Development of Pilger Dies 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. These both tools are the critical components for obtaining the precise tubes of nuclear grade quality in the cold pilgering. Development of pilger die and mandrel has been a significant importance in the zirconium tube manufacturing and a major goal of KEPCO NF. In this paper, the major die manufacturing processes which includes heat treatment, machining, milling, and final grinding by Computerized Numerical Control(CNC) grinding machine are introduced and the effects of pilger die in cold pilgering on the tube quality are described.

2. Development of 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 give a longer tool life. In brief, the die manufacturing consists of processes from the die material selection, several steps of machining, and final CNC grinding to the final inspection by Coordinate Measuring Machine (CMM).

2.1 Die Materials at TSA

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 by cold pilgers are using AISI H13 materials with the intent to improve both ductility and hardness of the dies. However, this study handles with the AISI 52100 for better productivity and longer life time as die material of TSA with chemical composition shown in Table1.

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 pilger dies 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 about the AISI 52100.

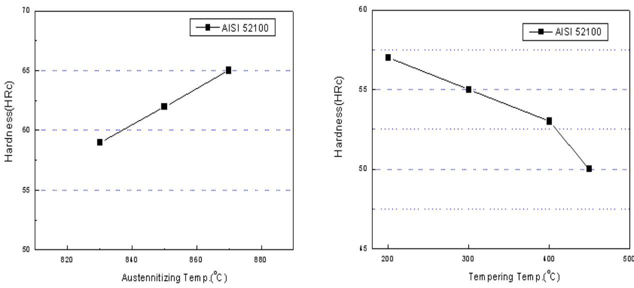

Fig. 1. Hardness at Austenitizing and Tempering Temperature

2.3 Machining, Milling, and Grinding

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 in the considerations of the dimensional deforming of die after heat treatment.

2.4 CNC Grinder

In the metal machining industry, the grinding operations is still intensively used for finishing and super finishing three-dimensional profiles of surface to impart them the desired shape and dimensional accuracy, and the required surface roughness. However, the CNC grinder used for this process needs to be stopped from time to time to dress the grinding wheel to eliminate the deviation in the grinding wheel profile resulted from the effect of the non-uniform wheel wear, which is achieved by a diamond tip that is being moved according to a CNC program. As a result of that, the change of the grinding wheel diameter and then accordingly new calculation of the tool path is required to compensate for the deviation of the actual wheel size from the initial one to make a precise dimension[2]. Fig.2 shows the principle of grinder of Granlund five-axis grinding system adapted for TSA. The work piece rotates about axis A, while the grinding wheel moves along axes X and Z and also has the ability to turn around axis Y. This turning of the wheel about axis Y and B provides the opportunity to position its axis of rotation along any perpendicular to any point of the machined profile.

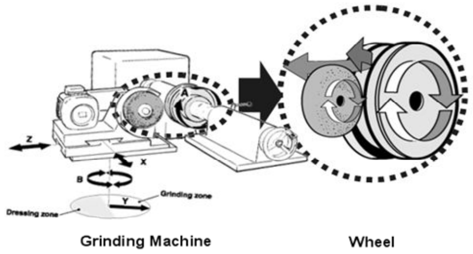

Fig. 2. Grinding Principle of Granlund five-axis CNC Grinder

3. Evaluation for Die Properties

3.1 Hardness of Die

The die machined by several steps of machining is followed by the heat treatment of austenitizing, called case hardening heat treatment, under the temperature at 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 samples for hardness measurement is cut from both groove part and tread part of outer diameter of die. The each hardness is checked at different depth of sample from the surface, the result of hardness is presented in Fig. 3.

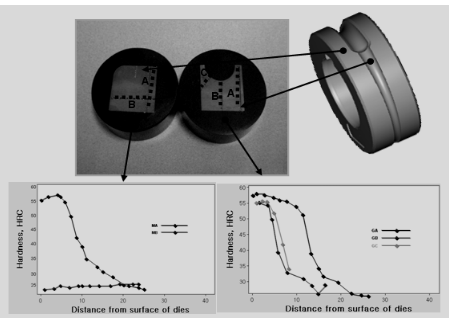

Fig. 3 Hardness measurements in each cross-sectional position

The hardness of die is in the range of 58~59 HRc for outer surface, and 30~35 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.

3.2 Comparisons of Measurements Between CNC Grinder and CMM Tolerances

The final CNC grinding for the groove of pilger die is conducted with five-axis CNC Grinder. Fig.4 shows a part of depth(Tx) and radius(Rx) deviation, which is resulted from a deviation between tolerance values for the built-in measuring machine of CNC Grinder and for the CMM at the position 0.0(sizing point) of pilger die for the cladding tube.

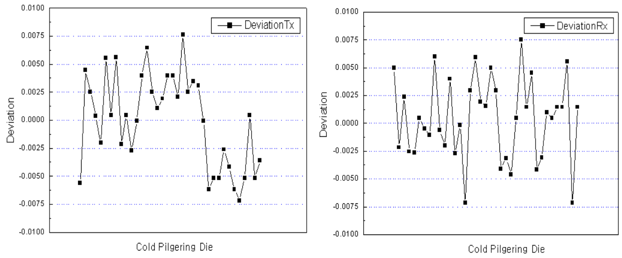

Fig. 4. Deviation in Tx and Rx of Pilger Die

This deviation measured by both measuring machines is within the design tolerance. This result shows the wheel dressing system and each five-axis moving system of CNC grinder is satisfactory for grinding the accurate dimensional groove of pilger die .

3.3 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 die quality problems occur at first. The average life time of die can be extended approximately 30%, compared to the existing imported die.

4. Conclusions

Through the results of this study, machining, milling heat treatment, and final CNC grinding system adapted by TSA seem to be satisfied to meet longer life time of die and good quality of tube production. It is also shown that evaluation tests on the developed die for the nuclear zirconium alloy tubes are well conformed to the desired specification. Thus, it is considered that the locally developed die is applicable to tool of cold pilgering.

REFERENCES

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