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R&D of joining technology for SiC components with channel

Hun-Chea Jung [a,*], Yi-Hyun Park [b], Joon-Soo Park [b], Tatsuya Hinoki [b], Akira Kohyama [b]

[a] Graduate School of Energy Science, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan
[b] Institute of Advanced Energy, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan

A B S T R A C T

The new joining method of SiC components with channel was developed in this study by using hot-press. The SiC ceramics was joined by using mixed Al_2O_3, Y_2O_3, SiO_2 and SiC powders. Joining was carried out at from 1500 °C to 1900 °C for 1 h, under an applied pressure, range from 5 MPa to 20 MPa. Microstructural characterization was carried out for the joined materials by optical and scanning electron microscopy. The mechanical property of the joint was evaluated through a tensile test. The joint strength was increased with increasing joining temperature and pressure. In joining of complex shape SiC components, the serious deformation of substrate occurred because of high joining temperature and pressure. The low joining condition, In case of 1800 °C and 20 MPa, deformation of substrate not occurred. It is possible that the deformation of substrate was controlled by joining temperature. The joint layer of SiC component by using new joining method was cleaned and uniformed.

1. Introduction

Silicon Carbide fiber reinforced silicon carbide matrix composites (SiC/SiC) have been recognized as high-temperature components as advanced energy system because of its unique combination of properties at high temperature [1–4]. Nevertheless, processing of large and complex shapes of SiC components is a challenge because of machining difficulties. The obvious alternative to this problem is to use some method of joining to build up complex or large shapes form a series of smaller and simply shaped components.

Joining of SiC ceramics has been demonstrated using various techniques including diffusion bonding, brazing bonding with alloy and hot pressing of sinterable SiC powder [5,6]. A method of joining SiC ceramics that satisfies the requirements of mechanical integrity, desirable thermal properties, safety during operation and maintenance or accident is required. Since thermomechanical stresses should be minimized by a material with properties similar to that of the material to be joined, silicon carbide was selected as the joining adhesives [7–9].

We have succeeded in getting strong joining strength of SiC ceramics joints materials at room temperature by using joining adhesives in previous work. The main purpose of this work is to develop joining methods of SiC component with channel by hot pressing of sinterable powder. In the joining method using sinterable powder, directly powder method and two step joining method were applied for SiC component with channel in this study. In case of joining of complex shape component, joining method must be simple and convenient. For this purpose, joint layer of SiC component with channel was investigated by optical method and joining strength of joined material was evaluated in order to identify optimum joining condition, such as joining temperature and pressure.

2. Experimental procedure

The commercial Hexoloy-SA (Saint-Gobain Ceramics, USA) used in this work as substrate material. The Hexoloy-SA was machined into two types of shapes in this study. The one is to test tensile strength of joined material and the other one is to investigate possibility of joining for SiC component with channel. These specimens were in the form of rectangular bars with dimensions 23 × 38 × 3 mm and 19 × 19 × 2 mm, respectively. For fabrication of channel, the hole was machined into 1 × 1 × 19 mm. The fine β-SiC nano-powder which the average particle size is below 30 nm, Al_2O_3, Y_2O_3, and SiO_2 were used as joining adhesives. Fig. 1 shows joining process of joining method, the direct powder method and the two step joining method. The direct powder joining method is joined by one time after machining of substrate. But the two step joining method is joined by twice. First, substrate is coated on the surface of substrate on hold time of zero and then machined to desire shape. Finally, joining between two bodies carried out. The samples for tensile test were joined with pressure (5–20 MPa) and temperature (1700–1900 °C) by hot pressing under argon atmosphere. After joining, specimen of 2.6mm × 3mm × 46mm were machined from the large specimen for tensile test. The cross-section of the joints was characterized by microstructural examination using an optical microscope and scanning electron microscopy (SEM) with energy dispersive spectrometer (EDS).

* Corresponding author. Tel.: +81 774 38 3465; fax: +81 774 38 3467.
E-mail address: hcjung@iae.kyoto-u.ac.jp (H.-C. Jung).

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3. Results and discussion

3.1. Direct powder joining method

The quality of the joints was determined by tensile test, using a crosshead speed of 0.5mm/min. Fig. 2(a) exhibits the joint strength of joining material on the joining temperature. In effect of joining temperature, strength increased with increasing joining temperature. For the joint fabricated at 1600 °C, the average of joining strength was 97 MPa. The failure occurred within the joining layer under this temperature. However, for the joint fabricated at 1800 °C, the average of joining strength was 249 MPa, while the

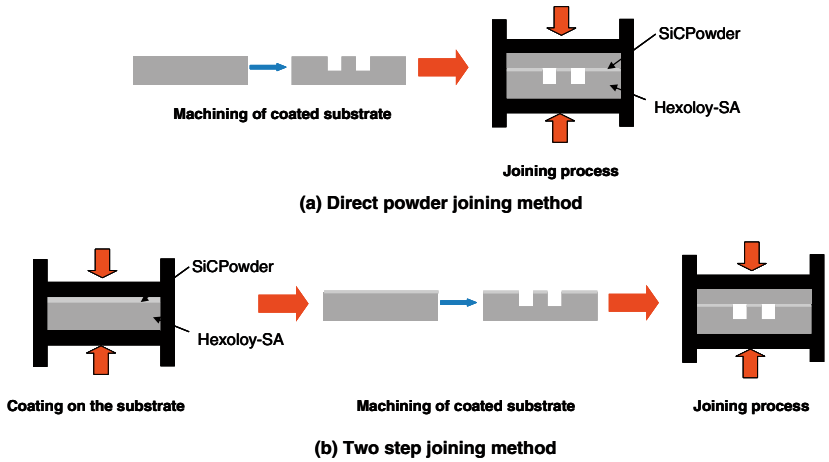

Fig. 1. Joining process of SiC component with channel: (a) the direct powder joining method, and (b) the two step joining method.

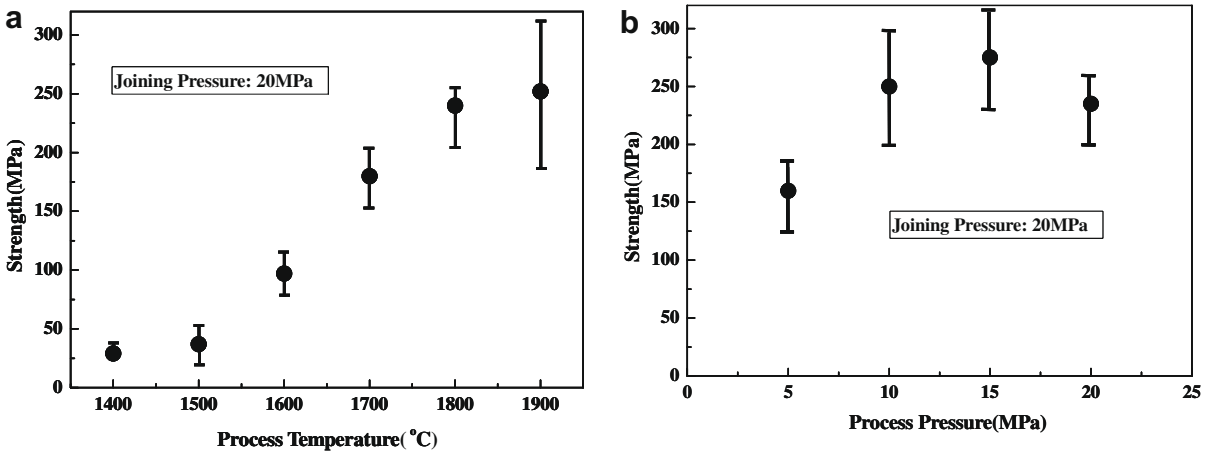

Fig. 2. Joining strength of joined SiC ceramics: (a) on the joining temperature, and (b) on the joining pressure.

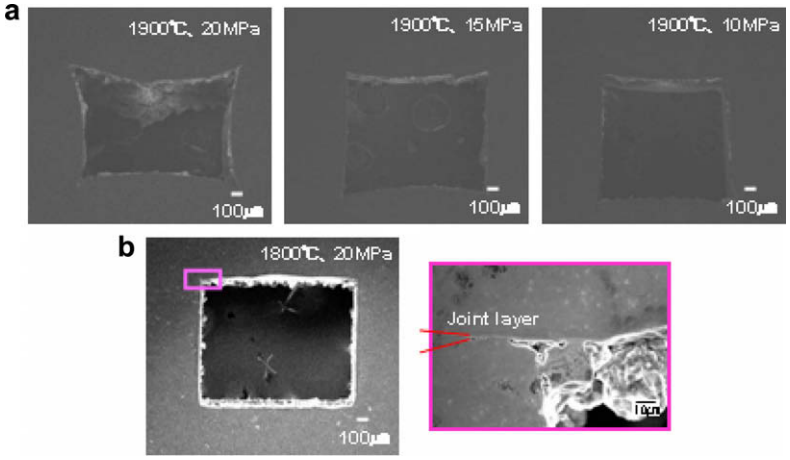

Fig. 3. SEM micrograph of the joined SiC ceramic with channel: (a) effect of joining pressure (1900 °C, 20 MPa, 15 MPa, 10 MPa), and (b) effect of joining temperature (1800 °C, 20 MPa).

failure occurred with in Hexoloy-SA substrate. Fig. 2(b) exhibits joining strength of joining material on the joining pressure. In effect of joining pressure, strength increased with increasing joining pressure. The joining strength at 13 MPa was 300 MPa. The failure occurred within the joining layer. The samples joints fabricated at low temperature and pressure exhibited low strength, which should be mainly caused by the presence of pore in the joining layer.

Fig. 3(a) shows effect of joining material with channel at joining condition, which shows excellent joining strength. Therefore, joining possibility of SiC ceramics with complex shape was investigated by using SEM. In joining of SiC ceramics with complex shape, the serious deformation of substrate occurred for the joint fabricated at 1900 °C and 20 MPa. The deformation of SiC substrate occurred even if joined SiC substrate under low pressure at 1900 °C. In case of 1800 °C and 20 MPa, deformation of substrate not occurred (Fig. 3b). It is possible that the deformation of substrate was controlled by joining temperature. However the uncompleted joining layer was observed at the corner of the hole. Fig. 4 shows the EDS analysis of corner of the hole. A reaction product including Al, Y, O was observed in the protruded powder. It could be associated with the additives powder flow to the hole, which has low pressure.

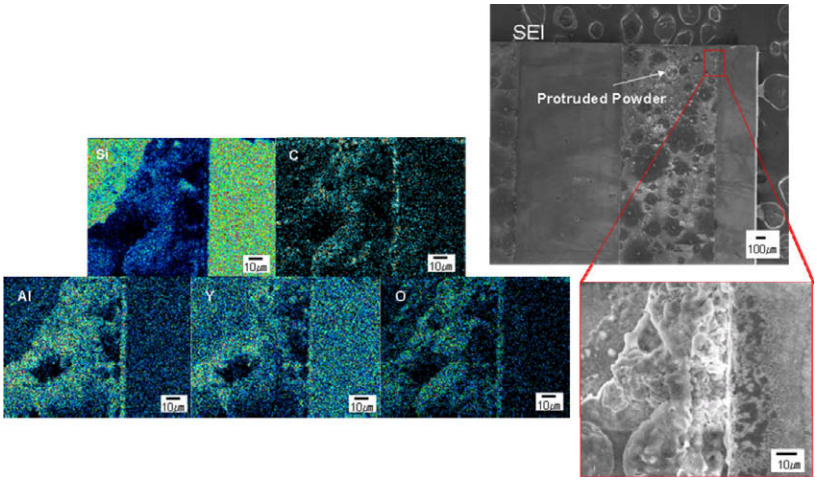

Fig. 4. EDS analisys of the joined SiC ceramic with channel (1800 °C, 20 MPa).

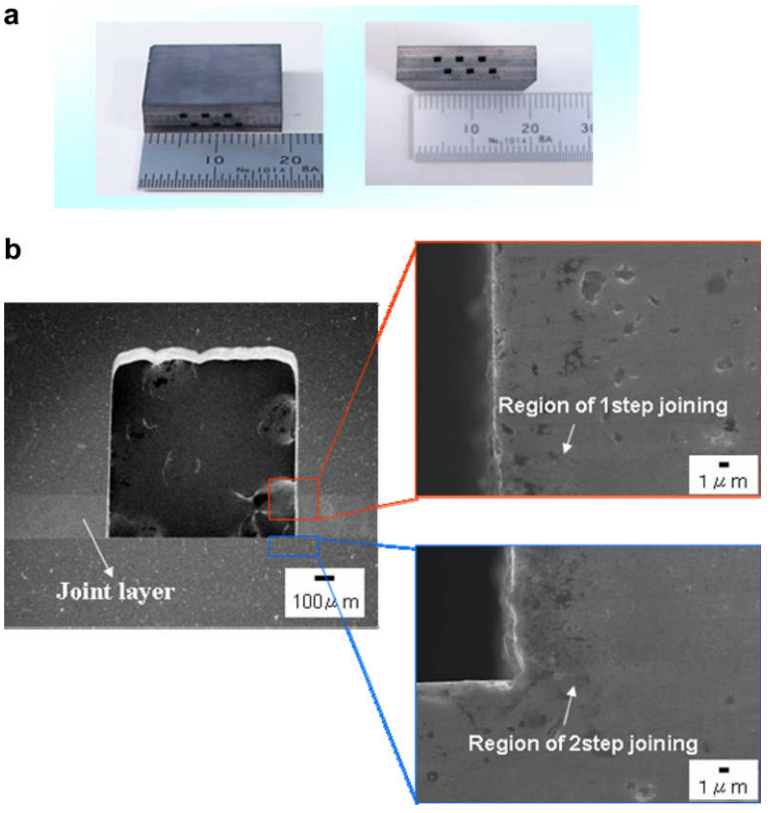

Fig. 5. (a) Joined SiC ceramics with multi-channel, and (b) SEM micrograph of Multi-channel.

3.2. Two step joining method

In this study, the two step joining method used to solve the poor property of direct joining method. The joining temperature and pressure of first step were applied 1800 °C and 20 MPa for 0 h, respectively. Then, the coated SiC ceramics were machined to simple shape for mechanical testing or channel. In second step joining, the joining temperature and pressure were applied 1800 °C, 20 MPa for 1 h, respectively. The properties of joined SiC ceramics were evaluated by using tensile test and SEM. Fig. 5 shows joined SiC ceramics with multi-channel and SEM micrograph of joint layer. The SiC ceramics were successfully joined by two step joining method for multi-channel. The protruded powder or uncompleted joint layer was not observed because the coated joint layer was solid-state after first step.

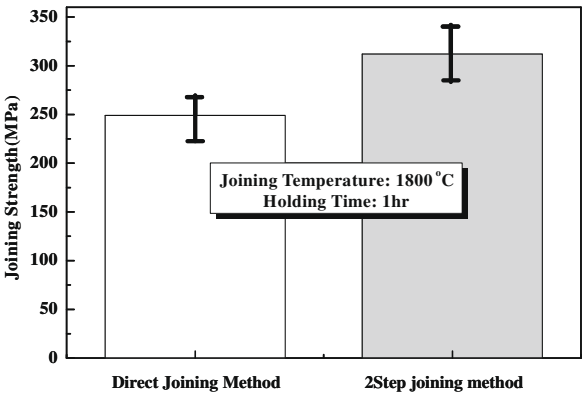

Fig. 6. Comparison between joining strength of direct joining method and two step joining method.

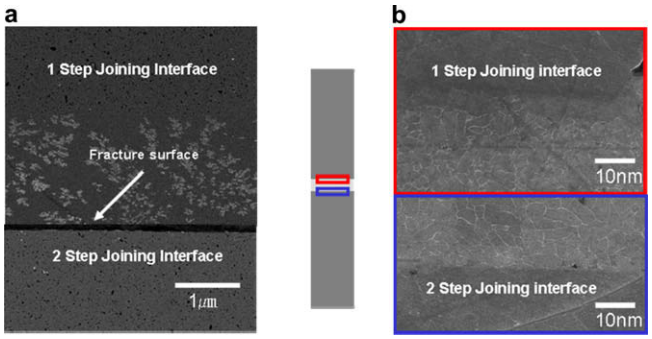

Fig. 7. SEM micrograph of joined SiC ceramics: (a) after fracture, and (b) before fracture.

Fig. 6 shows the comparison between joining strength of direct joining method and two step joining method. The joining strength of two step joining was higher than that of direct joining method. In case of direct joining, specimen was fractured at SiC substrate. The other hand, specimen of two step joining was fractured at interface between joint layer and second step joining interface as shown in Fig. 7(a). The second step joining interface was too weak in comparison with first step joining interface. Fig. 7(b) shows the joint layer by using two step joining method. In the first step joining interface, the SiC substrate was deformed because of SiC particle before first step joining. On the other hand, the second step joining interface, the SiC substrate was not deformed because the joining was accomplished by additives powder as liquid state. Therefore, fracture of specimen occurred between the interfaces of second step joining.

Fig. 8(a) shows the variation of density of SiC ceramics on the different sintering temperature. The density of SiC ceramics was measured by Archimedes method. The density was increased with increasing of sintering temperature. Fig. 8(b) shows effect of first step joining temperature on the joining strength. The joining strength of joined SiC ceramics by using two step joining method was increased with increasing of first step joining temperature. In the high joining strength, the size of grain in the first step was grown; therefore the grain of SiC ceramics in the joining layer causes deformation of SiC substrate caused by high joining strength.

4. Summary

In order to develop joining method of SiC ceramics with complex shape, the direct joining method and two step joining method was conducted. The tensile test was conducted for mechanical properties of joined SiC ceramics. Following results were obtained.

1. In case of direct joining, the deformation of SiC substrates was observed by high temperature and pressure. This deformation was relaxed at 1800 °C. However the uncompleted joining layer was observed at the corner of the hole by liquid additives powder in high joining temperature.
2. It is possible to join the SiC ceramics with multi-channel by two step joining method. And joined SiC components have uniform joint layer.

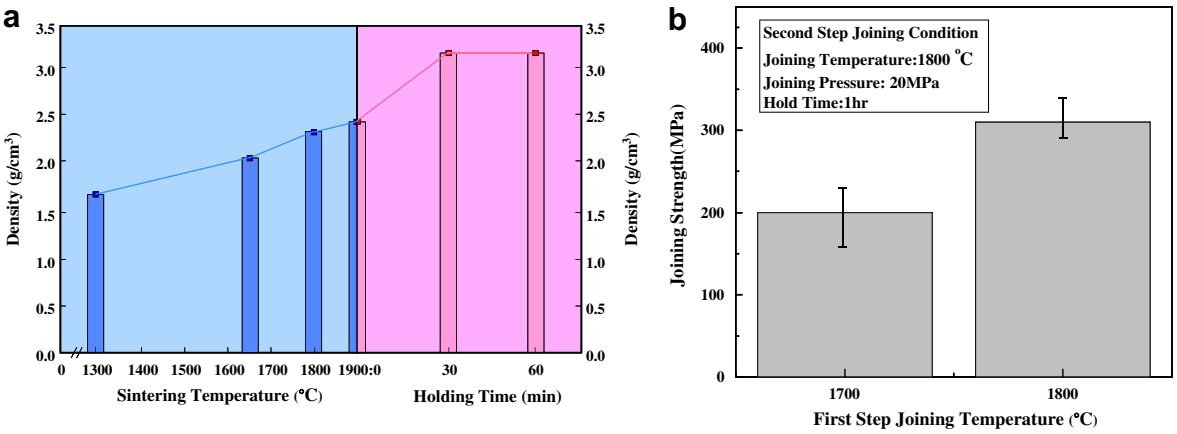

Fig. 8. (a) Variation of density of SiC ceramics on the different sintering temperature, and (b) Joining strength of joined SiC ceramics on first step joining temperature.

3. Fracture of joined specimen at 1800 °C, occurred between the interfaces of two step joining in all specimens. The first step joining interface has higher joining strength than second step joining interface caused by deformation of SiC substrate.
4. The joining strength increased with increasing the first step joining temperature because the deformation of SiC substrate is large in high joining temperature.

References

[1] P. Fenici, A.J. Frias Rebelo, R.H. Jones, A. Kohyama, L.L. Snead, Nucl. Mater. 215 (1998) 258.
[2] A.R. Raffray, R. Jones, G. Aiello, M. Billone, L. Giancarli, H. Golfier, A. Hasegawa, Y. Katoh, A. Kohyama, S. Nishio, B. Riccardi, M.S. Tillack, Fusion Eng. Des. 55 (2001) 55.
[3] A.J. Frias Rebelo, H.W. Scholz, H. Kolbe, G.P. Tartagalia, P. Fenici, J. Nucl. Mater. 258–263 (1998) 1582.
[4] L.L. Snead, Y. Katoh, A. Kohyama, J.L. Bailey, N.L. Vaughn, R.A. Lowden, J. Nucl. Mater. 283–287 (2000) 551.
[5] Parviz Dadras, Gopal M. Mehrotra, J. Am. Ceram. Soc. 76 (5) (1993) 1274.
[6] Manfred Bobeth, David R. Clarke, Wolfgang Pompe, J. Am. Ceram. Soc. 82 (6) (1999) 1537.
[7] T.J. Moore, J. Am. Ceram. Soc. 68 (6) (1985) C-151.
[8] T. Iseki, K. Arakawa, H. Suzuki, J. Mater. Sci. Lett. 15 (1980) 1049.
[9] C.A. Lewinsohn, M. Singh, T. Shibayama, T. Hinoki, M. Ando, Y. Katoh, A. Kohyama, Nucl. Mater. 283–287 (2000) 1258.