Structural Design and Evaluation of KO HCCR TBM First Wall for ITER

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1. Introduction

Korea has developed Helium Cooled Molten Lithium (HCML) Test Blanket Module (TBM) and Helium Cooled Solid Breeder (HCSB) TBM to test in the ITER. The test will be conducted on the modules including a demonstration of the breeding capability which leads to a tritium self sufficiency and an extraction of heat suitable for an electricity generation. Recently, the solid-type HCSB TBM was decided as a leading concept in National Fusion Committee and the name is Helium Cooled Ceramic Reflector (HCCR) considering the unique concept of using the graphite reflector. Based on the HCCR TBM the first wall (FW) is one of the important component because it is faced the plasma directly and subjected to high heat and neutron loads.In this study, the structural analysis of FW was performed according to RCC-MR Codes which is French nuclear power plant design codes. It needs the design satisfaction of TBM to conform to the safety performance in ITER.

2. RCC-MR Codes

RCC-MR Codes classified the primary and the non primary stress in the total stress from the elastic analysis as shown in Fig. 1. And the total stress obtained by elastic analysis must be broken down into the various stresses categories as shown in Fig. 2.

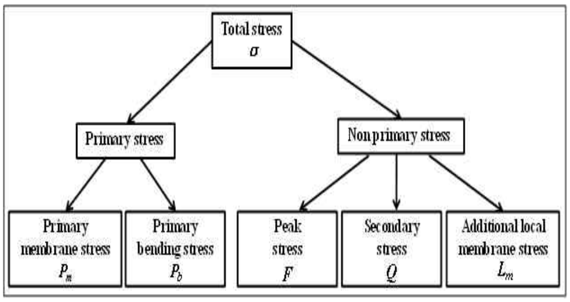

Fig. 1 Classification of Stresses obtained by elastic analysis according to RCC-MR Code

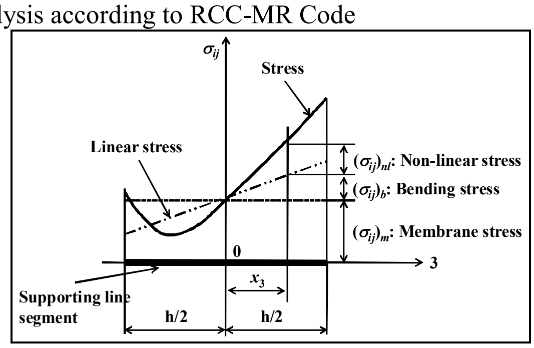

Fig. 2 Various stress categories from breakdown of the stress by elastic analysis according to RCC-MR Code

3. FW design and Structural analysis

The conceptual design and basic dimension of the KO TBM is 1670 mm height and 462 mm width and it consists of 4 sub–modules as shown in Fig. 3. The surface heat flux from plasma side was reduced from 0.5 to 0.35 MW/m^2. Figure 4 shows the temperature distribution in the FW of TBM by using thermal hydraulic analysis. In this condition, the flow velocity in single FW channel is about 50 m/sec and total mass flow rate is about 1.14 kg/sec. The maximum temperature of the FW does not exceed 550 ^{o}C of the design requirement. Based on the thermal flow analysis the mechanical analysis and the thermal-structural analysis were preformed to evaluate and satisfy requirements of the RCC-MR design code. In the mechanical analysis in FW, the internal pressure of 9 MPa as a design pressure was considered. The Tresca yield criterion was used for the results from the elastic analysis. The mechanical properties of RAFM (Reduced Activation Ferritic Martensitic) steel were used for mechanical and thermal-structural analysis as shown in Table 1, where Temp. is the temperature, E is Young's modulus (GPa), and α is

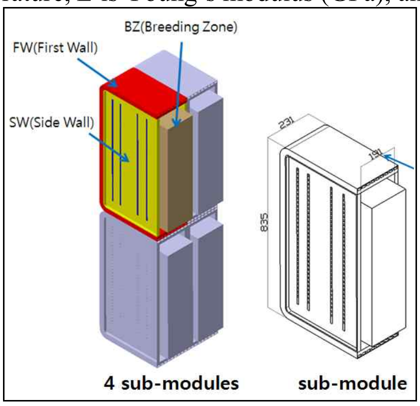

Fig. 3 Concept of KO HCCR TBM and its sub-module dimensions

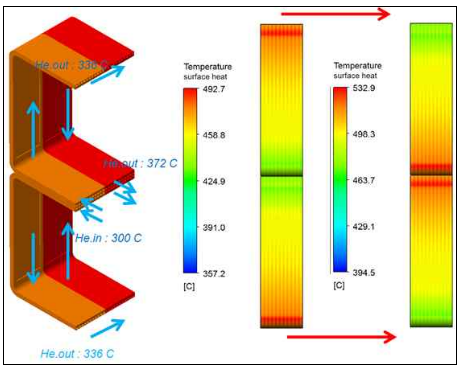

Fig. 4 Flow scheme and temperature distribution of TBM

thermal expansion coefficient and Poission's Ratio (ν) has constant value of 0.3 in the analysis.

Table I Mechanical Properties of RAFM steel

Temp. [°C]	20	100	200	300	400	500	550	600
E	206	201	194	188	182	175	163	161
α	10.4	10.8	11.2	11.6	11.9	12.2	12.4	12.5

4. Results and Discussion

The FW is one of the most loaded component faced the plasma directly in the TBM. For the mechanical analysis, the inner pressure of 9 MPa was only considered in the coolant channels in FW.

Figure 5 shows Tresca stress distribution as the result of mechanical analysis without thermal stress. The stress concentration was occurred in the channel corner at the middle section in TBM toward the plasma and the highest value is 60.26 MPa.

At the maximum point in the Tresca stress distribution in Fig. 5, the primary stresses for inner pressure was obtained along the supporting line segment (PATH) according to RCC-MR Code as shown in Fig. 6. The general primary membrane stress (P_m) was 17.08 MPa and the sum of local primary membrane stress (P_L) and primary bending stress (P_b) was 48.78 MPa. The P_L is defined as the sum of P_m and L_m as shown in Fig. 1 and RCC-MR Codes. The allowable stress(S_m) of the average temperature (500 °C) is 132 MPa.

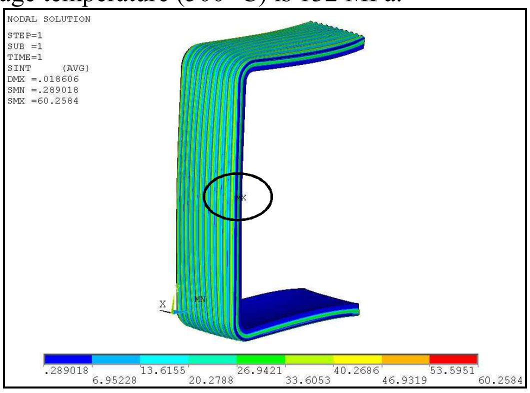

Fig. 5 Tresca stress distribution considering only inner pressure (9 MPa)

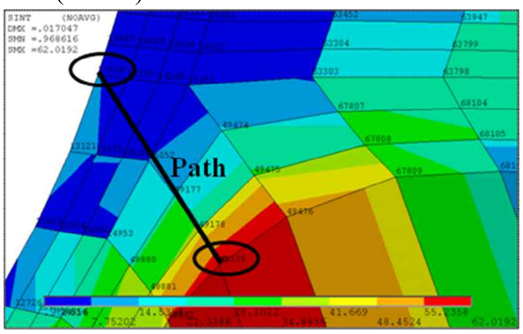

Fig. 6 Stress analysis from the maximum point in the inner surface to the outer surface trough PATH considering only inner pressure (9 MPa)

By using $1.5S_m$ criterion, the stress analysis results considered the inner pressure satisfied ITER design requirement.

Figure 7 shows Tresca stress distribution as the result of thermal-structural analysis. The stress concentration was occurred in the lower channel section in FW.

The primary and secondary stresses were obtained at the maximum stress point and assessed along the supporting line segment as the same method as in Fig. 6. The highest stress value in Fig. 7 is 281.85 MPa.

In this evaluation $3S_m$ criterion was used if the results were fulfilled the ITER design requirement. The allowable stress(S_m) at the maximum temperature (520 °C) by thermal flow analysis is 119 MPa, and $3S_m$ is 357 MPa. The sum of primary and secondary stresses (P_L+P_b+Q) by thermal-structural analysis were 285.1 MPa, and it gave lower value than $3S_m$. The thermal-structural analysis results also satisfied ITER design requirement.

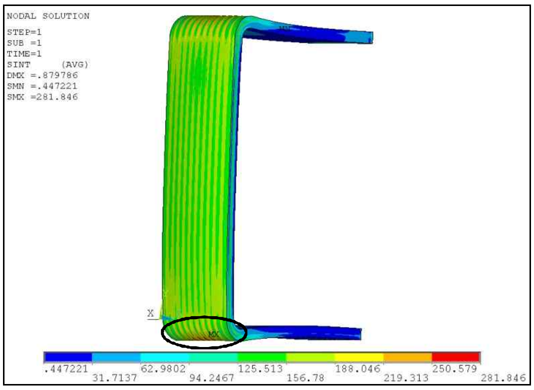

Fig. 7 Tresca stress distribution considering inner pressure and thermal stress

5. Conclusion

The mechanical and thermal-structural stress analyses were performed for FW in TBM sub-module. The analyses were evaluated according to the RCC-MR Codes. Two kinds of load categories were considered in this study; (1) considering only the design pressure of 9MPa and (2) considering internal pressure and thermal stress with its operating conditions. The both results were evaluated based on the $1.5S_m$ or $3S_m$ rules and it was concluded that the results were fulfilled ITER design requirements.

References

[1] P. Chaudhuri, et. al., "Thermal–hydraulic and thermo-structural analysis of first wall for Indian DEMO blanket module," J Fusion Engineering and Design, Vol.84, pp. 573-577, 2009.

[2] D.W. Lee, et. al., "Design and preliminary safety analysis of a helium cooled molten lithium test blanket module for the ITER in Korea," Fusion Eng. Des., Vol. 83, pp. 1217-1221, 2008.

[3] RCC-MR Code, Section 1-Subsection B: Class 1 Components, AFCEN, French, 2007.

[4] ANSYS User Manual, ANSYS-Mechanical, 2012.