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Characteristics of Pilger Die Materials for Nuclear Zirconium Alloy Tubes

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1. Introduction

KEPCO Nuclear Fuel Company's (KEPCO NF) tube manufacturing facility, Techno Special Alloy (TSA) Plant, has started cold pilgering operation since 2008. It is obvious that the cold pilgering process is one of the key processes controlling the quality and the character istics of the tubes manufactured, i.e. nuclear zirconium alloy tube in KEPCO NF. Cold pilgering is a rolling process for forming metal tubes in which diameter and wall thickness are reduced in a number of forming steps, using ring dies at outside of the tube and a curved mandrel at inside to reduce tube cross sections by up to 90 percent[1]. The OD size of tube is reduced by a pair of dies, and ID size and wall thickness is controlled simultaneously by mandrel. During the cold pilgering process, both tools are the critical components for providing qualified tube. Development of pilger die and mandrel has been a significant importance in the zirconium tube manufacturing and a major goal of KEPCO NF. The objective of this study is to evaluate the life time of pilger die during pilgering. Therefore, a comparison of the heat treatment and mechanical properties of between AISI 52100 and AISI H13 materials was made in this study.

2. Die Manufacturing Process

In order to increase tube productivity and quality in normal operation, many cold pilger mills have been exploited for continuous operations. Especially, TSA's cold pilgering is Lancaster Continuous (LC) type which enables non-stop loading and pilgering of a new incoming shell. Therefore, pilger die should be precisely manufactured to produce the desired quality of tube and to give a longer tool life. In brief, the die manufacturing consists of processes from the die material selection, several steps of pre- machining, and final CNC grinding to the final inspection by Coordinate Measuring Machine (CMM).

2.1 Die Materials

It has been strongly demanded to improve a productivity and increase a life time of die in the cold pilgering. Recently, seamless tube manufacturing companies using cold pilgers are utilizing AISI H13 materials to improve both internal ductility and outer hardness of the dies. So, this study handles with both the AISI 52100 and AISI H13 for better productivity and longer life time with chemical composition shown in Table 1.

Table 1 : Chemical Composition(wt%) of Die Materials

Alloy	C	Mn	Si	Cr	Mo	V
AISI 52100	0.98 ~1.10	0.25 ~0.45	0.20 ~0.35	1.30 ~1.60	-	-
AISI H13	0.40	0.35	1.00	5.20	1.30	0.95

2.2 Heat Treatment

The heat treatment is very important and critical in the manufacturing of pilger dies. Its effect on the properties of the die material is investigated. Fig. 1 shows surface hardness of AISI 52100 in each heat treatment condition, being treated at three different austenitizing temperatures (830, 850, 870℃ for 50min.), and at four different tempering temperatures (200, 300, 400, 450℃ for 3hr) immediately after quenching from 870℃ for 50 min.

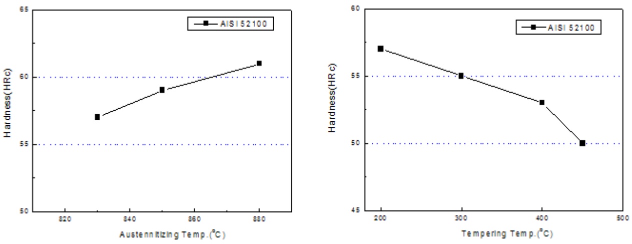


Fig. 1. Hardness of AISI 52100 in the each condition

Fig. 2 shows surface hardness of AISI H13 in each heat treatment condition, being treated at three different austenitizing temperatures (1020, 1050, 1070℃ for 120min.), and at four different tempering temperatures (450, 500, 550, 600℃ for 4hr) immediately after quenching from 1070℃ for 120 min.

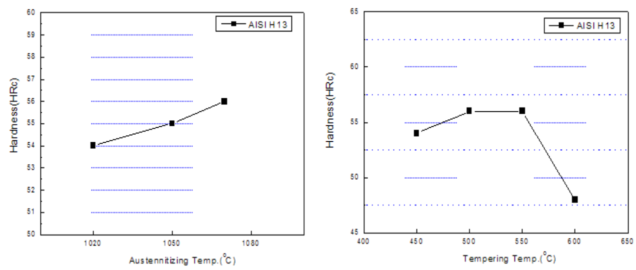


Fig. 2. Hardness of AISI H13 in the each condition

2.3 Machining, Milling, Grinding and CNC Grinder

Machining, milling, and grinding for pilger die are conducted before and after the heat treatment. In the each process, the tolerance should be controlled in the range of 0.01~0.001mm because die tolerance for the nuclear cladding tube is much tighter than general industrial tubes. So, machining of die before the heat treatment should be conducted for final CNC grinding within proper tolerance considering dimensional change of die after heat treatment.

3. Evaluation for Die Properties

3.1 Hardness under the Heat Treatment Condition

The die of AISI 52100 is followed by the heat treatment of austenitizing, called case hardening, under the temperature at 830 ~ 870℃ for 50 min in the salt bath and then quenching in the condition of oil bath at 60℃ for 40 min. In sequence, the first tempering is at 180℃ for 40 min in the oil bath to prevent inner residual stresses and then the second tempering is at 200℃ for 3 hrs to obtain required outer and internal hardness. The die of AISI H13 is followed by the heat treatment of austenitizing, called vaccum heat treatment, under the temperature at 1020~1070℃ for 120 min in the salt bath and then quenching in the condition of air. And then the tempering is at 550℃ for 4 hr at two times. Fig. 3 shows the result of hardenability test about two alloys under the each condition. The hardness of AISI 52100 is in the range of 58~59 HRc for outer surface, and 25~50 HRc for internal part. With this result, the die breakage due to peak stress in the pilgering can be prevented far more and the service life of die can be extended. The hardness of AISI H13 is in the range of 54~55 HRc for outer and inner surface.

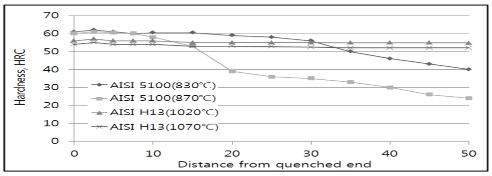


Fig. 3. Result of Hardenability test

3.2 Tension Test

The mechanical properties of two alloys after pheroidized annealing was evaluated by the tension tester. Fig. 4 shows the result of tension test. The AISI 52100 is higher than AISI H13 for the yield and tensile strength and lower than for the elongation and % of reduction area.

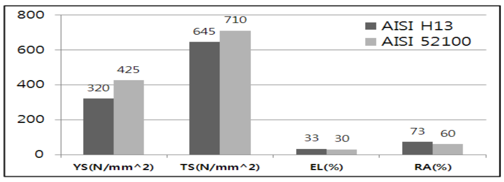


Fig. 4. Mechanical Properties of AISI 52100 and AISI H13

3.3 Abrasion Test

The abrasion resistance for the two alloys is conducted with abrasion tester. The wear rate, as follows

$$W = \frac{Bb^3}{12r} \times P \qquad (1)$$

where W is amount of the wear, B is the thickness of the rotation disc, b is width of the wear, r is the radius of the rotation disc, and P is defined as the specific gravity. Fig.5 shows the result of abrasion test under the each condition. The AISI 52100 is lower than AISI H13 for amount of wear under the condition of each speed.

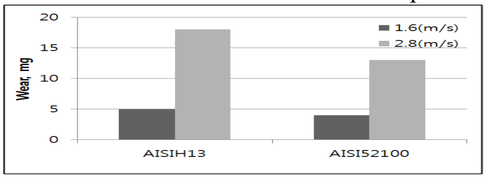
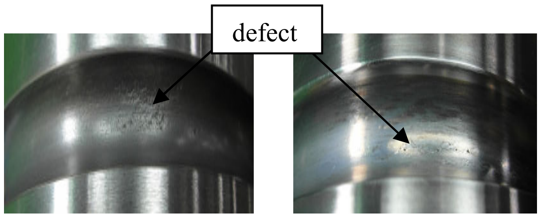


Fig. 5. Result of abrasion test

3.4 Life Time of Die

Through the pilgering tests, the life time of the developed die is recorded as a function of the production amount until the quality problems of die groove occur at first. Fig.6 shows the groove defect of each dies after pilgering. The defect of the AISI 52100 is spalling that bring about metal wear, and that of the AISI H13 is macro crack which is severe problem in tube manufacturing[2]. The life time of the AISI 52100 is about 12km and the life time of the AISI H13 is 4.8km.



(AISI 52100) (AISI H13)

Fig. 6. Defect shape of the die groove

4. Conclusions

Through the results of this study, it is concluded that the AISI 52100 material of die shows better performance than AISI H13 in the sense of life time and quality of tube. The life time of die is dependent on surface hardness and hardenability which is required to prevent the defect of die during pilgering.

REFERENCES

[1] Hideaki Abe, et al., Zirconium in the Nuclear Industry (Twelfth International Symposium), ASTM STP 1354, 2000, pp. 425-459.

[2] Cold Pilger Tube Design : Prevention of Defects. H.Stinnertz. ASM Conference.May 1988.