The Synergistic Effect of Radiation Damage and Helium on the Hardening and Embrittlement of Ferritic / Martensitic Steels

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In the first-wall blankets of the future fusion reactors, radiation damage and helium (He) would be produced simultaneously at a ratio of about 15 appm He/dpa. The radiation damage and helium effects in the first-wall blanket materials can be well studied by irradiation under a proton / neutron mixed spectrum in a spallation target, where radiation damage and He are produced simultaneously at ratios between 20 and 100 appm He/dpa.

Ferritic / martensitic (FM) steels Eurofer-97, F82H, Optifer-V and -IX, T91 (9Cr-1MoNbV) etc. were irradiated in the targets of the Swiss Spallation Neutron Source (SINQ) to doses up to 20 dpa / 1800 appm He at temperatures up to about 500°C. Tensile properties, fracture toughness and ductile-to-brittle transition temperature (DBTT) and microstructure have been investigated. A number of interesting findings have been observed: (1) DBTT shift of different FM steels quite close and much higher than that obtained from neutron irradiations at doses above ~5 dpa, and the shift does not saturate at doses up to 15 dpa. (2) Specimens irradiated at above ~400°C show tremendous hardening as compared to slight or no hardening in neutron irradiation cases, and meanwhile large uniform elongation as well. (3) After annealing at 400°C or above, the ductility of specimens irradiated at lower temperatures (< 350°C) recovers significantly while the hardening reduces just slightly. (4) Small bubbles of high-density are readily observed in specimens with about 500 appm He irradiated at ≥200°C.

It is believed that for specimens irradiated in low temperature regime, due to formation of defect clusters the deformation is controlled by the dislocation channeling mechanism although high-density small He bubbles exist as well. While for specimens irradiated or annealed at ≥400°C, where small defect clusters or dislocation loops disappear or of very low density, He bubbles are dominant in hardening. As mobile dislocations cannot remove He bubbles, the channeling deformation mechanism should not work in this case, and therefore, the ductility can be little affected.

An overview of the results obtained from different FM steels irradiated in SINQ targets will be presented and compared with the published results from neutron irradiations. The synergistic effects of radiation damage and He in FM steels will be discussed.

Number of words in abstract: 365

Keywords:
Technical area: 21. Radiation effects Microstructural evolution
Special session: Not specified
Presentation: No preference
Special equipement: No special equipment