15-433

TEM Study of Irradiation Induced Copper Precipitation in the Presence of Helium

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Material research for innovative fission and fusion systems has become a field of growing relevance worldwide. The sensitivity of ferric steels to irradiation induced Copper precipitates and related embrittlement issues is of ongoing scientific interest and has led to "Cu free" steels. In addition, Copper in not a "low activation" element. It is known that the nucleation of cooper clusters is caused by the displacement cascades during neutron irradiation. The clustering results in an increased hardening and embrittlement as it was indicated by the ductile-to-brittle transition shift towards higher temperatures. Although, such a degradation of mechanical properties does not ensure the secure work of existing fission plants, they might affect the present lifetime extension discussion of reactor pressure vessels if they have copper impurities.

The standard Cu concentration in EUROFER 97 is in the range of 0.005-0.04 wt.%. For the present investigation, a model alloy of EUROFER was fabricated containing 1160appm boron and 0.56%wt. cooper – additionally to the EUROFER 97 typical composition. The neutron irradiation of this model alloy allows the study of both, the effect of high concentrations of helium bubbles and their interaction with Cu precipitates, this helping to understand its severe impact on tensile and fracture toughness degradation. The microstructural investigations have been performed by TEM using imaging and elemental analysis on nano-scale level.

The three specimens have been characterized: one specimen before neutron irradiation and two specimen after up to 16.3 dpa at 300°C and 400°C. The investigation of unirradiated material shows that Cu forms 2-3 nm clusters only on the grain or lath boundaries. Within the grains Cu was found to be in a dispersed state – that means that Cu possibly forms clusters with size down to 1 nm. The neutron irradiation at 300°C and 400°C leads to the formation of well detectable Cu clusters, which usually are located on the grain or lath boundaries and He bubbles. The size of the clusters varied from 3nm to 10nm in the specimen after irradiation at 300°C and increases to the 10-25nm range after irradiation at 400°C. "Dumbbell" shaped complex defects consisting of two helium bubbles trapped at the surface of Cu precipitates were often observed. Finally, the TEM results are correlated with tensile tests done in the whole temperature range investigated.

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