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Design and performance analysis of structural components for a Korean He Cooled Ceramic Reflector TBM in ITER

Kyu In Shin[a], Dong Won Lee[a,*], Eo Hwak Lee[a], Suk-Kwon Kim[a], Jae Sung Yoon[a], Seungyon Cho[b]

[a] Korea Atomic Research Institute, Daejeon, Republic of Korea
[b] National Fusion Research Institute, Daejeon, Republic of Korea

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ABSTRACT

Korea has developed a Helium Cooled Ceramic Reflector (HCCR) Test Blanket Module (TBM) testing in ITER, which was considered one of the fusion DEMO-relevant blankets in Korea. The design and performance analysis of the TBM body have been carried out considering the uniqueness of the KO TBM and design requirements by the IO and KO design concept: (1) KO TBM has 4 sub-modules considering a post irradiation test (PIE) and its delivery. (2) A first wall (FW) design was changed into a 15 × 11 rectangular shape and its performance was confirmed by thermal-hydraulic and thermo-mechanical analyses using commercial ANSYS code. The results showed that the revised design model satisfied 1.5S_m and 3S_m of the allowable stress (S_m) in the RCC-MR code at the maximum stress region of the components for mechanical and thermo-mechanical analyses, respectively. (3) Considering the tritium breeding and cooling, a breeding zone (BZ) design was investigated. Three Li and Be layers, and one graphite layer, were proposed by the iteration, and the appropriate temperature distribution was obtained. The design for other components such as a side wall (SW) and back manifold (BM) is on-going considering 9 MPa of channel pressure and its functions of flow distribution as a manifold.

1. Introduction

One of the main engineering performance goals of ITER is to test and validate the design concepts of the tritium breeding blankets relevant to a power producing reactor. The tests will focus on modules including a demonstration of the breeding capability that will lead to a tritium self sufficiency and extraction of heat suitable for an electricity generation [1–3]. Korea has developed a Helium Cooled Molten Lithium (HCML) Test Blanket Module (TBM) and Helium Cooled Solid Breeder (HCSB) TBM for testing in the ITER. Recently, solid-type HCSB TBM was decided as a leading concept in the National Fusion Committee and the other is developing as the breeding blanket for DEMO. The name of the solid type TBM was changed to a Helium Cooled Ceramic Reflector (HCCR) considering the unique concept using a graphite reflector [4].

In this study, the overall design procedure of the main components of TBM such as a first wall (FW) and an array of breeding zone (BZ) including its performance analysis was introduced. Until the performance analysis results satisfied the design requirement, the geometries and arrays of BZ were modified, and finally the optimized design was obtained.

2. Design concept and requirements

From the proposed ITER Organization (IO) requirements in the PMG-18-06 meeting (the 6th meeting on Port-18 Management Group), the following were decided: (1) a 15 mm gap from the port frame to TBM, and a 120 mm recession should be considered. Since the port dimension is fixed, the TBM dimension is decided as follows: 1670 mm in height and 462 mm in width. (2) The surface heat flux from plasma side was reduced from 0.5 to 0.35 MW/m^2. Considering the design requirements such as (1) the KO DEMO relevancy, (2) compact size for a delivery for a Post Irradiation Examination (PIE), (3) adopting a graphite reflector, which is a unique concept to replace some of the Be multiplier with cheap and stable in high temperature graphite, and (4) TBR is higher than 1.4 under local assumptions, the conceptual design and basic dimension of the KO TBM was determined, as shown in Fig. 1.

The RCC-MR code was used for the design criteria in this study, and classified as the primary and non primary stress in the total stress from the elastic analysis, as shown in Fig. 2 [5,6]. The total stress obtained by an elastic analysis must also be broken down into various stress categories, as shown in Fig. 3. The general primary

* Corresponding author. Tel.: +82 42 868 4659.
E-mail address: dwlee@kaeri.re.kr (D.W. Lee).

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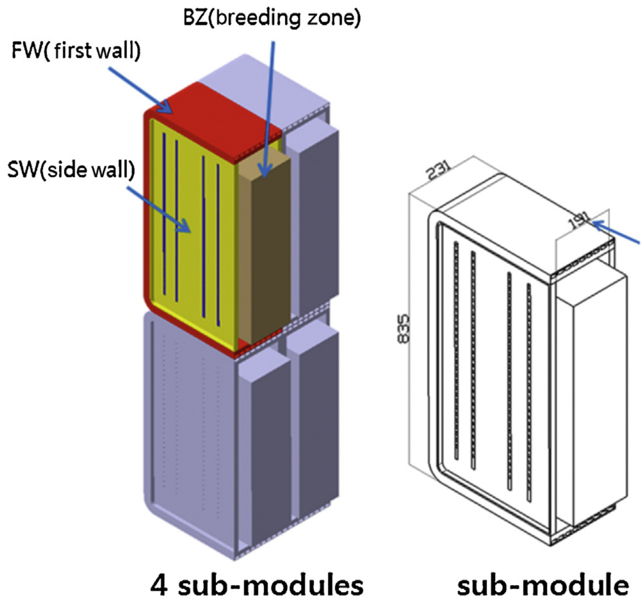

Fig. 1. Concept of KO HCCR TBM and its sub-module dimensions.

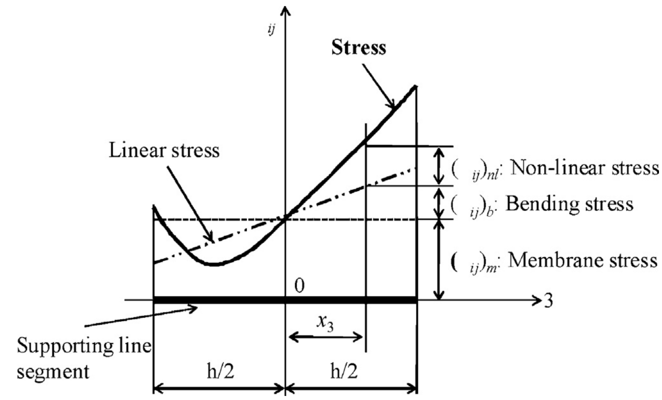

Fig. 3. Various stress categories from a breakdown of stress by elastic analysis according to the RCC-MR code.

membrane stress (P_m) is the mean value of the primary stress within the thickness of the wall, and the primary bending stress (P_b) is the stress distributed linearly within the thickness, which has the same moment as the primary stress obtained by applying the procedure given in the RCC-MR codes. The local primary membrane stress (P_L) is the stress equal to the sum of stress P_m and L_m: $\overline{P_L} = \overline{P_m + L_m}$. Although it does not have all the properties of a primary stress, P_L is classified in the primary stress category. And for the stress range evaluation, it should be noted that the sum of the stress intensity of P_L (or P_m) and P_b is $\overline{P_L(\text{or}\, P_m) + P_b}$, not the sum of $\overline{P_L}(\text{or}\, \overline{P_m}) + \overline{P_b}$ in the RCC-MR codes.

In this study, the equivalent stress according to the Tresca theory was calculated in the mechanical and thermo-mechanical analyses using ANSYS [7].

3. TBM components design and analyses

3.1. FW design and its performance

From the old HCML TBM design, which has a 20 × 10 rectangular U-shape FW, the mechanical analysis considering 9 MPa design pressure was performed. The result showed that the maximum stress in FW was 165 MPa, which was higher than the allowable stress of 123 MPa for RAFM (Reduced Activation Ferritic Martensitic) steel at 500 °C, which is the reference structural material for a KO TBM. Therefore, the channel design needs to be changed to meet the RCC-MR code requirement.

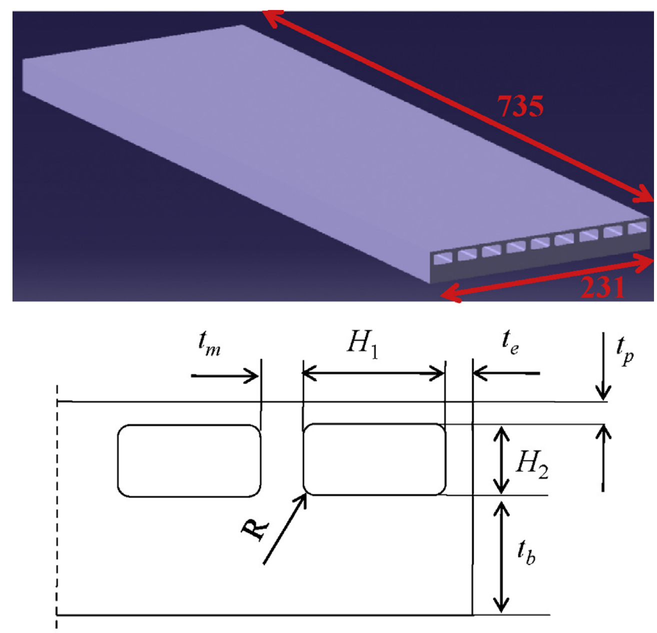

Fig. 4. View of simplified straight FW for a structural analysis.

The simplified straight FW was considered to evaluate the stress, as shown in Fig. 4, where t_m is a thickness between the channels, H_1 is the width of the channel, H_2 is the height of the channel, t_p is the thickness from the surface which is directly faced with plasma to the channel, t_b is the thickness from the bottom of the channel to a bottom surface in the FW, and R is the curvature in the channel. The mechanical analysis only considered the design pressure, and the thermal analyses were also carried out. The

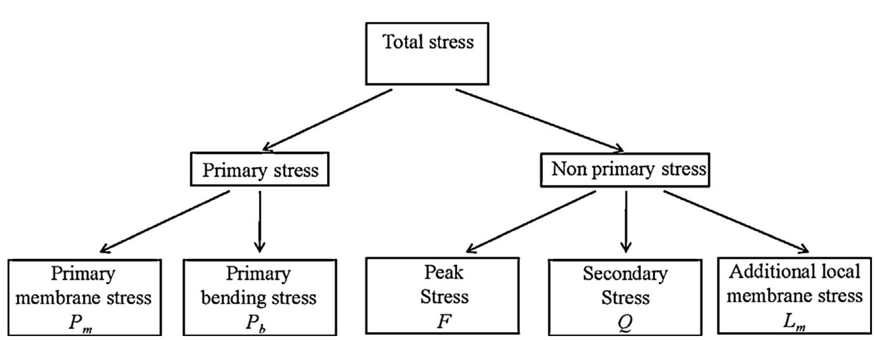

Fig. 2. Classification of stresses obtained by an elastic analysis according to the RCC-MR code.