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SCIENCE DIRECT®
Fusion Engineering and Design 75–79 (2005) 387–390
Fusion Engineering and Design
www.elsevier.com/locate/fusengdes

A mature industrial solution for ITER divertor plasma facing components: Hypervapotron cooling concept adapted to Tore Supra flat tile technology

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Available online 18 August 2005

Abstract

The use of flat tile technology to handle heat fluxes in the range of 20 MW/m^2 with components relevant for fusion experiment applications is technically possible with the hypervapotron cooling concept. This paper deals with recent high heat flux performances operated with success in two different electron gun facilities and highlights the high potential of this technology for ITER divertor application.

Keywords: Hypervapotron; Flat tile; Divertor; CFC; W

1. Introduction

The design heat flux for specific plasma facing components in ITER is in the same range (10–20 MW/m^2) as that observed in electron tubes. Historically, the so-called hypervapotron concept with enhanced cooling capabilities implying boiling/condensation effects due to a fin design was developed by Thomson CSF tube Company [1] for such purposes and later designed for neutral beam heating systems [2].

The concept adapted to a CuCrZr heat sink armoured with carbon fibre composite (CFC) or tungsten (W) was envisaged for the vertical targets of the ITER divertor, since the beginning of ITER EDA, but finally abandoned mainly because of the postulated occurrence of a "cascade tile failure" effect. It was also suspected that the joint temperature between CFC or W and CuCrZr may be too high.

The latest experimental results accompanied by progress in modelling have shown excellent behaviour

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doi:10.1016/j.fusengdes.2005.06.328

of flat tile armoured hypervapotrons with regards to the two mentioned supposed disadvantages: cascade tile failure occurrence under ITER nominal heat flux of 10 MW/m^2 was not experimentally observed [3] and temperature of the armour/heat sink joint (strongly dependent on the flow velocity) was measured below a tolerated limit even under ITER slow-transient heat flux of 20 MW/m^2 [4].

In order to validate the hypervapotron concept, in terms of required high heat flux performances, as a design solution for the ITER divertor, thermal fatigue testing has been successfully performed on two medium scale mock-ups and is reported in this paper.

2. Mock-ups description

Two identical mock-ups were manufactured by Plansee AG: each consisted of a CuCrZr heat sink (741 mm length × 27 mm width) armoured with 25 flat tiles (18.5 mm length × 6 mm thick) of the 3D carbon fibre composite material SEPcarb NS31 assembled with pure copper by active metal casting (AMC). The manufacturing route respected the main technological features of a TORE SUPRA toroidal limiter finger element [5]: firstly AMC tiles were electron beam welded on the CuCrZr bar, then fins and slots based on the neutral beam JET design [2] were machined into the bar, afterwards, the bar was closed with a thick CuCrZr rear plug including hydraulic connections then electron beam welded onto the sidewalls (Fig. 1). The two mock-ups were equipped with 6 K-type thermocouples positioned at the copper/CuCrZr joint.

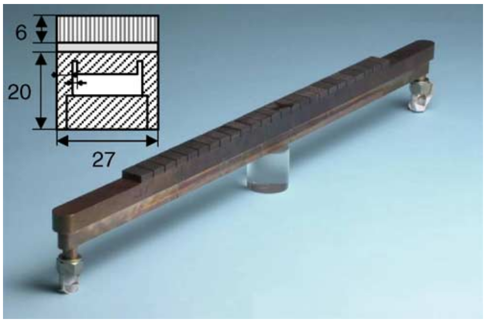

Fig. 1. View of one of the components and sketch of the design.

Table 1
Testing procedure

ITER specifications	FE200	TSEFEY-M
3000 cycles 10 MW/m^2	3000 cycles 15 MW/m^2	3000 cycles 15 MW/m^2
300 cycles 20 MW/m^2	800 cycles 5 MW/m^2	1000 cycles 25 MW/m^2
Critical Heat flux	A few cycles >30 MW/m^2	A few cycles >30 MW/m^2

3. Testing facilities and procedure

One mock-up was tested at TSEFEY-M (60 kW) in St. Petersburg and the second one at the FE200 (200 kW), located in Le Creusot. Main features of the electron gun facilities are described in refs. [6,7].

The same testing procedure was operated at the two facilities, aimed at demonstrating the ability of the technology to achieve the full ITER divertor target requirements with significant margins (Table 1). The heated area was generally 100 mm length × 27 mm width, e.g. five tiles, reduced down to three tiles due to power limitation at TSEFEY-M for fluxes higher than 20 MW/m^2.

4. Results, metallographic examination and discussion

4.1. Initial screening

The difference of inlet water temperature (respectively 20 and 120 °C at TSEFEY-M and FE200) led to a shift of 100 °C in the range of the temperature measurements. Three tiles were missing on the mock-up tested at TSEFEY-M (nos. 23, 24 and 25) due to a mistake during the final machining operation and tiles 5 and 8 were shown to overheat on the mock-up tested at FE200 during initial screening at 5 MW/m^2 absorbed in the water (Fig. 2). Post testing examination performed by Plansee showed that the X and Y directions of the NS31 were mixed on these tiles (Fig. 3).

4.2. Fatigue testing at 15 MW/m^2

Three thousand pulses of 10 s duration at 15 MW/m^2 were performed as a first step in fatigue testing