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USE OF ELECTROMAGNETIC EQUIPMENT FOR SLAB AND THIN SLAB STEEL CONTINUOUS CASTER

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ABSTRACT

Electromagnetic products drastically improve quality and productivity in continuous casting and ladle refining. ABB supplies:

Induction stirrers and related know-how for ladle furnaces.

Full range of electromagnetic stirrers for billets, blooms and slabs continuous casting.

ElectroMagnetic BRake, EMBR, and Flow Control Mold, FC Mold, reduces the risk of corner cracks, longitudinal cracks, breakouts, quarter-band inclusions, mould powder entrapments and surface defects in slab casting.

Key words: EMS, Clean Steel, Continuous casting, Surface quality, EMBR, MC Mould, FC Mold, ABB, Slab, Thin Slab, Electromagnetic Brake, Casting Speed, Stirrer

INTRODUCTION

ABB has more than 50 years of experience in the field of electromagnetic products, e.g. stirrers, for the steel industry. Through the years extensive know-how has been built up, providing expertise in:

- Selecting the proper equipment for the metallurgical process
- Supplying the most reliable equipment on the market with technical and metallurgical guarantees
- Offering commissioning services for quick start-up of the new process
- Developing new products.

ELECTROMAGNETIC STIRRING AND ELECTRO – MAGNETIC BRAKE FOR CONTINUOUS CASTING

In order to continuously cast high quality steels for demanding purposes electro-magnetic stirring are a must for billets and blooms. Stirring will improve strand quality, reproducibility, yield, production flexibility and productivity. For each application the optimum stirrer choice can be made taking into account the steel grades cast, the strand sizes, reduction ratio, etc. Optimizing the molten steel flow pattern is equally important for slab casting, and here the electromagnetic brake is a successful alternative to stirrers.

Electromagnetic brake, EMBR

Minimills with thin slab casting have quickly become real competition to the integrated mills and today very few integrated mills or conventional slab casters are being built or planned. One of the remaining issues for the integrated mills has been the steel quality, especially in terms of cleanliness and mold powder entrapments. However, this situation has changed with the introduction of the ElectroMagnetic BRake (EMBR) for thin slab casters and today, minimills can effectively compete in terms of cost and quality.

Recent results from thin slab casting at Nucor Steel, Berkeley [1] show that with the EMBR, mold powder entrapments in hot-rolled coils can be reduced by as much as 90 %, all while casting at higher speeds. These quality improvements, coupled with operating costs reductions, for example, increased mold life, has enabled Nucor to compete more effectively with the integrated mills.

Since commissioning of the first CSP plant at Nucor Steel, Crawfordsville, IN, USA, where the first cast took place on June 20, 1989, plant engineering and the degree of automation of all plants which were subsequently put into operation have been systematically and consistently developed further in accordance with market and customer requirements.

At present there are 25 CSP plants in operation worldwide.

ABB has equipped a total of 26 thin slab caster strands with the EMBR. (CSP and also other types of thin slab caster).

In 1999, the production capacity of all CSP plants was 27 million tonnes/year. Up to now, more than 60 million tonnes of hot strip have been produced with the CSP technology (Figure 1).

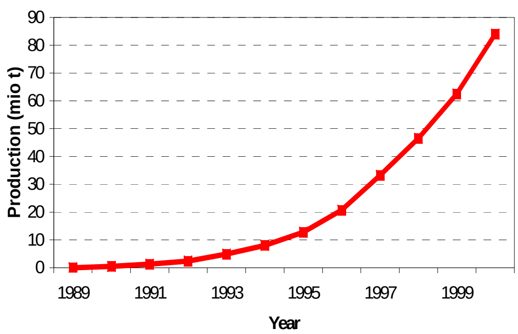

Fig.1. Production of hot rolled coil worldwide with CSP technology.

In spite of the optimized mold and Submerged Entry Nozzle (SEN) geometry which has been adapted to the casting parameters and the steel qualities, the planned increase of the casting speed far beyond 6 m/min and the high throughput rates lead to increasingly unstable flow conditions which might adversely influence the surface quality.

By using the ElectroMagnetic Brake (EMBR) the flow conditions in the mold can be systematically influenced as a function of the casting width, the casting speed, the steel grade, the superheat and the SEN geometry. This means that by using an ElectroMagnetic Brake it is possible to achieve a good and reproducible surface quality within a wide range of casting speeds and steel grades while ensuring a high operational safety.

EMBR function and equipment

Production of steel with high demands on cleanliness requires good control of both chemistry and fluid flow in the continuous casting process. The problem with too high flow speeds in continuous casting and associated problems with non-metallic inclusions was addressed by ABB and KSC (Kawasaki Steel Corp) at the beginning of the 1980s during the pioneering work on the electromagnetic brake technology for normal slabs. The EMBR brakes the steel flow by applying a static magnetic field across the mold, perpendicular to the casting direction. The steel flow induces voltages and thus electric currents in the melt and these currents together with the static field produce a braking force opposite to the steel movements. The higher the casting speed, the higher will be the speed of the steel and the larger will be the braking force. The reduction in steel velocity and turbulence provides many benefits, such as increased cleanliness, fewer rejects and a possibility to increase the casting speed. At the beginning of the 1990s, development leading to a further improvement of the EMBR was made with a single magnetic field covering the total width of the slab or the EMBR Ruler (Figure 2). The corresponding configuration with surrounding yoke and two iron cores with part coils is shown in Figure 3.

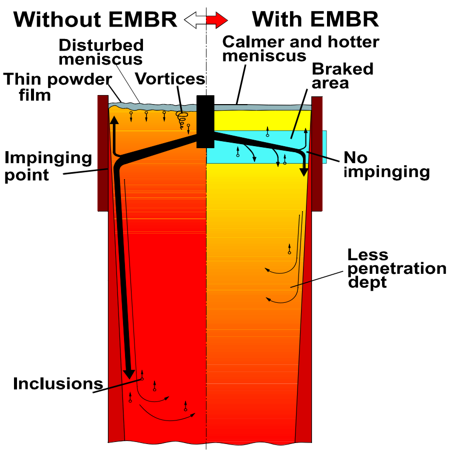

Fig.2. EMBR Ruler. The left part is shown without EMBR and the right part with EMBR. Important differences are highlighted.

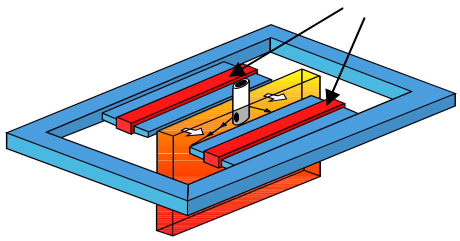

Fig.3. EMBR Ruler with a surrounding yoke and cores with part coils guiding the magnetic field towards the mold.

The first commercial installation in a thin slab caster used the EMBR Ruler and today, it is also used in most thin slab casters.

The EMBR Ruler means that the oscillation mechanism has to carry an extra weight of several tonnes. As a result of the extra weight on the oscillation mechanism, new building-in principles were developed and today, there are two different designs:

Internal design (Figure 4). The part coils, the magnetic cores and yoke are built into the mold and go in and out of the caster with the mold has to support the extra weight, typically 5 – 10 tonnes. This design is normally used for existing casters.

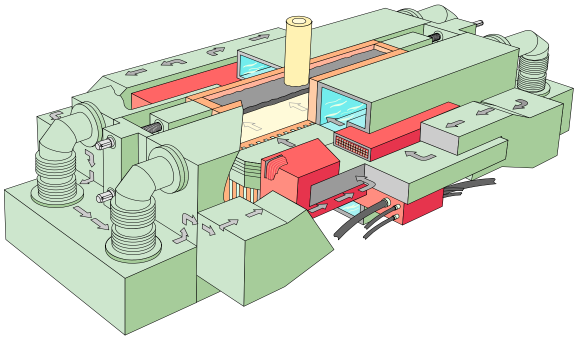

Fig.4. EMBR Ruler, internal design.

External design (Figure 5). A non-oscillating magnetic yoke surrounds the mold. From this yoke, movable magnetic iron cores are guiding the field to the mold. The part coils are mounted on the iron cores that move in through windows in the water jackets to minimize the non-magnetic gap. These windows are large enough to allow for the oscillation to take place. The non-oscillating iron cores and part coils are retracted and remain in the caster during mold exchange. This design is normally used for new casters.

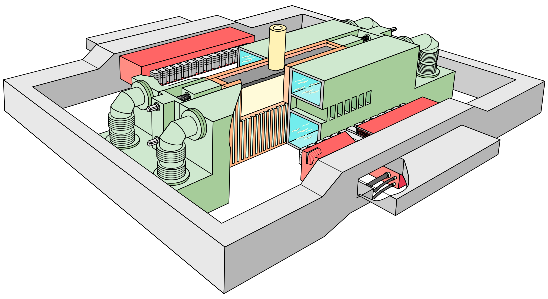

Fig.5. EMBR Ruler, external design and with retracted iron cores.

FC MOLD

The Flow Control Mold /FC Mold) was developed on the basis of Kawasaki Steel's operational experience of the first generation of EMBR. This system produces two static magnetic fields covering the entire width of the strand, one at the meniscus and the other through the lower part of the mold (Figure 6).

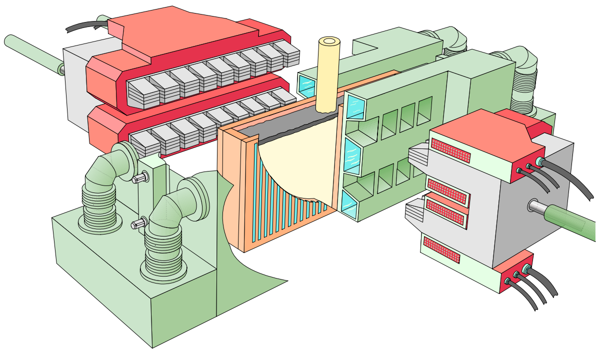

Fig.6. FC Mold, external design with inserted mold.

The FC Mold was developed to further improve the quality and productivity through a better control of the steel flow in the mold.

When molten steel moves in the magnetic fields, eddy currents are induced in the melt, interacting with the magnetic field to create a braking force in the opposite direction to the movement of the melt. The upper pole stabilizes the meniscus and thus prevents vortex formation and mold powder entrapments in the solidifying shell (Figure 7).

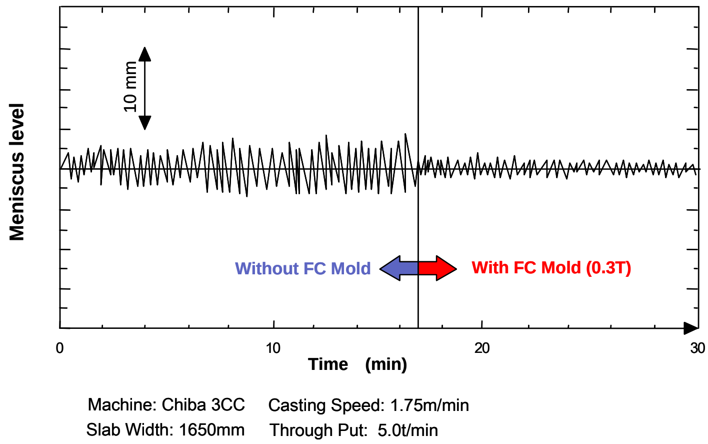

Fig.7. FC Mold stabilizes the meniscus.

The lower pole suppresses the deep penetration of the molten steel into the strand and promotes the upward flow of inclusions and argon gas bubbles to the meniscus. Further, the steel temperature in the mold increases, thereby contributing to more complete mold powder melting (Figure 8).

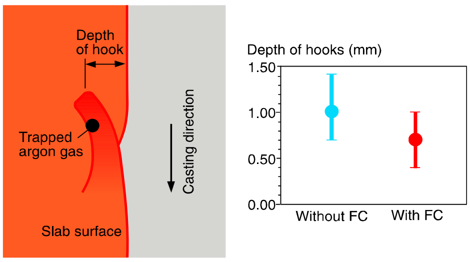

Fig. 8. Increased Mold temperature with FC Mold Machine Mizushima 4CC Slab Width 1250… 1300mm
Investigation Method: Thermocouple dipped into the molten steel directly

A hot and calm meniscus also decreases the depth of the solidified hooks and reduces the entrapment of non-metallic particles (Figure 9).

These factors result in a drastically reduced number of sliver and pencil pipe defects in cold rolled coils.

In addition, the FC Mold system with its configuration is insensitive to different casting conditions. The system has, however, its greatest impact on high-speed casting, contributing to a higher productivity and improved economy.

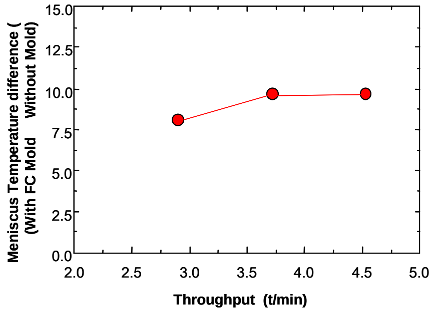

Fig. 9. Reduced depth of solidification hooks with FC Mold

METALLURGICAL RESULTS
EMBR

Thin slab casting means increased demands on the casting process. The casting speed compared to normal slab casting is two to six times higher, which means meniscus turbulence increases leading to mold powder entrapments. Likewise, steel residence time in the mold will become too short for separation of normal-sized inclusions and argon bubbles. The steel in thin slab casting is therefore always Ca-treated so that the inclusions coming with the steel do not clog the SEN but remain very small and thus harmless. Consequently, no clogging of the SEN occurs and thus argon use is not required. Further, the narrower the mold thickness, the greater will be the tendency for asymmetric steel flow, which leads to the risk of a static wave generation at one of the mold narrow sides resulting in associated lubrication problems and surface cracking.

The EMBR results from thin slab casting show the same beneficial effects as has been established for normal slab casting, but with the difference that the need for an EMBR is still further increased for thin slab casting. Thus, many of the new thin slab caster installations have included EMBR.

By using an EMBR, the steel flow speed is lowered and the “standing” wave close to the mold narrow side is reduced. An imprint of the meniscus profile can be obtained by dipping down a thin steel sheet in the mold and letting it melt off (Figure 10).

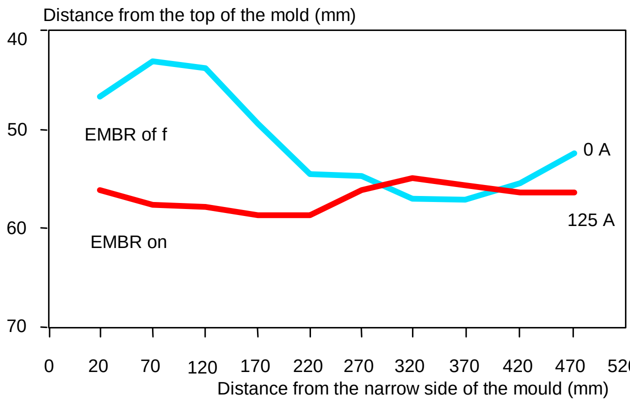

Fig. 10. The standing wave close to the narrow side in the thin slab is reduced when using the EMBR. (Nucor Crawfordsville)

As reported by Nucor Steel, Berkeley, casting at 5 mpm through a 3-port nozzle without EMBR produces a 15 mm wave. With EMBR, the maximum wave is 4 mm. A flat meniscus is of great importance since waves higher than the molten mold powder thickness can cause lubrication problems and thus surface cracks. The corresponding reduction in longitudinal cracking is shown in Figure 11.

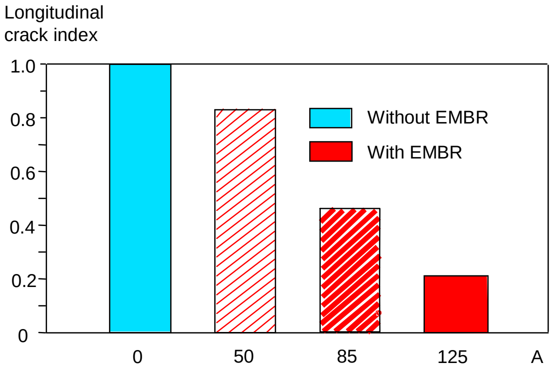

Fig.11. EMBR reduces the longitudinal cracks.

However, the most important obvious feature having a flat meniscus is that the metal flow speed below meniscus is reduced and therefore, the risk for vortices and mold powder entrapments. These inclusions are hidden inside the slab and are brought towards the surface during rolling. Therefore, the best possibility to detect them is after hot rolling. The use of an automatic surface inspection system is then vital for reliable detection, for failure classification as well as statistical treatment.

Results from normal operation show that the decrease of surface defects resulting from the use of EMBR gives savings in customer rejects of **about 1.75 USD per ton**. The results from 50 coils regarding mold powder entrapments have been summarized in Figure 12, which shows a reduction of 90 percent.

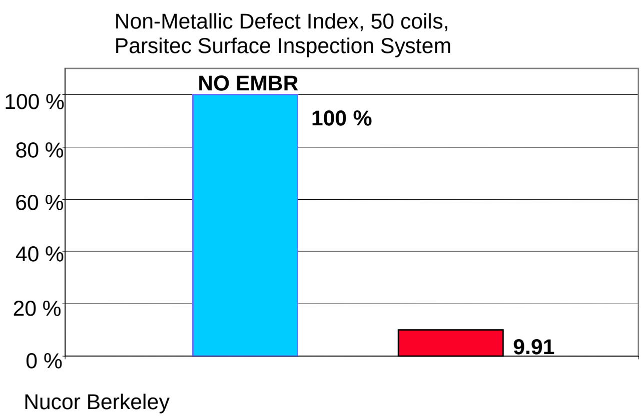

Fig.12. Non-metallic defect index in coils with/ without EMBR.
(Nucor Barkely 1999)

This achievement has allowed Nucor Berkeley to enter new market segments, namely white products, a segment that would not have been reached without EMBR.

Another equally important result of a flatter and stable bath level profile is that the temperature cycling of the mold copper plates is reduced and that the lubrication between the solidified shell and copper plate is more uniform (see Figure 13), resulting in a reduction of the mold copper plate distortion. Results from operation show that the lifetime of the mold copper plates are significantly increased (doubled), and with corresponding savings.

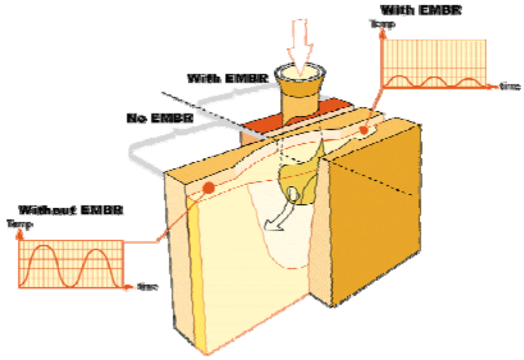

Fig. 13. Less temperature cycling of the mold copper plates doubles mold lifetime.

FC MOLD

FC Mold brings the possibility to further improve slab quality. Results from Kawasaki show a considerable increase in slab surface quality and sub surface quality (Figures 14 and 15). Altogether, a high slab quality can be maintained even at high casting speeds (Figure 16).

ABB has equipped more than 20 conventional slab casters with FC Mold. Among recent orders can be mentioned Baosteel, Azovstal, Corus Ijmuiden, Handan Steel, Anben Steel and Maastel.

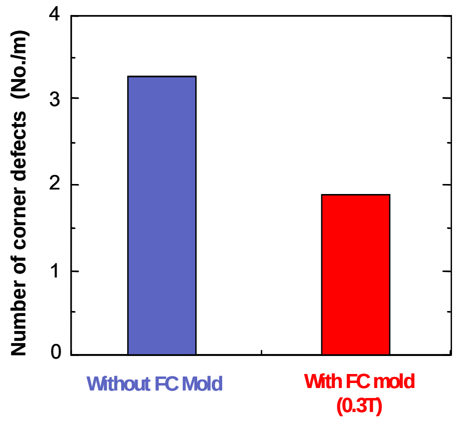

Fig. 14. Improved surface quality with FC Mold Machine Mizushima 4CC - Steel Grade: Middle carbon CC /0.08% Nb 0.044% Ti/O
Investigation method: Visual Inspection

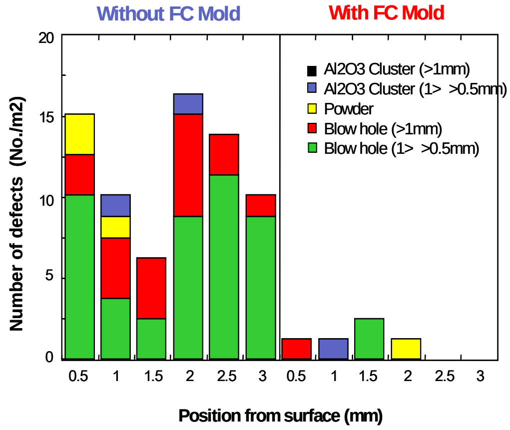

Fig. 15. Improvements of sub surface with FC Mold. Machine Chiba 3CC Steel Grade ULC Slab Width 1650 mm Through put 5 t / min , Casting Speed 1,75 m/min Investigation method: Alumina Etching

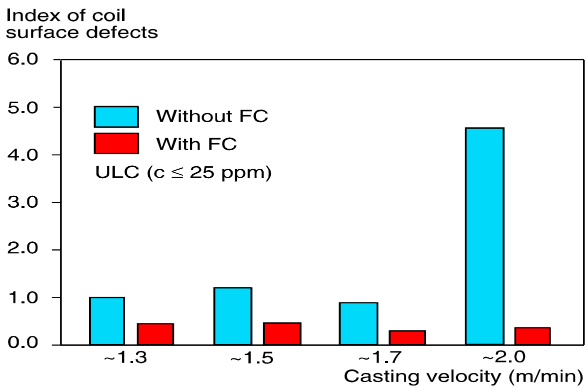

Fig.16 Improved slab quality at high casting speeds

SLAB MEMS

Early trials by ABB showed that slab MEMS is an interesting technology for improving the casting process, but so far the EMBR alternative has achieved far greater market acceptance. Several different slab MEMS designs have been tried and some of these will most probably become optimum choices for certain applications.

SLAB SEMS

SEMS for slabs will create an equiaxed centre, thereby reducing centre segregation in the same way as for billets and blooms. This is especially important for plate grades with high carbon and alloy content, in particular for lower reduction ratios.

Ferritic stainless steels and silicon steels display a ridging behaviour, i.e. surface defects on the cold rolled sheets, when the solidification structure of the slab is columnar. By using SEMS this defect is controlled. Figure 17 shows the equiaxed ratio as a function of superheat with and without SEMS for ferritic stainless steels.

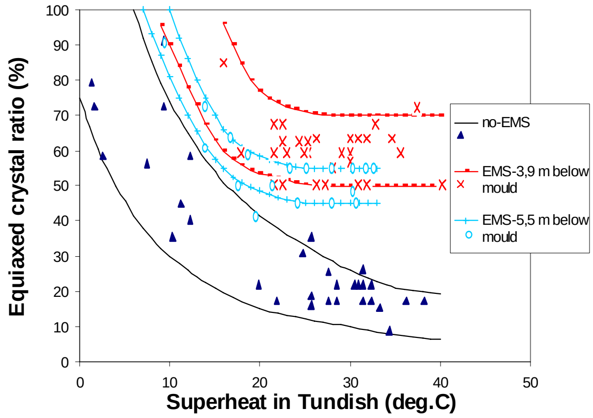

Fig. 17. Slab SEMS gives a high equiaxed ratio for ferritic stainless steel

SUMMARY

The Application of Electromagnetic Device in the Slab Caster Mould Area allows increasing the Casting Speed and/or improvement of metallurgical quality of the Steel Slab.