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Joining between SiC composites cladding and end cap using CrAl interlayer

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1. Introduction

SiC fiber reinforced composites cladding is considered as long term item of accident tolerant fuel cladding for LWR and shows the best accident tolerant performance among the ATF fuel systems under severe accident condition[1,2]. SiC ceramics shows good chemical stability, excellent strength at high temperature and good irradiation tolerance properties but its low fracture toughness has been a great hurdle to the application of structural components for fission system[3,4]. SiC fiber reinforced composites are not easily broken due to the fiber pull out phenomenon. SiC composites claddings are suggested to have various structure with triplex, duplex, and sandwich[5,6]. The research is ongoing to solve some problems of the SiC composites cladding for applying ATF cladding of LWR. There are mainly two problems. The one is hydrothermal corrosion in normal operation condition and the other is joining technology between SiC composites cladding and SiC end cap. Ti, Al element containing brazing materials is usually considered as interlayer for the joining of SiC ceramics[7,8]. For the application of fuel cladding, Joint between SiC composites cladding and SiC end cap have to satisfy the high joining strength and hydrothermal corrosion resistance.

In this study, CrAl thin coating is used as s sacrificial interlayer of SiC composites cladding joining. Cr and Al elements are proven element that improves the hydrothermal corrosion and high temperature steam oxidation resistance in ATF coating studies[9,10]. Joining of CVD (Chemical Vapor Deposition) SiC-CVD-SiC are achieved at high temperature heat treatment with quite high joining strength under 0.1 MPa pressure condition. Joining between SiC composites cladding and SiC end cap was conducted and microstructure of joint were investigated by SEM and TEM analysis.

2. Experimental and Results

SiC joining technology for SiC composites cladding was developed considering the following point. End cap joint have to meet hydrothermal corrosion and gas tightness condition and a joining pressure has to be minimized so as not to damage the thin-walled cladding. Joining with thin sacrificial interlayer is selected to satisfy all conditions. CrAl thin coating was deposited on SiC substrate or SiC end cap using arc ion plating with CrAl target, the ratio of Cr and Al is 8 to 2 which have been already developed for ATF coating. The CrAl coating was developed in KAERI for ATF cladding coating. CrAl coating has superior oxidation and corrosion resistance. The CrAl alloy material shows the melting temperature near 1800 ^{o}C. Cr and Al element can be diffused into SiC substrate after heat treatment at 1700, 1800 ^{o}C[11,12]. CrAl coating layer of 200 nm thickness was used as a sacrificial interlayer of SiC joining.

Fig. 1 shows the SEM microstructure of the joints of CVD SiC plates which are bonded at 1700, 1800 ^{o}C under 0.1MPa. CVD SiC is partially joined without interlayer at 1700 ^{o}C heat treatment condition (Fig.1 (a), (b)). White particles are observed around the joint. From the EDS analysis, the main element of white particles are Cr element. Interfacial layer is assumed as carbon related phase from the EDS results. TEM analysis is needed for more detailed analysis. CVD SiC shows almost seamless joining at 1800 ^{o}C heat treatment condition (Fig. 1 (c), (d)). The microstructure around the joint showed similar results to the microstructure of 1700 ^{o}C joining specimen. Many Cr related white particles are observed around the joint and carbon related phases are exists in the location of the joint.

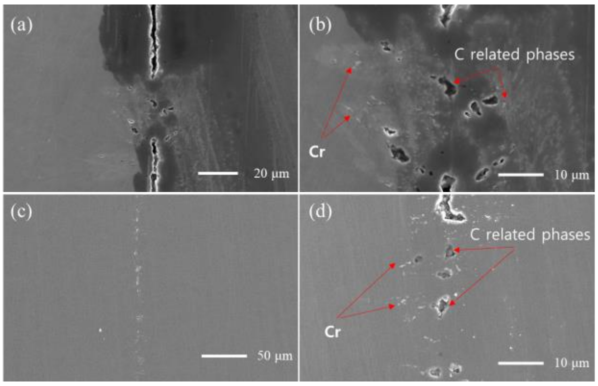
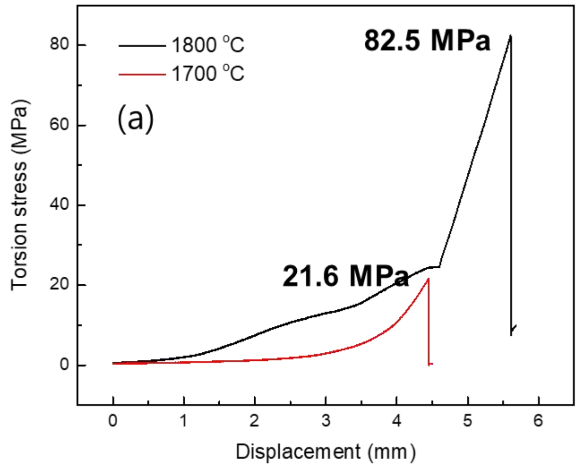


Fig. 1 SEM microstructure the CVD SiC bonded at (a), (b) 1700 ^{o}C, (c), (d) 1800 ^{o}C

Fig. 2 shows the torsion test results of CVD SiC specimens which are bonded at 1700 and 1800 ^{o}C with a CrAl interlayer. The joining stress of CVD SiC shows 21.6 MPa in the specimen bonded at 1700 ^{o}C and 82.5 MPa in the specimen bonded at 1800 ^{o}C. In the graph of the sample bonded at 1800 ^{o}C, the torsion stress increases slowly at the beginning and then rapidly increases after the specimen is fully tightened to the jig due to the problem of specimen fastening. SiC joining specimen bonded at 1700 ^{o}C was divided into two parts at joint surface. In the specimen bonded at 1800 ^{o}C, the fracture started at the joint and the crack propagated in the direction in which the CVD SiC plate was broken. From the results of the fracture behavior and the high torsion stress value, it is confirmed that CVD SiC was strongly bonded using CrAl interlayer at high temperature with almost no external pressure.



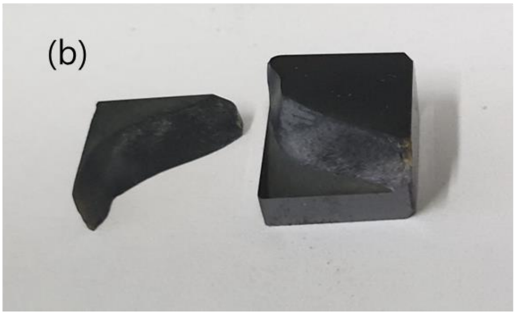


Fig. 2. (a) Torsion test results of CVD SiC joining specimen bonded at 1700 °C, 1800 °C, (b) the image of fractured specimen

SiC composites cladding of duplex structure and SiC end cap were joined with CrAl interlayer at 1800 °C under 0.1 MPa pressure. Duplex SiC composites cladding is composed of outer CVD SiC layer and inner SiC fiber reinforced composites layer. CrAl interlayer was deposited on both SiC composites cladding and SiC end cap with 200 nm thickness. Fig. 3 show the microstructures of the joint between SiC composites cladding and SiC end cap. SiC composites cladding has three kinds of SiC according to the fabrication process: CVD (Chemical Vapor Deposition) SiC, CVI (Chemical Vapor Infiltration) SiC and SiC fiber(sintering process). It is observed that three kinds of SiC are well bonded with SiC end cap using CrAl interlayer. In the SEM microstructure, CrAl interlayer was not observed in whole joint part and it is seen that CrAl interlayer was used as a sacrificial layer. White Cr related particle was not observed and only carbon related phase was observed around the joint. From the microstructure analysis, the joining between SiC composites cladding and SiC end cap was successfully achieved with almost no external pressure. Hydrothermal corrosion test and gas tightness test of the joint will be carried out.

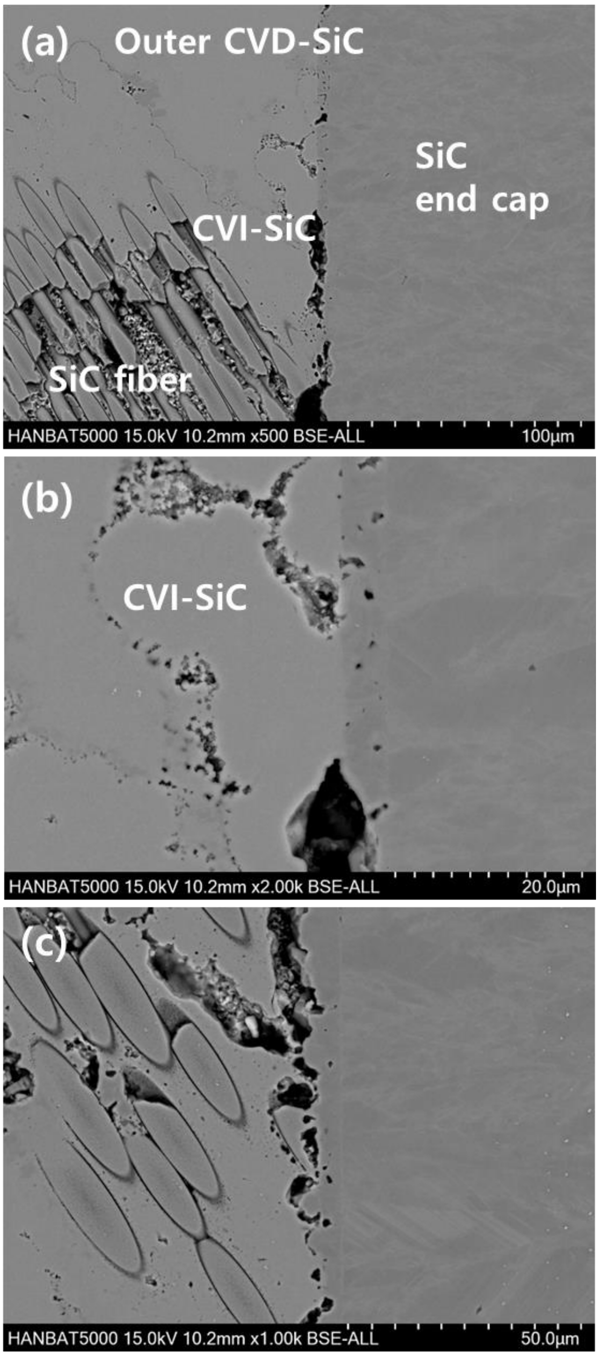


Fig. 3. SEM microstructure images of joint between (a) SiC composites cladding and SiC end cap, (b) CVI SiC and SiC end cap, (c) SiC fiber and SiC end cap.

3. Summary

CrAl thin layer which is deposited using arc ion plating was used as a sacrificial interlayer of SiC joining. CVD SiC was joined using CrAl coating at 1700, 1800

^{o}C under very low pressure. After heat treatment at 1800 ^{o}C, CrAl coating layer was disappeared and nearly seamless joining was achieved. Cr and C related phase was located around the joint of CVD SiC. The joining stress of CrAl coated CVD SiC shows 82.5 MPa. SiC composites cladding was successfully joined with end cap using sacrificial CrAl coating layer. C related phase was observed around the joint of SiC composited cladding and end cap.

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