Disruptive Manufacturing of Oxide Dispersion Strengthened Steels for Nuclear Applications

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ABSTRACT:

Our proposed project involves the manufacturing of oxide dispersion strengthened (ODS) steels 14YWT (Fe–14%Cr–3%W–0.4%Ti–0.25%Y_2O_3, wt.%) and MA957 (Fe–14Cr–0.3Mo–1.0Ti–0.25Y_2O_3, wt.%) via a disruptive technology based on liquid metallurgy, and their microstructural characterization, mechanical testing at room temperature and elevated temperatures, ion irradiation, neutron irradiation, as well as post-irradiation examination. The microstructure, mechanical properties, irradiation resistance, and scalability will be compared against those of powder metallurgy manufactured counterparts, a conventionally and widely used manufacturing technique. Ion irradiation will be carried out to high doses, while neutron irradiation will be conducted to low doses. The combination of the two will make the evaluation of the irradiation behavior feasible, practical, and effective, considering the project's time and budget limits.

The overarching goals of this proposal are to develop a disruptive and low-cost manufacturing paradigm for ODS steels and to assess the properties and performance of the manufactured materials, for nuclear applications (e.g., fuel cladding, heat exchangers, pumps, and piping). We propose to formulate and implement the manufacturing science base and technical capabilities that will allow us to enable the manufacture of advanced ODS steels into different parts and geometries. We will accomplish the goals by implementing a highly cost-effective and scalable approach that will solve the long-standing problems with manufacturability and cost for the powder metallurgy route of producing ODS steels. It will significantly advance the fundamental understanding of oxide nanoparticle (NP) dispersion in steels to establish a revolutionary manufacturing paradigm for producing low-cost, high-performance, ODS steels for nuclear applications.

The anticipated result of the proposed research is the development of a novel technology aimed at producing ODS steels. This technology is expected to exhibit a high degree of scalability while significantly reducing manufacturing costs. Additionally, the research will include an evaluation of the feasibility of applying this technology in producing nuclear components. The envisaged outcomes hold the promise of delivering a manufacturing technology that is both cost-

effective and dependable for the production of high-performance nuclear components. This, in turn, is anticipated to contribute substantially to the life extension of current reactors and to the advancement and deployment of advanced reactors.

The relevance of this proposed research is underscored by its alignment with the objectives of the DOE-NE's Advanced Fuels Campaign Program, Advanced Reactor Technologies Program, and Advanced Materials and Manufacturing Program. The expected deliverables from this project encompass technical journal articles, conference presentations, and comprehensive reports to the Department of Energy (DOE), providing detailed insights into the conducted work. Furthermore, the project is poised to contribute to the academic landscape by conferring graduate degrees as part of its tangible outcomes.

The proposed project will significantly advance the fundamental understanding of oxide NP dispersion in both solid and liquid steels to empower a revolutionary manufacturing paradigm and to harness the potential of ODS steels for widespread nuclear applications. It will establish the required knowledge base for the design, manufacturing, and properties of ODS steels through a hybrid solid-state and liquid metallurgy. The proposed manufacturing approach will enable the disruptive manufacturing of ODS steels with cost and energy reductions by one to two orders of magnitude. ODS steels produced by the proposed new manufacturing process will find widespread nuclear applications based on the cost and geometrical complexity of parts. This will help establish the USA as the undisputed global leader in manufacturing high-performance ODS steels.

The research activities are grouped into four highly interrelated tasks. Task 1 involves the design of steel-oxide systems for NP dispersion. We will focus on ferritic steel systems. Task 2 focuses on manufacturing master ODS steel feedstock by solid-state metallurgy. Task 3 focuses on manufacturing of ODS steel billets, tubes and complex parts by liquid metallurgy. Task 4 seeks to study the microstructure and mechanical properties of the manufactured ODS steels. Task 5 involves ion irradiation and post-irradiation examination. Task 6 includes neutron irradiation and post-irradiation examination.