A STUDY ON THE FLATNESS CONTROL OF HIGH HARDNESS THIN PLATE IN QUENCHING PROCESS*

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Abstract

Recently, the demand for ultra-thin steel plate with high hardness and strength has been increasing in various industries. In order to satisfy this requirement, steel company designs the chemistry with low CEQ and obtains the required characteristics through quenching and tempering process. Especially, these steels are accompanied by low temperature tempering as a necessary process. Unlike ordinary high temperature tempering steels, it is impossible to improve the flatness after low temperature tempering. Therefore, shape control in the quenching process is very important for securing the excellent quality flatness. In order to obtain flatness in the quenching process, uniform cooling inside the plate should be accompanied. However, the quenching process has limitations in estimating the temperature behavior during cooling because the plate temperature is lowered to room temperature. In this study, a thermocouple was installed inside the actual quenching plate to measure the temperature behavior during cooling and to establish the manufacturing conditions of the quenching plate to ensure excellent flatness quality.

Keywords: High harness plate; Quenching flatness; Thin plate flatness.

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1 INTRODUCTION

In recent years, the high strength products required in various industries have to meet the tensile strength of about 1.5GPa. To meet this requirement, quenching and tempering processes must be applied to rolled plate designed with a low ceq composition. General quenching and tempering plates are tempered at high temperatures, which is effective in improving the shape and homogenizing the plate. However, in case of hardened steel, the mechanical properties are sensitive to the tempering temperature and the required properties can be obtained by applying only low-temperature tempering or quenching process [1]. The quenching process is a process which is difficult to control the flatness by reheating the hot-rolled plate to about 900°C and cooling it to about 20°C by rapid cooling.The flatness of the quenching process is mainly affected by water distribution and cooling homogeneity. It has been shown to be due to different cooling from top and bottom sides of the steel plate and, different water distribution in the center and corners of a steel plate [2,3]. In addition, the difference in the flatness of the quenching process results in a change in sensitivity to a small temperature difference as the thickness becomes thinner. In this study, various process condition for uniform cooling of the plate was investigated and thermocouple was installed inside the actual quenching plate to measure the temperature behavior during cooling. Based on these results, I have established the manufacturing conditions of the quenching plate(6mm) to ensure excellent flatness quality.

2 MEASUREMENT OF TEMPERATURE BEHAVIOR DURING ROLLER QUENCHING

The roller quenching process is a process in which the plate is re-heated from the heat treatment furnace to the Austenite area of 900°C and rapidly cooled to room temperature through about 400°C at which the martensite begins to be produced. The change in the shape of the rapidly quenched plate is caused by multiple causes such as thermal shrinkage due to cooling, thermal expansion due to phase transformation and uneven cooling in the plate. In particular, the thinner the thickness, the more sensitive it becomes, which makes it more difficult to control the flatness. Therefor, the temperature history was measured by inserting a thermocouple in the actual quenching plate(50t) to check the cooling non-uniformity for the plate during rapid cooling. Thermocouples were inserted at 1/4 and 3/4 of the thickness of the plate to identify the influencing factors that caused the temperature difference between top and bottom of the plate. Thermocouple with a diameter of 3mm was used, and the temperature was obtained at a total of 6 positions, three at the upper and lower parts. Installation schematics and actual installations are shown in Figure 1 and 2.

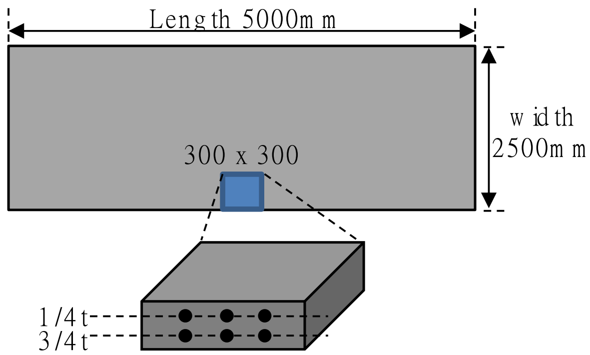

Figure 1. Thermocouple installation schematic

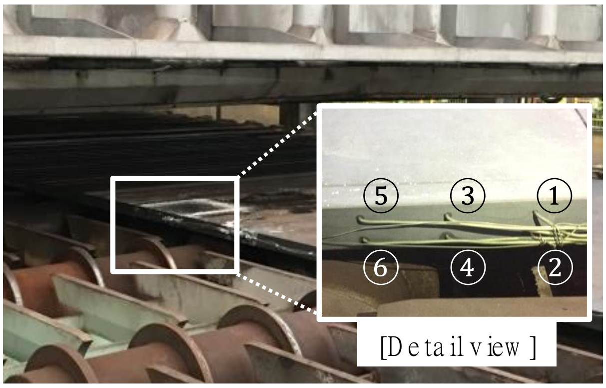

Figure 2. Actual installation of thermocouples

The quenching condition was applied by changing two kinds of conditions. In the first, the top and bottom ratio were changed to unsure a uniform cooling rate in both parts. And the seconds, amount of water was changed in order to symmetrically cooling top and bottom face.

3 MEASUREMENT RESULTS AND DISCUSSION

The temperature measurements showed an interesting fact. Flatness after quenching of the test plate (50t) was very flat. However, the measured temperature history clearly shows the difference in cooling rate between top and bottom faces. During the actual quenching process, uneven cooling occurred due to various factors, but it was judged that the difference was not enough to change the flatness.
As described above, the non-uniform cooling becomes sensitive to the shape change as the thickness of the plate becomes thinner. Therefore, in order to achieve the target 6mm flatness, it was considered necessary to optimize the factors causing uneven cooling.

3.1 SYMMETRICAL COOLING ON THE TOP AND BOTTOM

In the ideal conditions of the quenching plant, the contact points of the top and bottom nozzles should coincide with the center of the plate. In other words, the contact point where the nozzle is injected and crossed should by vertically symmetric. Figure 3 shows the incident points according to the nozzle injection angle [4].
In order to symmetry the contact point, the error of the thickness information of the plate should be minimized, and the value according to the durability of the equipment should be kept as close as possible to zero. Figure 4 shows a detailed description of the contact point symmetry. If the contact point is mismatched and a difference of distance S as shown in Figure 4 occurs, even though the top and bottom surface cooling rates are the same, the top and bottom cooling are asymmetric. Therefore, cooling starts first from the point of spaying on the top surface, and the volume change due to heat shrinkage and phase transformation appears unevenly. In this case, even if other factors are controlled, there is a limit to securing the flatness after quenching. In this study, the thickness information and the equipment optimization were carried out to match the incidence points.

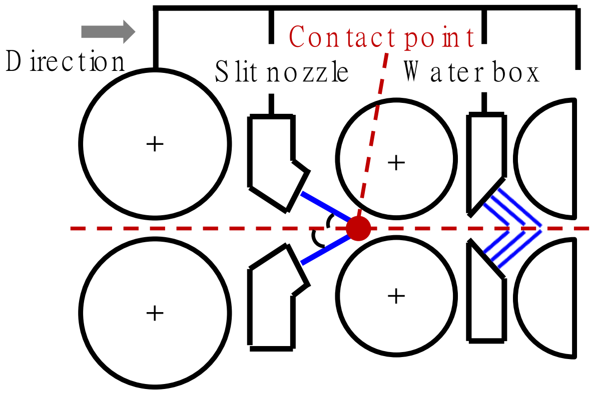

Figure 3. Contact point according to nozzle angle

$$s = \frac{(h+L)}{tan\alpha} - \frac{(L+\Delta L)}{\tan(\alpha+\Delta\alpha)}$$

h: $information\ error$
$\Delta L, \Delta\alpha$: $durability\ value\ of\ equipment \fallingdotseq 0$

$$\boldsymbol{h = 0, \text{then } s = 0}$$

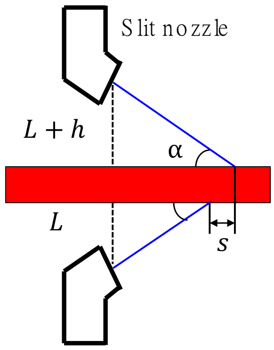

Figure 4. Examples of asymmetric cooling

3.2 UNIFORM COOLING ON THE TOP AND BOTTOM

In the cooling process, uniform cooling of the top and bottom parts of the plate is always difficult to solve. The upper cooling water always stays on the surface of the plate and the lower cooling water falls down the plate. So, the cooling phenomenon at the upper and lower parts of the plate is different. In the case of a roller quenching system, it is necessary to confirm the influence of the pinch roll, which is located between the nozzle and the nozzle, which serves to block the cooling water confined in the upper part. In this study, the target plate has a theoretical cooling rate over 100°C/s sufficiently, and the thickness is also thin so that even the little difference can have a sensitive effect the temperature drop. Therefore, it is important to understand the influence of confined the cooling water on the upper part.

From the results of the temperature measurement, it was confirmed that the upper surface was already cooled before passing through the first nozzle in which the cooling water was injected. This phenomenon was visually confirmed during the quenching process as well as the temperature measurement results. Figure 5 shows that the cooling water injected at the top just before quenching seeps through the pinch rolls gap. Considering that there are two more pinch rolls in front of the point, the cooling water that stayed in the upper surface was already causing uneven cooling of the plate before cooling started.

Optimization work has been carried out to minimize the above two uneven phenomena.

Figure 5. Seeping phenomenon of cooling water through the pinch roll

4 Flatness results after quenching

The effects of quenching control parameters on the flatness were confirmed in the above-mentioned contents, and the optimization test was carried out. The plate to be tested consisted of 11 ~ 6.3t thickness. Figure 6 shows the flatness after quenching at the beginning of the test. Figure 7 shows the improved flatness after the mid-test quenching. And figure 9 shows the flatness after the improved quenching of 6.3t. The initial flatness measurement wave maximum value exceeded about 300mm, however the test showed that the flatness gradually improved and finally it was achieved to the level of 20mm or less.

The final flatness is obtained with a cold plate leveler because there is a limit to the complete control of the flatness of 6.3t in the quenching process. The cold plate leveler is a large facility for thick plates with a diameter and roll pitch of 360mm. That is, even though it is not the leveler equipment optimized for the thin plate, the flatness of the quenching is improved, and finally, I was able to obtain the excellent flatness of 6.3t plate.

Figure 6. Flatness results after initial quenching test

Figure 7. Flatness results after mid quenching test

Figure 8. Flatness results after final quenching test

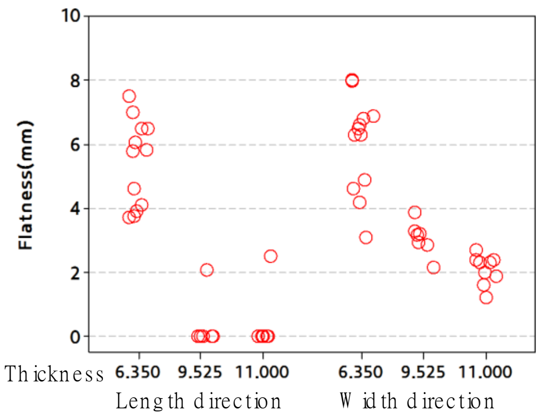

Figure 9. Flatness results after leveling

5 CONCLUSIONS

The following is a summary of the conclusion.

(1) The thermocouple was inserted into the quenching plate to ensure the temperature behavior in the actual quenching process.
(2) The thickness information and the equipment optimization were carried out to match the incidence point.
(3) An optimal cooling pattern was carried out for top and bottom uniform cooling.
(4) The maximum wave value of quenching flatness of 6.3t plate in the initial test exceeded 300mm, however it was able to reach flatness below 20mm by testing.
(5) Cold plate leveler was applied to ensure the flatness of the final product. A flatness level of less than 8mm was achieved for a thickness of 6.3t and a flatness of less than 4mm was achieved for a thickness of less than 11t(Figure 9).

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