LA-UR-16-28110

Title: Production of FR Tubing from Advanced ODS Alloys

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Intended for: Report

Issued: 2016-10-25

Production of FR Tubing from Advanced ODS Alloys

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Advanced Fuels Campaign

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July 22, 2016
FCRD-FUEL-2014-000xxx

SUMMARY

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Significant research is underway to develop LWR nuclear fuels with improved accident tolerance. One of the leading candidate materials for cladding are the FeCrAl alloys. New alloys produced at ORNL called Gen I and Gen II FeCrAl alloys possess excellent oxidation resistance in steam up to 1400°C and in parallel methods are being developed to produce tubing from these alloys. Century tubing continues to produce excellent tubing from FeCrAl alloys. This memo reports receipt of ~21 feet of Gen I FeCrAl alloy tubing. This tubing will be used for future tests including burst testing, mechanical testing and irradiation testing.

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1. Introduction

Oxide dispersion strengthened steels are leading candidates for high dose applications as core materials for fast reactors. Significant progress has been made in processing these steels including producing large powder batches of powders through gas atomization (e.g. 50 kg), milling of powders in 15kg batches and extrusion of powders into plate and rod forms. Mechanical testing and initial ion irradiation testing of these materials show that they possess excellent properties including a low DBTT, good toughness up to high temperatures and excellent swelling resistance measured through ion irradiation. For high dose cladding applications, these materials will be required in tube form with approximate dimensions of 6 mm diameter and 0.5 mm wall thickness. Efforts are underway to produce tubing through hydrostatic extrusion and pilger processing. An update on progress to date is provided on hydrostatic extrusion runs at Case Western Reserve University and extrusion/pilger processing at PNNL/Sandvik.

2. Progress on Tube Production by Hydrostatic Extrusion at CWRU

CWRU participated in the fabrication trials of ODS tube samples using their laboratory scale, hot extrusion apparatus with a 1.00" bore container. The "mother tubes" were clad in Cu-10Ni alloy and fitted with a chromium-copper alloy 18200 core OR 1018 steel [deformable mandrel] for hot extrusion at 815 ^{o}C.

After the hydrostatic extrusion, the outer shell or cladding layers were machined off of the extrudate to a level close to the underlying ODS tube, followed by etching to remove both the remaining can and core. Removal of the Cu alloy or 1018 core was a challenge but could eventually be etched out with nitric acid.

LANL supplied four (4) "mother tubes" that were 1.26" long, Figure 1. In order to select appropriate can and mandrel materials that will flow along with the ODS tube during extrusion at high temperature, it is necessary to know the flow stress of the ODS material as a function of temperature. This was accomplished by conducting hot hardness tests using a Nikon QM1 Hot Hardness machine on the ODS material. Figure 2 shows VHN up to 950^{o}C. This information was used to select the appropriate can and mandrels for extrusion.

Figure 3 shows the billet design for ID 026, 027, 028, 029. Samples 026 and 028 used a 1018 mandrel as the deformable core while samples 027 and 029 used copper alloy C18200 as the deformable core. Extrusions were conducted on a laboratory scale hot extrusion apparatus at CWRU, starting with Sample ID 026 using the 1018 steel core.

Figures 4 shows the extruded 026 sample. In this case, the sample did not fully extrude because the hot extrusion apparatus did not possess adequate clearance for the back extrusion. The hot extrusion apparatus was modified to enable full-length extrusion of samples 027, 028, and 029. After extrusion, the can material was machined to a level approaching the ODS tube, followed by etching to remove both the remaining can and core.

Figures 5 (A and B) show the extruded and then machined and etched samples 026, 027, 028, and 029, respectively. The etching procedure used a 23% Nitric acid solution to remove the remaining can and core. Nitric acid etching is often used in industrial scale processes for large-scale extrusions indicating that the present procedures should be scalable to larger diameter extrusions. The etched samples were sent to LANL for subsequent analyses.

Figure 1- Photo showing original tubes of 14YWT sent to CWRU from LANL.

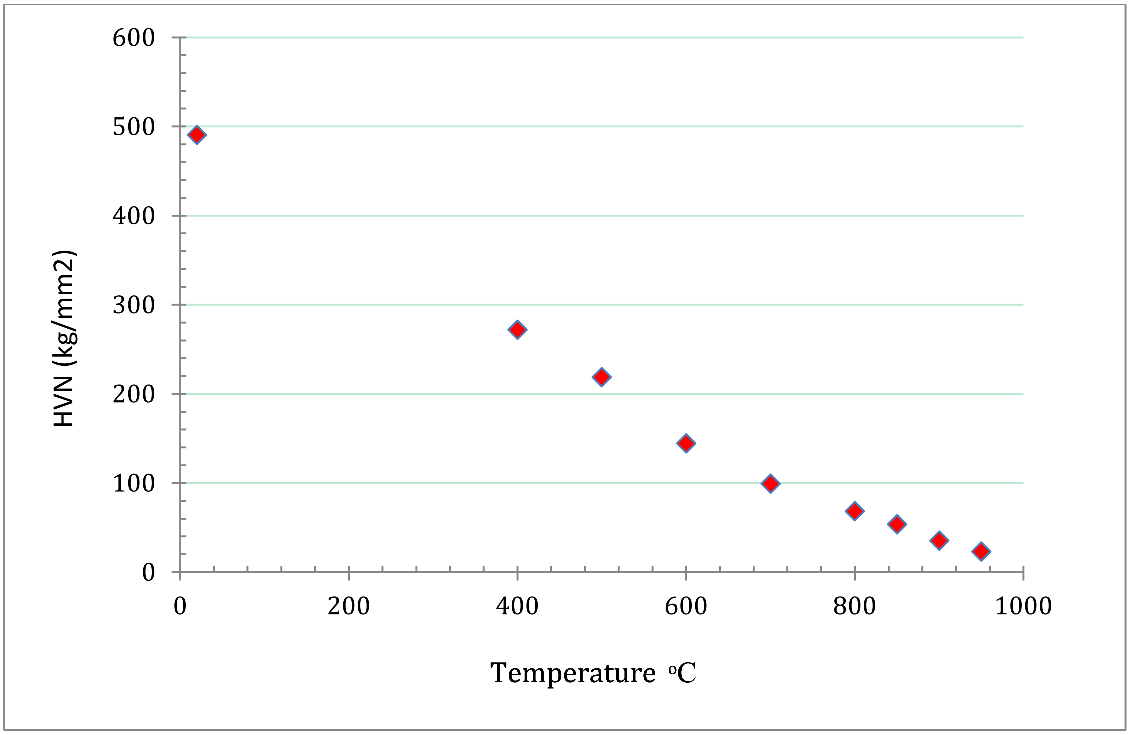

Figure 2- Graph showing Vickers Hardness (HVN) vs. temperature for 14YWT alloy up to 950C.

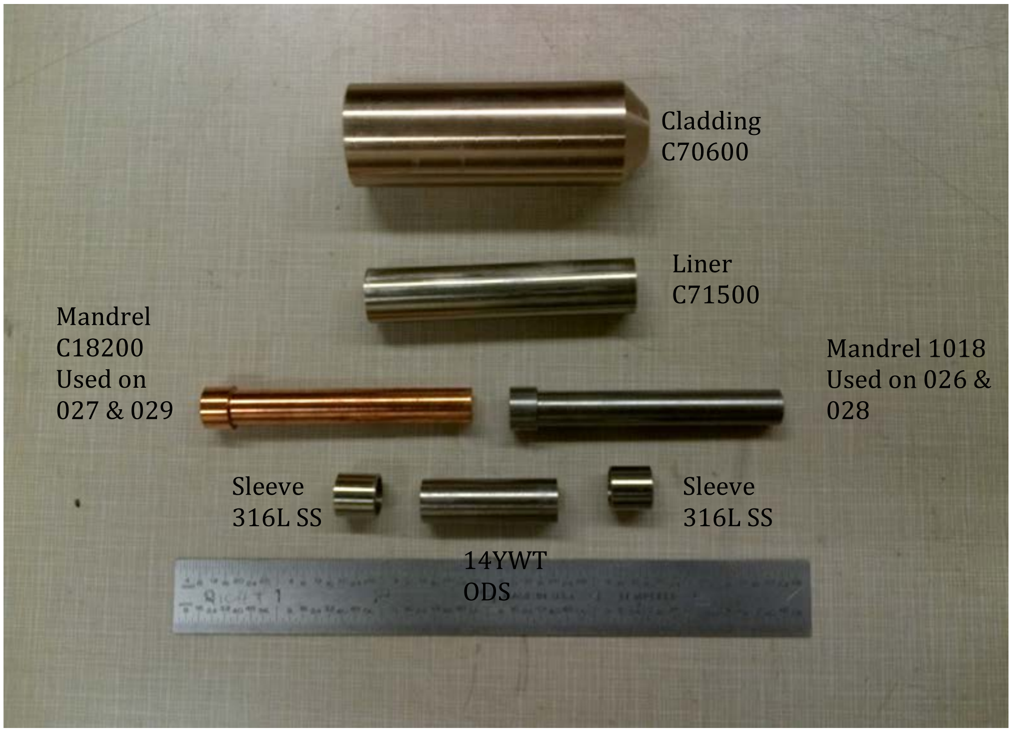

Figure 3- Photo showing billet design for hydrostatic extrusion on 14YWT.

Figure 4- Photo showing the 026 extrusion with the die still attached.

A.

B.

Figure 5 Photos showing hydrostatically extruded tubes after removal of billet cladding and mandrel materials.

3. Progress on Tube Production by Pilger processing at PNNL

As part of the activity to fabricate tubing for cladding from difficult to fabricate materials, the Pacific Northwest National Laboratory (PNNL) is fabricating MA-956, 14YWT, and 9YWT for the Los Alamos National Laboratory (LANL). The process being employed is to initially extrude billets into annular tubes and then to finish the process by pilgering on the pilger mill at Sandvik Special Metals.

Progress to date is as follows. A total of nine billets have been prepared: six of MA-956, 2 of 14YWT, and one of 9YWT. Two MA-956 billets have been extruded and core-drilled and are ready for pilgering at Sandvik. These are shown in Figure 6 below.

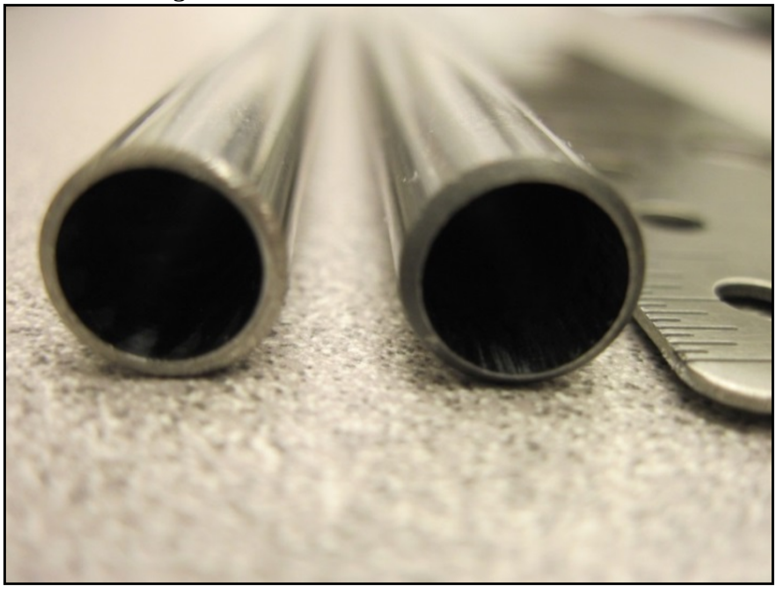

Figure 6 – MA-956 Tubing Ready for Pligering at Sandvik

In addition, 14YWT and 9YWT billets have been formed and the first stage extrusion is complete. One such billet in preparation for a first stage extrusion is shown in Figure 7 below.

Figure 7 – 9YWT Billet with Machined Copper Tube and End Caps in Preparation for the First Stage Extrusion

Subsequent second stage extrusions are to be performed in two stages with the second stage being an annular extrusion. The performance of the extrusion in two steps is a result of extrusion press capacity

(70 ton limit) which will require the work to be completed in two reductions. Evaluation of lubricants and extrusion methods will be performed to further refine and improve the hot working process.
The annular extrusion requires the design and fabrication of special tooling in order to get the correct extruded product. The tooling for this is currently being machined for this by Precision Products, and an isometric view of this is shown in Figure 8 below.

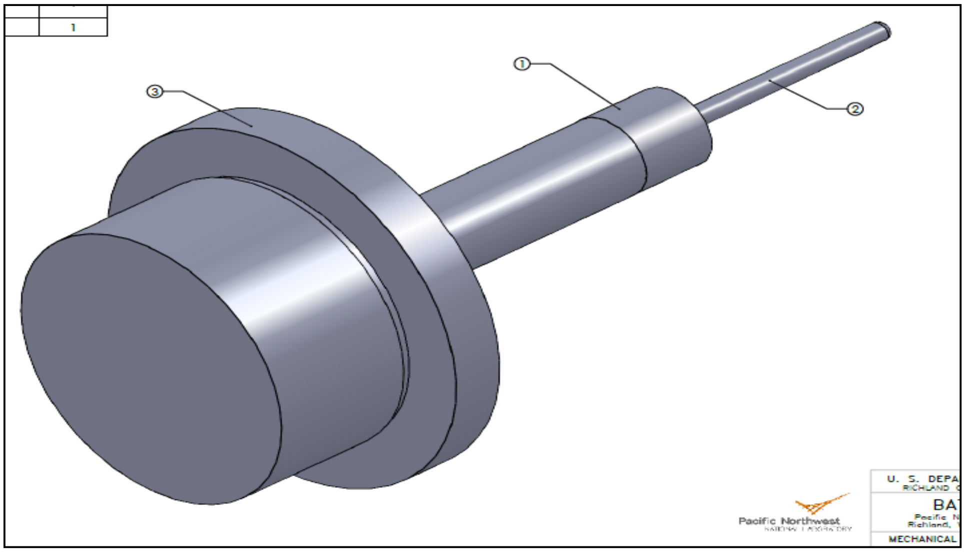

Figure 8 – Isometric View of Tooling Being Machined for Annular Extrusions

Interactions between senior staff at PNNL and management at Sandvik are currently underway to schedule time on the Sandvik pilger mill. Sandvik pilger mills consist of a typical pilger mill configuration with two vertically opposed tapered rolls used for reducing the outside diameter of the product with a tapered or cylindrical mandrel utilized for producing the ID of the finished tube. Efforts will be made to optimize final extrusion dimensions with existing Sandvik tooling to minimize the impact on production. A photo of the pilger mill is provided in Figure 9 below.

Figure 9 - Pilger Mill Intended for Use in This Project

So, initial extrusions of MA956, 14YWT and 9YWT are complete and once time is scheduled on the Sandvik pilger mill, progress will continue to develop processing steps for pilger processing of ODS tubing. Details include the following:

- Selection of tooling at Sandvik to produce desired final dimensions or closest possible dimensions
- Extrusion lubrication (canning vs glass vs high temperature paste)
- Extrusion method traditional vs. "flying start"

4. Summary and Future Efforts

Progress has been made toward producing tubing from ODS ferritic alloys through both the hydrostatic extrusion process at CWRU and extrusion/pilger processing at PNNL/Sandvik. Final tubes were formed without cracks by hydrostatic extrusion and have been used for further analysis and testing. Tubes are also available for future irradiations with fuel as soon as the welding procedures are determined. Although less progress has been made on developing the processing conditions for pilger processing, this would be the preferred method of producing tubing as it can be used to produced full length cladding tubes and produces a preferred texture in the radial direction.