Effect of High Dose Ion-irradiation on Laser Weld Repairs of Previously Neutron Irradiated AISI 304 Stainless Steel

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The objective of this study is to assess the microstructural and mechanical changes of the high-dose post-ion-irradiation laser weld repair of previously neutron irradiated, He-containing AISI 304L stainless steel (SS). Life extension of light water reactors (LWR) may require weld repairs of cracking in nuclear reactor internal components. Conventional weld repair techniques such as gas tungsten arc welding generate high thermal stresses that cause He to coalesce into bubbles at the grain boundaries. This exacerbates cracking in the vicinity of the weld melt boundary. Laser welding is proposed as a promising low-heat-input technology to reduce the size of the heat affected zone (HAZ), to potentially mitigate He-induced cracking. However, deployment of laser weld repairs requires these repairs to withstand further irradiation-induced microstructural, microchemical, and micromechanical changes. Therefore, there is a critical need to assess the integrity of these laser weld repairs over extended irradiation service; more specifically, the weld repair must be demonstrate tolerance to extended service over a wide range of temperatures, irradiation damage levels, and He concentrations.

To address this critical need, single-pass pulsed laser welds were made on AISI 304L SS neutron irradiated in the EBR-II fast reactor. This material is prototypical of steel in current LWR internals and contains potentially appropriate He concentrations and distributions over a range of swelling conditions, specifically: (1) 0.4 displacement per atom (dpa), 415°C, ~1 atomic parts per million (appm) He, 0.5% swelling; (2) 23 dpa, 415°C, ~3 appm He, 1.5% swelling; and (3) 29 dpa, 430°C, ~8 appm He, 2.5% swelling. Weld cross-sections were then subjected to additional irradiation using 5 MeV Fe^{2+} self-ions to achieve damage doses potentially as high as ~50 additional displacements per atom (dpa) at 400°C and 460°C, respectively. Subsequently, welds were examined for microstructure evolution with welding and additional irradiation, with special emphasis on cavities, loops, and grain boundary chemistry. Void annealing by the self-ions was observed at depths corresponding to the ion injection peak. Nanoindentation experiments have also been performed in the base metal and HAZ to measure the hardness and modulus before and after self-ion irradiation.