DEVELOPMENT AND EVALUATION OF PLASMA FACING MATERIALS FOR FUTURE THERMONUCLEAR FUSION REACTORS

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Extended abstract

More and more attention is directed towards thermonuclear fusion as a possible future energy source. Major advantages of this energy conversion technology are the almost inexhaustible resources and the option to produce energy without CO₂-emissions. However, in the most advanced field of magnetic plasma confinement a number of technological challenges have to be met. In particular high-temperature resistant and plasma compatible materials have to be developed and qualified which are able to withstand the extreme environments in a commercial thermonuclear power reactor. The plasma facing materials (PFMs) and components (PFCs) in such fusion devices, i.e. the first wall (FW), the limiters and the divertor, are strongly affected by the plasma wall interaction processes and the applied intense thermal loads during plasma operation [1]. On the one hand, these mechanisms have a strong influence on the plasma performance; on the other hand, they have major impact on the lifetime of the plasma facing armour.

Materials for plasma facing components have to fulfill a number of requirements. First of all the materials have to be plasma compatible, i.e. they should exhibit a low atomic number to avoid radiative losses whenever atoms from the wall material will be ionized in the plasma. In addition, the materials must have a high melting point, a high thermal conductivity, and adequate mechanical properties. To select the most suitable material candidates, a comprehensive data base is required which includes all thermo-physical and mechanical properties [2-5]. In present-day and next step devices the resulting thermal steady state heat loads to the first wall remain below 1 MWM⁻², meanwhile the limiters and the divertor are expected to be exposed to power densities being at least one order of magnitude above the FW-level, i.e. up to 20 MWM⁻² for next step tokamaks such as ITER or DEMO. These requirements are responsible for high demands on the selection of qualified PFMs and heat sink materials as well as reliable fabrication processes for actively cooled plasma facing components. The technical solutions which are considered today are mainly based on the PFMs beryllium, carbon or tungsten joined to copper alloys or stainless steel heat sinks [6-8]. To test and to demonstrate the acceptability of plasma facing materials and components special high heat flux test facilities based on intense ion or electron beams [6] are being used routinely to demonstrate the heat removal efficiency and the lifetime under fusion specific loading conditions [9].

In addition to the above mentioned quasi-stationary heat loads, short transient thermal pulses with deposited energy densities up to several tens of MJm⁻² are a serious concern for next step tokamak devices. The most frequent events are so-called Edge Localized Modes (type I ELMs) and plasma disruptions. Here a considerable fraction of the plasma energy is deposited on a localized surface area in the divertor strike zone; the time scale of these events is typically in the order of 1 ms [10-12]. As a consequence, thermal shock induced crack
formation, vaporization, surface melting and droplet ejection as well as particle emission induced by brittle destruction processes will limit the lifetime of the components. This is also valid for instabilities in the plasma positioning (vertical displacement events) which cause irreversible damage to plasma facing components, particularly to the metallic wall armour. Moreover, dust particles (neutron activated or toxic metals or tritium enriched carbon) are a serious concern form a safety point of view. In order to investigate the thermally induced plasma wall interaction under fusion specific thermal loads, high heat flux simulation tests are performed in electron or ion beam test facilities [9] as well as in quasi stationary plasma devices [10]. These experiments cover thermal fatigue loads and/or thermal shock tests with relevant operational loading conditions [13 – 15].

Furthermore, the wall bombardment with 14 MeV neutrons in D-T-burning plasma devices and the resulting material damage are another critical issue, both, from a safety point of view, but also under the aspect of the component lifetime. While the integrated neutron fluence in ITER will be only in the order of 1 dpa (displacements per atom), future devices such as DEMO or commercial fusion reactors will experience integrated neutron wall loads of 80 to 150 dpa. Therefore the development of new radiation resistant materials and their testing under realistic conditions is required. Due to the lack of an intense 14 MeV neutron source, complex neutron irradiation experiments are performed in material test reactors to quantify the neutron-induced material damage [16, 17]. These tests provide a valuable data base on the degradation of thermal and mechanical parameters [18, 19].

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