DESIGN AND DEVELOPMENT OF CERAMIC BREEDER DEMO BLANKET

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Abstract

Ceramic breeder blanket development has been widely conducted in Japan from fundamental researches to project-oriented engineering scaled development. A long term R&D program has been launched in JAERI since 1996 as a course of DEMO blanket development. The objectives of this program are to provide engineering data base and fabrication technologies of the DEMO blanket, aiming at module testing in ITER currently scheduled to start from the beginning of the ITER operation as a near-term target. Two types of DEMO blanket systems, water cooled blanket and helium cooled blanket, have been designed to be consistent with the SSTR (Steady State Tokamak Reactor) which is the reference DEMO reactor design in JAERI. Both of them utilize packed small pebbles of breeder Li_2O or Li_2TiO_3 as a candidate) and neutron multiplier (Be) and rely on the development of advanced structural materials (a reduced activation ferritic steel F82H) compatible with high temperature operation.

1. INTRODUCTION

Ceramic breeder blanket development has been widely conducted in Japan from fundamental researches to project-oriented engineering scaled development. The target of the latter activities is the breeding blanket for DEMO reactors, while the former activities provide information on fundamental understanding of the basic phenomena and innovative concepts to the latter activities. A long term R&D program has been launched in JAERI since 1996 as a course of DEMO blanket development. The objectives of this program are to provide engineering data base and fabrication technologies of the DEMO blanket, aiming at module testing in ITER currently scheduled to start from the beginning of the ITER operation as a near-term target.

2. GENERAL DESCRIPTION OF DESIGN AND R&D ISSUES

Two types of DEMO blanket systems [1] have been designed to be consistent with the DEMO reactor design in JAERI (SSTR : Steady State Tokamak Reactor) [2]. The primary blanket concept, as a near-at-hand concept, is high temperature and high pressure water (pressure of 15 MPa and inlet/outlet temperatures of 280°C/320°C) cooled ceramic breeder blanket ,based on well-experienced PWR technologies. The alternative concept is a high temperature helium gas (8.5 MPa and more than 360°C/480°C) cooled ceramic breeder blanket with inherent safety and potential higher efficiency. Both of them utilize packed small pebbles of breeder Li_2O as a candidate) and neutron multiplier (Be) and rely on the development of advanced structural materials (a reduced activation ferritic steel F82H) compatible with high temperature operation. Both of blanket design refurbished as an ITER test module design [3]. A layered configuration of breeder and beryllium packed beds is applied to maximize the tritium breeding performance. Figure 1 shows the schematic configuration and critical R&D issues unique to the design. Temperatures of the breeder layers are designed to be maintained between 450°C and 750°C to enhance in-situ tritium release with keeping materials integrity as well, while those of the beryllium layers are kept below 600°C to avoid excessive swelling. Evaluated local tritium breeding ratios are 1.2 and 1.3 for water and helium concepts, respectively. The long term R&D program in Japan is mainly composed of a) fabrication technologies development and elementary tests, b) in-pile tests with some instrumentation development and c) out-of-pile thermo-mechanical performance tests, and is consistent with materials irradiation program. As the beginning of the long term R&D, the fabrication technology development and elementary tests have been intensely performed to clarify the feasibility of the urgent issues for each elements summarized

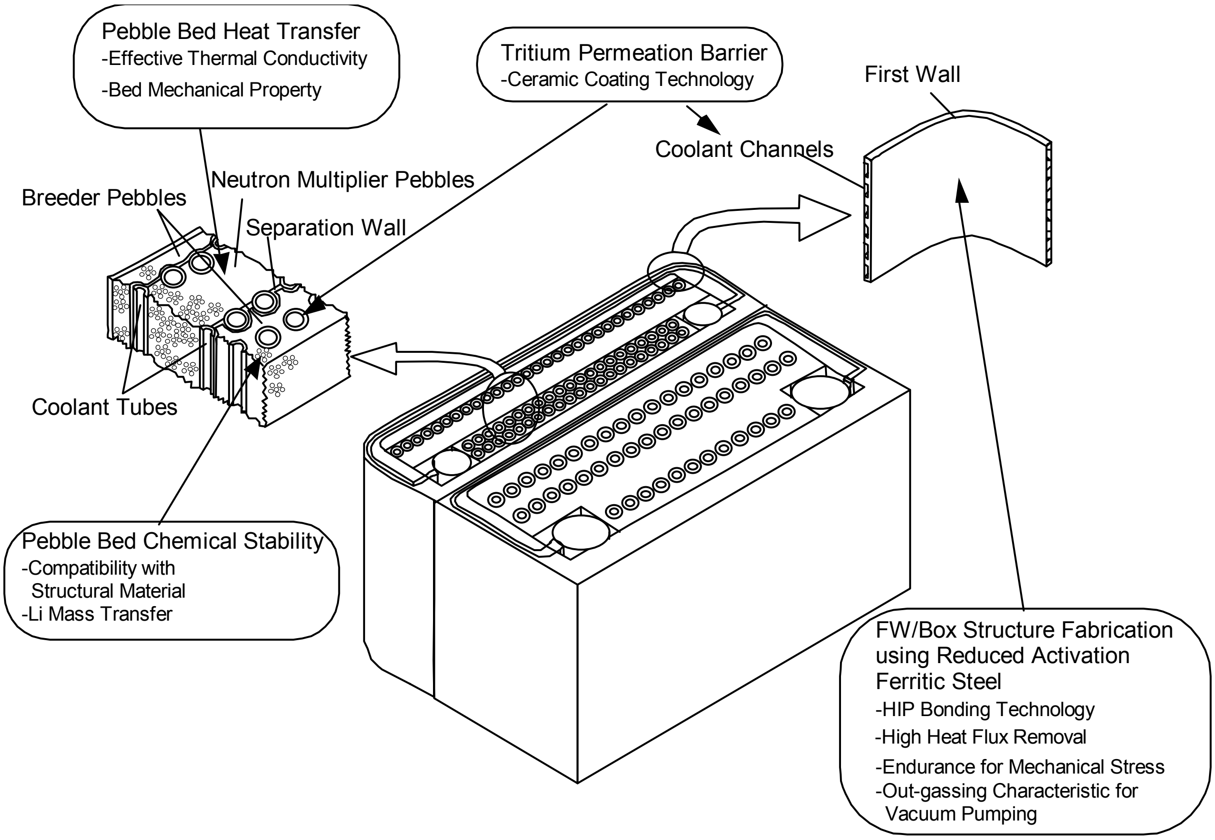

Fig. 1 Configuration of Ceramic Breeder DEMO Blanket and R&D issues in the fabrication technology and elementary tests

in Fig.1. This paper overviews the recent achievement of the fabrication technology development and elementary tests.

3. MAJOR R&D RESULTS

3.1 Development of blanket structure fabrication technology

In the fabrication technology development for the blanket box structure and the first wall , R&D of advanced fabrication method such as HIP (Hot Isostatic Pressing) bonding have been conducted to examine optimum HIP conditions and following post heat treatment procedures for F82H. Figure 2 shows the result for optimization of HIP temperature from the viewpoint of Charpy impact toughness for HIP bonding layer of F82H. It was identified that optimum HIP condition was 1,040 °C and 150 MPa for 2 hr and 740 °C for 2 hr for HIP and post-HIP heat treatment conditions, respectively [4]. Other mechanical properties of F82H after these thermal processes have been proven almost equal to those of the base metal [5].

By applying these HIP conditions to F82H plates, small-sized first wall panels with ten rectangular cooling

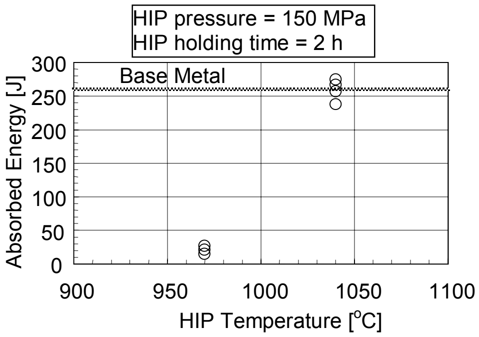

Fig. 2 Result of Charpy impact toughness test for HIP bonding pieces in various HIP temperature

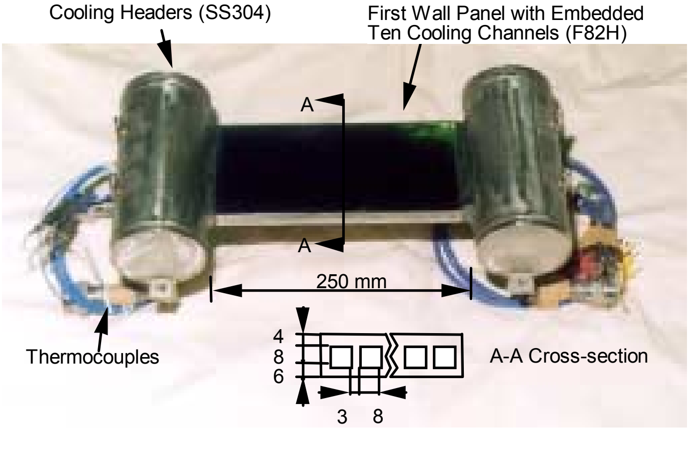

Fig. 3 Appearance of F82H first wall panel fabricated by HIP bonding method.

channels embedded have been successfully fabricated [6]. Fabricated first wall panel is shown in Fig. 3. The dimension of the fabricated first wall panel agreed with design dimension in the range of 1 to 2 mm deviation.

Out-gassing and hydrogen absorption characteristics of F82H is a critical issue because it faces directly in high vacuum in the Vacuum Vessel. Out-gassing characteristics have been examined by through-put method. Figure 4 shows the experimental result of the out-gassing characteristics of F82H after four cycles of bakeout at the temperature up to 300 °C. As can be seen from Fig. 4, ultimate out-gassing rate of 3 x 10^{-9} Pam^3/sm^2 has been achieved [7], which seems sufficient to keep high vacuum needed for plasma operation, though it is higher than the austenitic stainless steel (SS316) by an order of magnitude. Hydrogen gas absorption characteristics of this steel has also been examined by using thermo-balance, and roughly one order higher absorption has been observed compared with SS316 [8].

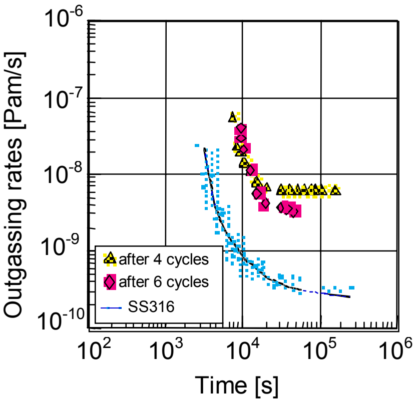

Fig. 4 Out-gassing rate of F82H after 4 and 6 cycles of 300°C bakeout

3.2 Important results of elementary tests

As one of the elementary tests, compatibility among beryllium, breeder materials and structural materials has been investigated, because it is the critical and urgent issue to select the candidate structural material due to the reactivity of beryllium[9]. As can be seen from Fig. 5, the growth rate of the F82H reaction zone showed a smaller reaction rate than SS316 by an order of magnitude, and it implies that the temperature of beryllium/F82H interface is limited not from their compatibility but from other factors such as beryllium swelling. The compatibility of F82H and Li$_2$O was also shown in the same order of magnitude with beryllium. Thus, it can be concluded that the compatibility issue is not critical in the temperature range of 500 - 550 ^{o}C, which was decided by the limitation for Be swelling rate.

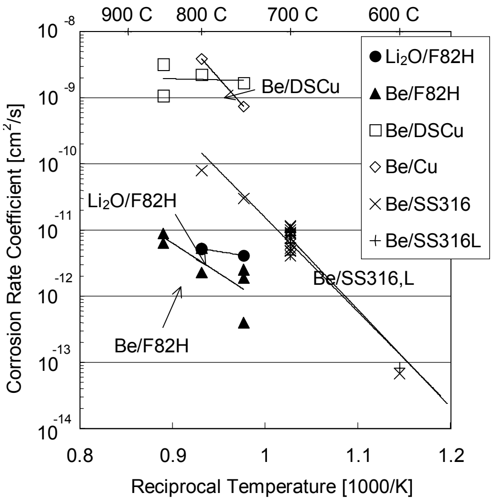

Fig. 5 Compatibility between Breeder, Multiplier and Structural Material(Li$_2$O, Be - SS, F82H)

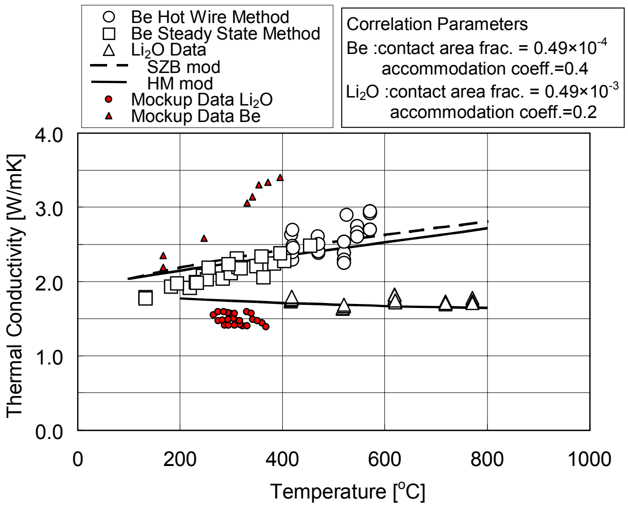

Fig. 6 Experimental results of effective thermal conductivity for 1mm Be and Li$_2$O pebble beds

Mechanical and thermal properties of packed small pebbles are key design issues, and engineering data on equivalent thermal conductivity [10], packing characteristics and purge gas flow characteristics through the bed [11] have been investigated as important engineering issue for designing pebble layers of breeder and multiplier. Recently, a hot wire method, a standardized method for measuring thermal conductivity of less thermally conductive materials, has been applied to measure the equivalent thermal conductivity of beryllium and Li$_2$O pebble beds [12]. The measured results for Be and Li$_2$O 1mm pebble beds are shown in Fig. 6. By the experimental results, the optimum parameters for correlation of bed thermal conductivity were determined as shown in Fig. 6. Thermal design of the breeding blanket was based on the parameters determined in these experiments. The mock-up tests have been conducted to confirm the thermal design by using cylindrical model with layered configuration of Be and Li$_2$O or Li$_2$TiO$_3$. The preliminary results of the mock-up tests [13] showed relatively good consistency on thermal conductivity of Li$_2$O pebble bed as shown by closed circle key in Fig. 6.

With respect to the measurement and inspection method of packing condition in the blanket structure, X-ray CT scanning method was applied. Figure 7 shows the CT scan image of test container which has the simulated thin container of breeder pebbles. The preliminary experiments showed that CT scan method is relevant for measuring distribution of packing fraction in the box structure [14].

With respect to the breeder pebble fabrication methods, rotation granulation method has the primary potential of mass production[15], while sol-gel method has been proposed with advantages of mass production and reprocessing with successful results of trial fabrication of Li_2O and Li_2TiO_3 pebbles [16,17]. Irradiation tests of ceramic breeder, Li_2O and Li_2ZrO_3 conducted in IEA BEATRIX-II program have confirmed integrity of the test specimens and sound tritium release up to 5% lithium burn-up [18,19]. Thermal cycle fatigue tests have been performed by applying thermal cycle to three types of ceramic breeder pebbles, to clarify the non-destructive rate and the pebble crash load. As the result, the integrity of Li_2O pebbles fabricated by rotating granulation method has been verified, while the other two ternaries, Li_2ZrO_3 and Li_4SiO_4, showed a large fraction of fragmentation [20]. As for the beryllium pebbles, rotating electrode method [21] has been identified as the candidate method for obtaining less impurities and better sphericity.

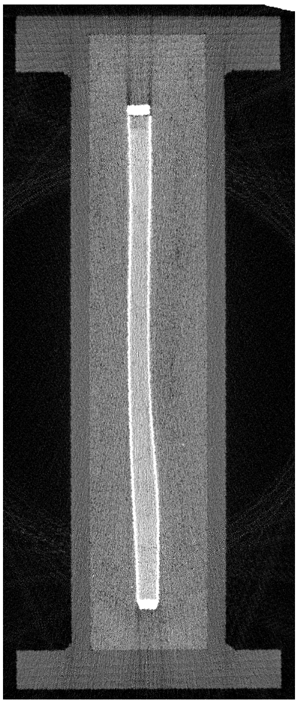

Fig.7 CT scan image of vertical cross-section of rectangular containers

4. CONCLUSIONS

The long term R&D on the development of ceramic breeder blanket for DEMO reactor has been performed to demonstrate the primary feasibility of the blanket design which applies the layered configuration of breeder pebbles, multiplier pebbles and coolant panels. Also, the basic design data such as, the effective thermal conductivity of breeder and multiplier pebble beds, the corrosion rate of reduced activation ferritic steel in contact with breeder and multiplier, were clarified to support the quantitative design of the ceramic breeder blanket in JAERI.

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