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The European ITER Test Blanket Modules: Current status of fabrication technologies development and a way forward

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HIGHLIGHTS

- Significant progress on development of welding procedures for European TBM achieved.
- Fabrication processes feasibility based on diffusion and fusion welding demonstrated.
- TBM box assembly welding scenarios investigated and welding scenarios identified.
- Future qualification of pF/WPS proposed through realization of a number of QMUs.

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ABSTRACT

The paper reviews fabrication technologies and procedures applied for manufacturing of the TBM sub-components, like, HCLL and HCPB cooling plates, HCLL/HCPB stiffening plates, and HCLL/HCPB first wall and side caps. The used technologies are based on fusion and diffusion welding techniques taking into account specificities of the EUROFER-97 steel. Development of a standardized procedure complying with professional codes and standards (RCC-MRx), a preliminary fabrication/welding procedure specification (pF/WPS), is described as well as a fabrication and characterization of feasibility mock-ups (FMU) aimed at assessing the suitability of a fabrication process for fulfilling the design and fabrication specifications. Also, fabrication procedures for the TBM box assembly are presently under development through collaboration between European Fusion Laboratories and Industry for the establishment of an optimized assembly sequence/scenario and development of standardized welding procedure specifications. Selection of optimized assembly scenario takes into accounts not only the design requirements and fabrication possibilities/constraints but also maximum accessibility to the welds for sound non-destructive examination in compliance with welds classification. A future approach towards qualification of the developed fabrication technologies and procedures, through a number of medium to full-size qualification mock-ups according to European standards, is outlined before construction of the first TBMs.

1. Introduction

Future fusion reactors will need to re-generate the tritium consumed in deuterium–tritium reactions and to extract the thermal power generated by the plasma under economically sound conditions for electricity production. These functions shall be ensured by a so-called tritium breeding blanket covering the inner side of the vacuum vessel and directly facing the plasma. For several years, Europe and other ITER parties have been developing tritium breeding blankets concepts that will be tested in ITER under the form of Test Blanket Modules (TBMs) located in equatorial ports of ITER. Up to six TBM concepts will be tested simultaneously in ITER [1].

Europe is currently developing two reference breeding blankets concepts for DEMO reactor specifications that will be tested in ITER under the form of TBMs [2,3]: (i) the helium-cooled lithium-lead (HCLL) concept which uses the eutectic Pb–16Li (enriched in ^{6}Li) as both tritium breeder and neutron multiplier, (ii) the

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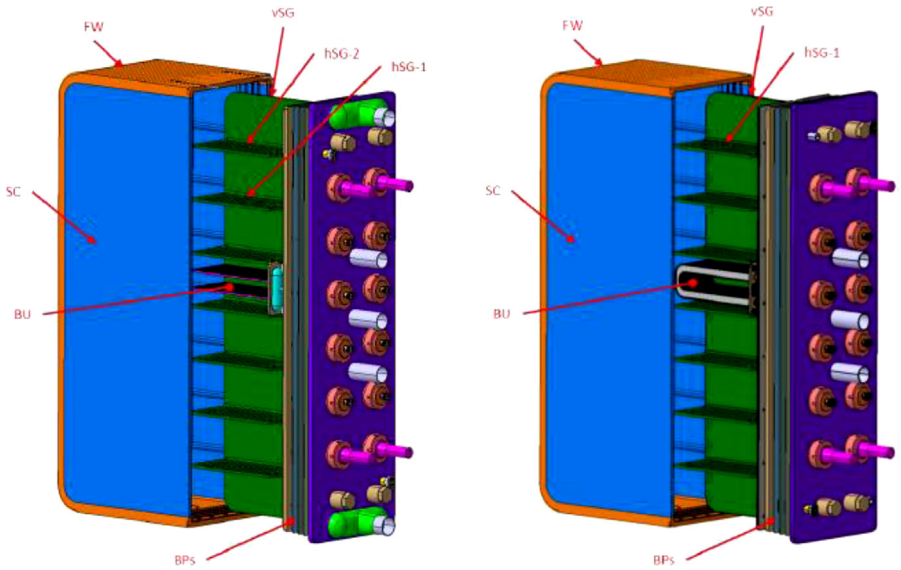

Fig. 1. HCLL (left) and HCPB (right) global view.

helium-cooled pebble-bed (HCPB) concept with lithiated ceramic (enriched in ^{6}Li) pebbles as tritium breeder and beryllium pebbles as neutron multiplier. Both concepts are using a reduced activation ferritic martensitic steel as structural material, the EUROFER-97 (X10CrWVTa9-1) [4], and pressurized helium technology for efficient heat extraction (300–500 °C, 8 MPa).

Each TBM (see Figs. 1 and 2) consists mainly of a EUROFER-97 steel box containing the tritium breeder and neutron multiplier materials as well as a series of heat extraction plates that are directly in contact with these materials. An internal stiffening grid provides mechanical resistance and segregates the volume into cuboids containing breeder/multiplier materials and cooling plates. All EUROFER-97 steel structures are actively cooled by circulation of pressurized Helium in internal channels. A manifold system located at the back of the TBM ensures the distribution/collecting of Helium to/from the various parts of the TBM structures, in a way that optimizes the temperature of TBM materials according to their function.

Both European HCLL and HCPB TBMs will be tested simultaneously in the ITER equatorial Port #16. TBMs will be vertically oriented and inserted in a port plug frame connected to the vacuum vessel port extension.

TBMs, like other ITER in-vessel components, are not part of the first confinement barrier (vacuum vessel), and are therefore classified as a non-safety important component. However, they fall under the scope of the French Decree on Pressure Equipment (PE) [5] and the French Order Nuclear Pressure Equipment (NPE) [6].

Up to now, the strategy for fulfilling Essential Safety Requirements imposed on TBMs by PE and NPE regulation was based on the French nuclear construction code RCC-MR 2007 completed by ITER Structural Design Criteria for In-Vessel Components (SDC-IC) for specific rules for irradiated materials. The 2012 edition of the RCC-MR code integrates specific rules for irradiated materials, thus forming a unique code, the RCC-MRx, which shall become a reference for the design and manufacturing of TBMs and, on a longer term, of DEMO blankets [7]. For that purpose, European efforts have been dedicated towards the addition of EUROFER-97 design limits and qualified fabrication procedure specifications in the RCC-MRx 2012 and next editions. Recently EUROFER-97 has been integrated in the RCC-MRx 2012 under the Section III Tome 6 “Probationary Phase Rules” [4].

2. Subcomponents fabrication development

2.1. Development strategy and requirements

The fabrication processes feasibility for TBM EUROFER-97 subcomponents, i.e. first wall (FW), side cap (SC), horizontal and vertical stiffening plate (hSP/vSP) and cooling plates (CP), and their assembly by welding was previously demonstrated at laboratory scale [8].

For the subcomponents fabrication, processes are mostly based on the use of diffusion welding (DW) and specific fusion welding technologies (e.g. laser welding) taking into account specificities of the EUROFER-97 steel. Welding procedure specifications (WPS) are needed in order to provide a well-defined basis for planning of the welding operations and for quality control during welding. In view of their integration in RCC-MRx or presentation as a code case for TBM licensing, welding procedures standardization and qualification according to the professional guides and standards is needed. Welding procedure qualification shall ensure and demonstrate that the welding process is suitable to meet the quality requirements

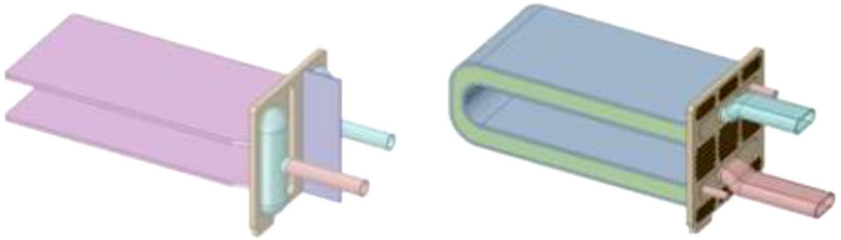

Fig. 2. HCLL (left) and HCPB (right) breeding unit (BU).