Investigation of Laser Shock Peening for Enhancing Fatigue and Stress Corrosion Cracking Resistance of Nuclear Energy Materials

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ABSTRACT

The goal of the proposed project, which will be conducted using the facilities in the recently established $3M Center for Laser Shock Processing for Advanced Materials and Devices at the lead university and in close collaboration with scientists from two DOE national laboratories (1&2), is to investigate and demonstrate the use of Laser Shock Peening–an advanced surface treatment process–and establish baseline parameters for enhancing the fatigue properties and stress corrosion cracking (SCC) resistance of nickel-based Alloys 600 and 690 that are currently used in nuclear steam generator tubing and are also candidates for future GEN IV reactors. The primary focus of the project will be on Alloy 600, whereas a few studies on Alloy 690 will be conducted for comparison with previous work on non-surface treated materials and future potential application. The research program designed accordingly includes the following key elements/tasks: (1) procurement of Alloys 600 and 690 and heat treatment studies; (2) LSP processing of base metal and welds/HAZ of Alloys 600 and 690; (3) measurement and mapping of surface and sub-surface residual strains/stresses and near-surface microstructural changes as a function of process parameters using novel methods; (4) determination of thermal relaxation of residual stresses (macro and micro) and microstructure evolution with time at high temperatures typical of service conditions and modeling of the kinetics of relaxation; (5) evaluation of the effects of residual stress, near-surface microstructure, and temperature on fatigue properties, fatigue crack initiation, and growth and mechanisms; and SCC initiation and growth behavior and associated microstructural mechanisms; and (6) development of a robust modeling and simulation approach for determining the effects of LSP on residual stress, microstructure, fatigue life, and SCC initiation mechanisms. The proposed project is generic, timely and transformative, has scientific and technological implications far beyond the materials and phenomena we study, and is directly aligned with the strategic goals of the nuclear energy program. The intellectual merit of the proposed work lies in the fact that the integrated experimental and modeling approach that will be used and the ensuing results will considerably advance the state-of-the-art scientific understanding of the effects of innovative surface treatments like LSP on enhancing the fatigue and SCC resistance of nuclear materials, as well as provide new scientific insights into the mechanisms governing the fatigue and SCC behavior of these materials. In terms of broader impacts, the project results will help guide the efforts of scientists in the DOE laboratory, university and industrial communities concerned with the technological development of materials and design of methods for improving the performance and safety of aging, and future nuclear reactor components through mitigation of the serious problem of SCC. Lastly, this project will stimulate our youth to pursue doctoral studies and cultivate a new breed of scientists/engineers much better trained for advanced careers in the nuclear energy field.