

Microstructure and fracture toughness of SiC-platelet reinforced SiC

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Silicon carbide (SiC) is acknowledged as one of the promising ceramics for high-temperature structural applications because of its excellent thermal and mechanical properties. However, its relatively low fracture toughness has long hindered this material from wider applications. A number of attempts have been made to improve the fracture toughness of SiC. The fracture toughness of SiC can be profoundly increased by suitable tailoring of the microstructure, e.g. by growing platelike grains associated with $\beta \rightarrow \alpha$ phase transformation and by manipulating the grain boundary phase [1–5]. On the other hand, the interest in ceramic platelet-reinforced material has continuously grown in many engineering ceramics in order to achieve improved fracture toughness [6–10]. In this study SiC platelet-reinforced SiC was developed by introducing

SiC platelets into SiC starting powder (α - or β -SiC) followed by hot pressing. Microstructures and fracture toughness were investigated. Interaction between the introduced SiC platelets and matrix SiC powders, associated with $\beta \rightarrow \alpha$ phase transformation, is discussed.

α -SiC (A20 H.C. Starck GmbH, Goslar, Germany) and β -SiC powder (Betarundum, Grade UF, IBDEM, Japan) were used as the starting raw materials for the matrix phases. The SiC platelets used as reinforcement were hexagonal SiC (C-Axis Technologies, Quebec, Canada) with diameter 10–25 μm and thickness 1–6 μm (mean aspect ratio = 6). Y_2O_3 (Fine Grade, H.C. Starck GmbH, Goslar, Germany) and Al_2O_3 (AKP50, Sumitomo Chemical Co. Ltd., Tokyo, Japan) were used as sintering additives. The α -SiC powder (90 wt%) and the additives (4 wt% Y_2O_3 + 6 wt% Al_2O_3) were

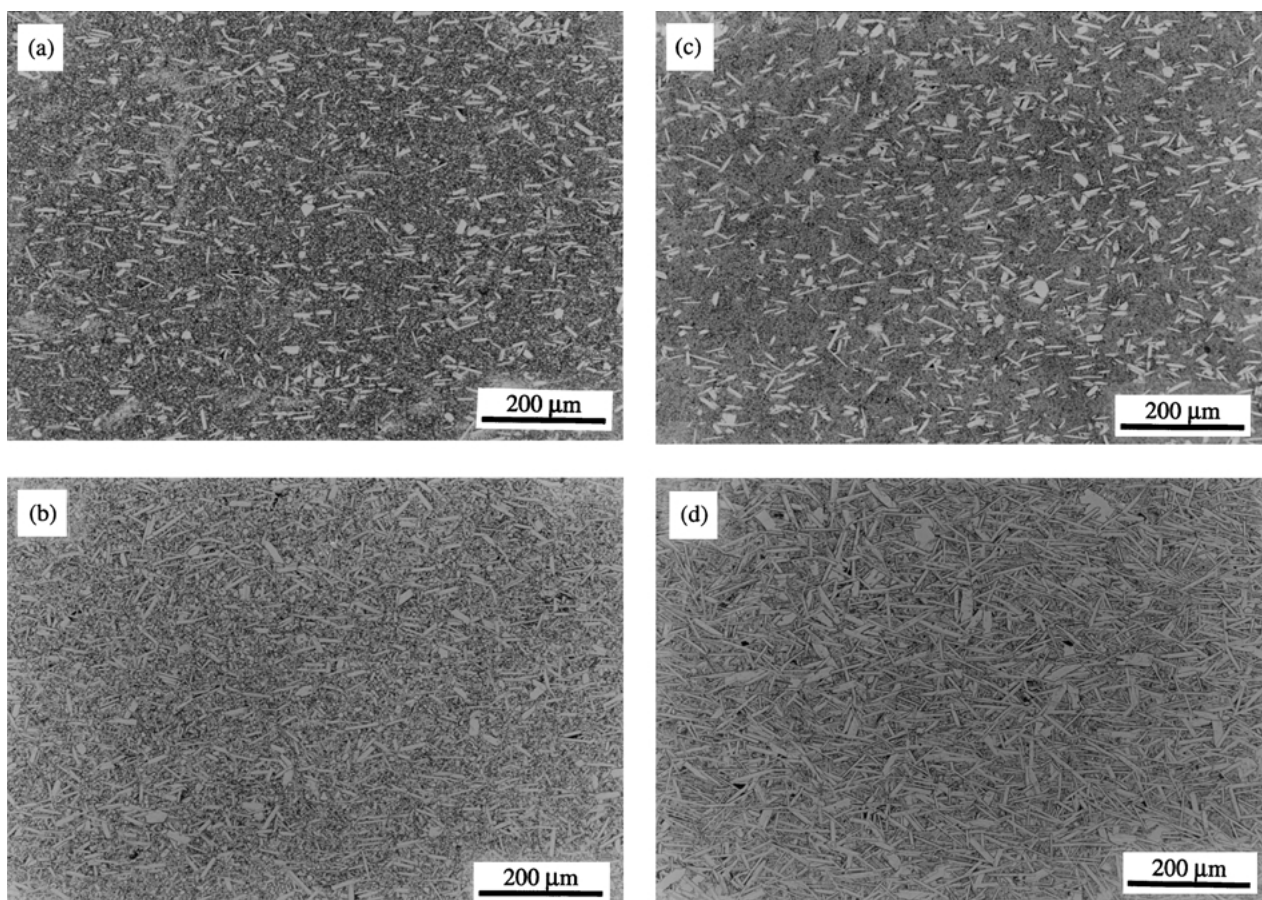


Figure 1 Optical micrographs of the polished and etched surfaces of the specimens hot-pressed at 2000 °C: α -SiC matrix + 10 vol% SiC platelet (a) for 1 and (b) for 120 min; β -matrix + 10 vol% SiC platelet (c) for 1 and (d) for 120 min.

mixed in a planetary mill for 12 h using alumina balls in isopropyl alcohol in a polypropylene container. After mixing, this slurry mixture was poured into a flat-bottomed flask, followed by the addition of 10 wt% SiC platelet as reinforcement. The flask was then placed in a heating mantle, resting on a magnetic stirring plate. The slurry was vigorously stirred at 25 °C for 1 h and then dried at 80 °C. After drying, the softly agglomerated powders were gently crushed and sieved through a 60 mesh screen. The batch using β -SiC powder was prepared by the same procedure. The powder mixtures were compacted in a graphite mold of 30 mm diameter. These were then hot-pressed at 2000 °C at a pressure of 30 MPa in an atmosphere of flowing argon. Holding time at 2000 °C was varied from 1 to 180 min. The hot-pressed blocks were cut into bars 25 × 4 × 3 mm for evaluation and testing. The bulk densities of the sintered specimens were measured by the Archimedes method. The phases of the sintered specimens were analyzed by X-ray diffractometry (XRD). Specimen surfaces were polished normal to the hot-press direction to 1 μ m diamond paste finish for characterization. These surfaces were etched with a mixture of molten salts (NaOH + K₃Fe(CN)₆) to highlight grain structures. After gold coating, the etched surfaces were examined by optical and scanning electron microscopy (SEM). Fig. 1 shows optical micrographs of the polished and etched surfaces of the specimens. No porosity is evident in the micrographs. Density determinations by Archimedes' method confirmed a porosity level <1% in each case. α -SiC platelets added were well dispersed in both α - and β -SiC matrix. For the specimens hot-pressed for 1 min (Fig. 1a and c), the apparent volume fraction of SiC platelets was about 10 vol% (volume fraction was measured by a linear intercept method), consistent with the amount of SiC platelets added in the beginning, indicating no considerable growth of SiC platelet in either α - or β -SiC matrix. Note that no significant difference in microstructure between α -SiC matrix (Fig. 1a) and β -SiC matrix (Fig. 1c) was found. For the specimens hot-pressed for 120 min, there was a significant difference in microstructure between α -SiC matrix (Fig. 1b) and β -SiC matrix (Fig. 1d). For α -SiC matrix, both α -SiC grains and α -SiC platelets grew slightly, showing a coarser microstructure (diameter 30–50 μ m and thickness 3–6 μ m). For β -SiC matrix (Fig. 2d), the size and volume fraction of α -SiC platelets increased significantly (diameter 50–100 μ m and thickness 4–7 μ m), indicating considerable growth of α -SiC platelets (compare with Fig. 2b). α -SiC platelets added to the β -SiC matrix were likely to act as seeds for the growth of α -SiC associated with $\beta \rightarrow \alpha$ phase transformation [1, 4]. The growth of SiC platelets proceeded predominantly along the direction of the basal planes of the platelets, indicating $\beta \rightarrow \alpha$ phase transformation in the SiC [3]. Higher volume fraction of platelets (about 85 vol%) resulted from grain growth of α -SiC platelets as β -SiC matrix was consumed. XRD analysis confirmed that β -SiC matrix was completely transformed to α -SiC phase. Grain growth of α -SiC platelets was enhanced by $\beta \rightarrow \alpha$ phase transformation. In other words, grain

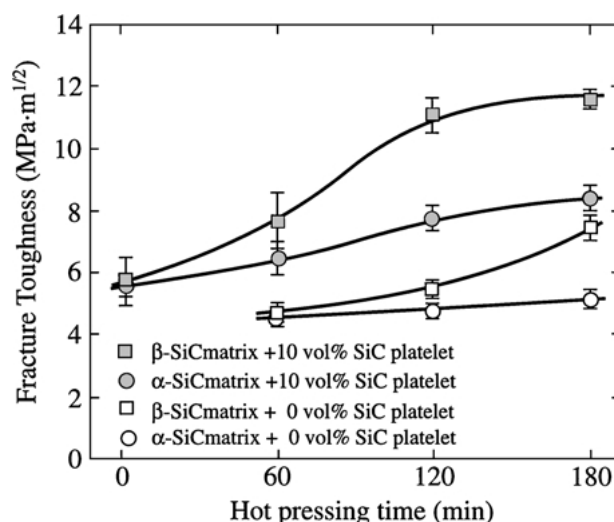


Figure 2 Fracture toughness as function of hot pressing time for α -SiC and β -SiC matrix with the addition of 10 vol% α -SiC platelet. Open symbols are data from previous work [3].

growth of α -SiC platelets in the β -SiC matrix is much faster than that in the α -SiC matrix. Fig. 2 shows fracture toughness versus hot pressing time for α - and β -SiC matrix with the addition of 10 wt% α -SiC platelets. Data from the previous work on α -SiC and β -SiC with no addition of SiC platelet are included for comparison [3]. The previous work indicated that improved fracture toughness with increasing holding time resulted from a microstructural change from equiaxed to elongated grains [2, 3]. The specimens with added SiC platelets have superior toughness to monolith SiC. For α -SiC matrix with additions of SiC platelets, the fracture toughness increased with increasing hot pressing time. Microstructure coarsening accounted for increasing fracture toughness. For β -SiC matrix with added SiC platelets, the fracture toughness increased even more up to 11.6 MPa · m^{1/2}. This increased toughness resulted from a coarse microstructure with high volume fraction and aspect ratio of SiC platelets. Fig. 3 shows an SEM micrograph of the fracture surface of this material. A mixture of intergranular and transgranular fracture mode is evident, indicating that crack bridging

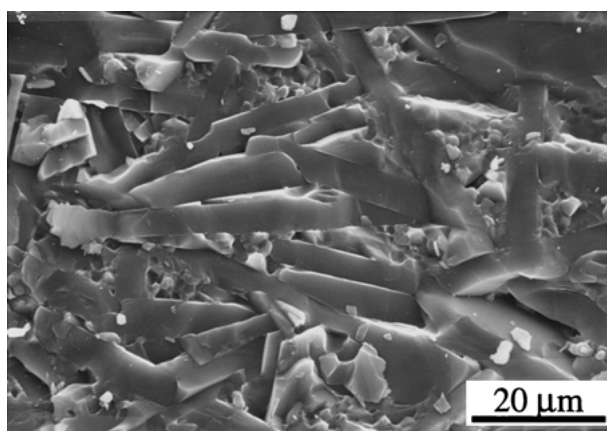


Figure 3 SEM micrograph of the fracture surface of the specimens hot-pressed at 2000 °C for 120 min (β -SiC matrix + 10 vol% SiC platelet).

[11, 12] by large SiC platelets a probable toughening mechanism.

References

1. N. P. PADTURE, *J. Amer. Ceram. Soc.* **77** (1994) 519.
2. S. K. LEE, Y. C. KIM and C. H. KIM, *J. Mater. Sci.* **29** (1994) 5321.
3. S. K. LEE and C. H. KIM, *J. Amer. Ceram. Soc.* **77** (1994) 1655.
4. Y.-W. KIM, M. MITOMO and H. HIROTSURU, *ibid.* **80** (1997) 99.
5. J. J. CAO, W. J. MOBERLYCHAN, L. C. D. JONGHE, C. J. GILBERT and R. O. RITCHIE, *ibid.* **79** (1996) 461.
6. M. BELMONTE and S. K. LEE, *J. Mater. Sci. Lett.* **16** (1997) 379.
7. Y.-S. CHOU and D. J. GREEN, *J. Amer. Ceram. Soc.* **75** (1992) 3346.
8. X.-N. HUANG and P. S. NICOLSON, *ibid.* **76** (1993) 1294.
9. G. PEZZOTTI, *ibid.* **76** (1993) 1313.
10. A. R. B. VERMA, V. S. R. MURTHY and G. S. MURTHY, *ibid.* **78** (1995) 2732.
11. P. L. SWANSON, C. J. FAIRBANKS, B. R. LAWN, Y.-W. MAI and B. J. HOCKEY, *J. Amer. Ceram. Soc.* **70** (1987) 279.
12. S. J. BENNISON and B. R. LAWN, *Acta Metall.* **37** (1989) 2659.
13. B. R. LAWN, "Fracture of Brittle Solids" (Cambridge University Press, Cambridge 1993).
14. G. R. ANSTIS, P. CHANTIKUL, D. B. MARSHALL and B. R. LAWN, *ibid.* **64** (1981) 533.

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