Electrophoretic Deposition for the Fabrication of High-Performance Metal-Ceramic Hybrid Cladding

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1. Introduction

The development of accident-tolerant fuel cladding has been widely studied since the Fukushima nuclear reactor accident. Ideas and new concepts have been proposed for accident-tolerant fuel cladding to reduce hydrogen emission under an accident. Metal-ceramic hybrid cladding consisting of a Zr liner and SiC_f/SiC composite is one of the candidate systems [1]. To achieve a high-performance metal-ceramic hybrid cladding, it is important to synthesize the SiC_f/SiC composites with high flexural strength. Therefore, a weak interphase layer is required between the fiber and the matrix in SiC/SiC ceramic matrix composites for strong and tough mechanical behavior [2,3]. The most common interphases, such as pyrolytic carbon (PyC) and boron nitride (BN) coating, have been applied on the surface of SiC fibers by chemical vapor deposition (CVD) or chemical vapor infiltration (CVI) [4,5]. In addition, the SiC matrix phase for SiC_f/SiC composites has been commonly formed by CVI and polymer infiltration and pyrolysis (PIP), which are very costly and complicated processes [6-8]. For this reason, the fabrication process of SiC_f/SiC composites that is low-cost and simple has been strongly needed.

In this study, weak phase coating using a commercial colloidal carbon black suspension was performed on SiC fibers through electrophoretic deposition (EPD), and carbon-coated SiC_f/SiC composites were fabricated by EPD. The mechanical properties at room temperature were evaluated to investigate the effect of the carbon interfacial layer on the mechanical properties of carbon-coated SiC_f/SiC composites.

2. Methods and Results

The preform material used in this investigation was two-dimensionally plain-woven Tyranno-Lox M (Ube Industry, Japan). The aqueous solution of carbon black particles for EPD was prepared using a commercial colloidal carbon black solution (Carbon black nanosol, Ditto Technology Co., Ltd, Korea). A small amount of n-butylamine was added to the suspension to adjust the pH of the suspension to 10. The SiC fabric and stainless steel plate were used as the anode and cathode, as shown in Fig 1. The distance between the SiC fabric and the stainless steel electrode was 10 mm. EPD was performed for incorporating carbon black particles on SiC fibers in the fabric under an applied voltage at 3V for 30 and 60 min, as shown in Fig 1. After EPD, the samples were dried at 120°C.

Nano-sized β-SiC powders (<100nm) were dispersed in ethanol. The concentration of SiC in ethanol was 10wt%. The pH was adjusted to 10 with n-butylamine. SiC nanoparticles were infiltrated into the carbon-coated SiC fabric by EPD under an applied voltage of 10V for 1h. Afterward, carbon-coated SiC_f/SiC composites were dried at 80°C, and heat treatment was then performed at 600°C for 1h in an Ar atmosphere.

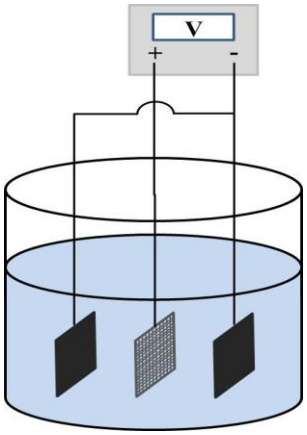

Fig. 1. Schematic representation of electrophoretic deposition apparatus.

2.1 Carbon coating on SiC fiber

In the EPD experiment, carbon black nanoparticles were negatively charged and moved toward the positively charged SiC fabrics in an aqueous suspension at pH 10. Fig. 2 shows SEM images of pristine SiC fibers and carbon-coated SiC fibers by EPD. As can be seen from Fig. 2, the pristine SiC fiber showed a smooth surface and a densified structure [9]. In the case of EPD, the surfaces of SiC fibers were coated with carbon particles. The amount of carbon on the SiC fibers increased with increasing deposition time. Using the EPD method, homogeneous carbon coating on SiC fibers was achieved using a commercial colloidal carbon black suspension.

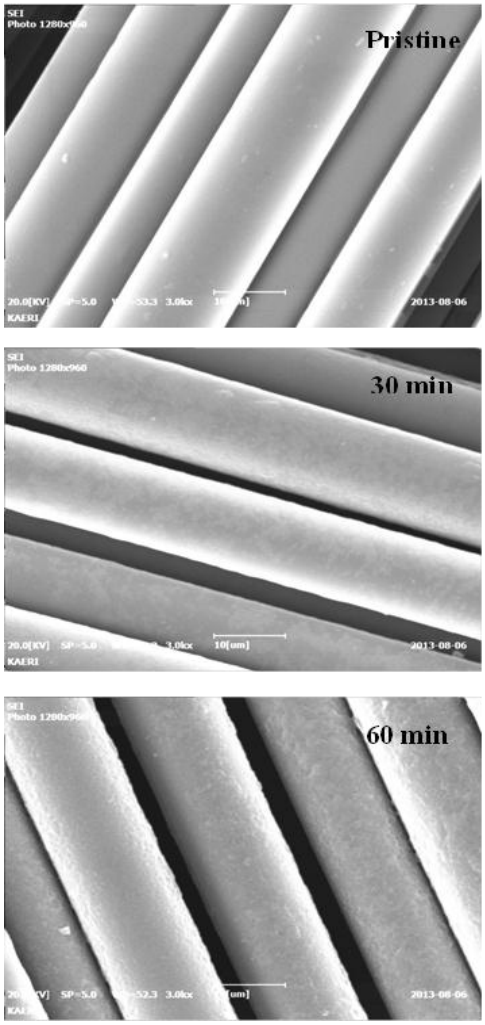

Fig. 2. SEM images of the surface of (a) pristine SiC fiber, and carbon-coated SiC fiber formed by EPD for (b) 30 min and (c) 60 min.

2.2 SiC_f/SiC composites

Fig. 3 shows the surfaces of SiC fabric infiltration by EPD. As shown in Fig. 3, SiC nanoparticles have effectively filled the narrow gaps between individual SiC fibers.

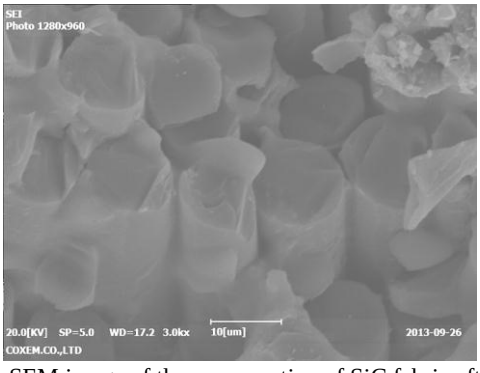

Fig. 3. SEM image of the cross-section of SiC fabric after infiltration by EPD

2.3 Mechanical properties of SiC_f/SiC composites

Fig. 4 indicates the load-displacement curve of the carbon-coated SiC_f/SiC composite, which was coated with carbon on fibers by EPD for 60 min as obtained in the three-point bending test. The shape of the curves suggests that the carbon-coated SiC_f/SiC composites exhibit pseudo-plastic deformation and damage-tolerant behavior.

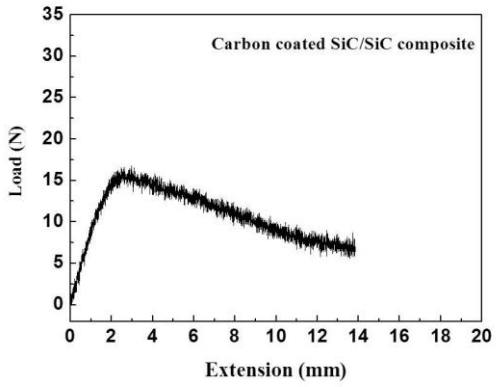

Fig. 4. Load-displacement curve of carbon coated SiC_f/SiC composite. Carbon-coated SiC fibers by EPD for 60min were used.

3. Conclusions

In this study, it was concluded that the EPD method is effective for homogeneous carbon black coating on SiC fibers, and that the carbon coating layer on SiC fibers plays an important role in optimizing the interface between fibers and the matrix, and enhances the toughness of carbon-coated SiC_f/SiC composites during fracture.

ACKNOWLEGEMENT

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