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Fabrication of a full-size mock-up for inboard 10° section of ITER vacuum vessel thermal shield☆

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ABSTRACT

A full-scale mock-up of VVTS inboard section was made in order to validate its manufacturing processes before manufacturing the vacuum vessel thermal shield (VVTS) for ITER tokamak. VVTS inboard 10° section consists of 20 mm shells on which cooling tubes are welded and flange joints that connect adjacent thermal shield sectors. The whole VVTS inboard is divided into two by bisectional flange joint located at the center. All the manufacturing processes except silver coating were tested and verified in the fabrication of mock-up. For the forming and the welding, pre-qualification tests were conducted to find proper process conditions. Shell thickness change was measured after bending, forming and buffing processes. Shell distortion was adjusted after the welding. Welding was validated by non-destructive examination. Bisectional flange joint was successfully assembled by inserting pins and tightening with bolt/nut. Bolt hole margin of 2 mm for sector flange was revealed to be sufficient by successful sector assembly of upper and lower parts of mock-up. Handling jig was found to be essential because the inboard section was flexible. Dimensional inspection of the fabricated mock-up was performed with a 3D laser scanner.

1. Introduction

Vacuum vessel thermal shield (VVTS) in ITER tokamak is located between vacuum vessel and magnet structure and protect the superconducting magnet by minimizing radiation heat load from vacuum vessel. The overall height of VVTS is about 12 m and its panel thickness is 20 mm. The VVTS surface is electroplated by silver, hence maintaining its emissivity below 0.05 [1]. The VVTS is cooled by pressurized helium gas flowing in the cooling tube, which is attached on the panel surface. The supplying temperature of helium gas is 80 K and its pressure is 1.8 MPa. Fig. 1 shows the 3D model of VVTS. The segments of VVTS are manufactured separately and then they are assembled each other to form a full torus shape. The VVTS is divided into two by bisecting joint located at the center (not shown in Fig. 1). ITER VVTS has progressed in its design as described in references [2–4]. The design has been supported by structural and thermal analyses [2,3].

As shown in Fig. 1, VVTS segment is a slender body and its structure is not closed, i.e. open structure. Therefore, each VVTS segment is susceptible to distortion caused by cutting, machining or welding. All segments are assembled by the flange joints, which are welded to the panels. Tolerance requirement of the flange is strict for proper assembly of entire VVTS. Manufacturing processes such as forming/bending, machining and welding are not verified yet for the huge, slender and open-structured VVTS.

In order to reduce the risks for the manufacturing processes of the entire VVTS, a full size mock-up was made for 10° inboard section. All processes of VVTS manufacture except silver electroplating were performed and verified in this mock-up fabrication. Several pre-qualification tests were done before the mock-up fabrication. Throughout the manufacturing processes, problems and solutions we have found are fully described in this paper. 3D scanning was performed to check the whole dimension of the mock-up. Finally, consideration points for future main manufacture are suggested.

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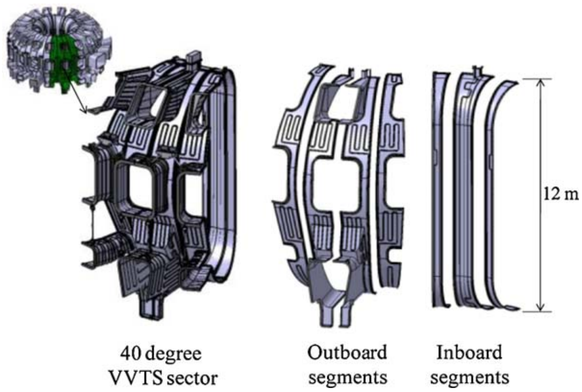

Fig. 1. VVTS 3D model.

2. Overview

2.1. *Specification of VVTS inboard 10° section*

Inboard 10° section consists of flange, shell and support as shown in Fig. 2. Bisecting flange divides inboard into upper and lower parts. VVTS inboard is assembled with outboard section by top and bottom flanges, while the inboard 10° section is assembled to adjacent section by side flange. Cooling tube is directly welded on the shell. The outer diameter of cooling tube is 13.5 mm and its thickness 2 mm, respectively. The thickness of shell is 20 mm, while the thickness of flange is 56 mm. M16 bolt is used for joining the flanges. Material of shell and flange is stainless steel 304L. The inboard support is a strip type so as to be fitted in the narrow gap between the VVTS and the magnet. The inboard support is attached to the shell and supported to the magnet structure.

2.2. *Overall manufacturing procedure of mock-up*

An overall procedure for the mock-up fabrication is schematically illustrated in Fig. 3. After upper/lower shells, central shell, flange and support are machined with or without forming, they are welded together. Then cooling tubes are welded on the shell surface. Final machining of flange is followed and finally bisecting flanges are fastened. Note that 3D forming is only applied to the upper and lower shells. Before forming and final machining of sector flange, jigs are prepared independently.

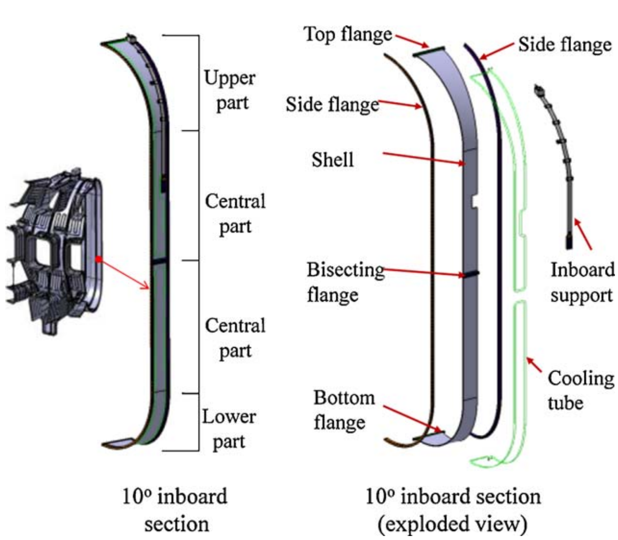

Fig. 2. 3D model of VVTS inboard 10° section.

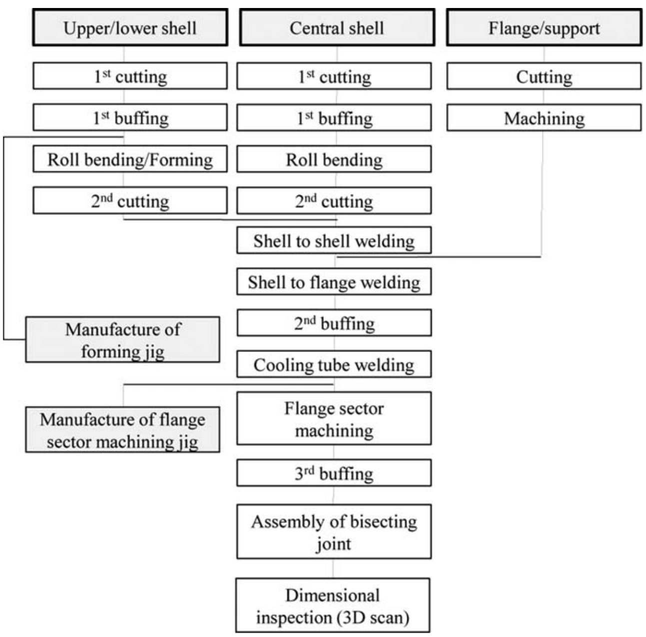

Fig. 3. Flow chart of manufacturing process for the mock-up.

3. Fabrication detail

3.1. *Cutting, bending and forming*

Shell plate is made by cutting stainless steel plate using a laser cutting machine. Margin for upper/lower shell cutting is 3 mm for width and 5 mm for lengthwise to compensate a possible shape change after forming. When the central shell is inserted in the roll bending machine, both ends of shell do not bend (Fig. 4). Therefore, large margin (∼170 mm) for widthwise is required for the cutting of central shell. For the cutting of flange raw material (thickness = 70 mm), a plasma cutting machine is used. 3 mm margin is considered for the plasma cutting to eliminate thermally affected zone of the flange material. Flange shape is then made by a milling machine.

Upper and lower shell needs 3D forming as shown in Fig. 5. A forming jig is prepared after several pre-qualification tests. The

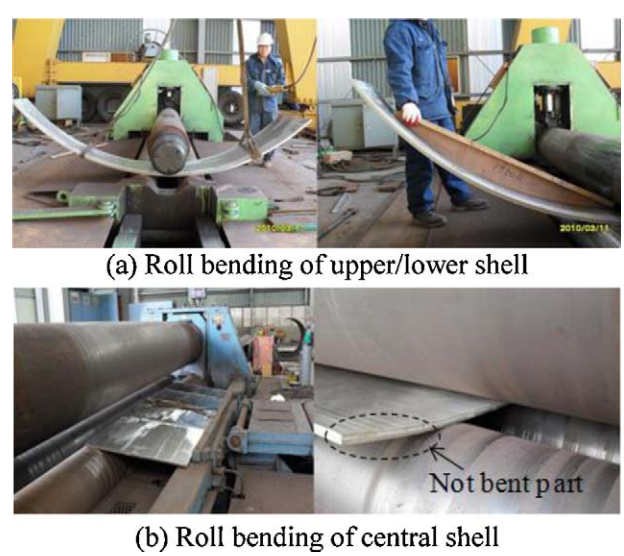

Fig. 4. Roll bending of shell. (a) Roll bending of upper/lower shell. (b) Roll bending of central shell.