The Korean Journal of Ceramics, **2** [4] 226 - 230 (1996)

Tribology of Clay Bonded Silicon Carbide

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(Received July 1, 1996)

A small amount of fine particle graphite was added to α-SiC and β-SiC having certain particle distributions, and they were mixed with clay and frit. After forming, they were sintered at 1400°C for 3 hours. Tribological properties of sintered α-SiC – β-SiC-graphite – clay (frit) system showed that kinetic friction coefficient was 0.108, specific wear rate was 1.3×10^{-5} $mm^3 \cdot kgf^{-1}$, and torque was 0.01 kgf cm at the wrench torque of 100 kgf cm.

Key words : *Tribology, Clay bonded SiC*

I. Introduction

Excellent abrasion resistance of SiC provides wide applications such as mechanical face sealing and bearing.[1-3] It is generally known that SiC had been sintered in controlled atmosphere and vacuum by using pressureless sintering, reaction sintering, hot pressing, and recrystallization method.

However, those processes limit mass production and large size production, as they are dependent upon special equipment and special atmosphere. Moreover, in the case of reaction sintering, unreacted Si may affect friction resistance.[4]

The present paper concerns SiC oxidation prevention in sintering process.[5-8] In this paper the system of clay bonded SiC sintering was carried on. In the system of clay bonded SiC sintering, the clay prevent the oxidation of SiC because melted clay would covered the surface of SiC particles and harzared the diffusion of oxygen.

One more point of clay bonded SiC sintering is to expect the roll of pore in tribological propertis.

It is well known that the controlled pores in a dense body on a sliding motion, acts as refuge of debris and and fluid resservoirs thus help in a maintance of clean on the sliding interface.[5-8]

II. Experimental Procedure

1. Raw materials

α-SiC powders were provided by Showden Co. β-SiC powders (99.8% purity) were provided by Alfa Co. Wamok clay was used for clay, and frit was made in the laboratory. Table 1 shows chemical compositions of clay and frit.

Graphite was obtained by pulverizing ingot (density= 1.72 g/cm^3) less than 45 mesh.

2. Experimental procedure

2.1 Specimen preparation and sintering

Table 2 shows appropriate composition of the mixture of α-SiC, β-SiC, frit, and graphite. PVA was used as binder, and 1200 kg/cm^2 was applied to form a specimen which have 4 cm diameter and 0.6 cm thickness disk type. Sintering was perfromed in a tube furnace at 1400°C for 3 hours. After specimens were loaded, the entrance of tube furnace was sealed. It means that the atsmosphere of the furnace was almost reduction.

2.2 Tribological properties measurement of sintered body

2.2.1 Ball on plate test

In order to measure specific wear rate and kinetic friction coefficient, ball-on-plate wear testing machine (EFM-III-F, Japan) was used. Density of the ball was 3.18 g/cm^3, and the Vicker's hardness was 2,500 kg/mm^2. The ball was made of pressureless sintered SiC. Specimens were disk shaped (thickness=6 mm and diameter=4 cm). An average surface roughness R_a was 0.532 μm and R_{max} was 5.428 μm. Testing was performed under the pressure of 4 kgf in water and sliding velocity was fixed at 500 mm/s, sliding distance 2.4 km. By dividing friction force by applied pressure, kinetic friction coefficient was obtained. After measuring the worn cross section dimensions by surface roughness tester, specific wear rate was calculated as shown in Fig. 1.

2.2.2 Plate on plate test

The sintered body of this experiment was proposed to be used for faucet sealing and sliding materials. So, torque measurement equipment was specially designed for changes of torque dependent upon number of sliding. Sliding motion of specimens is as good as that of a faucet, which is repeatedly doing on-sliding-off-on-sliding-off. The motion requires about 1.5 second per one cycle, and the repeated motion was numbered 200,000 cycle. Wrench torque of specimens was kept 1000 kgf·cm and the inner water pressure was 1 kgf.

Table 1. Chemical Composition of Clay and Frit (unit: wt%)

	Clay	Frit
SiO_2	57.87	61.50
Al_2O_3	27.78	18.68
Fe_2O_3	0.95	–
TiO_2	0.60	–
CaO	0.67	4.94
MgO	0 24	2.0
K_2O	1.96	4.4
Na_2O	0.22	2.8
B_2O_3	–	2.3
ZrO_3	–	3.4
Li	–	1.9
Ig.Loss	9.51	–

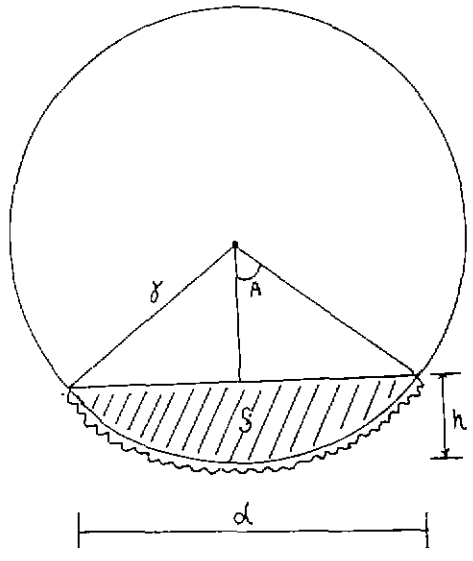


Fig. 1. Schematic illustration for calculation of the cross section area of wear track.

$$r = [(d^2/4) + h^2]/2h \quad (1)$$

$$A = \tan^{-1}[(d/2)/(r-h)] \quad (2)$$

$$S = \pi r^2(2A/360) - d(r-h)/2 \quad (3)$$

$$w = \pi D S \quad (4)$$

$$WS = W/PX \quad (5)$$

※ D=radius of wear track, W=total wear track volume, X=linear speed×friction time, P=pressure. WS=amount of specific wear.

III. Results and Discussion

1. Physical properties of sintered specimens

Figure 2 shows one of the typical results of sintered density variations which have 2 wt% of graphite, upon forming pressure. There are almost no changes of density above 1200 kg/cm^2. The green density is about 2.55 g/cm^2 and the sintered density is 2.64 g/cm^2.

Table 2. Combination of Samples (unit: wt%)

α-SiC			β-SiC	Clay	Frit	Graphite < 45 μm
#120	#220	#320				
27	13.5	4.5	49	5.4	0.6	0

Basic Formulation.

Sample No.	Graphite Contents
No. 1	0.5
No. 2	1.0
No. 3	1.5
No 4	2.0
No. 5	0

Sample No. and Graphite Contents.

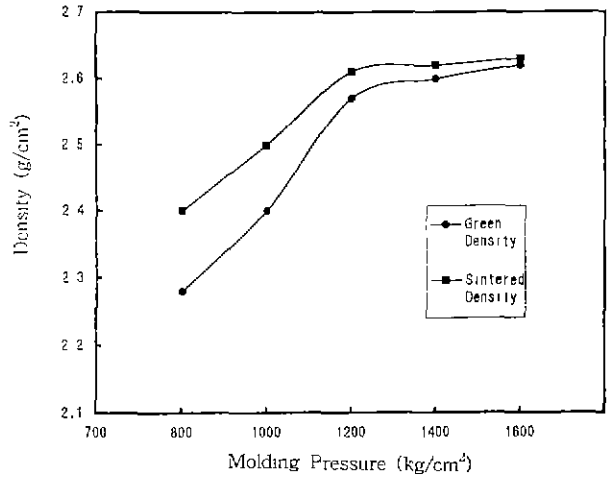


Fig. 2. Density of green and sintered body (graphite content 2 wt%).

Figure 3 shows flexural strength of the specimens varies according to graphite additions. The flexural strength decreases gradually as the graphite content increases. The highest strength is 1080 kg/cm^2 at 0.5 wt% of graphite, which is about $\frac{1}{3}$ of that of pressureless sintered SiC specimens.

Figure 4 shows SEM and EDX analyses of the surface of the sintered body and fractured surface. SEM shows that relatively uniform surface is seen with many micro pores. These micro pores are considered to result from oxidation of part of graphite, besides pre-present pores Because clay and frit melted glass covered SiC particle uniformly, the shape of SiC particles disappeared. From the fractured surfaces, the shape of particles are seen clearly, because glass are not uniformly covered the SiC particles.

The results of EDX show that Si and Al concentrations are distributed uniformly on the surfaces, but they are not on the fractured surfaces. It can be said that the

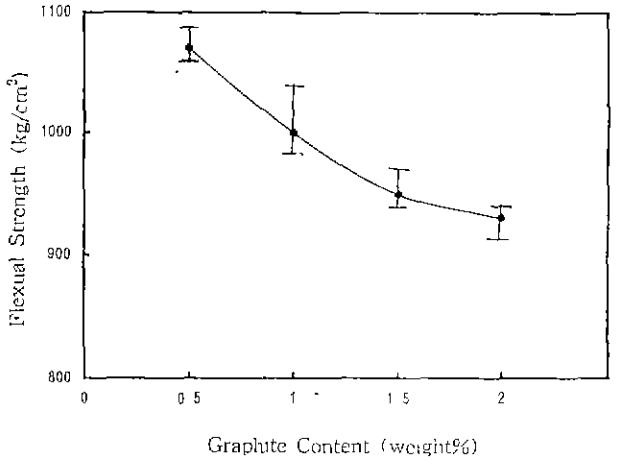
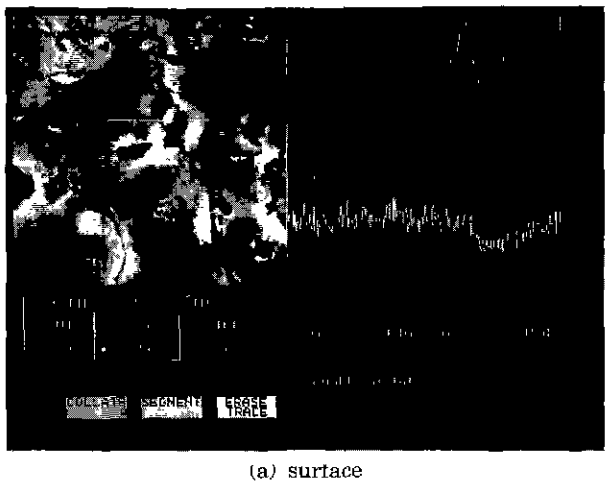
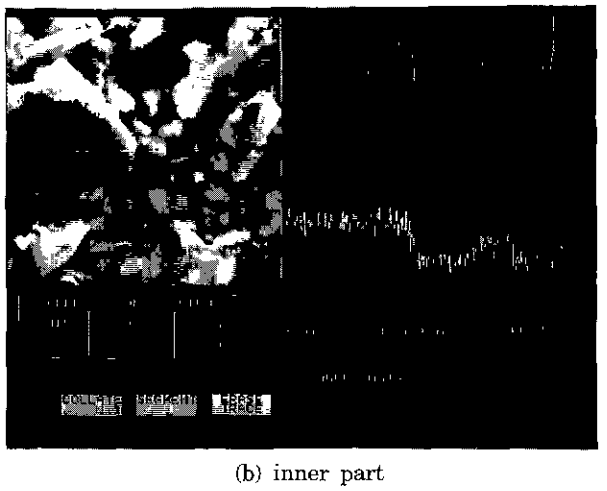


Fig. 3. Flexual strength dependence on the graphite contents.



(a) surface



(b) inner part

Fig. 4. EDX line scanning of sample: (a) surface (b) inner part (1400°C, 3 hr, graphite content 2 wt%).

amounted of melted phase of clay and frit are not same in the surface and inner part of sample. This phenomena may be explained by insufficient melting of clay and frit

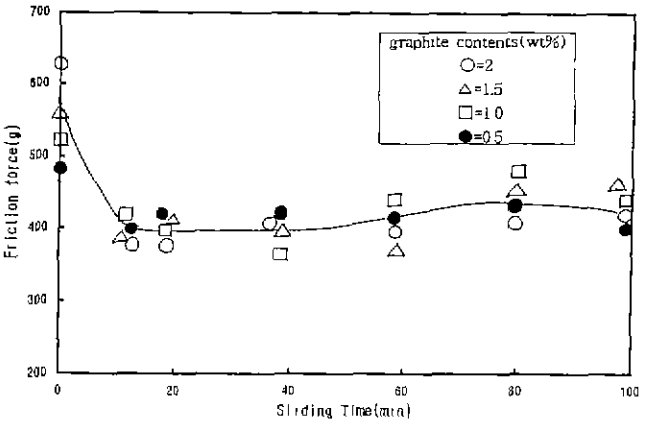


Fig. 5. Friction force with sliding time.

due to the shortage of oxygen supply into the inside of the specimens. However, the surface of the specimen is fully oxidized, which made clay and frit melted properly.

From these results, in clay bonded sic sintering which contains graphic the clay melt only in the atmosphere of high oxigen pontial pressure. The shortage of oxigen induce on poor melt of clay.

On the other hand a part of graphite was changed to CO_2 and the generation of CO_2, drive out the glass phase to the surface of body.

2. Ball on plate test

Figure 5 shows that the variation of friction force depend upon the sliding time, in ball on plate test. It is seen that friction force approaches to a certain value as the sliding time increases.[9] In the early beginning of the test, the friction force is 1 5 times as high as that of the value of after 10 minute. This phenomena was observed for all of the samples, but in case of Al_2O_3, or presureless sintering and reaction sintering SiC, it takes long time for settle down for instance 30~40 minute in a case of Al_2O_3. In this experiment, however, the convergence of the friction force was found around 10 minutes. This result is due to the easier removal of debris having a large amount of pores.[10,11]

Figure 6 shows the depend on specific wear rate the graphite content. When the 0 and 0.5 wt% graphite was added , the specific wear rate was minimized, and it was increased with more additions of graphite. It may be interpreted that the inter-granular strength was decreased as pores were increased owing to higher additions of graphite. Because all of the graphite on the surface of the specimens was almost oxidized, graphite didn't play a role of solid lubricant in this condition.

Figure 7 shows the variations of kinetic friction coefficient dependent upon graphite contents. According to the graphite content, the kinetic friction coefficient was increased, and then after the maxium point, it decrease again. In general, the kinetic friction coefficients ranged under 0.1, showing the good results compared with other materials.

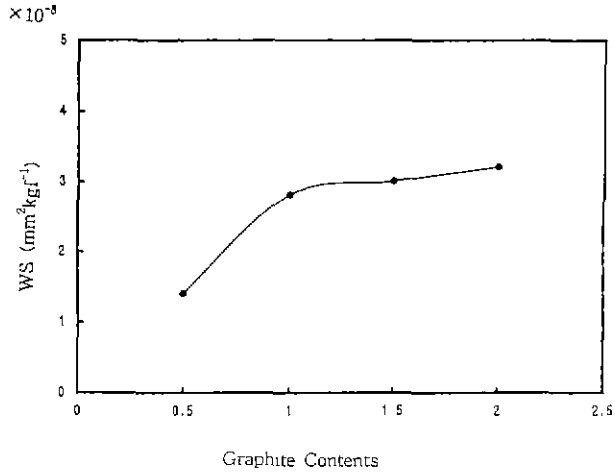


Fig. 6. Specific wear rate with graphite contents.

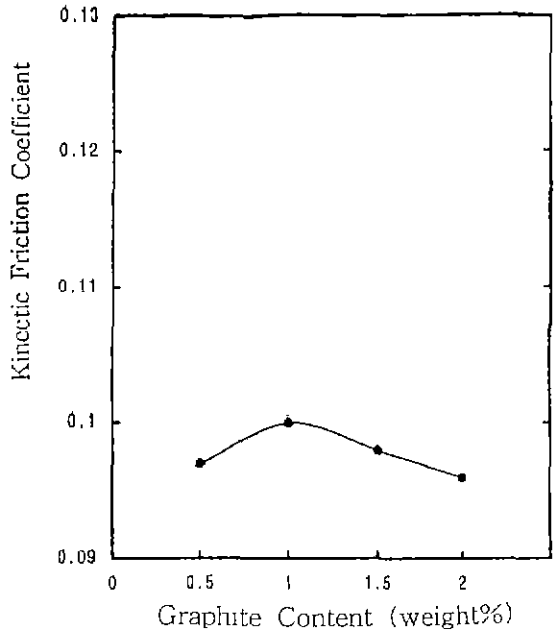


Fig. 7. Static and kinetic friction coefficient with graphite contents.

3. Plate on plate test

Table 3 shows the results of torque test. Nearly no variation of the torque was observed with the graphite contents. This torque value is almost as good as that of reaction sintered α-SiC.

Table 4 is the torque test result of the inside of the sintered body after the specimens were milled by 3 mm. From the comparison between Table 3 and Table 4, it is seen that the torque value is increased 2.5-3.0 times as a whole, and the wear rate is increased as well.

These results suggest that the surface of the sintered specimens was so well covered with clay and frit molten glass to show good sinterbility and tribological characteristics. Inside of the sintered body, however, incomplete melting of clay, due to the shortage of oxygen content.

Table 3. Results of Torque Test, kgfcm (surface of the sintered body)

Number of cycle / Sample	0	50,000	100,000	150,000	200,000	Wear rate (%)
No. 1	1.5	1.4	1.4	1.4	1.4	0.01
No. 2	1.6	1.6	1.5	1.5	1.5	0.02
No. 3	1.4	1.3	1.3	1.3	1.3	0.02
No. 4	1.5	1.5	1.5	1.5	1.5	0.03
No. 5	1.6	1.6	1.7	1.7	1.8	0.02

Table 4. Results of Torque Test, kgfcm (inside of the sintered body)

Number of cycle / Sample	0	50,000	100,000	150,000	200,000	Wear rate (%)
No. 1	3.2	2.9	3.1	3.3	3.3	0.03
No. 2	2.8	3.1	3.4	3.3	3.4	0.08
No. 3	2.7	2.9	3.2	3.2	3.3	0.12
No. 4	3.2	3.1	2.9	3.1	3.2	0.14
No. 5	3.5	3.5	3 5	3.5	3.5	0.05

IV. Conclusions

α-SiC, β-SiC, clay (frit), and graphite composite sintered body was pressed at 1200 kg/cm^2, and sintered at 1400°C for 3 hours. Following results are obtained from the friction and wear tests.

1. Density of the sintered specimen was 2.64 g/cm^2, and flexural strength 1080 kg/cm^2.

2. Specific wear rate was 1.3 mm^2 · kgf^{-1}, and kinetic friction coefficient 0.106.

3. The torque test showed the average torque of the specimen surface was 1.3 kgf · cm, but the average torque of the fractured surface was 3 kgf · cm, which shows wide deviations.

4. Sintered SiC-graphite-clay system in the closed tube furnace suggested that the surface and the inside of the sintered body had different molten state of clay and frit. On the surface, SiC oxidation was prevented by molten clay. However, the inside sintering was incomplete and the sinterbility was poor.

5. The compressive strength of Sintered body of SiC-graphite-clay system is almost ⅓ of the pressureless sintered SiC but the hinetic friction coefficient of it was almost same to the presssureless sintered SiC. From these results may explain that the pores on the surface acts as

to keep a clean interface.

Acknowledgements

The authors are grateful to the support of ministry of education. Research fund for Advanced Material in 1995.

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