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[33] Japan
[31] 43/17873

[50] Field of Search..... 72/201,
200, 202; 266/6 S, 314; 134/122; 148/156, 143,
131

[56]

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[54] **METHOD FOR COOLING THICK STEEL PLATES**
6 Claims, 7 Drawing Figs.

[52] U.S. Cl..... 148/143,
148/153, 266/6 S, 72/202
[51] Int. Cl..... B21b 27/06

ABSTRACT: Method for cooling thick steel plates such as slabs and thick plates, while they are not on the rolling lane just after being hot rolled, by showers of cooling water supplied at a rate of 0.1 to 0.6 m.³ per m.² of the plate per minute simultaneously over the top and bottom surfaces thereof.

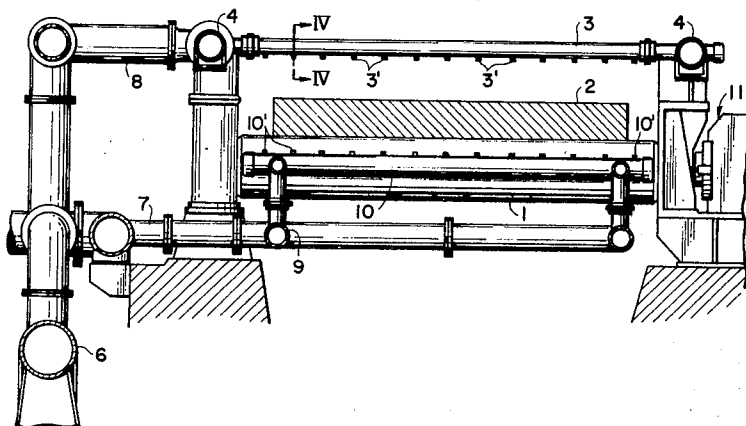


FIG. 1

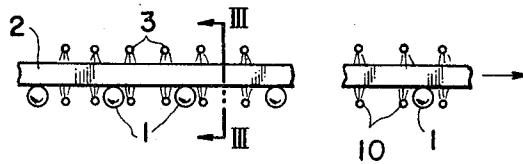


FIG. 3

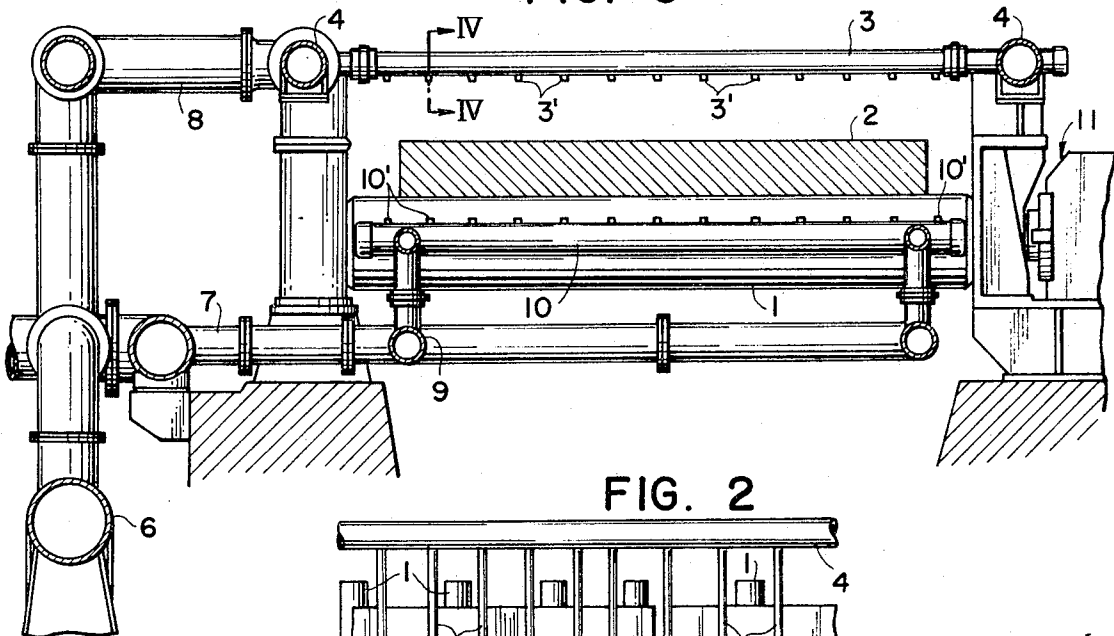


FIG. 2

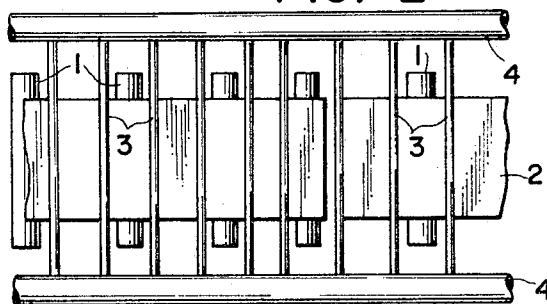
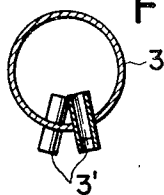


FIG. 4



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FIG. 5

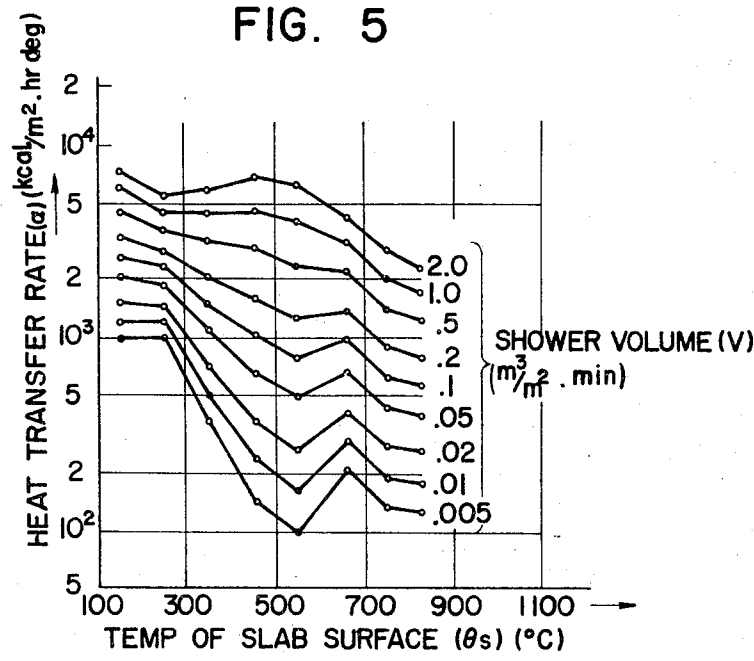


FIG. 6

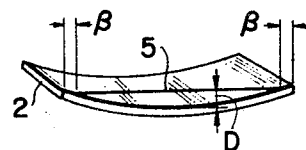
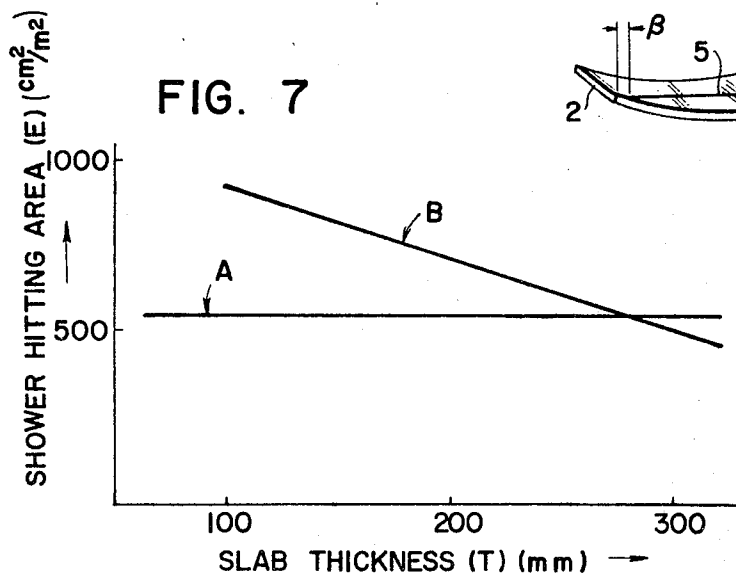


FIG. 7



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METHOD FOR COOLING THICK STEEL PLATES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method for cooling steel materials which are hot after being hot rolled, particularly thick slabs and plates (hereafter called "thick steel plates").

2. Description of the Prior Art

It is publicly known that there are two methods for cooling steel materials which are hot after being hot rolled to room temperature, that is, water-cooling and air-cooling methods.

Thin sheet steel such as a strip can be cooled on the same rolling line merely by water supplied from the showering system, hardly causing deformation.

However, such showering tends to cause warp of hot-rolled steel materials as they get thicker. As for steel plate of for instance about 80 mm. thick, such special device as use of showers of atomized water is necessary to cool as evenly as possible over the whole surface thereof. Without such device, it is difficult to cool the plate without deformation such as warp; in which case, therefore, it is necessary to press both the top and the bottom sides by a press or rolls, while it is cooled.

The warped plates lie one upon another in subsequent processes, say, in the heating furnace, which causes such troubles as being caught before being taken into the subsequent rolling mill. Therefore, it is desirable to reduce the production of warped steel plates to the minimum.

In order to prevent warp production in cooling steel slabs of, say, more than 50 mm. thick, there are no other ways than the above-mentioned cooling while the material is pressed and the conventional air-cooling and water-cooling methods. The first method requires a large investment in equipment. Cooling of thick steel plates is carried out in most cases by the conventional air-cooling method. Such cooling, however, is so inefficient as to take a long time, for instance, 9 to 10 hours to lower the temperature of a slab 190 mm. thick, 940 mm. wide and 9 meters long from 1,000° to 150° C. To shorten this time requires large equipment and a wide cooling site at great investment cost, constituting financial and operational disadvantages of this method.

SUMMARY OF THE INVENTION

An object of the present invention which is made as a result of various research efforts to solve troubles arising from cooling of thick steel plates, is to provide a method for water cooling thick steel plates, by which warp production of such plates can be reduced, by controlling the supply of cooling water to the volume appropriate for such cooling, thus eliminating the need for the pressing equipment.

Another object of the present invention is to provide a method for water-cooling high-temperature slabs or thick steel plates about 50 mm. thick or more which are hot just after hot rolled, on the hot-rolling line, in a short time by showers cooling of water with almost no such deformations such as warp.

In order to obtain these objects, the present invention provides for showering cooling water at a rate of 0.1 to 0.6 m.³ per m.² of thick steel plate per minute at a pressure of more than 0.8 kg./cm.² simultaneously over the top the bottom surfaces of the thick steel plate with a shower hitting area of more than 0.05 m.²/m.².

BRIEF DESCRIPTION OF THE DRAWINGS

The following is brief description of attached drawings:

FIG. 1 is a side view of an embodiment of the apparatus for use in accordance with the present invention.

FIG. 2 is plan figure of the apparatus of FIG. 1.

FIG. 3 is detail cross-sectional view of the apparatus of FIG. 1 along the line III—III.

FIG. 4 is cross-sectional view of the cooling water supplying pipe of FIG. 3 along the line IV—IV.

FIG. 5 is a graphic illustration of the relation between temperature of slab surface and the heat transfer rate:

FIG. 6 is perspective view of the measurement of warp of the thick steel plate.

FIG. 7 is a graphic illustration of the relation between thickness of the thick steel plate and shower hitting area thereon.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The following is an explanation of the present invention using one preferred embodiment with reference to the attached drawings.

FIGS. 1-4 show one embodiment of a cooling apparatus which may be used in accordance with the present invention, in which a slab 2 which is hot just after being hot rolled, is placed on rollers 1 to be conveyed, and water is sent through a pipe 4 and 9 to cooling water supplying pipes 3 and 10. While the slab is conveyed by the rollers 1 in the direction of the arrow or while it stops at appropriate intervals, the slab 2 is cooled by water jetted from said cooling water supplying pipes 3 and 10 over both the top and the bottom surfaces. Unless the slab 2 is cooled over both surfaces, it warps so as to become unusable.

Explaining more detailedly according to FIG. 3, cooling water sent through the main pipe 6 is branched at an appropriate place to lower cooling water pipes 7 and upper cooling water pipes 8, and is then sent to cooling water forwarding pipes 4 and 9 which extend in the direction of the movement of the slab 2 on the apparatus. An appropriate number of upper cooling water supplying pipes 3 and lower cooling water supplying pipes 10 branched respectively from the cooling water forwarding pipes 4 and 9 are arranged across the slab 2 on the roller table 1. Said cooling water supplying pipes 3 and 10 are equipped with a great number of nozzles 3' and 10'. By using such equipment, the high temperature slab 2 is rapidly cooled to the desired temperature.

In this case, it is necessary to have cooling water supplying pipes 3 and 10 with nozzles 3' and 10' provided in such a number as is sufficient to cover the entire surfaces of slab 2. 11 indicates the device for driving the roller table 1.

According to the present invention, it is preferred to be able to cool the slabs while they are standing still, but in the case where the space for the cooling line is limited so that the front part or the rear part of the slab 2 is over the end of the cooling zone, it is necessary to cool the slab as it is moved forward or backward; and in the case where a large area is available for the cooling line, cooling can be carried out while the slab 2 is moving forward very slowly.

FIG. 4 is cross-sectional view of the cooling water supplying pipe shown in FIG. 3 along the line IV—IV, illustrating the relation between the cooling water supplying pipe 3 and nozzles 3'. As shown in the figure nozzles of one group are arranged zigzag at a certain angle from an adjacent group.

In order to develop a cooling method by which no warp of the slab 2 is caused in the operation of the above apparatus, the following study was carried out:

FIG. 5 illustrates the relation between surface temperature (θ_s) (°C.) of the slab 2 (along the horizontal axis) and heat transfer rate (α) (Kcal./m.², hr. deg.) along the vertical axis, varying according to the change of graduation and volume of cooling water supply (V). It is proved by the graph that in general the higher the surface temperature of the slab (θ_s), the lower the heat transfer rate (α).

As is clear its dimension, heat transfer rate (α) is the function of cooling, that is, the higher the heat transfer rate (α), the greater the cooling effect.

At a cooling water supply rate of 0.05 m.³/m.²/min., and in case the surface temperature (θ_s) of the slab is more than 250° C, the heat transfer rate (α) falls abruptly. This is because water drops stay on the steam layer produced over the surface of metal when the temperature of said metal is very high, but the drops reach the metal immediately when the temperature is below the critical point, which is generally called "Leidenfrost point." The above phenomenon takes

place due to the Leindenfrost point of water drops located around 250° C.

At a cooling water supply rate of more than 1 m.³/m.²/min., the heat transfer rate (α) does not fall abruptly, but decreases gradually, even though the surface temperature (θ_s) of the slab 2 has risen. This is because the large volume of water and the great difference between the saturation temperature of the water and its actual temperature, cause water drops to be purged from the surface of the slab 2 before or immediately after their temperature has reached saturation temperature, thus making difficult boiling of the water for the production of a steam layer and raising the heat transfer rate (α) very high. But, in case the volume of water (V) is small, and in case the surface temperature (θ_s) of the slab 2 is above 500° C., the water drops are nearly completely in the state of layer boiling, therefore, at a rate of 0.005 m.³/m.²/min., the heat transfer rate (α) is $1 \approx 2 \times 10^2$ Kcal./m.², hr.deg., thus producing a very poor cooling effect.

Also, in case the volume of cooling water (V) is small, and at a surface temperature (θ_s) of the slab 2 between 500° and 700° C., the heat transfer rate (α) reaches a peak, that is, it stays lower between 500° and 600° C., and rises when the temperature is between 600° and 700° C.,

This reflects an error caused by handling the transformation point of the heat capacity of the steel including the transformation point, which in equilibrium is so large as to be around 750° C., but when cooling steel, the temperature for releasing the transformation point is excessively on the side of a low temperature. On the contrary, in FIG. 5, the temperature-heat capacity curve is in equilibrium. Therefore, within a range of the surface temperature (θ_s) of the slab 2 between 600° and 700° C., transformation heat is assumed to have been released, thus raising heat transfer rate (α). Within a range between 500° and 600° C., however, the reverse phenomenon occurs, that is, the heat transfer rate (α) is lowered.

Meanwhile, in case the volume of cooling water (V) is large, the surface temperature (θ_s) of the slab 2 is rapidly cooled, thereby making great the temperature gradient, that is, the difference in temperature between within and the surface of the slab 2. For this reason and also because of its high cooling speed, the temperature for releasing transformation heat is excessively low, resulting in the released transformation heat distributed, as a whole, over a wide range of the surface temperature (θ_s) of the slab 2. It is believed that this constitutes the reason that no peak of the heat transfer rate (α) comes about, as mentioned above.

Having studied warp production according to a variety of volumes of cooling water (V), on the basis of the above reasoning, it has been found that, as shown in FIG. 5, when cooling is carried out at a cooling water supply rate of less than 0.1 m.³/m.²/min. where a peak heat transfer rate (α) comes about at a temperature between 500° and 800° C., or according to the method by which the heat transfer rate (α) temperature curve of the whole surface rises abruptly, cooling is carried out unevenly, thereby causing warp.

On the contrary, in the case of cooling with showers at a rate of more than 0.1 m.³/m.²/min. where the heat transfer rate (α) changes gradually and shows a high value, such cooling has little influence on the transformation point which is one factor of warp production, and it passes through the range around this point so quickly that no warp is produced.

The above-mentioned fact is made clearer by looking at table 1 which summarizes the experiments conducted on 140 samples of slabs each being 130 mm. thick, 1,200 mm. wide and 7000 mm. long showered with cooling water at a rate of less than 0.1 m.³/m.²/min. more specifically, 0.04 m.³/m.²/min., using the apparatus shown in FIG. 3. In this experiment, greater warp than the allowance of 90 mm. was produced as often as 28.6 percent of the time. With warp production beyond this allowance, slabs become unusable. The result of the experiment explains that this volume of cooling water is not sufficient.

TABLE 1

(Number of samples: 140)

size of warp Item	Warp (mm.)			Total
	10-50	51-90	Above 90	
Number	10	90	40	140
Production Rate (%)	7.2	64.2	28.6	100

"Warp" (mm.) of the cooled steel slab (or plate) mentioned in the table is measured, as illustrated in FIG. 6, by the distance (D) to the bottom of the warped slab from the piano wire 5 strained between the points (B) on the slab about 40 mm. inwardly from both ends. The experiment of table 1 was conducted also on the following conditions:

Average temperature of the slab:	1,000° C.
Pressure of cooling water:	1.2 kg./cm. ²
Shower hitting area:	500 cm. ² /m. ²

As for the temperature of slabs after cooled, it was 100° C.

Table 2 shows the result of experiments conducted on samples showered with cooling water at a rate of 0.1 m.³/m.²/min.

TABLE 2

(Number of samples: 176)

Size of warp Item	Warp (mm.)			Total
	10-50	51-90	Above 90	
Number	12	4	3	19
Production Rate (%)	6.8	2.3	1.7	10.8

In the experiment of table 2, greater warp than the allowance of 90 mm. was produced only 1.7 percent, of the time much less than the production rate of table 1.

The experiment of table 3 was conducted on 48 samples of slabs of the same size as those used in the experiments of tables 1 and 2, and by the same method as used in these experiments, and also on the following conditions:

Volume of cooling water:	0.2 m. ³ /m. ² /min.
Pressure of cooling water:	2 kg./cm. ² (G)
Average temperature of slabs:	1,000° C.

As for the temperature of slabs after cooled, it was 60° C.

TABLE 3

(Number of samples: 48)

Size of warp Item	Warp (mm.)			Total
	10-50	51-90	Above 90	
Number	14	6	0	20
Production Rate (%)	29.1	12.5	0	41.6

It can be seen in table 3 that the supply of cooling water at a rate of 0.2 m.³/m.²/min., did not produce warp of more than 90 mm.

As mentioned above, the greater the cooling water supply rate, the less the warp production. This does not necessarily mean that the greater the rate, the better, but the rate of about 0.6 m.³/m.²/min., is best for the purpose, because any greater rate does not influence cooling after saturation. Rather, only the temperature of the cooling water does. In actual operation, the supply of cooling water more than needed results in the necessity of a greater scale of equipment and wasted operation cost and cooling water, thus making the operation uneconomical.

Thus, by controlling the cooling water supply rate, it is possible to cool the slab 2 just after hot-rolled to the desired temperature. In putting this method into practice, however, such things as the layout of nozzles 3' and 10' to cover the top and the bottom surfaces of the slab 2, the shower hitting area (E) which is an area of the surfaces of the slab 2 (expressed in percentage against the whole area) directly hit by cooling water, and pressure of cooling water, should be taken into consideration.

FIG. 7 illustrates the relation between thickness (T) of the slab 2 and the shower hitting area (E) when cooling the slab 2 with showers supplied from the upper cooling water supplying pipes 3 and the lower cooling water supply pipes 10 all of fixed type. As for the shower hitting area (E) it is determined by the distance from the surface of the slab 2 to the nozzles 3' and 10' and the spreading angle of a jet of cooling water from the nozzles 3' and 10'; and when it is so determined, the required number, positions and layout of the nozzles will be determined.

In this FIGURE, the straight line (A) indicates the minimum shower hitting area (E) of the bottom surface of the slab 2, which is determined irrespective of the thickness (T) of the slab 2; if this value is below 530 cm.² per m.² of the slab 2, that is, below 5.3 percent of the slab 2, uneven cooling takes place, causing warp. This process applies also to the top surface of the slab 2.

Regarding the top surface, however, if the thickness (T) of the slab 2 on the roller table 1 changes, and if the nozzles are of fixed type, the distance between the surface of the slab 2 and the nozzles 3' or 10' changes accordingly, such tendency being reflected in the inclination formed by the straight line (B), which means that the slab of greater thickness takes a smaller shower hitting area (E) and vice versa.

Since these values are so changeable, the principles that the shower hitting area (E) of respective top and bottom surfaces of the slab should be at least 500 cm.², more preferably more than 530 cm.² per m.² of each surface, and that the shower hitting area (E) of the top surface should be the same as or slightly smaller than that of the bottom surface, will not be effective for even cooling.

According to experiments, it has been found that a slab 2 of less than 100 mm. thickness is subjected to upward warp because the shower hitting area (E) of the top surface is much larger than that of the bottom surface. Therefore, with the apparatus for actual use, it is important that the position of the cooling water supplying pipes 3 should be so devised as to be adjustable according to the thickness (T) of the slab 2, to make constant the distance between the surface of the slab 2 and the end of nozzles 3' and 10' and that nozzles 3' and 10' should be so designed and arranged that the shower hitting area (E) takes the above value.

While cooling water supplied over the bottom surface of the slab 2 leaves it soon after hitting, cooling water supplied over the top surface stays or runs thereon, thus resulting in the dif-

ference in cooling effect. Therefore, it is necessary to make the cooling water supply rate for the top surface smaller than that for the bottom surface, to make up such difference.

Particularly over the top surface of the slab 2, there is formed a layer of steam generated from the supplied cooling water, such steam layer greatly reducing the cooling effect. A jet of cooling water from the nozzles 3' and 10' should be provided with a pressure sufficient to break up the steam layer, that is, 0.8 to 0.9 kg./cm.² in most cases, more preferably more than 1 kg./cm.² (G). If such considerations as the arrangement of nozzles 3' and 10' and pressure are made, as mentioned above, cooling with showers of cooling water at a rate of 0.1 to 0.6 m.³/m.²/min. will cool the high-temperature slab 2 to room temperature rapidly without warp.

The above description refers to cooling with showers of cooling water supplied exclusively over the top and the bottom surfaces of the slab 2, but showering over the sides of the slab 2 which is very thick, is not beyond the scope of the present invention.

In the above experiments slabs were made. As slabs are semifinal products, and may be again heated after being cooled, the cooling method of the present invention can be applied thereto irrespective of their thickness. However, final product steel plates, even if they are thick or medium thick, may be subjected to a change in quality as cooling tends to harden unless the slabs are as thick as about 50 mm. or more. Therefore, according to the present invention, the cooling is of steel plates of a thickness of about 50 mm. or more.

What we claim is:

1. A method for cooling hot-rolled steel plates having a thickness of more than 50 mm. which comprises cooling said plates by showers of cooling water supplied at a rate of 0.1 to 0.6 m.³ per m.² of said plates per minute simultaneously over the top and bottom surfaces thereof.

2. Method according to claim 1, wherein said cooling is carried out so that the shower hitting area of said top and bottom surfaces is more than 0.05 m.² per m.².

3. Method according to claim 2, wherein, said cooling is carried out so that the shower hitting area of said top surface of the thick steel plate is slightly smaller than that of said bottom surface.

4. Method according to claim 1, wherein said top surface of the thick steel plate is cooled with a smaller volume of cooling water than said bottom surface.

5. Method according to claim 1, wherein said cooling is carried out with said showers supplied at a pressure of more than 0.8 kg./cm.² over said top and the bottom surfaces.

6. A method for cooling hot-rolled steel plates having a thickness of more than 50 mm. which comprises cooling said plates by showers of cooling water supplied at a rate of 0.1 to 0.6 m.³ per m.² of said plates per minute at a pressure of more than 0.8 kg./cm.² evenly and simultaneously over the top and bottom surfaces thereof with a shower hitting area of 0.05 m.² per m.².

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