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NANO-SCALE BEHAVIOR OF IRRADIATED NANOSTRUCTURED ALLOYS

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Future fast neutron fusion and fission nuclear systems will be subjected to levels of radiation damage from fast neutrons which is significantly higher than the current generation of nuclear power stations. This will require innovative materials solutions to allow long term mechanical stability of reactors. One proposed class of materials are nanostructured alloys where the large number of interfaces allow for recombination defects and reduce the degree of radiation hardening seen. However their response under irradiation has not thoroughly been studied. In this work, two irradiated nanostructured alloys have been studied W-5%Re in both a nanostructured and annealed variant and a novel Hf-Ti-Ta-V-Zr high entropy alloy. I will outline the benefits nanostructured materials offer under irradiation and some of the problems and challenges in measuring their mechanical properties after irradiation and relating this to the nano-structure using XRD, TEM, HR-EBSD and atom probe tomography.

Rolled tungsten 5 wt% rhenium sheet was studied in two microstructural variants: (a) as received with a high dislocation density (mean value of 1.4×1014lines/m^2), measured using HR-EBSD, and pancake shaped grains with a thickness of≈200nm and (b) annealed at 1400^{o}C for 24 hours to produce equiaxed grains with average grain size of ≈90 µm and low dislocation density (with a mean value of 4.8×10^{13} lines/m^2). Both materials were ion implanted with 2MeV W^+ ions at 300^{o}C to damage levels from 0.07, to 33 displacements per atom (dpa). Nanoindentation was used to measure the change in hardness after implantations. Irradiation induced hardening saturated in the as-received material at an increase of 0.4dpa from the unimplanted hardness of 8GPa at 0.4dpa. In the annealed material saturation does not occur by 13dpa and the hardness change of 1.3GPa from the unimplanted hardness of 6.2GPa was over four times higher. At 33dpa both material types showed a further increase in hardening. In these samples Atom probe tomography showed clustering of Re in ≈4nm precipitates with a rhenium concentration of ≈11%. In both cases the number density and volume fraction are similar at ≈3100 x1000/µm^3 and volume fraction of ≈13%.

These differences in radiation response are likely to be due to the high damage sink density in the as-received microstructure in the form of dislocation networks, as even in the as-received material the average grain size is too large to provide sufficient sinks. Initially this provides a large sink network for radiation damage resulting in less hardening in the rolled material. However at 33dpa the formation of rhenium clusters occurs at similar levels in both material conditions. These dominate the hardening mechanisms and result in secondary hardening at high damage levels. The difficulties in extracting hardness values from 200nm deep ion implanted layers will be discussed, with reference to minimizing the influence of the substrate material and how changes in pile up effects in irradiated materials can change mechanical responses, and proposed methods to minimize these.

High entropy alloys have been proposed as potential nuclear materials as high configurational entropy may provide resistance to radiation damage. We have produced a novel high entropy alloy (Hf-Ti-Ta-V-Zr) in which is single phase on casting but two high entropy phases (one bcc and one hcp) are produced during heat treatment. This material then has a nano-lamella structure with an average lamella thickness of 200nm. Samples of the as cast single phase material, the dual phase high entropy alloy and single crystal vanadium were ion irradiated with V+ ions at 300^{o}C to a dose of 5e14 ions/cm^2. In the vanadium control samples the hardness as measured using CSM-nanoindentation was seen to increase from 2GPa in the unimplanted condition to 3.5GPa in the ion irradiated condition. The high entropy alloy in both the as cast and heat treated condition showed no increase in hardness after irradiation, demonstrating the intrinsic resistance to radiation damage of HEA's.

These studies show the ability of nanostructured alloys to have improved irradiation hardening resistance over conventional alloys. However challenges still remain in the production of large scale engineering components in such materials.