EFFECT OF MgO NANO PARTICLES ON SINTERING BEHAVIOR OF Al₂O₃-SiC-MgO NANO COMPOSITES

FERESHTEH SURANI

Sciences and Research Department, Islamic Azad University, Tehran, Iran
surani1184@yahoo.com

HOSSEIN ABDIZADEH*

School of Metallurgy and Materials Engineering, University of Tehran, Tehran, Iran
abdizade@ut.ac.ir

HAMID REZA BAHARVANDI

Department of Materials and Manufacturing process, Malek Ashtar University of Technology, Tehran, Iran
baharvandee@yahoo.com

ALI NEMATI

Faculty of Materials Engineering, Sharif University of Technology, Tehran, Iran
nemati@sharif.edu

Small amount of MgO in the range of ppm and distribution of SiC particles in Al₂O₃-10vol%SiC nanocomposite has an obvious effect on improving of density and mechanical properties such as hardness of sintered nanocomposite. Improving of these properties continues to 1000 ppm of MgO, but decreases above this amount. Transgranularly fractured alumina grains were observed on the fracture surface of this kind of nanocomposites. The effects of such a small amount of MgO on the sintering and microstructural development of Al₂O₃-10vol%SiC nanocomposite may be explained using the arguments which have been documented for the beneficial effects of a small amount of MgO in alumina ceramics. In Al₂O₃-10vol%SiC nanocomposite, Al₂O₃ particles were coated by nano scale SiC particles which inhibited the abnormal grain growth of Al₂O₃.

Keywords: Nanocomposite; Sintering additive; Mechanical properties; Microstructure; Al₂O₃-SiC.

Introduction

Al₂O₃ ceramics are widely used in many fields due to improved fracture strength, toughness and sintered density¹⁻³. There are several approaches to avoid the abnormal growth of alumina grains; one of them is through addition of MgO⁴⁻⁶. Small amount of MgO can effectively inhibit the abnormal growth of the alumina grains. Another way is

* Corresponding author at: School of Metallurgy and Material Engineering, University of Tehran, Tehran, Iran, Tel.: +98 21 61114085; fax: +98 21 88006076.

addition of second phase particles⁷⁻⁸. SiC particles were located within Al₂O₃ matrix grains and formed the ceramic nanocomposite⁹⁻¹³. It has been observed that nano sized SiC particles are effective in inhibiting the grain growth of alumina ceramics by pinning the grain boundaries and grain junctions at sintering temperature^{14, 15}. MgO particles could, similarly, inhibit the Al₂O₃ grain growth. The residual stresses could be due to the thermal expansion between alumina and SiC particles, dislocation, sub-grain-boundary formation, and microcracking^{1, 2, 4, 5}. Al₂O₃-10vol%SiC nanocomposite have been marked by mixing small size of alumina and SiC particles (<100nm), then hot pressed in the range of 1500 to 1800°C^{1, 6}. The important roles of MgO dopant in Al₂O₃-SiC nanocomposite are as: (i) lowering the grain boundary mobility^{16, 17}; (ii) increasing the surface diffusivity then increasing the pore mobility¹⁸⁻²⁰; and (iii) decreasing the grain boundary anisotropy²¹.

The objective of this work is to investigate the effects of adding a small amount of MgO (up to 1500ppm) to alumina based nanocomposites containing 10vol%SiC particles.

Experimental

Commercially available of very fine γ -Al₂O₃ (CR15, Baikowski Chemie, France), SiC powders (Bsc-21c, Performance Ceramics Company, Peninsula, OH, USA), and high purity magnesium oxide were used as the starting materials. Average size of Al₂O₃ powder was 100nm and the particle size of β -SiC powder was in the range of ~80nm. The compositions, containing of 0, 1000, 1500ppm MgO (<100nm) were prepared by ball milling. Alumina, silicon carbide, and magnesium oxide were mixed in propanol for 3hr. The milled mixtures were then dried into an electric furnace to remove the propanol. Compositions were compacted by pressure of 20 and 30MPa for 90 seconds. Sintering of compacted green specimens has been carried out in a high temperature graphite furnace in argon atmosphere at 1700°C for 1.5hr., and then healed in 900°C for 4hr. The density of sintered nanocomposites was measured on the basis of specimen and using Archimedes method in water. The sintered segment has been then polished, using 100, 200, and 400 grit SiC papers, followed by a final polish using 3 and then 1 μ m diamond pastes. Vickers hardness of nanocomposites was measured on polished surface using a diamond pyramid indenter (Future tech FM-700) at an indentation load of 10Kg. Scanning electron microscopy method was used to characterize the fracture surfaces of the sintered nanocomposites. The average grain size, G , has been then calculated using equation (1):

$$G = \frac{1.5}{M.N.L} \quad (1)$$

where 1.5 is a geometry-dependent proportionality constant, L the total test line length, M the magnification, and N the total number of intercepts.

Results and discussion

Figure 1 shows the sintered relative density as a function of MgO content in Al₂O₃-10vol%SiC nanocomposite when sintered at 1700°C for 1.5 hr. The sintered density

increases with increasing of MgO content in the range of 0 to 1000ppm. For example, the undoped nanocomposite exhibits a relative density of 98.45, compare to a relative density of 99.73 for the nanocomposite containing 1000 ppm MgO. Decreasing occurs after increasing of MgO to 1500ppm.

Fig. 1. Relative density as a function of MgO content in Al_2O_3 -10vol%SiC nanocomposites sintered at 1700°C for 1.5hr.

Fig. 2. Vicker's hardness value as a function of MgO content in Al_2O_3 -10vol%SiC nanocomposites sintered at 1700°C for 1.5hr.

A sintered density of 99% of theoretical density was measured for the composition containing 1000 ppm MgO. In figure 2, the Vickers hardness as a function of MgO content in the Al_2O_3 - 10vol%SiC nanocomposite is very similar to that of the relative density on MgO content. The Vickers hardness increases with increasing of MgO content in the range from 0 to 1000ppm, and then almost decreases with further increasing of MgO content up to 1500ppm. Increasing of 1000ppm MgO into Al_2O_3 -10vol%SiC results in a hardness of 2150 Vickers which is more than that of the undoped nanocomposite (1750 Vickers).

A denser nanocomposite ceramic exhibits a higher Vickers hardness than that of a porous material. Increasing in density of sintered Al₂O₃-10vol% SiC nanocomposite, when a small amount of MgO is added, is confirmed by figure 3, showing the SEM micrographs for the compositions containing 0, 1000, and 1500 ppmMgO. In Al₂O₃-10%volSiC nanocomposites; both the nanosized SiC particles and MgO are expected to affect the sintering behavior of the alumina matrix. The former is effective in restraining the grain growth of alumina grains by pinning at the grain boundaries and grain junctions, as evidenced by refinement in grain size observed in Al₂O₃-10%volSiC nanocomposites^{5,14}. Above of 1000 to 1500ppm, relative density and hardness decrease while the grain size of alumina particles increases (table 1). The average grain size of samples has been calculated by the linear intercept. The Al₂O₃ matrix grain size decreased with the increase of the MgO content.

Fig. 3. The grain size of the monolithic Al₂O₃ and the composites: (a): without MgO, (b) with 1000ppm MgO, (c) with 1500ppm MgO.

Table 1. The average grain sizes of samples calculated by the linear intercept method

Sample	MgO	HP temperature	Time (h)	Average grain size of Al ₂ O ₃ (μm)
A1	0	1700	2	8.5
A2	1000	1700	2	4.7
A3	1500	1700	2	5

The Al₂O₃ grains size decreases with the presence of 1000ppm MgO but then increases in 1500ppm MgO. Nanoscale SiC particles were distributed throughout the Al₂O₃ matrix. It should be noted that most of SiC particles were present inside the Al₂O₃ grains, only few large particles were located on the boundaries or junctions of grains, according to Nii-hara's classification ¹⁰.

Conclusions

Adding a few hundred ppm MgO into Al₂O₃-10vol% SiC nanocomposites increases the sintered density of the nanocomposites. This property increases significantly with addition of MgO from 0 to 1000 ppm then decreases at 1500ppm MgO.

Transgranular fracture was observed on the fracture surface of the MgO doped nanocomposites. Small amount of MgO in alumina ceramics, although has the exact mechanism played by MgO in the nanocomposite but may be further complicated by the presence of nanosized SiC particles at the grain boundaries and grain junctions.

Most SiC particles were located within the Al₂O₃ grains because of the transformation of Al₂O₃ from the γ phase to α phase.

Nanoscale SiC particles inhibited the grain growth of Al₂O₃, made the matrix grains smaller, and raised the sintering temperature.

The fracture mode of Al₂O₃-10%volSiC nanocomposites were mainly intragranular fracture compared to the intergranular fracture of the monolithic Al₂O₃ ceramic.

References

1. K. Niihara, J. Ceram. Soc. Jpn., 9(1991)974.
2. K. Niihara and A. Nakahira, Proceedings of the 3rd International Symposium on Ceramic Materials and Components for Engines, Am. Ceram. Soc., Westerville, OH, (1988), pp. 9 19-926.
3. J. Zhao, L.C. Stearns, M.P. Harmer, H.M. Chan, G.A. Miller, and R.F. Cook, J. Am. Ceram. Soc. 76(1993)
4. A.M. Thompson, H.M. Chan, and M.P. Warner, J. Am. Ceram. Soc., 78(1995)567.
5. L.C. Stearns, J. Zhao, and M.P. Harmer, J. Euro. Ceram. Soc., 10(1992) 473.
6. S.I. Bae and S. Baik, Critical concentration of MgO for the prevention of abnormal grain growth in alumina, J. Am. Ceram. Soc., 77(10)(1994)2499-2504.
7. F.F. Lange and M.M. Hirlinger, Hindrance of grain growth in Al₂O₃ by ZrO₂ inclusions, J. Am. Ceram. Soc. 67(3)(1984).
8. L.C. Sterns and M.P. Harmer, Particle-inhibited grain growth in Al₂O₃-SiC: I, experimental results, II, equilibrium and kinetic analyses, J. Am. Ceram. Soc., 79(12)(1996)3013-3028.
9. J. Zhao, L.C. Stearns, M.P. Harmer, H.M. Chan, G.A. Miller, and R.F. Cook, Mechanical behavior of alumina-SiC nanocomposites, J. Am. Ceram. Soc., 76(2)(1993)503-510.

10. L.C. Stearns, J. Zhao, and M.P. Harmer, Processing and micro-structure development in Al₂O₃-SiC nanocomposites, *J. Eur.Ceram. Soc.*, 10(1992)473-477.
11. I.A. Chou, H.M. Chan, and M.P. Harmer, Machining-induced sur-face residual stress behavior in Al₂O₃-SiC nanocomposites, *J.Am. Ceram. Soc.*, 79(9)(1996)2403-2409.
12. B. Jang, M. Enoki, and T. Kishi, Control of microstructure of alumina ceramics by dispersion of nano SiC particulates, *J. Ceram. Soc. Jpn.*, 102 (9) (1994) 863-867.
13. R.J. Brook, *Proc. Br. Ceram. Soc.*, 32(1982)74.
14. L.C. Stearns and M.P. Harmer, *J. Am. Ceram. Soc.*, 79(1996)3013.
15. J. Wang, C.B. Ponton, and P.M. Marquis, *J. Mater. Sci.*, 30(1995)321.
16. S.J. Bennison and M.P. Harmer, *J. Am. Ceram. Soc.*, 68(1985).
17. J.E. Burke, K.W. Lay, and S. Procnazka, *Mater. Sci. Res.*, 13(1980)417.
18. A.H. Heuer, *J. Am. Ceram. Soc.*, 62(1979)17.
19. J. Roedel and A.M. Cilaeser, *J. Am. Ceram. Soc.*, 73(1990)3302.
20. C. Sung, G. Wei, K.J. Ostreicher, and W.H. Rhodes, *J. Am.Ceram. Soc.*, 75(1992)1796.
21. C.A. Handwerker, J.M. Dynys, R.M. Cannon, and R.L. Cable, *J. Am. Ceram. Soc.*, 73(1990)1371.