Fusion Engineering and Design 85 (2010) 1766–1771

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Overview of the TBM R&D activities in Japan

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ARTICLE INFO

Article history:
Available online 16 June 2010

Keywords:
Water cooled ceramic breeder TBM
Blanket module fabrication technology
F82H
High temperature Li–Pb blanket
Li/V blanket
Flibe blanket

ABSTRACT

In Japan, development of Water Cooled Ceramic Breeder (WCCB) blanket is being performed as the primary candidate of Test Blanket Module (TBM) toward DEMO. Also development of high temperature Li–Pb blanket, Li/V blanket and Flibe blanket are being performed toward the advanced DEMO blanket. Regarding the WCCB TBM development, real scale First Wall (FW) was fabricated using Reduced Activation Ferritic Martensitic Steel (RAFMS), F82H and successfully tested by heat flux equivalent to ITER TBM condition, 0.5 MW/m^2, 80 cycles with the same coolant condition as DEMO. Also, real scale Side Wall (SW) and real scale breeder pebble bed structure are successfully fabricated. Furthermore, asemmbling test of the real scale FW plate mockup and SW plate mockup was performed to clarify the welding condition to form TBM box structure. All key technologies of blanket module fabrication has been addressed and almost achieved toward TBM. Regarding the development of liquid breeder blankets, all key technologies, such as, material compatibility and mass transfer, tritium recovery performance, insulation coating development, were covered, by using elementary experiments to convection loops of Li–Pb, Li and Flibe. High temperature heat exchange test up to 900 °C has been initiated by using Li–Pb test loop.

1. Introduction

In Japan, ceramic breeder blankets are developed as a primary option of the DEMO blanket. Also, liquid breeder blankets are developed as potential options for the advanced DEMO blanket. In the development strategy of Japan toward the DEMO blanket, Test Blanket Module (TBM) test program in ITER is regarded as one of the most important milestones, by which integrity of candidate blanket concepts and structures will be qualified by the same scale as DEMO blanket module in a real fusion environment in ITER. In the TBM program, Japan is proposing to test the Water Cooled Ceramic Breeder (WCCB) TBM as the primary candidate blanket. Also, Japan has a position to participate testing of other types of TBMs, such as liquid breeder blankets and helium cooled ceramic breeder blankets. For the TBM testing in the real fusion environment in ITER, it will be required to clear milestones to demonstrate the consistency with ITER design and ITER safety requirements, and the integrity of the TBM and its systems, prior to the installation in ITER. Milestones of ITER TBMs prior to the installation consist of milestones on safety assessment, module qualification and design integration in ITER. Japan Atomic Energy Agency (JAEA) is performing the development of fabrication technologies and design and safety assessment for the WCCB TBM with a collaboration of universities and National Institute for Fusion Science (NIFS). Currently, the engineering R&Ds and design and safety work are being performed, on the basis of well accumulated element technologies, aiming at the verification of TBM milestones and initiation of testing of the WCCB TBM in ITER in earliest timing of ITER operation. Regarding the liquid breeder blankets, universities and NIFS are performing development of key technologies for all of Li–Pb blankets, Li based blankets and Flibe blanket, aiming at the establishment of advanced DEMO blanket concepts and potential participation to the TBM testing program. Currently, the technology development of liquid breeder blankets in Japan is showing significant progress by scientific research and proceeding to the engineering scale loop tests. This paper overviews the recent achievements of R&Ds of the WCCB TBM and liquid breeder blankets in Japan.

2. Activities of the development of the WCCB TBM

2.1. Design of WCCB TBM

The WCCB TBM is designed to represent important features of the design of DEMO blanket [1], such as the concept of layered pebble beds of breeder and multiplier which is parallel to the first wall surface, a concept of the first wall with built-in rectangular cooling channels, and so on. Fig. 1 shows the structure of the WCCB TBM [2]. The WCCB TBM consists of two sub-modules integrated at the rear

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doi:10.1016/j.fusengdes.2010.05.029

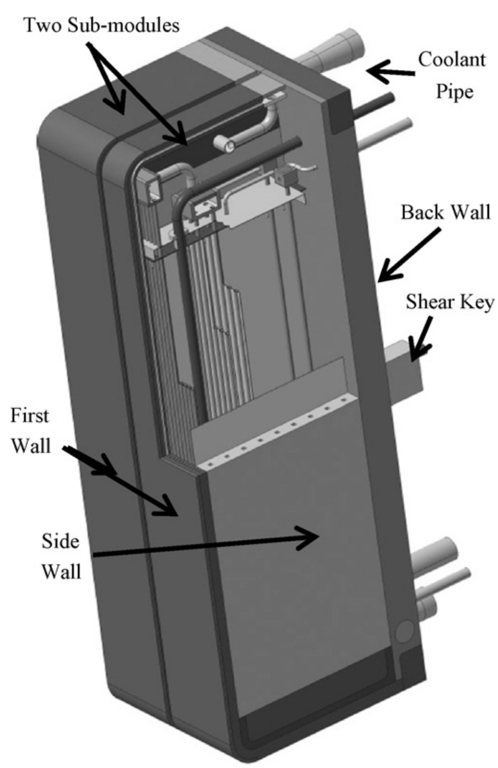

Fig. 1. Structure of the WCCB TBM.

wall. Each sub-module contains tritium breeder pebbles, neutron multiplier pebbles, and box structures. Small pebbles of Li_2TiO_3 and Be are used as the tritium breeder and the neutron multiplier, respectively. Reduced Activation Ferritic/Martensitic steel (RAFM), F82H [3], has been selected as the structural material for the box structures. Major design parameters are summarized in Table 1. The dimension is 0.484 m (width) × 1.66 m (height) × 0.6 m (thickness). The box of the TBM is designed to withstand the pressurization in the box with the coolant pressure of 15 MPa at 550 °C [2]. As for the internal structure, multi-layer pebble bed boxes are formed by using separation walls with circular cooling pipes. These pebble bed boxes are fabricated with thin plates and circular tubes [4] made by F82H. Tritium breeder (Li_2TiO_3) pebbles and neutron multiplier (Be) pebbles are packed in the boxes separately, one after another. Since neutronics environment is the fundamental and most important test condition for evaluation of the results of the TBM testing, micro-fission chambers and pneumatic tubes for multi-activation foils are taken into account in the design of the WCCB TBM. Structure design of the back side shield, which is the interfacing components between the WCCB TBM and the test port of ITER, is being performed. The structure of the backside shield is unique to the corresponding TBM structure and should be integrated with the design of the TBM. Based on the structural design, various performance analysis have been performed to show the soundness during operation [5].

Table 1
Design conditions of the WCCB TBM.

Items	Unit	
Structural material		F82H
Coolant		Water
Multiplier		Be, BeTi alloy
Breeder		Li_2TiO_3, other Li ceramics
Surface heat flux (max.)	MW/m^2	0.3 (0.5)
Neutron wall load	MW/m^2	0.78
Total heat deposit	MW	0.904
Total tritium production	g/FPD	0.134
Coolant pressure	MPa	15.5
Coolant Inlet temperature	°C	280.0
Coolant outlet temperature	°C	325.0
Coolant flow rate	kg/s	3.59

Preliminary safety evaluation of the WCCB TBM has been performed. In the preliminary safety evaluation, source term evaluation, Failure Mode and Effect Analysis (FMEA) and identification of Postulated Initiating Events (PIEs) have been performed [6]. Also, the safety analysis was performed for representative accident cases, which was derived by the grouped PIEs [7]. The results of the safety evaluation are incorporated to the design of the WCCB TBM.

2.2. Fabrication technology development of the WCCB TBM

2.2.1. HIP technology for first wall fabrication

In fabrication technology development, a Hot Isostatic Pressing (HIP) bonding method has been developed and improved to prevent the degradation of the mechanical properties of HIP joint for the first wall structure with built-in cooling tubes [8]. Also, evaluation of the soundness of small scale first wall mockup which was fabricated by HIP, has been performed by high heat flux test and showed soundness [9].

2.2.2. Fabrication of near full scale first wall mockup

Real scale mock-up fabrication and tests are one of the most critical milestones for qualification of TBM prior to installation in ITER. In fabrication of the WCCB TBM, cylindrical and rectangular tubes with 1.5 mm wall thickness are required as cooling tubes and assembly parts of the first wall panel. The cold roll technology to form $\phi 15.9 \times 1.5$(thickness) cylindrical tubes and 11 mm × 1.5 mm (thickness) square tubes by F82H was developed [4]. Then, a near full scale first wall mockup was successfully fabricated by Hot Isostatic Pressing (HIP) method by using plates and rectangular tubes of F82H. The HIP heat treatment was performed in the optimized condition where HIP temperature and pressure are 1100 °C and 150 MPa [8]. Fig. 2 shows appearance of fabricated mockup and macro-observation of the cross section of the first wall panel. Dimension of fabricated mockup is 1.5 m × 0.6 m × 0.16 m width with 15 square (8 mm × 8 mm) cooling channel inside. Deformation of the first wall at the center was less than 1%, which is acceptable for further fabrication of blanket box structure. Deformation of internal dimensions of rectangular cooling channel was less than 5%, which is acceptable from the view point of coolant flow distribution and heat removal. By the observation of HIP layer, it was confirmed that HIP joining process was successfully performed with no major pores along the HIP interface.

2.2.3. Verification tests of near full scale TBM first wall mockup

High heat flux test of a near full scale first wall mockup with real operation coolant condition is one of the most important performance tests to be performed for the verification of the fabrication technology and fabrication process. Fig. 3 shows the appearance of the mockup for the verification tests. The verification tests using fabricated near full scale mockup consisted of the measurement of coolant flow distribution in channels, flow test of high pressure and temperature water in the real operating condition, and high heat flux test with equivalent surface heat flux in ITER.

Flow distribution in cooling channels of the first wall is one of the major concern because of their long flow distance and small cross section areas. A flow distribution of the 15 cooling channels has been measured by an ultrasonic flow meter. Cooling water conditions are 25 °C, total flow rate of 2.16×10^{-3} m^3/s. at an inlet pressure of 15.5 MPa. By using an ultrasonic flow meter, a relative flow rate of each channel was measured and normalized to the total flow rate, which is measured by a conventional flow meter.