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Improvement in Service Life of Continuous Casting Mold

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The body can be viewed from the next page.

Improvement in Service Life of Continuous Casting Mold*

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1 Introduction

With successful commercialization of advanced techniques such as the casting of different steel grades and the high-speed automatic slab width changing,[1] the continuous casting has recently made noticeable progress, raising productivity markedly high.

Further, the hot charging technique by way of high-speed casting has made a significant saving in energy, and a technique for casting hot and defect-free slabs is almost complete aimed at the direct linking of continuous casting with rolling process.[2] All these technological developments have come to place rigid demand on the functional capabilities of continuous casting molds, making their specifications ever more severe.

Kawasaki Steel Corp. introduced the continuous casting in 1968, and the ratio of steel made by continuous casting reached 95.4% in 1985. During these years, technical development has been made for expanding functional capabilities of continuous casting molds and prolonging their service life.

This paper describes the results of the studies on how to extend service life of casting molds.

2 Functions Required of Casting Molds

2.1 Changes of Functional Requirements

Basic functions which are required of casting molds (copper plates assembled with wide and narrow faces) are the following:

(1) No gap shall exist at the corner where wide face meets narrow face.
(2) All surfaces shall be smooth and correct in shape.
(3) Cooling capability shall be sufficient and uniform.

The demand for these basic functions has become severe in degree along with the progress of the continuous casting process. Changes in functional requirements for casting molds accompanying the process

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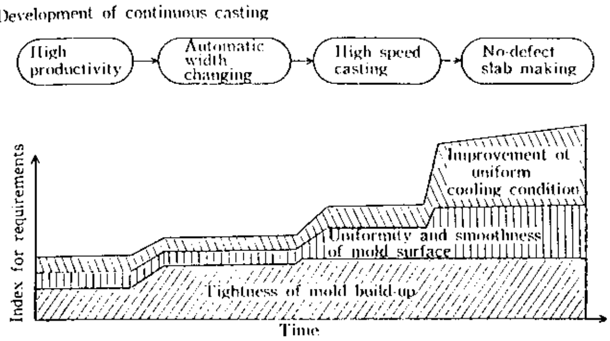

Fig. 1 Development of continuous casting and requirements for mold specifications

development are shown in **Fig. 1**.

At the introductory stage of the continuous casting process a stable casting was necessary first of all. For this reason, it was important to control the movement of the wide and the narrow faces so that they would make no gap between them, since the gap was the main cause of sticking type breakouts by the penetration of molten steel from the gap.

Next, after the automatic width-changing technique was developed, width-change scratches[3,4] occurred on the wide-face surface of the casting mold. These scratches also became the main cause of the breakout, and thus studies on scratch occuring mechanisms and the clamping system were made.

More recently, the practice of high-speed casting and no-defect high-temperature slab making came to raise the temperatures of the casting molds, and this necessitated studies on copper plates which would retain strength even at high temperatures, the development of surface plating as well as the enhancement of cooling power and the development of uniform cooling techniques.

2.2 Function Deterioration Phenomena and Problem Analysis

Figure 2 shows phenomena which occur when major functions required of the casting mold deteriorate. An increase in the gap which itself is one of basic functional deteriorations, and in more concrete terms, an increase in the corner gap due to the width shrinking of the narrow face of the casting mold, or width-change scratches of its wide face, leads to the penetration of molten steel, which then solidifies into fin shapes and constrained, thereby generating a breakout.

Spalling and cracking, namely, the deterioration of flatness of the mold plating, reduces the lubricity between the cast slab and the mold, generating a sticking type breakout.[5] On the other hand, the cast slab surface develops scattered oscillation marks, from which cracks are liable to initiate.

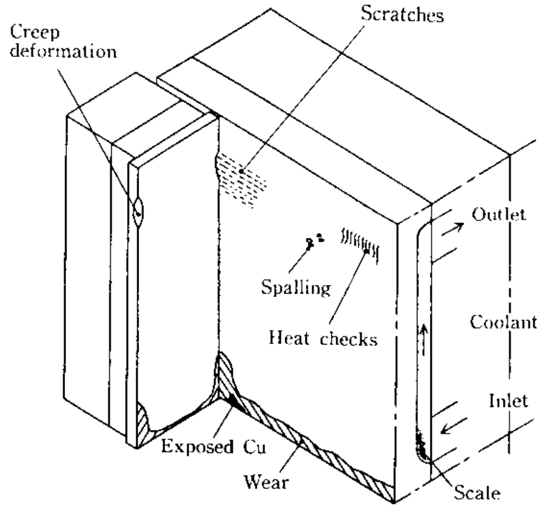

Fig. 2 Typical examples of surface deterioration of mold

When the wear of the lower plating of the casting mold advances, exposing the copper base texture, the copper enters the slab surface by diffusion, resulting in the surface defect called the "star crack," and in the grain boundary embrittlement crack for the Nb-containing steel.

Further, when scale depositions on the water cooling groove of the copper plate or corrosion of its water passage occur, cooling power in the width direction becomes uneven, and the solidified steel thickness becomes non-uniform during the solidification process. When this nonuniformity exceeds certain limits, stress concentration causes a longitudinal crack[6] on the slab surface.

2.3 Basic Concept of Life Prolongation

To achieve life prolongation of the casting mold, it is important to thoroughly clarify the aforementioned function deterioration, and execute function maintenance and improvement measures to cope with these causes of deterioration, with these measures securely followed. Further, to achieve overall long life of the casting mold, it is necessary to clearly establish the replacing standard and to have a diagnostic technique whereby the condition of facilities can be monitored.

On the basis of the above-mentioned concepts, major technical problems with life prolongation can be listed as follows when viewed from the progress of the continuous casting process:

(1) Techniques for preventing the width-change scratch and width shrinking of the narrow face of the casting mold in the case of the automatic width change
(2) Heat-resistance and wear-resistance techniques of surface plating of the casting mold accompanying the trend toward higher-speed casting operation

(3) Casting mold cooling techniques for defect-free and high-temperature slab making
(4) Accurate and comprehensive diagnostic techniques for guaranteeing high quality

3 Casting-Mold Clamping Force Control Techniques

3.1 Background of Development

The life of the casting mold which performs width changes during casting is governed by scratches at the top of the wide face during width changes, and the cost of casting molds accounts for as much as some 30% of the total facility maintenance cost. The scratches also necessitates mold replacing work, which tends to intrude prescheduled casting time, thereby hampering productivity.

Conventional soft clamping system is shown in **Fig. 3**. This system has a possibility of preventing the width-change scratches, if the following conditions are achieved:

$$S > S_n$$

where

$$S_a \geqq S - S_n$$

and

S: Initial set value which permits soft clamping (Fig. 3)
S_n: Width-direction elongation due to thermal expansion of narrow face
S_a: Maximum corner gap permissible under all conditions

In general, S_n is about 0.7 mm (width, 200 mm; temperature, 250°C), and S_a comes to 0.2–0.3 mm in order to prevent the breakout; therefore, S will be 0.7 mm at minimum and 0.9–1.0 mm at maximum.

It was measured[7] that the meniscus surface of molten steel caused sudden boosting of ferrostatic pressure at the time of the casting start and sequential casting of different steel grades and further at the time of casting narrow-width slabs. This pressure spread out the casting mold up to the set value (S); as a result, the corner gap ($S - S_n$) exceeded the allowable value S_a. Therefore, the set value S had to be 0.2–0.3 mm, resulting in the occurrence of width-change scratches at the upper side of the casting mold, as will be mentioned later; and it became necessary to establish a technique which would be able to prevent width-change scratches at all times, under any casting conditions and against any slab width changes.

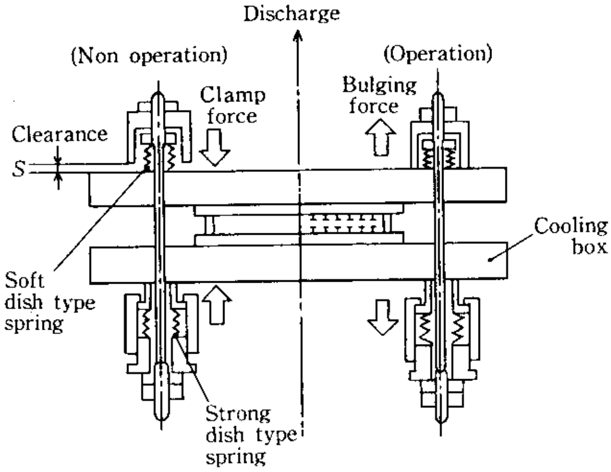

Fig. 3 Original arrangement for soft clamp system

3.2 Development and Features of New Clamp Control System

To meet the aforementioned needs, the authors investigated the process of width-change scratch generation, confirmed the following mechanisms and found out the means of preventing the width-change scratches:

(1) At the time of casting, the narrow face flank develops thermal expansion, its surface pressure against the wide side rises, and the copper plate develops creep deformation. This creep deformation shrinks when cooled, thereby causing the so-called "width-shrinking phenomenon."
(2) As a result, a gap occurs between the narrow and wide faces, permitting the penetration of micrograin molten steel into the casting mold.
(3) This metal is harder than the copper plate, and scratches the copper plate at the time of width changes.
(4) Clamping force is required to exceed ferrostatic pressure at all times, maintain its allowable minimum value, and follow the thermal expansion of the narrow face.

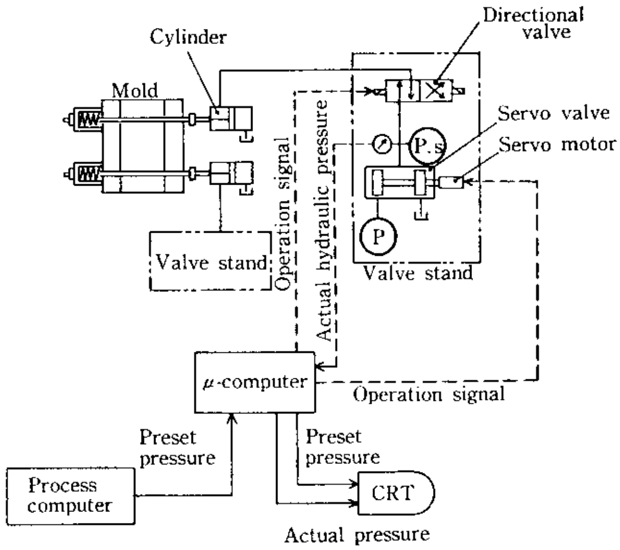

Fig. 4 Schematic illustrations for the arrangement of controlled clamp system

Based on the above-mentioned findings, the authors have developed a system which automatically controls the clamping force continuously according to the operation process and cast slab widths. The system is shown in **Fig. 4**. Features of this system are as follows:

(1) It always maintains clamping force that will satisfy casting conditions.
(2) It controls clamping force according to slab widths and keeps it at an allowable minimum value.
(3) It employs hydraulic control that can follow thermal expansion of the narrow-face widths.
(4) At the time of width changes, ferrostatic pressure decreases; consequently, clamping force is also controlled.
(5) It employs in combination a spring force that will not release clamping force, even if the hydraulic unit develops trouble.

4 Mold Plating Techniques

4.1 Background of the Development

Functions which are required of mold platings include splash resistance, heat-check resistance, spalling resistance, and high thermal conductivity. Particularly, at the lower part of the casting mold, the wear resistance and corrosion resistance of platings are required.

Changes of the mold plating specifications and problems posed at respective times are shown in **Fig. 5**. At the initial period of platings, Cr plating was employed for its wear resistance and splash resistance, but this practice was ceased because its spalling was liable to cause breakout and lead to quality defects.

Next, to compensate for these drawbacks, an Ni-Cr plating was employed which permitted an increase in the plating thickness and possessed excellent adhesion, but this plating posed problems of breakout generation due to the lowering of thermal conductivity and the difficulty in maintaining accuracy control because of uneven wear.

Later, a tapered plating was adopted in which fluctuation factors such as thickness and cooling power were optimized, but the life of the plating at the lower part of the mold was short, thereby requiring more wear resistance. On the other hand, a three-layer plating method (Ni-NiP-Cr)[8], which was called the multicoating method, was used for trial but this type of plating failed to prolong its life in spite of its high price.

Thus, development needs grew stronger for the mold plating which was low-priced and expected to prolong its life, and the authors developed an Ni-Fe method[9] and Ni-W-Fe method[10] both to be mentioned later, and succeeded in their practical applications.

4.2 Development and Features of Ni-Fe Platings

Figure 6 shows hardness distribution of Ni-based platings which contain Fe only and both Fe and W, respectively.

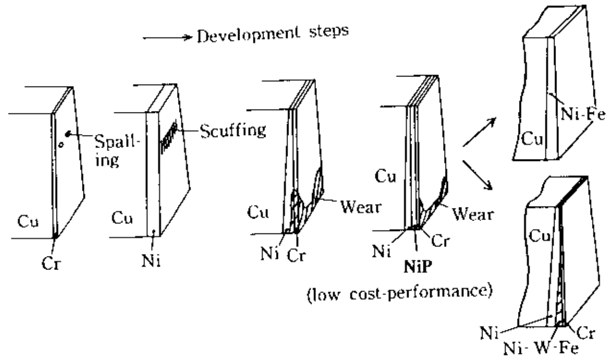

Fig. 5 Development steps of plating specifications on mold surface

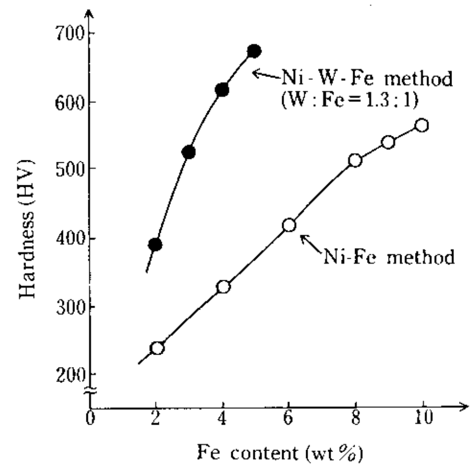

Fig. 6 Relation between Fe, W contents of Ni-based plating and hardness

The Ni-Fe method was developed by paying attention to the fact that when Fe was added to Ni, hardness of the alloy increased, giving high wear resistance. Further, during the process of this development, a tapered plating method[9] was conceived, permitting a decrease in the amount of grinding at the time of machining.

Features of the Ni-Fe plating method are as follows:

(1) Hardness of Ni-Fe plating can be adjusted within the range of HV 250 to 550 depending upon Fe content.
(2) Its high-temperature tensile strength (at 400°C) is 2.5 times that of Ni.
(3) A Single-layered and thick plating is possible, making the cost comparatively low.

4.3 Development and Features of Ni-W-Fe Platings

When W and Fe are added to Ni, plating hardness can be further increased as shown in Fig. 6. The Ni-W-Fe method is an application of this principle and improved heat-check resistance without losing the high-hardness and thick plating, by properly using the splash resistance

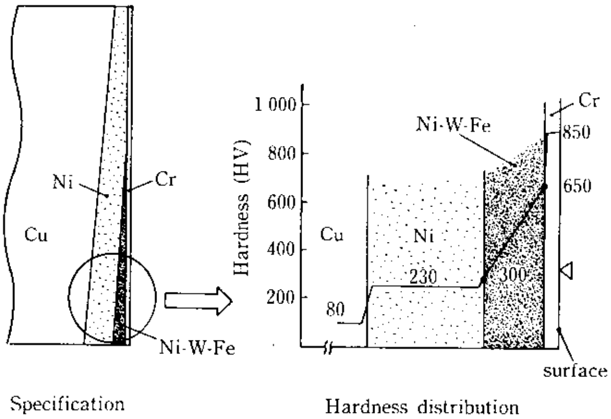

Fig. 7 Examples of plating specifications and hardness

of Cr and by adjusting hardness in the thickness-direction.

Detailed construction example of plating by the Ni-W-Fe method and an example of the hardness distribution in the thickness direction are shown in **Fig. 7**. A thin Ni-Cr plating is incorporated at the upper part of the mold, and an Ni-W-Fe plating is used at the lower part of the mold.

Features of the Ni-W-Fe plating method are given below.

(1) Hardness of the Ni-W-Fe plating can be adjusted within the range from HV 300 to 650 depending upon W and Fe contents.
(2) High-temperature strength (at 400°C) is 1.5 times that by the Ni-Fe method.
(3) Thermal expansion coefficient and thermal conductivity are excellent in the same way as with the Ni-Fe plating.

At Kawasaki Steel, the Ni-Fe plating method is applied to the medium-speed (0.6 to 0.8 m/min) casting mold in which the thermal load at the meniscus is comparatively small, and the Ni-W-Fe plating method with hardness-taper is applied only to the lower part of the high-speed (1.4 to 2.0 m/min) casting mold.

5 Cooling Technique of Mold Copper Plate

5.1 Needs for Improving Cooling Power and Its Improving Techniques

As the casting speed becomes higher, the thermal load to the mold copper plate has increased. Particularly at the meniscus on the narrow face of the mold, the temperature of the mold surface reaches 300 to 350°C. The result is that the narrow face on its way for thermal expansion is restrained by clamping force and develops creep deformation, resulting in width shrinkage by cooling, as mentioned earlier.

As another method to solve this problem, studies for improving cooling power have been taken up. The concrete example of the studies is shown in **Fig. 8**. It indicates the temperature distribution before and after the remodeling by taking the case where the construction of the water-cooling groove adopts the slit type[11] or the bore type.[12]

In the slit type, a spacer was newly installed on the meniscus level, and flow velocity was increased to improve thermal conductivity. In the bore type, auxiliary cooling holes were additionally installed, and heat transfer resistance in the thickness direction was reduced to improve cooling power.

Through these remodeling, the surface temperature of the plating was lowered to 250°C, resulting in the prevention of creep deformation. These techniques were

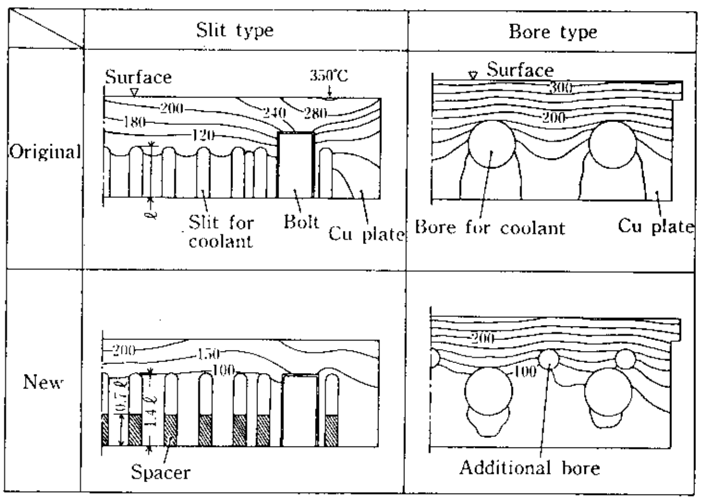

Fig. 8 Comparison of temperature distribution in a horizontal cross section between original and new type molds

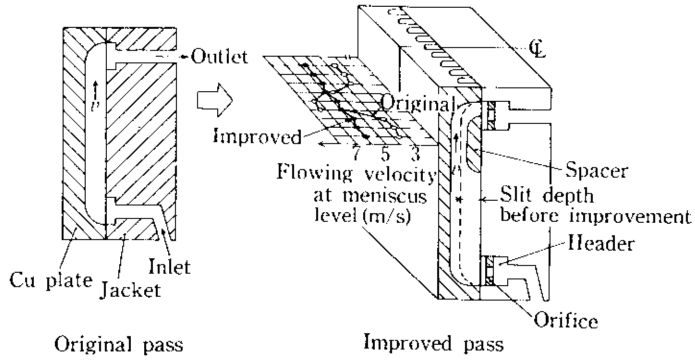

Fig. 9 Improvement of flow uniformity in cooling system

also used in preventing the deformation of the copper plate of the mold wide face.

5.2 Needs for Uniform Cooling and Its Improvement Techniques

In general, cooling water is supplied to copper plates from the header, which is installed at the stationary frame at the back, and passes through the water cooling groove or water cooling hole.

If the flow velocity of the cooling water is nonuniform or the velocity distribution becomes uneven, insufficient heat removal occurs at the location of slow velocity, and then cause a sticking between mould and slab, inducing breakout. This phenomenon is particularly conspicuous during high-speed casting. Uneven cooling also is liable to cause quality deterioration such as the longitudinal cracking of the slab.

Against the above background, the authors took up the task of equalizing the velocity of cooling water, because an uneven flow velocity was found by measuring the flow velocity in casting molds. As a concrete example of measures for equalizing the flow velocity, the sectional structure of the narrow face of the mold before and after the remodeling and the flow velocity are shown in **Fig. 9**.

In the conventional type, velocity at the center in the width direction was found to be about twice as fast. Conceivable reasons for this were that the inlet and outlet ports of cooling water were situated at the center, and that the volumetric capacity of the header at the stationary frame was too small.

In the new type, therefore, the header was remodeled and its volumetric capacity was increased to such a degree that the effects of the inlet and outlet of cooling water could be disregarded. An orifice hole was also newly installed, so that flow velocity would become strictly uniform. As a result, velocity was made virtually uniform even at the meniscus level as shown in Fig. 9.

Further, studies were made on the control operations in maintaining cooling power, a periodical cleaning method of the water-cooling groove of the copper plate was established, and an anticorrosion method was also practiced.

6 Mold Equipment Diagnosis Techniques

6.1 Background of Development

As the measures for achieving the long life of the casting mold, there is an improvement in software in addition to the aforementioned improvements in hardware. The improvement in software mentioned here means application of an equipment diagnosis technique to find out the deterioration of equipment quantitatively, predict mold life up to the allowable criterion, and replace the mold at proper timing just before the criterion is reached. As an example, **Fig. 10** shows the wear quantities of the mold plating before and after the remodeling, together with operating time. The difference between A and B in the figure shows the effect of the hardware improvement on the conventional control level. The difference between C and B shows the length of life prolonged when the equipment diagnosis technique has been established. Therefore, through the use of this diagnosis technique in combination, the effect of hardware improvement can be made more conspicuous.

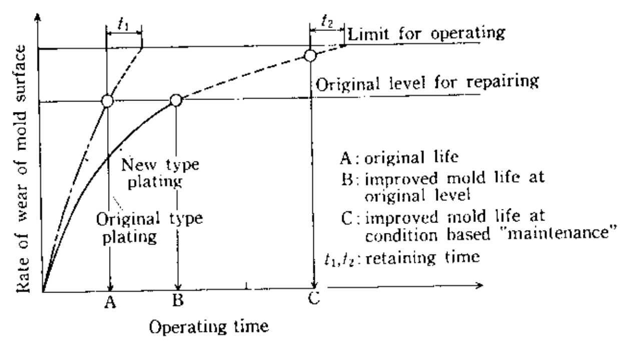

Fig. 10 Example of control technology of mold

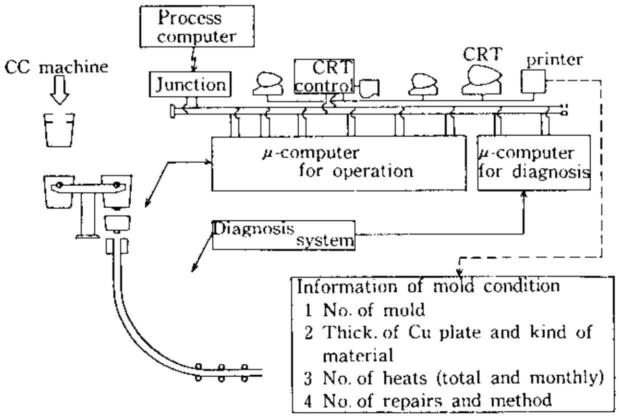

Fig. 11 Computer aided systems of machine diagnosis and maintenance

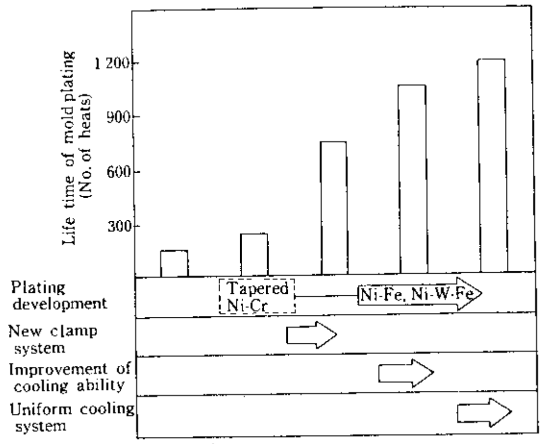

Fig. 12 Change in mold life time

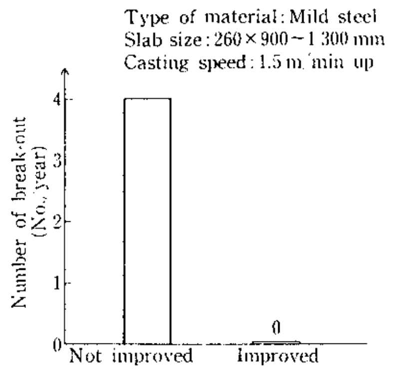

Fig. 13 Comparison of numbers of break-out between after and before improvement of cooling system

6.2 Development of Equipment Diagnosis System

In recent years, due to a small-lot, multi-type steel slab manufacture and the synchronization between continuous casting and rolling processes, changing of casting molds has become more frequent. On the other hand, owing to various using conditions of casting molds, the grasping of the state of each copper plate as to its functioning efficiency requires a great deal of work. Consequently, this task is too difficult to realize, and the prediction of future residual mold life tends to be made on an extremely safer side, thereby inviting a loss.

Now **Fig. 11** shows an example of a system developed and has contributed to the solution of this problem and prolongation of the mold life. This system[13] uses a microcomputer for equipment diagnosis purpose, which is directly coupled to the host process computer, and diagnoses important factors such as continuous casting molds, the slab supporting rolls, and further cooling water. As for the casting mold, the system is possible to predict the wear of the copper plate and analyze its proper life on the basis of the operation data such as the mold using plan.

On the other hand, a diagnosis system of the entire continuous casting system including the operating condition of utility equipment[14] has been developed. This system can collect a great deal of information which is scattered over an wide area and has succeeded in early detection of equipment abnormalities and reduction of the preset water quantity based on data analyses.

7 Effects

As a result of developing and improving the aforementioned various corrective techniques, a variety of beneficial effects have been obtained. Execution time of various concrete examples and the corresponding plating life are shown in **Fig. 12**.

First, the development of the system for controlling clamping force depending upon the casting width eliminated width shrinking due to creep of the narrow face of the mold. As a result, the number of width-change scratches decreased, and the life of the mold in continuous use was increased from 250 heats to 750 heats.

To cope with an increased speed of casting, measures for increasing cooling power was effective. Namely, creep deformation due to an increased thermal load was prevented and the continuous-use life of the mold is now expected to reach 1 050 heats.

As a result of development of the mold plating, the Ni-Fe method and the Ni-W-Fe method were obtained. When these two methods were applied to the continuous casting machine which could fully utilize the feature of the new plating, the life of molds have significantly improved their heats to 1 200.

Next, **Fig. 13** shows the changes in the number of breakout occurrences, when measures combining an increased cooling power and uniformed cooling velocity were applied, taking as examples the number of times of generations of the sticking type corner breakouts under the conditions of 260-mm thick × 900 ~ 1 300-mm wide slabs and a casting speed of 1.5 m/min. From the results of the thermal analysis of uneven degrees of cooling and cooling deterioration, it was verified that the probability of breakout occurrence would become higher under these operating conditions. After corrective measures were taken on the basis of these analysis results, the number of the sticking type breakouts was reduced from 4 times a year to 0 in a comparison for a one-year operation period from pre-modification 1982 to post-modification 1983.

8 Conclusions

The authors advanced the research and development aimed at manufacturing high-quality continuously-cast slabs and prolonging the life of the casting molds, and endeavored to make practical use of the results of the research and development. As a result, the following outcome was obtained:

(1) Through the development and practical application of clamping force control system according to slab widths, width-change scratches during casting were eliminated and the life of the mold plating was prolonged by about three times.

(2) Through measures for increasing and uniforming cooling power, it became possible to eliminate creep-deformation due to the high-temperature rise of the molds at high speed casting, thereby further increasing the life of the mold plating.

(3) An average life of the mold came to extend to 1200 heats as a result of development and practical application of the mold plating by the Ni-Fe method and the Ni-W-Fe method and utilization of the features of these plating methods in suitable continuous casting machines.

(4) Through measures for increasing and uniforming the mold cooling power it was possible to avoid breakouts which were liable to generate during the manufacture of defect-free and high-temperature slabs, thereby achieving stabilized production of high-quality-slabs.

In the future, operation processes are foreseen to change drastically, and new problem are also occurring. The authors intend to investigate these matters as fast as possible and continue studies on the prolongation of the mold life.

Finally the authors would like to express their deep gratitude to the staff concerned of Nomura Plating Co. and also of Koka Chrome Industry Ltd. for all kinds of warm cooperation and assistance extended; the former on the Ni-Fe method of mold plating and the latter on the Ni-W-Fe method both reviewed in this report.

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