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Mechanical Properties and Thermal Shock Behaviors of Triplex SiC Composite Tube

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1. Introduction

The triplex SiC composite consisting of a SiC inner layer, a SiC_f/SiC intermediate layer, and a SiC outer layer are under investigation for the fuel cladding in the light water nuclear reactors because of its excellent high temperature strength and corrosion resistance against hot steam under the severe accident conditions. [1-3]. In this study, hoop strength and thermal shock behaviors of the triplex SiC tube were investigated.

2. Experimental Procedure

The triplex SiC tubes were reinforced by nuclear grade SiC fibers such as Tyranno SA3 and Cef-NITE with pre-coated PyC. SiC and PyC phases were deposited by the chemical vapor processes. The tubular specimens with the three constituent layers have a dimension of a length of 10 mm, an inner diameter of 8.5 mm, and an outer diameter of 9.8 – 10.1 mm. Hoop strength was measured via internal pressurization at room temperature. Axial pressure was applied with loading rate of 0.01 mm/s to the cylindrical polyurethane plug. Tubular specimens were quenched from 1200°C to room temperature water. Three kinds of triplex tubes were selected to investigate the influence of PyC interphase between fiber/matrix phases, and inner SiC/intermediate SiC_f/SiC composite layers, as listed in Table I.

3. Results and Discussion

3.1 Weibull statistics of hoop strength of triplex tubes

Fig. 1(a) shows load-axial displacement curves of triplex SiC tubes (Tyranno with PyC). The ultimate hoop strength for 20 samples was within the 235.0 – 337.8 MPa. The SiC triplex tubes had a quite high average strength, 282.4 MPa, with a relatively small standard deviation, 44.3 MPa. Most of the triplex tube samples experienced load drop phenomena which was associated with a fracture of a SiC inner layer prior to failure [4]. It could be caused by a large expansion of the quasi-ductile composite layer after the failure of the inner SiC layer. Fig. 1(b) shows Weibull distribution of the hoop strength of the triplex tubes. Weibull modulus of the ultimate hoop strength of the SiC triplex tubes was quite high to be 11.05. Hoop strength at the first load drop was in the wide range of 155.3 –309.5 MPa. The average hoop strength was 226.95 MPa. Weibull modulus for hoop strength at the first load drop was calculated to be 5.30.

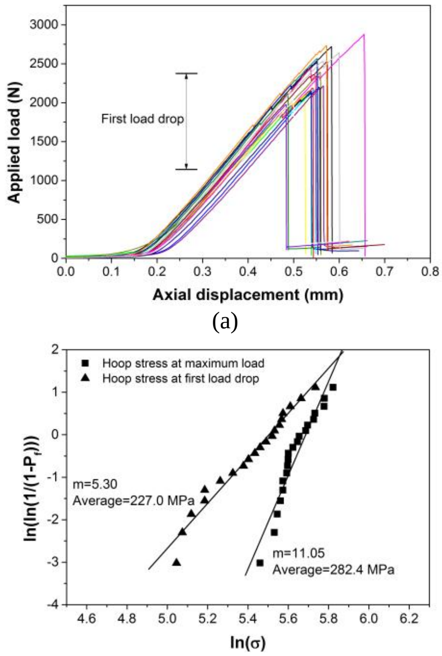


Fig. 1. (a) Load-axial displacement curves of the triplex SiC composite tube showing a load drop phenomenon and (b) Weibull distribution of hoop strength at initial load drop.

3.2 Effect of fiber volume fraction

Assuming the uniaxial tensile stress is applied to the circumferential direction of the SiC triplex tube during

Table I. Properties of triplex SiC composite tubes

Sample Designation	Inner SiC	PyC layer	Intermediate SiC_f/SiC Composite			Outer SiC	Layer thickness (inner:intermediate:outer)
			Reinforcement SiC Fiber(Dia.)	PyC inter-phase	Infiltration of SiC matrix		
Tyranno without PyC	CVD β-SiC	X	Tyranno SA3(7.5μm)	X	CVI β-SiC	CVD β-SiC	300:280:90
Tyranno with PyC	CVD β-SiC	O	Tyranno SA3(7.5μm)	O	CVI β-SiC	CVD β-SiC	300:280:90
Cef-NITE with PyC	CVD β-SiC	X	Cef-NITE(10μm)	O	CVI β-SiC	CVD β-SiC	300:260:110

the expanding plug test, the hoop strength of the SiC triplex tube with the fixed winding angle increased with the aligned fiber volume fraction, as shown in Fig. 2. The highest fiber volume fraction was obtained when the composite layer was wound by Tyranno SA3-0.8k fiber which resulted in the highest hoop strength. In the case of the Hi-Nicalon Type S-reinforced triplex tubes, the fiber volume fraction is less than Tyranno SA3 that has the same winding architecture because a diameter of Hi-Nicalon type S is higher than Tyranno SA3 and thus Hi-Nicalon Type S is less flexible.

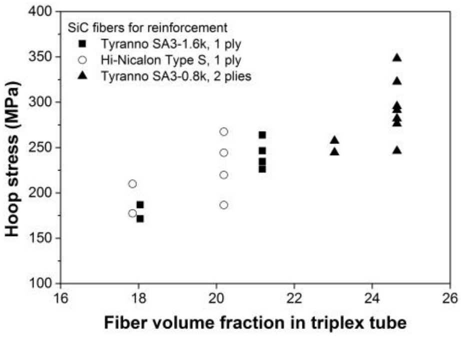
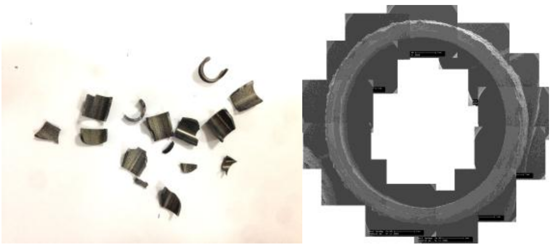


Fig. 2. Ultimate hoop strength of the triplex SiC composite tubes as a function of the fiber volume fraction.

3.3 Thermal shock properties of SiC ceramics

Monolith CVD SiC samples were shattered after water quenching from 1200°C to room temperature as shown in Fig. 3(a). On the other hand, the triplex SiC composite tubes retained their tubular geometry after quenching (Fig. 3(b)). Thermal shock led to the failure of the monolith SiC layers such as inner and outer layers but the composite layer was not damages because the PyC interphase played a role as obstacles to crack propagation.



(a) (b)

Fig. 3. (a) Monolith CVD SiC and (b) the triplex SiC composite tube (Tyranno with PyC) after thermal shock.

After thermal shock, the hoop strength of triplex SiC composite tubes with PyC interphase slightly decreased and on the other hand, by 36% for the tubes without PyC interphase, as shown in Fig. 4. Hoop strength of the Tyranno SA with PyC was much higher than Cef-NITE with PyC. It was revealed that surface roughness of Cef-NITE fiber was quite higher than Tyranno SA3 which might result in the decrease in hoop strength.

3. Summary

The Tyranno SA3-0.8k reinforced SiC triplex tube exhibited the highest hoop strength because the highest fiber volume fraction was achieved by a filament winding method. Weibull modulus was 11.05. However a SiC inner layer was under maximum tensile stress and failed at the lower stress with the wide distribution. Monolith SiC tubes were shattered but the triplex SiC composite tube retained their tubular geometry during quenching from 1200°C to RT. After thermal shock, the hoop strength of triplex SiC composite tubes with PyC interphase slightly decreased. Surface roughness of Cef-NITE fiber was quite higher than Tyranno SA3 which might result in the decrease in hoop strength.

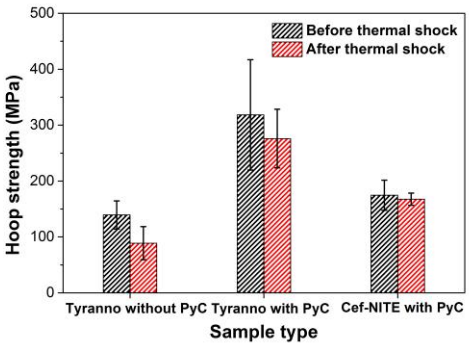


Fig. 4. Change in the ultimate hoop strength of the triplex SiC composite tube.

Acknowledgement

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