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Preliminary Structural Design of Copper Bonded Steam Generator

S. H. Kim [a*], J. B. Kim [a], S. K. Kim [a]
[a]*Korea Atomic Energy Research Institute, Daejeon 305-600, The Republic of Korea*
[*]*Corresponding author: shkim5@kaeri.re.kr*

1. Introduction

The Copper Bonded Steam Generator (CBSG) uses water and sodium as a heat transfer medium, which is a steam generator with a triple solid barrier using a copper alloy (CuCrZr) to prevent sodium-water reaction. The mechanical load such as dead weight and pressure on these structures and the thermal load at steady state are the primary criteria for evaluating the structural feasibility of the structure and the structure should be designed to meet this. This requires the modeling for structural analysis and the establishment of a structural analysis procedure. Fig. 1 shows a preliminary conceptual drawing of the CBSG designed by the Korea Atomic Energy Research Institute (KAERI). Hot sodium from the top flows down through the pipe and the square tube inside the CBSG module. Water is introduced through the nozzle entrance at the bottom of the CBSG, which flows into the upper part through circular tubes and water connection headers between the CBSG modules and is discharged through the steam header [1]. The CBSG consists of 17 CBSG modules with internal pores, which are difficult to interpret due to the complexity of the structure. Therefore, submodels for major parts will be evaluated and utilized in the preliminary structural design of CBSG.

In this study, structural analysis and case study for the submodels of the designed CBSG are performed to evaluate its structural feasibility.

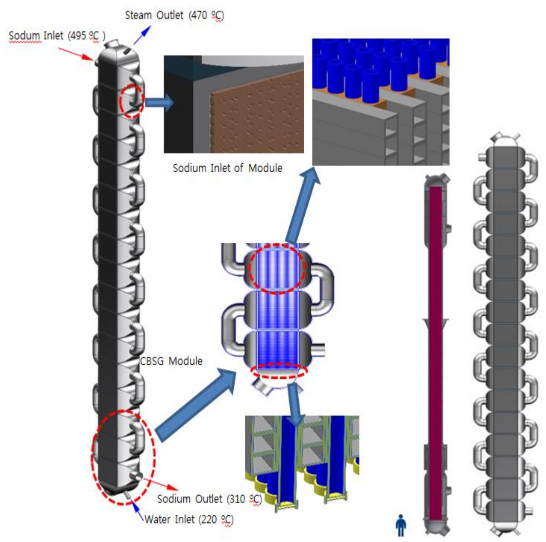


Fig. 1. Preliminary conceptual drawing of the CBSG designed by KAERI

2. Modeling of the CBSG

2.1 Analysis Model

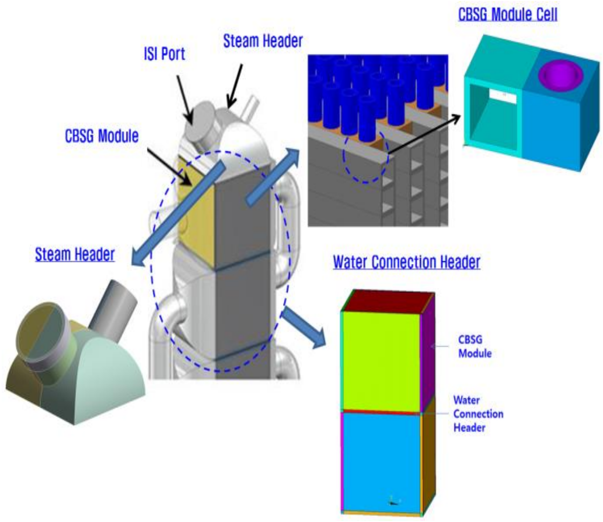


Fig. 2. Submodels of the CBSG

Submodels of the CBSG have been modeled for stress evaluation using the FEM code ANSYS [2]. As shown in Fig. 2, one cell inside the CBSG module, water connection header, and steam header are modeled. Water connection header is a square shell type structure that connects between CBSG modules. Considering the complexity of the model, the CBSG modules located on the top and bottom of the water connection header don't take into account the inside porous structures.

2.2 Loading Condition

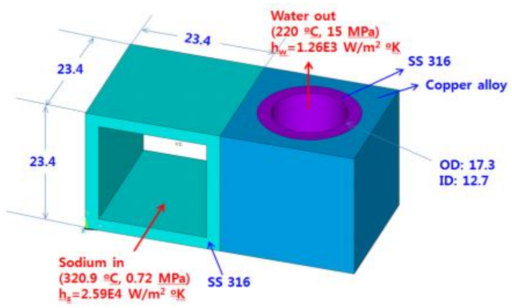
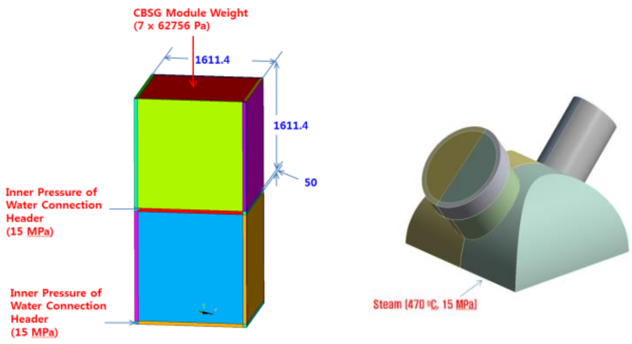


Fig. 3. Loading condition of CBSG Module cell



(a) Water connection header (b) Steam header

Fig. 4. Loading condition of water connection header and steam header

The temperature distributions of sodium and water in the submodels of the CBSG are applied to the model assuming a linear distribution of the inlet and outlet temperature of the CBSG as shown in Fig. 1. Fig. 3 shows the loading condition of the CBSG Module cell which is considered in this analysis. A corner cell of the lowest level CBSG module with the greatest temperature difference between sodium and water was selected for the analysis, and the temperatures of 320.9 ^{o}C and 220 ^{o}C are used for the sodium and water. In addition, the design pressures of sodium and water are 0.72 MPa and 15MPa, respectively. Fig. 4 (a) presents the loading condition of water connection header. The design pressure inside the water connection header is also 15 MPa. If a support structure is installed in the middle of the CBSG, the weight applied to the top surface of the CBSG module should be considered as shown in Fig. 4 (a). As shown in this figure, the water connection header is a cube structure with a side length of 1611.4 mm. Fig. 4 (b) shows the loading condition of the steam header.

3. Results and Discussions

3.1 Analysis result

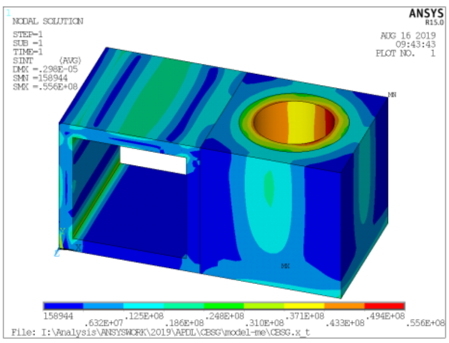


Fig. 5. Stress distribution of the CBSG module cell for the pressure

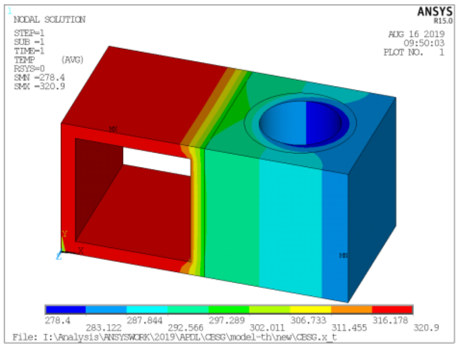


Fig. 6. Temperature distribution of the CBSG module cell for the thermal load

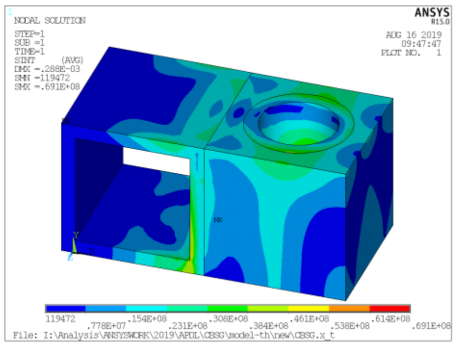


Fig. 7. Stress distribution of the CBSG module cell for the thermal load

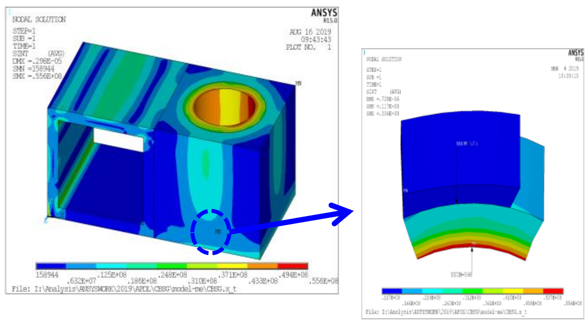


Fig. 8. Structural integrity evaluation section of CBSG module cell

Fig. 5 presents the stress distribution of the CBSG module cell for the pressure load. The maximum stress due to internal pressure is 55.6 MPa in a water tube. The inside of the water tube is in high pressure of 15 MPa, which is designed to withstand this pressure by a circular stainless steel tube. Figs. 6 and 7 show the temperature and stress distributions of the CBSG module cell for the thermal load. The maximum thermal stress due to steady-state thermal load occurs at the corner of the sodium square tube with 69.1 MPa as shown in Fig. 7. Fig. 8 shows the section of the structural integrity evaluation for the CBSG module cell.

The evaluation results according to ASME Div.5-HBA regulations in the evaluation section are as follows [3].

$$P_m = 31.9 \ < \ S_m = 121 \ MPa$$

$$P_L + P_b = 50.7 \ < \ 1.5 \, S_m = 181.5 \ MPa$$

$$P_L + P_b + Q = 73.7 \ < 3 \, S_m = 363 \ MPa$$

Primary membrane stress Pm, bending stress Pb, and secondary stress Q are considered to meet the design stress intensity (Sm) requirements.

In the case of a CBSG module cell, it is shown that the structure shape satisfies the ASME design requirements. However, for the copper alloy (CuCrZr) used in the CBSG module cell, it was excluded from the structural integrity evaluation because it is not an ASME material. It will be considered in a later detailed analysis.

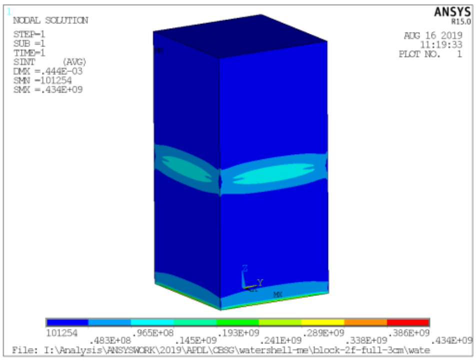


Fig. 9. Stress distribution of the water connection header for the pressure

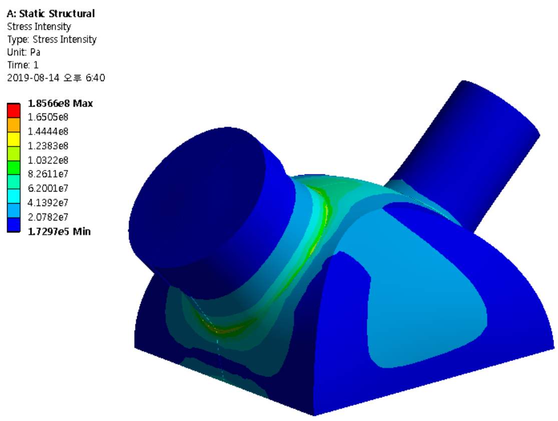


Fig. 10. Stress distribution of the steam header for the pressure

The stress distribution of water connection header due to pressure load is shown in Fig. 9. In the current design, where the thickness and height of the water connection header are 30 mm and 50 mm, respectively, the maximum stress due to pressure is 434MPa which exceeds the integrity limit and it occurs at the inside corner of the water connection header. Therefore, it is necessary to change the dimension of the water connection header to reduce the stress under the current design conditions. The thermal stress was not considered in the analysis of the submodel because the height of the water connection header is very small at 50 mm and the temperature gradient of the water inside is very small.

Fig. 10 shows the stress distribution of the steam header for pressure. The section size of the steam header for the analysis is 805.7 mm X 805.7 mm, which is reduced to a quarter of the area of the original design model. This is based on the case study results of the water connection header in the following section. A suitable size was selected for satisfying the stress requirements according to the results of the case study. As shown in Fig. 10, the maximum stress of the steam header is 186 MPa, which occurs at the lower discontinuity of the left ISI port.

3.2 Case Study

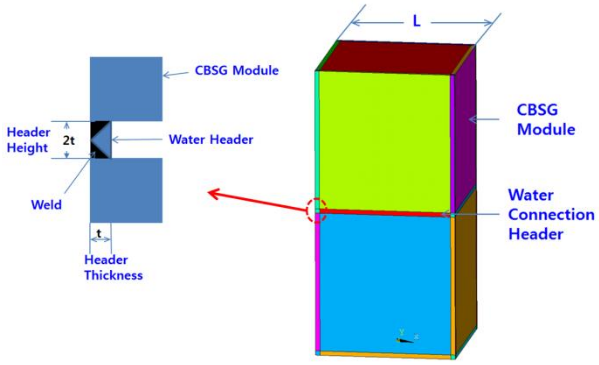


Fig. 11. Design configuration of the water connection header

Due to the high stress by the pressure of the water connection header, dimensional changes are required. Fig. 11 presents design configuration of the water connection header. The water connection header contains welds as shown in Fig. 11 and the thickness and height of the water connection header are correlated. The water connection header of thickness t requires a minimum height of 2t by considering welds. If the water connection header can be manufactured as an integrated part when the CBSG module is manufactured using HIP (Hot Isostatic Pressing), the water connection header of thickness t can be made of height t. The case study is performed by considering the weld geometry of the water connection header. Table 1 shows the calculation results of maximum stress and displacement with varying thickness and size of water connection headers for pressure loads. The cases of 1 to 3 represent the calculation results of the maximum stress and displacement according to the change in the section size for the water connection header with thickness of 30 mm. The cases of 4 to 6 represent the calculation results of the maximum stress and displacement according to thickness and height changes when the cross section size is 805.7 mm X 805.7 mm. If the thickness of the water connection headers is between 80 mm and 100 mm, the maximum stress distribution is between 110 and 142MPa.

In the consideration of analysis results of the submodels, if the cross section size of the water connection header is 805.7 mm X 805.7 mm and the thickness is 100 mm, the maximum local stress of 186 MPa is generated in the steam header and the maximum stresses of 110 to 142 MPa is generated in the water connection header.

Table 1 Case study for the size of water connection header

Items	Cases	Dimensions		Max. Stress (MPa)	Max. Displ. (mm)	Remarks
		Size[*1] (mm)	Thick. (mm)			
Water connection header	1	1611.4 x 1611.4	30	434	0.44	H[*2]= 50 mm
	2	805.7 x 805.7	30	208	0.17	H= 50 mm
	3	402.9 x 402.9	30	107	0.06	H= 50 mm
	4	805.7 x 805.7	80	122	0.08	H= 50 mm
	5	805.7 x 805.7	100	142	0.08	H= 200 mm
	6	805.7 x 805.7	100	110	0.07	H= 100 mm

[*1] Size represents the dimension for the cross sectional area of water connection header
[*2] H represents the height of water connection header

4. Conclusions

Preliminary structural analysis and case study of the submodels of the CBSG were performed and reviewed. The analysis is to determine the approximate dimensions of the CBSG for further analysis of the full model. As a result of the analysis, the cross sectional size of the CBSG was preliminarily determined to be 805.7 mm X 805.7 mm, and the thickness of the water connection header was selected to be 100 mm. Further structural integrity evaluation based on this dimension is necessary through the detailed analysis of the full model in the future, and the evaluation of the structural integrity assessment of the upper parts of CBSG which are in elevated temperature condition is necessary per ASME Div.5-HBB [4].

Acknowledgements

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