

EDITORIAL

17th international conference on plasma-facing materials and components for fusion applications

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Editorial

17th international conference on plasma-facing materials and components for fusion applications

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(Some figures may appear in
colour only in the online journal)

The 17th International Conference on Plasma-Facing Materials and Components (PFMC) for Fusion Applications (PFMC-15) was held in Eindhoven in the Netherlands, May 2019 and jointly organized by the Dutch Institute for Fundamental Energy Research (DIFFER), part of the institutes organization of the Netherlands Organization for Scientific Research (NWO), and the Eindhoven University of Technology (TU/e).

Created in 1985, as the ‘Carbon workshop’, ten editions were organized in Jülich, Stockholm and Hohenkammer (Germany) up to 2003. Starting with about 40 participants for one and a half days, the number of participants and the duration increased substantially in a short time. At the workshop in 2009 it was acknowledged that this growth meant that the symposium name should change from ‘workshop’ to the ‘International Conference on PMFC-15’. In recent years, typically 200 scientists from Europe, Japan, China, Korea, Russia and USA regularly participate in each conference.

The main objective of this conference series is to provide a discussion forum for experts from research institutions and industry dealing with materials for plasma-facing components (PFCs) in current and future nuclear fusion devices. Progress in ITER construction and intensified discussions regarding wall materials for future demonstration power plants, like DEMO and CFETR, emphasize the importance of plasma–wall interactions and components. In this context, the properties and behaviour of beryllium, liquid metals and tungsten under plasma impact are research topics of foremost relevance and importance. The key role of materials in the development of the fusion power plant has been clearly identified.

The conference was opened by Niek Lopes Cardozo, Professor of ‘Science and Technology of Nuclear Fusion’ in the Applied Physics department of TU/e, and interim chair of the Science Domain of NWO as well as a member of the executive board of NWO. He highlighted the importance of PFCs in making fusion a reality.

Starting with a presentation on the design and R&D for plasma facing components in JT-60SA by D Tsuru [1] the conference in this edition focused on advanced materials such as composites (Mueller *et al* [2]), new manufacturing techniques like functional grading (Heuer *et al* [3]) as well as new concepts overcoming brittleness issues for tungsten (Terra *et al* [4]) in addition to the recurring issues tackled, such as component testing for ITER and beyond (e.g. Morgan *et al* [5], Pintsuk *et al* [6], Greuner *et al* [7]). New results from devices such as EAST (Zhu *et al* [8]) and ASDEX-Upgrade (Krieger *et al* [9]) on operation on damaged components gave valuable hints for operating a future divertor in ITER.

Recrystallisation and the effect of helium on material properties are critical aspects for tungsten application in ITER as they impact lifetime issues as

discussed by several presenters (e.g. Cheng *et al* [10], Durif *et al* [11], and Hasegawa *et al* [12]).

For low Z-materials, such as beryllium, new studies on melting, erosion (Jepu *et al* [13]) as well as retention (Hakola *et al* [14], Zlobinski *et al* [15], Baldwin *et al* [16]), gave additional information for the extrapolation to ITER operation of beryllium first wall components.

Neutron effects on materials (e.g. Ueda *et al* [17], Katoh *et al* [18], Riesch *et al* [19], Parish *et al* [20]), new approaches for modelling (e.g. Lasa *et al* [21], Stadlmayr *et al* [22], Eksaeva *et al* [23]) as well results from edge plasma physics directly impacting the material (e.g. Dittmar *et al* [24], Wang *et al* [25], Bucalossi *et al* [26]) completed the picture.

The presentations given at this year's PFMC presented aspects of fundamental processes, experimental findings, advanced modelling and technology of fusion reactor components.

Major topics of PFMC-17 were:

Tungsten, tungsten alloys, and advanced steels:

- Low-Z and liquid materials.
- Erosion, re-deposition, mixing, and dust formation.
- Fuel retention and removal.
- Materials under extreme thermal and particle loads.
- Technology and qualification of PFCs.
- Neutron effects in plasma-facing materials.
- Fusion devices and edge plasma physics.

A total of 18 invited talks, 20 contributed orals and 170 posters (two sessions) were presented. The majority of contributions were in the areas of tungsten and tungsten alloys and erosion, re-deposition, dust and fuel retention. Low Z-materials, neutron effects and advanced materials were other areas of keen interest.

A total of 244 people representing countries from all over the world (Canada, China, India, Japan, Korea, the Netherlands, Mexico, Russia, Ukraine, USA and more than 100 Europeans embedded in EUROfusion) joined the conference.

It is a long standing tradition that, prior to the actual conference, a series of tutorial presentations are organized to give students and young scientists an insight into the present-day knowledge of important areas related to plasma-facing materials and components and the associated major issues and challenges.

Apart from the knowledge transfer from senior scientists, experts in dedicated fields, to young enthusiastic students and researchers, beginners in this field who are looking for guidance and orientation, a personnel get-together took place. However, more than just students participated in the tutorials, but also senior scientists used the opportunity to get an easy understandable insight in the status of research in fields other than their own.

The lectures covered topics from the basic aspects of power-exhaust in fusion devices to modelling of plasma interactions with materials, advanced materials and components design for ITER. to the engineering of PFCs for ITER and DEMO:

- Particle and heat exhaust in future fusion reactors: challenges and solutions (H Reimerdes).
- Plasma facing material and component design for DEMO (J W Coenen).
- Computational science approaches to understanding plasma facing material performance (K Nordlund).
- Design and testing of plasma facing components for ITER (T Hirai).

The tutorials and the conference itself took place in the main auditorium of the campus at the Eindhoven University of Technology (TU/e) (TU/e) and was

jointly hosted by DIFFER and TU/e. The conference location was most suited for the size of the PFMC-17 meeting due to the availability of the whole of the auditorium building and its facilities.

The social program allowed either a visit to the Efteling, one of the oldest theme parks in the world, the La Trappe Brewery or Slot Loevestein, a beautiful and historic castle located at a strategic location at the confluence of the Maas and Waal rivers. The social program included the reception at DIFFER as well as the conference dinner at Asparagus in the Fields, a locally-renowned pop-up restaurant in the middle of the asparagus fields of nearby Veldhoven. Both were well appreciated by the participants of the conference indicating that the local organizing committee made a good selection.

The conference was financially supported by DIFFER and NWO, for which we are thankful. Moreover, the following sponsors, Pfeiffer Vacuum, Research Instruments, A De Jong TH, Acclon Technologies and EUROfusion, contributed in various ways to the success of the conference.

During the conference prizes for the best poster presented by a young researcher in each of the two poster sessions were chosen and presented during the dinner. M Tokitani from the Department of Helical Plasma Research at the National Institute for Fusion Science in Japan, and C P Dhard from the Max-Planck-Institut für Plasmaphysik, Greifswald, Germany were presented for the posters with the respective titles of ‘Surface morphology of the bulk tungsten divertor tiles from JET ITER-like wall’ [27] and ‘Inspection of W7-X Plasma facing Components after the Operation Phase 1.2b: observations and first assessments’ [28].

Copies of the posters are attached to this editorial with the authors permission (figures 1 and 2, respectively).

We are very thankful to the members of the Local Organizing Committee (LOC), the Members of DIFFER and the team at TU/e who helped to organize and execute the conference so smoothly as it happened in May 2019.

Our special thanks and gratitude are given to Dr Thomas Morgan, the Chair of LOC, and Ms Karine van den Wildenberg and Ms Lotte Krah, who ensured the conference ran well, technically and logistically, and arranged the excellent social program. Additionally, we thank the whole LOC: Thomas Morgan, Hans van Eck, Lotte Krah, Niek Lopes Cardozo, Peter Rindt, Bebe van der Vlis, Karine van den Wildenberg and Egbert Westerhof for all the superb work and great engagement in the overall preparation of work in the year prior to the conference. Dear colleagues, your efforts have been very highly praised by all participants of the PFMC-17 conference.

The proceedings of the PFMC-17 finally contain a total of 76 high-class peer-reviewed publications selected by the scientific programme committee out of the invited contributions, oral contributions, and a number of poster contributions. These papers reflect the development and actual status of the major topics of the PFMC for fusion applications. We thank all participants for their contributions and we particularly thank the referees for their diligent and systematic reviews of all submitted articles. In order to manage the provision of the proceedings less than 12 months after the conference, we used the electronic submission and review system of IOP with strong support from the IOP Team for the first time during the PFMC series. The interplay between authors, referees, guest editors and the editor worked very well indeed as it can be seen in this topical issue T171. A special thanks go to the Editorial team at IOP Publishing for their continuous and friendly support to get things done in an efficient and professional way. Finally, on behalf of Dr Marius Wirtz, the chairman of the PFMC-18, we take the liberty to invite you to the next conference in Bonn in 2021 organized by Forschungszentrum Juelich in Germany.

Surface morphology of the bulk tungsten divertor tiles from JET ITER-like wall

PB-078

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Introduction

- A large-scale test of a metal PFC has been realized at JET with ITER-Like Wall (JET-ILW): bulk beryllium (Be) limiters and Be coating in the main chamber, while bulk W lamellae-type and W-coated tiles are in the divertor [1].
- Micro/nanoscale observation on the surface of the divertor tiles used in the first ILW campaign (2011-2012) have been carried out by means of several material analysis techniques (TEM, FIB, EPMA) at QST Rokkasho, Japan, since FY2014 [2,3].
- Although many surface analysis studies have been made on the W-coated tiles made of carbon fibre composites, there are very few reports on the W lamellae.

This study is focused on the morphology of plasma-facing surfaces (PFS) of W lamellae and of side surfaces located in the gaps between the stacks of lamellae. The aim was determine the material modification on PFS and deposition in the gaps which are considered as a good representation of castellation.

[1] G.F. Matthews et al., Phys. Scr. T145 (2011) 014001., [2] M. Tokitani et al., Fusion Eng. Des. 116 (2017) 1-4., [3] M. Tokitani et al., Fusion Eng. Des. 136 (2018) 199-204.

Experimental procedures

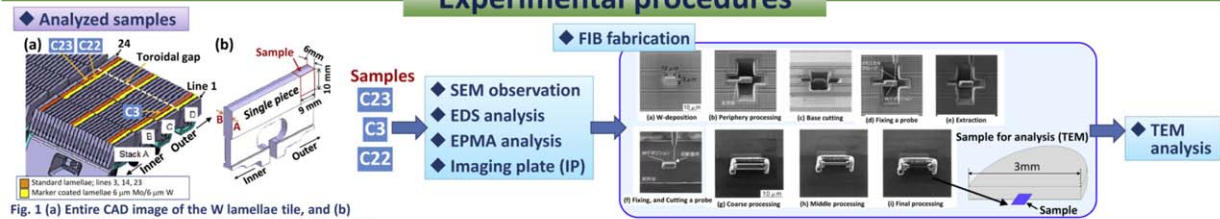


Fig. 1 (a) Entire CAD image of the W lamellae tile, and (b) Enlargement CAD image of a single piece of W lamellae.

Results and Discussions

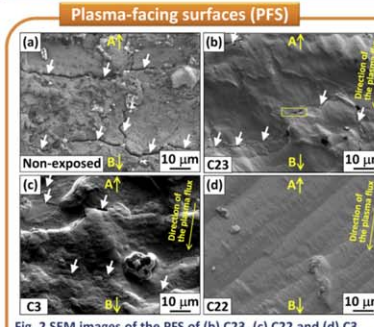


Fig. 2 SEM images of the PFS of (b) C23, (c) C22 and (d) C3 lamellae. Non-exposed W lamellae is also shown in (a). White arrows show the micro-crack positions.

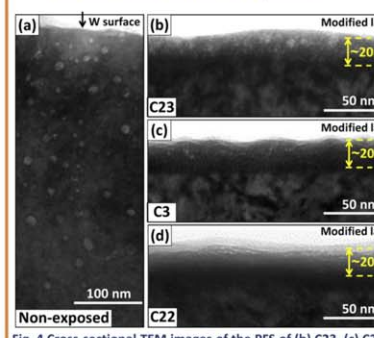


Fig. 4 Cross-sectional TEM images of the PFS of (b) C23, (c) C22 and (d) C3 lamellae. Non-exposed lamellae is also shown in (a).

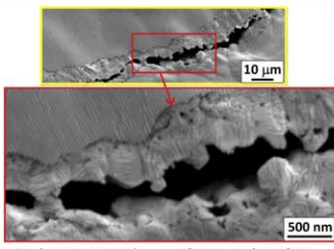


Fig. 3 Enlargement SEM images of C23 sample surface corresponds to the yellow rectangle area in Fig. 2-(b).

Plasma-facing surfaces (PFS)

- Erosion identified on C23, C3 and C22. C23 is the strongest.
- Network of micro-cracks can be identified on the non-exposed material. Initial micro-cracks also exist on the C23 and C3.
- Edges of micro-cracks in C23 have a melt-like, and a micro-scale plastic deformation.
- Cavities of ~15 nm in diameter densely and uniformly populate the region over 500 nm in depth in the non-exposed lamella.
- A dense modified layer with the thickness of ~20 nm has been formed on C23, C3 and C22.

Side surface in the toroidal gap

- The very fine and stratified mixed-material deposition layer with W, C, O and Be can be identified.
- The mixed-material deposition layer acted as the trapping site of tritium.

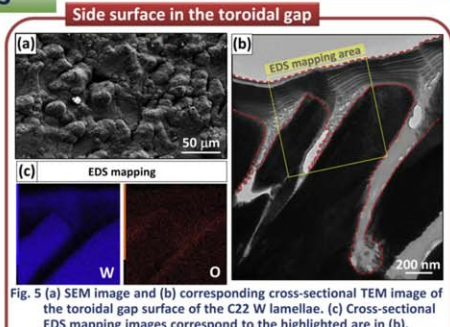


Fig. 5 (a) SEM image and (b) corresponding cross-sectional TEM image of the toroidal gap surface of the C22 W lamellae. (c) Cross-sectional EDS mapping images correspond to the highlighted area in (b).

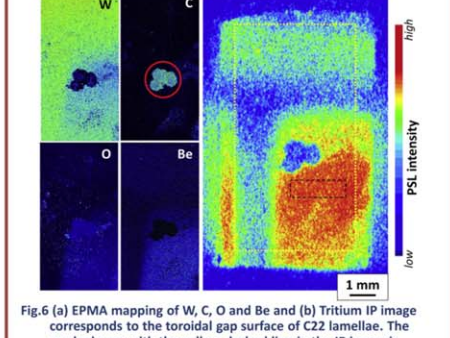


Fig.6 (a) EPMA mapping of W, C, O and Be and (b) Tritium IP image corresponds to the toroidal gap surface of C22 lamellae. The marked area with the yellow dashed line in the IP image is corresponds to the EPMA mapping area.

Summary

The study of the divertor after ILW-1 revealed both imperfections in the original as-manufactured material and the modification of PFC surfaces under the plasma impact.

- Plasma-facing surfaces (PFS)**
- A network of micro-cracks on the non-exposed material can be identified. The edges of micro-cracks caused a micro-scale plastic deformation due to a high-heat loading.
 - A dense modified layer with the thickness of ~20 nm has been formed on C23, C3 and C22. The layer includes defects with bubble-like structures.
- Side surface in the toroidal gap**
- First-ever data is related to a very detailed documentation of deposition and fuel inventory on side surfaces of the lamellae.
 - Mixed-material deposition layer (mainly Be) was formed on the side surface of the toroidal gap and act as the effective trapping site of tritium.

Figure 1. Poster by Tokitani [27]. Reproduced with permission from [27]. reproduced with permission from Tokitani et al., © The Authors.

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Inspection of W7-X Plasma-Facing Components after the Operation Phase 1.2b: observations and first assessments



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Motivation

- The safe operation of the Wendelstein 7-X (W7-X) machine is of vital importance
- A close inspection of the Plasma-Facing Components (PFC's) after the plasma campaign helps to judge the actual condition and identify the problems
- A first general inspection was carried out immediately after the plasma vessel was accessible after operation phase OP1.2b, the specific observations followed later
- A couple of events such as melting of probes, deposition of materials, loosely bound particles, arc trail etc. were observed
- A first assessment was made to analyse these events.

Melted probes

- One of the long term erosion/deposition Si-wafer probes found melted at position 10
- Simulations showed, this had occurred due to neutral beam injected fast ion orbit losses [1]

- Melted magnetic flux surface measurement probe

Conclusions

- The deposition stripes on the plasma vessel consist of mainly of C with minor amounts of O and B. The estimated overall amount of C at the vessel wall behind the inner heat shield, is 0.3 g, which could be tolerated for the next plasma campaign, however the mechanism of these depositions through very small gaps between the tiles will be further investigated
- For the inner divertor closure as well the deposition is C dominated. These closures will be replaced with new ones for the next phase of operation, in order to understand the depositions, simulations will be performed
- The investigation of loosely bound particles will be followed more closely by installing in addition the collection boxes at selected locations within the plasma vessel
- No further Si-wafer probes shall be installed at the melted position and the mirror opposite site
- The arcing and optical reflection measurements [2] will be continued after each of the subsequent plasma campaign.

[1] S. Äkäslompolo et al, Validating the ASCOT modeling of NBI fast ions in Wendelstein 7-X, in preparation for the submission to JINST, proceedings of ECPD2019 Lisbon

[2] G. Motojima et al, In-vessel colorimetry of Wendelstein 7-X first wall components: variation of the layer deposition distribution in OP1.2a and OP1.2b, see Poster PB-015, PFCM2019

Deposition stripes on vessel wall

	#3	#2	#1	Uncertainties
Statistical	$\times 10^{17}$ at./cm ²	$\times 10^{18}$ at./cm ²	$\times 10^{19}$ at./cm ²	
B	< 20	76.4 ± 25.1	75.5 ± 25.2	+ 5% Systematic
C	80.2 ± 47.1	406.5 ± 51.0	457.9 ± 52.2	
O	61.0 ± 41.2	131.4 ± 41.1	98.1 ± 40.9	

- W7-X tiles area: 89.9 m². Deposited area: 3.23 m²
- Total C deposition: 1.39 $\times 10^{22}$ atoms
- Weight of deposited C on W7-X vessel: 0.3 g

Deposition on inner divertor closures

- Inner divertor plates were installed behind the test divertor unit
- Samples were retrieved after operation phase OP1.2b
- Depositions were found at several locations for each divertor

Loosely bound particles

- After OP1.2b: 25 sticky probes, 3 vacuum filters, 16 Al-foil samples collected from all the modules
- Analysed with SEM/EDX measurements
- Observed particles could be classified in three categories: C-dominated flakes, Fe particles (with Cr, Ni, Mn) and Al-Cu particles
- Boron impurities were below measurable levels

Arcing






- 212 arc trails observed: front / back side
- Trace directions: No clear dependence on magnetic field, mostly random

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Figure 2. Poster by Dhard [28]. Reproduced from [28]. © IOP Publishing Ltd. All rights reserved. Reproduced with permission from [28]. Reproduced with permission from Dhard et al, © The Authors.

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