Structural Materials for Fusion Power Plants: State-of-the-Art, Prospects and Critical Issues

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Based on conceptual studies of commercial fusion power plants like the European PPCS and the American ARIES studies, the associated performance goals and requirements for structural materials will be briefly reviewed. In all studies, the challenging environments require structural materials highly resistant to a combination of high heat fluxes, radiation damage, thermo-mechanical stresses and chemical erosion or corrosion. While for ITER or first generation fission reactor designs the maximum damage level achieved by any structural material was on the order of a few displacements per atom (dpa), the structural materials of first demonstration fusion reactors will operate up to damage levels approaching 150-200 dpa. Even more, fusion neutrons will generate high production rates of He (≤10 appm/dpa) and hydrogen isotopes (≤50 appm/dpa), enhancing sensitively irradiation embrittlement.

A review is given on the state-of-the-art of the major classes of materials that are presently the basis of the PPCS with emphasis on reduced activation high-performance ferritic/martensitic steels, nanocomposited oxide dispersion strengthened ferritic steels, V alloys and SiC composites. Data on refractory materials like W and Mo alloys and their present limitations are also summarized. For the timely availability of materials design data for fusion power plants, the international fusion materials community is working on a broad based IEA coordinated R&D programme, including neutron irradiation programs (presently up 30 dpa in mixed spectrum and 70 dpa in fast breeder reactors), and avanced manufacturing and joining technologies. For some materials relevant for PPCS, “general design requirements documents” are presently set up that also contains traceable information on (i) procurement specification, and (ii) section designations corresponding to material properties groups with “material design limit data”. A special feature of some Tokamak type power plants is the pulsed operation with oscillating temperature gradients giving rise to thermal creep-fatigue which is at present considered as the main lifetime-limiting phenomenon in plasma-near structural components. Therefore, typical examples for fusion relevant fatigue life reduction will be also presented, together with the sensitivity of different loading conditions (including irradiation) to fatigue properties.

Although the different classes of materials already fulfill major requirements of “low level waste” capability, the different materials are hardly comparable because the level of knowledge differs remarkably. Finally the critical issues and prospects of the high performance materials are discussed together with the major near and long-term research activities of the international materials development strategy.