Development and testing of ultrafine-grained and nanocrystalline steels for enhanced irradiation tolerance

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Steels have important applications in current and advanced nuclear reactors, however, their irradiation tolerance and mechanical properties need to be improved. Bulk ultrafine-grained and nanocrystalline metals possess drastically higher strength than their conventional coarse-grained counterparts due to significant grain boundary strengthening, and are anticipated to have significantly enhanced irradiation tolerance owing to the role of grain boundaries as sinks for irradiation-induced defects. In this study, ultrafine-grained and nanocrystalline austenitic and ferritic-martenstic steels were manufactured by equal-channel angular pressing (ECAP) and high-pressure torsion (HPT), respectively. The microstructure and mechanical behavior of the steels manufactured by ECAP and HPT were carefully studied. Advanced microstructural characterization techniques were utilized to investigate the microstructures and chemistry of the steels before irradiation. The thermal stability of the ultrafine-grained and nanocrystalline steels was also investigated. Neutron irradiation was designed and is being performed to study irradiation behavior of the steels. Limited ion irradiation was also conducted to compared with the neutron irradiation. Preliminary corrosion studies were executed to investigate the corrosion performance of the ultrafine-grained and nanocrystalline steels as compared to that of the coarse-grained counterparts. Limited welding experiments were also performed to assess the weldability of the ultrafine-grained and nanocrystalline steels. Results indicated that the ultrafine-grained and nanocrystalline steels manufactured by ECAP and HPT possess significantly improved hardness/strength compared to their conventionally manufactured coarse-grained counterparts. Grain size of HPT samples is smaller (~100nm) than ECAP samples (~400nm). All the ECAP and HPT steels are thermally stable at least up to 500 °C, and many of them are stable up to 600 °C. Ion irradiation indicated that smaller grains possess reduced irradiation-induced hardening, segregation and precipitation compared to larger grains. Ultrafine-grained steels have enhanced phase stability during irradiation compared to the coarse-grained counterpart.