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The dependence of the bending strength property of SiC composite ceramics depending on surface grinding conditions

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This study examined the strength of SiC composite ceramics according to the effect of surface roughness. If high strength of SiC composite ceramics are obtainable without a mirror polishing, the machining cost can be decreased. In this regard, non-polished and polished smooth specimens which were polished at several grinding conditions were heat treated at an optimum heating temperature of 1373 K for 1~10 hours, and, the strength was investigated in relation to heat treatment time and surface roughness. The strength of the non-polished smooth specimen increased after heat treatment, but the surface cracks were not healed completely. Besides, the strength reached a saturation point at any heat treatment time. The bending strength depends on the surface roughness. The bending strength using a polishing plate of 125 μm is higher than that of 6 μm at a heat treatment of three hours. This result shows that cracks and defects from machining can be healed by heat treatment within the limits of surface roughness.

Key words: SiC ceramics, Surface roughness, Crack healing, Bending strength.

Introduction

Some structural engineering ceramics can heal their cracks by themselves. This phenomenon occurs by heat treatment at some temperature in air atmosphere, and we usually call this "crack-healing" [1-5]. Many researchers have studied the crack-healing behavior of various type of ceramics, and clarified that Si-oxide, in most cases, is the main crack-healing material produced by an oxidation reaction [6-11]. If it can be applied to ceramics components, many advantages can be anticipated, such as an increase in reliability, and decreases in inspection, machining and polishing costs, etc. This study focuses on the effect of the surface condition on the crack-healing ability of two types of SiC ceramics. At first, the optimum heat treatment temperature for polished specimens was investigated. Then, the bending strength properties and crack-healing behaviors depending on surface condition were examined.

Materials and Test method

Table 1 shows the batch composition of specimens used in this study. Two types of SiC ceramics based on a SiO_2 additive were made to investigate the effect of the SiO_2 addtive on the crack-healing behavior. Materials used in this study are as follows: SiC powder with a mean particle size of 0.27 μm was obtained from the Ibiden Co. Ltd., Japan. The Al_2O_3 powder was AKP-700 (mean particle size = 0.1 μm), purchased from the Sumitomo Chemical Co. Ltd., Japan. The Y_2O_3 powder with a mean particle size of 33 nm, was obtained from the CI Chemical Co. Ltd., Japan. The SiO_2 employed was a nano-colloid (SiO_2 12% solid solution, NGE Tech, Korea), not a powder. This is because SiO_2 nano-colloid is cheaper than SiO_2 nano-powder with the same properties. The SiC ceramics were prepared using a mixture of 85 or 90 wt.% SiC powder and sintering additives ($Al_2O_3 + Y_2O_3 = 10$ or 12 wt.% ($Al_2O_3 : Y_2O_3 = 60 : 40$) and $SiO_2 = 0$ or 3 wt.%). Individual batches were milled in isopropanol for 24 hours using Si_3N_4 balls (φ5 mm). The mixture was placed in a 363 K furnace to extract the solvent and to make a dry powder mixture. The dry powder was then passed through a 106 μm sieve. The mixtures were subsequently hot-pressed in N_2 gas for one hour via hot-pressing conducted under 35 MPa at 2053 K. The sintered plates were cut into test specimens measuring 3 × 4 × 18 mm. A semi-elliptical surface crack was made at the center of the tension surface of the test specimen with a Vickers indenter using a load of 24.5 N. In this method, a crack length of 125 μm was created.

Table 1. Batch composition of specimens

Specimen	SiC	Al_2O_3	Y_2O_3	SiO_2
S-1	90	6	4	0
S-2	85	7.2	4.8	3

Table 2 shows the polishing plate information with varying surface conditions. Surface conditions and crack-healing conditions have a large effect on the fracture behavior.

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Table 2. Information of polishing plates

Specimen	# number	Order of polishing
Non-polished	#60 (260 μm)	Grinding
Polished	#120 (125 μm)	First
Polished	#500 (30 μm)	Second
Polished	#3000 (6 μm)	Third

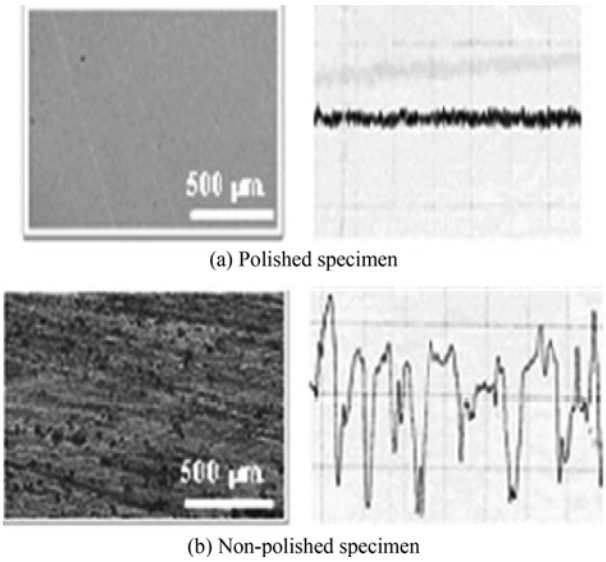

Fig. 1. Appearance of surface conditions Polished specimen Non-polished specimen.

Fig. 1 shows the appearance of polished and non-polished specimen surfaces. The surface roughness (R_{max}) of both the polished and non-polished specimens were 0.07 μm and 14.80 μm, respectively. The specimens were treated by heating in various ranges from 1173 K to 1573 K for 1 to 10 hours. Cooling was spontaneous in the furnace. The heat-treated specimens were subsequently tested in three-point bending at a cross head speed of 0.5 mm/minute, using a fixture with a span of 16 mm. After testing, all specimens were inspected to ensure that failures had initiated from the indentation sites. After the crack-healing process, the specimen surfaces were observed by SEM (Scanning Electron Microscope).

Results and Discussion

Effect of crack-healing temperature on the bending strength (Polished specimen)

Fig. 2 shows the effect of the crack-healing temperature on the bending strength at room temperature. The strengths of smooth specimens were found to be 674 MPa for S-1, and 720 MPa for S-2. In case of specimens using a SiO_2 additive, the strength is higher. On the other hand, the strengths of the cracked specimens with a crack dimension of 2c 125 μm were shown to be less than half of the smooth strength, such as 337 MPa for S-1 and 353 sMPa for specimen S-2. Each material generally has an optimum

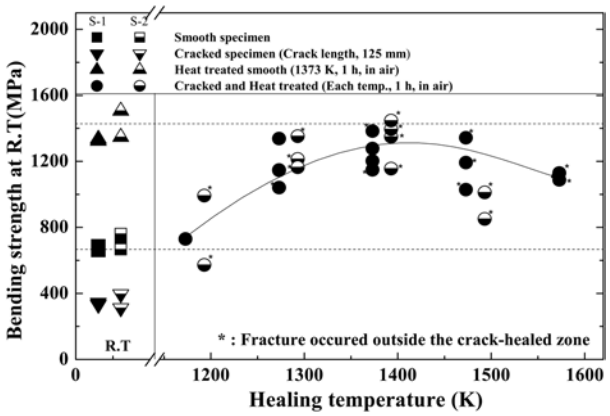

Fig. 2. Effect of healing temperature on the strength of crack-healed specimens.

crack healing temperature at which the maximum strength has been obtained. After healing from 1173 K to 1573 K, not only had the cracked specimens recovered to the strength similar to that of the smooth specimens, but in most cases had actually surpassed it. Based on the room temperature strength and smooth heat treated strength, the optimum healing temperature of cracked specimens was found to be 1373 K for two specimens. The sintering additive for crack healing had nothing to do with the SiO_2 employed. As shown in Fig. 2, the symbol (*) indicates a crack initiated outside of the crack-healed zone. Fractures generally occurred outside of the Vickers indentation area in most crack-healed specimens. These results indicate that the cracks had completely healed.

Effect of surface condition on crack-healing behavior of non-polished specimen

Fig. 3 displays the relation between crack-healing time and bending strength in the case of non-polished specimens (S-2). The strengths of the non-polished smooth specimen, non-polished, and cracked specimens were found to be similar to that of the polished and cracked specimen. Although crack-healing was conducted at the optimum

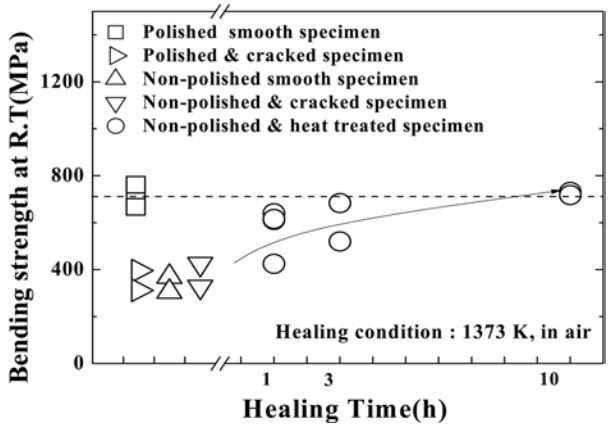

Fig. 3. Relationship between bending strength and healing time of non-polished specimens.

temperature (1373 K), the strengths of the non-polished and specimen healed for one hour were lower than that of the polished smooth specimen. However, as the crack-healing time increased, the strengths of S-1 and S-2 recovered to the level exhibited by the relevant types of polished smooth specimens. These results indicate that the strength can be recovered by healing at the optimum temperature regardless of the surface roughness.

To investigate in detail, surface SEM images of the non-polished specimen before and after crack-healing were made as shown Fig. 4. Fig. 4(a) shows the non-polished surface before crack-healing. Many cracks and flaws were seen due to the grinding. Fig. 4(b) shows the surface after crack-healing at 1373 K for one hour. Compared with Fig. 4(a), the surface flaws have disappeared with heat treatment. However, large flaws still remained on the surface. As the crack-healing time was increased, as shown in Fig. 4(c), the flaws nearly disappeared, but, as shown in Fig. 4(d) of the magnification of part A in Fig. 4(c), the surface was very rough and many oxidation holes were observed. Thus, it resulted in a slow increase in strength. Oxide evaporation and the formation of gases with increased crack-healing time were found to be harmful to the crack-healing ability. The estimated reactions were as follows.

$$SiC(s) + 2SiO_2(s) \rightarrow 3SiO(g) + CO(g),$$
$$SiC(s) + O_2(g) \rightarrow SiO(g) + CO(g) \quad (1)$$

Crack-healing characteristics of polished specimen using the #120 polishing plate

In the case of the non-polished specimens, the flaws and cracks can be healed by increasing the crack-healing time at the optimum temperature of 1373 K. From these results, we carried out a second experiment using a specimen that was polished by a #120 polishing plate used after to grinding. Fig. 5 shows the strength results after crack-healing (S-1).The interesting thing is that the strength of the polished specimen with the #120 polishing plate is higher than that of the smooth polished specimen. This seemed to be an effect of a surface compressive residual stress produced during the polishing. The strength of the specimen that was crack-healed for 1 hour was similar to that of the polished specimen. This indicates that the crack was healed completely. Moreover, the strength with an increase of the healing time was higher by about 250 MPa.

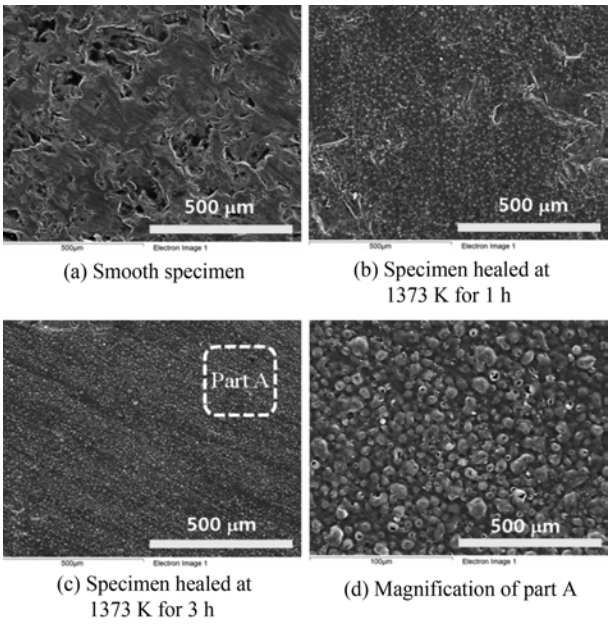

Fig. 4. Surface SEM images of non-polished specimen.

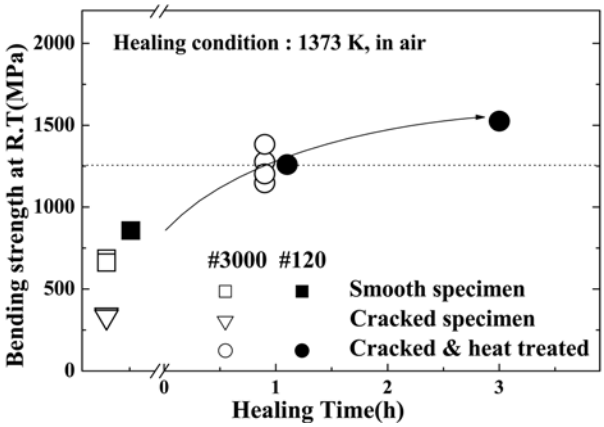

Fig. 5. Relationship between bending strength and healing time of a polished specimen on a #120 polishing plate.

Conclusions

The effect of surface conditions on the crack-healing ability was examined. The main results are as follows. (1) The optimized crack-healing condition was one hour at 1373 K in an air atmosphere. (2) The strength could be recovered by the crack-healing process at the optimum temperature regardless of surface roughness. Such a development would be helpful to significantly reduce the cost of machining and polishing ceramic components. However, oxide evaporation and the formation of gases (i.e. SiO, CO) were found to be harmful to the crack-healing ability. The crack-healing behavior with increased healing time is the subject of a further study.

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