Comparison of Properties of CX-270G and DACC C/C Composites for the Development of Structural Materials in HTGRs

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1. Introduction

Carbon-carbon (C/C) composites have been widely used for high-temperature structural applications because they possess excellent mechanical properties such as high specific strength and thermal shock resistance [1]. In the nuclear industry, the composites have been also considered for plasma facing materials in fusion reactors [2] and high-temperature structural parts in gas cooled reactors [3]. In the high-temperature gas cooled reactor (HTGR) designs such as GT-MHR and HTTR, the reactor core temperature can approach 1600°C during severe loss of coolant accidents. A high-temperature control rod is therefore desirable, and assures control rod availability under all conceivable reactor conditions. With this goal in mind, efforts have been directed in the USA and Japan toward the development of C/C composite control rods [4]. Recently, the C/C composites have also been considered for the application of high-temperature structural parts such as upper core restraint blocks, upper plenum shroud, hot duct insulation cover sheets, and floor blocks [5].

In this study, we evaluated basic properties of the C/C composite fabricated by a domestic company, aiming at the development of core components in HTGR. The nuclear grade CX-270G composite, which has been developed by JAERI for the control rod components of the HTTR, was also tested for comparison purpose. Through the comparison of the microstructure, flexural strength, and thermal conductivity of the two composites, we tried to bring up some directions for an improvement of the domestic composite.

2. Experimental Procedure

C/C composites used in this study were DACC1 (DACC Co., Ltd., Korea) and CX-270G (Toyo Tanso Co., Ltd., Japan). In Korea, the C/C composites are being produced solely by DACC. Characteristics of both composites are shown in Table 1. Chemical vapor infiltration (CVI) and polymer impregnation and pyrolysis (PIP) processes are applied for the matrix formation of the DACC1 and the CX-270G composites, respectively.

For the 3 point flexural test in either the across or parallel direction, bar specimens with dimensions of 6×2.5×45 mm were cut from composite panels. The span length and the cross-head speed were 30 mm and 0.5 mm/min, respectively.

Table 1. Characteristics of DACC and CX-270G [6] C/C composites

	DACC	CX-270G
Fiber type	Oxy-PAN	PAN
Fiber architecture	2.5D needle-punched	2D plain weave
# of filaments	320K	6K
Fiber Vol%	28%	50%
Bulk density (g/cc)	1.74	1.6
Matrix formation	CVI	Pitch impreg.
Graphitization temp.	2500°C	2800°~3000°C

Thermal diffusivity was measured by a laser flash method using specimens with dimensions of 12.5 mm in diameter and 3 mm in thickness. Thermal conductivity was calculated by multiplying the thermal diffusivity, the density of the composite, and the heat capacity of graphite. Microstructures were observed using optical and scanning electron microscopes.

3. Results and Discussion

Fig. 1 shows optical micrographs for the cross-sections of the flexural specimens with thicknesses of 2.5 mm. In case of the CX-270G composite, most of the large pores are parallel to the in-plane direction and cracks exist in the thickness direction, being due to the matrix shrinkage during the pyrolysis process. The DACC1 specimen fabricated by the CVI method does not contain the shrinkage cracks but the large residual pores are located both in thickness and in-plane directions. The CX-270G flexural specimen consists of more than 10 stacking layers of the fiber cloth while the DACC1 specimen less than 2 layers, which are due to the much higher number of filaments in the fiber yarn of the DACC1 composite (320K) compared with the

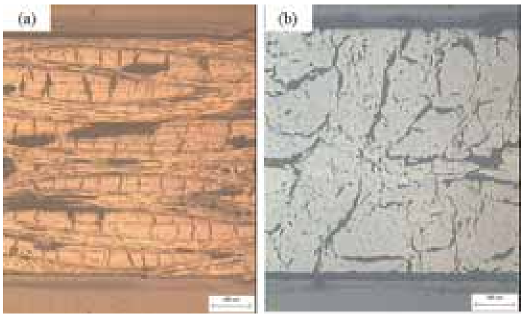

Fig. 1. Optical micrographs for the cross-sections of the CX-270G (a) and the DACC1 (b) flexural specimens.

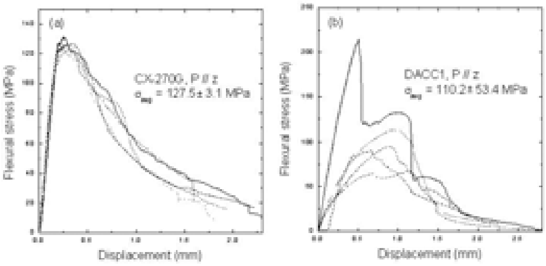

Fig. 2. Flexural strength of CX-270G (a) and DACC1 (b) composites in the loading direction perpendicular to the x-y plane of the fiber preform.

CX-270G composite (6K).

Fig. 2 shows the flexural strength of the CX-270G and DACC1 composites when the loading direction is perpendicular to the x-y plane of the woven fiber preform. The average flexural strength of the CX-270G composite is 127.5 MPa with a very small scattering, which is similar to the reported value of 133 MPa [6]. The DACC1 composite has a slightly lower strength and a very large scattering. The large scattering of the strength seems to be attributed to the small number of the stacking layers contained in the flexural specimen as mentioned in Fig. 1. The thick fiber cloth can not make the thin specimen to have a representative strength value. The dimension of the flexural specimen was, therefore, increased to 15×5×80 mm. The flexural strength of the larger specimen is shown in Fig. 3. Even though the standard deviation of the strength decreased from 53.4 to 24.7 MPa, the scattering is still larger than the CX-270G composite. If we consider that the thin part of the control rod components has a thickness of 4 mm [7], the number of filaments should be decreased significantly.

When the loading direction was parallel to the x-y plane of the fiber cloth, the flexural strengths of the composites were 6.1 ± 0.4 MPa and 31.9 ± 5.7 MPa for the CX-270G and the DACC1 composites, respectively. The CX-270G composite had a much lower interlaminar strength than the DACC1 composite because the CX-270G composite did not have reinforcements in the thickness direction. Therefore, the components should be designed not to induce a high interlaminar shear stress or multidirectionally reinforced C/C composites have to be applied.

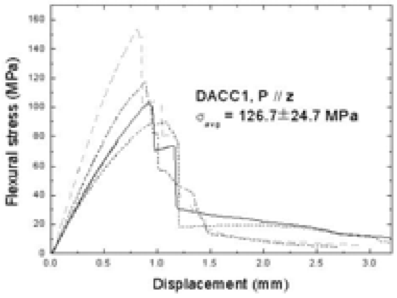

Fig. 3. Flexural strength of the DACC1 composite with a dimension of 15×5×80 mm.

Thermal conductivity of the DACC1 composite measured from room temperature to 1200°C is shown in Fig. 4. At room temperature the in-plane and the transverse thermal conductivities are 19.8 and 13.8 W/m·K, respectively. The reported values for the CX-270G are 155 and 24 W/m·K. The DACC1 composite has a lower thermal conductivity especially in the in-plane direction. The lower thermal conductivity of the DACC1 composite may be due to complex reasons. At first, the CVI-processed DACC1 composite has a layer-by-layer growth of the carbon matrix. The thermal conductivity perpendicular to the graphite plane is known to be very low. Secondly, Oxy-PAN fiber having a lower thermal conductivity than PAN-based fiber was used for the DACC1 composite. Finally, the graphitization temperature was lower (see Table 1).

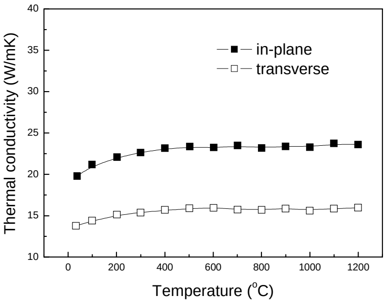

Fig. 4. In-plane and transverse thermal conductivities of the DACC1 composite as a function of temperature.

4. Conclusions

The DACC1 composite revealed a similar flexural strength to the CX-270G but a much larger scattering of the strength. This was partly due to the much larger number of filaments of the DACC1 composite and partly to a processing inhomogeneity. In addition to these factors, the use of PAN-based fiber, pitch-derived matrix, and a higher graphitization temperature are thought to be required to increase the mechanical property and the thermal conductivity of the DACC1 composite.

REFERENCES

[1] G. Savage, Carbon-Carbon Composites, Chapman & Hall, London, 1992.

[2] G. Federici et al., Plasma-Material Interactions in Current Tokamaks and Their Implications for Next Step Fusion Reactors, Nuclear Fusion, Vol.41, p.1967, 2001.

[3] M. Eto, S. Ishiyama, H. Ugachi, Status of the Research and Development at JAERI on the C/C Composite Control Rod for HTGR, IAEA-TECDOC-901, p.205, 1995.

[4] T. D. Burchell, Carbon Materials for Advanced Technologies, Pergamon, Amsterdam, pp.429-484, 1999.

[5] T. D. Burchell, J. Klett, Graphite and Composites Development for VHTR Applications, VHTR Materials R&D Collaboration Meeting, May 4-6, 2004, Idaho Falls, ID.

[6] T. Sogabe et al., Development of the Carbon Fiber Reinforced Carbon-Carbon Composite for High Temperature Gas-Cooled Reactors, JAERI-Research 2002-026, 2002.

[7] M. Eto et al., Development of Carbon/Carbon Composite Control Rod for HTTR (II), JAERI-Research 98-003, 1998.