UNDERSTANDING THE PERFORMANCE OF NANOSTRUCTURED FERRITIC ALLOYS USING MICRO-MECHANICAL TESTING

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Oxide dispersion strengthened (ODS) steels are one of the most promising candidate materials for fuel cladding tubes, in GenIV nuclear reactors, and plasma facing components for tritium breeding blankets in fusion reactors. Although first developed during the 1960's, recent research has demonstrated an improved high temperature strength and irradiation resistance over the more conventional high chromium reduced activation ferritic/martensitic (RAF/M) steels. This improved performance is obtained through microstructures that contain a high density of insoluble nanoscale oxides dispersed in the ferrite matrix (typically 2 -10 nm yttrium- titanium oxides). However, concerns remain over their use in future nuclear application and the following questions are of key issue;

- Due to the mechanical alloying and powder processing manufacturing routes typically used the microstructures can display significant inhomogeneity in local chemistry, grain size and oxide distribution. How this affects local mechanical properties needs to be measured.
- The exact mechanisms of strengthening (solid solution, grain refinement or hard particle hardening) are not well understood and individual contributions need to be assessed for better alloy design.
- How the mechanical properties of these alloys are affected by radiation damage is not well documented and is must be known if they are to be used in a nuclear environment.

This work uses state of the art nanoindentation and micro-cantilever bending experiments on a series of systematically varied nanostructured ferritic alloys based on a Fe-14Cr-3W-0.2Ti-0.25Y_2O_3 in both as processed and irradiated conditions to answer these questions

Nanoindentation was used to investigate the hardness and elastic modulus of each specimen, and effect of indent size on hardness. Indentation modulus was found to be similar for each sample but the nanocrystalline samples showed higher levels of hardness, confirmed using microscopic techniques. The variation in hardness was seen to increase in oxide containing samples. This was investigated using EBSD and EDX, and was determined to be caused by a pronounced heterogeneity of the microstructure. While Hall-Petch strengthening and changes in the local chemistry had some effect on the measured hardness, the most likely cause of the large variation in local hardness was heterogeneity in the nanoscale oxide population. By using TEM and atom probe tomography this inhomogeneous dispersion of the oxide particles can be demonstrated. Nanoindentation was also used to measure the strain rate sensitivity and creep rate of each specimen, where it is shown that the oxide containing alloy has superior performance.

To simulate neutron damage samples were implanted with 2MeV protons to a peak damage level of 0.2dpa at 20μm depth below the surface. Samples were then rotated 90 degrees and polished to produce a cross section through the damaged layer. The cross-sectional surface of the irradiated layer was then exposed and inclined linear arrays of 250 nm deep indents were placed across the damage profile. 14WT (non-oxide containing) revealed a clear proton damage profile in plots of hardness against irradiation depth, No appreciable hardening was observed in either 14YWT specimens, attributed to fine dispersion of nanoscale oxides providing a high number density of defect sink sites.

Micro-cantilevers were fabricated out of the irradiated layer cross-section. Larger micro-cantilevers, with 5 μm beam depth, were place with their beam centre at 0.026 dpa. Smaller micro-cantilevers, with 1.5 μm beam depth, were placed with their beam centre at 0.2 dpa. Both the large and the small micro-cantilevers fabricated in 14WT (non-Oxide containing) displayed significant irradiation hardening (from 0.5GPa to 1.04GPa yield stress) while in the oxide containing variant, irradiation hardening is suppressed. This paper will demonstrate that when the size effects inherent in these tests are accounted for the data produced is comparable to bulk mechanical testing and suggest some key next steps if these alloys are to be pursued as nuclear materials.