Beryllium plasma-facing components for the ITER-Like Wall Project at JET

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Abstract. ITER-Like Wall Project has been launched at the JET tokamak in order to study a tokamak operation with beryllium components on the main chamber wall and tungsten in the divertor. To perform this first comprehensive test of both materials in a thermonuclear fusion environment, a broad program has been undertaken to develop plasma-facing components and assess their performance under high power loads. The paper provides a concise report on scientific and technical issues in the development of a beryllium first wall at JET.

1. Introduction

The Joint European Torus (JET) is the largest present-day tokamak, i.e. a magnetic controlled thermonuclear fusion device for energy research. Its main scientific mission is to develop plasma operation scenarios for a reactor-class machine such as ITER [1]. Equally important is to test the performance of plasma-facing components (PFC). At present, most components are made of carbon fibre composites (CFC). JET is fully compatible with operation using deuterium-tritium mixture and beryllium PFC, which are key features for the next-step fusion device. To achieve further progress in controlled fusion, the ITER-Like Wall (ILW) Project at JET is under way in order to explore tokamak operation and plasma-wall interaction processes with a full metal wall: beryllium (Be) in the main chamber and tungsten (W) in the divertor [2-4]. The main driving forces for a large scale test of the metal wall are: (i) expected reduced retention of hydrogen isotopes in operation with a metal wall in comparison to carbon PFC; (ii) good plasma performance and gettering of oxygen impurities by beryllium; (iii) low erosion of tungsten at low ion temperature in the divertor [5]. Experimental campaigns with the fully modified PFC structure are planned to begin in year 2010.

The aim of this paper is to overview scientific and technical issues related to the development of Be components of two major categories: (i) bulk limiter tiles including so-called markers designed for studies of beryllium erosion from the wall and (ii) Be-coated inconel plates for the inner wall cladding.

2. Bulk beryllium components

Images in figure 1 show the present structure of the JET in-vessel components (a) and the distribution of materials to be implemented for ILW (b). Beryllium tiles are to be located in the main chamber wall. These are the inner wall guard limiter and the outer poloidal limiters, lower hybrid launcher frame, upper dump plates and other protection tiles (antenna private limiters, mushroom tiles, saddle coil protection tiles). Dump plates and mushroom-shaped limiters protect the upper part of the vessel. The size of the main limiter tiles (approx. 10x30x6 cm) has imposed the search for engineering solutions to ensure proper performance of the limiters. Figure 2 provides details of a wide poloidal limiter tile assembly consisting of seven bulk Be segments (Brush Wellman Inc. grade S65J, hipped structural Be) installed on a vacuum cast Inconel-625 carrier. The segmented construction reduces eddy currents, whereas the castellation is to improve thermal durability under heat loads. The optimized surface profile and lack of plasma-facing bolt holes ensure better power handling.

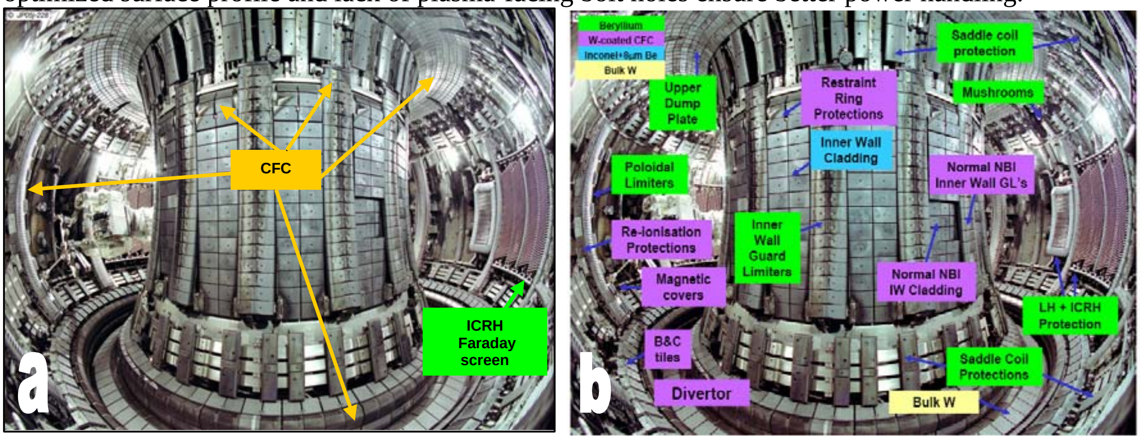

Figure 1. View inside the JET vessel: (a) present structure of wall components with CFC limiter and divertor tiles and Be ICRH Faraday screens; (b) planned distribution of beryllium and tungsten for the ITER-Like Wall operation.

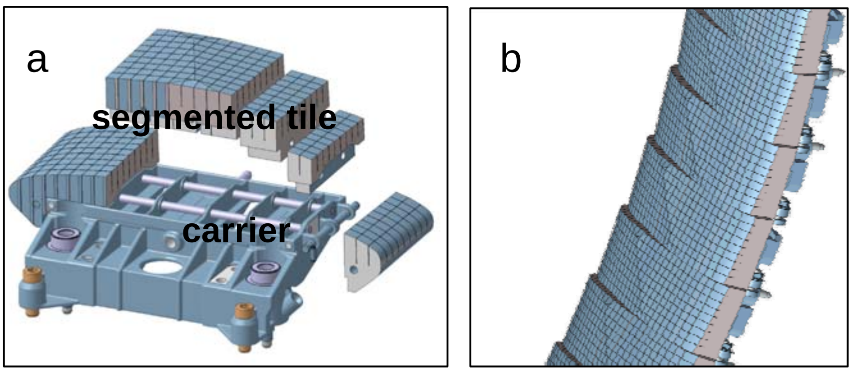

Figure 2. Structure of a carrier and a segmented Be tile (a); assembly of wide poloidal limiter.

3. Beryllium marker tiles

An important goal of the ILW Project is to assess the erosion of beryllium components in order to give best-possible predictions for ITER. To facilitate such studies, so-called marker tiles are being developed. They will be placed in several toroidal and poloidal locations in the vessel. A marker is a regular beryllium tile coated first with a high-Z metal film acting as an interlayer and then with a Be layer of density similar to that of bulk beryllium. To ensure good adherence and thermo-mechanical (best match of linear thermal expansion coefficients) and physical properties of the marker coatings nickel (2-3 μm) was selected as an interlayer material to separate the bulk Be tile from a 7-10 μm thick beryllium coating. The films are obtained by the thermionic vacuum arc (TVA) method [6] which allows production of high-density layers. For measurements of erosion greater that 10 μm, there will be precise notches (10, 20 μm deep) on the tile surface. A series of marker coupons were produced and examined by several material analysis techniques before and after high-heat flux (HHF) testing with an electron beam in the JUDITH facility. HHF screening tests allowed the determination of power and energy density limits deposited onto the surface until the damage to a marker occurred. A cyclic test served to assess the thermal fatigue under repetitive power loads. Not coated Be blocks were tested for comparison. The major results may be summarised by the following: (i) the markers survived without noticeable damage power loads of 4.5 MW m^{-2} for 10 s (energy density 45 MJ m^{-2}) and fifty repetitive pulses performed at 3.5 MW m^{-2} each lasting 10 s, i.e. corresponding to the total energy deposition of 1750 MJ m^{-2}; (ii) in both cases the surface temperature measured with an infrared camera was around 600 ^{o}C; (iii) the damage to the Be coating occurred at power loads of 5 MW m^{-2} for 10 s.

Plots in figure 3 show depth profiles obtained by secondary ion mass spectrometry (SIMS) for two marker coupons: (a) unexposed to heat loads and (b) after HHF test carried out for 10 s at power density of 4 MW m^{-2}, i.e. total energy density of 40 MJ m^{-2}. Both profiles are quite similar (Be coating thickness ~9.5 μm) thus indicating that the applied power loads neither damage the coating nor cause intermixing of Be and Ni. There are some impurity species (Al, Si, Fe) but their content is below 1 % as determined by ion beam analysis, energy and wavelength dispersive X-ray spectroscopy. Figure 4 shows a metallographic cross-section of the HHF tested coupon. A clear separation of beryllium and nickel proves the durability of the coatings.

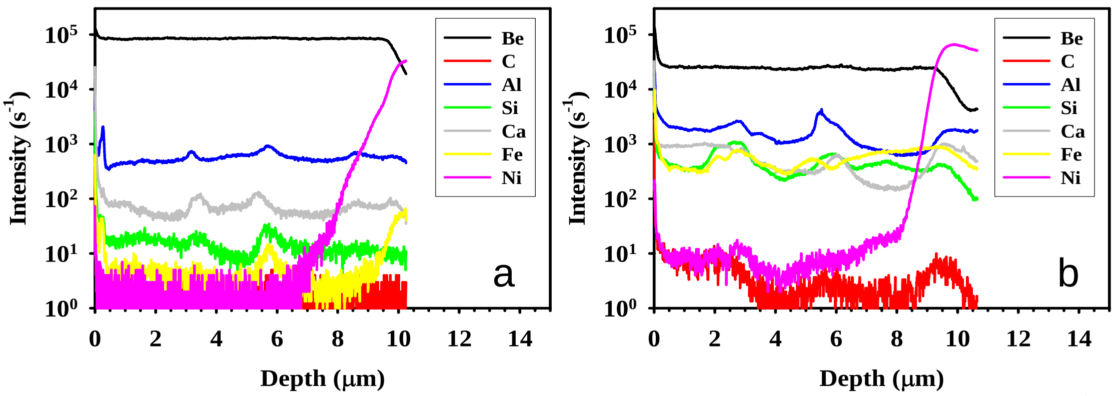

Figure 3. SIMS depth profiles for two markers: (a) "as produced"; (b) HHF tested at 40 MJ m^{-2}.

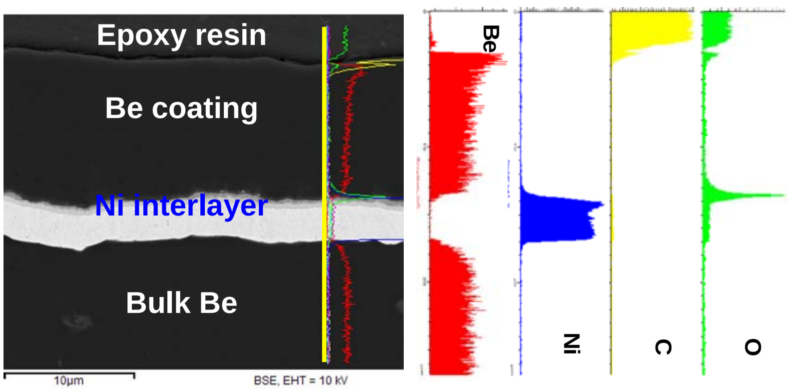

Figure 4. Metallographic cross-section of a marker coupon after cyclic test (50 pulses) at 3.5 MW m^{-2}.

4. Beryllium coatings on Inconel

The inner wall cladding and the dump plate tile carriers will be made of cast Inconel. These tiles are in the shadow of bulk Be tiles, but to minimize the risk of high-Z impurity (Ni, Cr, Fe) influx, the Inconel tiles will be protected by 8 μm thick evaporated Be coatings.

During regular plasma operation in JET, the estimated power load to the cladding is 0.5-0.7 MW m^{-2} for 10 s corresponding to energy deposition of 5-7 MJ m^{-2}. To check the adherence and thermo-mechanical properties of the Be layer, a number of test coupons were exposed to high power loads in JUDITH [7]. The screening test was carried out in the range from 0.4 MW m^{-2} to 2.6 MW m^{-2} in pulses lasting of up to 11 s. In the cyclic test fifty consecutive 10 s pulses were performed at the power of 1 MW m^{-2}, i.e. 10 MJ m^{-2} per pulse. Figure 5 shows the layer structure before (a) and after the test at the power load of 1.8 MW m^{-2} for 11 s corresponding to the energy load of 20 MJ m^{-2} (b). In both cases the coating topography is nearly identical. It proves that no damage (e.g. melting or exfoliation) is caused by energy loads exceeding at least three times the level characteristic for a regular plasma operation. As assessed, the coating on Inconel would melt at energy loads exceeding 30 MJ m^{-2} [7].

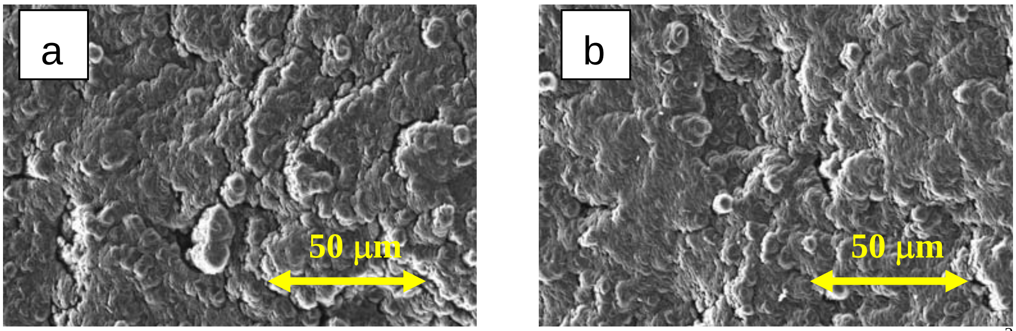

Figure 5. Beryllium coatings on Inconel: (a) “as produced”; (b) after HHF test of 20 MJ m^{-2}.

5. Concluding remarks

The best efforts have been taken to develop and test the performance of beryllium components being prepared for the installation in the ILW operation of JET. Power handling capabilities and purity have been of primary interest. The results of material analysis before and after HHF testing indicate that the coatings on Inconel and marker limiters should withstand conditions of the regular JET operation without melting, exfoliation or phase transformation. This is particularly important in case of the marker tiles for long-term Be erosion studies in the main chamber. However, local melting of Be tiles (with and without markers) cannot be excluded in case of events resulting in deposition of excessive power loads. In this case the extent of erosion will be assessed by mechanical methods. The scientific and technical program has led to the selection of methods for a large-scale manufacturing of protective coatings on the inner wall cladding and marker tiles. The thickness of markers, prior to their installation in JET, will be determined by means of ion beam analysis methods.

References

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