at elevated temperatures. The present study has been carried out to explore the influence of dispersion nano-structured Al2O3 reinforcements on the dimensional stability of pure aluminum.

2. Experimental Procedures

2.1 Materials

To produce the Al/Al2O3 composites, pure aluminum powders, 99.7% purity, with average size of about 75 μm were obtained. Three kinds of Al2O3 and average size of about 25 μm (size-range 5 to 50 μm), 5 μm (size-range 0.5 to 10 μm), and 70nm (size-range 5 to 100 nm) have been provided.

2.2 Sample Preparation

High energy FRETSCH MA 400 ball mill with different diameters steel balls were employed. The Al powder and Al2O3 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 4 hours at 400 rpm. Three Al/Al2O3 composites with different Al2O3 content were consolidated using uniaxial cold pressing at 500 MPa for 1hr followed by hot extrusion at 500^{o}C for 1 h using 4:1 extrusion ratio.

Since the density is an effective parameter on physical properties of Al/ Al2O3 composite, particularly on its dimensional stability; therefore, the manufacturing parameters were designed to achieve density of approximately 98% and more of the theoretical density, based on previous studies by the author.

2.3 Dilatometry Test

To understand the effect of Al2O3 particle size on dimensional stability of pure Al matrix, dilatometry test was applied. 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.

3. Results and Discussion

Microscopic inspection of the samples revealed that the Al2O3 particles are dispersed in the matrix and a minor of particles agglomerated.

Figure 1 shows the variation of change in length versus temperature of Al matrix reinforced with 7.5 Vol.%Al2O3 with average particle sizes of about 25 μm, 5 μm, and 70 nm at heating rate of 10◦C/min. All materials, including composite and nanocomposite, recorded an increase in length change as temperature increases. It may be concluded from Figure 2, that the temperature sensitivity of aluminum decreases in the presence of both micro and nanosized alumina. It can be observed that the effect of nanosized alumina is much higher than that of microsized.

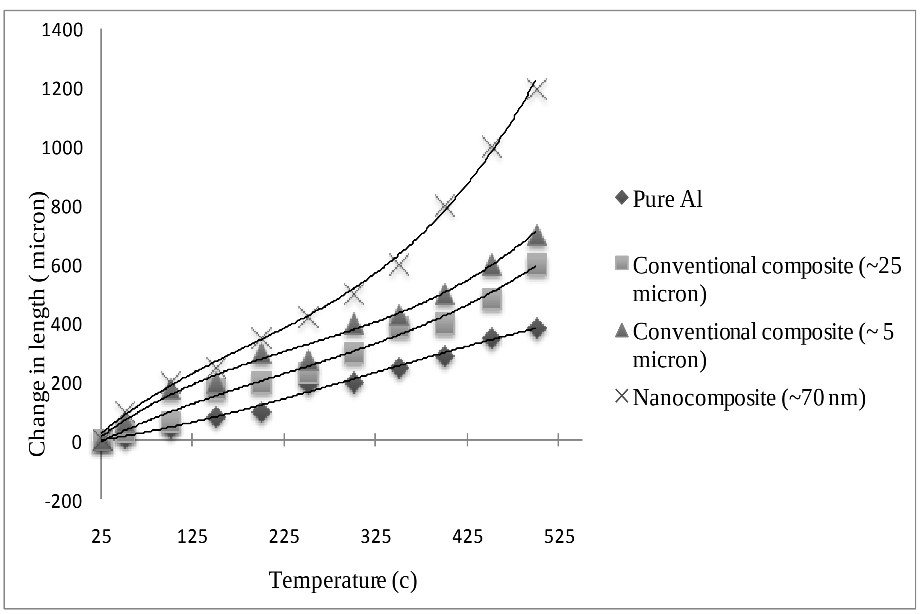

Fig. 1: Variation of change in length versus temperature for aluminum and its composites at constant Al2O3 content (7.5 Vol.% Al2O3)

Figure 2 compares the role of different particle sizes of Al2O3 on dimensional stability of aluminum matrix at 350◦C. The reported results of dimensional stability of aluminum matrix in the presence of nanosized Al2O3 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.% Al2O3 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 Al2O3 size leads to reducing the distance between them.

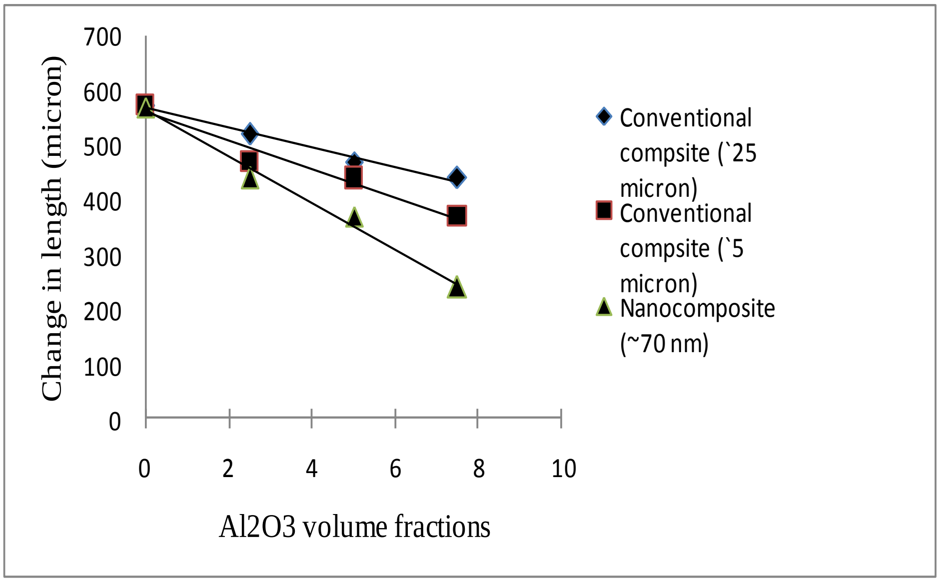

Fig.2: Effect of different particle sizes of Al2O3 on dimensional stability of aluminum matrix at 350°C

The values 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 3. The results show that the influence of nanosized aluminum oxide on linear thermal expansion of pure Al is much higher than that of microsized Al2O3.

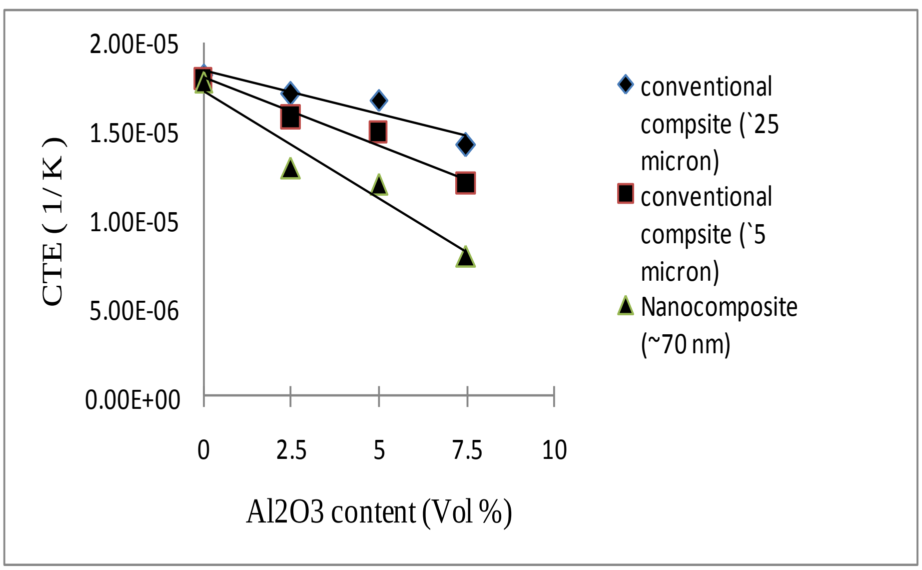

Fig.3: Influence of nanosized alumina on linear thermal expansion of pure aluminum

Figure 4 illustrates the dependence of change in length of Al/5Vol.% Al2O3 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 [9–11], at constant volume fraction, the role of nanosized reinforcements 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 alumina. This is why Al/Al2O3 nanocomposite provides higher-dimensional stability in comparison with Al/Al2O3 composites.

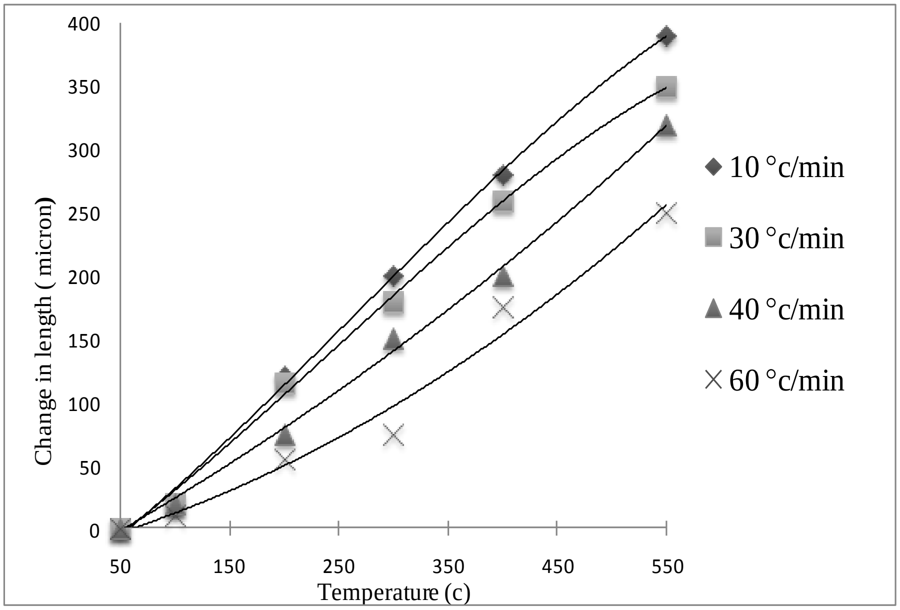

Fig. 4: Dependence of change in length of Al/5Vol.% Al2O3 nanocomposite on heating rate

4. Conclusions

1) The dimensional stability of aluminum matrix in the presence of nanosized Al2O3 is much higher than that of conventional composite.
2) The effect of nanosized Al2O3 on linear thermal expansion of Al is much higher than that of microsized Al2O3.
3) Increasing heating rate causes to promote dimensional stability of the aluminum matrixnanocomposites.

5. References

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