

Vacuum plasma-sprayed tungsten on EUROFER and 316L: Results of characterisation and thermal loading tests

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Abstract

Vacuum plasma-spraying (VPS) can be used for the industrial deposition of thick W coatings on actively water-cooled components made of low activation steel or stainless steel. Mock-ups made of martensitic steels, EUROFER and F82H, as well as steel 316L, were coated with 2 mm thick W-VPS layers. The coated materials are candidates for first wall components (ITER and DEMO) receiving moderate heat load of up to 1 MW/m². Mixed tungsten/steel interlayers were applied to reduce the residual and thermal stresses at the substrate–coating interface and to improve the adhesion of the coating. The advantage of this mixed interlayer is that no further (high activation) materials have to be introduced to improve coating adhesion.

The characterisation of the W-VPS layers includes the evaluation of the coating microstructure, the measurement of physical and mechanical properties and the metallographical examination before and after heat load tests.

Heat load tests with steady state operation up to 2.5 MW/m² and cycling heat loads of 2 MW/m², were successfully completed. They confirm the thermomechanical suitability of industrially manufactured W-VPS coatings for plasma facing first wall components made of steel.

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1. Introduction

Tungsten is being considered as a potential plasma facing material for future fusion devices, primarily due

to its low erosion rate and heat resistance. Vacuum plasma-spraying (VPS) of tungsten offers an efficient coating of components made of low activation steels, EUROFER and F82H, respectively, as well as stainless steel 316L. These materials would be potential candidates for plasma facing components (PFC) receiving moderate heat loads up to 1 MW/m². The limited capability of heat removal of these steels follows from their

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relatively low thermal conductivity and their operation temperature, is restricted to maximal 550 °C. Residual stresses, generated from the high processing temperature of VPS and from the strong mismatch in the coefficient of thermal expansion between steel substrates and W coatings, limit the adhesion of coatings. It is necessary to apply intermediate layers on an actively cooled substrate to reduce the residual stresses.

Based on the results concerning the application of W coatings on PFC [1–3] and of the development of thick VPS-B₄C coatings on stainless steel panels [4], a development programme was started in co-operation with PLANSEE AG to investigate the deposition of 2 mm thick W layers on actively cooled steel substrates by applying an industrial VPS coating. For the application as protective layer, it is important to find a balance in the thermo-mechanical behaviour of the coating and substrate to guarantee a high reliability in operation.

2. Manufacturing

VPS is used for metallic and ceramic materials which are sensitive to oxygen during deposition. This technique provides layers with low contents of impurities and residual gas, especially the content of oxides, and oxygen is reduced.

Several steel substrates with outer dimension of 80 mm × 80 mm were coated with different spraying parameters to qualify the manufacturing process. The thickness of the substrates takes into account the different thermal conductivities of martensitic and austenitic steels. This ensures comparable cooling conditions for the W-VPS layers on both substrate materials during manufacturing and thermal loading.

The power, the relative velocity of the plasma gun and the feed rate of W powder were varied to find an optimal set of coating parameters. Furthermore, the substrates were actively cooled during the spraying process in order to keep the substrate at low temperature. All substrates were coated with a mixed W/steel interlayer of 500 µm thickness at first, immediately followed by a 2 mm thick coating of pure W. As a result of a metallographical examination of these samples, the VPS process parameters were determined to cover the larger scale mock-ups for the following thermo-mechanical investigations. In each case, three mock-

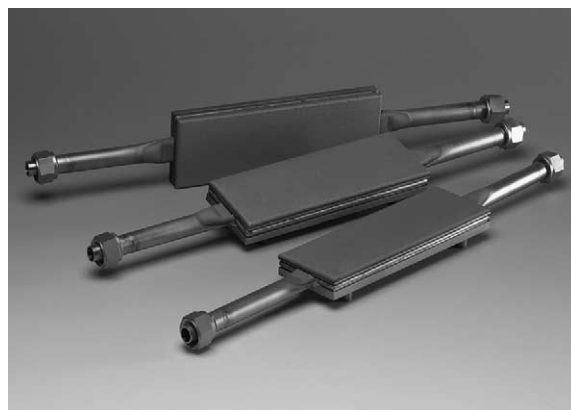


Fig. 1. W-VPS coated mock-ups made of EUROFER, F82H and 316L. Dimensions of coated area are 60 mm × 190 mm.

ups made of EUROFER, F82H and stainless steel 316L with surface areas of 190 mm × 60 mm, were coated. Fig. 1 shows the fabricated mock-ups.

3. Thermal loading tests

Thermal tests of one EUROFER and one 316L mock-up, were carried out in the JUDITH facility at FZ Jülich. In the frame of a co-operation with JAERI, one F82H mock-up was tested in the JAERI electron beam test facility JEBIS.

The surface temperatures of the samples were measured with pyrometers and the temperature distribution on the surface was monitored with IR cameras in both facilities. Thermocouples (TC), installed at four positions, measured the temperatures of the substrates in the heat loaded zone. The measured temperatures are in good agreement with the FEM calculations performed in preparation of the tests for each mock-up (Fig. 2). Table 1 summarises the accomplished test programme.

All mock-ups successfully survived the planned test programme up to 2.5 MW/m² without any damages. In the case of the ferritic–martensitic steel mock-ups, the aim was to reach interface temperatures during thermal cycling (500 °C) which are characteristics of operational conditions in DEMO with such steels as first wall material. No increase of surface temperatures has been observed during cycling. The heat load test of the W-F82H sample was extended up to 3.5 MW/m² supplementary. The surface temperature reached up to

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