Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Evaluation of Two Passes Cold Pilgering Property for PLUS7™ Guide Thimble and Instrumentation Tubing

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1. Introduction

The thermo-mechanical property of zirconium alloy tube is well known to be influenced by pilgering pass schedule and its tooling; thus the control of its microstructure and mechanical property in the final tube production stage for nuclear fuel applications is a major concern of tube manufacture. To fabricate final tube, the 3 passes pilgering is applied in general by using TREX(Tube Reduced EXtrusion), 63.5mm outer diameter(OD), in KEPCO NF and most of Zr tube manufacturing companies. They are also taking big efforts to reduce pilgering step for the sake of increasing the efficiency of production in the forming stage of tube. The objective of this study is to develop two passes of pilgering schedule from the conventional three passes of pilgering schedule for manufacturing the Guide Thimble & Instrumentation tube conforming to specification, which are newly developing component for the advanced nuclear fuel assembly in KEPCO NF.

2. Development of Die and Mandrel

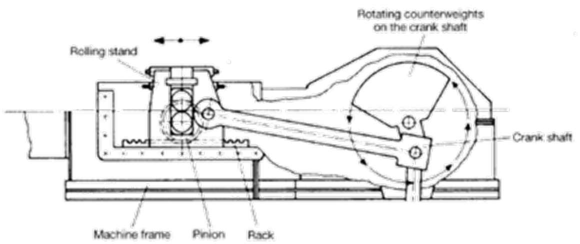

Fig. 1. Schematic cold pilgering machine[LC type]

Fig.1. shows the structure of cold pilgering machine. the cold reduction from TREX to the subject tube dimension is processed in several passes of reduction. During each pass of pilger reduction process, the tube is elongated over a tapered stationary mandrel by pair of two grooved dies rolling back and forth over the length of the mandrel. This process is a key to manufacture the tubes with most desirable crystallographic texture, uniform OD/ID dimension and minimum ovality[1]. In an effort to form desirable tube characteristics, the tube reduction schedule should be optimized because crystallographic orientations depend largely on tube OD and wall thickness reductions, which are major factors in optimization of Die/Mandrel design. The major factor of Die/Mandrel design depends on not only precise reduction schedule but also the specification of pilger machine. So two types of pilger tool were designed in this study to evaluate the influence of different pilger machine(50LC and 25LC).

2.1 Percent Area Reduction

The change in cross-sectional area of ingoing and outgoing tube is used to calculate the Percent Area Reduction for a pilgering pass which can be used to compare pilger passes about how much work has been done to the tubing. This test is designed to use over 70% of area reduction for two passes of pilgering.

2.2 Q Factor

The Q factor that is very important in the manufacturing of zirconium alloy tubing is defined as a ratio of the OD reduction to the wall thickness reduction. This factor should always be above 1.0 in order to prevent any pilgering defects in the pilgered tube and obtain the necessary crystallographic texture. The Q factor value is established in this study at the second pass pilgering for two passes reduction. The natural logarithmic Q factor of each position in the working section of both die designs are presented in Fig. 2.

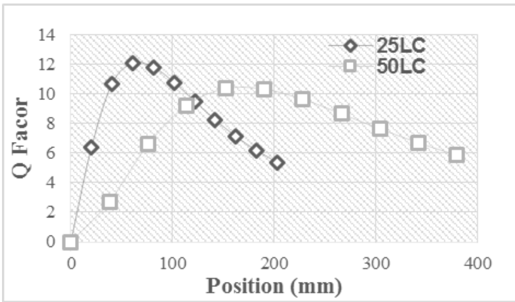

Fig. 2. Q factor values in the die working section

2.3 Elongation factor

As the tube is rolled over by the dies, the cross-sectional area of the tube is reduced and its length is increased. The ratio of the starting tube cross-sectional area to the final tube cross-sectional area is called the elongation factor of the tube. This factor is used in the die design to determine the die groove profile decided by pass schedule. The Percent Area Reduction(%RA), Q factor(Q) and Elongation factor(E) values are developed for two passes of pilgering.

3. Manufacturing Test

3.1 Pilgering Test

Tube shells which has completed 1st pilgering process was fabricated by new design pilger tool at 50LC and

25LC pilger machine. The results of visual inspection of second pilgered tubes were acceptable on this manufacturing tests and Fig.3. shows the status of specimens after second pilering process.

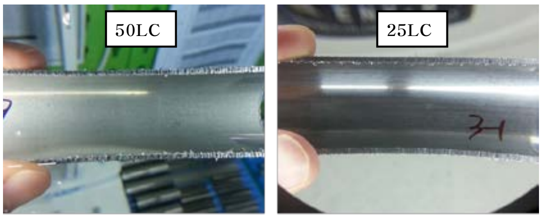

Fig. 3. Surface inspection of specimens

3.2 Temperature of Final Heat Treatment

To setting final annealing temperature, final pilgered tubes of two passes were subjected to final heat treatment in a temperature range of 400~600℃ Beginning recrystallization is similar in temperature range 450~475℃ on both tests. The hardness falls off rapidly with increasing anneal temperature until re-crystallization is complete. The slope of the curve in the region of partial recrystallization depends on the amount of cold work in the final pass and it is a little different each other. Fig.4. shows microstructures and micro vickers hardness test results for finished tubes after each heat treatment in a temperature range of 400 ~600℃.

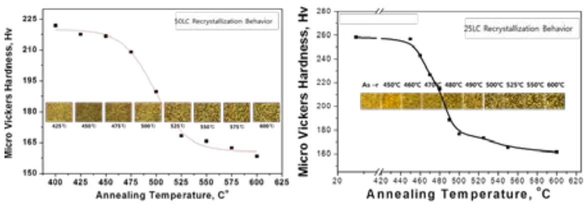

Fig.4. Micro vickers hardness & micrograph of the Zr alloys with various annealing temperature

4. Specification Test for Physical properties

4.1 Tension Test at RT

Tension test at room temperature is performed to confirm if satisfied physical properties. The results of tension test exceed minimum specification requirement of YS, UTS and elongation.

4.2 Contractile Strain Ratio & Texture Testing

Contractile Strain Ratio(CSR) test is performed to check the degree of texture developed in the course of pilgering and the measured CSR value is acceptable and ranged within 2.23~2.33[at 50LC] and 2.03~2.08[at 25LC]. The method of characterizing texture in tubing is the texture parameter obtained from inverse pole figure data by X-ray diffraction using the mathematical procedure defined by Kearns[2].

4.3 Hydride Orientation & Grain Size

The hydride orientation factor(Fn value) is to check the degree of circumferential hydrides and the result is Fn < 0.2 and acceptable to the requirement like shown in Fig.5. The grain size test is also performed and the average grain size is ASTM No. 13.

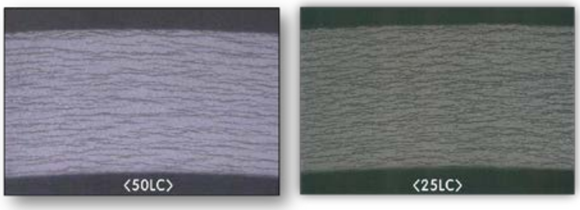

Fig.5. Hydride orientation(Fn<0.2)

4.3 Irradiation Growth

Axial length change of two passes pilgering calculated by the following equation in MATPRO code to evaluate structural integrity for irradiation growth. The calculation result of two passes pilgering is improved by 4~10% compare to three passes.

$$\frac{(\frac{\Delta L}{L})_{2passGT}}{(\frac{\Delta L}{L})_{3passGT}} = \frac{(1-3f_{z,2passGT})}{(1-3f_{z,3passGT})}$$

5. Conclusions

From this study of two passes pilgering for PLUS7^{TM} guide thimble and instrumentation tubes, it should be concluded as follows:

1) CSR, hydride orientation, and structural integrity are well conformed to the desired targets so it is expected that both die and mandrel were newly designed for the PLUS7^{TM} guide thimble and instrumentation tube with higher Q factor for two passes of pilgering at 50LC and 25LC pilger machine, instead of three passes of pilgering, are able to be applicable to this design of fuel component.
2) If developed two passes pilgering is applied to current manufacturing process, it would improve not only productivity but also yield rate by reducing 3 steps(pilgering, heat-treatment, pickiling&cleaning) of manufacturing process.
3) But additional tests(including in-pile test) should be performed in order to evaluate integrity in reactor.

REFERENCES

[1] Sandvik Special Metals, Zirconium Alloy Fuel Clad Tubing Engineering Guide, 1989, USA
[2] Kearns,J,J., et al., Zirconium in the Nuclear Industry(Seventh Conference), ASTM STP 939,1987, pp. 653-662.