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Low Cycle Fatigue Behavior of EUROFER97-Steel after 16.3 dpa Neutron Irradiation at 250, 350 and 450°C

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The loading of First Wall and blanket structures of Tokamak type fusion reactors includes a combined effect of oscillating temperature gradients giving rise to thermal fatigue and damage due to high fluxes of fusion neutrons. For lifetime predictions and for the design of structural components, it is therefore important to quantify the changes of material properties e.g. as LCF (low cycle fatigue) tests. Therefore, an irradiation program was performed in the framework of the European steel developing program. LCF specimens were fabricated of the martensitic-ferritic RAFM-steel EUROFER97 (8-10Cr-WTaV steel) and irradiated to determine the influence of neutron irradiation on the material properties. The irradiation was set up to 16.3 dpa (771 full power days) in HFR, Petten, The Netherlands. The irradiation temperatures were between 250 and 450 °C. All post-LCF tests were carried out at the same temperatures in the Fusion Material Laboratory of the KIT hot cells. The specimens were push-pull fatigue tested under strain controlled conditions to determine the impact of irradiation on lifetime.

Further accompanying material tests as tensile and impact tests proved the irradiation induced strengthening and reduction of ductility at lower irradiation temperatures. Microstructural investigations could document the hardening of the material by a high density of dislocation loops, which generated the increase of strength. Hence, it was interesting to observe that the results of the LCF experiments revealed a pronounced increase of fatigue life of up to almost one order of magnitude at 250 °C irradiation temperature. The typical cell formation could be seen in the microstructure, but just a part of the cells were free of dislocation loops, other cells had a high density of these irradiation induced defects. However, comparison tests at 350 °C had lifetimes similar to the un-irradiated materials. At 450 °C, there was the tendency of a shortening of lifetime at lower strain rates compared to the un-irradiated material. The microstructure consisted of recovered cell structures.

Various correlations between irradiation hardening, fatigue lifetime, cyclic softening, fracture behavior and microstructural properties like loop stability, dislocation motion and subcell formation will be shown for all irradiation temperatures investigated. Finally, from these fatigue results some initial guidelines for the blanket design will be recommended.

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