Enhancing mold flow control

Tata Steel Europe (Ijmuiden) has installed an OptiMold monitoring system, co-developed by ABB and Proximion. The system was developed to measure flow conditions online, in real-time, and adjust the flow control device accordingly. By **Martin Sedén[1], Jan-Erik Eriksson[1], Arnoud Kamperman[2], Edward Dekker[2], Johan Pejnefors[3] and Krister Fröjdh[3]**

ELECTROMAGNETIC flow control is a well-proven technology for improving quality in continuous slab casting[1]-[4]. Electromagnetic stirrers, based on the principles of travelling magnetic fields, have been shown as particularly efficient for flow acceleration, temperature homogenisation and inclusion washing in surface/sub-surface regions of the strand. Different configurations of static magnetic fields have also been utilised to brake and stabilise high speed processes. For varying casting conditions such as throughput, slab format, slag type, steel grade, argon flow injection, SEN type and immersion depth mold level and so on, different electromagnetic settings are needed to create the best possible flow conditions. Appropriate settings can be found through trials where an experience database can slowly be built up, or by numerically simulating the process with modern computer technology and software. Both methods, however, are very time-consuming. The OptiMold Monitor has been developed to measure flow conditions online, in real-time and adjust the flow control device accordingly. This technology provides superior thermal monitoring

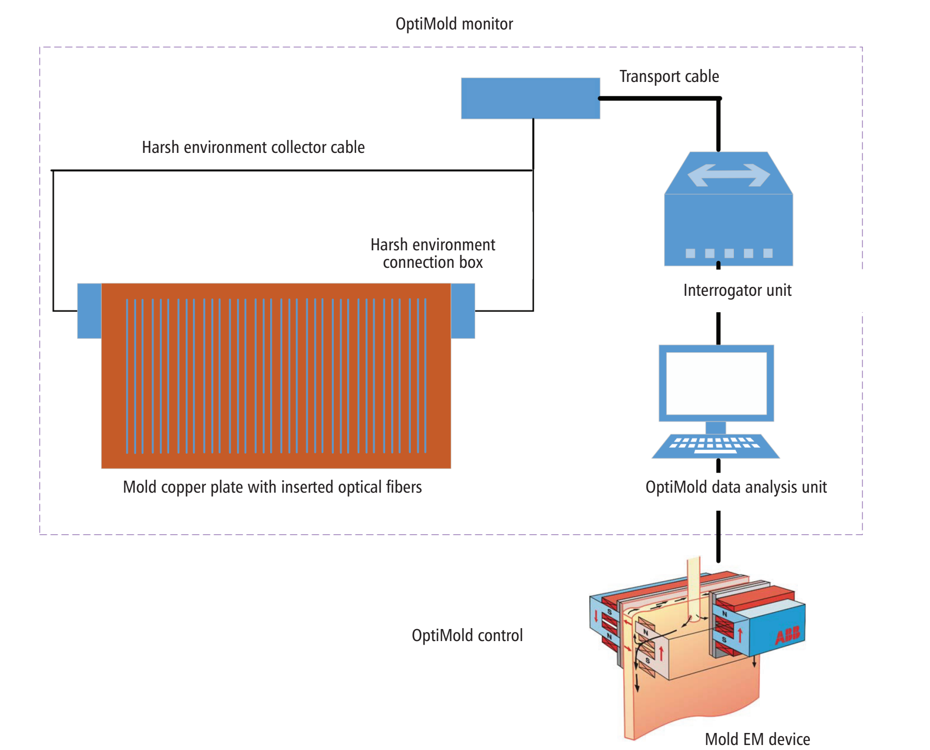

Fig 1. Schematic setup of OptiMold monitor

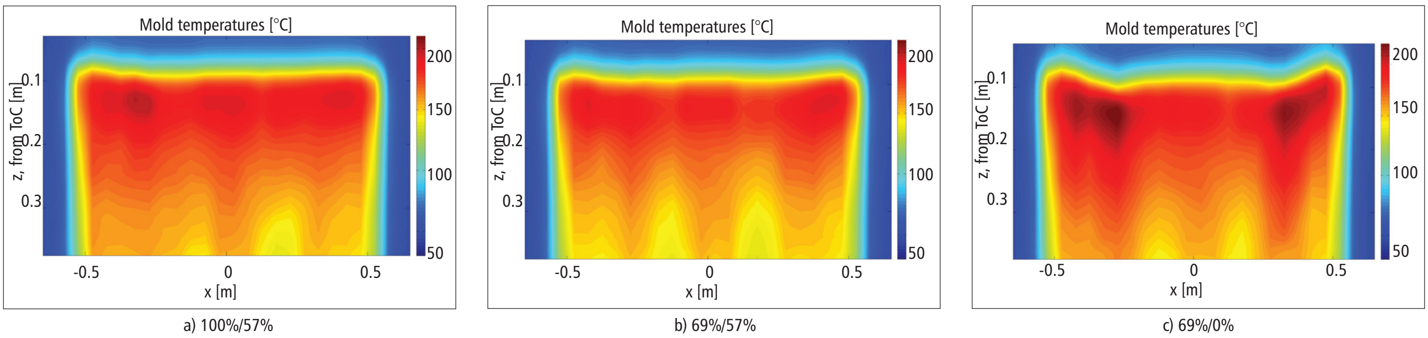

Fig 2. Time averaged OptiMold monitor 2D heat maps for different FC Mold magnetic field configurations (Bbottom/Btop)

1ABB AB, Terminalvägen 24, SE-721 59 Västerås, Sweden, 2 Tata Steel Europe, P.O. Box 10000, 1970CA IJmuiden, Netherlands, 3 Proximion AB, Skalholtsgatan 10, SE-164 40 Kista, Sweden

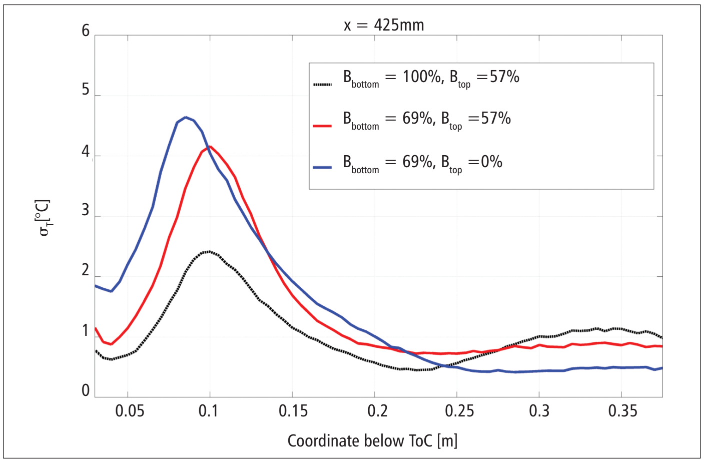

Fig 3. Meniscus shape along the width of the mold for different FC mold settings. Estimated from measured temperature

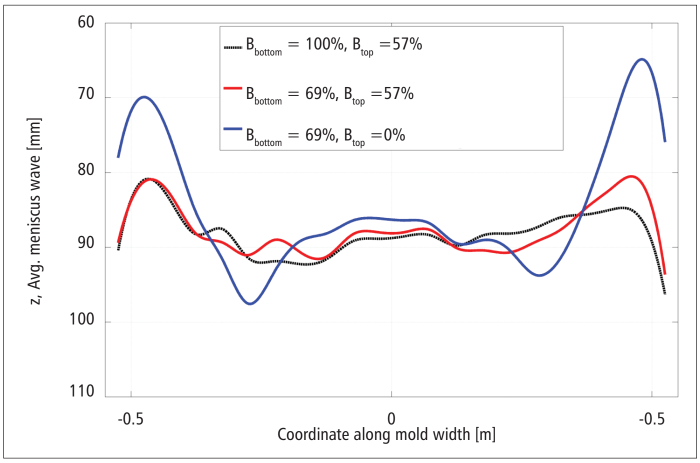

Fig 4. Standard deviation of the meniscus height over the entire mold width for different FC Mold settings

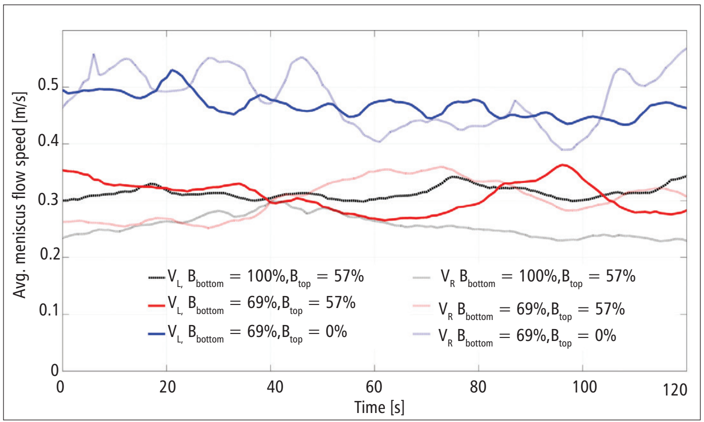

Fig 5. Calculated meniscus flow speeds, left and right hand side of mold, for different FC mold configurations

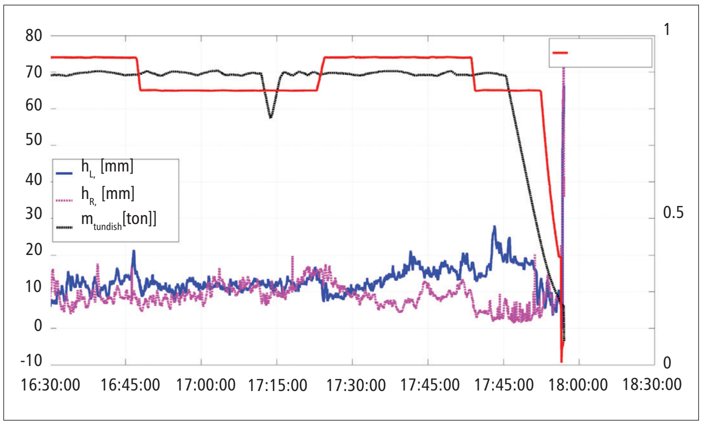

Fig 6. Monitored left and right hand side estimated meniscus wave heights (hL and hR) for last 2 heats before tundish and SEN change

resolution and has been co-developed by ABB and Proximion. It is installed at Tata Steel Europe (Ijmuiden).

Measurement system and test set-up

The core of the installed OptiMold Monitor (**Fig. 1**) is a set of 38 measuring optical fibres. One end is mounted into evenly spaced vertical holes in the top half of a new copper broad face plate, 15mm from the hot face, and the other end is spliced into a multi-strand harsh environment collector cable in a connection box mounted on the side of the mold plate. At the mold end of each fibre, 70 Fibre Bragg Gratings (FBGs) have been accurately positioned every 5mm,[5] starting 30mm from the top of the copper plate and covering the upper broad face down to 375mm from the top of the copper. Each FBG acts as a single temperature sensor, equipping the broad face plate with a total of 2,660 sensors. See[10] for system set-up details.

Using robust, expanded beam connectors, four 15m long collector cables are plugged in to an intermediate box positioned close to the caster. From the intermediate box, the optical transmission is carried by a 125m transport cable, which connects all the caster fibres to interrogators in a climate-controlled room. The light source in the interrogator sends a broadband light pulse into the fibres. Reflections caused by the FBGs are picked up by the interrogator unit and translated by software to temperature data for all sensor points. Temperature data is scanned and treated online for the entire mold plate twice every second.

High resolution temperature mappings

The slab caster at Tata Steel Europe (IJmuiden), where the OptiMold Monitor has been installed, is also equipped with an ABB FC Mold, a two-level electromagnetic brake controlling the flow of molten steel in the mold. During a trial, the FC Mold's magnetic fields were varied, as the OptiMold Monitor scanned the thermal status of the mold.

The time-averaged temperature mappings (**Fig. 2**) show that a strong magnetic field (2a) results in a relatively homogeneous temperature distribution. For a vanishing top magnetic field (2c), temperature distribution becomes inhomogeneous with accentuated hot-spots close to the narrow faces.

Meniscus shape has been estimated based on measured temperature distributions. **Fig. 3** illustrates the resulting time average calculated meniscus shape for the FC Mold configurations described above for the 1100mm width, 190 mm SEN immersion depth and 1.9 m/min casting speed.

The estimated meniscus shape results indicate that the stronger top magnetic fields ensure a lower wave peak close to the narrow faces, whereas the meniscus wave height is much more pronounced for the un-braked top domain. In **Fig.4**, an estimate of dynamic meniscus fluctuations is shown. It also indicates a stabilisation over the entire width of the mold with the application of magnetic fields.

A set of numerical simulations of molten steel flow in the mold was produced to illustrate the causes of the observed meniscus shapes and flow speeds. The CFD-simulated meniscus shapes are very similar to the OptiMold Monitor's estimated meniscus shapes shown in **Fig. 3**. As the top magnetic field is missing, the flow pattern shows a strong upward directed flow along the upper part of the narrow faces. This vertical momentum pushes the meniscus wave upward and creates a high crest of potential energy close to the narrow face; energy that is converted into kinetic energy in the form of meniscus flow speed towards the SEN. For the stronger top magnetic field, the upper recirculation loop is restricted in speed and hence has a flatter meniscus with lower flow speeds. A strong bottom field restricts downward-directed flow momentum, reducing the penetration depth of the lower recirculation loop.

Meniscus flow speed can be calculated based on the meniscus shape. In **Fig. 5** the variation of meniscus flow speed is given over the two-minute trial period. The connection between the top magnetic field and meniscus general flow speed level is apparent. It is also clear that the unbraked high flow speeds undergo large fluctuations as well as left/right-asymmetry over time. A stable meniscus flow level around 0.3 m/s is in this 237x1100 mm, 1.9 m/min casting sequence found for an FC Mold field setting of 57%/100% (top/bottom).

Meniscus speed control

Implementing the algorithms for meniscus profile and meniscus flow speed in the OptiMold system analysis unit, the deduced in-mold flow speeds can be monitored over time. In **Fig. 6** the meniscus wave height has been monitored over the last two heats of a casting sequence before tundish and SEN change.

Before the ladle change at 17:14, temperature distribution and meniscus wave are relatively symmetric. In the last part of the sequence, asymmetry becomes more pronounced, biasing the meniscus wave on the left side. It can be concluded that clogging affects flow pattern symmetry in the last stages of casting.

These results reveal the OptiMold Monitor's potential in conjunction with a flow control device for counteracting and controlling in-mold flow asymmetries as soon as they are detected by the temperature measurements. A modern generation FC Mold has the ability to control left and right side magnetic fields independently and consequently apply different electro-magnetic forces to the mold flow on the left and right sides, and is a perfect fit for OptiMold Control to regulate symmetry as well as the appropriate flow speed levels in real time.

Conclusions

By means of high-resolution temperature measurements the OptiMold Monitor can allow for powerful analysis of casting conditions and detection of mold flow pattern characteristics such as meniscus shape, flow velocity and flow asymmetry. This opens up new possibilities for enhancing mold flow control where it can, in a closed-loop connection to an electromagnetic actuator, dampen or accelerate flow speeds as well as control flow asymmetry. What's more, the OptiMold Monitor can extend functionality and performance of conventional thermocouple systems and detect local thermal phenomena. Fibre-optics measure undisturbed in the presence of magnetic fields.

To read the white paper that this article is based on or for more information on our offerings visit www.abb.com/metals ■

References

[1] S. Kenichiro et al., "Flow field control of liquid steel in the mold of a continuous slab caster by an electromagnetic brake", Tetsu-to-Hagane (1983), Vol. 69, No.12, pp. 912

[2] H. Okuda et al., "Effects of electro-magnetic brake on surface quality of medium carbon strand cast slabs", Tetsu-to-Hagane (1986), Vol. 72, No.4, pp. 196

[3] H. Yamamura, T. Toh et al., "Optimum magnetic flux density in quality control of casts with level DC magnetic field in continuous casting mold", ISIJ International (2001), Vol.41, No. 10, pp.1229-1235

[4] Y. Miki, S. Takeuchi, "Internal defects of continuous casting slabs caused by asymmetric unbalanced steel flow in mold", ISIJ International (2003), Vol. 43, No. 10, pp. 1548-1555

[5] A. Asseh et al.,"A writing technique for long fibre Bragg gratings with complex reflectivity profiles", Lightwave Technology, Volume 15, 1997, Issue 8, pp. 1419-1423.

[6] G. Hedin, A. Kamperman, M. Sedén, K. Fröjdh, J. Pejnefors, "Exploring Opportunities in Mold Temperature Monitoring Utilising Fibre Bragg Gratings", Presented at SCANMET V, (Luleå, 2016).