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Hoop strength evaluation of triplex SiC composite tube using by oil compression pressures

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1. Introduction

SiC composites tubes are one of the candidate fuel cladding for LWR (Light Water Reactor) within the ATF (Accident Tolerant Fuel) design concept owing to the excellent high temperature mechanical properties and low hydrogen generation under severe accident condition[1-2]. The accident tolerance enhanced nuclear fuel system is needed to satisfy two parts. First, the performance and stability has to be equal or greater than the existing UO_2 nuclear fuel and zircaloy cladding system under the normal operation condition. Second, under the severe accident condition, the high temperature structural integrity has to be kept and the generation rate of hydrogen has to be reduced largely. The stability test of SiC composite cladding under a normal operation and severe accident condition is required to apply the SiC composites cladding to an accident tolerance fuel cladding. To be applied as an ATF fuel cladding, the mechanical strength and gas tightness must be maintained without damaging the internal pressure generated by the fission product[3,4]. The internal pressure by the fission product causes a circumferential hoop stress in the cladding. In general, the hoop strength of a cladding tube shape material is measured by inserting a polyurethane plug into the tube, compressing it, and destroying the tube by applying stress in the circumferential direction. However, in the above method, the hoop stress is not uniformly distributed throughout the tube due to the shear characteristics and friction coefficient of the plug. In this study, we developed an equipment that uniformly applies internal pressure to the entire tube using oil compression to measure hoop strength of SiC composite tube. The hoop strength of the triplex SiC composite tube was measured and confirmed to be fractured due to the hoop stress caused by the internal pressure. The hoop strength values of the triplex SiC composite tube measured by internal pressure and the effective area concept were compared with those of the polyurethane plug.

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2. Methods and Results

Hoop strength evaluation equipment on tube shape specimen was developed using internal oil compression pressure. Fig. 1 shows the schematic of oil compression test fixture to fix the tube specimen. A teflon pressure ring was used to resist the oil compression pressure. The outer diameter and length of triplex SiC composite tube was fixed 10 mm and 40 mm due to the pressure ring and fixture size. 100 kN load cell instron was used to apply sufficient oil compression pressure. The external load by instron was applied to 100 mm diameter disc shape fixture. The pressure limit of all equipment part was set at 100 MPa.

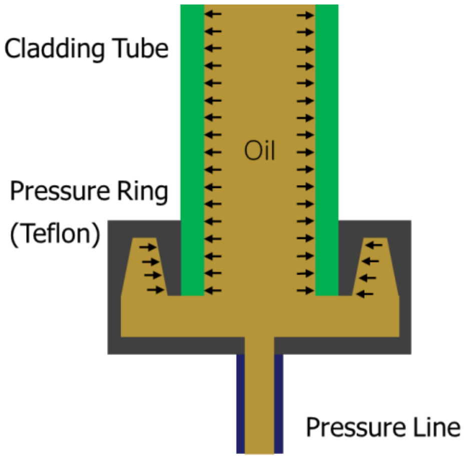

Fig. 1. Schematic of oil compression test fixture of hoop strength evaluation equipment.

Triplex SiC composite tube consist of inner monolith SiC layer, SiC composite layer, and outer monolith SiC layer. Inner diameter of triplex tube was 8.5 mm and outer surface was polished to have sufficient roughness.

The load-displacement curves of hoop strength test of three specimens were shown at fig. 2. All three samples showed significant load changes or drop near 40 ~ 50 kN. This means that oil leak occurred due to the crack initiation in triplex SiC composite tube. The inset OM images of fig. 2 shows cracks on outer SiC layer after the breakage of triplex tube specimen.

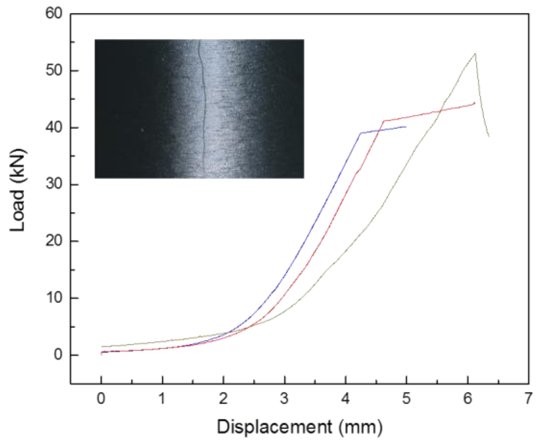

Fig. 2. Load-displacement curves of triplex SiC composite on hoop strength test

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The internal pressure applied to the inside of the specimen tube was calculated from the applied load and the external disc fixture area. Hoop strength was evaluated by thick-walled cylinder model equation as follows.

$$\sigma_r = \frac{r_i^{\,2} p_i}{r_o^2 - r_i^2}\left(1 - \frac{r_o^{\,2}}{r^2}\right) \;\; \& \;\; \sigma_t = \frac{r_i^{\,2} p_i}{r_o^2 - r_i^2}\left(1 + \frac{r_o^{\,2}}{r^2}\right) \quad (1)$$

Table 1. Applied load, internal pressure, hoop strength, effective area considered hoop strength of triplex SiC composite tube.

Sample	Load (kN)	I. P. (MPa)	Hoop strength (MPa)	Effective area considered hoop strength (MPa)
1	41.12	14.54	90.27	129.31
2	39.02	13.80	85.66	122.70
3	53.08	18.77	116.53	166.92
avg.	44.41	15.71	97.49	139.64

* Effective area at m = 5.30 was considered

Table 1 shows the measured hoop strength and the effective area considered hoop strength of triplex SiC composite tubes. The average measured hoop strength value shows 97.49 MPa. This hoop strength value is slightly larger than the value of 63 MPa, which is the hoop strength of the only SiC composite tube measured by Eric Rohmer using internal pressure. The hoop strength of triplex SiC composite tube show higher value due to the presence of inner monolith SiC layer which has higher strength than SiC composite layer.

The hoop strength of triplex SiC composites specimens was analyzed considering the effective area of both methods to compare the hoop strength using polyurethane plug and the hoop strength using internal pressure. The effective area of the hoop strength evaluation method using internal pressure was determined from the internal surface area of the tube specimen. The effective area of the hoop strength evaluation method using the polyurethane plug was calculated from the FEM simulation results by Lee et al.[5] The weibull modulus value of 5.3 was obtained from the results of Kim et al. which evaluated the hoop strength of triplex SiC composite using polyurethane plugs[6]. Considering the effective area, the hoop strength value converted to the hoop strength value using polyurethane plug was about 139.64 MPa, which is smaller than the value of 227 MPa shown by Kim et al. Kim et al. measured the breakage of the inner SiC layer depending on the load drop of the load-displacement graph. The actual break point of the inner SiC layer should be measured through the correct AE signal. We will then compare the two evaluation methods by measuring the hoop strength more accurately through the AE signal.

3. Conclusions

Hoop strength of triplex SiC composite tube was measured by applied internal pressure using oil compression. Hoop strength test equipment using oil compression pressure was developed. The value of hoop strength of outer diameter 10 mm triplex SiC composite tube was 97.49 MPa. Hoop strength values of triplex SiC composite tube measured by polyurethane plug test and oil compression pressure test were compared and analyzed by considering effective area. The effective area considered hoop strength of triplex tube measured by oil compression test is smaller than hoop strength measured by plug test since it is difficult to specify the break point of inner SiC layer.

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