

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

Mohamed M. Emara

Department of Manufacturing Engineering, Canadian International College (CIC)

Cairo Campus of Ottawa and Cape Breton Universities – Canada

New Cairo, Cairo - Egypt

E-Mail: mohamed_emara@cic-cairo.com, mmemara@aucegypt.edu

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. They act 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 FRETSCHE MA 400 ball mill with different diameters steel balls were employed. The Al powder and Al₂O₃ particles with different average sizes (25 μ m, 5 μ m, 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°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 μ m, 5 μ m, 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.

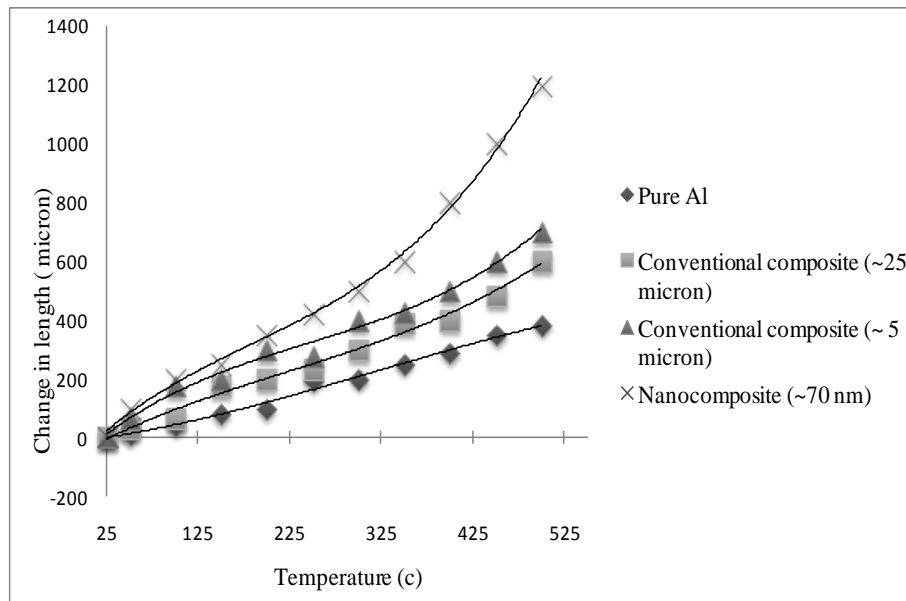


Fig. 1: Variation of change in length versus temperature for aluminum and its composites at constant Al₂O₃ content (7.5 Vol.% Al₂O₃)

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.

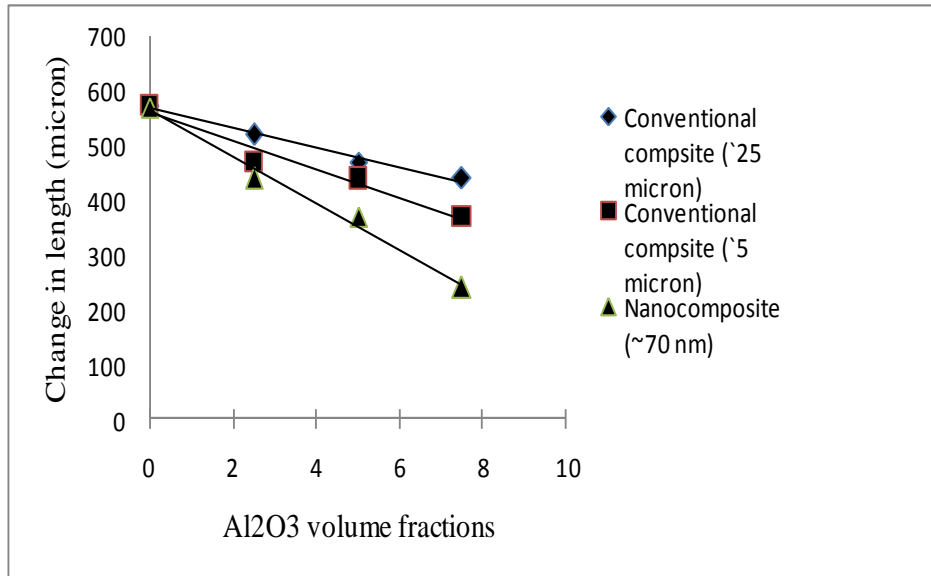


Fig.2: Effect of different particle sizes of Al₂O₃ on dimensional stability of aluminum matrix at 350°C

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.

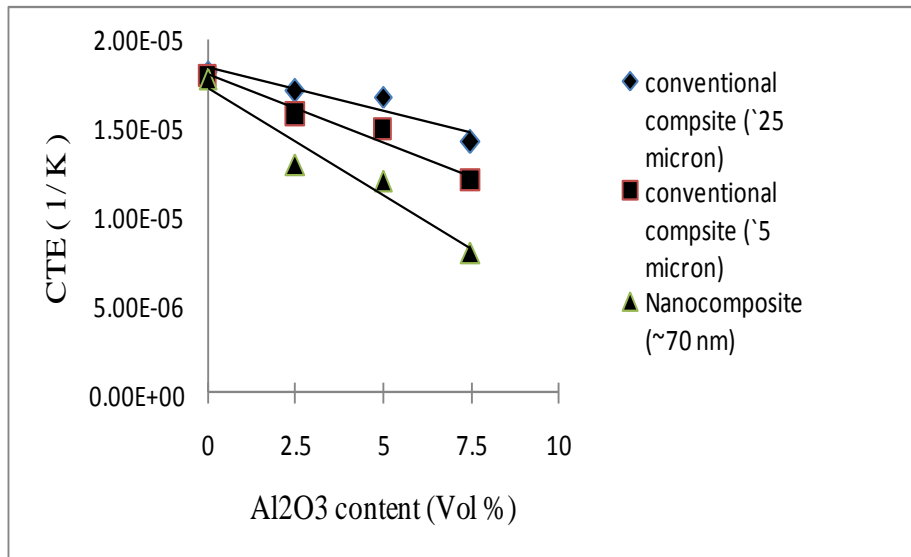


Fig.3: Influence of nanosized alumina on linear thermal expansion of pure aluminum

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.

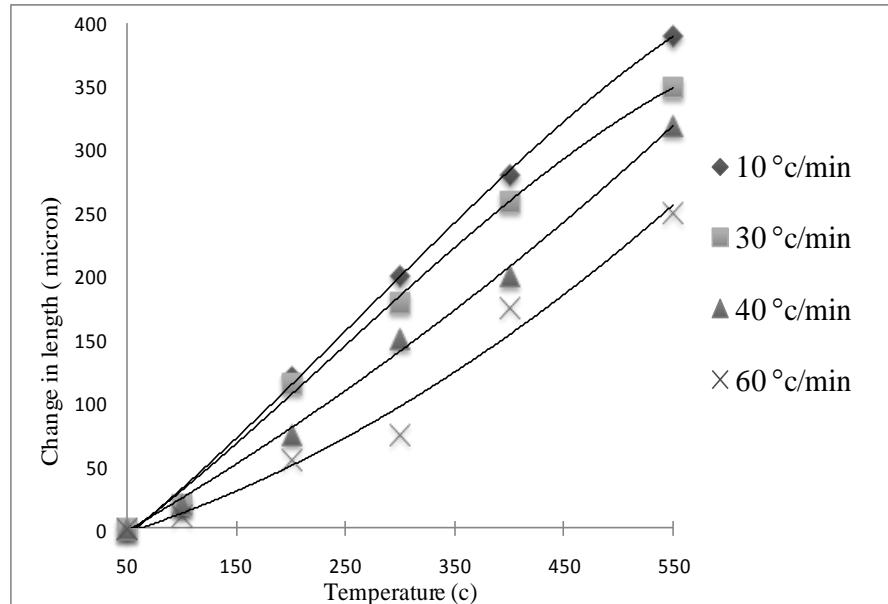


Fig. 4: Dependence of change in length of Al/5Vol.% Al₂O₃ nanocomposite on heating rate

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 matrix nanocomposites.

5. References

- [1] J. Hashim, L. Looney, and M. S. J. Hashmi, "Particle distribution in cast metal matrix composites-Part II," *Journal of Materials Processing Technology*, vol. 123, no. 2, pp. 258–263, 2002.
- [2] J.B. Fogagnolo, E.M. Ruiz-Navas, M. H. Robert, and J.M. Torralba, "The effects of mechanical alloying on the compressibility of aluminium matrix composite powder," *Materials Science and Engineering A*, vol. 355, no. 1-2, pp. 50–55, 2003.
- [3] S. Candan, "Effect of SiC particle size on corrosion behavior of pressure infiltrated Al matrix composites in a NaCl solution," *Materials Letters*, vol. 58, no. 27-28, pp. 3601–3605, 2004.
- [4] C. C. Anya, "Wet erosive wear of alumina and its composites with SiC nano-particles," *Ceramics International*, vol. 24, no. 7, pp. 533–542, 1998.
- [5] K. Gopinath, R. Balasubramaniam, and V. S. R. Murthy, "Corrosion behavior of cast Al-Al₂O₃ particulate composites," *Journal of Materials Science Letters*, vol. 20, no. 9, pp. 793–794, 2001.
- [6] R. C. Paciej and V. S. Agarwala, "Influence of processing variables on the corrosion susceptibility of metal-matrix composites," *Corrosion*, vol. 44, no. 10, pp. 680–684, 1988.
- [7] C. Kaynak and S. Boylu, "Effects of SiC Particulates on the Fatigue Behaviour of an Al-Alloy Matrix Composite," *Materials & Design*, vol. 27, pp. 776–782, 2006.
- [8] W. L. Prater, "Comparison of ceramic material effects on the flexural Weibull statistics and fracture of high volume fraction particle reinforced aluminum," *Materials Science and Engineering A*, vol. 420, no. 1-2, pp. 187–198, 2006.

- [9] N. Chawla, J. J. Williams, and R. Saha, "Mechanical behavior and microstructure characterization of sinter-forged SiC particle reinforced aluminum matrix composites," *Journal of Light Metals*, vol. 2, no. 4, pp. 215–227, 2002.
- [10] Z. Gnjidić, D. Božić, and M. Mitkov, "The influence of SiC particles on the compressive properties of metal matrix composites," *Materials Characterization*, vol. 47, no. 2, pp. 129–138, 2001.
- [11] A. Martin, M. A. Martinez, and J. Llorca, "Wear of SiC reinforced Al-matrix composites in the temperature range 20–200°C," *Wear*, vol. 193, pp. 169–179, 2006.
- [12] E. Candan, "Effect of alloying additions on the porosity of SiCp preforms infiltrated by aluminium," *Materials Letters*, vol. 60, no. 9-10, pp. 1204–1208, 2006.
- [13] V. P. Klyuev and B. Z. Pevzner, "The influence of aluminum oxide on the thermal expansion, glass transition temperature, and viscosity of lithium and sodium aluminoborate glasses," *Glass Physics and Chemistry*, vol. 28, no. 4, pp. 207–220, 2002.