18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-C06-1

STRESS ANALYSIS OF TWO-DIMENSIONAL C/C COMPOSITE COMPONENTS FOR HTGR'S CORE RESTRAINT MECHANISM

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ABSTRACT

Carbon fiber reinforced carbon matrix composite (C/C composite) is one of the most promising materials for HTGRs core components due to their high strength as well as high temperature resistibility. One of the most attractive applications of C/C composite is the core restraint mechanism. The core restraint mechanism is located around the reflector block and it works to tighten reactor core blocks so as to restrict un-supposition flow pass of coolant gas (bypass flow) in the core. The restriction of bypass flow reads to the high efficiency of coolant flow rate inside of the reactor core. For the future HTGRs and VHTR (Very High Temperature Reactor), it is important to develop the core restraint mechanism with C/C composite substitute for metallic materials as used for HTTR. For the application of C/C composite to core restraint mechanism, it is important to investigate the applicability of C/C composite in viewpoint of structural integrity. In the present study, supposing the application of 2D-C/C composite to core restraint mechanism, thermal stress behavior was analyzed by considering the thickness of the C/C composite and the gap between reflector block and core restraint. It was shown from the thermal stress analysis that the circumferential stress decreases with increasing the gap and that the restraint force increases with increasing the thickness. By optimizing the thickness of C/C composite and gap between reflector block and core restraint, the C/C composite is applicable to the core restraint mechanism.

Keywords: core restraint mechanism, C/C composite, stress analysis, HTGR, VHTR

1. INTRODUCTION

High temperature gas-cooled reactors (HTGRs) are attractive due to their performance to supply high-temperature helium gas about 1000°C at reactor outlet[1]. To enhance the performance of the HTGRs, it is important to develop heat-resistant ceramic materials substitute for metallic materials in the core so as to increase operating temperature. Carbon fiber reinforced carbon matrix composites (C/C composites) shows excellent heat resistibility on the strength. It is, therefore, attractive materials to the in-core components application in the HTGRs. At this moment, one of the most promising applications is the core restraint mechanism. The core of typical HTGRs such as the High-Temperature Engineering Test Reactor (HTTR) consists of fuel blocks, replaceable and permanent reflector blocks etc. The core restraint mechanism works to tighten reflector blocks so as to restrict un-supposition flow pass of coolant gas (bypass flow) in the core. The restriction of bypass flow reads to the high efficiency of coolant flow rate inside of the reactor core. For the future HTGRs and VHTR (Very High Temperature Reactor), it is important to develop the core restraint mechanism with C/C composite substitute for metallic materials as used for HTTR.

Two-dimensional C/C composite is received much attention for the application at the standpoints of fabricability and cost. However, it has great anisotropy of thermal and mechanical properties between parallel and perpendicular to lamina directions because of two-dimensional layer structure. In viewpoint of C/C composite application to reactor core restraint mechanism, relatively large restraint force could produced due to the small amount of thermal expansion to fiber direction compared to that of reflector block which is made of graphite material. Moreover, restraint force would change with increasing the thickness of core restraint mechanism. Therefore, with respect to the application of C/C composite components to reactor core restrain mechanis, it is important to evaluate the relation between restraint force and circumferential stress and thickness and the compressive stress on the reflector block to assure their structural integrity.

In this study, stress analyses were performed supposing the application of C/C composite to core restraint mechanism using a simple shape model. This paper reports thermal stress of C/C composite core restraint mechanism by considering the thickness of the C/C composite and the gap between reflector block and core restraint. From the analytical results, applicability of C/C composite for core restraint mechanism is discussed.

2. ANALYSIS

2.1 Core restraint mechanism

The concept of the core restraint mechanism with C/C composite is shown in Fig.1. Blocks are tightened by core restraint mechanism made of C/C composite bands. Each band is connected by connecting keys to surround the reflector blocks. As the core restraint material, PAN-based 2D-C/C composite, CX-270G grade (TOYO TANSO Co.), is one of the candidate materials. Table 1 shows typical material properties of CX-270G[2]. In expectation of high strength on fiber direction of composite materials, fiber direction is supposed to be parallel to circumferential direction that will be maximum tensile stress direction on the core restraint mechanism. The restraint mechanism is tensed by the inner graphite blocks at the reactor operating condition, because the coefficient of thermal expansion of the 2D-C/C in parallel to the lamina direction is lower than that of the graphite.

It causes the restraint force. For the design of the core restraint mechanism, it is important to investigate the restraint force as well as thermal stress behavior.

Table 1 Material properties of CX-270G. [2]

Grade	Bulk density Mg/m^3	Electrical resistivity μΩ m	Bending strenght MPa	Thermal conductivity W/m K
2D-C/C CX-270G	1.63	6.5(//)	133(⊥)	129(//), 26(⊥)

(//) parallel to lamia
(⊥) perpendicular to lamia

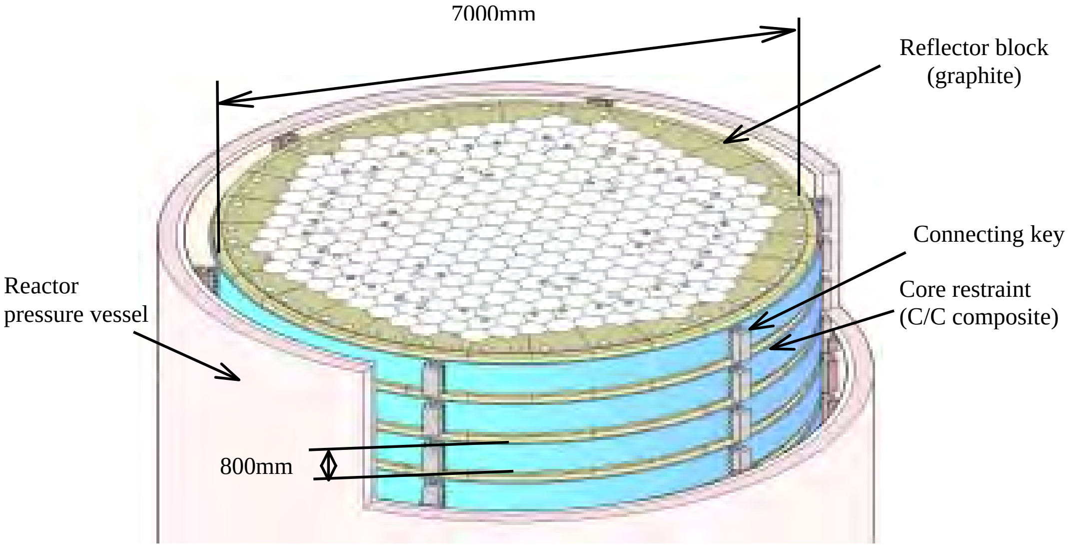

Fig.1 Proposed core restraint mechanism made of C/C

2.2 Analytical condition

Restraint force of core restraint mechanism can be accommodated by changing the thickness of C/C composite or gap between reflector block and core restraint. As the analysis case-1, the relationship between thickness and restraint force and compressive stress on the reflector block is investigated by parametric study to clarify the optimum thickness in view point of the integrity of reflector block. Parameters are shown in Table 2. Then, as the analysis case-2, employing two kinds of thickness, the relationship between restraint force and thickness or gap is investigated in viewpoint of the integrity of C/C composite. As shown in Table 3, three kinds of gap were employed in this analysis. For the thermal stress analysis, FEM code was used. Considering the symmetry of analytical object, axisymmetric model was employed. Analytical model is shown in Fig.2. Material properties of graphite and C/C composite employed in this study are shown in Table 4.

Table 2 Parameters for the analysis case-1.

Thickness of C/C composite	2mm, 10mm, 30mm, 50mm
Temperature at the inner surface of reflector block	600°C
Temperature at the outer surface of C/C composite	510°C

Table 3 Parameters for the analysis case-2.

Thickness of C/C composite	10mm, 30mm
Gap between reflector block and core restraint	0mm, 3mm, 6mm
Temperature at the inner surface of reflector block	600°C
Temperature at the outer surface of C/C composite	510°C

Table 4 Material properties of graphite [3] and C/C composite [2].

Material properties	Graphite (IG-110 graphite)	C/C composite (CX-270G)
Elastic moduls [GPa]	9.4	106.5 (//) 0.8 (⊥)
Shear moduls [GPa]	4.2	3.0
Poisson’s ratio	0.11	0.12
CTE [1/°C]	4.3×10^{-6}	2.0×10^{-7} (//) 10.8×10^{-6} (⊥)

(//) parallel to lamia
(⊥) perpendicular to lamia

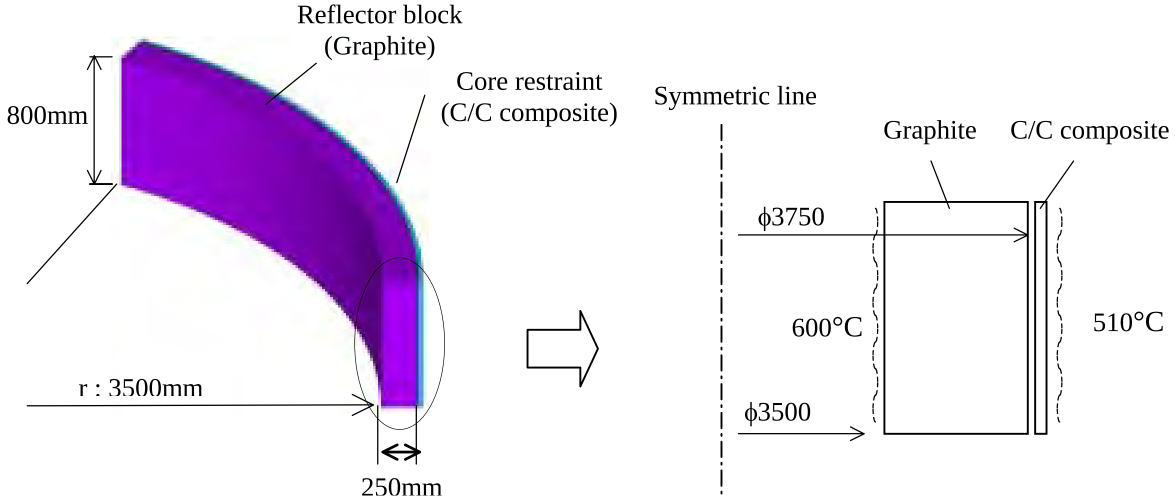

Fig.2 Analytical model for thermal stress analysis.

3. RESULT AND DISCUSSION

The relationship between thickness and restraint force and compressive stress on reflector block are shown in Fig.3. From this figure it is clear that the restraint force as well as compressive stress increases with increasing the thickness of C/C composite and larger restraint force can be obtained by thicker C/C composite. On the other hand, If we follow the graphite structural design code for the HTTR[4], stress limit of reflector block is 1/4 of the specified minimum ultimate compressive strength (61MPa)[4]. Therefore, form the viewpoint of structural integrity of reflector block, thickness of C/C composite should be less than 50mm.

Table 5 shows the correlation between circumferential stress and thickness of C/C composite or gap between reflector block and C/C composite. It is clear from this table that the circumferential stress decreases with increasing the gap for both thickness of C/C composite and that the restraint force increases with increasing the thickness. The restraint force of 30mm thickness composite is almost twice to that of 10mm. The gap acts to the circumferential stress and restraint force.

On the other hand, tensile strength of CX-270G for lamina direction is reported as 167MPa[2]. Therefore, in order to evaluate the safety margin of C/C composite, ratio of circumferential stress vs. tensile strength (R_{ct}) was analyzed as shown in Table 5. As described in the ASME Sec.III NB, design stress limit for metallic component is defined at 1/3 of ultimate tensile strength. If we follow this stress limit, gap should be prepared more than 3mm. From these results, it can be said that the C/C composite core restraint mechanism is applicable by optimizing the thickness of C/C composite and gap between reflector block and core restraint. For the designing of the restraint mechanism, not only the structural integrity of C/C composite but also that of graphite should be confirmed. At this point, the evaluation of restraint force as well as the circumferential stress becomes important. Therefore, investigation for the structural integrity of graphite will be performed in the continuous study.

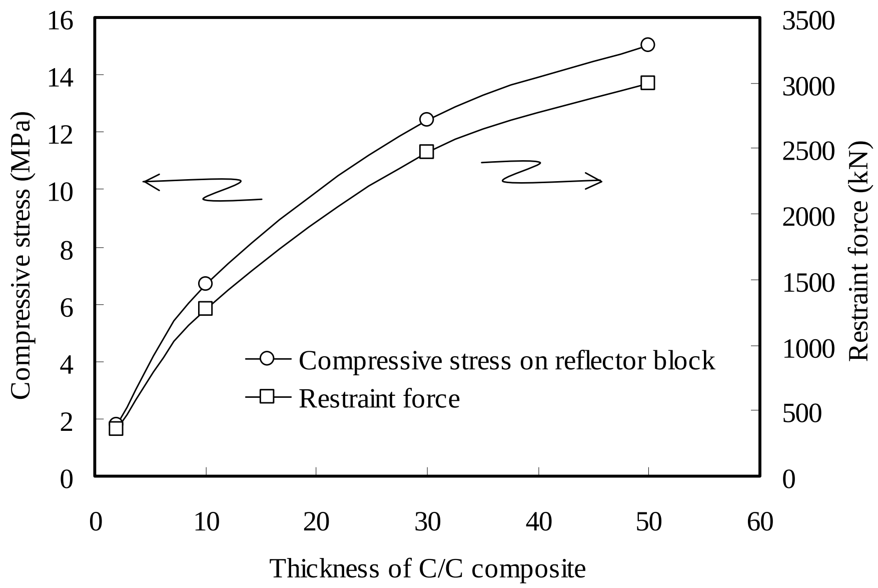

Fig.3 Relationship between thickness and restraint force or compressive stress

Table 5 Relationship between circumferential stress and thickness or gap.

Thickness of C/C composite (mm)	Gap (mm)	Circumferential stress (MPa)	Restraint force (kN)	Circumferential stress / Tensile strength (R_{ct})
10	0	159	1270	0.95
	3	102	816	0.61
	6	44	350	0.26
30	0	102	2470	0.61
	3	67	1610	0.40
	6	31	740	0.19

4. CONCLUSION

Stress analyses of two dimensional C/C composite components were carried out supposing the application to core restraint mechanism of HTGRs. As the two dimensional C/C composite, PAN-based C/C composite of CX-270G was focused in this study. Main results obtained in this study are summarized as follows:

(1) The restraint force as well as compressive stress on reflector block increases with increasing the thickness of C/C composite and larger restraint force can be obtained by thicker C/C composite. Form the viewpoint of structural integrity of reflector block, thickness of C/C composite should be less than 50mm.

(2) The circumferential stress decreases with increasing the gap and that the restraint force increases with increasing the thickness. By optimizing the thickness of C/C composite and gap between reflector block and core restraint, the C/C composite is applicable to the core restraint mechanism.

(The present study is entrusted from Ministry of Education, Culture, Sports, Science and Technology of Japan.)

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