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The evaluation on the effect of shell thickness reduction for ITER vacuum vessel sector 1 and 6

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HIGHLIGHTS

- ► The thickness reduction effect of vacuum vessel during fabrication was evaluated.
- ► Linear elastic and nonlinear limit analyses were performed to confirm the design.
- ► The effect of thickness reduction is not critical in the structural point of view.
- ► The vacuum vessel with thickness reduction meets the design criteria of RCC-MR.

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ABSTRACT

The structural analyses of vacuum vessel have been performed to investigate the effect of shell thickness reduction on structural integrity. The finite element models of vacuum vessel considering original design and thickness reduction have been developed. The expected maximum thickness reduction possibly caused by forming and bending processes during fabrication was applied to the curved region of the analysis models. The linear elastic and nonlinear limit analyses have been performed. The structural integrity of main vessel including lower port stub extension has been verified in accordance with the requirements of RCC-MR. It is concluded that the inner and outer shells of main vessel still have enough strength margins under pressure and VDE (Vertical Displacement Event) load conditions in spite of thickness reduction. These results have been reviewed and approved by ITER Organization and ANB (Agreed Notified Body).

1. Introduction

The ITER main vessel is a torus-shaped, double wall structure with shielding and cooling water between the shells as shown in Fig. 1. The vessel consists of inner and outer shells, ribs, shield structures, splice plates, shielding structures for field joints, and mechanical structures on the inner and outer shells to support in-vessel components and to support the vessel weight. The double-wall structure of the main vessel is made of SS 316L(N)-IG with stiffening ribs between the shells to give the required mechanical strength and separate the shells. The inner and outer shells are both 60 mm plates and the stiffening ribs mainly 40 mm plate. The basic vessel design is an all-welded structure. The minor and maximum radii of the main vessel are 3.2 m and 9.7 m respectively, and the overall height is 11.3 m [1].

In accordance with the ITER agreement, the procurement of the major components of the ITER facility will be mostly provided in kind by the ITER parties via established Domestic Agencies (DA), which will enter into contract with companies for the fabrication and the supply of the equipment. HHI (Hyundai Heavy Industries Co., Ltd.) has received an order of the manufacturing project for the vacuum vessel sector 1 and 6 of ITER from Korea DA in 2010 and will provide the equipment by 2017 for the site construction of the whole facility. For successful fabrication of vacuum vessel, detail design and research on structural integrity is in progress by HHI. As one of the issues for manufacturing, the bending or forming process can induce the thickness reduction of shell plate and this may deteriorate the structural integrity. Therefore, the thickness reduction effect during fabrication should be investigated in the structural point of view.

2. Design requirements and analysis model

According to the forming analysis conducted by a fabrication team of HHI, the thickness reduction rate of 2–7% is expected for the

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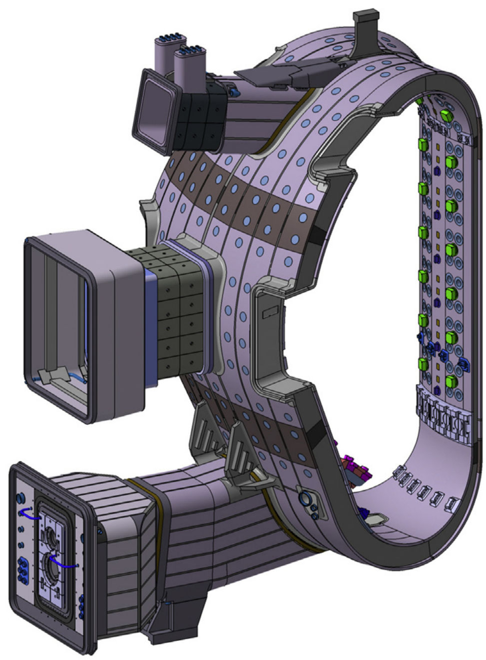

Fig. 1. Configuration of ITER vacuum vessel sector.

inner and outer shell of main vessel as shown in Fig. 2. This means that the shell thickness of 60 mm can be reduced to 58.8–55.8 mm in the curved region of main vessel. The thickness reduction in the curved region of lower port's stub extension is also expected to be 3%.

To investigate the thickness reduction effects of the main vessel, the finite element (FE) analysis is performed considering reduced shell thickness distribution. The structural analyses are performed by using the ANSYS finite element program. The units used in these analyses are mm and N. Therefore, the pressure and stress shown in the analysis results are in MPa (N/mm^2).

The FE model used for the linear analysis is a half of the 40° vacuum vessel sector in Fig. 3. The different model with coarser mesh in Fig. 4 is used for the nonlinear analysis considering the calculation time and the developed design change of support. These models have been provided by ITER Organization and developed by HHI.

The basic material used for the structural analysis is steel 316L(N)-IG and the properties change according to the actual design temperature [2]. The fixed boundary condition at the VV support and the symmetry condition at the toroidal edges are applied to the models.

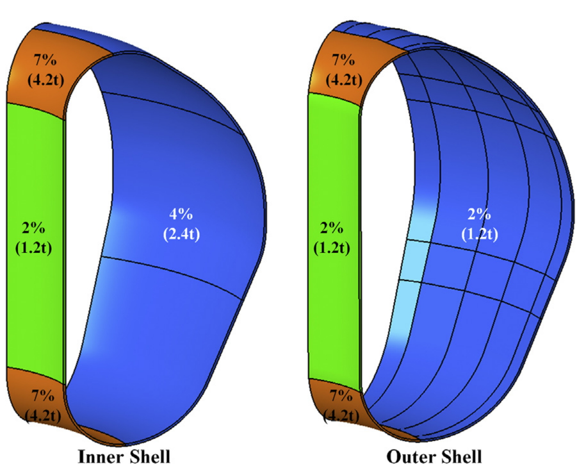

Fig. 2. Thickness reduction rate for inner and outer shell.

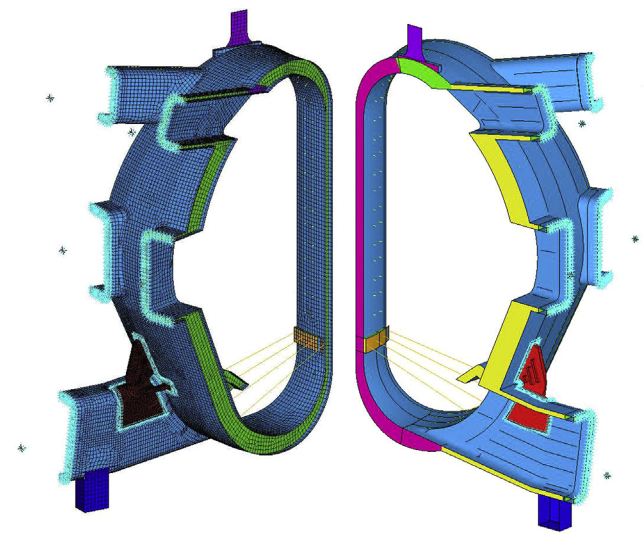

Fig. 3. Finite element model for linear analysis.

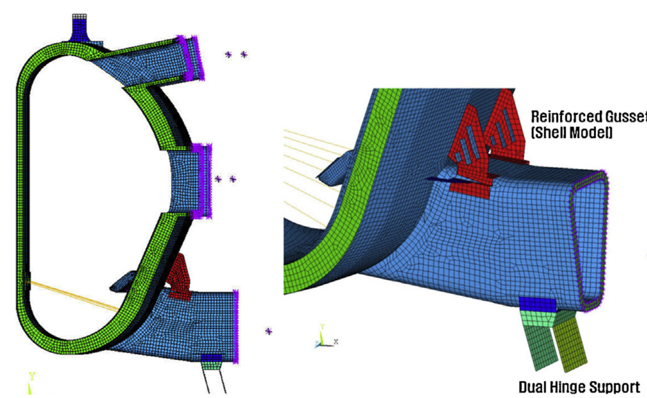

Fig. 4. Finite element model for nonlinear analysis.

ITER vacuum vessel and port components are an assembly of pressure equipment with multi-chambers. In this analysis, the baking pressure, the test pressure, and the vertical displacement event (VDE) load are selected as critical load condition for shell thickness reduction since these loads show minimum margin in IO's stress reports for ANB review [3] and for the estimation of lower port gusset [4]. The critical load conditions used in the analyses are listed in Table 1. The analyses are performed adjusting the thicknesses of inner and outer shells of main vessel according to the thickness reduction distribution. Structural design criteria of the vacuum vessel components of ITER are in accordance with RCC-MR and specified in reference document [5].

Table 1
Critical load conditions.

Design load	Temp.
Baking pressure = 2.6 MPa (2.4 ± 0.2 MPa)	200 °C
Test pressure = 3.72 MPa (1.43 × 2.6 MPa)	20 °C
$VDE(SD)_{TM}$ = Maximum of CP + DW + VDEII(SD)	100 °C
$VDE(SD)_{TM}$ + ICEII	100 °C

SD: slow downward; CP: coolant pressure; DW: dead weight; ICE: ingress of coolant event.