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Assessment of HCLL-TBM optimum welding sequence scenario to minimize welding distortions

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HIGHLIGHTS

- A specific experimental and numerical simulation method is proposed.
- The best TBM mock-up welding sequence is identified among four.
- One of the key points to minimize welding distortions is to alternate the weld passes order from one groove side to another.
- When the passes order alternates from both groove side and v-SP top/bottom, a favorable v-SP S-curved profile is obtained.
- Measured TBM mock-up welding distortions are qualitatively in accordance with the simulation.

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ABSTRACT

The ITER HCLL-TBM (Helium Cooled Lithium Lead Test Blanket Module) box assembly development implies the welding development of the following components: the Box and the Stiffening Grid (SG) made of vertical and horizontal Stiffening Plates (noted respectively v-SP and h-SP). This multi-chamber box structure in EUROFER97 steel is made of plates cooled by multiple meandering channels where circulates pressurized helium. For the assembly of these components, characterized by numerous multipass welds, Gas Tungsten Arc Welding (GTAW) is envisaged as reference process. Moreover, the TBM has large dimensions and thin plates which makes it very sensitive to welding distortions and is problematic regarding the assembly feasibility and compliance with geometric tolerances. This paper presents the numerical simulation and experimental work performed to optimize the v-SP to box assembly sequence, which is the most critical assembly regarding distortions, in order to minimize welding distortions.

One of the technical lock of this study is high calculation times needed for this large component which implies to set up a simplified welding simulation method. The study is composed of three main phases: an experimental-numerical study of a T-joint fillet mock-up GTAW used to develop the preliminary welding procedure and to validate a simplified simulation method, a numerical optimization of the v-SP to box welding sequence via the simplified method, and the experimental application of the optimized v-SP to Box welding sequence on the TBM mock-up. The calculation and comparison of four different v-SP to box welding sequences allowed to identify the best sequence regarding welding distortions and to apply it experimentally.

1. Introduction

The ITER HCLL-TBM (Helium Cooled Lithium Lead Test Blanket Module) box assembly development implies the welding development of the following components (Fig. 1a): the Box, made of the First Wall (FW) and Side Cap (SC), and the Stiffening Grid (SG), made of the vertical and horizontal Stiffening Plates (noted respectively v-SP and h-SP). This multi-chamber box structure is made of plates cooled by multiple meandering channels where circulates pressurized helium. For the assembly of these components, characterized by numerous welds, automatic multipass Gas Tungsten Arc Welding (GTAW) is envisaged as reference process [1].

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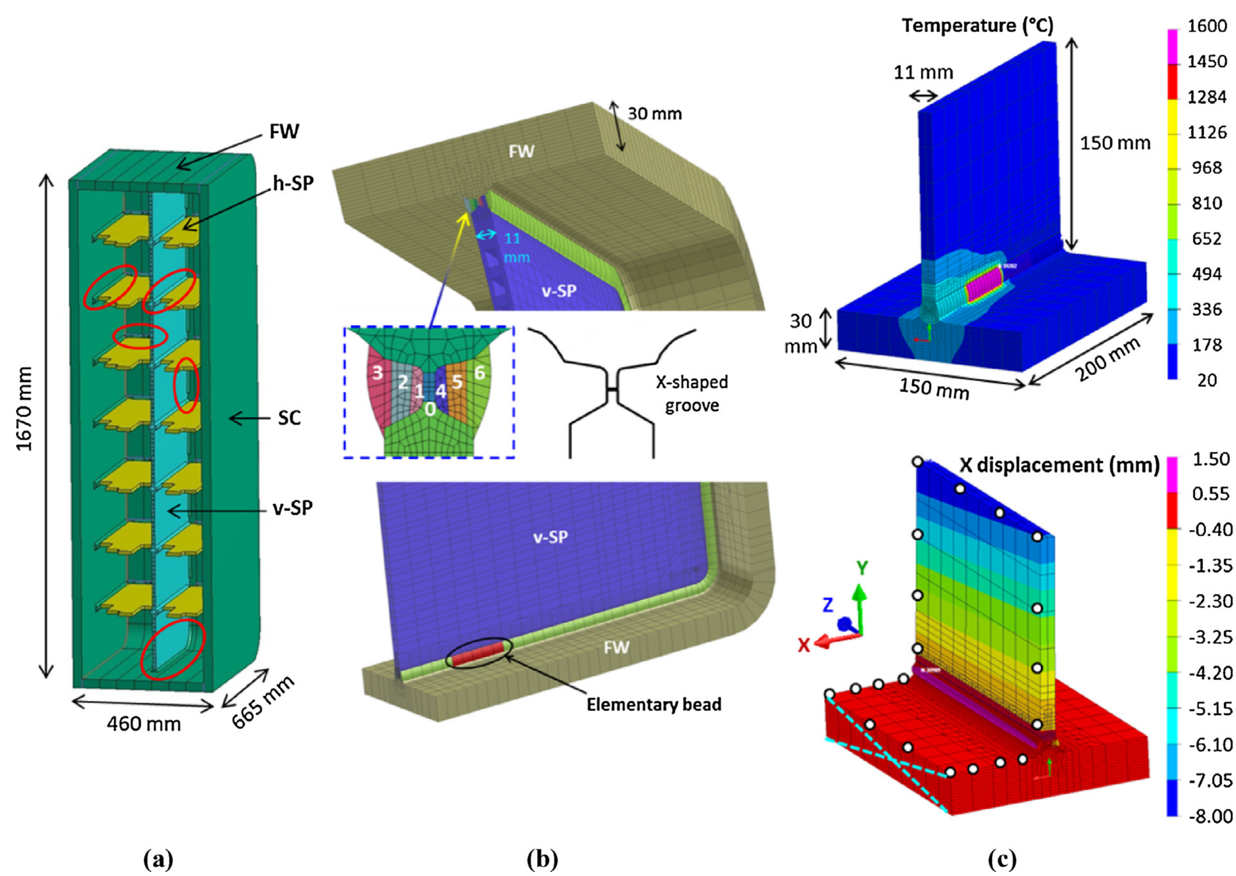

Fig. 1. Schematic of the TBM mock-up and welds localization (a); Mesh images for v-SP to Box welding simulation (b); Temperature during welding (up) and X displacements after welding (down) for the T-joint mock-up (c).

Moreover, the TBM has large dimensions (Fig. 1a) and thin plates (thickness of 11 mm for v-SP and 30 mm for the Box) which makes it very sensitive to welding distortions and is problematic regarding the assembly feasibility and compliance with geometric tolerances. The goal of this study is to optimize the TBM welding sequence so as to minimize welding distortions. The choice made is first to weld the v-SP inside of the Box and then to insert and assemble the h-SPs. We focus on the most critical assembly regarding distortions which is v-SP to Box assembly (Fig. 1b). Indeed, the main difficulty is to be able to insert all h-SPs into the Box after v-SP welding; once all h-SPs are inserted and clamped, no major distortion should occur during h-SP welding. TBM distortion optimization is evoked in the literature [2–4] and is treated only at a local scale on elementary and small components. Nevertheless, in ITER framework, distortion studies at the global component scale were carried out on a vacuum vessel sector [5–7].

The methodology used and presented in this paper implies experimental and numerical simulation work on a TBM mock-up made of P91 steel (X10CrMoVNb9-1) instead of EUROFER 97 for the real TBM, their weldability behavior is very similar. This mock-up has the same dimensions as the real TBM (Fig. 1a) but channels are present only in the v-SP and are generated by drilling. The approach is first to set up the welding parameters and operatory conditions, then to identify the best welding sequence by simulation and at last to reproduce it experimentally and check the consistency with the calculation. One of the technical challenges of the numerical study is the very high calculation times needed for this large component which implies to set up a simplified welding simulation method. Several simplified methods exist to decrease calculation times of large component welding [8–16].

Specifically, three main phases follow one another in this study: an experimental-numerical study of a T-joint fillet mock-up GTAW (representative of the TBM welds and illustrated in Fig. 1c) used to develop the preliminary welding procedure and to validate the simplified welding simulation method, a numerical optimization of the v-SP to Box welding sequence via the simplified method validated in the first phase, and the experimental application of the optimized v-SP to Box welding sequence on the TBM mock-up. We first present the experimental work performed on T-joint and TBM mock-ups, then we detail the numerical simulation of the relevant mock-ups, and at last and evoke the obtained results which allowed us to identify the best welding sequence, among the tested four, and to apply it experimentally.

2. Experimental work

2.1. T-joint mock-up welding

The T-joint mock-up is representative of most of the TBM welds (Fig. 1c). In particular, it has the same chamfer geometry and it is composed of two plates with the same thicknesses as v-SP and Box (respectively 11 and 30 mm). No channels are present. This mock-up is used to develop the preliminary welding procedure, applied on the TBM mock-up, and to validate welding simulation via welding instrumentation and post welding measurements.

The X-shaped welding groove is machined on the 11 mm thick plate (Fig. 1b). The welding filler metal used is Thermanit MTS3 (wire diameter of 1.2 mm). After a tack weld (made of three 20 mm long tacks), 7 welding passes are performed: one root pass to guarantee the full penetration and six filling passes (three passes in each groove side). The welding sequence used implies to fill com-