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Determination through the distortions analysis of the best welding sequence in longitudinal welds VATS electron beam welding FE simulation

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ABSTRACT

This paper presents a detailed finite element simulation of the longitudinal rib welds of Vessel Advanced Technology Segment (VATS) by e-beam welding. Nine different simulation sequences were carried out to explain the different mechanisms that drive the distortions process during welding and to lead to an optimum sequence which minimizes the final distortions. The simulations were used to guide the manufacture of the final sequence of the VATS. Distortion measurements taken after welding compared very well with the simulated results.

1. Introduction

The ITER vacuum vessel (VV) is an all-welded torus-shaped double-wall structure with stiffening ribs between the shells. It is on the critical path in the construction schedule and it is also a safety important class component (SIC) [1–4].

This paper describes the methodology and conclusions from FEA simulations performed to determinate improved sequences for the VATS electron beam welding.

The influence of welding sequences on welding residual stresses was studied in [5], in a thin plate in [6], in joints with X-shaped groove in [7] and on welding distortions in pipes in [8]. In this paper the influence of the sequences are studied in a very large structure taking into account the characteristics mechanical-thermal of the material and the real boundary conditions of the model. Fig. 1 shows the VATS in the vacuum chamber of DCNS before welding.

Previously, a proposed ITER vacuum vessel fabrication specification and results of the full-scale partial mock-up test were made [9].

In previous papers [10–11], the finite element simulation was used to validate the model by means of distortions and residual tensions. In this case the simulation was used to manufacture the VATS with an improved welding sequence based on the indicated tolerances.

2. Finite element model

A realistic finite element model of the VATS was coded using ANSYS® [12]. Fig. 2 shows the whole finite element model built to perform the simulation and the boundary conditions used in the analysis. Eight-node 3D structural elements were used to mesh the model, which simulated the VATS structure in a realistic way. To constrain the model, complex boundary conditions were set using 3D node-to-node contact element to simulate a simply supported condition of the whole assembly on a flat surface. These elements were characterized with a small gap (0.1 mm) and contact stiffness in order to achieve a realistic contact condition. In addition the contact elements were provided with an elastic Coulomb friction model to prevent solid rigid lateral displacements. The same boundary conditions described in Fig. 2 have been used in every simulation performed. They take into account in a realistic way one fixation alternative and the gravity loads for weld position as well.

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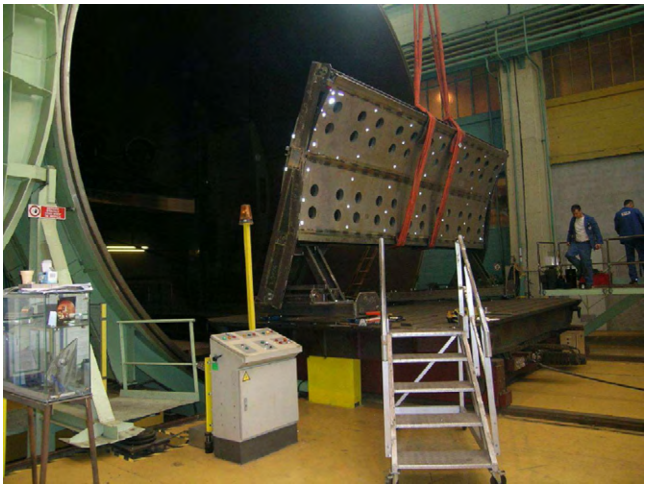

Fig. 1. VATS in the vacuum chamber of DCNS before welding.

EB tack welds (one tack weld, 150 mm long and 10.5 mm deep, every 150 mm) were included in the FE model using elements instead of using coupled DOF. The tack welds were placed in the external sides of the assembly.

For material characterization physical thermal properties are considered variable over the whole temperature range expected [13–15]. Table 1 shows the thermal and mechanical properties assumed [16–21].

In order to obtain accurate predictions of welding distortions and residual stress fields, it is necessary to use a realistic material behaviour model over the whole range of analysis temperatures. Austenitic stainless steel designated as 316L(N)-IG has been selected as the main structural material for the ITER vacuum vessel [22]. The chosen behaviour model for steel 316 L(N)-IG [23] is characterized by an isotropic hardening rule (associative flow rule: same yield and flow functions).

The yield criterion assumed is Von Mises criterion and the hardening law is based on the Voce's law [24]. Field coupling due to plastic heat generation is neglected in the analysis. Material behaviour model is summarized in [10,11].

3. VATS initial weld sequence

Fig. 3 shows the weld sequence considered in the first analysis. In the three sequences, each pair of passes (P1, P2, . . ., P7, P8) was welded in inverse mode, that is, one starts on one side and the other on the opposite. The simulated cycle includes the weld runs and the cooling periods according to the process specifications of DCNS (Direction des Constructions Navales Services), the manufacturer in charge of building the mock-up. For each change of weld position it is necessary to break the vacuum in the chamber. Therefore, this means a complete cooling period. In this scenario, every sequence analyzed has three cooling periods. First, three alternative sequences have been studied without any internal jig to fix or restrain any part of the assembly (VATS1, VATS2 and VATS3).

During the initial process set up several internal jigs were proposed by DCNS to fix the left part of the two main shells. To evaluate the effects of the proposed jigs in the final distortions computed, the three mentioned sequences were analyzed again including internal jigs (VATS1J, VATS2J and VATS3J) as shown in the Fig. 4.

The chosen boundary conditions allow solid rigid movement during the analysis. Then, the distortions predicted in every sequence analyzed should be compared in the same reference by superimposing the different deformed configurations. Before the end of the analysis a new solution is performed in order to fix a unique reference frame. This additional solution run imposes a translational and rotational displacement as a solid rigid over the whole assembly in order to place it in the defined reference. Fig. 5 shows the reference frame chosen.

To control the transient solution 18 control points have been defined in the model in order to capture the transient displacement and temperature evolution during the whole weld cycle. To show the analysis process Fig. 6 shows the mentioned post process procedures for the VATS1 without jigs and with jigs (Fig. 7) sequence.

The main conclusions derived from the first analysis are that it is difficult to find independent causes associated with the distortion process and the fact that the predicted effects are not intuitive at all. Comparing the results for both sequences it is observed that the effect of the jigs over the final distortions is negligible. The same trends are observed in VATS2/VATS2J and VATS3/VATS3J sequences.

4. VATS alternative weld sequences

The previous analysis suggested that the weld runs in each rib (direct sequence means that each pair of passes is carried out in the same direction and inverse sequence means that each pair of passes is carried out each one in opposite directions) could have certain influence in the distortion process. In order to study this issue two new alternative sequences were simulated, using direct schemes. They were referenced as VATS4 and VATS5 sequences (Fig. 8).

The results given by these two new analyses confirm that direct sequences look more suitable in order to minimize weld distortions. However this conclusion could not be clearly established because of the fact that there are several other overlapping effects which drive the distortion. Then a new approach was developed in order to understand these simple mechanisms which govern the distortion process and analyse them separately. This new analysis approach was based on comparing the distortions due to only two longitudinal runs. Up to eight different alternatives were simulated in order to isolate each different single distortion mechanism through a detailed analysis of the effects achieved in the two rib welds simulated under several execution conditions (direct/inverse, rigid/flexible side, etc.).

5. A new analysis approach: understanding the distortion process

The new simulations performed lead to the identification of three essential distortion mechanisms associated to different process variables.

5.1. Use of inverse rib weld sequence

5.1.1. Simulation calculated effects

Twist distortion of the whole assembly for both are achieved starting the welds in both rigid and flexible side. Twist distortions lead to an edge relative displacement of 5 mm approximately per each pair of rib welds (Fig. 9).

The amplitude of dimension "*D*" in the transient displacement solution (Fig. 10) gives an approximate measure of the shape edge distortion (twist effect). Same effects were observed in VATS2 and VATS3 simulations.