Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Crack Propagation Behaviors of Multi-Layered SiC Composite Tubes

Daejong Kim*, Donghee Lee, Hyeon-Geun Lee, Ji Yeon Park, and Weon-Ju Kim
Nuclear Materials Development Division, KAERI, 989-111Daedeok-daero, Yuseong-gu, Daejeon 305-353
**Corresponding author: dkim@kaeri.re.kr*

1. Introduction

The multi-layered SiC composite is one of the accident-tolerance fuel (ATF) cladding concepts. Its general philosophy is to use monolith SiC to provide hermeticity and corrosion resistance, and the composite to provide structural integrity. SiC composite cladding has various advantages compared to current Zr alloy cladding in terms of accident resistance and neutron economy. However, its brittle properties and corresponding low reliability make it difficult for a use of SiC ceramics as cladding materials [1-3]. In this study, fracture behaviors of several SiC composite cladding tubes, particularly crack propagation behavior were evaluated using an acoustic emission method.

2. Experimental Procedure

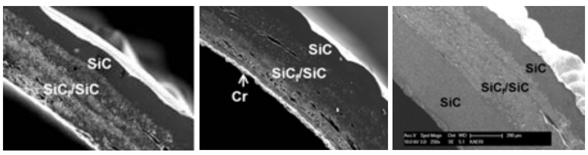
SiC and SiC_f/SiC were chemically vapor-deposited or -infiltrated using methyltricholorosilane (MTS, CH_3SiCl_3). Inner Cr was deposited by arc ion plating. The SiC_f/SiC composite was reinforced by commercial generation III SiC fibers, Tyranno SA3. Fibers were filament-wound onto the Cr liner or the inner monolith SiC with $\pm 55^o$ of the winding angle. Finally graphite substrate was removed by oxidation at 950°C for 5 h.

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 9.2 – 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. R-case AE sensor with 200 kHz was directly attached on the surface of the tubular specimens. The threshold was 40 dB of amplitude.

3. Results and Discusion

3.1 Microstructure of multi-layered SiC composite tubes

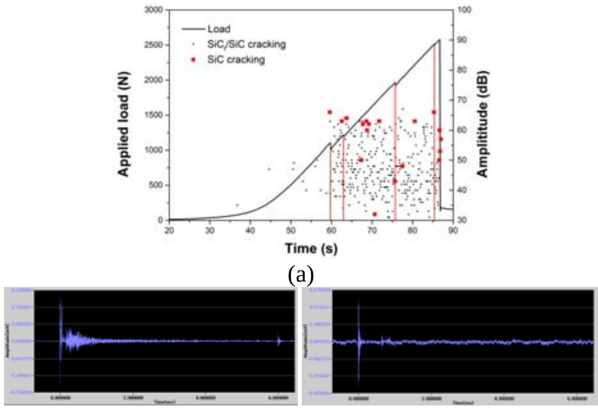
Fig. 1 shows microstructure of the duplex SiC composite tube, the duplex SiC composite tube with Cr liner, and the triplex SiC composite tube. High density SiC matrix was obtained by optimizing CVI parameters. Thickness of a Cr liner was about 25 μm.



(a) (b) (c)
Fig. 1. Typical microstructure showing (a) the duplex SiC composite tube, (b) the duplex SiC composite tube with Cr liner, and (c) triplex SiC composite tube.

3.2 Fracture of triplex SiC composite tube

Fig. 2 shows the load vs. elapsed time curve and AE signals for the triplex SiC composite tube during hoop testing. Several load drops were observed before failure of the tube. During hoop test, two kinds of burst AE signals were detected. AE signals with longer duration were always observed at the load drop. This represents the load drop is caused by the formation of the large axial crack of monolith SiC layers. Majority of AE signals exhibit short duration which is related with the damage of the SiC_f/SiC composite such as breakage of SiC fiber bundle, matrix cracking.



(a)
(b) (c)
Fig. 2. Load vs. elapsed time curve (a) and AE signals of the triplex SiC composite tube (b-c).

AE signals was classified into two based on the waveforms as shown in Fig. 3. Damage of the SiCf/SiC initiated at the fracture of inner monolith SiC.

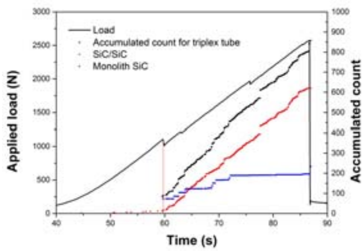
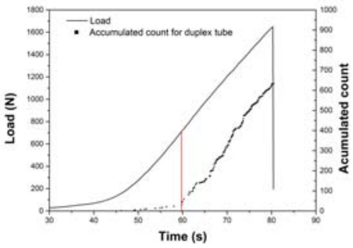


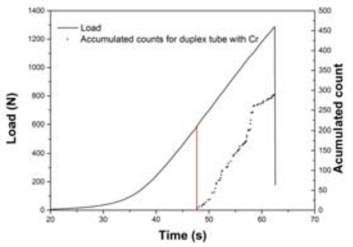
Fig. 3. Accumulated AE counts related with cracking in SiC_f/SiC and monolith SiC of the triplex SiC composite tubes.

3.3 Fracture of duplex SiC composite tube

Fig. 4 shows the load vs. elapsed time curves, and corresponding accumulated AE counts for the duplex SiC composite tubes. Load drop phenomena were only observed at the maximum load because of an absence in inner monolith SiC. Crack initiation of the SiC_f/SiC composite can be easily determined using AE analysis, well-known as proportional limit stress (PLS). The PLS of the duplex SiC composite tube was measured to be about 130 MPa. Any AE signal for the Cr liner, usually continuous AE signal with long duration was not detected in this study. This is believed that Cr liner was severely oxidized during the high temperature process for graphite removal.



(a)



(b)

Fig. 4. Load vs. elapsed time curves, and corresponding accumulated AE counts for the duplex SiC composite tubes: (a) without Cr liner and (b) with Cr liner

3. Conclusions

AE analysis is a useful tool for examination of the multi-layered SiC composite with complex structure which provides information of crack propagation. Failure of an inner monolith SiC in the triplex SiC composite tube will cause significant problems such as hermeticity, degradation of SiC_f/SiC. Duplex SiC composite might be the alternative. Metal liner has advantages in terms of hermeticity, reliability, and protection of SiC_f/SiC composite. However, the fabrication method should be optimized.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2015M2A8A4001841).

REFERENCES

[1] D. Kim, H.-G. Lee, J.Y. Park, W.-J. Kim, Fabrication and Measurement of Hoop Strength of SiC Triplex Tube for Nuclear Fuel Cladding Applications, Journal of Nuclear Materials Vol.458, p.29, 2015.

[2] Y. Katoh, K.A. Terrani, and L.L. Snead, Systematic Technology Evaluation Program for SiC/SiC Composite-based Accident-Tolerant LWR Fuel Cladding and Core Structures, ORNL Report, ORNL/TM-2014/102, 2014.

[3] Y. Lee, M.S. Kazimi, A Structural Model for Multi-Layered Ceramic Cylinders and Its Application to Silicon Carbide Cladding of Light Water Reactor Fuel, Journal of Nuclear Materials Vol. 458, p.87, 2015.