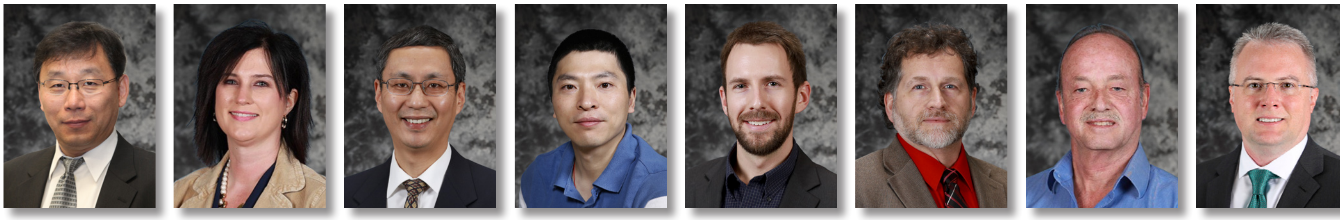
Weld Repair of Irradiated Reactor Components: Breakthrough Progress of Advanced Laser Welding and Friction Stir Welding on Irradiated Material



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Welding is widely used for repair, maintenance, and upgrades of nuclear reactor components. As a critical technology for supporting the extension of nuclear power plant service lifetimes beyond 60 years, there is an industry need to develop welding technology for highly irradiated materials. Techniques are needed to control weld heat input and mitigate residual stresses that result in detrimental effects during weld repair. During welding of irradiated materials, helium, a transmutation byproduct from boron and nickel contained in the structural alloys, can coalesce into bubbles along grain boundaries in the material under the driving force of temperature and welding thermal stress. This leads to embrittlement and potential intergranular cracking in the heat-affected zone of the weld, as shown in Figure 3. Our strategy is to develop advanced laser beam welding and friction stir welding technologies that provide

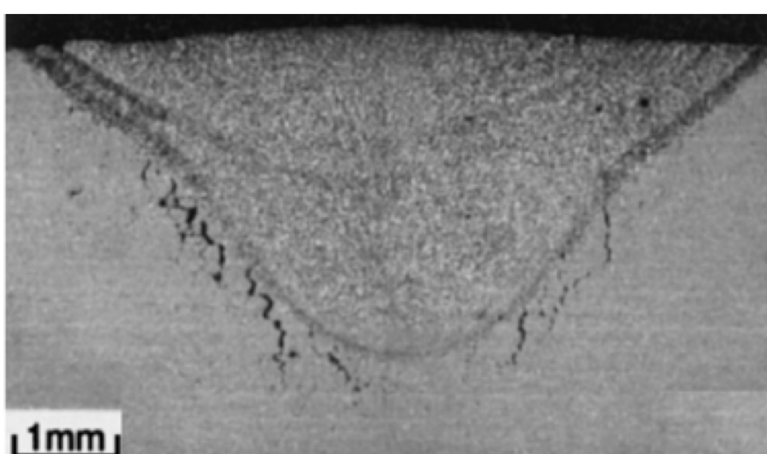

Figure 3. Irradiated material heat-affected zone cracking after regular fusion repair welding (Asano et al., 1999).

limited heat input and proper stress distribution to suppress helium induced cracking of the welded material.

Breakthrough Initial Welding Trials on Irradiated Materials

The Materials Research Pathway in collaboration with the Electrical Power Research Institute's Long-Term Operation Program, accomplished a significant research milestone on November 17, 2017, of welding irradiated material in the advanced welding facility at the Radiochemical Engineering Development Center (REDC) at Oak Ridge National Laboratory. This was performed using an advanced laser welding process to produce a multi-pass and multi-layer laser weld on an irradiated 304L grade stainless steel coupon containing 20 appm Helium (calculated). Figure 4 shows the advanced laser beam welding being performed on the irradiated coupon and the completed welded coupon inside Hot Cell C at REDC.

The welding team followed up the laser beam welding accomplishment with a friction stir weld on irradiated material on November 21, 2017, followed by a second friction stir weld on December 4, 2017. The irradiated 304L coupons welded those days contained 10 and 5 appm helium (calculated), respectively. Figure 5 shows the friction stir weld process being performed on an irradiated coupon and the completed coupon inside Hot Cell C at REDC are shown in Figure 5.

Both laser and friction stir welded coupons exhibited high welding quality and surface finish. No helium induced welding defects were observed on the weld surfaces or adjacent base metals.

Future Work

The initial welding trials marked a significant step in the beginning of an extensive welding research and development campaign for irradiated materials. The near-term future work will include full characterization of the welded coupons with further process optimization through additional welding of irradiated materials and the preparation of additional test coupons that include Nickel-based alloys. The irradiated material welding carried out at Oak Ridge National Laboratory by the Materials Research Pathway is an advancement that will support producing validated techniques and guidelines for weld repair activities that can be carried out to support extended operational lifetimes of nuclear power plants.

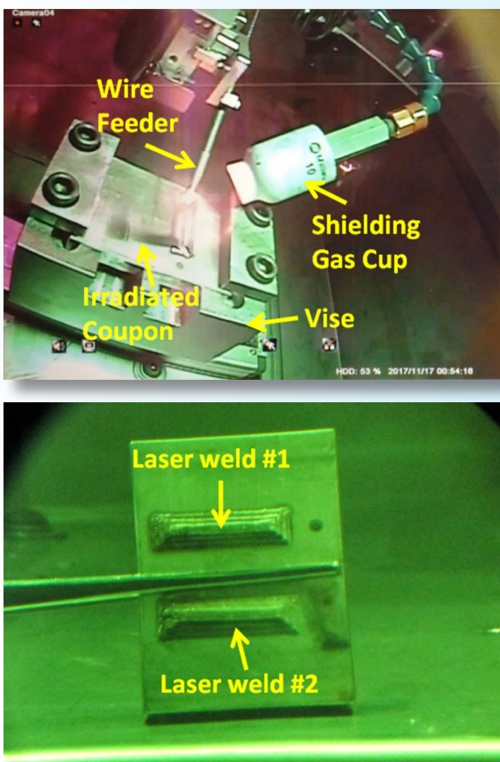

Figure 4. Advanced laser welding in operation on an irradiated coupon (top) and the completed welded coupon (bottom) showing two laser welds produced multilayer weld overlays.

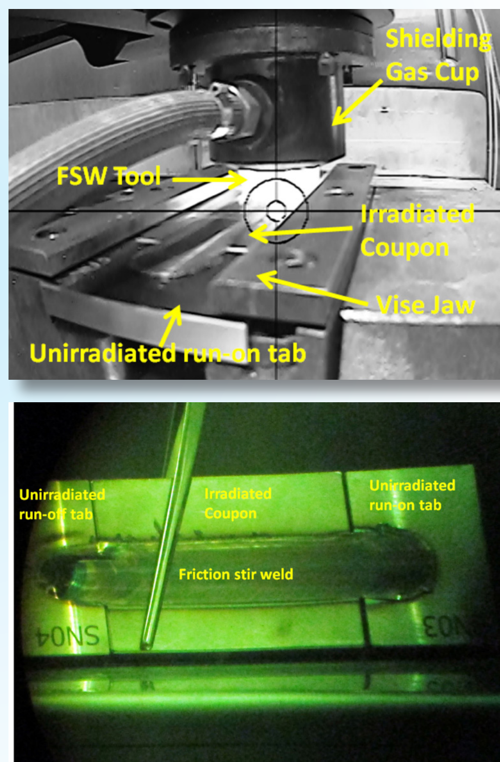

Figure 5. In-cell camera view of the friction stir welding in operation on an irradiated coupon (top) and the view of the welded coupon (bottom) being held by the hot cell manipulator.