Mechanical Properties of SiC Whisker-Reinforced Mullite Composites (Part 1)

—Effects of Dispersant Contents in Mixing Solvents on the Strength and Microstructure of Sintered Bodies—

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炭化ケイ素ウイスキー強化ムライト複合材料の機械的性質 (第1報)
——焼結体の強度及び微細組織に対する混合溶媒中での分散剤濃度の影響——

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The dispersibility of mixed powder consisting of mullite and SiC whisker in solvents was assessed by carrying out sedimentation tests and viscosity measurements. The dispersibility was improved with increasing dispersant content and became good by adding dispersant over 0.5 mass%. On the other hand, the dispersibility of mixed powder consisting of mullite and carbon-coated SiC whisker W(AC) was better than that of mixed powder consisting of mullite and W(A), despite the dispersibility of W(AC) being worse than that of W(A) if their particles existed alone in solvent. However, the dispersibility of the mixed powder consisting of mullite and W(AC) was lowered on addition of 0.5 mass% dispersant and improved again on addition of 1.0 mass%. The strength of SiC whisker-reinforced mullite composites became maximum by addition of 0.5-1.0 mass% dispersant to the solvent used in powder-mixing.

[Received December 8, 1997; Accepted May 19, 1998]

Key-words : Composite, Mullite, SiC whisker, Dispersibility, Sedimentation, Viscosity, Strength

1. Introduction

Mullite ceramics exhibit the characteristics whereby the decrease in strength is low even at a high temperature of around 1400°C.¹⁾⁻³⁾ However, their applications have been limited due to their low strength and fracture toughness.⁴⁾ Therefore, we have tried to improve the mechanical properties of the mullite by addition of SiC whisker. However, if the dispersibility of SiC whiskers in mullite matrix is poor, the mechanical properties also become poor as the addition of whisker leads to the introduction of defects. Therefore, it is necessary that the dispersibility of SiC whiskers and mullite particles in solvents used during a wet mixing process is good.

We have already studied the dispersibility of mullite and SiC whiskers which exist individually in the solvent.^{5),6)} However, the mullite and the SiC whiskers exist simultaneously in a practical mixing process. Therefore, it is necessary to assess the dispersibility under the condition that the mullite and the SiC whiskers exist simultaneously. If the sign of electric charges (plus or minus) and the charging quantities for the two coexisting particles are different, it is assumed that the dispersion behavior of particles coexisting in the solution is different from the behavior of each particle type existing individually in the solution.

In this study, the dispersibility of mixed powder was assessed by carrying out sedimentation tests and viscosity measurements^{7),8)} for the slurry containing powder blended in a practical mixing ratio. Furthermore, the influence of dispersant content in the slurry on the strength of sintered composites was examined and the most suitable conditions for fabricating SiC whisker-reinforced mullite composites

were decided on the basis of the results of this study.

2. Experimental procedure

SiC whiskers used in this study were of two types; those with an average diameter of 0.4 μm and a length of 30 μm (W(A)), and the other was carbon-coated whiskers with an average diameter of 0.5 μm and a length of 35 μm (W(AC)). Both SiC whiskers are commercially available (manufactured by Tokai Carbon Co., Ltd.). Furthermore, the mullite used as a matrix contains 72 mass% Al_2O_3 (manufactured by Chichibu-Onoda Co., Ltd.) with an average particle size of 1.56 μm . The material characterized in our previous paper⁵⁾ was used as dispersant.

A sedimentation test similar to that in the previous paper is performed.⁵⁾ However, the concentrations of particles in solvent are 1 vol% for mullite and 0.2 vol% for SiC whiskers. The solvents containing these mixed particles were allowed to stand after agitation with an ultrasonic equipment, and the heights of interfaces between a sediment and a cloudy layer as well as between two cloudy layers were measured as a function of time after agitating-standing.

A rotation viscometer was used for determining the viscosity of slurry. Ethanol and 20 vol% SiC whisker-containing mullite were mixed for 10h in a ball-mill, and the viscosity of slurry containing the mixed particles was measured. In this case, the concentration of mixed particles in ethanol was 10 vol%.

Mixed powder consisting of 80 vol% mullite, 20 vol% SiC whiskers and a fixed quantity of dispersant were mixed in ethanol using a ball-mill for 10h. The slurry was dried using an evaporator. The mixed powder was placed in a graphite die of 20 mm in diameter, and was hot-pressed at 29.4 MPa and 1650°C for 2h. Disklike specimens were cut into rectangular bars of 4 mm in width, 2 mm in thickness

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and 20 mm in length, and their surfaces were mirror-polished using 1- μ m diamond paste for strength measurement. The length of the rectangular bar was perpendicular to the direction of hot pressing. The strength was measured at a crosshead speed of 0.5 mm/min using a three-point bending equipment with a span of 16 mm. In addition, the concentration of dispersant in this paper is indicated by mass% of dispersant to mixed powder.

3. Results and discussion

3.1 Sedimentation test of mullite and SiC whiskers coexisting in ethanol

The sedimentation measurement reported in the previous paper⁵⁾ was the assessment of dispersibility in the case where SiC whiskers⁵⁾ or mullite⁶⁾ existed individually in solvent. In contrast, the sedimentation phenomenon in this study is measured under the condition that mullite and SiC whiskers exist simultaneously in solvent. The height of an interface between two sediment layers in measuring sedimentation velocity and the height of a sediment layer at the bottom of the messcylinder were measured as a function of settling time.⁵⁾ A low sedimentation velocity and a high density of the sediment layer correspond to good dispersibility.^{7),8)}

Figure 1(a) shows the result of a sedimentation test carried out for mixed particles of 80 vol% mullite and 20 vol% SiC whisker W(A). The layer of mixed powder estimated to contain high concentration of SiC whiskers was sedimented in about 1 min after agitating-standing. Par-

ticles in the remaining solution after the first-time sedimentation were very stable and a second-time sedimentation occurred after about 2000 min. On the other hand, at the bottom of the messcylinder, a thin sediment layer estimated to contain a large fraction of SiC whiskers was formed after about 1000 min after agitating-standing. A homogeneous mixture was accumulated on the layer after about 2000 min, and furthermore a very diluted layer estimated to contain a large fraction of mullite was produced at about 8000 min. Hereafter, the first- and second-time sediment layers are denoted as Height 1 and Height 2 in the figures, respectively.

Figure 1(b) shows the result of a sedimentation test carried out in a solution containing 0.5 mass% dispersant. The phenomenon corresponding to the first-time sedimentation observed in Fig. 1(a) was not observed, and mixed particles existed in a stable floating state in the solution. The first sedimentation occurred after about 1000 min. However, at the bottom of the messcylinder, a sediment layer estimated to contain a large fraction of SiC whiskers was similar to that observed in Fig. 1(a). A homogeneous mixture began to accumulate after about 1000 min and furthermore a very thin layer estimated to contain a large fraction of mullite was sedimented at about 8000 min.

Figure 1(c) shows the result in ethanol to which 1 mass% dispersant was added. The sedimentation situation was almost similar to that observed in Fig. 1(b). However, the thin layer estimated to contain a large fraction of mullite observed in Fig. 1(b) was not observed in Fig. 1(c). Moreover, the sediment layer observed in Fig. 1(c) was denser than that observed in Fig. 1(a). That is, the sedimentation velocity of mixed powders consisting of mullite and W(A) whiskers in ethanol decreased with increasing dispersant content and became slow at dispersant values of 0.5 and 1.0 mass%. Furthermore, the sediment layer at the bottom was dense and homogeneous at 1.0 mass% addition. The improvement in the dispersibility of the mixed powder by the addition of dispersant was similar to that of W(A) whiskers existing individually in ethanol.

Figure 2 shows the result of a sedimentation test for mixed powder consisting of 80 vol% mullite and 20 vol% carbon-coated SiC whisker W(AC). Figure 2(a) shows the result in solvent without dispersant. The sedimentation after the lapse of 1 min, as observed in Fig. 1(a), did not occur. A large percentage of particles existed in a stable floating state up to 1000 min, and rapid sedimentation occurred after 1000 min. In the bottom of the messcylinder, a thin sediment layer estimated to contain a large fraction of whisker was first formed at about 3 min after agitation-standing. A homogeneous mixture was accumulated on the layer at about 1000 min, and furthermore a very thin layer estimated to contain a large fraction of mullite was observed at about 8000 min. That is, the sedimentation velocity of the mixed powder consisting of mullite and W(AC) whiskers in ethanol became slower than that of mullite and W(A) whiskers without the dispersant.

Figure 2(b) shows the result of a sedimentation test in solvent containing 0.5 mass% dispersant. The sedimentation phenomenon observed in Fig. 2(b) is much different from that observed in Fig. 2(a). The phenomenon corresponding to the first-time sedimentation shown in Fig. 1(a) occurred immediately after agitation-standing and was observed as a lower layer at about 3 min. However, a large fraction of the remaining powder was stable in solution until 1000 min, and rapid sedimentation occurred after 1000 min. On the other hand, at the bottom of the messcylinder, a thin sediment layer estimated to contain a large fraction of SiC whisker was first formed after about 100 min. A homogeneous mixture was accumulated on the layer at

Fig. 1. The height of dispersion layer as a function of settling time for mullite and SiC whisker W(A) coexisting in ethanol. The percentage in figures denotes mass% of dispersant. Dispersion layer: ● Height(1), ○ height(2). Sediment layer: △ Whisker, ◆ mixture, □ mullite.

Fig. 2. The height of dispersion layer as a function of settling time for mullite and carbon-coated SiC whisker W(AC) coexisting in ethanol. The percentage in figures denotes mass% of dispersant. Dispersion layer: ● Height (1), ○ height (2). Sediment layer: △ Whisker, ◆ mixture, □ mullite.

about 1000 min, and furthermore a thin layer estimated to contain a large fraction of mullite was observed at about 4000 min. In other words, by comparing Fig. 2(b) with Fig. 2(a), it is concluded that the sedimentation velocity of mixed powder consisting of mullite and W(AC) whiskers increases by addition of 0.5 mass% dispersant.

Figure 2(c) shows the result for a solvent to which 1.0 mass% dispersant was added. The sedimentation of only whisker or mullite was not observed, and mixed particles were stable in solution up to 1000 min, and a first-time sedimentation occurred after 1000 min. In this case, an accumulated layer at the bottom of the measuring cylinder was homogenous and dense. That is, the sedimentation velocity of mixed powder consisting of mullite and W(AC) whisker reduced significantly again by addition of 1.0 mass% dispersant.

Summarizing the results of the sedimentation experiments, the dispersibility of mixed powder consisting of mullite and W(A) whiskers in ethanol was improved by addition of 0.5 mass% dispersant and improved further by addition of 1.0 mass%. On the other hand, the dispersibility of mixed powder consisting of mullite and W(AC) whiskers became better than that of mullite and W(A) whiskers in ethanol without the addition of a dispersant, despite the dispersibility of W(AC) whiskers being worse than that of W(A) whiskers if these whiskers existed individually in the solvent. However, the dispersibility of the mixed powder became poor by addition of 0.5 mass% dispersant and was significantly improved again by addition of 1.0 mass%

dispersant.

3.2 Viscosity of the solvent containing mixed powder of mullite particles and SiC whiskers

It has been already described that dispersibility of mixed powder where mullite particles and SiC whisker exist simultaneously in the solvent was different from that of each particle type existing individually. The dispersibility of particles in slurry can also be assessed by carrying out viscosity measurements. If the viscosity of slurry reduces by the addition of a dispersant, it is concluded that the dispersibility of mixed particle is improved.⁹⁾⁻¹²⁾

Figure 3 shows the relationship between viscosity at a rotation velocity of 12 rpm and dispersant content in slurry containing 10 vol% mixed powder (consisting of 80 vol% mullite and 20 vol% SiC whisker). The viscosity at 12 rpm for mixed powder containing SiC whisker W(A) was 171 mPa·s which suddenly decreased to 47 mPa·s by the addition of 0.5 mass% dispersant. The viscosity decreased to 35 mPa·s by the addition of 1.0 mass%. That is, the viscosity of slurry consisting of mullite and W(A) whiskers remarkably decreased by addition of 0.5 mass% dispersant and monotonously decreased with increasing dispersant content over 0.5 mass%. The viscosity was very low at 1.0 mass% dispersant.

On the other hand, the viscosity of slurry of mixed powder containing W(AC) whiskers was 53 mPa·s in solvent without dispersant which increased to 71 mPa·s by the addition of 0.5 mass% dispersant in contrast to the earlier behavior. However, if dispersant content increased to 1.0 mass%, the viscosity decreased to 23 mPa·s. That is, the viscosity of slurry consisting of mullite and W(AC) whiskers became smaller than that of the slurry consisting of mullite and W(A). However, the viscosity increased by the addition of 0.5 mass% dispersant and monotonously decreased with increasing dispersant content over 0.5 mass%. The viscosity was very low at 1.0 mass% dispersant. In the addition of more than 1.0 mass% dispersant, the viscosity of both W(A) and W(AC) whiskers gradually decreased with increasing dispersant in the same manner.

Summarizing the results of the viscosity measurement, it is estimated that the dispersibility of mixed powder consisting of mullite and W(A) whiskers was improved by addition of 0.5 mass% dispersant and was remarkably improved by addition of 1.0 mass%. On the other hand, the dispersibility of carbon-coated SiC whisker W(AC) was poor if it existed alone but was improved if it coexisted with mullite. Furthermore, the dispersibility of mixed powder consisting of mullite and W(AC) whiskers became better than that of mullite and W(A). However, the dispersibility became poor by addition of 0.5 mass% dispersant and was significantly improved by addition of 1.0 mass% disper-

Fig. 3. Viscosity in slurry containing mixed powder of mullite and SiC whisker W(A) in ethanol.

sant. The relationship between dispersibility and dispersant contents in the viscosity measurement was similar to that in the sedimentation measurement.

3.3 Dispersibility of the SiC whiskers coexisting with the mullite particles

The improvement in dispersibility by the addition of organic dispersant to the mixing solvents is attributed to the electrostatic repulsion and the steric hindrance by adhesion of organic polymer.¹³⁾ The dispersibility of particles in solvent was improved due to the electrostatic repulsion at the zeta-potential of over 20 mV and was remarkably improved over 40 mV.¹³⁾

We have already studied zeta-potentials of mullite and W(A) whiskers in several alcohols, and reported that their particles in ethanol had positive charges of 28 mV and 23 mV, respectively.^{5),6)} That is, the electric charges of mullite and W(A) whiskers have the same sign but the quantity of the electric charge was not large. Therefore, mullite particles and SiC whiskers W(A) are weakly repelled in ethanol. Figure 4(a) shows a schematic diagram for electric charge states of mullite particles and SiC whisker W(A) in ethanol.

On the other hand, W(AC) whiskers in ethanol have a negative charge of -30 mV and the opposite sign (positive) to that of mullite. That is, if the carbon-coated SiC whiskers W(AC) coexisted with mullite particles, the mullite particles were stuck to a circumference of W(AC)

whisker as shown in Fig. 4(b).¹⁴⁾ Consequently, electrostatic repulsion occurs between the mullite-stuck W(AC) whiskers and the mullite particles.

We have already obtained the result that the relationship⁶⁾ between electric charge situations of mullite and dispersant contents is similar to that of W(A) whiskers reported in the previous paper.⁵⁾ Summarizing these results, the electric charges decreased with increasing dispersant content, and attained minimum negative values of -38 mV by addition of 0.01 g/l for mullite and -42 mV by addition of 0.001 g/l for W(A) whisker by way of a zero charge. That is, their particles were remarkably repelled because the quantity of electric charges (-24 to -38 mV for mullite and -38 to -42 mV for W(A) whisker) at dispersant contents from 0.001 to 0.01 g/l showing minimum zeta-potentials was larger. The electric charge state for mullite and W(A) whisker having minus electric charges is shown in Fig. 4(c). On the other hand, mullite has a zero potential at the dispersant contents between 0.0002 and 0.0005 g/l and W(A) whisker between 0.0001 and 0.0002 g/l. In other words, it is estimated that the dispersibility of mixed powder consisting of mullite and W(A) whisker becomes poor in the dispersant content from 0.0001 to 0.0005 g/l because their particles are not repelled so that their electric charges are little.

The electric charges of mullite and W(A) whiskers greatly change from plus to minus by the addition of dispersant, while the dispersibility of the mixed powder estimated from sedimentation experiments and viscosity measurements monotonously increased with increase in dispersant contents. In other words, the dispersibility estimated from the change in the zeta-potential does not correspond to that from sedimentation experiments and viscosity measurements. Therefore, it is estimated that the dispersibility of W(A) whiskers in solvents is significantly affected by an effect other than the electric repulsion force. At present, it is considered that the dispersibility of mixed powder consisting of mullite and W(A) whiskers is attributed to a remarkable effect of the steric hindrance of polymer and a slight effect of the electrostatic repulsion in the same manner as discussed in the previous paper.⁵⁾

As reported in the previous paper,⁵⁾ the quality of negative charge of W(AC) whiskers increased with increasing dispersant content and had a minimum zeta-potential of -69 mV at the addition of 0.001 g/l in ethanol. The effect of dispersant contents on electric charges of W(AC) whiskers was different from that of mullite. In the case that the dispersant was not added, W(AC) whisker in ethanol was stuck with mullite. However, by adding the dispersant content (0.0002 – 0.0005 g/l) corresponding to zero charge for mullite, the mullite particles stuck on the surface of the W(AC) whiskers were detached. The dispersibility becomes poor because the electrostatic repulsion force between the detached mullite and W(AC) whiskers is weaker.

However, by the addition of more dispersant, mullite had a negative charge of -24 mV at dispersant content of 0.001 g/l where W(AC) whisker showed a minimum electric charge (-69 mV), while W(AC) whisker had a large negative charge of -64 mV at dispersant content of 0.01 g/l where mullite showed a minimum electric charge (-38 mV). In other words, mullite and W(AC) whisker were remarkably repelled together because their particles in ethanol-containing dispersant in the range from 0.001 to 0.01 g/l were charged to large minus values (-24 to -38 mV for mullite and -64 to -69 mV for W(AC) whisker). The electric charge state of mullite and W(AC) whisker in the range of dispersant contents showing the large minus values is shown in Fig. 4(c).

In the case that dispersant was not added, the dispersibili-

Fig. 4. Schematic illustration of mullite particle and SiC whisker in ethanol.

ty of mixed powder consisting of mullite and W(AC) whisker in ethanol was improved over that of mullite and W(A), as observed from the results of the sedimentation experiment and the viscosity measurement, despite the dispersibility of W(AC) whisker in ethanol being much worse than that of W(A). These phenomena originate from the difference in mutual interactions between their particles. That is, the mixed powder of mullite and W(A) is slightly charged in 23–28 eV and is weakly repelled, whereas W(AC) whiskers is stuck with mullite, and the mullite-stuck W(AC) whiskers and the mullite particles are mutually repelled.

Mullite particles stuck to W(AC) whisker are detached from the W(AC) whisker by the addition of dispersant such that the electric charge becomes zero. At present, the relationship between the concentration of dispersant in a zeta-potential experiment shown by weight (g) in 1 liter of solvent and the concentration in a sedimentation experiment and viscosity measurement shown by mass% of dispersant to mullite or whisker has not been clarified. Therefore, as a qualitative consideration, it is estimated to originate from the phenomena that mullite was detached from W(AC) whiskers that the dispersibility becomes poor by addition of 0.5 mass% dispersant in a sedimentation experiment and a viscosity measurement. However, by addition of more dispersant, their particles were largely charged to minus values and the dispersibility was improved.

If the electrostatic repulsion is mainly responsible for the dispersibility, the dispersibility of mullite and W(AC) whiskers having a large minus charge is expected to be better than that of mullite and W(A). However, contrary to the expectation, the viscosity of mixed powder consisting of mullite and W(AC) whiskers is almost the same as that of mullite and W(A) whiskers by addition of dispersant over 1.0 mass%.

In summary, it is considered that the improved dispersibility of mixed powder consisting of mullite and W(AC) whiskers by the addition of dispersant is attributed to the main effect of the steric hindrance by adhesion of organic polymer dispersant and an additional effect of the electrostatic repulsion.¹⁴⁾

3.4 Effect of dispersant content in mixing solvent on the strength

Figure 5 shows the effect of the dispersant content in ethanol used in powder-mixing on the strength of mullite composites containing 20 and 30 vol% SiC whisker. Data points and error bars were average strength for 7–8 specimens and standard deviation. The strength of 20 vol% W(A) whisker-containing mullite composite increased by adding the dispersant to the ethanol and achieved the maximum value at the contents from 0.5 to 1.0 mass%. On the other hand, it was observed in the previous section that the dispersibility of the mixed powder consisting of mullite and W(A) whiskers estimated from the sedimentation experiment and the viscosity measurement was improved by adding the dispersant over 0.5 mass%. In other words, it is concluded that the increment of strength is attributed to the improvement in dispersibility.

On the other hand, the strength of W(AC) whisker-containing composites exhibits the maximum value at 1.0 mass% dispersant. The maximum strength observed by the addition of 1.0 mass% dispersant corresponds to significant improvement in the dispersibility by the addition of 1.0 mass% dispersant as observed from the sedimentation experiment and the viscosity measurement.

The strength of the W(A) and the W(AC) whiskers-containing composites reduced, in contrast, by the addition of 1.5 mass% dispersant, although the dispersibility of the mixed powder in ethanol was improved by the addition of

Fig. 5. Strength of 20 and 30 vol% SiC whisker-reinforced mullite composites as a function of dispersant contents in ethanol used as solvent in powder mixing process.

the dispersant over 1.0 mass%. The addition of dispersant raises dispersibility of mixed powder. However, on the other hand, the organic dispersant which did not volatilize in rising temperature up to about 1000°C was decomposed and remained as free carbon in the sintering process under a reducing atmosphere. The increase in such remaining carbon leads to strength depression because the carbon changes to pores or defects in sintering. In other words, it is assumed that the strength deterioration by the addition of 1.5 mass% dispersant relates to increment of the remaining carbon.

The relationship between strengths of 30 vol% SiC whisker-containing mullite composite and dispersant contents showed the highest strength at the addition of 1 mass% dispersant for W(A) and W(AC) whiskers.

Figure 6 shows an effect of dispersant contents in 2-propanol on the strength of the composites. The strength of the mullite composites containing 20 vol% SiC whisker mixed in 2-propanol becomes slightly larger than that in the ethanol in the case that the dispersant is not added. The zeta-potential of the mullite particles have positive charges

Fig. 6. Strength of 20 vol% SiC whisker-reinforced mullite composites as a function of dispersant contents in 2-propanol used as solvent in powder mixing process.

of 28 and 21 mV in the ethanol and the 2-propanol, respectively. On the other hand, zeta-potential of the SiC whisker W(A) has a positive charge of 23 mV in ethanol and a negative charge of -29 mV in the 2-propanol. That is, W(A) whisker in 2-propanol is stuck with the mullite particles and the mullite-stuck SiC whiskers are repelled among themselves. On the other hand, the W(A) whiskers as well as the mullite in the ethanol have positive charges. In other words, the mullite and the W(A) whiskers in the ethanol are weakly repelled by the electrostatic repulsion as has already been described. That is, the strength of the composites prepared by mixing the powder in 2-propanol is larger than that in ethanol because W(A) whisker in 2-propanol is stuck with mullite.

The charge of W(AC) was minus in both ethanol and 2-propanol. However, since the minus charge in 2-propanol was more than that in ethanol, W(AC) whiskers in the 2-propanol was stuck with more mullite than that in the ethanol. In other words, the strength of composites prepared in the 2-propanol became larger than that in ethanol because the stuck mullite was more in the former case.

The relationship between the strength of the mullite composites in 2-propanol and dispersant contents was similar to the relationship in ethanol. However, the maximum strength in 2-propanol was somewhat smaller than that in ethanol. This result may originate from the structure of the dispersant which is optimized for ethanol.

Summarizing results of strength measurements, it is concluded that optimum contents of dispersant added to solvents used in preparing the mixed powders for SiC whisker-reinforced mullite composite are 0.5–1.0 mass% for 20 vol% W(A) whisker and 1.0 mass% for 20 vol% W(AC) whisker, while the optimum content for 30 vol% W(A) and W(AC) whiskers was 1.0 mass%.

Figure 7 shows microstructures of 20 and 30 vol% SiC whisker-reinforced mullite composites. Figures 7(a) and 7(b) show the specimens fabricated under the most suitable dispersion conditions in this study. There were a few pores in these specimens and the relative densities were 99% or more, until the added amount of SiC whisker was 30 vol%. Figures 7(c) and 7(d) show microstructures of the specimens fabricated by mixing in ethanol or 2-propanol without dispersant. There were slightly more number of pores than the specimens fabricated under optimum conditions but relative density was around 99% and a remarkable differential in a microstructure was not observed. Figure 7(e) shows a microstructure of specimen fabricated by 1.5% addition of dispersant to ethanol, and number of pores and the sizes in the specimen increased, and the relative density reduced slightly to 98–99%.

Figure 8 shows the flexural strength of SiC whisker-reinforced mullite composites prepared using the best mixing process as a function of the SiC whisker contents. In this case, the dispersant contents in ethanol as mixing solvent were 0.5 mass% below 20 vol% SiC whisker and 1.0 mass% above 30 vol% SiC whisker. The results obtained by Kumazawa et al.¹⁵⁾ and Claussen and Petzow¹⁶⁾ were also plotted together for comparison. The strength of composites obtained in this study increased with increasing SiC whisker content up to 30 vol% and decreased abruptly at 40 vol%. On the other hand, the strength reported by Kumazawa et al. increased with increasing SiC whisker content up to 10 vol%, but show a constant value in the range from 10 to 30 vol% SiC whisker and decreased abruptly at 40 vol%. The maximum values were 704 MPa at 30 vol% SiC in this study and 590 MPa at 10–30 vol% SiC in the result obtained by Kumazawa et al.¹⁵⁾ It is concluded that the strength of composites obtained in this study became

Fig. 7. Microstructure of SiC whisker-reinforced mullite composites. (a)–(b) correspond to specimens fabricated under best mixing conditions, (c) and (d) correspond to no-addition of dispersant to ethanol (eth.) or 2-propanol (2-pro.), and (e) to 1.5% addition of dispersant to ethanol. The percentage in eth. or 2-pro. denotes mass% of dispersant.

Fig. 8. Strength of whisker-reinforced mullite composites obtained under the best mixing conditions as a function of SiC whisker contents. The results of Claussen and Petzow¹⁶⁾ and Kumazawa et al.¹⁵⁾ are plotted together for comparison.

higher than that reported by Kumazawa et al. in the range of high SiC whisker contents over 10 vol%, in spite of showing lower strength in the range of low SiC whisker contents below 10 vol% because the dispersibility of the composites prepared in this study was improved by the addition of the dispersant.

4. Conclusions

The dispersibility under the conditions that mullite and SiC whisker exist simultaneously was assessed by the

sedimentation test and the viscosity measurement. Furthermore, the influence of dispersant contents in the mixing solvent on the strength of sintered composites was examined. Results obtained are as follows:

(1) The sedimentation velocity of mixed powder consisting of mullite and SiC whisker W(A) decreased with increasing dispersant content.

(2) The sedimentation velocity of mixed powder consisting of mullite and carbon-coated SiC whisker W(AC) was slower than that of mullite and W(A) which exist individually in solvent. However, the sedimentation velocity became somewhat high by the addition of 0.5 mass% dispersant and became slow again by the addition of 1.0 mass% dispersant.

(3) The viscosity of slurry consisting of mullite and W(A) remarkably decreased by the addition of 0.5 mass% dispersant and monotonously decreased with increasing dispersant content over 0.5 mass%. On the other hand, the viscosity of slurry consisting of mullite and W(AC) became lower than that in the slurry consisting of mullite and W(A) but adversely increased by the addition of 0.5 mass% dispersant. The viscosity of the slurry monotonously decreased with increasing dispersant content over 0.5 mass%.

(4) The strength of mullite composites containing 20 vol% SiC whisker was maximum at 0.5–1.0 mass% dispersant in ethanol and 2-propanol for W(A). On the other hand, the strength was maximum at 1.0 mass% dispersant for W(AC).

(5) The strength of mullite composites containing 30 vol% SiC whisker was maximum at 1.0 mass% dispersant in ethanol for both W(A) and W(AC).

(6) Pores in the specimens fabricated under the most suitable dispersion conditions were few, and the dispersibili-

ty of whisker in the matrix was good.

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