R&D ON W FIRST WALL FOR ITER AND FUTURE FUSION REACTORS

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1. INTRODUCTION

First wall (FW) is to provide 100% thermal shielding to blanket at 1~2 MW/m^2 level and to form a friendly interface with burning plasma in future fusion reactors. To reach permanently to acceptable performances under intense 14 MeV neutron irradiation and high heat flux, it is essential to develop a feasible FW structure to remove the heat with reliable materials bonding together. W, a promising plasma-facing material (PFM) with the highest melting-point and low tritium retention, have been decided to replace Beryllium as armor material for ITER FW as well. Reduced-activation ferritic/martensitic (RAFM) steel will be used as structural material for near-term DEMO reactor and V-base alloys for mid-term application relying on their strong neutron irradiation resistance and high-temperature strength, while ITER FW has to use CuCrZr as heat-sink material due to its much higher heat flux up to 4.7 MW/m^2 at plasma limiter operation phase. After two-decades investigations by qualification of various material bonding technologies, the production process qualification has been completed by manufacturing full-scale prototypes (FSP) in China, EU and Russia. Recently R&Ds focused on enhanced heat flux (EHF) tungsten FW, mock-ups and full-size fingers have been made with acceptable thermal fatigue performances. A semi-prototype with 20 fingers is in 65% completion of manufacturing. Besides, FW technologies investigation for future reactors covers helium- and water-cooling RAFMs and V4Cr4Ti ones for various blankets, to address material issues under severe neutron irradiation and to provide strong tritium barrier by specific-designed and in-situ formed material-bonding interface. The deuterium permeation rate could be reduced by 2~5 orders at elevated temperatures.

2. FW DESIGN AND R&D PROGRESS

ITER enhance heat flux (EHF) FW utilizes a hypervapotron heat sink to remove the surface heat. To withstand ultra-strong thermal shock from runaway electrons, the armored W tiles are in thickness of 6~12 mm for various ITER FW panels [1], which provide strong neutron shielding as well. However, the W armor need to be much thinner as 1~2mm for future reactor in order to have more neutrons to produce tritium in blanket. The neutron irradiation dose in the FW for ITER is merely ~3 dpa but will be 1~2 orders higher in DEMO reactor and fusion power plant, where copper alloy and austenitic stainless steel (ASS) will be excluded because their high activation issues. Consequently, future FW for DEMO will be a structure with W armoring on low activation structural materials, such as RAFM steel [2] and V4Cr4Ti alloy. RAFM steels, typically 9Cr-2WTaV, can endure 20 dpa neutron irradiation, which is not enough for DEMO. V4Cr4Ti could provide stronger irradiation resistance, but cannot be used in He-cooling and water-cooling conditions because of sever corrosion in the coolants. To overcome this issue, a helium-cooling FW integrated with both materials is designed with rectangular channel, to prevent vanadium alloy contact with the coolant, as shown in Figure 1.

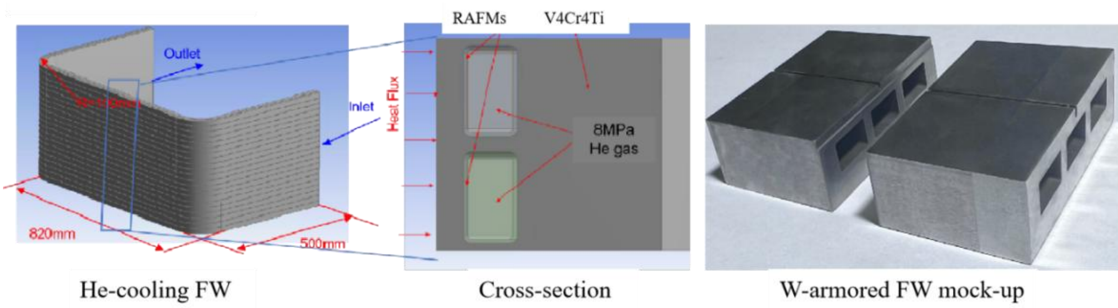

Figure 1 The He-cooling FW layout, its cross-section showing the materials and cooling channels and the mock-ups

China would manufacture and supply 10% of ITER FW panels, joins the ITER TBM (test blanket module) program to develop helium-cooling ceramic blanket for future DEMO. A full-scale prototype (FSP) of Be-armoring EHF FW has been manufactured for ITER and successfully passed all of the acceptance tests. W-armored ITER FW has the same structure and materials as the FSP. R&Ds activities on the W tiles bonding on CuCrZr heat sink, technologies for mock-ups and fingers manufacturing have been started since last year. The capability of the components to withstand 4.7MW/m^2 heat load for 15,000 cycles has been demonstrated and a semi-prototype with 20 fingers mounted on a 316L(N) central beam is soon getting to its assemble phase. However, the heat-sink to withstand 30,000 cycles for a full-operation life is still a challenge, needs to be further addressed. For ITER TBM and other blanket, the technologies to make W-armoring RFAM steel FW mock-ups with sound bonding have been obtained [3]. Recently, a helium-cooling FW with V4Cr4Ti alloy as structural materials was developed with inherent tolerance to neutron irradiation to high dose and high-temperature operation capability up to 700^{o}C. By cladding a thin RAFMs layer facing the coolant, issue of oxidation resistance could be solved and furthermore, the structure showed strong tritium permeation barrier with a rate reduction by more than 3 orders while having a heat removal capability more than 1 MW/m^2 for 1000 cycles. For tritium permeation barrier, cladding the RAFM structure with a FeCrAl layer was also investigated. Neutron irradiation of the RAFM steels (such as CLF-1) and ODS-9Cr steel has been completed for about 10 dpa, other irradiation campaigns are under preparations. These FW technologies will significantly enhance the design and construction of engineering experimental and DEMO reactors in China, to be used in various components according to their neutron irradiation dose in the reactors.

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