Technical Basis of Microstructure Criteria and Accelerated Testing for Qualifying Additively-manufactured 316H Stainless Steel for High-temperature Cyclic Service

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ABSTRACT:

Over the past decade, the interests in laser-based additive manufacturing (AM) have been greatly elevated in the nuclear industry through several government and industry-sponsored initiatives. The code and nuclear regulatory bodies are still skeptical about adopting AM due to the scattered metallurgical and mechanical properties. Qualification of AM metallic materials for nuclear use is crucial towards the reliable insertion of the technology in reactor operation. Progress has been recently made by EPRI and other nuclear technology providers to submit the data package to an ASME code case application for AM 316L stainless steel (SS) components. Most work has been limited to static applications at room temperature. The knowledge base of the process-microstructure-properties relationship for high-temperature nuclear cyclic service has not been established.

Besides the common porosity defects, one of the key findings from EPRI's code case study and other reported work is that a significant microstructural heterogeneity existed and resulted in machine-to-machine and vendor-to-vendor variations in the microstructure. More importantly, such heterogeneity may not be "fixed" by post-AM treatment, such as hot isostatic pressing (HIP) and annealing. While the microstructural variations in AM parts seemed to have less negative impacts on room-temperature mechanical properties, the findings raised concerns for the consistency in high-temperature properties, e.g., creep and creep-fatigue, where microstructure generally plays a more dominant role.

This project seeks to reveal the fundamental relationship for AM 316H SS working at 500-750 ^{0}C between AM microstructures and creep/creep-fatigue properties through a multiscale experimental and modeling approach, and establish the technical basis for the microstructure criteria and accelerated testing method to support near-term nuclear qualification.

<u>**Five major objectives will be achieved.**</u> **First**, creep and creep-fatigue data package of AM 316H SS will be produced over a range of relevant microstructures and accelerated testing conditions. It fulfills the data needs for qualifying AM 316H SS for high-temperature services. Microstructurally-graded specimens will be utilized as the high-throughput method for creep evaluation. Digital image correlation (DIC) and direct current potential drop (DCPD) methods will also support the testing. **Second**, the relationships between AM microstructural features and high-temperature properties will be obtained through experiments across different length scales. In-depth mechanistic understandings serve as the crucial basis for developing the accelerated qualification testing methods for AM materials. **Third**, the accelerated testing methods by utilizing high-stress state, notch specimen design, and pre-test thermal-aging will be validated. **Fourth**, a viscoplastic constitutive model and damage assessment will be developed for creep/creep-fatigue/rupture behavior. **Fifth**, an ex-situ qualification framework based on microstructure evaluation, accelerated testing of witness samples, and model assessment will be developed and validated at the component level for high-temperature service.