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R&Ds on W First Wall for ITER and Future Fusion Reactors

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ABSTRACT

- It has been developed for first wall of the W armor reliably bonding on CuCrZr/316L(N) bi-metallic heat sink for ITER and on low activation structural materials for future reactor.
- An ITER FW semi-prototype with 20 fingers assembly via a HIP diffusion bonding process is capable of 5.9 MW/m² for 8,800 cycles.
- For DEMO, He-cooling W/RAFMs and W/V4Cr4Ti/RAFMs FW mock-ups are capble of 1 MW/m² for 1,000 cycles, with the latter showing strong D_2 gas permeation barrier. Instead, FeCrAl/RAFMs is also studied.

BACKGROUND

- First wall (FW) provides 100% thermal shielding to other components by active-cooling an armored heat-sink and support structure.
- ITER Enhanced heat flux (EHF) FW had been qualified via full-scale prototyping when it occured the change of the armor from Be to W, a promising plasma-facing material (PFM) for future.
- Towards future from ITER consists of other changes of CuCrZr/316L(N) bi-metallic hypervapotron (HVT) heat-sink to rectangular cooling channel of low activation structural materials , with heat flux from 4.7 to ~1 MW/m² for a reduced number of cycles from 30000 to ~1000, and thinning W tiles from 6~12mm to 2~3mm for better neutronic performances.
- R&Ds to improve manufacturing tech., thermal fatigue performance and tritium permeation barrier are of great importance, including those with 9Cr-WVTa RAFM steel and V4Cr4Ti alloy as structural material.

CHALLENGES / METHODS / IMPLEMENTATION

CHALLENGES TO MEET THE REQUIRED PERFORMANCES

- Despite of well-developed ITER W divertor dome HVT units, it is a challenge to meet the much longer thermal fatigue lifetime of EHF FW.
- To incooperate a reliable tritium permeation barrier for duture reactor.

FW DESIGN TO HAVE TRITIUM PERMEATION BARRIER

- Typical FW in Figure 1 with an rectangular insert to protect the main structural material from oxidation by O_2 impurity in He coolant: RAFMs-FeCrAl insert and V4Cr4Ti-RAFMs insert.
- The materials bonding interface would be served as a tritium permeation barrier by forming diffusion-reaction layer.

HIP DIFFUSION BONDING TO MAKE FW

- For ITER FW: casting 1mm pure Cu on W tiles → HIPing to CuCrZr/316L(N) heat sink at 580°C for 2h in pressure of 150 MPa.
- For DEMO FW: W/Fe/RAFMs and W/V/V4Cr4Ti/RAFMs bonding at 900°C for 2h in pressure of 150 MPa.
- Laser welding various steel covers to form internal cooling channels and water boxes.

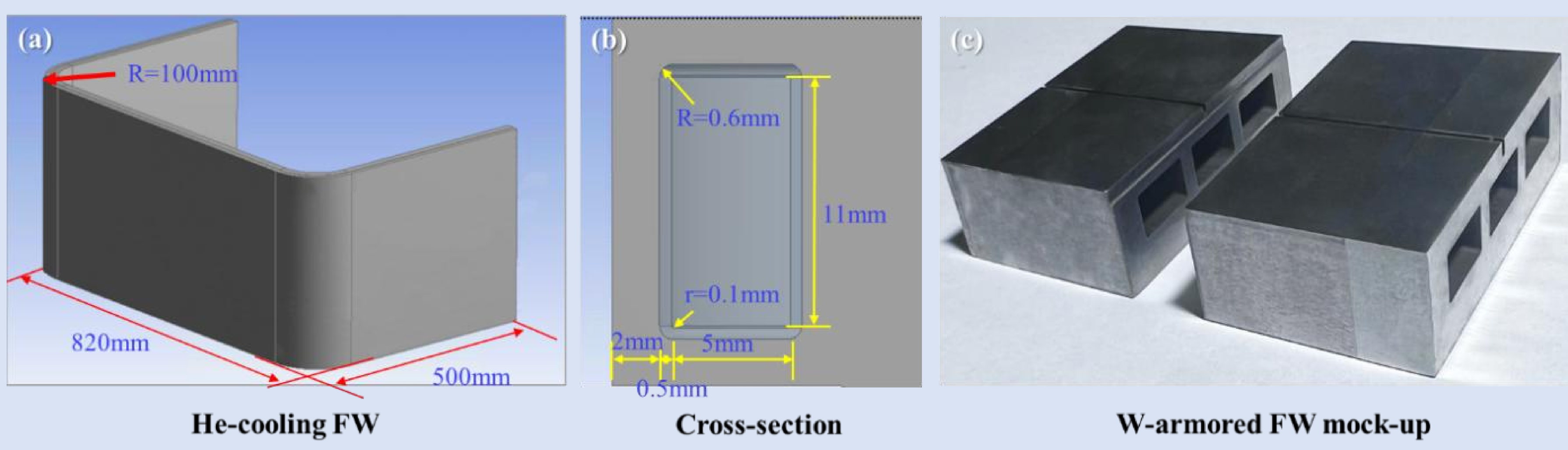

Figure 1 He-cooling FW heat-sink with rectangular insert (FeCrAl or RAFMs) as cooling channel, (a) overall layout, (b) cooling channel, (c) the manufactured V4Cr4Ti/RAFMs mock-ups

OUTCOME

ITER EHF W FW AND ITS THERMAL FATIGUE PERFORMANCE

A semi-prototype (Fig. 2 (b)) indicates maturity towards series production.

- 20 fingers (Fig. 2 (a)) with Defect-free W/CuCrZr bonding (Fig. 2(c)).
- Durable for 8,800 cycles at 5.9 MW/m² (Fig.2 (d)) and 23,000 cycles at 4.7 MW/m² where after a water leakage at HVT bi-metallic joint.

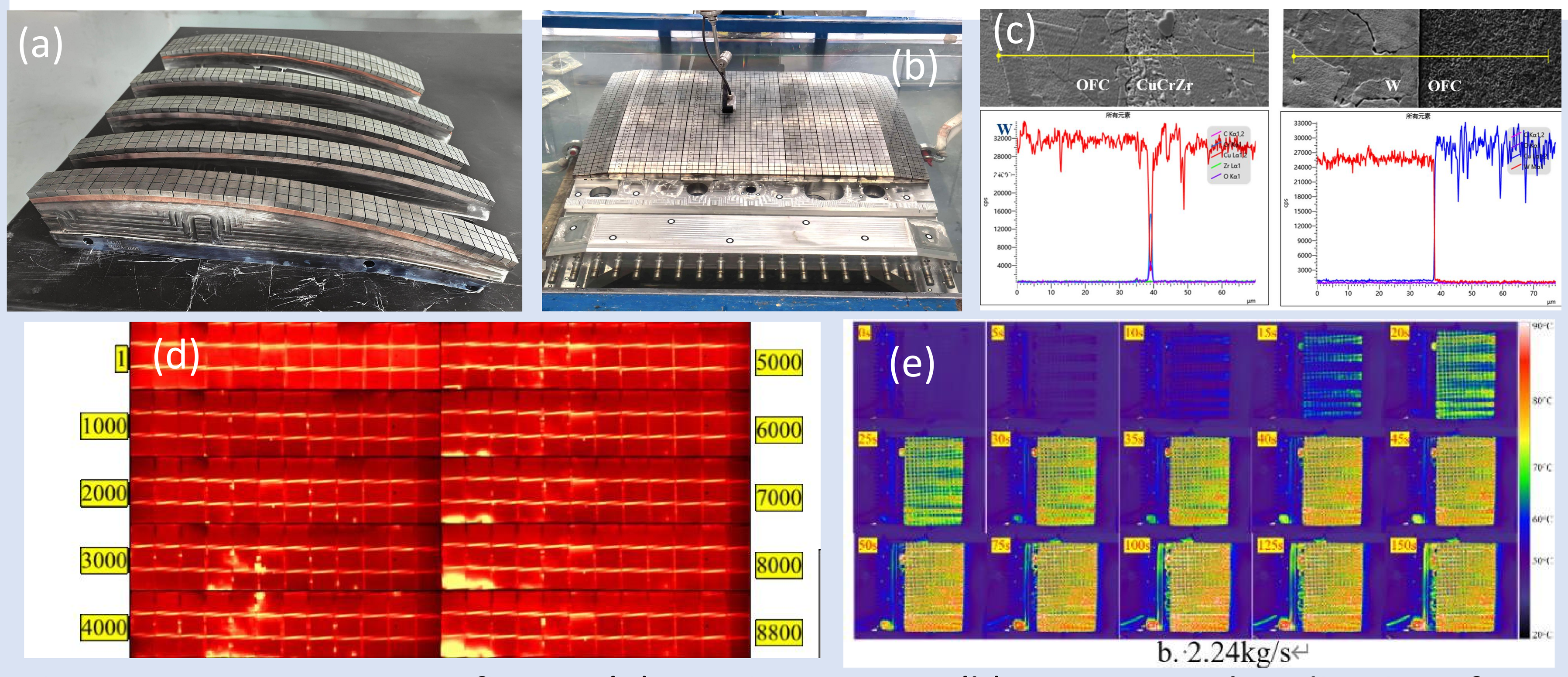

Figure. 2 ITER EHF W FW fingers (a), semi-prototype (b), EDS across bonding interface (c), IR images at various number of cycles at 5.9 MW/m² (d) and the IR images (e) showing the uniform hot-water (85°C) flow in the non-blocked channel at 2.24 kg/s

ADVANCED V-BASE ALLOY FW WITH RAFM STEEL INSERT

Material bonding strength up to 240 MPa, providing a dispersion TiC barrier to reduce D_2 permeation rate by 3 orders. FW mock-up is durable for 1.25 MW/m² heat flux when the vanadium alloy temperature reaches > 700°C.

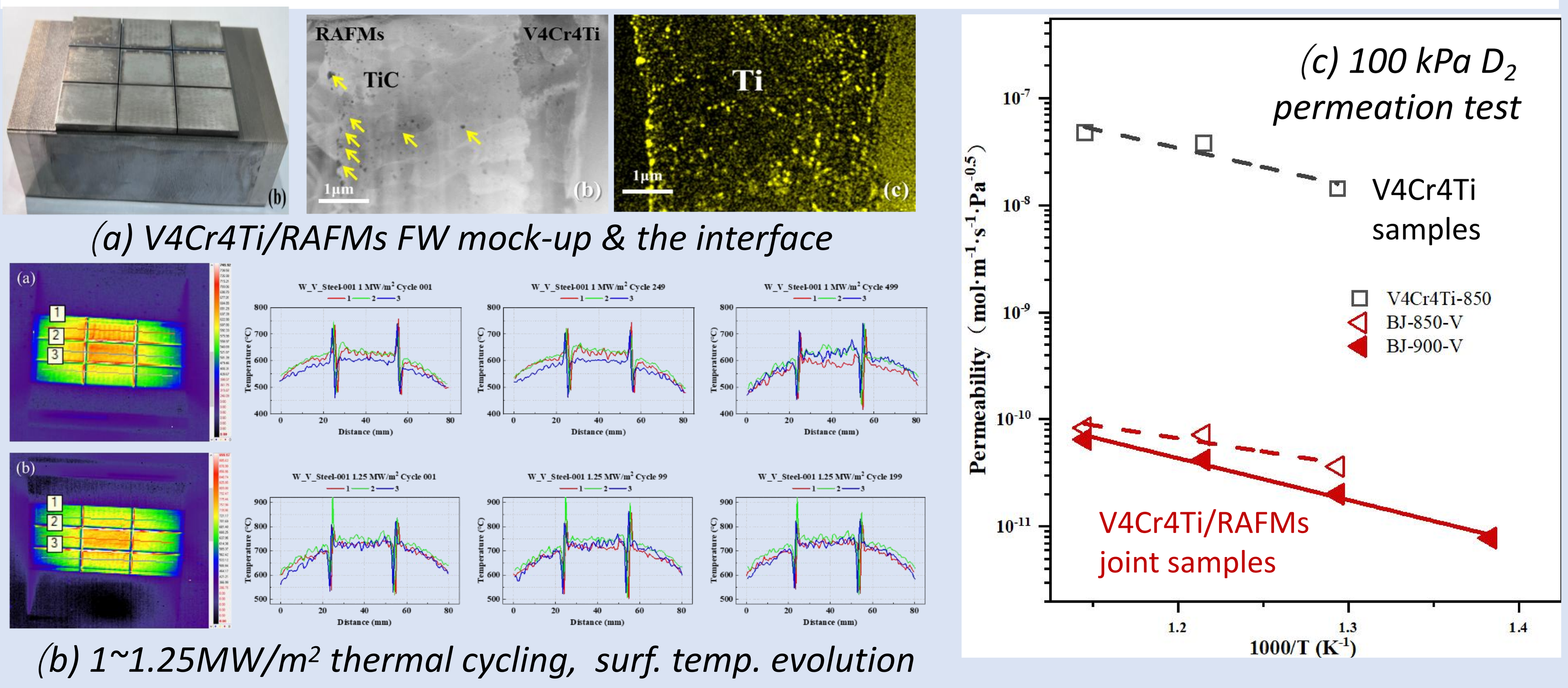

Figure 3 The 2.5mm thick W tiles armored V4Cr4Ti/RAFMs mock-ups, its interface nano-meter TiC particles, thermal cycling test and D2 gas permeation test results

SCALING-UP FW panel FOR CFETR

EB-welding to assembly 1/9 size FW units to a full-size FW (1.2x1x1m) .

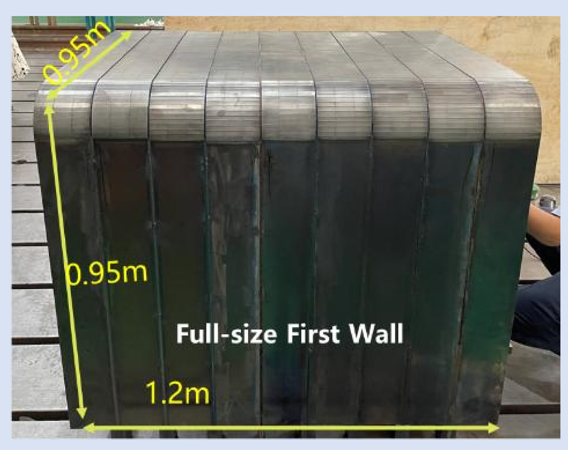

Figure 4 EB-welding 9 units for a full-size FW assembly, 2mm W tiles HIP bonded to RAFMs

Summary

- The manufacturing of ITER W EHF FW and its major properties have been demonstrated, futher improvement to de-risk water leak at the heat sink bi-metallic interface is required.
- FW technologies for future are invetigated and are scaling up, focusing on low activation materials operating at higher temperature, strong tritium barriers.

ACKNOWLEDGEMENTS / REFERENCES

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