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Structural Analysis of the Current KO HCCR TBM Considering Contact Stress

K. I. Shin[a*] D. W. Lee[a], H. G. Jin[a], J. S. Yoon[a], S. K. Kim[a], E. H. Lee[a], and S. Cho[b]
[a]*Korea Atomic Energy Research Institute, Republic of Korea*
[b]*National Fusion Research Institute, Republic of Korea*
[*]*Corresponding author: kyuinshin@kaeri.re.kr*

1. Introduction

The KO HCCR TBM (Korean Helium Cooled Ceramic Reflector Test Blanket Module) has been developed to test and validate the tritium self-sufficiency and heat transfer extraction for an electricity generation in the ITER. It consists of 4 sub-modules, as shown in Fig. 1, and the first wall (FW) is one of the important component because it was directly faced a high level of a heat and the fast neutrons from the plasma side and has to protect the other components in the TBM. The sub-module dimension of the KO HCCR TBM is 1670 *mm* in height and 462 *mm* in width.

In this study, the structural analysis of the FWs was performed according to the RCC-MR and ESP/ESPN, which is a French nuclear power plant design code. The contact stress among the TBM sub-modules was also evaluated to confirm the design satisfaction for the safety performance in ITER.

2. Updated Single FW Design and Analysis

The FW is one of the most loaded components facing the plasma directly in the TBM. For a mechanical analysis in FW, the internal design channel pressure of 10 MPa was considered and Tresca yield criterion was used in the elastic analysis.

In this study the allowable stress of Gr 92 material was used in the stress analysis. But Korean RAFM steel (ARRA, Advanced Radiation Reduced Alloy) has been developed, and the stress analysis will be reevaluated using ARRA material properties to satisfy RCC-MR code requirement.

Table 1 shows mechanical properties of Gr92 for

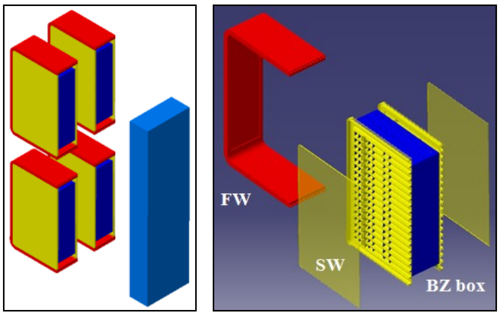


Fig. 1 KO HCCR TBM and its sub-modules

Table 1 Mechanical Properties of Gr 92

Temp.(°C)	20	100	200	300	400	500	550	600
E	191	184	184	173	160	152	138	981
α	11.7	11.7	12.0	12.3	12.4	12.4	12.4	12.4

mechanical and thermal-structural analyses where Temp. is the temperature (°C), E is Young's modulus (GPa), and α is the thermal expansion coefficient (10^{-6}/°C). Poisson's Ratio (ν) has a constant value of 0.3 in the analysis.

Figure 2 shows the cooling flow scheme and temperature distribution in TBM by a thermal hydraulic analysis. In this condition, the flow velocity in a single FW channel is about 50 *m*/sec, and the total mass flow rate is about 1.14 kg/sec. The maximum temperature of the FW does not exceed 550°C of the design requirement in ITER.

Based on the thermal hydraulic analysis, the thermal-structural analysis considered the thermal stress and the channel pressure (10 MPa) was carried out to satisfy RCC-MR code of the design requirements using ANSYS. And the contact stress among the TBM sub-modules was also evaluated to confirm the design satisfaction for ITER.

Figure 3 shows Tresca stress distribution considering the design pressure of 10 MPa in the coolant channels and Fig. 4 shows the stress breakdown from the maximum stress in the inner surface to the outer surface trough PATH to classify the stress categories. The maximum stress (67 MPa) occurred in the channel corner at the middle section in TBM.

From the breakdown results of the stress analysis, the general primary membrane stress (P_m) was 18.98 MPa and the sum of the primary membrane stress (P_L) and bending stress (P_b) was 66.95 MPa according to RCC-MR Code. The allowable stress (S_m) at the average temperature (510 °C) in Gr 92 is 132 MPa and both results satisfied the design requirement.

For the thermal-structural analysis in the Group A temperature condition, as shown in Fig 2, the maximum

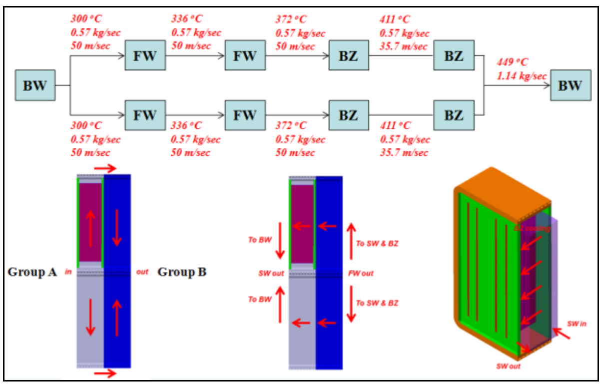


Fig. 2 Cooling flow scheme and temperature distribution in TBM

stress (272.4 MPa) occurred in the upper channel section in TBM, and the sum of $\overline{P_L + P_b + Q}$ was 211.0 MPa, which is less than $3S_m$ (396 MPa).

In the case of the Group B temperature condition, the maximum stress was 237.3 MPa and it occurred in the lower channel section in TBM. The sum of $\overline{P_L + P_b + Q}$ was 184.7 MPa and it also satisfied $3S_m$ requirement in RCC-MR code.

3. Contact Stress Analysis in HCCR TBMs

Generally a contacted area in TBM sub-modules results in a high stress. It is necessary to evaluate the contact stress to satisfy the safety performance in ITER. Three kinds of the contact stress among the TBM sub-modules were carried out to confirm the design satisfaction: the first was the contact area in the Group A sub-modules, the second was the contact area in the Group B sub-modules, and the last was the contact area in the Group A /B sub-modules.

Figure 5 shows Tresca stress distribution of the contact stress results in TBM Sub-modules. Fig. 5 (a) shows the Group A sub-modules and the maximum stress was 293 MPa. It was higher than Group A single TBM, but the maximum contact stress was lower than $3S_m$ in RCC- MR Code.

Fig. 5 (b) shows the Group B sub-modules, and the maximum contact stress was 235.3 MPa. It was slightly lower than the Group B single TBM because the

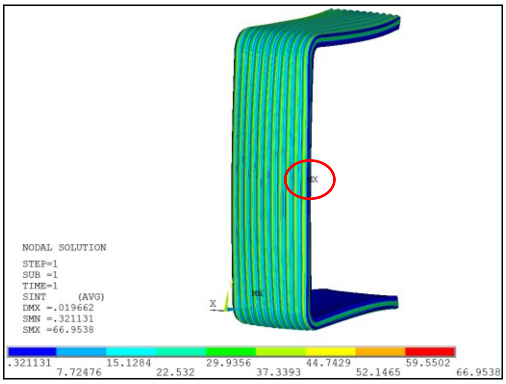


Fig. 3 Tresca stress distribution considering only the inner pressure (10 MPa)

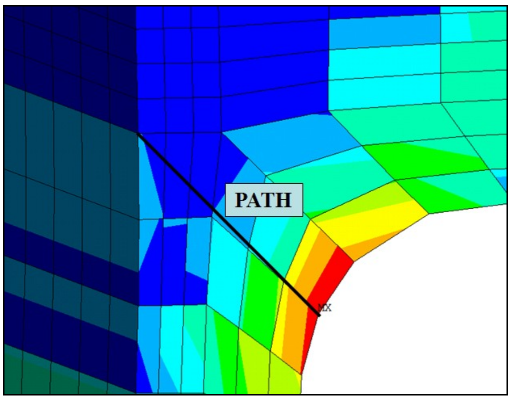
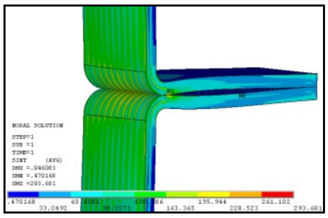


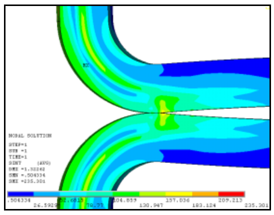
Fig. 4 Breakdown of stress analysis from the maximum stress in the inner surface to the outer surface trough PATH considering the inner pressure (10 MPa)

maximum stress occurred in the lower channel part in the Group B single TBM. It was also lower than $3S_m$ in the requirement.

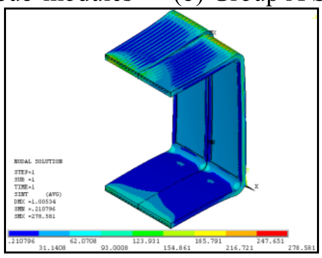
And Fig. 5 (C) shows the Group A/B sub-modules, and the maximum stress was 278.6 MPa. It gave the highest value among the three cases, but it was also lower than $3S_m$ requirement. It could be noted that the contact stress in the TBM sub-modules satisfied the design requirement for ITER.



(a) Group A Sub-modules



(b) Group A Sub-modules



(C) Group A/B Sub-modules

Fig. 5 Tresca stress distribution considered the contact in the TBM Sub-modules

4. Conclusion

Mechanical and thermal-structural stress analyses were performed for FW in a TBM single sub-module. Also three kinds of the contact stresses among the TBM sub-modules were evaluated to confirm the ITER design requirements.

Breakdown of the stress analysis in the TBM single module of Group A and B was carried out according to RCC-MR Code as follows: (1) considering only the design channel pressure of 10MPa and (2) a design pressure and a thermal stress. Also both results fulfilled RCC-MR codes.

Considering the contact effects, the contact stress in the TBM sub-modules was lower than the $3S_m$ rules. It was concluded that the results satisfied ITER design requirements.

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