Progress of and Future Plans for the L-4 Blanket Project

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Abstract. The ITER L-4 Blanket Project has achieved substantial progress over the last two years. The qualification of materials so far considered as reference for the shield module fabrication has been completed, as well as the developments for joining the triplex First Wall structure. Several Primary Wall, baffle, and limiter mock-ups have been manufactured and tested showing comfortable margins against the loads expected in ITER. Shield prototypes have been manufactured by conventional and advanced technology, which have finally demonstrated the manufacturing feasibility. More recently, activities for the qualification of the module attachment system have been started, and first results from materials and mock-up tests have become available. Several test campaigns are still to be finished to complete the data base for the design. In the meantime, further activities have been initiated to adapt the R&D programme to the ITER-FEAT design features, with the aim to further reduce the cost.

1. Introduction

The ITER L-4 Blanket Project [1] has progressed over the last two years as a collaborative effort between the European, the Japanese, and the Russian Home Teams (HT), under a joint ITER JCT and EU HT management. Its main objectives are the demonstration of the manufacturing feasibility and the operational performance of the components of the ITER Shield Blanket system. It includes material qualification, the development of manufacturing techniques, and the fabrication and testing of mock-ups and prototype components. The main achievements reported below are the results of the R&D launched in support of the 1998 ITER design. Although these results are fully relevant for ITER-FEAT, new activities were implemented since late 1998 to explore and validate more cost effective design solutions.

2. Materials Qualification

Within the past two years, the irradiation testing of 316 L(N) (IG) stainless steel has been completed. The most recent data for powder HIPed material irradiated at 290 °C to 0.7 and 2.5 dpa obtained by the EU HT, confirm the trends observed by the RF HT after irradiation at 265 °C to 4 and 10 dpa [2]. At doses relevant for ITER-FEAT, a significant increase of strength, and a modest reduction of the total (~19 %) and uniform elongation (~5-10 %) has to be expected which are similar to the data obtained for plate and solid HIPed material. The fatigue life is only slightly reduced at higher doses. The fracture toughness, although lower by about a factor of 3 compared with plate material and further decreasing with increasing irradiation dose (~250 kJ/m^2 at 2.5 dpa) remains in an acceptable range. Therefore, all the envisaged manufacturing routes for the shield blanket structure are feasible with respect to the irradiation behaviour.

The data base for the CuAl25 (IG) reference heat sink material for the primary First Wall has been complemented by fatigue data which show a marginal influence of irradiation (up to 0.3 dpa) at 250 °C, but a more significant one at 350 °C.The alloy shows poor fracture toughness [3], and the reasons have been identified to be due to the inherent distribution of the oxide and impurity particles in the copper matrix. In spite of the attractive behaviour of this alloy during heat treatment and irradiation, this intrinsic weakness, together with the concerns about cost and availability, has triggered the R&D to explore in the future in more detail the precipitation hardened CuCrZr as an alternative alloy.

The data base for unirradiated titanium alloys envisaged for the manufacture of the flexible supports of the module attachment system has been reproduced. Neutron irradiation for hydrogen free and hydrogen loaded specimens is still underway. The first indications from proton irradiation tests already suggest the currently preferred ($\alpha+\beta$)-alloy (Ti-6Al-4V) to be more sensitive to irradiation than α-alloys (e.g. Ti-4Al-2.5Sn). Irradiation creep data for Inconel 718, used for highly prestressed bolts, have been obtained. The results suggest that the stress relaxation to be expected at the rear side of the shield modules is acceptable.

3. Manufacturing Technologies

Although the manufacturing techniques for the primary First Wall modules had been fully established in the past [1,3], and utilised by the EU and JA HT’s [1] Industry for the manufacture of prototypes, the R&D on this subject was continued to further optimise the fabrication routes, and to explore more cost effective alternatives. One of the major achievements of the past two years is the cross-confirmation of the one-step solid HIP process (1040 - 1050 °C, 120 MPa, 2h) for SS/SS and CuAl25/SS joining by the EU HT, and of the solid HIP process for Be/CuAl25 joining. While the EU HT uses HIP temperatures of ≥800 °C with Ti interlayers, the JA HT prefers a temperature of 555 °C, using combined interface materials, such as Al/Ti/Cu. Obviously, such temperatures do not provide the same margins with respect to those reached in the event of off-normal heat loads. For this very reason, the EU HT has put aside the use of Al interlayers, HIPed at about 530 °C. The JA HT also investigates a pure Cu interlayer applied by physical vapour deposition (PVD). In this case, the HIP joining is done at 620 °C to avoid the formation of brittle intermetallic compounds. The best compromise between strength, temperature and cost has still to be found.

While the EU HT is also continuing the optimisation of the Be/Cu-alloy HIP joint, it devotes in parallel substantial efforts to exploring brazing and diffusion bonding as alternative and potentially cheaper fabrication routes. These techniques have got a higher chance of success for the new ITER-FEAT shield blanket design in which the First Wall is separated from the shield block, smaller in size, and bounded by flat instead of curved or even double-curved surfaces. In view of the increased interest in CuCrZr, fast brazing as developed in the EU HT in the past, and actually applied by the RF HT for the manufacture of limiter components, is recommended to preserve the CuCrZr and CuCrZr/SS joint properties. In case of HIPing,

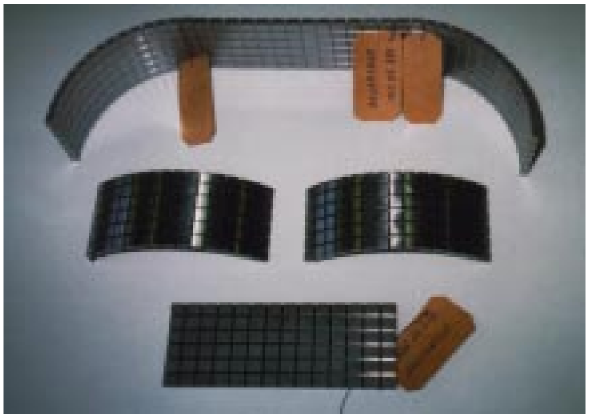

FIG. 1. Beryllium Castellation (RF HT)

FIG. 2. Shield Block Slotting (JA HT)

rapid cool-down and good temperature control of HIP facilities is important, and addressed by the EU HT.

To reduce the electromagnetic loads on the shield module, First Wall castellation, and deep slotting of the shield block are mandatory for the ITER-FEAT shield blanket. To verify the manufacturing routes, the RF HT has demonstrated two-side milling of beryllium plates performed prior to the joining to the copper heat sink (Fig.1), while the JA HT has succeeded in cutting deep slots into a shield block mock-up by water-jet gouging (Fig. 2).

4. Mock-up Fabrication and Testing

With the testing of small scale primary first wall mock-ups (~250 cm^2 heated surface), the EU HT has demonstrated that the solid HIP joint between the CuAl25 (IG0) heat sink and the 316L(N) (IG) SS structure survives 30,000 cycles at 0.75 MW/m^2, and withstands ~500 cycles at 5 MW/m^2 without failure. A JA HT mock-up has reached 1000 cycles at 5, and an additional 1500 cycles at 7 MW/m^2 [4], although with a reduced thickness of the steel backing. A mid scale mock-up (~4000 cm^2) was successfully tested by the JA HT for 1000 cycles up to 0.3 MW/m^2. Two mock-ups with HIPed beryllium tile protection manufactured by EU HT Industry (Fig. 3) have so far reached 13,000 cycles at 0.7 MW/m^2. Further mock-ups with different tile geometry and joining conditions are ready for testing. A flat port limiter mock-up with brazed beryllium tiles, manufactured and tested by the RF HT, survived 1000 cycles at 6.5 MW/m^2 without visible damage. A medium scale mock-up with curved ends and reduced length of the straight part has recently been completed (Fig. 4). EU HT tungsten armoured mock-ups for baffle application have reached 1000 cycles at 7 MW/m^2 for the plasma sprayed, and at 18 MW/m^2 for the macrobrush version, while CFC armoured mock-ups manufactured via Active Metal Cast® technology survived 20 MW/m^2.

Although the above results meet with sufficient margin the ITER requirements new primary first wall mock-ups are currently being prepared by the EU HT, to explore the more cost effective CuCrZr and alternative joining techniques for the beryllium armour (see paragraph 3), which were so far disregarded because of the size and the curvature of the 1998 ITER First Wall. The competitiveness with the above reference approach remains to be shown.

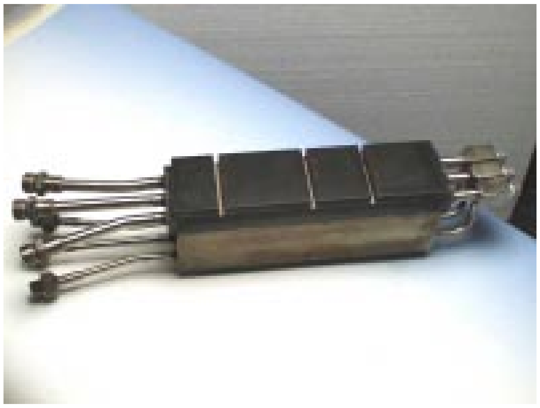

FIG. 3. Be/CuAl25/SS Mock-up (EU HT)

FIG. 4. Port Limiter Mock-up (RF HT)

5. Prototype Manufacture and Testing

The EU HT prototype for the double curved powder HIPed shield block [3] has been completed (Figs. 5 and 6) and tested by ultrasonic (US) inspection for the accuracy of the coolant channel shape and location. Destructive examination is now underway. The development work for the first wall joining to the shield block by solid HIP has been successfully completed with the manufacture of several medium scale parts, each one addressing particular critical fabrication issues. The developed know-how will now be utilised for the manufacture of two prototypical separate first wall panels made from the specified reference materials,with beryllium tiles joined by HIPing and brazing, respectively. They will undergo thermal fatigue testing in early 2001.

By mid 2001, three more first wall panels will be procured which are expected to demonstrate the manufacturing feasibility of alternative and less expensive fabrication routes. The two near full-scale baffle prototypes, one with beryllium armour, and one with CFC and tungsten armour, will also be completed by mid 2001. Some delay in the industrial activities has accumulated due to unexpected technical difficulties. These later components can, however, only be tested in the second half of 2001.

FIG.5.
Module Prototype Front View (EU HT)

FIG.6.
Module Prototype Rear View (EU HT)

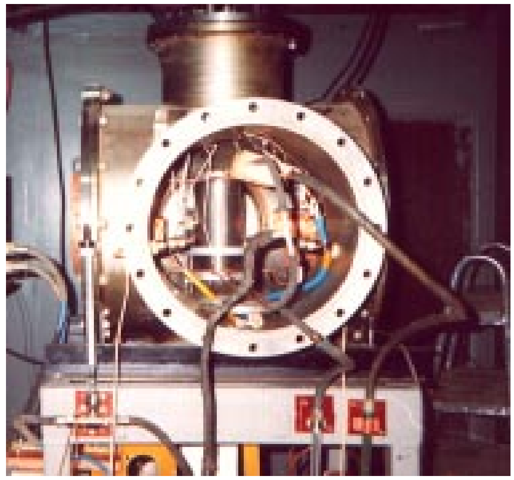

FIG. 7. Module Prototype (JA HT) *FIG. 8. Ti Flexible Supports under Testing (RF HT)*

The JA HT primary wall module prototype manufactured in 1998 by forging, drilling, and subsequent bending, has been cut (Fig. 7) for examination of the various types of joints. No defects were found by microscopy. Recently, a partial separate first wall panel was completed, and full prototypes are scheduled for completion by June 2001.

Prototypical flexible cartridges for the module-to-vessel attachment had been manufactured from Ti-6Al-4V by the RF HT in 1998. They were subjected to mechanical (static, cyclic, and dynamic loads) and thermal testing (Fig. 8). The results fully confirmed the predicted behaviour, and revealed a margin of >2.6 against buckling loads.

6. Conclusions

Within the last two years, the L-4 Blanket Project experienced a substantial progress as a joint effort of the EU, the JA, the RF Home Teams, and the JCT. The initial target of demonstrating manufacturing feasibility and operational performance of the most challenging components of the 1998 ITER design will be achieved by mid 2001. The results of this R&D, together with the programmatic adaptations initiated from late 1998 onwards, are considered as a sound and reliable basis for the construction of ITER-FEAT.

References

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