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High heat flux tests of the WENDELSTEIN 7-X pre-series target elements Experimental evaluation of the thermo-mechanical behaviour

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Abstract

The high heat flux (HHF) testing of WENDELSTEIN 7-X pre-series target elements is an indispensable step in the qualification of the manufacturing process. A set of 20 full scale pre-series elements was manufactured by PLANSEE SE to validate the materials and manufacturing technologies prior to the start of the series production.

The HHF tests were performed in the ion beam test facility GLADIS. All actively water-cooled elements were tested for about 100 cycles at 10 MW/m^2 (10–15 s pulse duration). Several elements were loaded with even higher cycle numbers (up to 1000) and heat loads up to 24 MW/m^2. Hot spots were, observed at the edges of several tiles during the HHF tests indicating local bonding problems of the CFC.

The thermo-mechanical behaviour under HHF loading has been evaluated and compared to the FEM predictions. The measured temperatures and strains confirm the chosen FEM approach. This allows a component optimisation to achieve a successful series production of the W7-X divertor target elements.

Keywords: W7-X; Divertor; Plasma facing components; HHF tests

1. Introduction

The envisaged steady-state operation of W7-X requires the installation of 19 m^2 actively water cooled divertor target area [1]. The 890 divertor target elements are made of CuCrZr heat sinks covered with flat tiles of CFC (carbon fibre reinforced composite) NB31 as plasma facing material. The elements are designed to withstand a steady-state heat flux of 10 MW/m^2 and a power load up to 100 kW for long term plasma operation of W7-X.

The aim of the activities described herein concern the validation of the materials and manufacturing technologies prior to the start of the series production of

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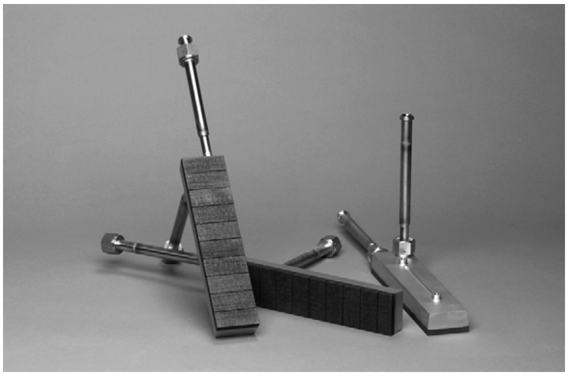

Fig. 1. Photograph of target elements type 4S with the cooling water inlet in axial direction and the perpendicular arranged outlet tube. The right hand element shows the 10 flat CFC NB 31 tiles.

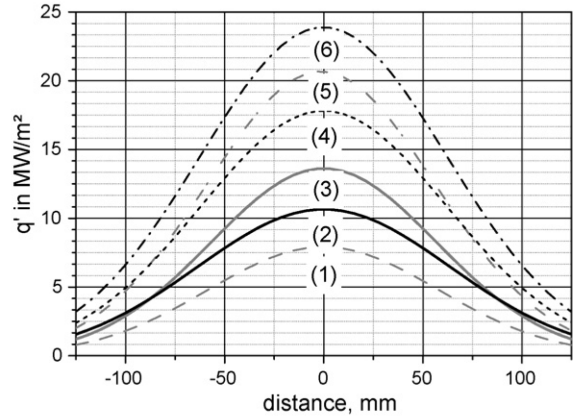

Fig. 2. Fits to measured beam profiles at target position. Three CFC tiles (width 75 mm) were loaded within 85–100% of the central power density on each test position.

the target elements by PLANSEE SE. Two different bonding techniques between CFC tiles and heat sink, electron beam welding (EBW) and hot isostatic pressing (HIP), have been evaluated. After the successfully tested CFC front tile bonding [2], a set of 20 full scale pre-series elements (length 250 mm, width 57 mm, 10 flat tiles per element, covered with NB31 from the second batch of the CFC production was produced, Fig. 1 [3]. These elements were tested in the ion beam high heat flux test facility GLADIS [4] in consecutive steps of power loading. At first, a screening at power densities from 6 to 10 MW/m^2 and 15 s duration was performed. Afterwards, all elements were loaded at 10.4 MW/m^2 for 80 or more cycles (in the majority of cases for 100 cycles, some up to 1000 cycles) to characterize their fatigue behaviour. Six elements were additionally loaded with 13.5 MW/m^2 and 50–100 cycles to evaluate the behaviour at safety factor of 1.3 above the nominal power density.

High power loading up to 24 MW/m^2, 15 s, on three elements completed the evaluation of the thermal performance of the W7-X target design.

2. Heat loading conditions in GLADIS

The target elements were installed perpendicular to the ion beam axis in the HHF test facility GLADIS. Three beam positions were used to test the targets with a uniform heat load of 85–100% of the central heat flux on each tile. The heat load on the end tiles no. 1 and 10 was reduced to 75% of the nominal heat flux. The power density at the target position was measured and checked with a linearly movable, inertially cooled calorimeter during the test campaign. 2D Gaussian fits to these data provide the beam profiles the target position shown in Fig. 2. Table 1 summarises the applied beam power densities. The comparison between the

Table 1
Comparison of the measured and calculated heat load at the target

Central heat flux (MW/m^2) (profile no.)	Power input calculated from beam profile (kW)	Power input calorimetrically measured on target (kW)	Agreement (%)
8 (1)	62	59 ± 2	95 ± 3
10.4 (2)	86	82 ± 2	95 ± 2.5
13.5 (3)	102	98 ± 2	96 ± 2
17.8 (4)	144	137 ± 3	95 ± 2
20.5 (5)	155	144 ± 3	93 ± 2
24 (6)	177	155 ± 3	88 ± 2

The measured power input includes the thermal radiation for the profile no. 6 only.