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U.S. Department of Energy

Electrically-Assisted Tubing Processes for Enhancing Manufacturability of Oxide Dispersion Strengthened Structural Materials for Nuclear Reactor Applications

PI: Jian Cao
Northwestern University

Kornel F. Ehmann,
Northwestern University

Program: Fuel Cycle

Collaborators: Stuart Maloy – Los Alamos National Laboratory

Osman Anderoglu - Los Alamos National Laboratory

Kester D. Clarke - Los Alamos National Laboratory

ABSTRACT:

The objective of this project is to enhance the formability of nanostructured ferritic alloys (NFAs) such that high-strength thin-walled claddings can be successfully and economically manufactured for use in future nuclear reactors.

NFAs are a promising class of structural materials which are extremely radiation damage tolerant for next generation of nuclear reactor applications. They have an iron-based matrix containing a fine, homogenous dispersion of nanosized oxide particles. These particles provide sinks for radiation induced defects, resulting in excellent resistance to radiation damage. In addition, nanosize oxides act as strong, stable barriers to dislocation glide, grain boundary motion, and grain growth providing high temperature strength and creep resistance. As a result, NFAs can be used at higher temperatures (up to 700°C) than traditional ferritic/martensitic steels (up to 550°C), and also withstand higher irradiation doses, resulting in increased fuel cladding lifetime of more than 20%.

For the application of fuel cladding, NFAs need to be formed into thin-walled tubes. However, the low formability of NFAs presents challenges to the forming of NFAs. The uniform elongation of NFAs is only about 5-7% at 200°C. This leads to easy cracking of the tubes during the forming process even after annealing. In order to ease the forming of NFAs, the tube forming process has to be conducted under high temperature in multiple passes and annealing has to be conducted in between the passes. This forming sequence greatly increases the manufacturing cost. Therefore, a new manufacturing technique for forming of NFAs is needed in order to make this promising material more feasible for advanced nuclear applications.

To accomplish the goal of successful and economical manufacture of NFA thin-walled claddings, the electrically-assisted (EA) forming technique is proposed here. This is a technique that uses the generated thermal and athermal effects of electric current passage to ease the deformation of the material. EA can be applied globally or locally in the deformation zone by controlling the path of the electric current. Furthermore, electropulsing has been found of having

positive effects on promoting crack healing, improving corrosion resistance, as well as enhancing recrystallization and grain refinement.

For the successful forming of NFA thin-walled tubes, both understanding of the effects of electric current on NFAs and designing an effective thin-walled tube forming process are essential. Therefore, in this project, three tasks are planned:

Task 1: Mechanical characterization of NFA coupon specimens in EA forming – This task focuses on the effects of continuous and pulsed electric currents on the mechanical properties of NFAs with different grain sizes, such as flow stress and elongation. Experimental investigations will be conducted and analytical models will be developed.

Task 2: Demonstration and process mechanics of EA flat rolling and EA tube drawing - Fundamental studies on the capabilities of EA forming of NFAs into plates and tubes will be performed through the EA flat rolling process using an existing custom-designed rolling mill at Northwestern University. Knowledge obtained from the coupon specimens and the flat rolling results will be used to design a new EA tube drawing machine/process.

Task 3: Microstructural characterization of EA formed samples - Raw material and EA-formed specimens from Task 1 and Task 2 will be examined at the Los Alamos National Lab in terms of grain size and its structure, recrystallization, dislocation distribution and density as well as the distribution of nanosized oxide particles using different measurement techniques including TEM, X-ray diffraction and small angle neutron scattering.

The established knowledge on electrically-assisted forming in this project will overcome the barrier of NFA fabrication limited by its low formability observed in the conventional processes. The innovative electrically-assisted tube forming process is expected to reduce the number of forming and annealing steps needed for making thin-walled claddings made of high-strength NFAs, and hence, significantly lower manufacturing cost while maintaining the desired microstructures. The success of the project will benefit the field of nuclear energy generation and nuclear safety related issues because NFAs are extremely radiation damage tolerant structural materials.