Colloidal Processing and Mechanical Properties of SiC with Al₂O₃ and Y₂O₃

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アルミナとイットリアを伴った炭化ケイ素のコロイドプロセッシングと力学特性

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A 30 vol% aqueous suspension of SiC/Al₂O₃/Y₂O₃ (1/0.02/0.016 volume ratio) system was consolidated by filtration through gypsum mold. The green compact was hot-pressed at 1700–1900°C under a pressure of 39 MPa in an Ar atmosphere. The sintering mechanisms were discussed based on the analysis of shrinkage curves of SiC/Al₂O₃/Y₂O₃ compacts during hot-pressing. The hot-pressing at 1800–1900°C gave dense SiC ceramics (> 99% theoretical density) with average four-point flexural strengths of 554–658 MPa, fracture toughness of 4.2–5.3 MPa·m^{1/2} and Vickers hardness of 20–25 GPa. The Weibull modulus of the SiC hot-pressed at 1800°C was in the range from 4.6 to 7.0. The processing in the heterocoagulation region (pH 5.0) for the SiC and sintering additives gave the highest mechanical properties after the hot-pressing.

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1. Introduction

Silicon carbide (SiC) is widely useful as a high temperature structural material because of its excellent high temperature strength, good oxidation resistance, high thermal shock resistance, and high hardness. However, it has been impossible to densify a submicrometer-sized SiC powder without sintering additives because of its strong covalent bonding character. Recently the chemical methods for the addition of sintering additives such as Al₂O₃ plus Y₂O₃ to SiC powder have been studied to control the liquid phase sintering and the resultant microstructures of SiC ceramics.^{1)–7)} Liden et al.²⁾ mixed 0.45 μm-SiC powder with 2 mass% Al₂O₃ (50 nm) powder-1 mass% Y₂O₃ (10 nm) powder in aqueous solutions and sintered the dried green compact of 51% of theoretical density to 99.7% density by the sintering at 1880°C for 4 h in an Ar atmosphere. Sciti and Belloso⁸⁾ studied the densification of SiC powder of a specific surface area of 11.6 m²/g by the hot-pressing under a pressure of 30 MPa at 1880°C in vacuum. The SiC powder, 2.2–4.8 vol% Al₂O₃ powder and 1.6–2.6 vol% Y₂O₃ powder were mixed in ethylalcohol. The prepared suspension was dispersed by pulsed ultrasonic vibration and dried at 80°C using a rotary evaporator. The dried and sieved powder started the densification at 1470–1520°C and was sintered to a density higher than 98% at 1880°C. The densification of Al₂O₃ plus Y₂O₃-doped SiC ceramics proceeds by the liquid phase sintering with a dissolution-precipitation mechanism of SiC in the eutectic liquid of the SiO₂–Al₂O₃–Y₂O₃ system.^{4),7)} The SiO₂ component forms to a slight extent on the surface of SiC powder. The sinterability of the SiC–Al₂O₃–Y₂O₃ compact depends on the amount and ratio of Al₂O₃–Y₂O₃ system.^{9),10)} Uniform addition of a small amount of sintering additives to SiC is effective to increase the sinterability. In this paper, the densification characteristics and mechanical properties of the SiC with Al₂O₃ and Y₂O₃ are reported. The starting powders were mixed by colloidal processing. The important interactions in the SiC–Al₂O₃–Y₂O₃ suspension depend on the isoelectric points of the powders and the suspension pH. In this

paper, the SiC compacts with Al₂O₃ and Y₂O₃ were processed in the wide processing pH from 3 to 10.

2. Experimental procedure

A following α-SiC powder was used in this experiment: SiC 97.5 mass%, SiO₂ 1.75 mass%, C 0.65 mass%, Al 0.025 mass%, Fe 0.027 mass%, median size 0.65 μm (weight standard distribution) and a specific surface area of 13.4 m²/g (equivalent spherical diameter 0.14 μm, Yakushima Electric Industry Co., Ltd., Kagoshima). As-received α-SiC powder was mixed with α-Al₂O₃ of a median size 0.2 μm (weight standard distribution) and a specific surface area 10.5 m²/g (equivalent spherical diameter 0.14 μm, Al₂O₃ > 99.99 mass%, Sumitomo Chemical Industry Co., Ltd., Tokyo) and Y₂O₃ of a specific surface area 15.0 m²/g (equivalent spherical diameter 0.08 μm, Y₂O₃ > 99.9 mass%, Shin-Etsu Chemical Industry Co., Ltd., Tokyo). The surface characteristics of SiC, Al₂O₃ and Y₂O₃ powders in dilute aqueous suspensions (0.02 mass%) were examined by measuring their zeta potentials at an ionic strength of 0.01 M NH₄NO₃ under a microscope by particle electrophoresis apparatus (Rank Mark II, Rank Brothers Ltd., UK). The zeta potentials of the mixed powders of SiC/Al₂O₃/Y₂O₃ = 1/0.30/0.30 volume ratio were also measured at pH 3.0, 5.0, 8.0 and 10.0 (Delsa 440, Coulter, USA).

The pH of each suspension was adjusted using 0.1 M HCl and 0.1 M NH₄OH solutions. The SiC/Al₂O₃/Y₂O₃ (1/0.020/0.016 volume ratio) mixed powders were dispersed at 30 vol% in the aqueous solutions at pH 3.0–10.0 for 5 h. The prepared suspension was formed into a rectangular green compact with 38 mm length, 25 mm width and 20 mm height by filtration through gypsum board at room temperature. Bakelite molds were set on a thick flat gypsum board to shape the suspension into the rectangular compact. The dried green compacts were calcined at 1200°C in an Ar atmosphere for 2 h (SPM 6513 electric furnace, Marusho Electro-Heat Co., Ltd., Hyogo) to measure the packing density. The consolidated green compacts were hot-pressed under a pressure

of 39 MPa at 1700, 1800 and 1900°C for 2 h in an Ar flow. The heating and cooling rates were 10°C/min. The densities of the calcined and hot-pressed compacts were measured by the Archimedes method using kerosene. The surface of hot-pressed SiC sample was polished with 1 µm diamond paste and etched with the mixture of NaCl/NaOH=85/15 (molar ratio) at 600°C for 5 min in air to observe the microstructure by scanning electron microscope (SM300, Topcon Technologies, Inc., Tokyo). The hot-pressed SiC was cut into the specimens with sizes of 3 mm height, 4 mm width, and 38 mm length. The specimens were polished with SiC papers of Nos. 600 and 2000 and diamond paste of 6 and 1 µm. The Vickers hardness of the hot-pressed SiC was measured at the load of 98 N (model MVF, Akashi Seisakusho Co., Ltd., Tokyo). The flexural strength of hot-pressed SiC was measured at room temperature by the four-point flexural method over spans of 30 mm (lower span) and 10 mm (upper span) at a crosshead speed of 0.5 mm/min. The fracture toughness was evaluated by single-edge V-notch beam (SEVNB) method. A thin diamond blade 1 mm thick, where the tip of V-notch had a curvature radius of 20 µm was used to introduce V-notch of $a/W = 0.1-0.6$ (a : notch length, W : width of the beam). The strength of the notched specimen was measured by three-point loading over a span 30 mm at a crosshead speed of 0.5 mm/min. Equation (1) provides the fracture toughness and Eq. (2) indicates the shape factor (Y) of crack at $S/W = 7.5$. S , P , and B in Eqs. (1) and (2) are the span width, applied load and thickness of beam, respectively.

$$K_{IC} = \frac{3PS}{2BW^2} Y\sqrt{a} \quad (1)$$

$$Y = 1.964 - 2.837\lambda + 13.711\lambda^2 - 23.250\lambda^3 + 24.129\lambda^4 \quad (2)$$

($\lambda = a/W$).

3. Results and discussion

3.1 Interactions of SiC, Al₂O₃ and Y₂O₃ powders in suspensions

Figure 1 shows the zeta potentials of SiC, Al₂O₃ and Y₂O₃ particles as a function of suspension pH. The isoelectric points of SiC, Al₂O₃ and Y₂O₃ were pH 2.5, 8.0 and 7.5, respectively. The asymmetry in the zeta potential profile about the isoelectric point for Al₂O₃ and Y₂O₃ revealed that the particle surfaces were charged positively in the acidic conditions below pH 8.0. The pH dependence of the zeta potential of the SiC powder was similar to that of the SiO₂ powder, because the surfaces of SiC particles were coated by thin SiO₂ layers.^{11)–13)}

Fig. 1. Zeta potentials of SiC, Al₂O₃ and Y₂O₃ powders as a function of suspension pH.

The mixed powder suspensions were prepared at pH 3.0 (near the isoelectric point of SiC), pH 5.0 (heterocoagulation region between SiC and Al₂O₃ or Y₂O₃), pH 8.0 (near the isoelectric points of Al₂O₃ and Y₂O₃) and pH 10.0 (codispersion region of SiC, Al₂O₃ and Y₂O₃). The SiC, Al₂O₃ and Y₂O₃ powders were mixed at a relatively high volume ratio (SiC/Al₂O₃/Y₂O₃ = 1/0.3/0.3) to clarify the difference in the zeta potentials of SiC with and without the sintering additives. Figures 2 and 3 show the possible interactions and zeta potentials of the mixed powders at pH 3.0, 5.0, 8.0 and 10.0. SiC particles near the isoelectric point (pH 2.5) are flocculated due to van der Waals attractive forces (Fig. 2(a)). In the acidic suspension, the surfaces of Al₂O₃ and Y₂O₃ are covered with hydroxyls. Some hydroxyls interact with HCl to form the positively charged sites: $M-OH + HCl \rightarrow M-OH_2^+ + Cl^-$, $M = Al$ and Y .¹⁴⁾ Electrostatic repulsion acts among the positively charged Al₂O₃ and Y₂O₃ particles. SiC particles with little charge attract Al₂O₃ and Y₂O₃ particles by van der Waals forces. The shift of the zeta potential of SiC to more positive values with the addition of Al₂O₃, Y₂O₃ and Al₂O₃ plus Y₂O₃ (Fig. 3(A)) is related to the adsorption of positively charged Al₂O₃ and Y₂O₃ particles on weakly charged SiC particles. At pH higher than 5.0, a part of SiC surface covered with hydroxyls interacts with NH₄OH added to form the negatively charged sites: $Si-OH + NH_4OH \rightarrow Si-O^- + NH_4^+ + H_2O$.¹¹⁾ The negatively charged SiC particles are well dispersed by their strong repulsive interaction (Fig. 2(b)). Positively charged Al₂O₃ and Y₂O₃ particles are adsorbed on the negatively charged SiC particles by their electrostatic attractive forces. As seen in Fig. 3(B), the heterocoagulation of SiC and Al₂O₃ plus Y₂O₃ shifted the zeta potential of SiC particles from a negative value to the positive value. At pH 8.0 near the isoelectric point of alumina, Al₂O₃ particles become agglomerated due to van der Waals attractive forces (Fig. 2(c)). Similar agglomerates are also formed for the weakly charged Y₂O₃ particles, because the van der Waals attractive energy is greater than the electrostatic repulsive energy. These Al₂O₃, Y₂O₃ and Al₂O₃-Y₂O₃ agglomerates are attracted to the

Fig. 2. Schematic possible structures of particle clusters in the SiC–Al₂O₃–Y₂O₃ suspensions at pH 3.0 (a), 5.0 (b), 8.0 (c) and 10.0 (d), based on the zeta potentials in Fig. 1.

Fig. 3. Zeta potentials of mixed powders of SiC/Al₂O₃/Y₂O₃=1/0.3/0.3 (volume ratio) at pH 3.0 (A), 5.0 (B), 8.0 (C) and 10.0 (D). The zeta potentials of mixed powder were measured by Laser Doppler method. The vertical axis of Fig. 3 indicates the intensity ratio of I_0/I , where I_0 is the intensity of reference light and I is the intensity of light detected after the scattering by colloidal particles. Increase in the concentration of colloidal particles leads to the decrease of I because of the large scattering, resulting in the increased ratio of I_0/I .

negatively charged SiC particles due to the small electrostatic repulsive force. The experimental data in Fig. 3(C) indicates that (1) little change of the zeta potential of SiC particles occurred with the addition of Al₂O₃ and Y₂O₃ and (2) no zeta potential data corresponding to Al₂O₃ and Y₂O₃ appeared in the zeta potential of the SiC–Al₂O₃–Y₂O₃ mixed powders. This result is interpreted in terms of the attractive interaction between negatively charged SiC particles and Al₂O₃ or Y₂O₃ particles with no significant charge. At pH 10, SiC, Al₂O₃ and Y₂O₃ particles have a similar zeta potential (Fig. 1). These negatively charged particles are co-dispersed due to the strong repulsive energy. The similar zeta potentials between SiC and the SiC–Al₂O₃–Y₂O₃ system in Fig. 3 (D) represent the codispersion of SiC, Al₂O₃ and Y₂O₃ particles. However, the negatively charged alumina particles in the basic suspension have a tendency to form agglomerated particle clusters.¹⁴⁾ In our previous study,¹⁴⁾ the size of agglomerated alumina clusters increased with increasing suspension pH. This result is explained by the dehydration and condensation reaction between hydroxyls on the alumina surface: $\text{Al}(\text{OH})_3 + \text{Al}(\text{OH})_3 \rightarrow \text{Al}(\text{OH})_2 - \text{O} - \text{Al}(\text{OH})_2 + \text{H}_2\text{O}$. This surface reaction is repeated to link three dimensionally. The hydroxyls remaining in the condensed network provide the negatively charged sites by the chemical reaction with NH₄OH.

Figure 4 shows the relative density of SiC/Al₂O₃/Y₂O₃ (1/0.020/0.016 volume ratio) compact consolidated by filtration of 30 vol% solid suspensions and calcined at 1200°C for 1 h in an

Fig. 4. Relative density of powder compacts of SiC and the SiC–Al₂O₃–Y₂O₃ (1/0.020/0.016 volume ratio) system, consolidated by filtration and calcined at 1200°C in an Ar atmosphere.

Ar atmosphere. The bulk density of all the samples became higher at higher pH of the suspensions, indicating the dispersibility of SiC particles dominates the packing density. The addition of a

Fig. 5. Relative density of the SiC–Al₂O₃–Y₂O₃ compact after hot-pressing at 1700–1900°C.

small amount of Al₂O₃ and Y₂O₃ particles to the SiC suspension reduced the bulk density as seen in Fig. 4. The above results are closely correlated to the interactions of the colloidal particles in the suspensions, as discussed in Figs. 2 and 3. The bulk density became a minimum value in the heterocoagulation region (pH 5) because of the formation of agglomerated particle clusters.

3.2 Hot-pressing of SiC with Al₂O₃ and Y₂O₃

Figure 5 shows the relative density of SiC hot-pressed at 1700–1900°C for 2 h under a pressure of 39 MPa as a function of suspension pH. When Al₂O₃ and Y₂O₃ were added to SiC, SiO₂ on the surface of SiC interacted with Al₂O₃ and Y₂O₃ to form a liquid phase, whose amount depends on the composition and heating temperature. The composition of SiO₂ (1.75 mass %)-Al₂O₃ (2.5 mass %)-Y₂O₃ (2.5 mass %) in this experiment forms a liquid at 1500°C in the phase diagram of SiO₂-Al₂O₃-Y₂O₃ system. The density of SiC–Al₂O₃–Y₂O₃ compact hot-pressed at 1700°C became higher at pH 5 and pH 10, reflecting the uniform distribution of Al₂O₃ and Y₂O₃ particles in the SiC matrix. Consolidation at the isoelectric points of SiC (pH 3) and Al₂O₃ or Y₂O₃ (pH 8) gave the lower sinterability of SiC–Al₂O₃–Y₂O₃ compact, suggesting the nonuniform distribution of Al₂O₃ and Y₂O₃ particles. When the hot-pressing temperature was increased, the increased amount of the liquid, the decreased viscosity of the liquid and the application of pressure were coupled to break the soft agglomerates formed at pH 3.0 and 8.0. Wang and Wei⁹⁾ also reported the sinterability of SiC with 4.5 vol% Al₂O₃ and 3.6 vol% Y₂O₃. Their β -SiC compacts were densified to 83.2, 86.0 and 89.5% of theoretical density by the pressureless-sintering at 1850, 1950 and 2000°C for 1 h in an Ar atmosphere, respectively. She and Ueno¹⁾ studied the densification of α -SiC with 6 vol% Al₂O₃ and 1.6 vol% Y₂O₃ at 1850–2000°C. The relative density higher than 98% is reported for the sintering at 1850°C. As compared with these reported sinterability, the densification of SiC in the present experiment proceeded significantly with a lower content of sintering additives.

When the SiC compact with Al₂O₃ and Y₂O₃ was heated to 1700–1900°C under a pressure of 39 MPa, the relative density of the compact reached the following values for heating time 0 h: 55–59% at 1700°C, 61–64% at 1800°C and 68–72% at 1900°C. The densification of the SiC compact during the heating process was accompanied by the linear shrinkage of 2–3% at 1700°C, 3–5% at 1800°C and 7–8% at 1900°C. The increase of relative density and the shrinkage of the SiC compact during the heating process indicates that the SiC compact was in the initial

stage of sintering when the compact reached the given hot-pressing temperature. Figure 6 shows the logarithmic relation between the shrinkage of the SiC compact and heating time after the compact reached the hot-pressing temperature. A good linear relation was observed at each hot-pressing temperature. Figure 7 summarizes the slope of the $\log(\Delta L/L_0) - \log t$ relation. In the initial stage of the heating, the slope was in the range from 0.373 to 0.590, depending on the processing pH. In the final stage of heating, the slope decreased to 0.155–0.249 at 1800–1900°C. The slope values of 0.33, 0.50 and 1.0 represent the early stage sintering mechanism dominated by diffusion in liquid, dissolution-precipitation mechanism, and viscous deformation mechanism, respectively. The experimental result suggests that (1) the diffusion of SiC in the liquid at 1700°C dominated the densification of the SiC compact processed at pH 3 and 8, (2) the influence of dissolution-precipitation mechanism became larger for the densification of the SiC processed at pH 5 and 10 in the initial stage of heating at 1700°C, and (3) all the SiC compacts were densified through the dissolution-precipitation mechanism in the early stage of sintering at 1800 and 1900°C. In the final stage of heating at 1800–1900°C, the slope in Fig. 7 was significantly low as compared with the values in the initial sintering models, because the SiC compact was in the final stage of sintering.

3.3 Microstructures and mechanical properties of the SiC–Al₂O₃–Y₂O₃ compact

Figure 8 shows the microstructures of SiC hot-pressed for 2 h at 1800°C. The microstructures consisted of SiC grains of small aspect ratios. The processing pH gave an influence on the grain size. Larger grains were observed for the SiC processed at pH 3 (near the isoelectric point of SiC). Smaller grains were observed for the SiC processed at pH 8 (near the isoelectric points of Al₂O₃ and Y₂O₃). Figure 9 shows the grain size distributions measured on the microstructures of Fig. 8. The cumulative particle size distributions of SiC hot-pressed at 1800°C were as follows: 0.46 μ m (10%)–1.11 μ m (50%)–2.61 μ m (90%) for processing pH 3, 0.17 μ m (10%)–0.85 μ m (50%)–2.26 μ m (90%) for processing pH 5, 0.09 μ m (10%)–0.71 μ m (50%)–1.80 μ m (90%) for processing pH 8 and 0.21 μ m (10%)–0.95 μ m (50%)–2.32 μ m (90%) for processing pH 10. The median size became larger in the following order of processing pH: pH 8 < pH 5 < pH 10 < pH 3. The measured grain size distribution is closely related to the dispersibility of sintering additives (Fig. 2). The nonuniform distribution of Al₂O₃ and Y₂O₃ particles at pH 8 may be responsible for the low grain growth rate of SiC. The uniform distribution of Al₂O₃ and Y₂O₃ particles in the SiC matrix at pH 5 and 10 promotes the formation of liquid uniformly distributed around SiC particles, which accelerates the densification of SiC with uniform grain growth.

Figure 10 shows the Vickers hardness at 98 N as a function of relative density of SiC hot-pressed at 1800°C. The hardness increased with the increasing density, reflecting the increased strength of chemical bonding at grain boundaries of SiC.^{15)–19)}

Figure 11 shows the Weibull plots of flexural strength of SiC hot-pressed at 1800°C. It has been reported²⁰⁾ that the monolithic SiC hot-pressed at 1800°C (77% relative density) showed 92 MPa of flexural strength. The addition of Al₂O₃ plus Y₂O₃ at pH 3–10 was effective to enhance the strength of SiC. The hot-pressing at 1800°C provided the flexural strength of 275–881 MPa. The strength at a failure probability of 50% and the Weibull modulus resulted in 658 MPa and 6.1 for pH 3, 647 MPa and 6.6 for pH 5, 556 MPa and 4.6 for pH 8 and 554 MPa and 7.0 for pH 10, respectively. The results in Fig. 11 indicate that (1) the processing of the SiC–Al₂O₃–Y₂O₃ system in the acidic suspension provides the higher strength of hot-pressed SiC than the processing in the basic suspension and (2) the heterocoagulation and codispersion of the

Fig. 6. Logarithmic relation between shrinkage ($\Delta L/L_0$) and hot-pressing time (t) of SiC with Al₂O₃ and Y₂O₃, processed at pH 3.0 (a), 5.0 (b), 8.0 (c) and 10.0 (d).

Fig. 7. Slope of the $\log(\Delta L/L_0)$ – $\log t$ relation as function of processing pH.

Fig. 8. Microstructures of SiC with Al₂O₃ and Y₂O₃ hot-pressed at 1800°C.

SiC–Al₂O₃–Y₂O₃ system leads to the relatively high Weibull modulus.

Figure 12 shows the fracture toughness of SiC at room temperature. The fracture toughness depended on the processing pH and hot-pressing temperature. The dependence of fracture toughness on processing pH was similar to the pH dependence of relative density (Fig. 5). That is, the interaction between SiC particles and sintering additives affects both the microstructure and resultant fracture toughness. The increase of fracture toughness with in-

creasing hot-pressing temperature is explained by two important factors: bulk density and interfacial strength of grain boundaries. Decrease of porosity and strengthening of grain boundaries cause the increase of Young's modulus and fracture energy, leading to the increase of fracture toughness. The strength of SiC is related to $K_{IC}/Y a^{1/2}$, where K_{IC} is the fracture toughness, Y the geometry factor of flaw, and a the flaw size. The relationship between the strength (Fig. 11) and fracture toughness (Fig. 12) suggests that

Fig. 9. Grain size distribution of SiC formed from the aqueous suspension at pH 3–10 and hot-pressed at 1800°C.

Fig. 10. Vickers hardness at a load of 98 N as a function of relative density of SiC hot-pressed at 1800°C.

Fig. 11. Weibull plots of flexural strength of SiC hot-pressed at 1800°C.

the flaw size gives a more significant influence rather than fracture toughness on the strength of SiC hot-pressed at 1800°C.

Figure 13 shows the flaws observed in the SiC with the highest flexural strength at each processing pH. Hot-pressing was carried out at 1800°C. In the SiC processed in the acidic suspensions (pH 3 and 5), the local rapid grain growth of SiC or large particles included in the raw SiC powder produced the flaws affecting the strength. The processing in the basic suspensions (pH 8 and 10) formed the flaws associated with the nonuniform distribution of

Fig. 12. Fracture toughness of SiC hot-pressed at 1700–1900°C as a function of processing pH.

Fig. 13. Flaws observed in hot-pressed SiC with the highest flexural strength at each processing pH. Hot-pressing was carried out at 1800°C.

the liquid, as discussed in Fig. 2. As seen in Fig. 13, the flaw size was smaller for the SiC processed in the acidic suspension than for the SiC processed in the basic suspension.

Figure 14 summarizes the mechanical properties as a function of processing pH. The processing of SiC with the acidic suspensions gave the characteristics of (1) high strength, (2) relatively high fracture toughness, (3) small flaw size and (4) relatively large Weibull modulus. The processing in the heterocoagulation region (pH 5) between SiC and Al_2O_3 or Y_2O_3 is superior to the processing at near the isoelectric point of SiC (pH 3) for the enhanced mechanical properties. On the other hand, the processing of SiC with the basic suspensions resulted in (1) low flexural strength and (2) large flaw size. The processing at near the isoelectric points of the sintering additives (pH 8) resulted in the minimum fracture toughness and Weibull modulus. Codispersion of SiC and sintering additives at pH 10 improved the fracture toughness and Weibull modulus but the strength was still low because of the large flaw size.

4. Conclusions

(1) The isoelectric points of SiC, Al_2O_3 and Y_2O_3 were pH 2.5, 8.0 and 7.5, respectively. The packing density of the SiC/ Al_2O_3 / Y_2O_3 (1/0.020/0.016 volume ratio) mixed powder compact became higher at a higher pH of the suspensions. That is, the packing density was greatly influenced by the dispersibility of the SiC particles.

Fig. 14. Average fracture strength (a), fracture toughness (b) flaw size (c) and Weibull modulus (d) for the SiC hot-pressed at 1800°C, as a function of processing pH.

(2) The density of SiC with Al₂O₃ and Y₂O₃ hot-pressed at 1700°C became higher at pH 5 and 10 of the suspension pH. The densification of the SiC compact was influenced by the dispersibility of sintering additives. The processing in the heterocoagulation region (pH 5) or in the codispersion region (pH 10) for the SiC and Al₂O₃ or Y₂O₃ enhanced the sinterability of SiC. However, the sinterability of SiC processed at the isoelectric points of SiC (pH 3) and the sintering additives (pH 8) was low.

(3) The SiC compacts with 2 vol% Al₂O₃ and 1.6 vol% Y₂O₃ were hot-pressed to the relative density higher than 99% at 1800–1900°C. The suspension pH gave little influence in these hot-pressing temperatures. The densification in the early stage of sintering at 1800–1900°C proceeded by the dissolution-reprecipitation mechanism of SiC in the liquid of the SiO₂–Al₂O₃–Y₂O₃ system. The grain size became larger in the following order of processing pH: pH 8 < pH 5 < pH 10 < pH 3.

(4) The dense SiC hot-pressed at 1800°C provided the following mechanical properties: average strength of 554–658 MPa,

Weibull modulus of 4.6–7.0, fracture toughness of 4.2–5.3 MPa·m^{1/2}. The Vickers hardness of SiC increased linearly with increasing density and reached 24.6 GPa at 99.4% relative density at the load of 98 N. The processing in the heterocoagulation region at pH 5 gave the superior properties (high strength, high fracture toughness, small flaw size and high Weibull modulus). The processing of SiC with the basic suspensions (pH 8 and 10) formed the relatively large flaws after the hot-pressing, resulting in the low flexural strength.

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