Determining the Effects of Neutron Irradiation on the Structural Integrity of Additively Manufactured Heat Exchangers for Very Small Modular Reactor Applications

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ABSTRACT:

Auburn University (AU), home to the National Center for Additive Manufacturing Excellence (NCAME) , has teamed with the University of Missouri Research Reactor (MURR) Center to determine how to best use laser-powder bed fusion (L-PBF) additive manufacturing (AM) methods for generating radiation resistant channel/pore-embedded structures from Inconel (alloy 625 or 718) nickel-based superalloys for special purpose reactor (SPR, or very small modular reactor) heat exchangers (HeXs). Compact, conformal and durable HeXs that are tolerant of extreme environments are needed for supporting the technical maturity of next-generation, portable compact reactors. AM is an enabler for realizing this new wave of HeXs – providing a means to make customizable hot and cold stream architectures with novel flow path geometries (e.g. tortuous channels with non-uniform, asymmetric cross-sections) and reduced layer-to-layer contact resistance (i.e. no separate bonding procedure required). AM further enables a more time/cost efficient means for fabricating SPRs by reducing the number of suppliers required for HeX assembly and allowing for on-site HeX fabrication.

The proposed Project aims is to better understand how neutron irradiation effects the microstructure and properties of additively-manufactured nickel-based superalloys, in order to accelerate their safe, reliable use in the modular reactor industry. The major Objective is to qualify/quantify the microstructure, surface roughness and microhardness of three nickel-based superalloys (including Inconel 718 and 625) additively manufactured via the L-PBF process in the neutron-dosed (irradiated) and non-irradiated states over a course of 3 years. Effects of part orientation during L-PBF and post-AM heat treatments on neutron resistance, microstructure and mechanical properties will also be investigated. Neutron damage mechanisms via embrittlement, swelling and hardening will be characterized. A secondary Objective is to generate property-performance relationships to enable the better design and L-PBF of next-generation HeXs for vSMRs.

This Project combines topic-matter experts in AM, mechanical/microstructure metallic part characterization, and neutron irradiation, as well as unique National-level assets/capabilities in NCAME at AU and MURR at MU, to ensure Project results translate to effectively addressing known gaps in nuclear science and engineering. Parts will be fabricated using L-PBF systems readily available at AU's NCAME. Specimens will then be irradiated using MURR facilities; a manipulator-equipped hot cell has also been dedicated to measure material hardness immediately after dosing. MURR, a 10 MW, light-water nuclear reactor is the largest, highest powered, highest-flux university-owned research reactor in the U.S. Unique scanning electron microscopy (SEM), X-ray computed tomography (CT) and electron backscatter detection (EBSD) imaging techniques will be used for microstructural characterization – all available using the Project Team resources at AU's Analytical Microscopy Center and MU's Electron Microscopy Core (EMC) Facility.