Materials for Fusion Reactors

N. Baluc

Centre of Research in Plasma Physics, Villigen PSI, Switzerland

In fusion reactors, the plasma facing (first wall, divertor) and breeding-blanket components will be exposed to plasma particles and electromagnetic radiation and will suffer from irradiation by 14 MeV neutrons. The high-energy fusion neutrons shall produce atomic displacement cascades and transmutation nuclear reactions within the irradiated materials. From the point of view of materials science, atomic displacement cascades induce the formation of point structure defects, i.e. vacancies and interstitial atoms, while transmutation nuclear reactions yield the production of impurities, e.g. helium or hydrogen gas atoms. The final microstructure of the irradiated material results from a balance between radiation damage and thermal annealing. It may be formed of small defect clusters, dislocation loops, precipitates, stacking-fault tetrahedra, voids and/or helium bubbles. This microstructure has a strong impact on the physical and mechanical properties of the irradiated material. It may engender important hardening, loss of ductility, fracture toughness and creep strength, as well as macroscopic swelling of the material. These effects are the main factors limiting the choice of candidate materials. The residual radioactivity of a large amount of exposed material is also a concern and will govern the handling methods, dictate the storage periods and the overall waste management and recycling scenarios. The development strategy that takes into account these limitations has led to the development of the so-called low activation materials. From the technological point of view, the temperature window of operation of fusion power reactors, and then their efficiency, will be mainly limited by the temperature window of use of structural materials, mainly determined by their resistance to irradiation. Candidate structural materials for plasma facing and breeding-blanket components have a chemical composition that is based on low activation elements (Fe, Cr, V, Ti, W, Si, C). They include reduced activation ferritic/martensitic (RAFM) steels, oxide dispersion strengthened RAFM and RAF steels, vanadium-based alloys, tungsten-based materials, and fibre reinforced SiC/SiC ceramic composites. Each alternative alloy class exhibits specific problems arising from radiation damage. For the time being, the most promising materials are the RAFM steels for which the greatest technology maturity has been achieved, i.e. qualified fabrication routes, welding technology and a general industrial experience are already available.