Fusion Engineering and Design xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Testing candidate interlayers for an enhanced water-cooled divertor target

David Hancock[a,*], Tom Barrett[a], James Foster[a], Mike Fursdon[a], Gregory Keech[a], Simon McIntosh[a], William Timmis[a], Michael Rieth[b], Jens Reiser[b]

[a] CCFE, Culham Science Centre, Oxfordshire OX14 3DB, UK
[b] Karlsruhe Institute of Technology, IAM-AWP, P.O. Box 3640, 76021 Karlsruhe, Germany

HIGHLIGHTS

- We introduce an optimised divertor target concept: the "Thermal Break".
- We suggest a candidate interlayer material for this concept: FeltMetal.
- We describe a bespoke rig for testing the thermal conductivity of this material.
- We present preliminary results for a number of samples.

ARTICLE INFO

Article history:
Received 5 October 2014
Received in revised form
16 December 2014
Accepted 18 December 2014
Available online xxx

Keywords:
DEMO
Divertor
Interlayer
Testing
Conductivity

ABSTRACT

The design of a divertor target for DEMO remains one of the most challenging engineering tasks to be overcome on the path to fusion power. Under the European DEMO programme, a promising concept known as Thermal Break has been developed at CCFE. This concept is a variation of the ITER tungsten divertor in which the pure Copper interlayer between Copper Chrome Zirconium coolant pipe and Tungsten monoblock armour is replaced with a low thermal conductivity compliant interlayer, with the aim of reducing the thermal mismatch stress between the armour and structure. One candidate material for this interlayer is FeltMetal^{TM} (Technetics Group, USA). This material consists of an amorphous matrix of fine copper wires which are sintered onto a thin copper foil, creating a sheet of approximately 1 mm thickness. FeltMetal has been successfully used for many years to provide compliant sliding electrical contacts for the MAST TF coils and on ALCATOR C-Mod and extensive material testing has therefore been undertaken to quantify thermal and mechanical properties. These tests, however, have not been performed under vacuum or DEMO-relevant conditions. A bespoke experimental test rig has therefore been designed and constructed with which to measure the interlayer thermal conductance as a function of temperature and pressure under vacuum conditions. The design of this apparatus and the results of experiments on FeltMetal as well as other candidate interlayers are presented here. In parallel, joint mockups using the candidate interlayers have been prepared and Thermal Break divertor target mockups have been manufactured, requiring the development of a dedicated joining process. These mockups will be subjected to high heat flux testing to further demonstrate the viability of the Thermal Break concept.

1. Introduction

1.1. Context

The design of a divertor target for DEMO remains one of the most challenging engineering tasks to be overcome on the path to fusion power. The decreased performance and overall lifetime due to increased neutron damage to the structural and armour materials, when compared to current machines and ITER, causes a significant challenge, particularly when coupled with the increased requirements for heat handling capability and material erosion lifetime.

1.2. Thermal Break divertor concept

Under the European programme, a promising concept known as "Thermal Break" has been developed at CCFE. This concept is a variation of the ITER Tungsten divertor in which the pure Copper

* Corresponding author. Tel.: +44 7968021712.
E-mail address: david.hancock@ccfe.ac.uk (D. Hancock).

http://dx.doi.org/10.1016/j.fusengdes.2014.12.026

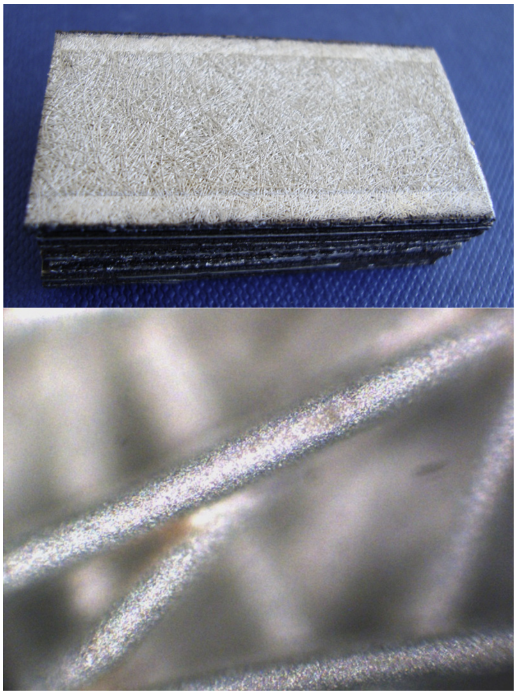

Fig. 1. Stack of 1 mm × 30 mm × 15 mm FeltMetal sheets and magnified (200×) photograph of silver plated FeltMetal.

interlayer between CuCrZr coolant pipe and Tungsten monoblock armour is replaced with a low thermal conductivity compliant interlayer, with the aim of reducing the thermal mismatch stress between the armour and structure.

An optimised version of this concept using irradiated property data and tailored interlayer properties, generated in 2013, was demonstrated to pass the ITER structural design criteria for in-vessel components and maintain a Tungsten surface temperature of <1300 °C when subjected to 10 MW/m^2 heat loads [1,2].

1.3. Candidate interlayer materials

One candidate material for this interlayer is FeltMetal^{TM} (Technetics Group, USA). This material consists of an amorphous matrix of 50 μm diameter copper wires which are sintered onto a thin copper foil, creating a sheet of approximately 1 mm thickness (Fig. 1).

FeltMetal has been successfully used for many years to provide compliant sliding electrical contacts for the MAST TF coils and on ALCATOR C-Mod and extensive material testing has therefore been undertaken to quantify thermal and mechanical properties [3]. These tests, however, had not previously been performed under vacuum or DEMO-relevant conditions.

Additional candidate interlayers for the Thermal Break concept have also been proposed. These include variations on FeltMetal such as using different thicknesses, materials and fibre parameters generated by advanced manufacturing techniques and alternative materials to more specifically tailor the properties of the interlayer. Analytical assessment of the relative impact of varying conductivity, thermal expansion, and Young's modulus is being undertaken within the Eurofusion WPDIV project and will guide the choice of interlayers to be explored in the next phase of this work.

1.4. Requirement for custom experimental apparatus

The conductivity of candidate interlayer materials must be well understood over a wide range of temperatures, vacuum conditions, and potentially under significant compression due to the thermal mismatch of armour and structural materials. While a number of methods exist for measuring thermal conductivity, including thermal flash and hot wire methods [4], these do not easily allow the samples to be subjected to the required pressures and do not lend themselves to testing conduction paths through more complex samples which include additional layers such as braze joints. The experimental apparatus detailed below provides a simple, flexible solution to these requirements.

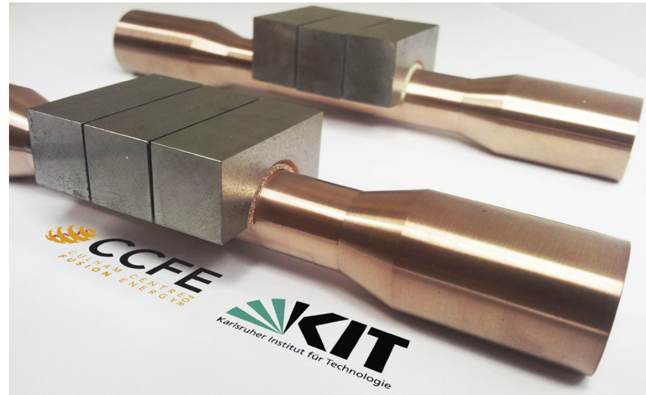

Fig. 2. High heat-flux mockups.

1.5. Manufacturing trials

In parallel, joint mockups using the candidate interlayers have been prepared and Thermal Break divertor target mockups have been manufactured, requiring the development of a dedicated joining process. These mockups (two of which are shown in Fig. 2) will be subjected to high heat flux testing to further demonstrate the viability of the Thermal Break concept.

2. Design of vacuum thermal conductivity experiments

2.1. Mechanical design

An overview of the mechanical design of the experimental apparatus is shown in Fig. 3.

The experiment was centred around a 70 mm × 15.8 mm × 15.8 mm test piece mounted vertically between two copper holding pieces, as shown.

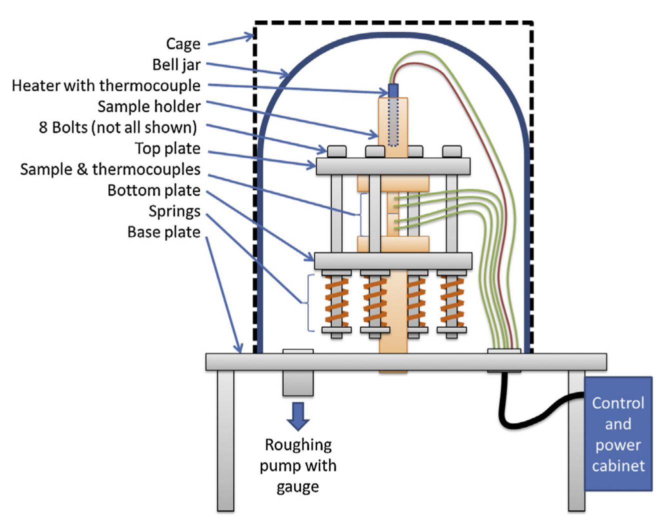

Fig. 3. Overview of thermal conductivity apparatus.

Please cite this article in press as: D. Hancock, et al., Testing candidate interlayers for an enhanced water-cooled divertor target, Fusion Eng. Des. (2015), http://dx.doi.org/10.1016/j.fusengdes.2014.12.026