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Integrating Dissolvable Supports, Topology Optimization, and Microstructure Design to Drastically Reduce Costs in Developing and Post-Processing Nuclear Plant Components Produced by Laser-based Powder Bed Additive Manufacturing

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ABSTRACT:

Due to its ability of manufacturing complex geometries, additive manufacturing (AM) has the potential to 1) significantly shorten the lead time by consolidating several components into a single AM build assembly; and 2) maximize the freedom to design for the highest efficiency possible. Hence AM offers a great opportunity in revolutionizing the design and manufacture of complex nuclear components. To achieve a wider adoption by the nuclear industry, there are several challenging issues that have yet to be overcome: 1) Inability to remove interior support structures; 2) expensive post-machining and processing for complex designs; and 3) difficulty in designing minimal support structure against residual stress induced failure.

This project aims to address these issues by developing an innovative approach to drastically reduce development and post-processing costs associated with laser powder bed AM of complex nuclear components. The approach will integrate dissolvable supports, fast process simulation, and topology optimization to achieve the above goal. The proposed research will address gaps in scientific understanding of AM-processed SS316L, 17-4PH and Stellite 6 alloys regarding the i) relationship of the dissolution activation energy of the etching regimes and phases with sensitization depth and microstructure, ii) phase stability and phase transformations in these AM alloys, and iii) true mechanical strains induced by the AM process. The project scope including the following tasks are proposed: 1) Develop and validate recipes to dissolve support structures and reduce surface roughness using a self-terminating dissolution process for SS316L and 17-4PH steels; 2) Develop an automated support structure design tool capable of maximizing the support dissolution rate and minimizing residual stress and distortion of AM parts; 3) Design AM processing with post-heat treatment to optimize hierarchical structure AM parts made of SS316L, 17-4PH and Stellite 6 alloys by applying the ICME (Integrated Computational Materials Engineering) process-structure-property modeling; 4) Design surface heat treatment recipes for enhanced mechanical properties; 5) Demonstrate that the integrated technology is capable of removing internal support structures, not assessable by post-machining, for two complex nuclear reactor components in less than 24 hours.

Key deliverables of this program include i) Optimized chemical recipe for dissolving SS316L and 17-4PH support structures; ii) a topology optimization tool for designing support structures for complex components to maximize dissolution rate and eliminate stress-induced failure; iii) optimized laser processing and post-processing strategy for achieving good mechanical properties of SS316L, 17-4PH and Stellite 6 components; iv) optimized surface heat treatment steps for enhanced mechanical properties of these alloys; and v) three nuclear components successfully printed without cracking, with all the support removed, whose deformation is less than 0.1 mm.

The proposed dissolvable support based technology is expected to have a huge impact to the nuclear industry. Using optimally designed dissolvable supports, this research will make state-of-the-art nuclear components much cheaper, have minimal distortion, and eliminate build failures altogether. The proposed technology will enable consolidation of many manufacturing steps currently required for complex nuclear components into one AM assembly, which would reduce manufacturing costs by at least 20%, improve manufacturing schedules by at least 6 months, and preclude unforeseen delays. Additionally, post-processing accounts for 70% of the cost of producing AM products, with support removal accounting for the majority of those costs. This work will help bring dissolvable supports to not just nuclear applications, but to the broader metal AM community so that AM costs can be significantly reduced. Metal AM is projected to be a $21.2 billion industry in 5 years; hence batch-processable dissolvable supports could save the industry $10 billion while also expanding design freedom and reducing surface roughness.

A critical aspect of this project is the synergy of the team members that is necessary to deliver the proposed dissolvable support based technology. The core project team consists of researchers from University of Pittsburgh, Arizona State University, Curtiss-Wright EMD, and Kennametal, whose expertise lies in AM, topology optimization, multiscale methods, metallurgy, chemistry, and nuclear component design and manufacturing. The configurations that Curtiss-Wright EMD will be providing to the project team to demonstrate the developed technology are applicable to a wide range of components related to the ASME Section III Nuclear Components Rules for design and manufacturing. Thus collaboration among the team members with complementary and nuclear design-manufacturing expertise will ensure that this project will have immediate impact and high relevance to the nuclear industry and that the developed technology will be rapidly adopted by the partners to fabricate nuclear components.