Processing and Microstructure of Alumina Coated with Al_2O_3/SiC Nanocomposite

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The surface modification of alumina by Al_2O_3/SiC nanocomposite coating was studied in terms of processing and microstructure. A powder slurry of 5 vol% SiC composition was dipcoated onto presintered alumina bodies and pressurelessly sintered at 1700℃ for 2 h in N_2. The use of organic binder and plasticizer in the slurry preparation, and the control of the density of presintered alumina body were found to be necessary to avoid cracking and warping during processing. The nanocomposite coating well bonded to the alumina body with thickness about 110 ㎛. The average grain size of coating (2 ㎛) was much finer than that of alumina body (13 ㎛). Fracture surface observations revealed mostly transgranular fracture for the coating, whereas intergranular fracture for the alumina body. Some pores (about 6 %) were observed in the coating layer, although the alumina body showed fully dense microstructure.

1. Introduction

Alumina has wide applications as a wear-resistant material due to its highest hardness among oxide ceramics, relatively high strength, low cost, and the ease of densification. In general, the wear resistance of ceramic materials is mainly determined by hardness, strength, and fracture toughness. Hence, a way to enhance the wear resistance of alumina is to improve such mechanical properties. Recently it was reported by Niihara [1, 2] that the dispersion of SiC particles with nanometer size (0.3 ㎛) into ceramic matrices, named "nanocomposites", could significantly improve the strength compared to pure matrix materials. For Al_2O_3, only 5 vol% SiC addition improved the strength from 350 to 1520 MPa as well as toughness increase from 3.5 to 4.8 $MPa \cdot m^{1/2}$. Most of the previous works on nanocomposites focused on the understanding of the strengthening and toughening mechanisms. In the present study, the surface modification of alumina by Al_2O_3/5 vol% SiC nanocomposite coating was attempted, and the processing condition and microstructure were studied as preliminaries to investigate the feasibility of strengthening by the coating.

2. Experimental Procedure

The coated samples were prepared by a slurry dipcoating process, in which presintered alumina bodies were dipped into a powder slurry of Al_2O_3-5 vol% SiC composition to form a coating layer by slipcasting mechanism. α-Al_2O_3 (0.4 ㎛, AKP-30, Sumitomo, Japan) and β-SiC (270 nm, Betarundum, Ibiden, Japan) powders were mixed with distilled water by ball milling to prepare the nanocomposite slurries with powder/water (P/W) ratios of 1/1 and 1/2. Dispersants, methyl cellulose and polyethylene glycol (0-2 wt%) were added to the slurries during ball milling. The alumina bodies with a bar shape (35x8x5 mm) were made using α-Al_2O_3 (0.5 ㎛, AES-11, Sumitomo, Japan), partially sintered (600℃-2 h or 1200℃-0.5 or 2 h) for a proper handling strength for the coating procedure. Dipcoating was performed for 10-20 sec. The dipcoated samples were dried at room temperature and calcined at 600℃ for 1 h to burn out organic additives. Final sintering for densification was done at 1700℃ for 2 h in N_2. SEM observations of fracture surfaces were performed to investigate coating thickness, grain size, and fracture morphology.

3. Results and Discussion

Table 1 summarizes the dipcoating results with variation of the processing parameters such as slurry concentration (i.e. P/W), addition and amount of binder and plasticizer, and the density of presintered alumina body. For P/W of 1/1, severe cracking of the coating layer occurred during drying at RT with no addition of MC (methyl cellulose) and PEG (polyethylene glycol). With 1 wt% addition of each of MC and PEG, cracking occurred too but the degree was not severe. The slurry with 2 wt% additions of MC and PEG resulted in successful dipcoating without cracking, but P/W of 1/2 was necessary to give fluidity for dipcoating. The alumina bodies prepared with presintering conditions of 1200℃-2 h and 600℃-2 h resulted in warping after sintering for densification of the coated samples. This is due to the difference in densities of the alumina body (67 or 56 %TD) and coating (60 % TD) before the final sintering, which induced different sintering shrinkages. The coated samples made with alumina body with nearly same density as coating, 1200℃-0.5 h, could be sintered without warping, and the sintered densities were 99 %TD. Figure 1 shows the fracture surfaces of the coated samples, observed by SEM. The thickness of the nanocomposite coating was about 110 ㎛ and well bonded to the alumina body. The average grain size of coating (2 ㎛) was much finer than that of alumina body (13 ㎛). Since there was no big difference in the average particle sizes of the starting Al_2O_3 powders for the alumina body and the coating, this result indicates that the SiC particles effectively inhibited the growth of the alumina matrix grains in the coating. Fracture surface observation at higher magnifications, Fig. 2, revealed mainly intergranular and transgranular fracture modes for the alumina body and the coating, respectively. It has been known that transgranular fracture mode is an evidence of strengthening in Al_2O_3/SiC nanocomposites [1, 2]. The alumina body had fully dense microstructure, but some pores (about 6 %) were present in the coating layer.

Acknowledgement

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References

1. K. Niihara, *The Centennial Memorial Issue of the Ceramic Society of Japan,* 99(10) 974-982 (1991).
2. K. Niihara and A. Nakahira, p. 637-644 in *Advanced Structural Inorganic Composites.* Edited by P. Vincenzini, Elsevier Science, 1991.

Table 1. Summary of dipcoating results with processing condition

P/W	Organic additives	Al_2O_3 body		Features of coated samples	
		Presintering condition	Presintered density (%TD)	During drying	After sintering
1/1	-	1200℃, 2 h	67	Severe cracking	-
	MC 1 wt% PEG 1 wt%	1200℃, 2 h	67	Some cracks	Warping
		600℃, 2 h	56	Some cracks	Warping
		1200℃, 0.5 h	61	Some cracks	No warping
1/2	MC 2 wt% PEG 2 wt%	600℃, 2 h	56	No crack	Warping
		1200℃, 0.5 h	61	No crack	No warping

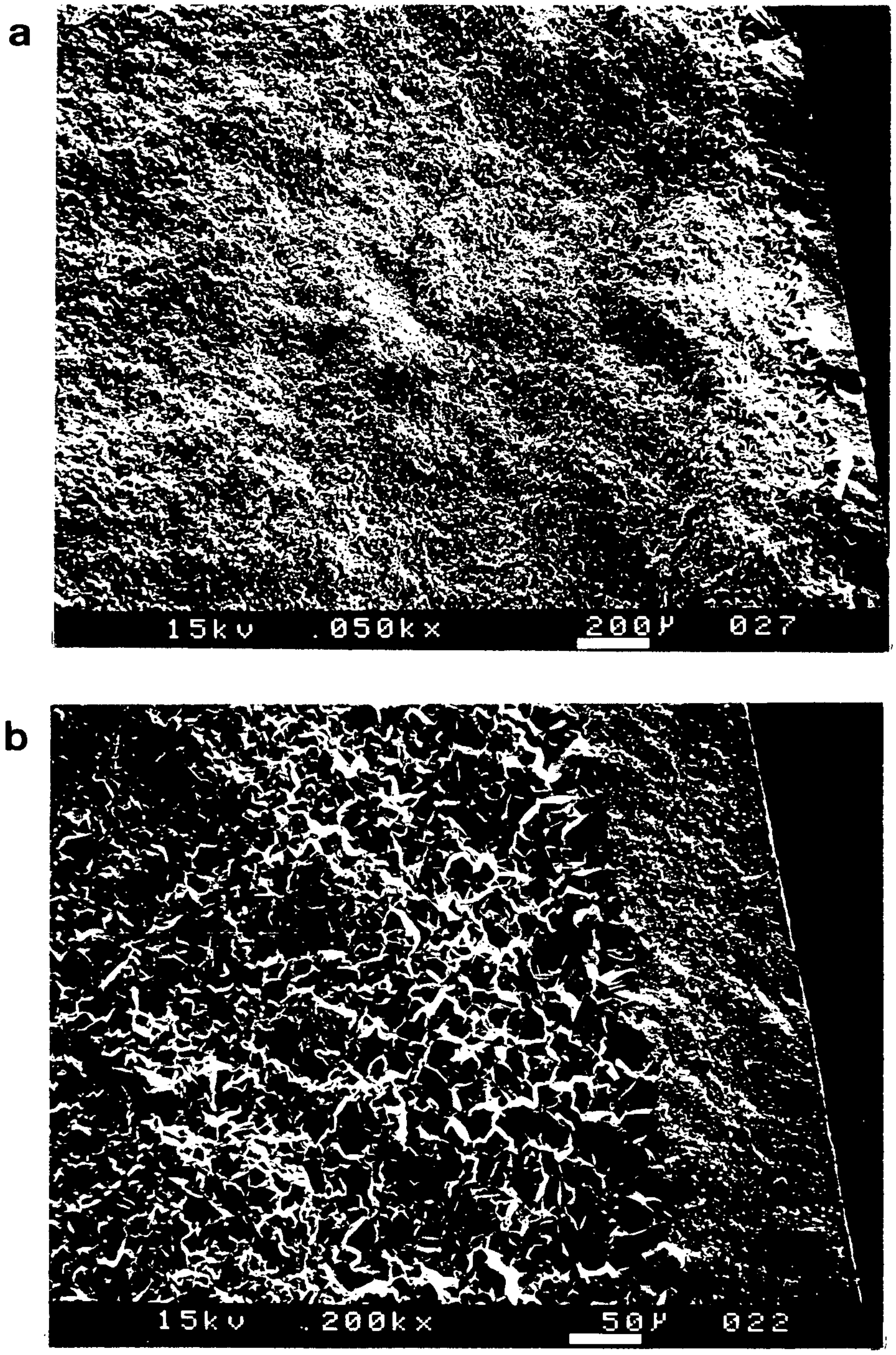

Fig. 1. SEM micrographs of fracture surfaces of coated samples showing coating thickness, bonding state and grain size: (a) low magnification and (b) high magnification.

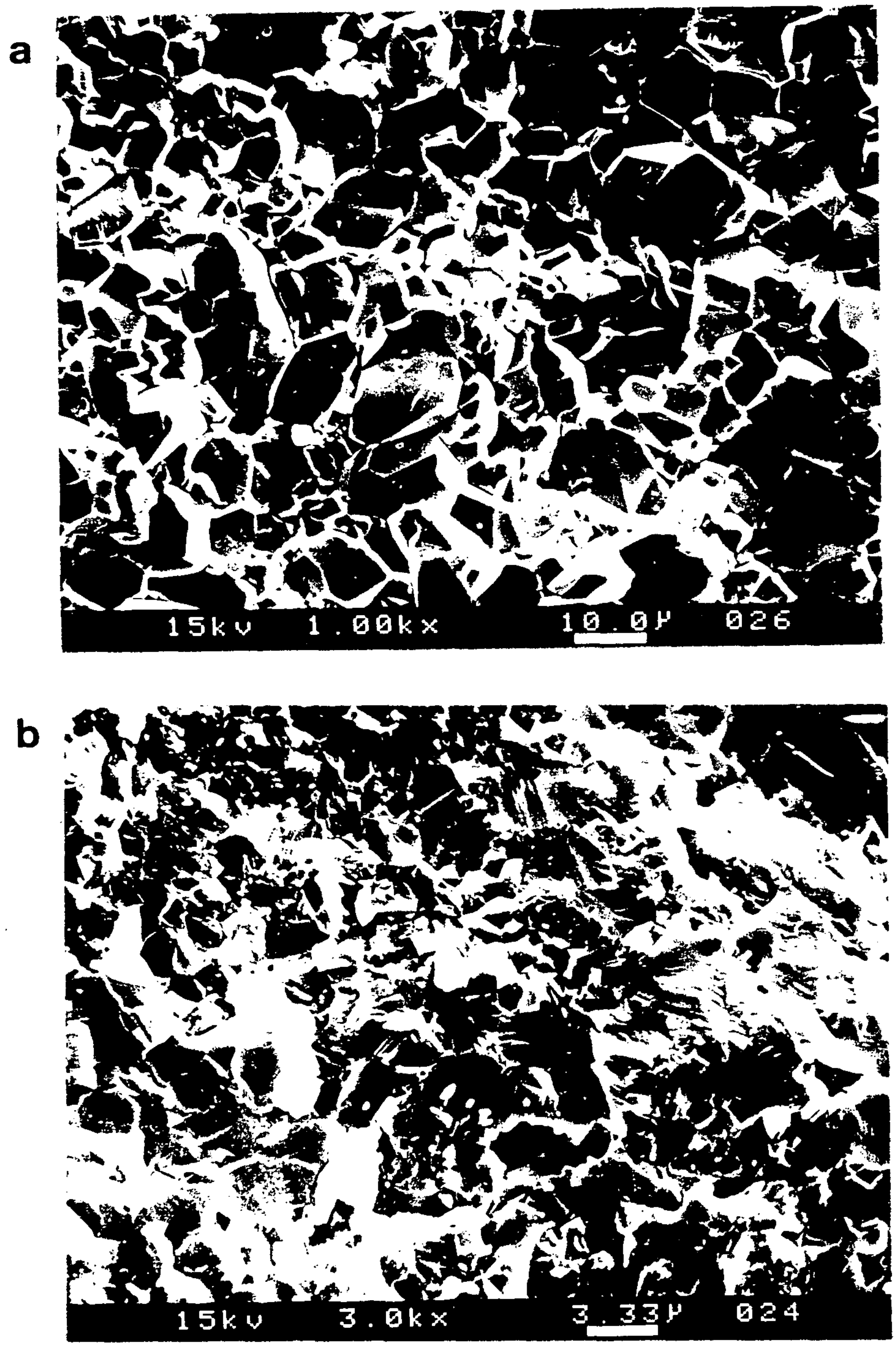

Fig. 2. SEM micrographs of fracture surfaces of coated samples showing grain size and fracture mode: (a) alumina body and (b) coating layer.