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First wall fabrication of 1/3 scale china dual functional lithium lead blanket

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HIGHLIGHTS

- RAFM rectangular tubes were fabricated by cold drawing, and the dimensional accuracy and mechanical properties of rectangular tubes were tested.
- Rectangular tubes were bent by rotary bending, and milled plates were curved by molding. Its accuracy meets the requirement for TBM assembly.
- FW were pre-sealed by electron beam welding, and assembled by hot isostatic pressing–diffusion bonding.
- The as-HIPed FW mock-up was tested by optical observation and X-ray detection, it revealed obviously that the tubes and plates were bonded well.

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ABSTRACT

The dual functional lithium lead blanket is chosen as one of the candidate blankets for China fusion reactor, for its advantages of tritium breeding and good heat exchange performance. As one of the most important components of the blanket, the first wall (FW) is assembled with China low activation martensitic (CLAM) rectangular tubes and plates by hot isostatic pressing (HIP)–diffusion bonding (DB). In this work, the rectangular tube fabrication and FW assembly were carried out in order to verify the feasibility of the FW fabrication scheme. The mechanical property and dimensional accuracy of CLAM rectangular tubes were tested, the microstructure observation and non-destructive detection revealed the sound of the FW mock-up, and the reliability of the FW mock-ups is under evaluation.

1. Introduction

The blanket is the most important functional component of fusion reactor for energy conversion and fuel breeding. According to different ways of cooling and tritium breeding, several blanket concepts were developed in EU, USA, Japan and China [1–4]. On account of the features of high tritium breeding ratio, online tritium extraction, excellent heat exchange performance and so on, the dual functional lithium lead (DFLL) blanket was proposed [5,6], and also developed in China [7–9], as Fig. 1 shown. However, the energy of fusion neutrons is as high as 14 MeV, and the maximum heat load on the first wall (FW) of the blanket is about 1.5 MW/m^2 even more, which proposes high requirements on the FW fabrication and its thermal-hydraulic performance [10].

The FW of the China DFLL blanket is a U-shaped component with lots of rectangular channels embedded, as Fig. 2 shown. From the impact of the fusion heat load point of view, the rectangular channels are beneficial for high pressure helium flow to remove high heat load from fusion plasma and prevent heat accumulation in the FW [11], and hot isostatic pressing–diffusion bonding (HIP–DB) is appropriate for the joint of components of the FW [12]. Moreover, the structural material should be as thin as possible in the breeding blanket, from the perspective of considering thermal stress [13]. Otherwise, The blanket is made with reduced activation ferritic/martensitic (RAFM) steel, taking radiation effects of fusion neutrons into account [14–16]. However, RAFM steel is a kind of martensitic steel with limited formability, which proposes high requirements on preparation of precision thin-walled parts for blanket. Overall, the FW is a very complex structure and its molding and assembly are key issues in blanket fabrication.

After careful consideration of the structure characteristics of the FW, the "tubes forming + HIP" is the preferred choice. It has

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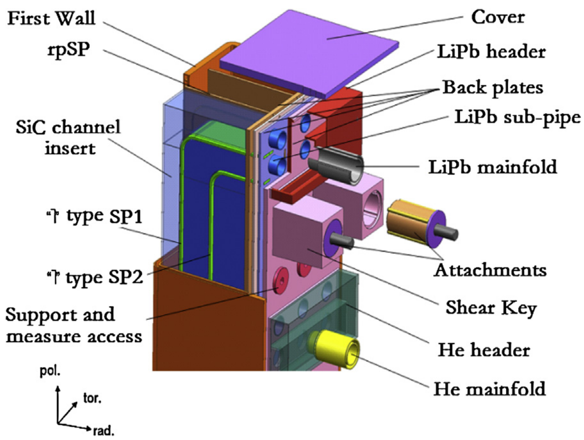

Fig. 1. The 3D model diagram of China DFLL blanket.

two kinds of assembly processes [17,18]. One is to use thin tubes inserted between the grooved plates before HIPing. During the HIP cycle, the thin tubes expand and conform to the rectangular grooves. The other is to use the relatively thick rectangular tube and two flat plates, and it is called sandwich method.

In this paper, the FW of 1/3 scale DFLL blanket was fabricated by sandwich method to demonstrate the feasibility of FW assembly. The RAFM rectangular tubes were fabricated by cold drawing to develop the helium cooling channels, and the FW was assembled with RAFM plates and rectangular tubes by HIP–DB.

2. FW fabrication

The China DFLL blanket is fabricated with China low activation martensitic (CLAM) steel, one of the RAFMs, which was developed at the Institute of Nuclear Safety and Technology, Chinese Academy of Sciences with wide collaborations [19–22]. The CLAM rectangular tubes were formed with seamless round tubes by cold drawing, hereafter, the rectangular tubes were bent by rotary bending, and the milled plates were bent by molding. Then, the two plates were inserted with rectangular tubes to get a sandwich structure, and the outer boundary of tubes and plates was sealed by electron beam welding (EBW). After that, degassing and vacuuming, as the pre-processing for the HIP treatment was conducted on the assembled part. Finally, the FW was formed by HIP–DB. The routine is given as Fig. 3 shown.

2.1. Rectangular tube

The CLAM rectangular tube was produced with seamless round tube which was manufactured by hot piercing and cold drawing method. The round tubes with dimensions of $\Phi 32 \times 2.5$ were cold drawn into rectangular tubes by cold-draw equipment, the outer dimension of the as – received rectangular tube was 25 mm × 20 mm, and the thickness of the tube was 2.5 mm, as seen in Fig. 4.

The dimensional accuracy of the as-drawn rectangular tubes was evaluated from head, middle, and tail of the tube. The twist deviation was less than 0.3 deg/m and the bow from 0.3 to 0.5 mm/m. The dimensional results were listed in Table 1. The tube thickness agreed well with expected, and its mean value was in the design tolerances. The outer radius was less than 2 mm, and the dimension tolerance of outer dimensions was good as far as the short side was concerned. Overall, the dimensional accuracy of the rectangular tubes met the requirement of the FW assembly.

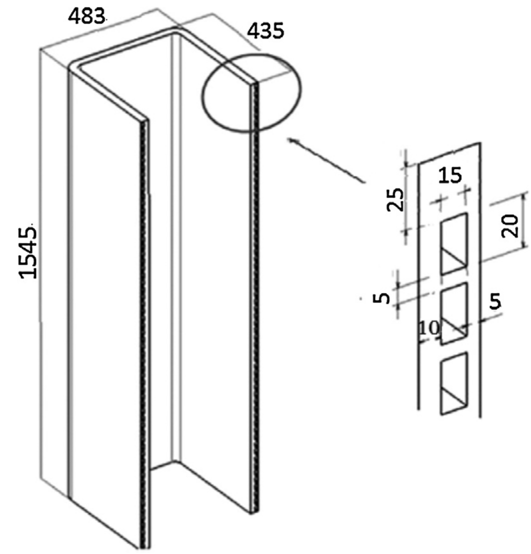

Fig. 2. Schematic of the China ITER DFLL blanket FW.

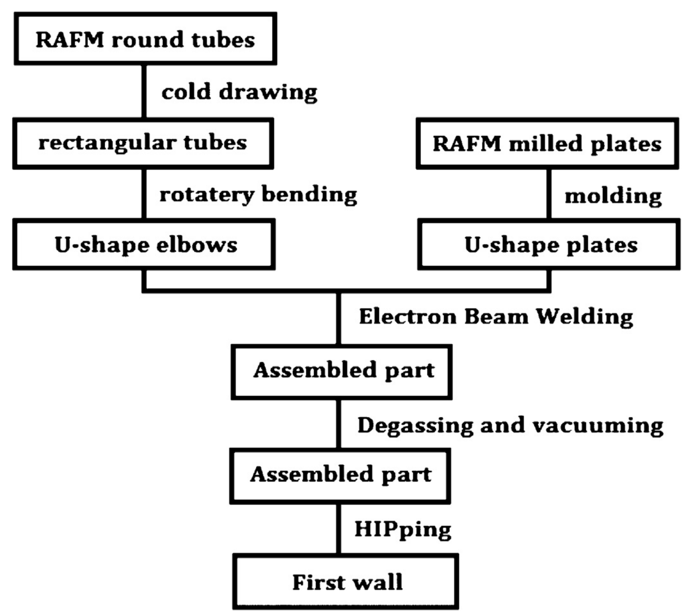

Fig. 3. The assembly routine of the first wall of DFLL blanket.

2.2. Bending

The CLAM rectangular tubes were bent by rotary bending, as seen in Fig. 5, and the plates were curved by molding, as Fig. 6 shown. The accuracy of the curved plates was evaluated.

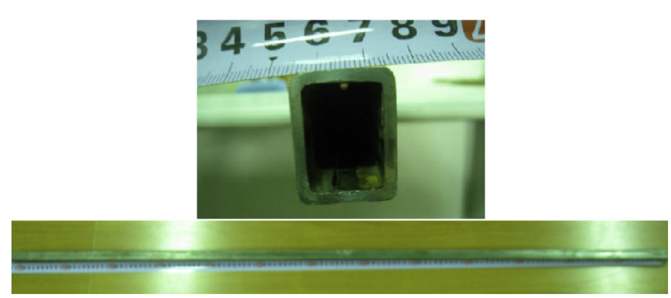

Fig. 4. The as-dawn CLAM rectangular tube.