Fracture and fatigue behaviors of pressure vessel steels and austenitic steels in light water reactor environments

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The structural integrity of the reactor pressure vessel (RPV) of light water reactors (LWR) is of utmost importance regarding operation safety and lifetime. In addition to neutron irradiation, high-temperature water (HTW) environments together with hydrogen absorbed from environment and corrosion reactions, may potentially reduce the fracture resistance of RPV steels. In addition, the effects of HTW and hydrogen can act synergistically with other embrittlement and degradation mechanisms such as irradiation embrittlement, dynamic strain aging (DSA), environmentally-assisted cracking (EAC) or temper embrittlement (TE). In the first part of the talk, the fracture behavior in the upper shelf region of various low-alloy RPV steels tested in various simulated LWR environments with different microstructures and DSA, EAC and TE susceptibilities will be discussed. The performed fracture tests were performed in a range of temperatures and strain rates and were supplemented by fractographic characterizations. Moderate but clear reduction of fracture initiation resistance in low sulphur RPV steels with high DSA susceptibility, high sulphur RPV steels with high EAC susceptibility and high phosphorus RPV steel with high TE susceptibility

In the second part of the talk, we will focus on the effect of LWR on fatigue life of austenitic stainless. The emphasis will be put on the concomitant influence of mean stress and LWR environments. The tests were performed hollow pressurized specimens in load-controlled mode. The fatigue life was found to increase with compressive and tensile mean stress in air and LWR environments. A modified Smith-Watson-Topper (SWT) model was considered to account for mean stress and was shown to predict fatigue life accurately in both environments. The corresponding reduction of fatigue life is discussed and compared with the currently used environmental factors (Fen), derived from strain-controlled experiments. Observations of the end-of-life dislocation arrangements by transmission electron microscopy showed that the dislocation microstructure is strongly correlated to stress amplitude and mean stress. At rather low plastic strain amplitudes, corduroy structure consisting of small dislocation loops was observed. Acting as significant obstacle to dislocation motion, corduroy structure affects overall dislocation mobility therefore contributing to notable secondary cyclic hardening.