Development of Induction Heating Device for Corner of Bloom in Continuous Casting machine

～Consideration of high efficiency induction heating system～

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Abstract

Recently, special steel, mainly produced through bloom casters, is indispensable material that maintains the leading technologies of Japanese manufacturing industry. One of the biggest problems in casting of special steel is surface crack in corner. We, Nippon Steel & Sumikin Engineering Co., Ltd., has developed induction heating device for corner of bloom. This device can raise the temperature at corner of bloom during straightening, reduce the corner crack of bloom, and consequently, minimize the cost for scarfing of surface cracks in later process. In this paper, the features and effects of this device are discussed.

Key word : heating system of corner, surface crack, straightening band, corner of Bloom

1 Introduction

Special steel is indispensable for manufacturing crank shafts, bearings, and other components critical to the performance and safety of automobiles. In addition, it influences the workability, a key factor of the manufacturing cost reduction of final products and components. Thus, special steel plays an important role in forming the basis of Japan’s manufacturing industry remaining competitive. The special steel manufacturers in Japan have continuously conducted joint development projects with automobile manufacturers in which the processing costs and product weight have been reduced by performing processes necessary for the used material to render the finished product quality close to perfection. Amid this, in pursuit of higher-quality blooms and billets as strongly demanded by special steel manufacturers, Nippon Steel & Sumikin Engineering has developed innovative manufacturing technologies of blooms and billets in cooperation with special steel manufacturers and put those developed technologies to practical use.

Figure 1 shows the challenges in quality required to be solved for improving the quality of special steel, and the corresponding technologies that we possess. One of these targets is the reduction of cracking on bloom surfaces. When using a vertical-bending type or circular-arc type continuous casting machine, blooms, which are in the shape of an arc, need to be straightened at the straightening band. During that process, the temperature at the corners of each bloom rapidly drops before the bloom reaches the straightening band, becoming brittle due to ferrite precipitating in the grain boundaries. For this reason, when the bloom is straightened, a tensile strain is produced in the area inside the L shape (Loose side) of the bloom, resulting in corner cracking. If a crack is formed as such, the surface repair in a subsequent process or discarding the bloom for reprocessing is required for the boom, causing an increase in the production cost. In order to prevent the occurrence of such cracking inside the L shape of a bloom during straightening of the bloom, there is a method involving heating the bloom before straightening it to raise the temperature, thereby avoiding the bloom from being straightened within the embrittlement temperature range. Using technology to heat bloom corners inside the L shape, we have developed a highly efficient induction heating device with a simple structure. This paper outlines the newly developed induction heating device for heating bloom corners and the development procedures undertaken.

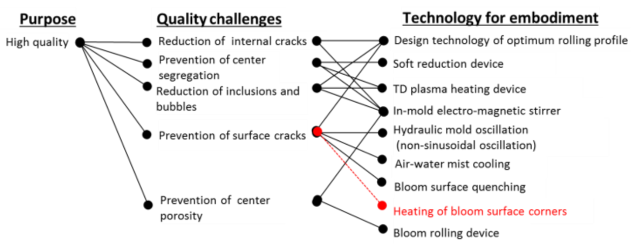


Fig. 1: NSENGI technology of continuous casting machine for special steel

2 Outline of the Bloom Corner Heating Technology in Continuous Casting

2.1 Mechanism of corner cracking

In the case of a vertical-bending type or circular-arc type continuous casting machine, the temperature at the corners of a bloom in the straightening band does not exceed the range between 600°C and 900°C,[1] which falls within the temperature range in which blooms become brittle. For this reason, a tensile strain from the straightening acting on the corners of the bloom at the corner causes corner cracking if the bloom is a steel type highly susceptible to stress cracking. One of the countermeasures against this is to set a heating device before the straightening in order to increase the temperature of the corners at the L shape during the straightening. This method can raise the corner temperature at the L shape beyond the embrittlement temperature range, thereby preventing corner cracking.

2.2 Major tasks in developing the corner heating device

Figure 2 shows the characteristics required for a corner heating device to be set in a continuous casting line facility and development challenges. As shown in the figure, reductions in the capital investment and running costs, easy maintenance, and downsizing are required for a heating device used in a continuous casting line. Given this, in order to put a heating device into practical use, realization of (1) a simplified structure and (2) high efficiency are required.

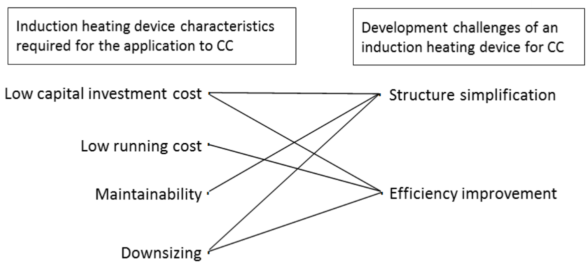


Fig. 2: Demand and corresponding targets for development of induction heating device

3 Development of the Induction Heating Device for Heating Continuously Cast Bloom Corners

3.1 Consideration on the heating device specifications

(1) Induction heating method

Figure 3 shows a comparison between a conventional heating method and the new method adopted for this heating device development. In the conventional steelmaking process, induction heating coils of C-shaped inductor types as shown in the figure have been used for heating steel component corners. Such heating method uses a C -shaped iron core positioned such that it covers the bloom curve corners, through which magnetic flux loops generated pass through the corners via the iron core. Therefore, this method can suppress the magnetic flux leak during heating. However, in addition to the high equipment cost due to the iron core, there is another disadvantage involved in the poor maintainability due to the complicated hardware structure used in this method.

To solve these problems, we have adopted a method using hairpin coils instead of an iron core to achieve a simple structure for the purpose of heating corners inside the bloom L shape alone, which is the location for which heating is required.

(2) Coil winding method[2)]

Figure 4 shows the winding method adopted for this heating method and the temperature simulation results (calculated using the simulation model described later). As shown in the figure, multiple coils are arranged on the top and sides of

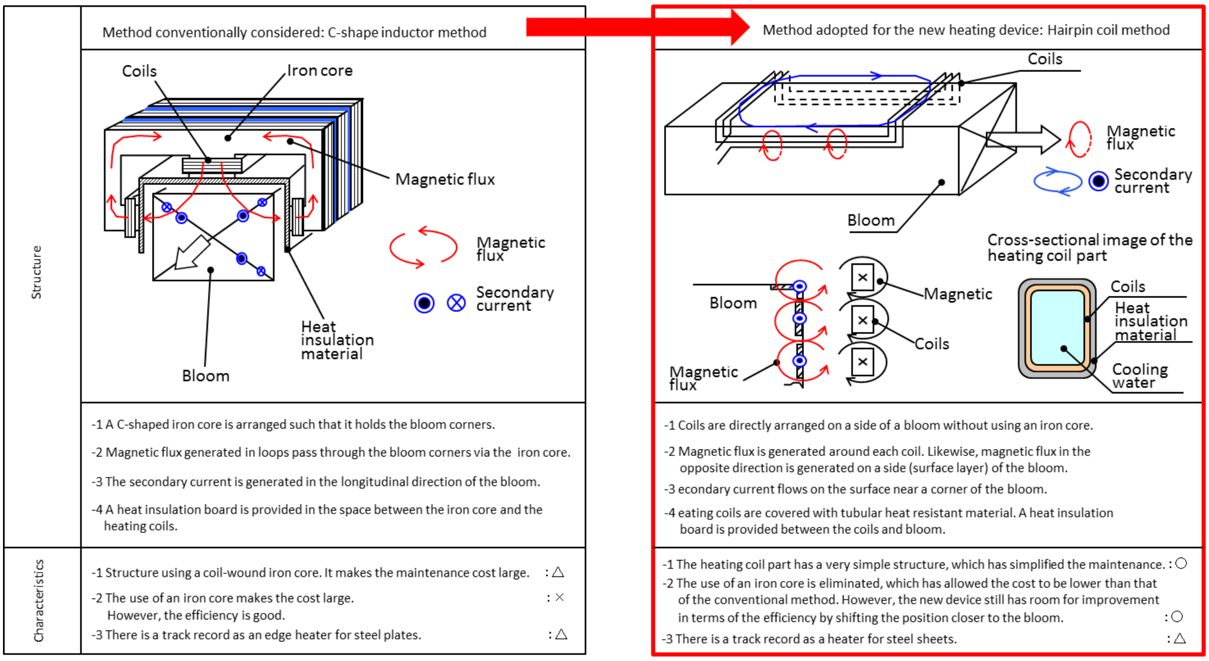


Fig.3: Comparison of heating method

the inside of a bloom L shape, and the coils run alternately passing by the two corners inside the L shape, in a manner of one stroke covering two corners. This winding method allows the electric current to flow in the same direction at the same corner, thereby effectively heating each corner. If each coil stroke covers only one corner as shown in Fig. 4, the electric current flowing inside the L shape and that on the side surfaces are opposite to each other, cancelling the magnetic flux at the corners, thus making it difficult to effectively heat the corners.

(3) Arrangement of coil

1) Study on the simulation model

Before considering the coil arrangement, we designed a simulation model. Figure 5 shows the simulation model. We designed a 3D model involving a bloom and heating coils, the bloom being moved at a constant speed passing under the heating coils, thereby inputting heat. In this model, the amount of input heat was obtained by repeatedly calculating the electromagnetic field and temperature field every minute. Physical properties were calculated taking into consideration the temperature dependency as necessary.

In order to determine the bloom temperature on the side of the coil entry, we used the cross-sectional temperature distribution that was obtained in advance by solidifying state calculation.

2) Confirmation of the simulation model appropriateness by testing with offline heating

To confirm that the analysis model described above was appropriate, we conducted a test in which a dummy workpiece used as a bloom was heated offline as shown in Fig. 6, and the

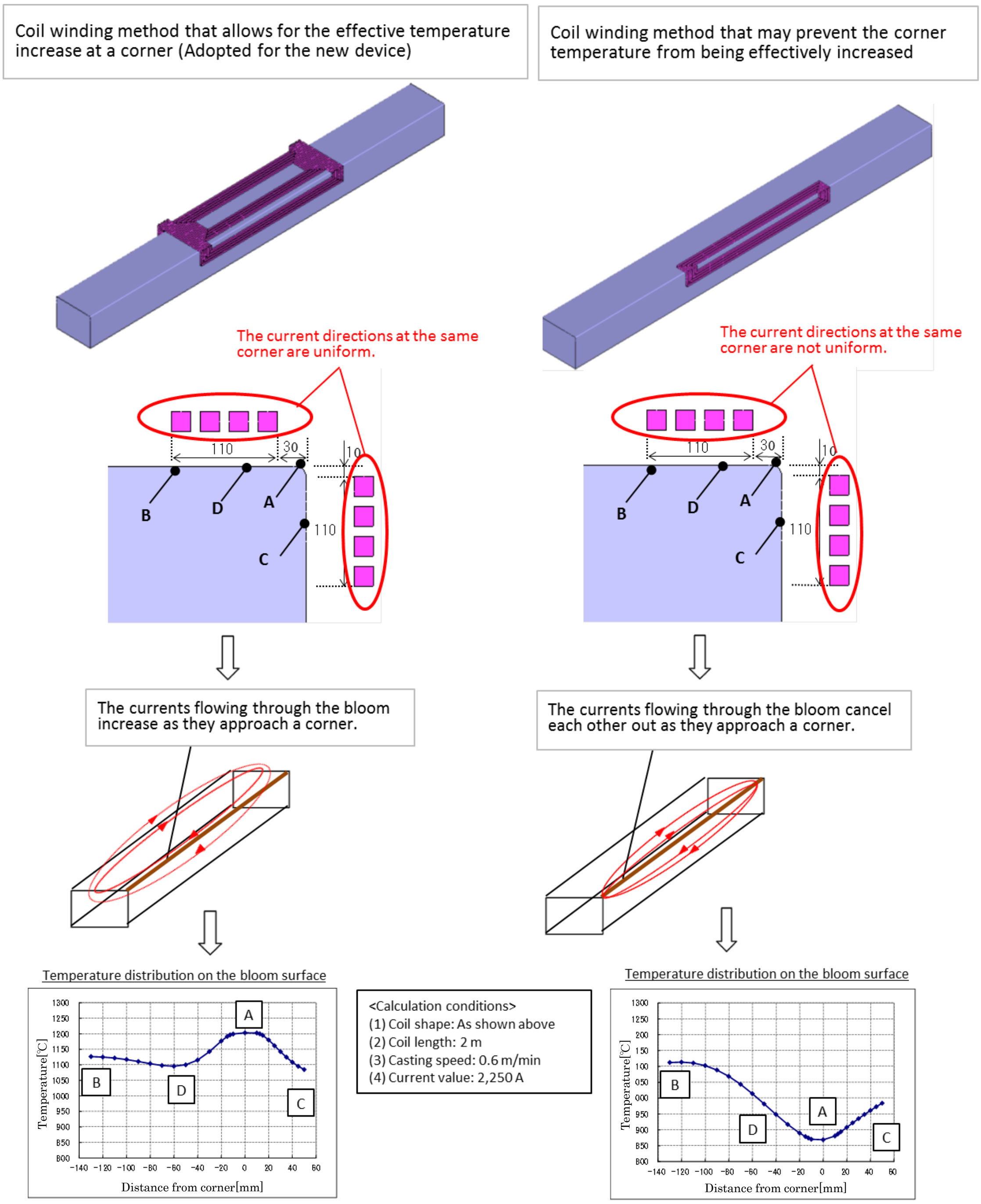


Fig. 4: Wiring method of induction heating device for corner of bloom

temperature increase was checked. Table 1 shows the test conditions. We raised the temperature of the dummy workpiece by moving it at the speed equivalent to that at which the bloom would be moved, and making the workpiece pass under the heating coils. The results of the heating were used to make a comparison with the temperature simulation results obtained under the same conditions. The dummy workpiece was austenitic stainless steel, non-magnetic at ordinary temperatures, aiming to create conditions of actual bloom heating, which takes place at or above the Curie temperature within the non-magnetic region. Figure 7 shows the test results. A thermocouple was used to measure the temperature of the dummy workpiece. As shown in the figure, the difference between the simulated temperatures and measured temperatures was no larger than 30°C at most. Thus, we confirmed that it was possible to estimate the amount of bloom temperature increase using the simulation model.

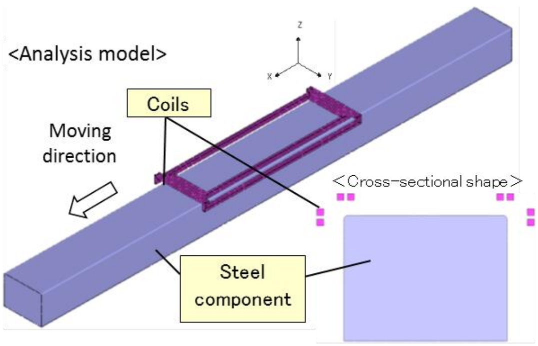


Fig. 5: Simulation model of heating temperature for corner of bloom

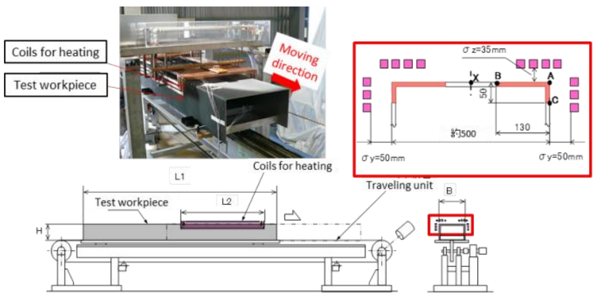


Fig. 6: Outline of heating device for offline test

Table1: Offline test condition

Material of the test workpiece		Austenitic stainless steel (SUS310S)
Test workpiece thickness		5 mm
Test workpiece moving speed		0. 6 and 1. 0 m/min
Heating coil length		1. 5 m
Input power		Approx. 70 kW
Clearance between the test workpiece and coils	Vertical direction	35 mm
	Width direction	50 mm

3) Study of coil arrangement

Using the simulation model for which appropriateness had been confirmed offline, we examined the coil arrangement that could efficiently heat a 50 mm x 50 mm area inside the L shape of a bloom, the target area for heating. Figure 8 shows the initial plan and improved plan of the heating coil arrangement in the cross-sectional direction. Since we found that a coil arrangement that intensely increases temperature at a corner to use the thermal conduction from the corner for raising the target area temperature was efficient, (1) the intervals between coils were shortened and (2) the coils were made closer to a corner. As a result, it was possible to increase the temperature of the target area to the specified value with approx. 88% of the heat input amount of the initial plan.

3.2 Verification of the heating device performance (temperature increase checking through an online heating test)

Furthermore, we conducted a test to actually heat a bloom using the heating device set online. Figure 9 shows a schematic view of the test equipment,[3)] and Table 2 shows the test conditions. The coils were suspended from the upper crossbar of a frame. Considering the warped shape of the unsteady part of blooms, a mechanism for moving up and down the entire frame was provided. A heat-resistant board was set between the coils and a bloom in order to protect the coils from heat. Figure 10 shows the comparison results between the heated bloom and unheated bloom regarding the temperature distribution in the width direction measured in a position where the blooms emerged from the

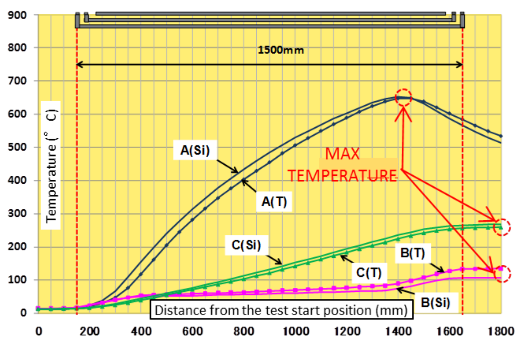
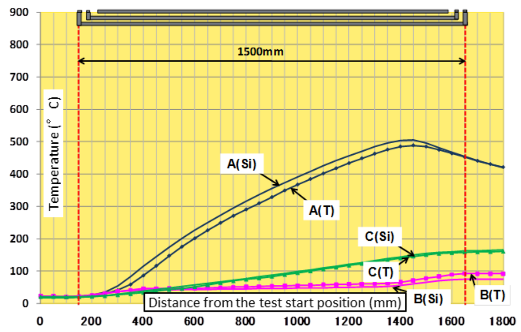
Test workpiece moving speed	0.6m/min	1.0m/min
Temperature history in the longitudinal direction <Graph legends> ※1 A, B and C correspond to the test workpiece positions in Fig. 6. ※2 T: Test result; Si: Simulation result		
Difference between test and simulation values at peak temperature — Point A	-5℃	-16℃
Point B	+28℃	+17℃
Point C	-8℃	-2℃

Fig. 7: Temperature at corner of test work in offline heating test

heating device. As shown in the figure, a scanning radiation thermometer was set to the position where the blooms emerged from the heating device, and the temperature distribution on the inner surface of the L shape of each bloom was measured. As shown in the figure, we confirmed the temperature rise of approx. 50°C in a position 50 mm from a corner using the heating device, over the target temperature. In Fig. 10, it appears that the temperature gradient in the width direction in the vicinity of the corner is larger in the case of the heated bloom than in the case of the unheated type, and the temperature decrease at the corner, therefore, is relatively intense. We assume that this is caused by incorrect measurement of the lower base iron temperature due to the thick scale layer on the bloom surface at the corner. Table 3 shows the thermal balance of the heating device. The heating efficiency (η (%) $= Qs/Qp \times 100$, Qs: Input heat quantity to a bloom, Qp: Input power quantity to a high-frequency power source was about 50%. In this test, with a method using no iron core, heating efficiency equivalent to the C -shaped inductor method was achieved by optimizing the coil winding method and coil arrangement.

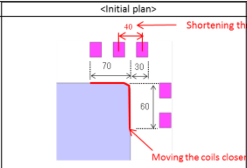
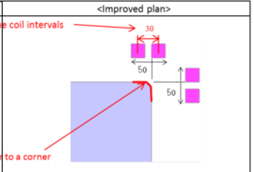
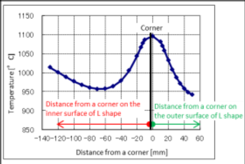
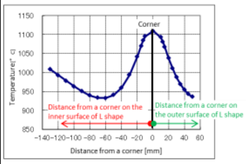
	<Initial plan>	<Improved plan>
Coil arrangement		
Temperature distribution in the width direction		
Input heat amount (kW) ratio required for achieving the target temperature	1	0.88

Fig. 8: Improvement of coil layout in cross section

Table 2: Online test condition

Bloom material		Alloy steel
Casting speed		0.6 m/min
Heating coil length		2 m
Input power		Approx. 300 kW
Clearance between the bloom and coils	Vertical direction	35 mm
	Width direction	50 mm

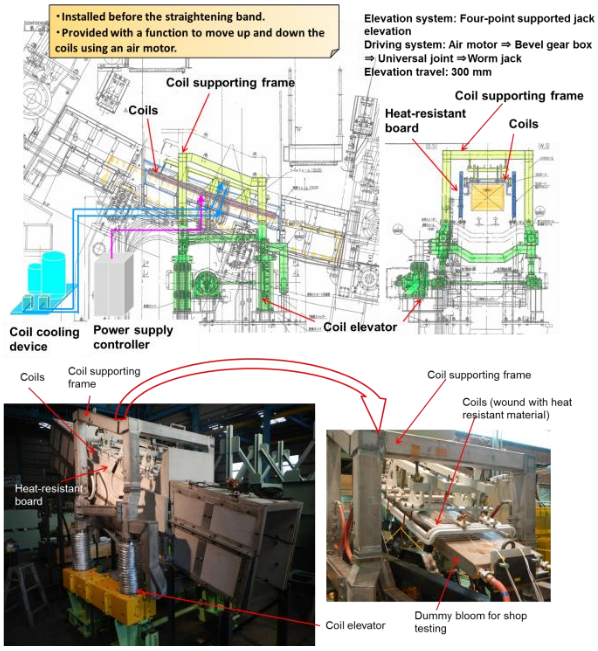


Fig. 9: Outline of heating device for online test

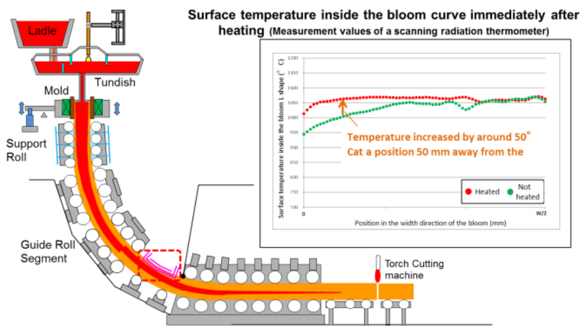


Fig. 10: Temperature at corner of bloom in online heating test

Table 3: Heat balance of heating device

Unit: %

Input heat amount from the power source		100
	Hardware heat loss (coil, power source, feeder, etc.)	49.4
	Input heat amount to the bloom	50.6

4 Conclusion

We developed a simple- structured induction heating device that effectively increases the temperature of corners inside the L shape of blooms, which are likely to sustain cracking. It is possible to prevent corner cracking, one of the major challenges regarding special steel quality, when setting this device online and increasing the temperature at corners before the straightening.

References

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2) Japanese Patent No. 5723660, Cast Slab Heating Device and Cast Slab Heating Method of Continuous Casting Apparatus

3) Japanese Unexamined Patent Application Publication No. 2014-237168, Heating Device of Slab and Heating Method Thereo