Experimental investigation of EU-DEMO Breeding Blanket First Wall mock-ups in support of the manufacturing and material development programmes

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Introduction

- The estimated surface loadings of the EU-DEMO blanket push the design of the Helium Cooled Pebble Bed blanket closer to the limits of the operating window of the EUROFER97; to mitigate this issue various approaches have been implemented.
- To increase temperature limits and improve neutron irradiation performance, nanostructured oxide dispersion strengthened (ODS) steel is developed.
- To reduce sputtering due to particles loading of the FW, tungsten coating is investigated. Given the difference of the thermal expansion coefficient between the two materials, the experimental demonstration of the good adhesion and stability of such a coating under high heat flux loading is required.

Objective & Plan

- To evaluate experimentally the behavior of an ODS steel at high temperatures as well as qualification of the tungsten coating, two FW mock-ups were manufactured and tested in HELOKA at KIT:
  1) ODS mock-up with 2-3 mm ODS plate joined to EUROFER97 plate by diffusion welding, and
  2) FG mock-up with Functionally Graded Tungsten/EUROFER97 coating.
- Testing of each mock-up was performed in a separate experimental campaign with dedicated testing parameters in the Helium Loop Karlsruhe (HELOKA), see Figure 1.
- The HELOKA is dedicated for testing fusion blanket modules and mock-ups of the First Wall (FW) and the divertor under relevant high heat flux while using high-pressure and high-temperature helium as a coolant.

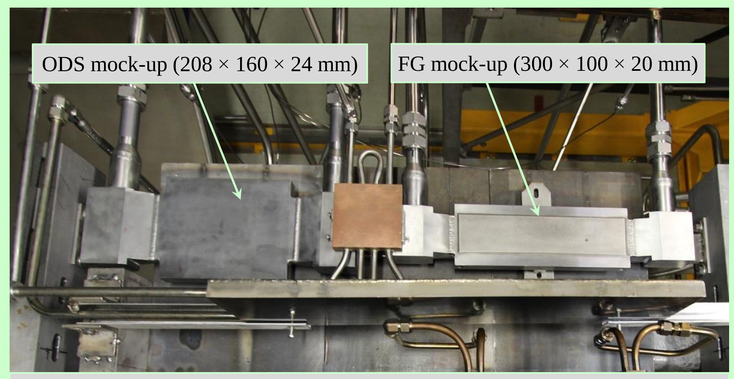


Figure 1: The two mock-ups are installed on a joint fixation structure.

Setup & Measurements

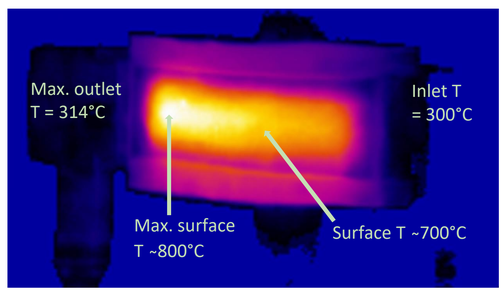
- The two mock-ups are installed on a joint fixation structure (see Figure 1) inside the vacuum vessel of the HELOKA test section 2.
- The mock-ups are subject to high heat flux cyclic loading by using the Electron Beam Gun; while cooled by helium at blanket conditions of 8 MPa and 300°C.
- The measurements include: (i) helium pressure at the inlet and outlet of both mock-ups as well as the differential pressure across the flowmeter downstream each mock-up, (ii) helium mass flow rate through each mock-up using 2 mass flow meters, (iii) helium temperature at inlet and outlet of each mock-up using thermocouples, and (iv) temperatures of the mock-up surface by the infrared camera FLIR X6580sc.

Testing of FG Mock-up

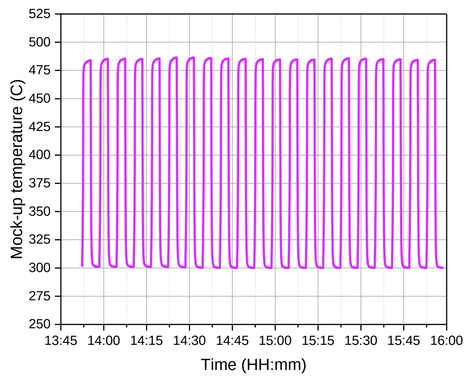
- The testing parameters of the FG mock-up is given in this table →
- The FG mock-up has 3 straight cooling channels with a rectangular cross section of 15 mm × 10 mm.

Helium mass flow rate [g/s]	170
Helium inlet temperature [°C]	300
Helium pressure [MPa]	8
Substrate temperature [°C]	≤ 520
Heating / dw ell time [s]	180 / 150
Number of Cycles	1000

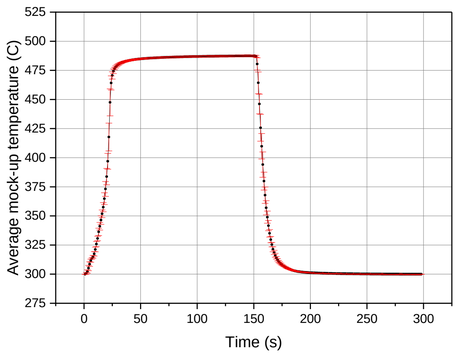
- The thermal profile of the FG mock-up surface is obtained by the infrared thermo-camera used to monitor the coating surface temperature.
- The maximum surface temperature is about 800°C while the maximum helium outlet temperature is 314°C.



- The mock-up temperature (shown versus time during 21 cycles) is measured by a TC inserted into a hole at the center of the plate (at the bottom surface).
- The TC (inside the hole) penetrates between cooling channels to reach a point 2 mm below the Eurofer/coating interface.



- Average values of mock-up temperatures in 13 cycles (run 05.08.2019) with the standard deviation values are shown →
- In parallel to the camera and the TC, inlet and outlet He temperatures are measured by HELOKA to evaluate calorimetrically the received surface heat flux



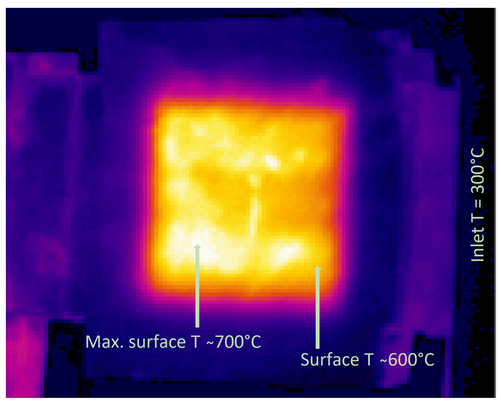
- The status of the heat-loaded surface of the FG mock-up after the experiments is here →
- The impact of the heat flux on the surface can be observed clearly.

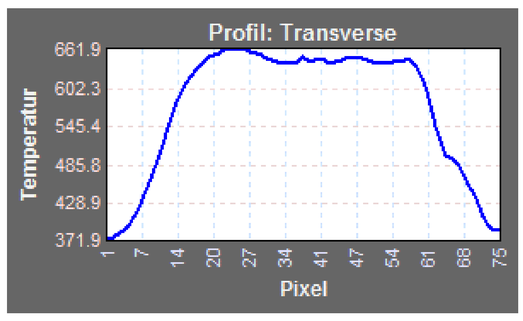
Testing of ODS Mock-up

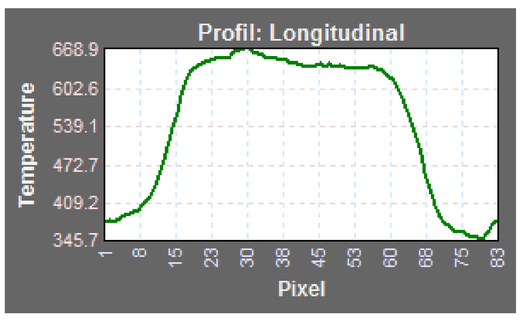
- The testing parameters of the ODS mock-up is given in this table →
- The ODS mock-up has 5 straight cooling channels with a rectangular cross section of 15 mm × 10 mm.

Helium mass flow rate [g/s]	200
Helium inlet temperature [°C]	300
Helium pressure [MPa]	8
Heating plateau time [s]	140 & 150
Surface temperature [°C]	550 – 650
Number of Cycles	307

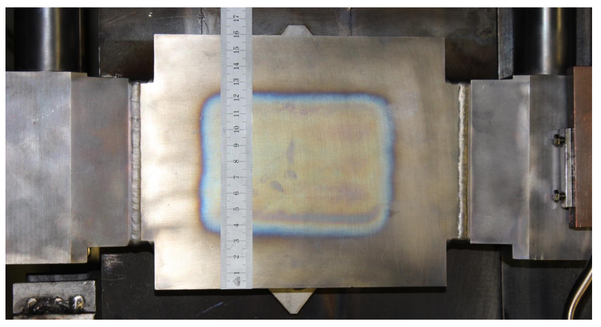
- The shape of the beam pattern and the uniformity of the heat load are estimated by looking at the infrared image of the mock-up surface.
- The surface temperature distribution of the ODS mock-up was produced by the infrared thermo-camera.
- The maximum surface temperature is about 700°C while the maximum helium outlet temperature is ~ 308°C.







- These thermal profiles (transverse and longitudinal) across the ODS mock-up were generated using the infrared camera software.
- In both thermal profiles, the maximum surface temperature ranges from 662°C to 669°C.
- The status of the heat-loaded surface of the ODS mock-up after the experimental campaign is shown in this picture →
- The surface area which received the EBG heat loading has a change of its color.



Summary

- This poster describes the experimental investigation of the two FW mock-ups with special consideration on the diagnostics used for this experiment, in particular the measurement of the surface temperature with an infrared camera and the evaluation of the surface heat flux.
- The experimental testing, under high heat flux and cyclic loading, of the two FW mock-ups was performed in HELOKA and successfully concluded.
- The results show that the reproducibility of the different measurements obtained in many cycles is good enough to generate meaningful conclusions.

EUROfusion

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