Irradiation Studies on Electron Beam Welded PM-HIP Pressure Vessel Steel

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ABSTRACT:

The objective of this project is to assess the structural and mechanical integrity of electron beam weldments on pressure vessel steel under service-relevant irradiation conditions. The recent Nuclear Regulatory Commission design certification of the first small modular reactor (SMR) has amplified the necessity to revolutionize pressure vessel manufacturing to ensure SMR construction is realized on a short timeline and at reasonable cost. Electron beam (EB) welding and powder metallurgy with hot isostatic pressing (PM-HIP) offer tremendous potential to accelerate production time and reduce costs, enabling SMR pressure vessel fabrication in as little as 12 months at 40% of the cost of conventional methods! The combination of EB welding and PM-HIP technologies enables production of high quality pressure vessel components with no evidence of a weld seam or heat affected zone after a solution anneal, quench, normalization, and tempering (SQNT) treatment. Hence, there is express interest amongst nuclear industry stakeholders to qualify the combination of EB welding and PM-HIP technologies for pressure vessel construction. Thus, there is a critical need to verify that EB welded PM-HIP materials exhibit improved performance, safety, and integrity under irradiation, as compared to conventional forgings.

This project will fulfill this critical industry need by conducting a neutron irradiation and post irradiation examination (PIE) campaign on EB welds of A508, Class 1, Grade 3 pressure vessel steel. Heat treatments will be applied after welding, enabling a systematic evaluation of the effects of a post-weld heat treatment (PWHT) or SQNT treatment on the irradiation response. Forgings, like those used in current reactors, will be studied as a control. Advanced Test Reactor (ATR) irradiation will be carried out at 300°C to doses up to 0.5 displacements per atom (dpa). We will use the irradiated microstructure and small-scale mechanical tests (i.e. nanoindentation and shear punch) to guide the selection of fracture testing parameters. The irradiation-induced ductile to brittle transition temperature (DBTT) shift will be determined, and its mechanisms will be understood through the microstructure and small-scale mechanical tests. Finally, the irradiation-induced DBTT shift will be validated against GRIZZLY cohesive zone and crystal plasticity models.

Scientifically, this project will shed light on microstructural and mechanical mechanisms underlying the irradiation-induced DBTT shift in pressure vessel steels and their EB weldments. More practically, this work will generate results necessary for qualifying the EB welding technique for irradiation-facing applications. The outcome is the wide acceptance of EB welding and PM-HIP as common nuclear pressure vessel manufacturing and joining techniques. This outcome directly supports the DOE-NE mission to enable an advanced reactor pipeline, boost the long-term viability and competitiveness of the existing fleet, and maintain the national strategic supply chain infrastructure. As a direct result of this project, all DOE-NE programs will see unprecedented reductions in time and cost to fabricating pressure vessels and overall new plant construction.