ML1-1, ML1-2 Microstructural & mechanical properties of irradiated structural materials

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This plenary lecture is naturally divided into two parts, since the mechanical property changes are driven by radiation-induced microstructural changes in materials. In ML1-1, the current understanding of defect production (point defects and extended defects) and associated microstructural changes in neutron-irradiated body centered cubic (BCC) and face centered cubic (FCC) metals are reviewed as function of irradiation flux, dose and temperature. A wide range of microstructural changes can be induced by irradiation depending on the materials and irradiation conditions, including various dislocation loops or stacking fault tetrahedra, changes in the network dislocation density, radiation-enhanced, induced, or –modified precipitation, and cavity formation. A summary of currently available experimental tools for examining the microstructure of irradiated materials will be given, with primary emphasis on transmission electron microscopy but other valuable techniques including positron annihilation spectroscopy, electrical resistivity, field ion microscopy/atom probe tomography, and X-ray and neutron diffraction spectroscopy will also be briefly reviewed. Fundamental differences in the defect production and accumulation in FCC and BCC crystal systems will be emphasized. The pronounced effect of irradiation at temperatures within specific regimes will be illustrated, such as above/below the temperature for long-range vacancy migration. Examples will be given for both pure metals and complex high-performance alloys. The existing information concerning the "classical" and emerging steel grades (e.g., 9Cr-1Mo or advanced 12Cr ferritic/martensitic steels such as HCM12A or T122) will be presented, and illustrated with exemplary results from the literature.

In ML1-2, which is focused on radiation-induced mechanical properties changes, an overview will be given regarding the effects of irradiation dose and temperature on the mechanical properties of FCC and BCC metals. Particular emphasis will be placed on the similarities and differences of neutron irradiation on the tensile properties of pure metals and complex alloys. The effects of test temperature and strain rate on the tensile properties before and after irradiation will also be summarized. A common feature in all metals irradiated at temperatures below $\sim 0.3T_M$, where T_M is the melting temperature, is an increase in tensile strength and a decrease in uniform tensile elongation. Possible microstructural causes of the decrease in uniform elongation (localization of plastic deformation) will be discussed, including dislocation channeling. The results from in-situ tensile straining of specimens containing a variety of defect clusters will be summarized, along with molecular dynamics modeling of dislocation interactions with defect clusters, in order to provide insight on possible physical mechanisms associated with flow localization. The increased strength associated with irradiation at low temperatures can produce large increases in the ductile to brittle transition temperature (DBTT) of BCC materials. In addition to hardening effects on fracture, irradiation can also induce changes in fracture mechanisms due to radiation induced solute segregation to grain boundaries or other features. The overall effect of irradiation on the deformation and fracture behavior of metals will be summarized using deformation mechanism maps and fracture mechanism maps. Areas where additional data are needed to support the development of accurate physics-based models of hardening and embrittlement will be discussed.