IV. Participation to the JET Enhancement Project

Manufacturing and testing of W-coated CFC tiles for installation in JET for the ITER-like Wall project
EFDA Task Agreement Code: JW6-TA-EP2-ILC-05
(MEdC Contribution)

Cristian Ruset, Eduard Grigore, Ion Munteanu, Nicolae Budica, Daniela Nendrean
National Institute for Lasers, Plasma and Radiation Physics, Magurele

1. INTRODUCTION

Currently, the primary ITER materials choice is a full beryllium main wall with CFC (Carbon Fibre Composite) at the strike points and tungsten at divertor baffles and dome. Since this combination has never been tested in a tokamak, ITER-like Wall project has been launched at JET (Joint European Torus) with the aim to replace the actual CFC first wall with a new one, comprising the same materials choice as it planned for ITER. In the R&D phase of this project (2005-2006) it was demonstrated that W coatings deposited on CFC by Combined Magnetron Sputtering and Ion Implantation (CMSII) technology, which was developed in MEdC Association, exhibited superior thermo-mechanical properties in comparison with other W coatings deposited by conventional PVD and CVD techniques. Consequently, this technology was selected for 10 μm W coating of about 1,000 tiles from the main chamber of tokamak, of different size and dimensions, under industrial conditions. The divertor tiles had to be coated with 200 μm W using Vacuum Plasma Spray technology. Due to the serious technical problems with this technology the strategy concerning the W coating of CFC tiles for JET has been changed. It was accepted that a W coating with a thickness of 20 – 25 μm would be enough for divertor. Under these conditions CMSII technology became a candidate for this job together with Cathodic Vacuum Arc technology. The High Heat Flux (HHF) tests were running in parallel at IPP Garching with GLADIS ion beam facility during the period September 2008 – June 2009. Again, Romanian CMSII new technology proved its superiority. As a result, the task of coating about 800 CFC tiles for divertor was transferred to MEdC Association by extended the existing Art. 6.3 Order to the Task Agreement JW6-TA-EP2-ILC-05.
Since the inner divertor tiles are subjected to deposition and only the outer tiles are subjected to erosion, two coating thickness were applied: 10-15 μm for G3, G4 and HFGC tiles and 20-25 μm for G1, G6, G7, G8 and LBSRP tiles.

2. OBJECTIVES

In the installation process of the JET first wall the divertor tiles are installed first. Consequently the priority concerning W coating of JET tiles has been changed. The specific objectives for 2009 became as follows:
- Qualification of the CMSII technology for divertor tiles (G1, G3, G4, HFGC, G6, G7, G8 and LBSRP)
- coating all G1, G3, G4, HFGC, G6, G7 and G8 tiles
- coating about 25 % of the tiles for the main chamber.
- deliver to JET all coated tiles
- LBSRP tiles was not a priority for JET because the tiles which should be installed were made of bulk W. Tungsten coated CFC tiles are a backup solution in case something goes wrong with the bulk tiles.

3. RESULTS AND DISCUSSION

3.1. Qualification of the CMSII technology for divertor tiles

Qualification of coating technology for a particular type of tile involves the following activities:

a) Designing and manufacturing of the jigging device for those tiles

The geometry of the tiles is very complicated. Their positioning on the jigging device requires a lot of imagination taking into account the following factors: distance between the surface to be coated and the magnetron targets, the number of the tiles in each load, the possible combination between different types of tiles, etc.

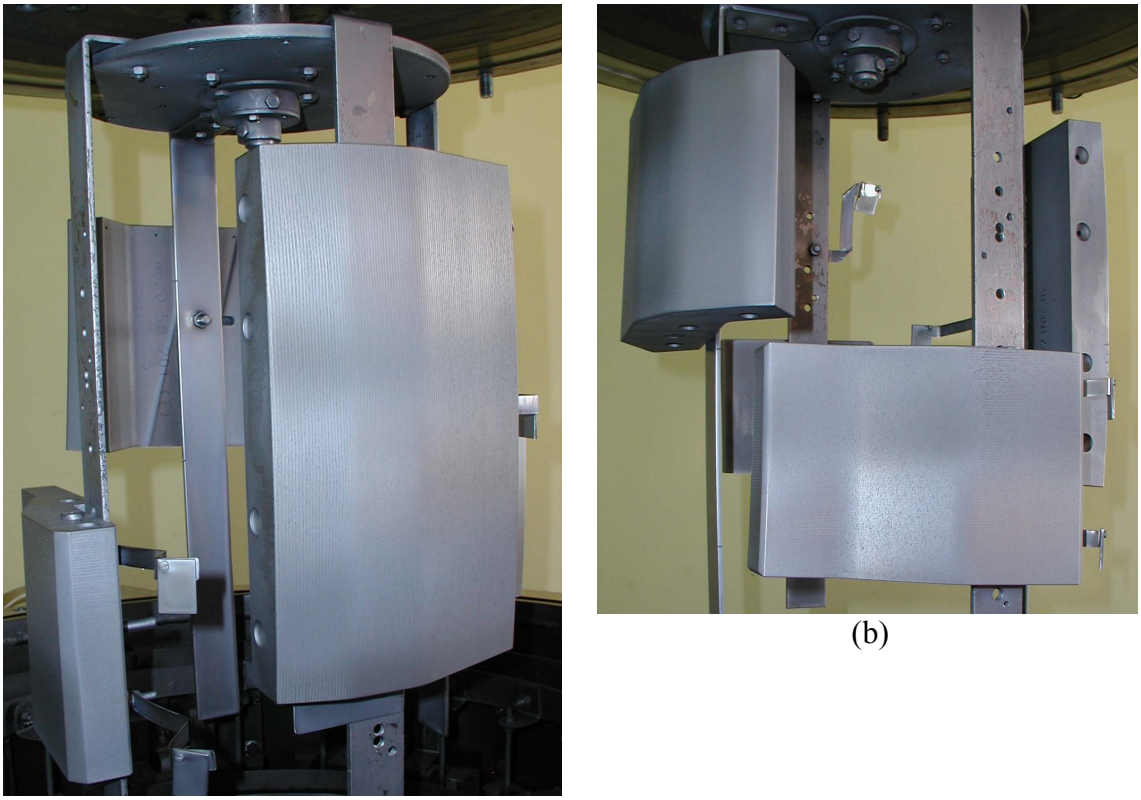
b) Producing of prototype W coating on those tiles

c) Successful testing of prototypes at HHF in GLADIS equipment at IPP Garching, Germany

The production can not start before successful test in GLADIS.

Initially, the 10-15 μm W coating was qualified for tiles G1, G3, G4 and HFGC. The prototype loads for these tiles are shown in Fig.1. They have been sent to IPP Garching and tested in January 2009 campaign. The results were „zero" defects after cycling heating up to 1,600 °C in different zones.

Since the testing time at GLADIS is very limited and the machine is not available for JET at any time, for the thick coatings two types of coatings were produced as prototypes. The first one was a multilayer Mo (2-3 μm)/W (10-12 μm)/Mo (2-3 μm)/W (8-10 μm) and the second configuration was Mo (2-3 μm)/W (18-20 μm). Both coatings were deposited on prototype lots of 6 Off G6 and 2 Off G7 tiles (Fig.2). These lots were tested in June and both configurations for thick coatings performed very well, with „zero" defects. Consequently, the production could start with G6 and G7 tiles as well.



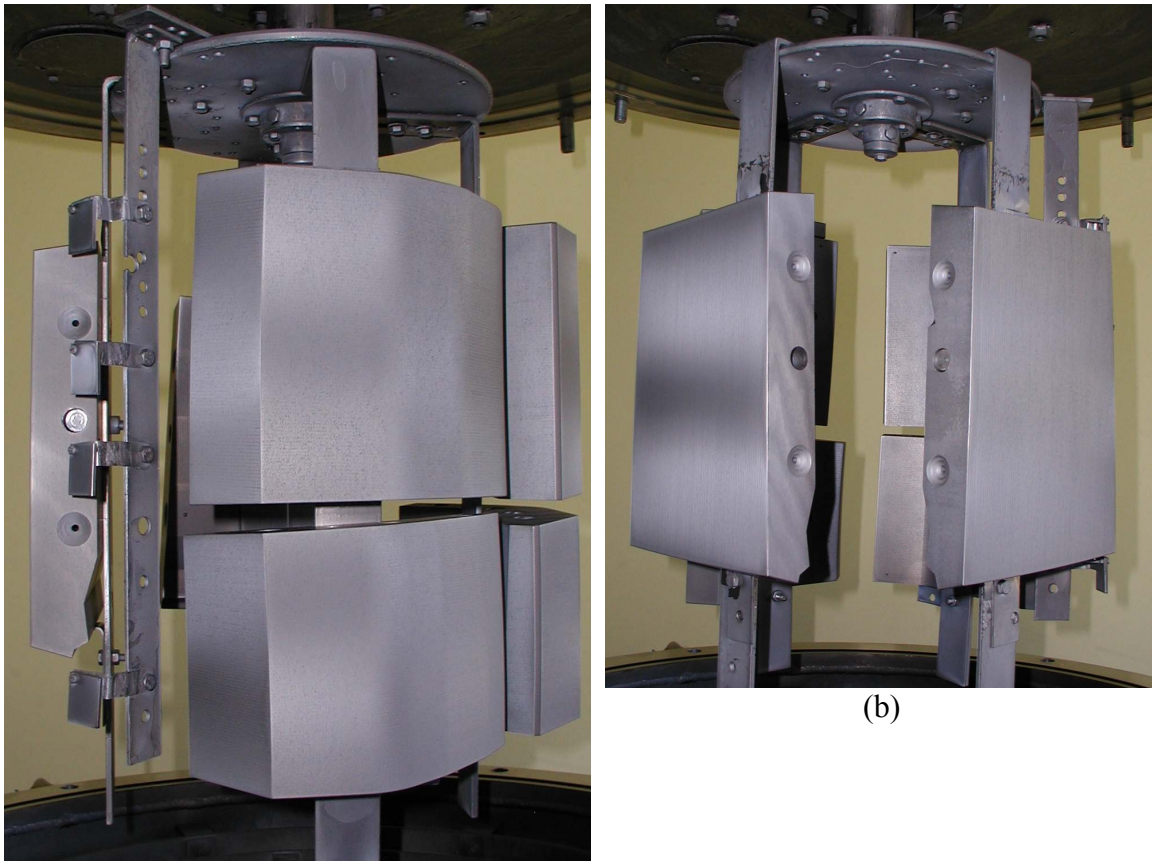
(a) (b)

Fig.1 Prototype W coating for G3 (a) and G1, G4 (b) divertor tiles

Later, in July the W coating process for G1, G8 and LBSRP tiles was qualified as well. The prototypes for G1, G8 and LBSRP tiles are shown in Fig. 3.

(a) (b)

Fig.2 Prototype W coating for G7 (a) and G6 (b) divertor tiles



(b)

(a)

Fig.3 Prototype W coating for G1, G8 (a) and LBSRP (b) divertor tiles

3.2. Coating production of divertor tiles

The following tiles have been coated by 15.12.2009.

- Divertor G3 tiles – 49 Off
- Divertor G4 tiles – 103 Off
- Divertor G6 tiles – 98 Off
- Divertor G7 tiles – 49 Off
- Divertor G1 tiles – 102 Off
- Divertor G8 tiles – 101 Off
- Divertor HFGC tiles – 100 Off
- Test tiles and W/Mo markers – 17 Off

Six lots of G3 (5 off), G4 (10 off), G6 (10 Off), G7 (6 Off), G1 (7 Off) and G8 (11 Off) have been sent to IPP Garching for HHF tests on production coatings. The tests revealed the good quality of the coatings with "zero" defects.

3.3. Qualification and production of the W coating for the main chamber tiles

All 7 prototypes for the main chamber tiles have been coated and successfully tested in GLADIS ion beam facility at IPP Garching. For each tested tile a quality control document is issued.

The following tiles have been coated by 15.12.2009.

- Inner Wall Cladding – 70 Off
- Shinethrough Protection – 23 Off
- Restrained Ring Protection – 57 Off
- LBSRP Protection – 93 Off
- Tile C– 52 Off
- Divertor C – 52 Off
- Saddle Coil Protection – 2 Off
- Diagnostic covers – Mushroom – 4 Off
- IWGL and IWGL (Be) – 36 Off
- Test tiles – 17 Off

The coated tiles were delivered to JET in two consignments.

A synthesis of the coated tiles and delivered to JET is shown below.

- Divertor tiles: 619 (85%)
- Main chamber tiles: 406 (40%)

According to the Milestone M6 of the Task Agreement 75% of the divertor tiles and 25% of the main chamber tiles should be coated and delivered to JET by 31.12.2009.

As it can be seen this milestone was accomplished.

4. DISSEMINATION OF RESULTS

Although the activity carried out in the framework of this project has mainly a technological character, some results were communicated at the 12th International Workshop on Plasma Facing Materials and Components for Fusion Applications which was held at Jülich, Germany on 11 – 14 May 2009 and at the 17th European Fusion Physics Workshop which was held at Velence, Hungary on 7 – 9 December 2009.

[1] C.Ruset, E.Grigore, H.Maier, S. Lindig, R.Neu, G.Matthews and JET-EFDA Contributors, The Influence of Mo Interlayer on the Properties of W Coating deposited on CFC and FGG Substrates by CMSII Technique, 12th International Workshop on Plasma Facing Materials and Components for Fusion Applications, Jülich, Germany, 11 – 14 May 2009.

[2] C.Ruset, E.Grigore, H.Maier, H.Greuner, R.Neu, M.Mayer and G.Matthews, Status of W coatings techniques, 17th European Fusion Physics Workshop, Velence, Hungary on 7 – 9 December 2009.

5. CONCLUSIONS

1) „ITER like Wall" project, with a budget of about 40 M€, is very important for both ITER and JET. It will provide information about the plasma-wall interaction under these particular conditions (Be wall in the main chamber and W at divertor), about the transport of the wall particles through the plasma and about the capability of these materials to sustain the real thermal loads they are subjected at.
2) EURATOM MEdC Association brings a significant contribution to the project by coating with W all the tiles which have to be coated. This means about 1,800 tiles of different shapes and dimensions. Approximately 60% of these tiles have been coated in 2009 and delivered to JET. This milestone has been successfully accomplished.
3) CMSII technology developed in the MEdC Association appears to be not only the best European technology for W coating of carbon based materials (CFC and FFG – Fine Grain Graphite), but the only technology able to produce at the industrial scale relative thick layers (20 – 25 μm) capable to sustain cyclic thermal loads up to 16 MW/m^2 (T ~ 1,600 °C) without delamination.

6. COLLABORATIVE ACTIONS

The tungsten coating activity is monitored by weekly meetings between JET and MEdC. Sometimes IPP participates as well. The current status of the production, the priorities in W coating of particular tiles and various problems are discussed in details.

In February 2009, the Plasma Surface Engineering Laboratory, where the W coating production occurs has been visited by Guy Matthews, the Project Leader from JET and Hans Maier responsible officer for W coating testing at IPP Garching Germany. On that occasion the capability of MEdC Association to coat both divertor and main chamber tiles in due time was evaluated. The evaluation was positive and as it was demonstrated later, it was realistic.

C.Ruset attended the Project Board and the associated technical meeting at JET.