INVESTIGATION OF TEMPER EMBRITTLEMENT IN REACTOR PRESSURE VESSEL STEELS FOLLOWING THERMAL AGING, IRRADIATION, AND THERMAL ANNEALING*

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ABSTRACT

The Heavy-Section Steel Irradiation (HSSI) Program at Oak Ridge National Laboratory includes a task to investigate the propensity for temper embrittlement in coarse grain regions of heat-affected zones in prototypic reactor pressure vessel steel weldments as a consequence of irradiation and thermal annealing. This task is one part of an ongoing project to investigate the existence of and consequences of local brittle zones in RPV steel weldments. Some previously reported studies of RPV steels have demonstrated the potential for substantial temper embrittlement due to grain boundary phosphorus segregation when extremely coarse grains were produced by high-temperature austenitization followed by thermal aging. For the present studies, five prototypic RPV steels with specifications of A302 grade B, A302 grade B (modified), A533 grade B class 1, and A508 class 2 were given two different austenitization treatments and various thermal aging treatments. Thermal aging treatments were conducted at 399, 425, 454 and 490EC for times of 168 and 2000 h. Charpy V-notch impact toughness vs temperature curves were developed for each condition with ductile-brittle transition temperatures used as the basis for comparing the effects of the various heat treatments. Very high austenitization heat treatment produced extremely large grains which exhibited very high propensity for temper embrittlement following thermal aging. Intergranular fracture was the predominant mode of failure in many of the materials and Auger analysis confirmed significant segregation of phosphorus at the grain boundaries. Lower temperature austenitization treatment performed in a super Gleeble to simulate prototypic coarse grain microstructures in submerged-arc weldments produced the expected grain size with varying propensity for temper embrittlement dependent on the material as well as on the thermal aging temperature and time. Although the lower temperature treatment resulted in decreased propensity for temper embrittlement, the results did provide motivation for the investigation of the potential for phosphorus segregation as a consequence of neutron irradiation and post-irradiation thermal aging at 454EC. One of the five steels was irradiated at 288EC to about 1 × 10 n/cm (>1 MeV) followed by thermal annealing at 454EC for 168 h. Charpy impact testing was conducted on the material in both conditions and all results are presented and discussed.

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