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Development of Cold Pilgering Technology for PLUS7 Guide Thimble Tube

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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, three pass 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 and instrumentation tube conforming to specification, which are components for the PLUS7 nuclear fuel assembly.

2. Development of Die and Mandrel

The cold reduction from TREX to the subject tube dimension is processed in several passes of reduction called cold pilgering. 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. So it is important to follow precise reduction schedule and then outgoing tube size is controlled strictly by using pilger control chart. Therefore, pilger tooling must be carefully designed to produce the desired crystallographic texture of tube and have a longer tool life.

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 is a ratio of the OD reduction to the wall thickness reduction that is very important in the manufacturing of zirconium alloy tubing. This factor should always be above 1.0 in order to prevent any pilgering defects in the pilgered tube and obtain the necessary tubing properties. The Q factor value is established in this study at the second pass pilgering for two passes of pilgering. The natural logarithmic Q factor of each position in the working section of die design is presented in Fig. 1.

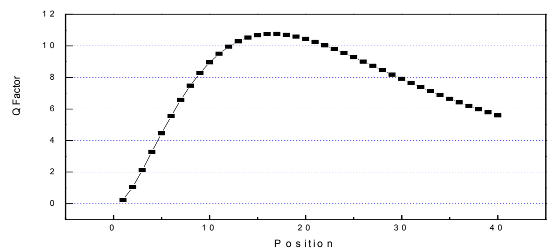

Fig. 1. Q factor values in the die working section

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(%R), Q factor(Q) and Elongation factor(E) values are developed for two passes of pilgering.

2.4 Reduction Schedule

The main factors to be considered when developing a Reduction Schedule are both Percent Area Reduction and Q factor at each pass. As can be seen in Fig.1, the die groove has the curved shape for achieving higher Q values. The Top Side Relief(TSR) of a die groove is very critical to the pilgering and more important than the base groove profile. Too much or too little side relief can cause bad OD/ID surfaces quality, mandrel breakage and poor tube dimensions. For mandrel which is used to control ID size, the mandrel OD size at the sizing point is designed to be more larger than tube ID size at the mandrel sizing position, considering spring back effects happened after pilgering due to higher Percent Area Reduction.

2.5 Temperature of Final Heat Treatment

To setting final heat temperature, final pilgered tubes of 2 passes were subjected to final heat treatment in a temperature range of 400~600℃. Micro Vickers Hardness tests were performed after each heat treatment as can be seen in Fig.3. Recrystallization begins in a temperature range of 450~475℃ and the hardness falls off rapidly with increasing anneal temperature until recrystallization is complete. The slope of the curve in the region of partial recrystallization depends on the amount of cold work in the final pass. Fig.4. show microstructures for finished tube in a temperature range of 400~600℃.

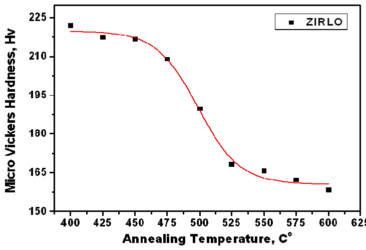

Fig.3. Micro Vickers Hardness of the zirconium alloys with various annealing temperature

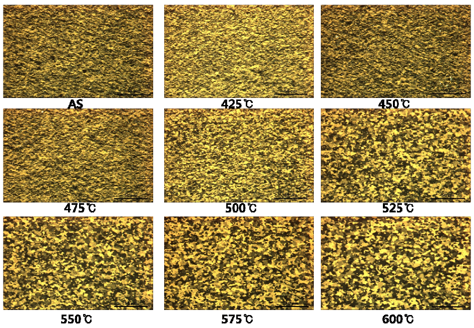

Fig.4. Micrograph of the zirconium alloys with various annealing temperature(Polarized Light 500x)

3. Specification Test for Physical properties

3.1 Dimensional & Visual Inspection

The short sample for dimensional inspection is cut from each leading end and trailing end of second pass pilgered tube. The OD and ID surface visual inspection is performed for short sample first and then for pilgered tubes by rolling over the surface plate after detergent cleaning. The result of dimensional and visual inspection is acceptable to specification requirement.

3.2 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. 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].

The sum of the texture parameters in all three (fn : radial, ft : circumferential , fr : axial direction) principal reference directions is equal to 1. The results of texture parameter for second pass pilgered tube of 2 passes of pilgering is fn = 0.6768, ft = 0.2420, and fr = 0.0822. Thus both radial texture parameter and CSR values are indications of radial crystallographic texture[3].

3.3 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 shown in Fig.6.

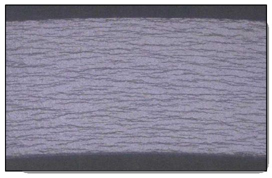

Fig.5. Hydride orientation (Fn<0.2)

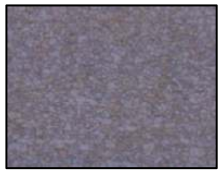

Fig.6. Grain Size (ASTM No. 13)

4. Conclusions

Through the results of this study, CSR, hydride orientation, and texture parameter are well conformed to the desired targets so it is expected that both die and mandrel were newly designed for the PLUS7 guide thimble with higher Q factor for two passes of pilgering, instead of three passes of pilgering, are able to be applicable to this design of fuel component.

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.
[3] C.S.Cook., et al., Zirconium in the Nuclear Industry(Ninth International Symposium), ASTM STP 1132,1991,pp. 80-95.