

Characterization of CVD SiC joining using thin CrAl interlayer for SiC composites cladding and end cap

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1. Introduction

CVD SiC and SiC composites have been considered for nuclear structural applications owing to their high irradiation resistance, low neutron absorption coefficient, good chemical stability and good stability at high temperatures[1,2]. SiC composites cladding is one of the candidate fuel cladding for Light Water Reactor within the Accident Tolerant Fuel Design concept[3,4]. SiC composite cladding, which exhibits high toughness due to the fiber pull out phenomenon, is in the spotlight as an accident tolerant nuclear fuel with the highest safety due to the excellent properties of SiC itself. There are still some problems that are being studied for the application of SiC composites tube as nuclear fuel cladding. Safety evaluation of joint between SiC composites cladding and end cap is a very important issue. Joining between SiC. Important joining properties for use as fuel cladding include joining strength, gas permeability, and hydrothermal corrosion resistance[5-7]. The joining method using the previously proposed endcap joining technology has sufficient joining strength, but has high external pressure during joining process or show poor resistance to hydrothermal corrosion. In order to achieve high resistance to hydrothermal corrosion of the joint, an interlayer with excellent hydrothermal corrosion or CVD SiC seamless bonding technology is required. We developed a seamless joining technology for the direct bonding of CVD SiC using thin CrAl interlayer[8]. A direct SiC bonding was formed through a process that the CrAl thin coating layer reacted with SiC to bond and diffused into the SiC to disappear.

In this study, the hydrothermal corrosion resistance of the joint was evaluated to assess the stability under normal operating condition. The joining shear strength of the joining specimen before and after hydrothermal corrosion were evaluated using a torsion test. Si coating layer was added to improve the joining shear strength and the microstructure of the joint, and the properties of the joint were evaluated.

2. Experimental and Results

SiC joining technology for SiC composites cladding and end cap was developed using the thin CrAl coating layer which is deposited by sputtering method in previous our research[8]. A CrAl thin coating layer was used an interlayer and removed during the joining process. During the bonding process (high temperature

heat treatment), Cr reacted with SiC to form CrSi_2 and carbon phases. Consequently, CVD SiC formed direct bonding with part of the carbon phases on the joining interface and some CrSi_2 particles around the reaction layer. The joining shear strength of the bonded CVD SiC specimen shows 82.5 MPa.

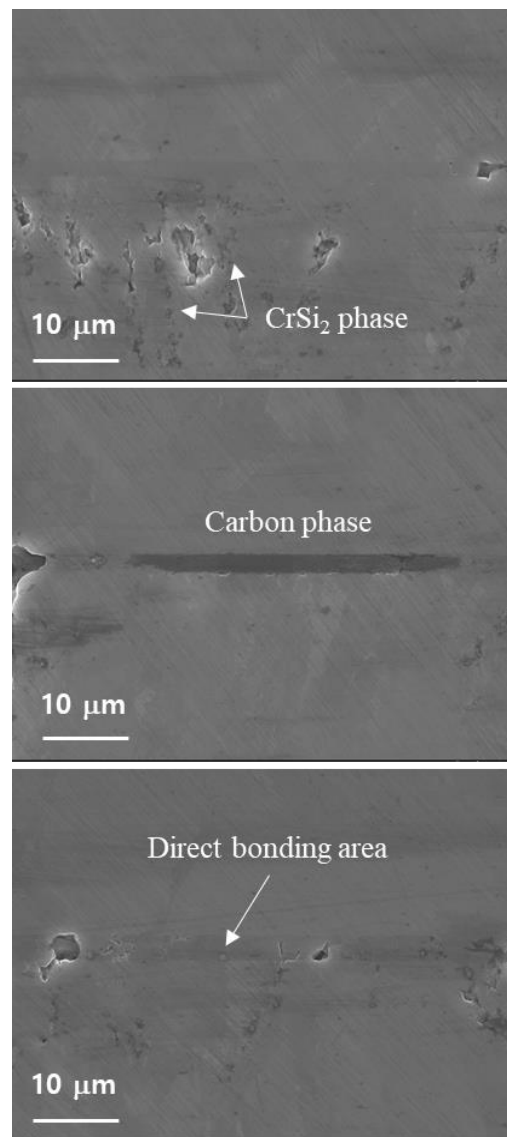


Fig. 1 The SEM microstructure of the SiC joining specimen using CrAl coating layer after hydrothermal corrosion

Hydrothermal corrosion of the joining specimen which was bonded at 1800 °C, 4 hr was carried out in

the condition of 360 °C, 19 MPa for 30 days. The solution for hydrothermal corrosion was maintained at a concentration of 1200 ppm B, 2 ppm Li and ion conductivity of 22.2 μ S/cm. Hydrothermal corrosion was controlled to less than 5 ppb of oxygen concentration and 6.24 pH. Fig. 1 shows SEM microstructure of the joint after hydrothermal corrosion test. CVD SiC substrate showed slight corrosion at the SiC grain boundary after the hydrothermal corrosion, which is consistent with the hydrothermal corrosion result of general CVD SiC. The CrSi₂ phase formed around the joint was separated from the SiC substrate during hydrothermal corrosion and it was observed as defects such as pores. The carbon phase produced due to the reaction of Cr and SiC was hardly corroded as a result of hydrothermal corrosion evaluation for 30 days. The SiC direct bonding area shows similar results to the CVD-SiC substrate. It was observed that the corrosion hardly proceeds in the region where the joint is formed of SiC grain due to the migration of SiC grain boundaries, and a slight corrosion occurs in the joint where the SiC grain boundary is formed. The SiC direct bonding area bonded using Cr-Al thin coating shows excellent hydrothermal corrosion resistance like general CVD SiC.

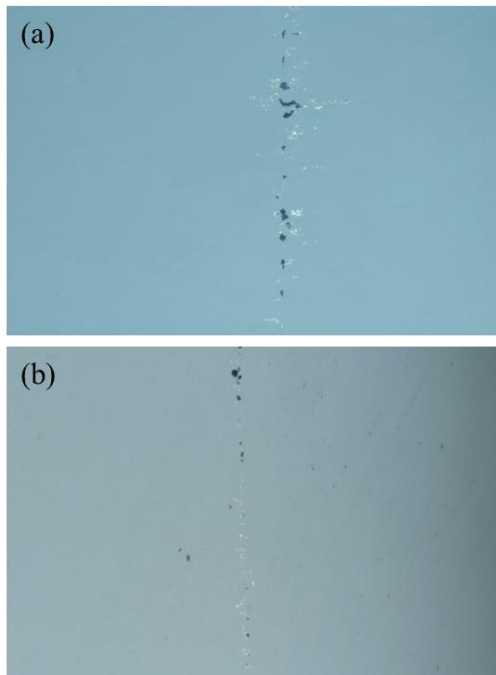


Fig. 2 SEM microstructure of joining specimens with (a) CrAl coating, (b) CrAl coating and Si coating

In order to reduce carbon phases for better joining properties, Si thin coating with 200 nm thickness added to CrAl coating layer by sputtering method. From the thermodynamic simulation of Cr, Al, SiC, C, and Si at a high temperature of 1700 °C, when Si was added, the formation of the CrSi₂ phase increased and the carbon phase which is a product after the reaction decreased.

Fig. 2 shows the microstructure of the joint using CrAl coating layer and CrAl coating with Si coating layer. In the joint of the SiC specimen using CrAl-Si as an interlayer, the SiC directly bonded area increased, and the carbon phase significantly decreased. Although the amount of CrSi₂ phase increased, the microstructure of CrSi₂ phase was uniformly distributed in the joint. The joining shear strength of CVD SiC bonded with CrAl coating and Si coating was measured via the torsion test. The shear strength of the joining specimen with CrAl-Si coating was evaluated at 94.9 ± 11.3 MPa, which was increased compared to the joining specimen bonded with CrAl coating.

3. Conclusions

CVD SiC was joined and characterized using joining technology using CrAl thin coating. The joint having the direct bonding microstructure showed almost the same hydrothermal corrosion resistance as CVD SiC. By adding thin Si coating to CrAl coating, the microstructure of the joint was improved, and the joining shear strength was increased.

REFERENCES

- [1] T. Chen, J. R. Keiser, M. P. Brady, K. A. Terrani, B. A. Pint, et al., Oxidation of fuel cladding candidate materials in steam environments at high temperature and pressure, *Journal of Nuclear Materials* Vol. 427 pp. 396-400, 2012.
- [2] L. L. Snead, T. Nozawa, Y. Katoh, T.-S. Byun, S. Kondo, D. A. Petti, et al., *Handbook of SiC properties for fuel performance modeling*, Vol. 371, pp. 329-377, 2007.
- [3] R. Naslain, Design, preparation and properties of non-oxide CMCs for application in engines and nuclear reactors: An overview, *Composite Science and Technology*, Vol. 64, pp. 155-170, 2004.
- [4] B. Riccardi, L. Giancarli, A. Hasegawa, et al., Issues and advances in SiCf/SiC composites development for fusion reactors, *Journal of Nuclear Materials*, Vol. 56-65, pp. 329-333, 2004.
- [5] Y. Katoh, L.L. Snead, T. Cheng, C. Shih, W.D. Lewis, T. Koyanagi, T. Hinoki, C.H. Henager Jr., M. Ferraris, Radiation-tolerant joining technologies for silicon carbide ceramics and composites. *Journal of Nuclear Materials* Vol. 448(1-3), pp. 497-511, 2014.
- [6] T. Koyanagi, Y. Katoh, J.O. Kiggans, T. Hinoki, H.E. Khalifa, C.P. Deck, C.A. Back, Irradiation resistance of silicon carbide joint at light water reactor-relevant temperature. *Journal of Nuclear Materials* Vol. 488, pp. 150-159, 2017/
- [7] T. Koyanagi, Y. Katoh, K.A. Terrani, Y.J. Kim, J.O. Kiggans, T. Hinoki, Hydrothermal corrosion of silicon carbide joints without radiation. *Journal of Nuclear Materials*, Vol. 481, pp. 226-233, 2016.
- [8] H. -G. Lee, D. Kim, W.-J. Kim, J. Y. Park, Reaction-diffusion bonding of CVD SiC using CrAl thin coating layer, *Journal of the Korean Ceramics Society*, Vol. 59(1), pp. 113-123, 2022.