Basic Characteristics of Pipe Nozzle Cooling with Retaining Water on Plate

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The basic characteristics of pipe nozzle cooling with retaining water on a plate has been studied in a laboratory test by using a moving hot plate.

The cooling ability of pipe nozzle flow changes with the amount of retaining water. It was found that maximum cooling ability can be obtained when the depth of retaining water is approximately 50 mm. The cooling ability with retaining water increases slightly as the nozzle is raised, while the cooling ability without retaining water decreases as the nozzle height increases.

The influence of the cooling conditions, such as flow-type and plate temperature, on the cooling ability with retaining water was also investigated and the cooling ability of pipe nozzle flow was compared with that of slit nozzle flow with a large gap. It was found that the slit nozzle flow has less cooling efficiency than the pipe one in the high water flux, though no difference can be seen when the water flux is low.

KEY WORDS: cooling; run-out-table; pipe nozzle flow; retaining water; cooling ability.

1. Introduction

Recently, an on-line heat-treatment such as controlled rolling or controlled cooling in a hot rolling process has begun to be used to control the mechanical properties of the material. Since it has been confirmed that the mechanical property of the hot rolled steel can be regulated in a wide range, the cooling system in many plate or hot strip mills has been renewed to a high performance one.

In order to regulate the mechanical properties in a wide range, the cooling system must have a variable cooling capacities, namely, it is necessary for the system to control the cooling capacity from heavy cooling to light cooling. It is generally said that a large water flux is needed to attain high cooling capacity. Therefore, in order to save on installation and running costs of the equipment, it is very important to design an optimum cooling device. Accordingly, many studies concerning pipe nozzle and slit nozzle cooling have been made recently to get good efficiency.

When the top surface of a plate is cooled with a large quantity of pipe nozzle flow, a lot of water is retained on the surface. As the retaining water may have an influence on the cooling efficiency, it was difficult to grasp the cooling efficiency of the heavy cooling precisely in a laboratory test. Because a small sized plate is used in the laboratory test, only a little water remains on the plate regardless of the variation on the water flux. However, in the actual mill, more water remains on the plate due to a larger water flux.

With regard to this effect of the retaining water on the cooling ability, A. Sigalla and P. M. Auman mentioned in their papers long time ago. However, the experiments which enable to investigate the effect of the retaining water were not carried out. Kunoika et al. conducted their studies concerning the cooling ability with retaining water in a laboratory by using a static hot plate and unit pipe nozzle flow. In the experimental condition of this test, the depth of the retaining water was less than 60 mm, though more water is retained in heavy cooling. In addition, as the cooling ability was investigated only locally along the distance from the point right under the nozzle, it is difficult to estimate the total cooling ability of the pipe nozzle flow. Moreover, very few studies concerning the effect of the retaining water on the cooling ability are found, in spite of its significance in designing the cooling device.

In this paper, the cooling ability of the pipe nozzle flow with the retaining water has been studied by retaining various amounts of cooling water on the moving hot plate up to 150 mm in depth in the laboratory test.

On the other hand, though the cooling ability of the slit nozzle flow is compared with that of a conventional pipe nozzle flow in several papers, most of the slit gaps were less than 15 mm. So, the cooling efficiency of the slit nozzle flow with a large gap was tested and compared with the cooling efficiency of the pipe nozzle flow with the retaining water in this study.

2. Retaining Water on the Plate at an Actual Mill

First, the amount of retaining water on the plate
at an actual mill using the pipe nozzle as cooling equipment, was measured. Fig. 1 is an example showing the depth of the water at the width center of plate in the accelerated cooling equipment of our plate mill. As shown in Fig. 1, the wider the plate or the higher the water flux is, the more water is retained on the plate.

Fig. 2 illustrates the depth distribution of the retaining water along the strip width in our hot-strip mill. According to this figure, the depth of the retaining water on the edge of the strip is as much as 60% as that of the center. Strictly speaking, as a cold plate is used to measure the depth of the retaining water, it differs from that in the actual cooling in which a hot plate is used, because of the difference in friction between water and the plate. However, it is considered that the difference in the amount of the retaining water is negligible, because the depth of the retaining water is great in heavy cooling.

3. Experiment

3.1. Experimental Procedure

A frame which can move only vertically under the nozzle was made, at the experimental mill of 600 mm in width as shown in Fig. 3. When the plate reached the position under the nozzle, the frame was lowered immediately on the plate to retain the water. Since the length of the plate is as much as five times longer than that of the frame, and the water flux is high (higher than 1.0 m³/min·m²), the plate, except for the top end, was cooled with the full amount of retaining water in the frame.

A test slab was heated to 1100°C and was descaled with high pressure water spray. The slab with a thickness of 230 mm was rolled to 15 mm. After rolling, the plate was moved back and forth several times under the shower from the nozzles.

The cooling ability was evaluated according to the temperature drop due to water cooling during each reverse pass, namely, from the difference between temperature drop due to water cooling and air cooling. The temperature of the plate surface after each reverse cooling pass was measured with a radiation pyrometer after heat recovery was completed.

3.2. Experimental Conditions

Experimental conditions are shown in Table 1. Since steel was used as the material for a test plate, the plate temperature was affected by transformation heat. Therefore, in this experiment, it was decided to use low carbon steel which was strictly confined to C%: 0.001~0.003, because transformation has less influence on the cooling curve of low carbon steel. According to this method of measuring temperature, adhering oxide scale on the plate surface has a large effect on the plate surface temperature. So, steel with a low silicon content was used to make the scale easy to remove. Furthermore, descaling was carried out perfectly with a high pressure (150 kg/cm²) water spray. Test plates from the same material were used for a series of experiments. The temperature of the cooling water was kept constant (36~40°C), as it affects greatly on the cooling ability.

In our previous laboratory test, since a long plate could not be used for the test piece, it was difficult to evaluate the cooling ability of the slit nozzle.
flow along the plate surface. So in this experiment, a very long test plate (5 m) was used to examine the cooling efficiency of the slit nozzle flow with a large gap.

4. Experimental Results

4.1. Water Flow Test

The water flow for cooling in this test is shown in Fig. 4. Fig. 4(a) is cooling without frame, and Fig. 4(b) is with frame. The height of the nozzle from the roller table is 1.7 m, so there is a lot of water splash from the plate surface in the case of cooling without frame. On the other hand, the splash was limited with the retained water in the frame as can be seen in Fig. 4(b).

From Fig. 4, it can be seen that the retaining water absorbs the kinetic energy of the dropping water, so the retaining water decreases the water splash and the pressure of the dropping water at the plate surface.

Fig. 5 indicates the effect of frame height and nozzle height on pressure at the plate surface right under the nozzle. The pressure was measured with a pressure gauge which was attached under the plate. According to this figure, the pressure on the plate becomes high as the frame height decreases in the case of constant nozzle height or as the nozzle height is raised in the case of constant frame height. In addition, the effect of these factors becomes smaller with the increase of retained water or nozzle height.

Table 1. Experimental condition.

| Pipe nozzle | Diameter | Height | Nozzle spacing | Header spacing |
|-------------|----------|--------|----------------|---------------|
| Water flux  | 1 - 4 m³/min m² |
| Height of frame | 50, 100, 150 mm |
| Temp. of plate | 500 - 800 °C |
| Temp. of water | 38 - 0.5 °C |
| Specimen (Steel plate) | Size | 150x300x5000 |
| Velocity | 1 m/s |
| Carbon content | 0.04 - 0.06 % |
| Slit nozzle | Slit gap | 24 mm |
| Height | 1700 mm |

4.2. Cooling Test

Fig. 6 shows the effect of frame height on the
ability of pipe nozzle cooling when the nozzle height is constant. According to this figure, the mean temperature drop reaches its maximum when the frame height is 50 mm. This means that an adequate amount of retaining water resulted in maximum cooling ability. In the region of large frame height, it is supposed that decreasing mean temperature drop and increasing water retention can be related by decreasing the pressure on the plate surface. It is also considered that this decrease of mean temperature drop without frame is caused by the water splash.

Fig. 7 shows the dependence of plate temperature on the cooling ability, under the condition of with and without frame, respectively. As shown in this figure, there is a small difference between the mean temperature drop, with and without frame, when the plate temperature is low. But at high temperatures, the temperature drop with frame is greater than that without frame. From this fact, it is clear that the effect of the retaining water on the cooling ability depends on the plate temperature.

The effect of nozzle height on the cooling ability with and without frame, is shown in Fig. 8, respectively. Since the splash of water on the plate becomes more as the nozzle is raised, the cooling ability without retained water decreases with raising nozzle, as was reported in other studies.\(^9,15\) In this test, however, the mean temperature drop with retained water increases slightly and converges to a certain value when the nozzle is raised. This slight increase occurs, not only from the decrease of splash due to the retaining water and the raise of water pressure at plate surface but also, from the increase in stirring of retaining water due to the raising of the nozzle. From the above results, it is indicated that the nozzle height should be designed higher than 1.7 m so as to increase the cooling efficiency.

Fig. 9 shows the effect of flow-type on the cooling ability with retaining water. The flow-types are laminar and turbulent. According to this figure, at low plate temperatures, the temperature drop of laminar flow is greater than that of turbulent flow, though there is no distinct difference between these two flow-types at high plate temperatures. It is generally said that the laminar flow has a larger cooling ability compared with the turbulent flow.\(^16\) However, in this
laboratory cooling test with retaining water, the cooling ability at high temperature is independent of flow-type as shown in Fig. 9.

5. Discussion

The experimental results were examined to clarify the effect of flow-type on the cooling ability.

The dropping point of laminar flow is almost constant, while that of turbulent flow varies, so it is considered from Fig. 10 that the degree of stirring water and the pressure of laminar flow at plate surface is larger than those of turbulent flow. It was thought that, at low temperatures, the difference in the cooling ability between the flow-types depended on the difference in the degree of stirring water and water pressure at plate surface, so a new experiment was carried out as shown in Fig. 11. In this new experiment, the temperature drop was investigated when the direct pressure of dropping water was lowered, by using a frame in which a filter was set in the middle of frame height, and by lowering nozzle height to 0.4 m.

Fig. 11 shows the data obtained from these experiments on cooling ability and is compared with the cooling ability in normal condition. According to this figure, the temperature drop with the filter is nearly equal to that without the filter in high plate temperatures. However, the temperature drop with the filter is much smaller than without the filter when plate temperature is low. The temperature drop with filter is also much smaller than that without frame at low temperatures.

Consequently, it can be confirmed that the stirring of retaining water and the pressure of dropping water at low plate temperatures have a great influence on the cooling ability. Fig. 11 also shows a very important result that a large cooling ability at high plate temperatures could be obtained by using only retaining water. In addition, the results from Fig. 11 agree well with those in Fig. 7.

From the above results, a cooling model with retaining water is explained as follows:

At the point right below the nozzle, in the case of without retaining water, the water pressure is higher than that with the water. But with retaining water, the pressure around the point is higher and the retaining water is stirred. Accordingly, as shown in Fig. 12(a), in the case of high plate temperature and without the water, it can be concluded that cooling is carried out almost only right below the nozzle (the black point), that is, cooling is very little around the point.

On the contrary, in the case of with retaining water, cooling is less at the black point, but when compared with coolings without the retaining water, it is greater around the point, as shown in Fig. 12(b), so that the total cooling ability with water is larger than that without water. When the plate temperature is low, since the cooling ability without water around the black point is also extremely high, the total ability with water is almost equal to that without water.

Finally, the cooling ability of slit nozzle flow with a large gap is presented in Fig. 13 and is compared with the cooling ability of the pipe nozzle. In this series of experiments, there is no data of pipe nozzle cooling with retaining water. So, an estimated value from the data of cooling without the retaining water is shown. According to this figure, distinct differences of cooling ability between these types of nozzles can not be seen at low flow rates.

However, the cooling ability of pipe nozzle flow becomes much larger with an increase of flow rate, while the cooling ability of slit nozzle flow does not
increase much at high flow rates. Namely, this figure also shows that slit nozzle flow has less cooling efficiency when water flow rate is high.

6. Conclusion

The effect of the retaining water on the cooling ability of a pipe nozzle flow has been studied. The results obtained are summarized as follows:

(1) The cooling ability of pipe nozzle flow reaches its maximum when the depth of the retaining water is approximately 50 mm. It can be estimated that the decrease of the cooling ability when the depth is less than and more than 50 mm is due to the increase of water splash and the decrease of water pressure at the plate surface, respectively.

(2) The cooling ability with the retaining water increases slightly as the nozzle is raised, while the cooling ability without retaining water decreases with the increase of the nozzle height.

(3) The slit nozzle flow with a large gap has less cooling efficiency than the pipe one in the high water flux, though no difference can be seen when the water flux is low.

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