Pilger Mill Processing

PNNL-28708

Nuclear Technology Research & Development

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

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MAY 24, 2019

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Abstract

The Nuclear Technology Research & Development program of the Office of Nuclear Energy has implemented a program to develop an advanced reactor cladding fabrication capability by using the extrusion and pilgering processes. Oxide-dispersion strengthened (ODS) steels are a promising class of advanced materials, but processes need to be developed to produce tubing for these advanced alloys. The Pacific Northwest National Laboratory (PNNL) has converted its rolling mill into a lab-scale pilger mill, which required designing pilger tooling and rolls that contained multiple pilgering grooves and designing a servo-driven feed mechanism. Upon assembling and checking out the system, pilgering runs on stainless steel, MA956, and 14YWT iron (Fe)-based alloys were completed. The feed rates and rotation rates were established, the reduction schedules were determined. This report will provide a description of the lab-scale pilger mill performance and processing results for the stainless steel, MA956, and 14YWT alloys.

Acronyms and Abbreviations

14YWT	ODS stainless steel cladding material that has been used in liquid metal reactors
MA956	Mechanically-alloyed ODS stainless steel
ODS	Oxide-Dispersion Strengthened
PNNL	Pacific Northwest National Laboratory
ROA	reduction of area

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1. EXECUTIVE SUMMARY

Pilgering is a promising technique for fabricating advanced alloys such as oxide-dispersion strengthened (ODS) cladding (MA956 and 14YWT) suitable for producing tubing for reactor use. This project is using the lab-scale pilger mill located at the Pacific Northwest National Laboratory (PNNL). Pilgering runs on stainless steel, MA956, and 14YWT Fe-based alloys were completed. The feed rates and rotation rates were established, the reduction schedules were determined. This report provides documentation of the progress made with the lab-scale pilger mill and processing of the stainless steel, MA956 and 14YWT alloys.

2. PNNL LAB-SCALE PILGER MILL

PNNL has been focused on the development of pilgering processes for the external cladding layer of nano-ferritic materials such as 14YWT and has modified a rolling mill to perform lab-scale pilgering. Figure 2.1 shows the PNNL setup. Commercial pilgering is a large-scale operation, therefore PNNL's lab-scale pilger mill allows for the greater flexibility that is needed with research and development. The PNNL design has rolls with multiple pilger grooves, which allow for different reduction ratios to be obtained without requiring tooling changes. The PNNL design also is servo motor-driven versus mechanically-driven. This allows for incremental changes to the degree of die rotation as well as the tube feed rate and die rotation synchronization.

Figure 2.1. Modifications to the PNNL Rolling Mill for Lab-Scale Pilgering

3. PILGERING DESIGN METHODOLOGY

The conversion of the rolling mill to a pilger mill design allows for more flexibility in the degree and speed of die rotation. The feed rate, rotation, and groove design all impact the resulting reduction of area (ROA). Consequently, it is possible for some of the grooves to be used for more than one of the reduction passes. For example, ROAs in the high 30s and low 40s may use the same groove, whereas the 11% ROA and the 77% ROA are drastically different than other ROAs, requiring their own groove designs. The pilger rolls developed for the pilger mill contain six different grooves of similar design but with differing ROAs.

The flexibility inherent with this six-groove design permits multiple passes to be conducted without die changes. Furthermore, synchronization of the servo-die-feed rotation can be programed with software without the need for mechanical linkage modifications.

4. PROCUREMENT AND FABRICATION OF THE ROLLS

The procurement and fabrication of the two rolling mill rolls used similar processes with several differences for each roll. The machining/precision grinding of the two rolling mill rolls were physically similar but had differing pilgering roll orientations for the precision cold working of the difficult to process nuclear cladding materials. The grooves had one-quarter symmetry in the plan view but had continual reduction in area in the rotation direction of the roll. They were also oriented differently in each roll, with a total of six (6) different groove segments located on three (3) groove locations across the length of the rolls. The PNNL report provided in FY18, "Pilgering Process Development", PNNL-27382, details the roll development and modifications to the rolling mill. Figure 4.1 shows a photograph of a single finished tube pilger roll with the three groove positions. Figure 4.2 shows the finished roll pairs with bearing surfaces and drive ends.

Figure 4.1. Close up of As-Received Pilger Roll

Figure 4.2. As-Received Pilger Rolls

5. TUBE PILGERING PROCESS DEVELOPMENT

The development of the tube pilgering process for the PNNL tube pilgering mill utilized three Fe-based alloys. Initial process development runs were performed using 304 stainless steel which is readily available from commercial suppliers. Following successful processing of the stainless steel a second process development effort utilized available MA956 alloy. MA956 is a mechanically-alloyed Fe-based material that is oxide-dispersion strengthened (ODS), and thus similar to the 14YWT alloy that is the ultimate focus of the tube pilgering effort. Because of the more limited quantities of suitable 14YWT alloy, it was the last of the three materials to be pilgered and utilized basic processing parameters developed for MA956. Table 5.1 below lists the three Fe-based materials utilized in the tube pilgering process development effort.

Table 5.1. Tube Pilgering Development Materials with Initial and Finished Dimensions

Material	Initial OD (in)	Initial ID (in)	Finished OD (in)	Finished ID (in)
304 Stainless Steel	0.375	0.209	0.242	0.192
MA956	0.380	0.209	0.242	0.209
14YWT	0.380	0.211	0.242	0.209

5.1 Tube Pilgering of 304 Stainless Steel

Sections of 304 stainless steel tube were purchased from a commercial vendor and cut to length and machined to the dimensions listed in Table 5.1. The use of stainless steel tubing (SST) allowed for multiple development runs to validate the tube pilgering mill set-up and to develop basic process parameters; including roll rotation, linear feed rates and mandrel rotation.

Figure 5.1 shows the stainless steel tube with the pilger mandrel inserted prior to pilgering.

Figure 5.2 shows the SS-304 tube being processed through the 0.340-inch diameter pilger groove.

Figure 5.1. SST Tube with Pilger Mandrel Inserted

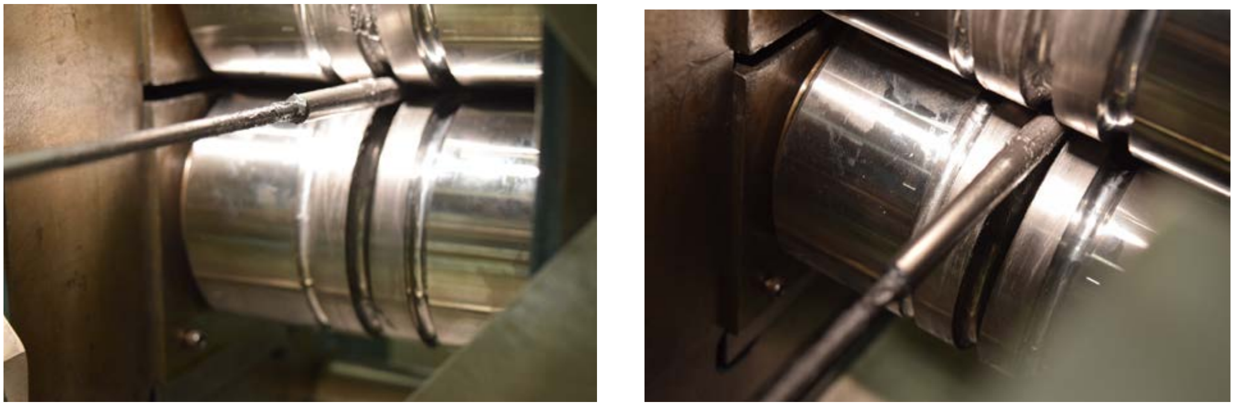

Figure 5.2. Incremental Steps as the Pilgered SS-304 Tube Exited on the Initial Reduction Pass

5.2 Tube Pilger Process Development for 304 Stainless Steel

To validate the operation of the PNNL tube pilgering mill and develop processing parameters for Fe-based alloys, two 304 stainless steel thick-wall tubes were processed to the desired finished thin-wall tube dimensions. Process parameter development included determination of roll rotation, linear actuator feed rates and rotations, and optimization of the area reduction schedules. Considerable effort was focused on development of the computer control system and the data acquisition system. Figure 5.3 shows a 304 stainless steel tube with the starting thick-wall tube blank and the finished thin-wall tube pictured below it. The overall ROA for the stainless steel tube is approximately 82%.

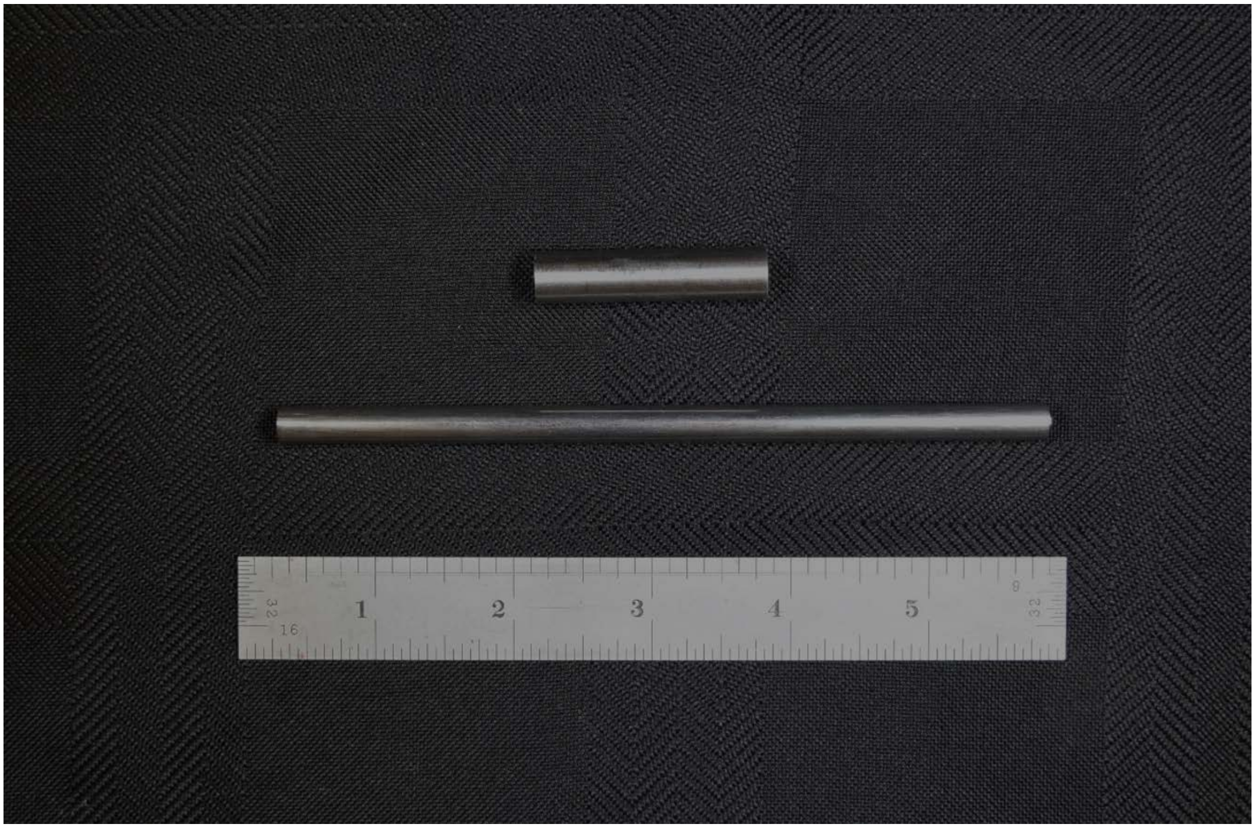

Figure 5.3. Photograph Showing 304 Stainless Steel Tube with Starting Thick-Wall Tube (top) and Finished Thin-Wall Tube (bottom)

5.3 Tube Pilger Process Development for MA956

Because mechanical alloyed ODS Fe-based alloys have significantly different microstructure and work-hardening characteristics than conventional commercial materials such as stainless steel, it was decided to perform further process development work using available MA956. Several thick wall starting blanks were prepared for tube pilger process development runs using the PNNL tube pilgering mill. MA956 was used to preserve the limited quantity of 14YWT material while providing the ability to develop pilgering process parameters for a similar ODS Fe-based material.

Pilger processing of the MA956 followed similar reduction steps as were developed for stainless steel, with the addition of an intermediate annealing heat treatment designed to reduce hardness during the overall 80% ROA. Figure 5.4 shows the starting MA956 thick wall tube blank with the finished MA956 thin wall tube pictured below it.

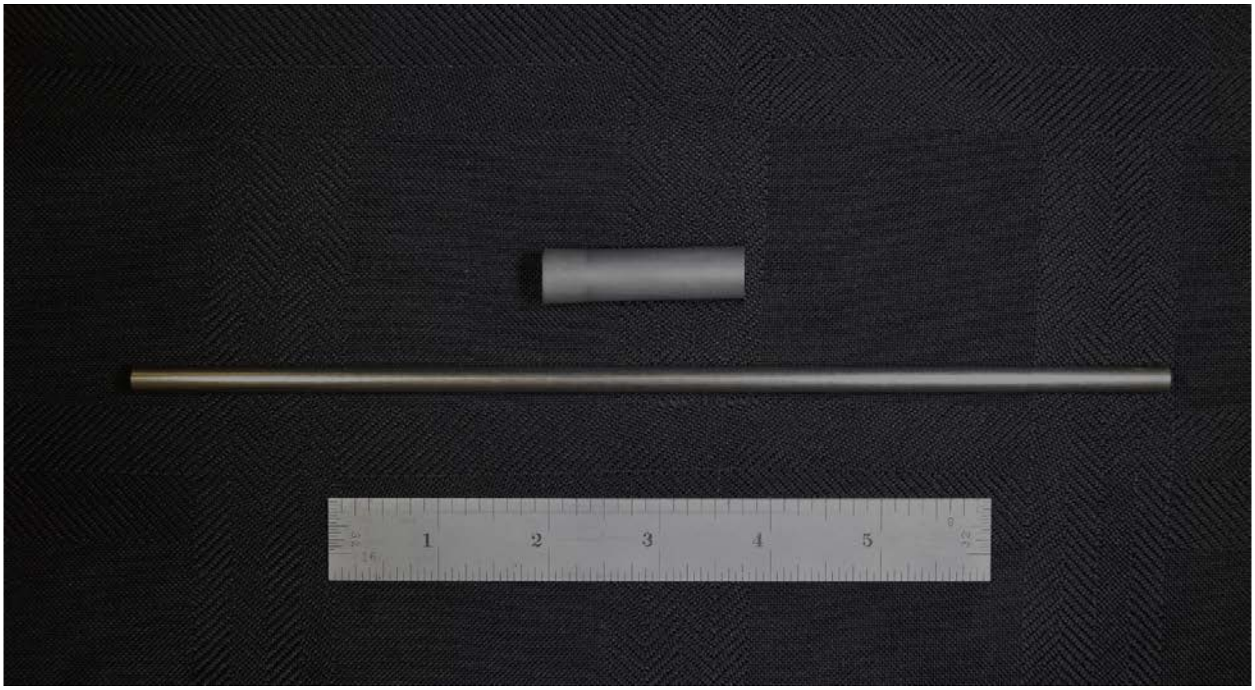

Figure 5.4. Photograph Showing MA956 Starting Blank (top) with Finished MA956 Thinwall Tube (bottom)

5.4 Tube Pilger Process Development for 14YWT

The final development task for the pilgering process demonstration was the pilgering of an extruded thick wall 14YWT starting blank down to a finished thin wall tube having an OD of approximately 0.240 inch with a wall thickness of 0.020 inch. Following a similar area reduction schedule that was developed for the MA956 tube, 14YWT was processed down to the target finished dimensions using the PNNL tube pilgering mill. As with MA956, the 14YWT was processed with an intermediate annealing step to reduce hardness and increase ductility during the high overall ROA. Figure 5.5 shows the starting 14YWT thick wall tube blank with the finished 14YWT thin wall tube pictured below.

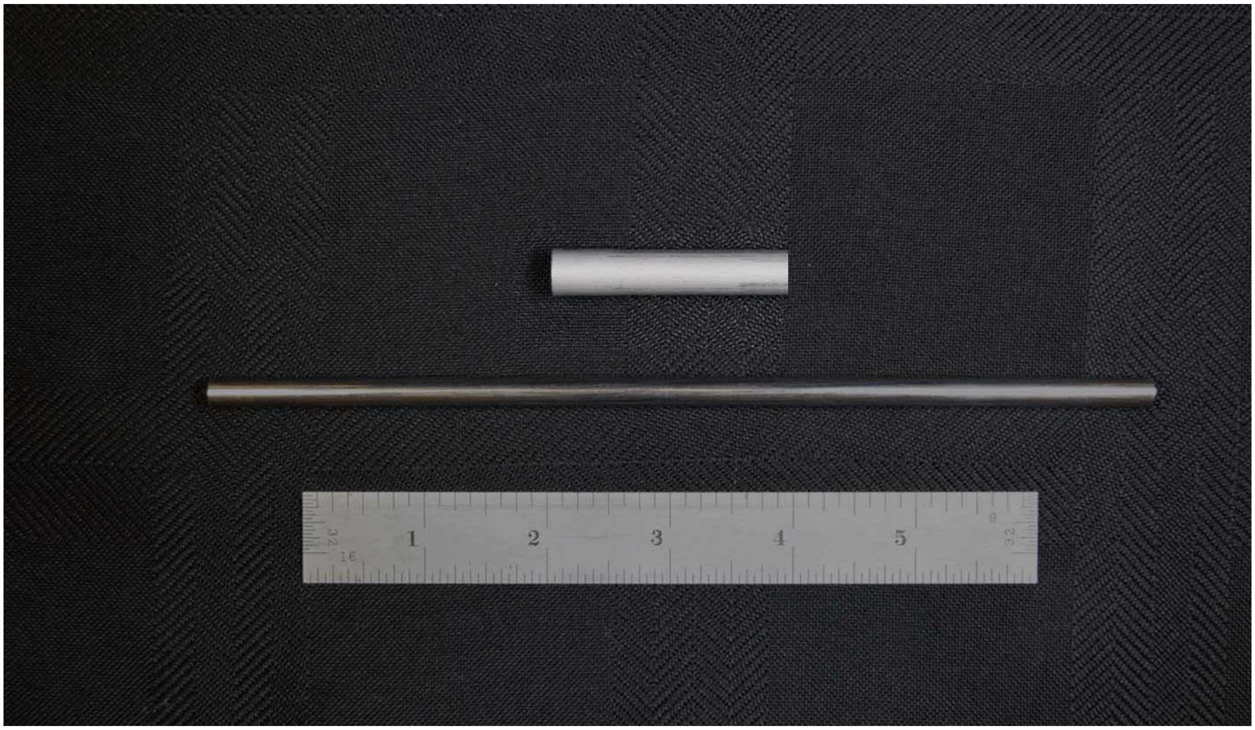

Figure 5.5. Photograph Showing 14YWT Starting Blank (top) with Finished 14YWT Thin Wall Tube (bottom)

5.5 Verification of Tube Pilgering Development Process

In order to confirm the results from the initial 14YWT run, we repeated the process with a second extruded thick wall 14YWT starting blank from the same feedstock. The objective was the same, a finished thin wall tube having an OD of approximately 0.240 inch with a wall thickness of 0.020 inch. Following the same area reduction schedule, 14YWT was processed using the PNNL tube pilgering mill. As with the initial 14YWT tube, the second 14YWT was processed with an intermediate annealing step to reduce hardness and increase ductility during the high overall ROA. Figure 5.6 shows the second starting 14YWT thick wall tube blank with the second finished 14YWT thin wall tube pictured below.

Figure 5.6. Photograph Showing 14YWT Starting Blank (top) with Finished 14YWT Thin Wall Tube (bottom)

6. RESULTS, STATUS, AND PATH FORWARD FOR ROLLING MILL-BASED PILGERING

The development process is illustrated in Figure 6.1, with all steps completed.

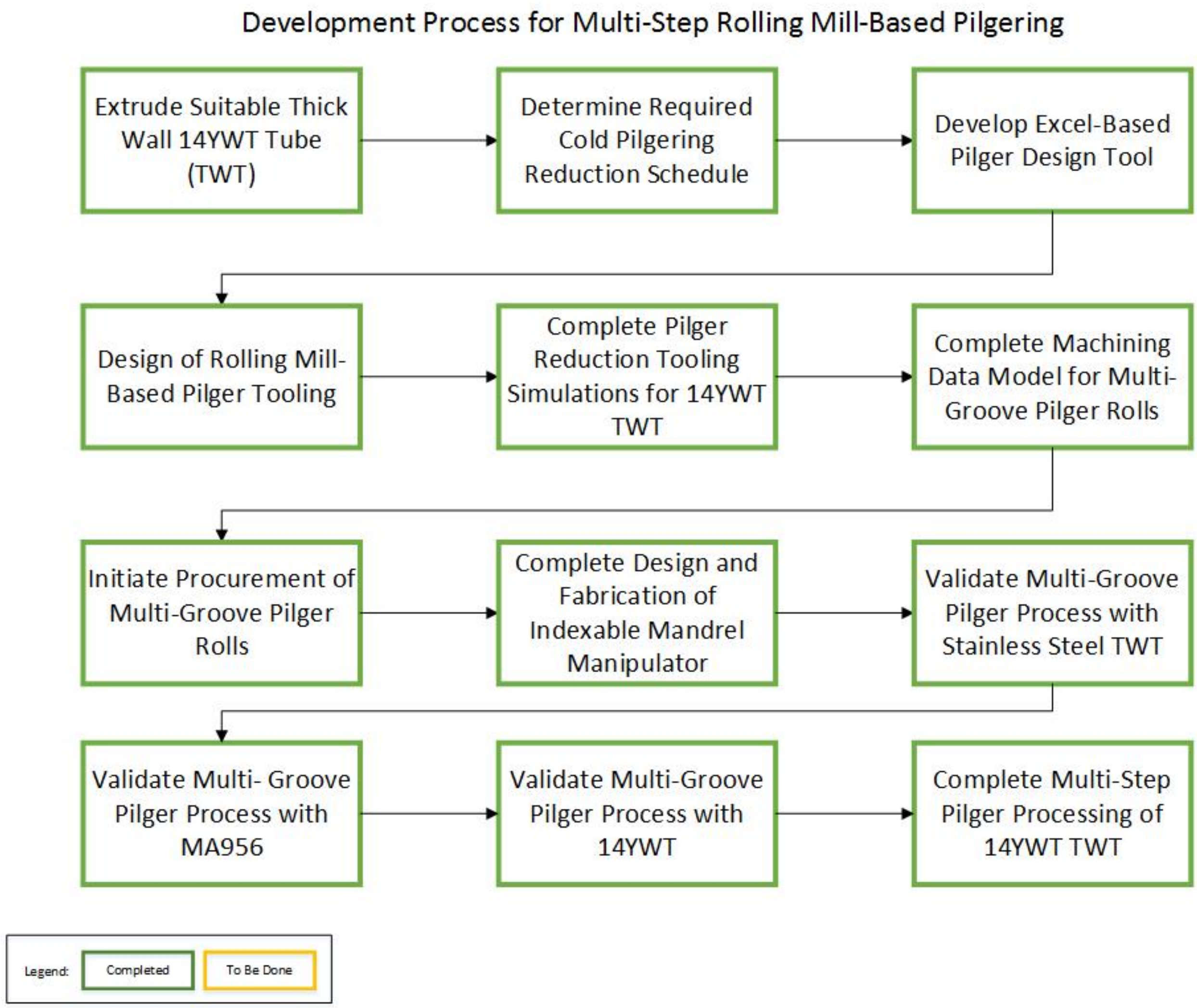

Figure 6.1. Development Process for Multi-Step Rolling Mill-Based Pilgering

7. BIBLIOGRAPHY

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