Assessment of Irradiated Microstructure and Mechanical Properties of FeCrAl Alloy Fabrication Routes

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Program: Area of Interest NSUF-2.1: Core and Structural Materials

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ABSTRACT:

1. Background, Scope, and Project Objectives

Under the support of the Department of Energy (DoE), GE Research (GRC) and GE-Hitachi, Global Nuclear Fuel are investigating FeCrAl alloys as a potential material for Accident Tolerant Fuel (ATF) cladding. Although FeCrAl alloys show great potential, when possessing a coarse-grained microstructure, these alloys suffer from embrittlement which concerns both manufacturing and service performance. It is imperative, therefore, to use manufacturing processes that can achieve a high-level of grain refinement. Currently, three manufacturing routes have been investigated by GE: conventional melting and forging (wrought), powder metallurgy hot-isostatic pressing (PM-HIP), and laser-based powder bed fusion additive manufacturing (LPBF-AM). All manufacturing methods can produce distinctively different microstructures, yet their performance under irradiation remains to be evaluated. **The major objective of this program is to evaluate the process-microstructure-irradiation response relationships for wrought, PM-HIP, and LPBF-AM FeCrAl alloys.**

2. Technical Approach

Irradiations will be performed using both proton and neutron irradiation. Proton irradiation results will be compared to neutron irradiation results to screen proton irradiation for faster, cheaper, and higher throughput screening of future FeCrAl concepts. Post irradiation examination (PIE) will study the response of the unique microstructures resulting from different fabrication techniques. Emphasis is placed on irradiation hardening due to irradiation induced precipitation and dislocation loop formation. These changes in microstructure will then be correlated to changes in mechanical properties (hardness, strength, ductility). Results will then be evaluated alongside other characteristics of these materials (with a focus on mechanical properties and corrosion) to make programmatic decisions on commercial fabrication routes for FeCrAl alloys.

Schedule—All samples have been fabricated and characterized at GRC and are ready to ship upon award. Proton irradiation and PIE of proton irradiated samples is expected to take ~1-year total including any scheduling for other customers. For neutron irradiation, the irradiation time is expected to be approximately 9-12 months for 0.5 dpa irradiation, and 2-3 years for 2.0 dpa irradiation. This leaves ample time for unexpected shutdowns and delays between ATR cycles. Because the PIE of neutron irradiation is a large matrix and time is required to allow for sufficient decay of the materials after removal from the reactor, this work has been given a conservative schedule of 3 years per dose condition allowing for flexible scheduling of equipment used on multiple programs.

3. Deliverables/Outcomes

This program is expected to provide: 1. An evaluation of the effectiveness of using proton irradiation as an alternative to neutron irradiation for faster/cheaper evaluation of future FeCrAl concepts 2. An understanding of how fabrication routes can affect the microstructure-irradiation response relationship in FeCrAl alloys 3. An evaluation of commercial viability for advanced manufacturing routes of FeCrAl alloys, and 4. Provide the scientific community with insights on the process-microstructure-irradiation response relationships for advanced manufacturing of ferritic stainless alloys.

4. Potential Impact

The primary impact of this study will be the accelerated commercialization of advanced manufacturing routes for FeCrAl alloys. This study not only provides valuable information for comparing these manufacturing routes for future commercial production but also fills a vast knowledge gap for these manufacturing techniques — not only for the FeCrAl system but ferritic stainless steels in general.

5. Major Participants

GRC will provide samples of wrought, PM-HIP, and LPBF-AM FeCrAl alloys. Proton irradiation and PIE of proton irradiated samples will be conducted at the University of Michigan (UM). Neutron irradiation will be conducted at the advanced test reactor (ATR) located at Idaho National Laboratory (INL), and PIE of neutron irradiated sample will be conducted at the materials and fuels complex also located at INL.