Production under scrutiny

In an ultra-competitive, unforgiving market, steelmakers must ensure that they produce good quality output at a competitive cost. To achieve this, they need to scrutinise every aspect of production to optimise processes and lower operating costs. **By Alex-Yuntao Zhong[2], Hanyu Pan[2], Nils Jacobsen[1] and Martin Sedén[1]**

TECHNOLOGY can be instrumental in unlocking profitability. Traditional aspects of steel production, such as slab casting, can benefit from improved quality across a broad throughput range using the latest generation of electromagnetic flow control (FC) technology to minimise the presence of contaminants in the final product.

By applying AC and DC fields simultaneously to the molten steel, third generation FC molds can, for example, decrease oxide inclusions in ultra-low carbon steel by 45% and final defects in cold-rolled coils by 79%. New mold sensor systems also give steelmakers the opportunity to improve quality further by optimising their electromagnetic (EM) device and through greater taper control and the reduction, if not elimination, of cracks, stickers and breakouts.

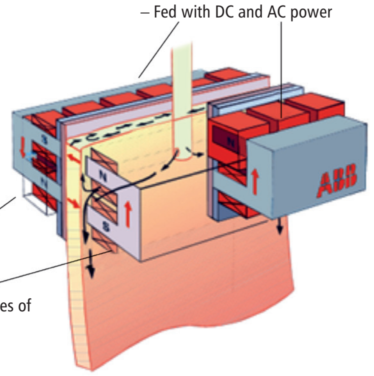
The challenges

Steel production demands exceptional end-product quality and high productivity, both of which are influenced by process cleanliness. Achieving these goals simultaneously demands accurate control of fluid flow during continuous slab casting.

Non-metallic and gas inclusions trapped within the steel degrade its quality. Flaws such as these are costly for producers. Quality is paramount in order to compete in challenging markets.

Continuous slab casting is at particular risk from impurities corrupting steel quality. Contaminants, in the form of non-metallic inclusions in the steel, entrapped casting powder and even argon bubbles, arise during processing. When these float up to the meniscus these are neutralised easily when they reach the liquid mold powder.

FC MOLD G3 – Inside and out structure



Lower and upper coils forms magnetic dircuit through back yokes

Operating modes

- DC
    - DC power to upper and lower coils
    - Used during high-speed casting
    - Static magnetic field is generated in air gap between lower coils
- Lower intensity static magnetic field also generated in air gap between upper coils
    - By applying DC to upper coils, a second DC magnetic field is imposed on magnetic field generated by the lower coils
    - Lower DC field reduces downward penetration
    - Upper DC field reduces high flow speeds at meniscus, reducing turbulence
    - DC fields stabilise flow, avoiding transitions between single and double roll
- AC
    - AC power to upper coils creates travelling magnetic field over each wide side
    - At low casting speed, it:
- Accelerates meniscus flow speed
- Increases washing over front of solidifying shell by means of upper level rotational AC magnetic field
- Combi
    - AC power to upper coils and DC power to lower coils applied
    - AC and DC magnetic fields applied simultaneously to optimise molten steel's flow speed
    - At lower level, below SEN jet spouts, DC field is applied for internal quality
    - At upper level, AC and DC magnetic fields are superimposed for improved surface/ sub-surface quality and meniscus stabilisation.
    - Deep penetrating downward flow is reduced by lower positioned DC field features
- Seamless transition between modes: no electrical connections to be modified
- Smooth transition between modes as currents are gradually adjusted between AC and DC
- Avoids quality deterioration due to turbulence caused by instantaneous field changes

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Steel grade	process	Number of coils examined	Number of coils with inclusions	Percentage of coils with inclusions
Ultra Low Carbon	FC Mold	1446	2	0.14%
	-	1467	10	0.68%

Table 1. Effect of FC Mold on the amount of coils with inclusion defects

However, when the inclusions follow the steel flow, carried downward via the momentum generated from the submerged entry nozzle (SEN), they become trapped in the solidified shell causing significant internal defects. The higher the speed the more likely the problem generated by the deep penetrating flow.

Electromagnetic FC technology

Inclusion minimisation is achieved through the proper interaction between mold powder and steel. FC devices assist with this as their principal objectives are to reduce downward penetrating flow, keep a constant meniscus flow velocity during any given condition while stabilising the overall flow pattern, and that of the meniscus in particular.

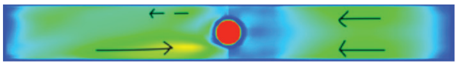
The second generation FC mold's double-level direct current (DC) magnetic fields provide stabilising zones at the meniscus and in the lower mold. It is recommended that casters be operated to maintain meniscus flow velocity between 0.2 and 0.4 m/s to obtain the desired inclusion removal properties[1]. Faster meniscus flow may result in mold powder entrapments, whereas slower flow velocity reduces the ability to exclude other non-metallic inclusions from the solidified steel shell. An efficient washing of inclusions is critical to prevent surface/sub-surface defects in the solidified shell[2].

There are a number of flow patterns, depending on format, casting speed, SEN geometry and the amount of dispersed Argon3. FC Mold technology provides a stable flow that avoids fluctuations between patterns, thereby optimising process parameters and enhancing output.

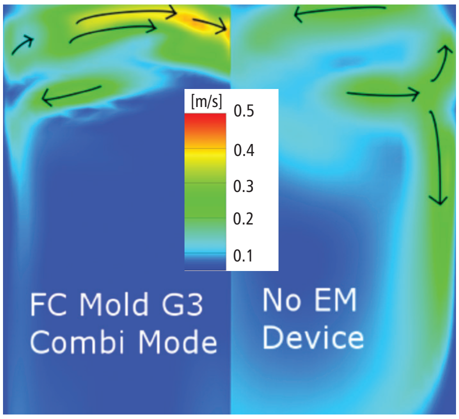
Earlier research has confirmed the various steel quality improvements that electromagnetic FC technology delivers[2,7]. The latest development of the FC Mold, which can be utilised for both mold stirring and braking, takes the slab's surface and sub-surface quality to even higher standards.

Further enhancing internal, surface and sub-surface quality

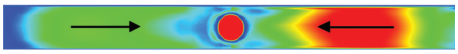
Third generation technology, as represented



Meniscus flow speed, FC Mold G3 Combi Mode vs. reference case without EM device



Wide side flow speed, FC Mold G3 Combi Mode vs.



FC Mold G3 DC Mode No EM Device

by the FC Mold G3, retains the two DC magnetic fields of its predecessor, yet adds a travelling alternating current (AC) one to stir in the upper part of the mold.

The DC fields ensure braking and stabilisation in high speed applications whereas the accelerating AC fields are well-suited for processes of low-to-medium casting throughputs.

Meniscus flow speed can be better controlled by simultaneously combining DC and AC magnetic fields in the mold's upper region, or smoothly transitioning between these modes. The DC component suppresses fluctuations and stabilises flows whereas a travelling AC field stirs the molten steel, thus washing non-metallic inclusions from the solidification.

The flexibility of applying DC and/or AC currents enables steelmakers to improve their control flow behaviour for a broad range of casting conditions yielding improved slab cleanliness and surface quality.

The ability to make real-time adjustments to magnetic field strengths and configurations catering to specific casting conditions further optimises steel quality. The FC Mold G3's control package automatically and seamlessly adapts casting operations to a wide variety of situations. The control is based on the mold index, the magnetic interaction number, numerical simulations and on-line mold monitoring.

Test results

The following tests were performed at customer sites in Asia.

• Mold level fluctuations

Without an electromagnetic device, the standard deviation of the meniscus level fluctuations is 1.47 mm. However, after 20 minutes the FC Mold G3 is switched into Combi mode and the standard deviation of the fluctuations falls to 0.97 mm[5]. Even with stirring for improved surface and sub-surface quality, there is increased stability of the meniscus level. This can be attributed to the DC magnetic flux density component. This result is obtained even though AC stirring is applied in the upper part of the mold.

• Oxide inclusion suppression

Using an ultra-low carbon slab sample, the effects of the DC mode on cleanliness was analysed in order to quantify oxide inclusions[6].

The detection was performed in seven positions along the direction of the slab thickness and at quarter width of it.

The device reduced the total oxygen value in all seven positions by an average of 45%, demonstrating that the FC Mold will improve the internal quality by lowering the amount of inclusions in slabs.

• Final defects in cold-rolled coils

In a comparison of casting with and without the electromagnetic device, the inclusion defect content of cold-rolled ultra-low carbon steel coils was analysed by the plant's quality control system[6]. The number of coils with inclusions were retrieved with and without the application of the DC fields of the FC Mold. The results are presented in **Table. 1**.

The number with inclusion defects is reduced from 0.68% to 0.14%. Yielding a 79% reduction of cold-rolled coils with inclusions, the device offers a significant improvement in surface quality[6].

Further improvements on the way

In an ideal world, steelmakers would find it useful to track shell thickness, flux thickness, flow patterns and speed as well as inclusion locations. While direct assessment of these features is not feasible, ABB has developed a solution which captures this

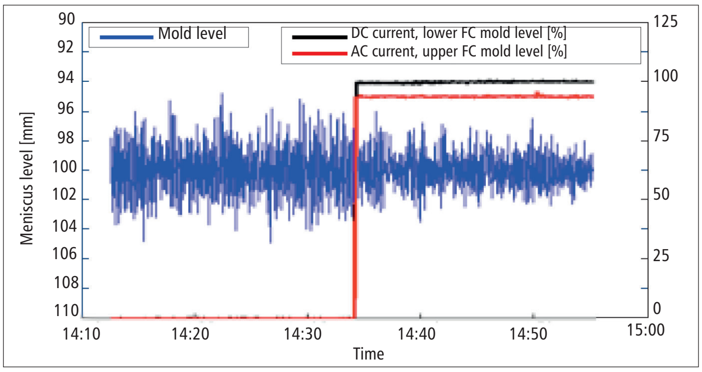


Fig 2. Meniscus level fluctuations without and with FC mold G3

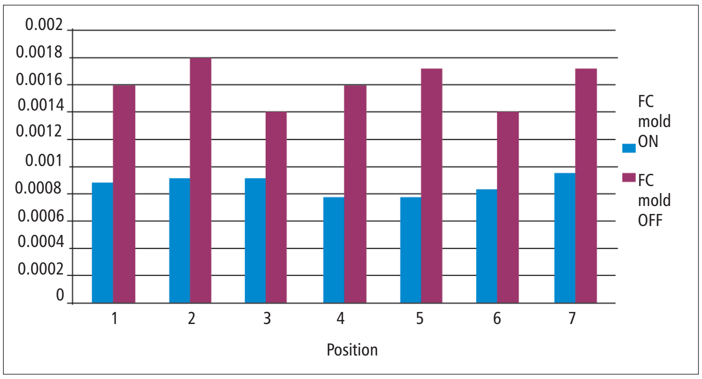


Fig 3. The effects of FC Mold on the total oxygen value in ultra-low carbon steel

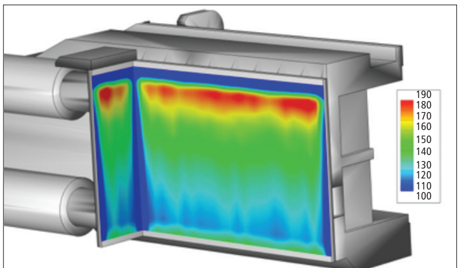
information indirectly by analysing heat flux and temperature measurements from a multitude of optical Fibre Bragg Gratings sensors.

Mold temperature distribution, measured by OptiMold Monitor.
ABB's new OptiMold Monitor, to be launched later this year, is a robust mold sensor system, providing quick monitoring and process evaluation to deliver full 2D maps of temperature in the copper plates of the mold.

The OptiMold Monitor's easy-to-populate mold plates are densely filled with sensors for particularly accurate results. For example, a fully equipped wide face mold plate may have several thousand sensor points. The optical fibres are very small and lightweight which allows a negligible impact on strand cooling when installed in the mold copper plates. They are also immune to electromagnetic interference and are intrinsically safe due to the absence of electrical voltage.

With high resolution mold temperature monitoring and an analysis of the temperature gradients, OptiMold allows for early sticker detection as well as crack and break-out warnings. Taper control is improved, submerged entry nozzle (SEN) clogging can be detected and mold cooling monitored. Additionally, the system provides information on meniscus level and mold lubrication.

As well as monitoring overall process characteristics, OptiMold can, in real-time, if connected to a flow control device, control and adjust operational parameters for the electromagnetic equipment (currency, frequency etc.). This enables users to obtain a desirable flow pattern where meniscus speed, asymmetry and steel flow stability are managed on-line as required for optimal steel production. This control feature is



Mold temperature distribution, measured by OptiMold Monitor

based on high resolution temperature sensor data at the top of the mold to infer the meniscus level profile at any given moment, enabling the meniscus speed to be fine-tuned in a timely manner.

The technological improvements offered by OptiMold enhance both the casting process and steel quality. The high resolution measurements provide valuable information on mold and mold flux, generating important insights which, in turn, lead to fewer caster disturbances and improved quality. More specifically, stickers, cracks and break-outs can be limited or avoided entirely, surface defects reduced, and temperature distributions homogenised with better taper control.

In conjunction with the latest generation of flow control device, FC Mold G3, OptiMold can control and optimise molten steel flows and substantially reduce inclusion defects for all casting conditions.

Conclusion

ABB's third generation FC Mold overcomes the various challenges in a modern dynamic caster. The FC Mold G3 delivers a stirring (AC) function for all casting speeds as well as a braking (DC) function which is conventionally applied at higher casting speeds. In addition to the braking and stabilisation benefits offered by DC magnetic fields using well-established FC Mold technology, meniscus fluctuations are reduced when AC and DC power are applied simultaneously via third generation technology's Combi mode. Use of this equipment can also significantly reduce the number of internal oxide inclusions and significantly improve the surface quality in final cold-rolled coils.

Even newer technology, in the form of advanced mold sensor systems, promises to perfect output even further. By providing the ability to infer shell thickness, flux thickness, flow patterns and speed, as well as inclusion locations, steelmakers will soon have the opportunity to tweak operational parameters to yield ever more defect-free steel. Improved production will yield higher profits and greater end-user satisfaction. ■

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