Pacific Northwest NATIONAL LABORATORY

PNNL-XXXXX

Oxide Dispersion Strengthened Ferritic Steel Wire Feedstock Development for Larger Format Additive Manufacturing (CRADA 620)

April 2025

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Jens Darsell
Dalong Zhang

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Pacific Northwest National Laboratory
Richland, Washington 99354

Cooperative Research and Development Agreement (CRADA) Final Report

Report Date:

In accordance with Requirements set forth in the terms of the CRADA, this document is the CRADA Final Report, including a list of Subject Inventions, to be provided to PNNL Information Release who will forward to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research. **PNNL acknowledges that the CRADA parties have been involved in the preparation of the report or reviewed the report.**

Parties to the Agreement:

Battelle, Pacific Northwest National Laboratory

Commonwealth Fusion Systems, LLC (CFS)

CRADA number: 620

CRADA Title: Oxide Dispersion Strengthened Ferritic Steel Wire Feedstock Development for Large Format Additive Manufacturing

Responsible Technical Contact at DOE Lab (PNNL): Xiao Li

Name and Email Address of POC at Partner Company(ies): Cody Dennett, cdennett@cfs.energy

Sponsoring DOE Program Office(s): Office of Science, Office of Fusion Energy Sciences, Innovation Network for Fusion Energy (INFUSE)

Provide a list of publications, conference papers, or other public releases of results, developed under this CRADA:

No publication, conference papers, or other public releases were generated under this CRADA.

Provide a detailed list of all subject inventions, to include patent applications, copyrights, and trademarks:

No subject inventions were generated under this CRADA.

Executive Summary of CRADA Work

This CRADA project funded through DOE’s INFUSE program sought to demonstrate the viability of fabricating large, complex parts from oxide dispersion strengthened (ODS) steel with advanced manufacturing. Exhibiting excellent radiation tolerance and high mechanical performance at elevated temperatures, ODS steel is a promising structural material candidate for near-plasma components in fusion energy systems. Its use, however, has been limited by a lack of manufacturability. This project sought to produce ODS steel wire through a solid-state shear assisted extrusion process and then demonstrate that the wire can undergo controlled local melting while being welded with the final part sufficiently retaining the beneficial properties of ODS steel. This would allow the use of wire-arc additive manufacturing (WAAM) to manufacture large-scale ODS parts, even though ODS is currently only available as a powder. WAAM is a promising technique for producing components like the replaceable ARC vacuum vessel in CFS’ fusion reactor design. Meanwhile, this project will also expand PNNL’s capability in producing custom wire feedstock with friction extrusion, enabling downstream large-scale manufacturing with WAAM and solid-state based additive manufacturing. The project achieved its goals of developing tooling and fixturing to produce ODS wire at smaller diameters than previous projects. Several small lengths of wire of 1.5 mm and 2.5 mm diameter in the range of 2.5-30 mm long were produced at tool temperatures that are known to cause ODS particle coarsening (~1200 ^{o}C). Fixtures and tooling for longer (>1 m) wires were developed but further process development is needed reduce tool temperature during extrusions and to increase wire length needed for WAAM testing and development.

Summary of Research Results

This CRADA project funded through DOE's INFUSE program sought to demonstrate the viability of fabricating large, complex parts from oxide dispersion strengthened (ODS) steel with advanced manufacturing. Exhibiting excellent radiation tolerance and high mechanical performance at elevated temperatures, ODS steel is a promising structural material candidate for near-plasma components in fusion energy systems. Its use, however, has been limited by a lack of manufacturability. This project sought to produce ODS steel wire through a solid-state shear assisted extrusion process and then demonstrate that the wire can undergo controlled local melting while being welded with the final part sufficiently retaining the beneficial properties of ODS steel. This would allow the use of wire-arc additive manufacturing (WAAM) to manufacture large-scale ODS parts, even though ODS is currently only available as a powder. WAAM is a promising technique for producing components like the replaceable ARC vacuum vessel in CFS' fusion reactor design. Meanwhile, this project will also expand PNNL's capability in producing custom wire feedstock with friction extrusion, enabling downstream large-scale manufacturing with WAAM and solid-state based additive manufacturing. The project achieved its goals of developing tooling and fixturing to produce ODS wire at smaller diameters than previous projects. Several small lengths of wire of 1.5 mm and 2.5 mm diameter in the range of 2.5-30 mm long were produced at tool temperatures known to cause ODS particle coarsening (~1200 ^{o}C). Fixtures and tooling for longer (>1 m) wires were developed but further process development is needed reduce tool temperature during extrusions and to increase wire length needed for WAAM testing and development.

Summary

Summary of key accomplishments made on the project:

- Purchase of ODS steel powder and delivery to PNNL (CFS):
    - CFS did not purchase ODS steel powders from AMES Laboratory to send to PNNL at the start of the project.
    - Instead PNNL used existing powders from prior projects to start the work, saving CFS $52k of in-kind.

- ShAPE tools and process development (PNNL):
    - Process development was initiated on PNNL's Friction Stir Welding gantry system using existing tooling from prior project. Process development experienced a 5 month pause due to lab move. During this time, effort was made for tool and fixture development to be used with Shear Assisted Processing and Extrusion (ShAPE-1) machine to produce ODS steel wire. Process development resumed on ShAPE-1 machine after the lab move.
    - Tungsten rhenium tools for friction extrusion of ODS steel wire were designed and fabricated. Several iterations of the tool design were made that included tools for extrusion of both 1.5mm and 2.5mm wire.
    - Water-cooled tool holders and fixtures designed and fabricated that allow for extrusion of longer (>1m) ODS steel wires than previously possible, figure 1.

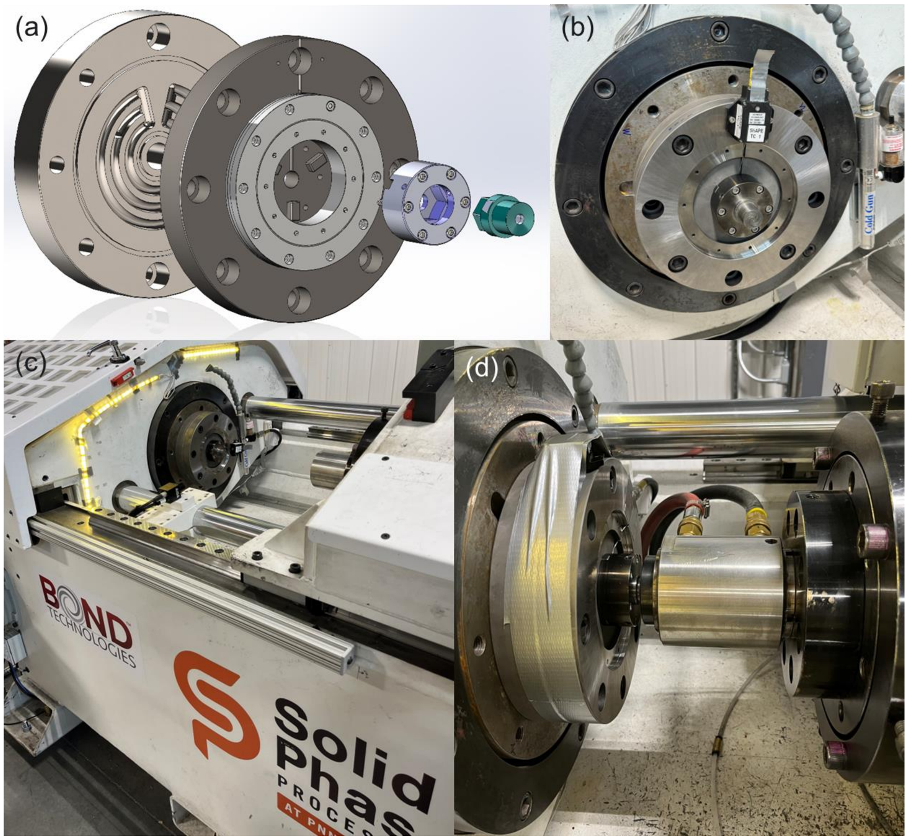

Figure 1. (a) Design of water-cooled mounting plates, tool holder, and die for extrusion of longer ODS steel wire, (b) & (c) Assembly of water-cooled mounting plates, tool holder, and die on ShAPE machine, (d) Experimental setup of ShAPE for extrusion of longer ODS steel wire

- Wire Production, wire microstructure characterization and ShAPE process optimization (PNNL):
    - Several short sections of ODS wire were produced ranging from 1.5 mm x 17mm to 2.5mm x 30mm using a parametric study that resulted in tool temperatures close to 1200C. Prior work suggests that this tool temperature may cause coarsening of ODS dispersoids.
    - Further development is needed to produce longer (1m) long wires at lower tool temperature and to complete characterization of produced wires.

- Weld trial of ODS steel wire, and weld process optimization (CFS-PNNL):
    - MIG welding trials were not performed since 1m long wires were not produced.

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