Butt welding of zircaloy-4 using electron beam welding: temperature, structure, property correlation

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ABSTRACT

The present study investigates the effect of heat input and beam oscillation on electron beam butt welded zircaloy-4 plates of similar and dissimilar thicknesses. Temperature and cooling rates are measured in weld using thermocouples, and FEM model, which correlates with the evolution of microstructure, and properties of the weld.

Full penetration butt joints of zircaloy-4 were prepared by electron beam welding at different heat inputs. The study revealed that joints produced with lower heat input possessed narrow fusion zone and heat-affected zone, and more refined grains, attributed to a lower peak temperature and faster cooling rate. Joint prepared with lower heat input further demonstrated the formation of fine basketweave widmanstätten structure in the fusion zone. In contrast, joints prepared with higher heat input showed a coarser parallel plate widmanstätten structure. The fusion zone of all joints consisted of the α-Zr and β-Zr phases with second phase particles, i.e., $ZrCr_2$ or $Zr(Cr, Fe)_2$. Joints produced with lower heat input possessed higher ductility, notch tensile strength, minimum pitting corrosion, and better wear resistance compared to joints produced at higher heat input. Enhanced weld properties at lower heat input were attributed to a finer microstructure and less second phase precipitation.

Plates of zircaloy-4 of dissimilar thicknesses were butt-welded by electron beam welding. Thicker plates demonstrated lower peak temperature, fast cooling rate, a more refined grain size, and narrow fusion zone and heat-affected zone than those on the thinner plate of the weld. Lack of penetration and porosity developed in the dissimilar joints of higher thickness ratio at constant heat input, attributed to heat deficiencies for full penetration. Such dissimilar joints also demonstrated lower ductility and impact strength than the joint prepared with similar thickness. Dissimilar joints made at higher heat input achieved full penetration but caused grain coarsening, producing inferior weld properties.

Full penetration butt joints of zircaloy-4 were prepared by electron beam welding using both oscillating and non-oscillating beams. Joints prepared with beam oscillation demonstrated lower peak temperature and faster cooling rate than their non-oscillating counterpart. Electron beam oscillation produced a narrow fusion zone and fine basketweave widmanstätten structure

in the fusion zone of the butt-weld. In contrast, joints produced with non-oscillating beams showed the evolution of coarse parallel plate widmanstätten structure. Segregation of solute elements (Cr, Fe) and precipitation of second-phase particles was found minimum in the fusion zone of the joint made with beam oscillation. Joints prepared with beam oscillation, especially with higher oscillation diameter, possessed better ductility, impact strength, notch tensile strength, and minimum corrosion rate than their non-oscillating counterparts. Better weld properties under beam oscillation were attributed to more uniform microstructure and defect distribution in the weld.

Keywords: Electron beam welding, zircaloy-4, heat input, beam oscillation, dissimilar thickness, Temperature measurement, Finite element analysis, Microstructure, Mechanical properties, Corrosion properties