

Achieving enhanced caster performance by utilizing accurate and reliable continuous temperature measurement

Erreichte Leistungssteigerung der Stranggießanlage durch Anwendung einer genauen und zuverlässigen kontinuierlichen Temperaturmessung

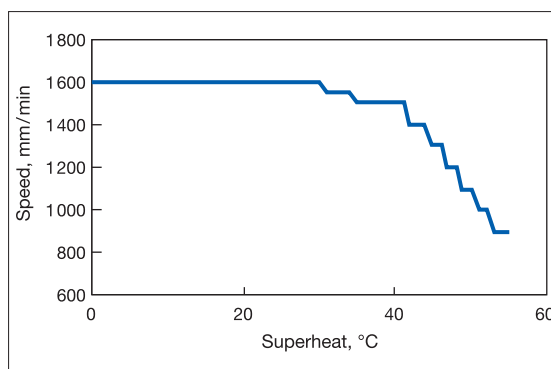
Richard Gass, Ron Kostyo and Martin Kendall

Caster process parameters dictated by tundish steel temperatures have developed over the years through a combination of operating experience and theoretical considerations. This paper reviews the important factors, as well as, the "state of the art" in measuring methods. The application of an accurate and reliable system for continuous temperature measurement, which can allow thermal models to be developed and improvement in caster productivity and quality, is explained.

Die durch die Verteilerrinnentemperatur beeinflussten Gießprozessparameter sind über Jahre im Zusammenhang mit Betriebserfahrungen und theoretischen Überlegungen entwickelt worden. Dieser Bericht gibt eine Übersicht über die wichtigsten Faktoren sowie den Stand der Technik bei den Messmethoden. Die Anwendung eines genauen und zuverlässigen Systems für eine kontinuierliche Temperaturmessung, die thermische Modellentwicklungen und Verbesserungen der Gießleistung und Qualität der Stranggießanlage ermöglicht, wird beschrieben.

Successful continuous casting depends upon knowledge of steel temperature in the tundish to control casting speed to the highest casting rate without incurring a breakout or problems with product quality. Substituting tundish temperature with steel superheat (as the difference between steel temperature and liquidus temperature) permits a common comparison of various steel grade chemistries with different liquidus temperatures. The maximum slab casting speed that can be safely obtained for a given superheat depends upon accurate knowledge of superheat between measurement location to the mould, cooling ability of the casting mould, the strength of the slab shell from the given steel chemistry, secondary cooling, and length of containment rolls below the mould. Most casting operations have predetermined sets of casting speed restrictions by steel grade, calling for strand speed to be reduced as superheat increases above a certain amount [1]. An example of a superheat speed pattern for steel grade A is shown in figure 1.

The more frequently the steel temperature is measured, the more confident the operators can be in casting at the maximum speed pattern. Additionally,



1 Superheat speed pattern for steel grade A
Überhitzungsgießgeschwindigkeit für die Musterstahlsorte A

the closer the temperature measurement is to the mould, the more accurately the steel temperature entering the mould can be determined.

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Measuring temperature in the tundish

Traditionally, measuring temperature in the tundish has been done by using a series of disposable immersion (dip) thermocouples, taken at the tundish entry position of the ladle pouring stream, figure 2. Disposable dip thermocouples give only spot measurements (non-continuous) and are dependent on the operator dipping the sensor to the same depth in the same position to maintain a repeatable measurement. These thermocouples cannot usually be taken during the first minutes of tundish fill or after a ladle change because the tundish level is too low.

As continuous thermocouples have gained acceptance and commercial use, continuous top thermocouple measurement of the tundish bath or tundish sidewall thermocouples have replaced dip probes for many casters. The factors that limit the use and accuracy of top mounted measuring systems can be summarized as follows:

- Top mounted sensors measure a significant distance away from the steel flowing out of the tundish through the casting nozzle. These sensors are limited to only measuring steel in the upper part of the tundish.
- Top mounted sensors have a large refractory mass for slag protection, which cause a lag in response time.

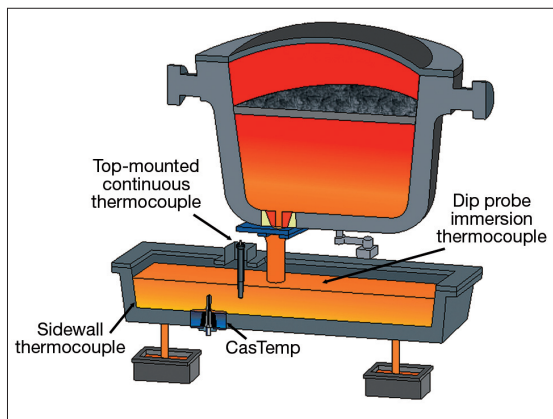
- Top mounted sensors are usually inserted after a new tundish has been filled, and will not register any temperatures until the tundish level reaches a minimum height. Handling and insertion of pre-heated sensors present a challenge to prevent breakage and can pose a safety risk to operators.
- During ladle changes top mount sensors are limited if the steel drops below the sensor and suffer a time lag for accurate measurement when the steel re-immerses the sensor.
- Viscous, aggressive tundish slags can severely reduce the life of top mounted thermocouples.
- With multi-strand casters there is not enough data from a single sensor to understand unbalanced flow effects on temperatures entering each strand.

While multiple sidewall thermocouples can be more easily used for each strand (with the probe tip at the interface between working lining and spray lining, they can be re-used on the same tundish), there are several factors that limit the use and accuracy of sidewall measuring systems, as summarized as follows: Sidewall sensors measure a significant distance away from the steel flowing out of the tundish through the casting nozzle, so abnormal flow patterns are not clearly detected. There is a thermal lag due to heat extraction from the tundish outer wall and the tundish brick in front of the thermocouple so that unsteady-state temperatures at tundish fill and ladle exchange will not be accurately measured.

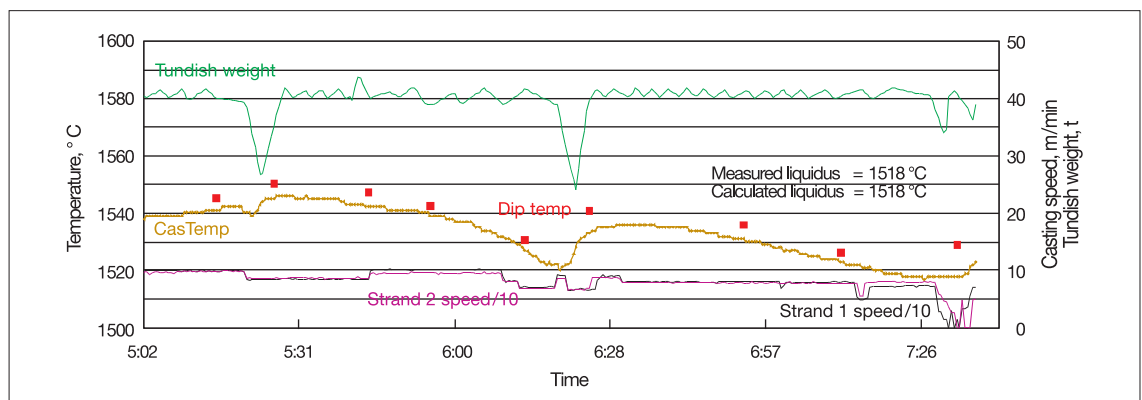
For two-strand slab casters with variable slab width and speed, temperature distribution to the individual strands was not consistently measured in the past. As an alternative to thermocouple-based temperature measurements, use of mathematical models of fluid flow in the tundish have not proven successful at predicting steel superheat from the tundish exit during the unsteady-state flow conditions that exist as casting speeds are changed and ladles are exchanged.

The advent of the Heraeus Electro-Nite CasTemp system has addressed the main problems of previous

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Measuring temperature in the tundish
Temperaturmessung im Verteiler



3
Cast termination due to low temperature
Giessabbruch aufgrund zu niedriger Temperatur



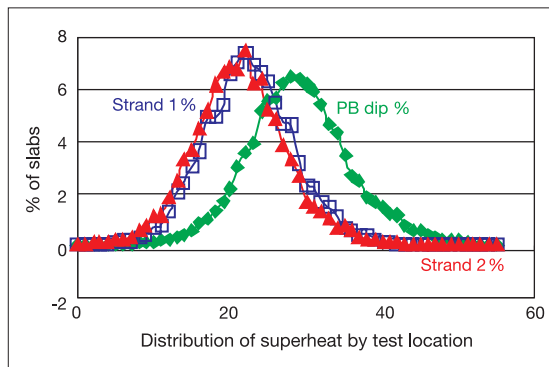
continuous tundish thermocouples by measurement within the liquid steel bath, near the exit nozzles of tundishes. The Heraeus Electro-Nite CasTemp system was described in a previous paper [2] and was successfully implemented on a significant number of steel plants during 2005. With normal heating of the tundish well prior to use, the CasTemp sensor overcomes all the problems discussed above and is 100 % available when properly maintained.

Sensor accuracy

Figure 3 shows a cast termination due to an unexpectedly cold ladle. The CasTemp data shows plant operators that the steel is starting to freeze in the tundish approximately 30 min before the final event, while the square points from the dip probes do not provide a very clear description of the problem. This result was obtained during the first trials at a European twin strand slab caster, thus preventative measures to prevent freeze-off were not in place. Possible actions with this new accurate data would be:

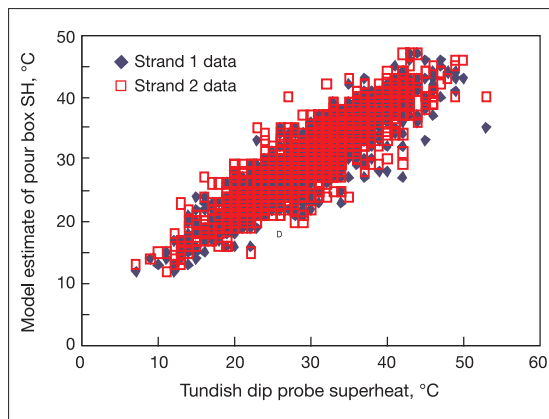
- feed the data directly in real time to the ladle treatment facility so the operators are fully aware of the problems at the caster
- increase casting speed to maximize yield and heat flow
- minimize tundish weight at the ladle change, (to allow new hot steel to flush through the tundish), giving the best possible chance of successful ladle exchange, or in the worst case to minimize the tundish skull if freezing cannot be avoided
- prepare the next tundish if possible to continue the strand also if freezing cannot be avoided.

The CasTemp system not only avoids many of the problems suffered by top mount sensors it also proves it's own accuracy by measuring the liquidus arrest temperature as the steel freezes in the tundish at

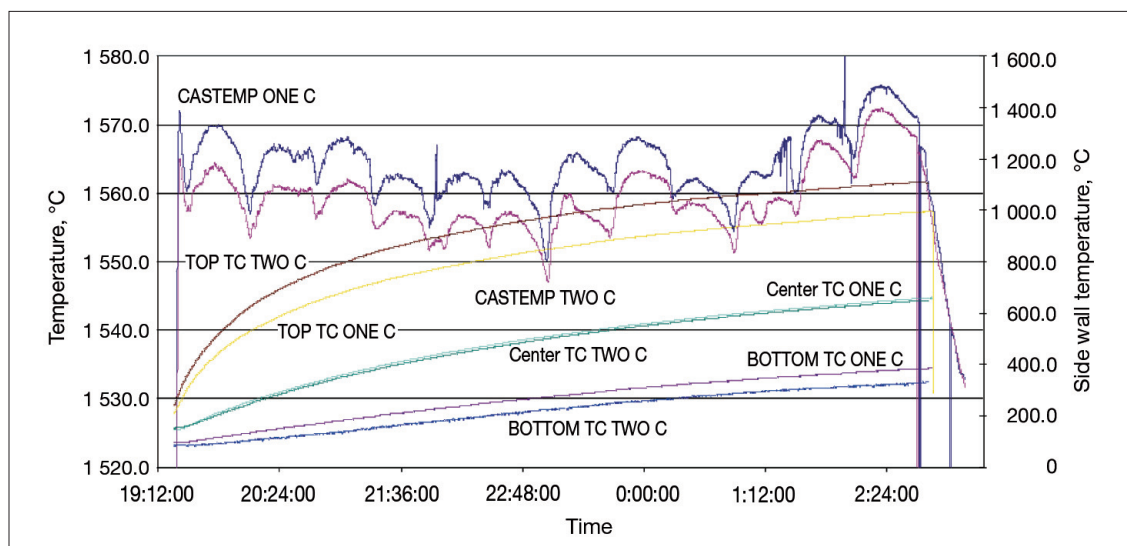


4 Temperature distribution dip-measurement vs. continuous temperature measurement with CasTemp
Temperaturverteilung der Tauchmessung gegenüber kontinuierlicher Temperaturmessung mit CasTemp

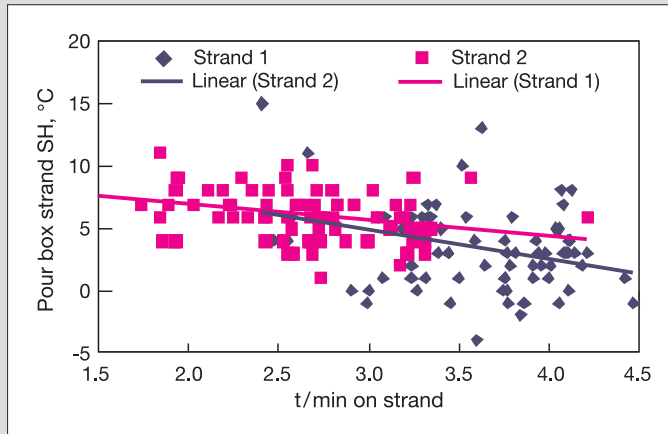
the end of a sequence. On a properly maintained system the arrest temperature always corresponds to the liquidus calculated from the steel chemistry, proving the absolute accuracy of the CasTemp system within ± 1 °C. The new sensor has given the plant the confidence to use the reliable data to investigate actions to improve the plant productivity with respect to tundish temperature.



5 Comparison of estimated pour box temperature vs. actual dip probes for steel grade A
Vergleich angenommener Gießkammertemperaturen gegenüber aktuellen Tauchproben für Stahl-sorte A

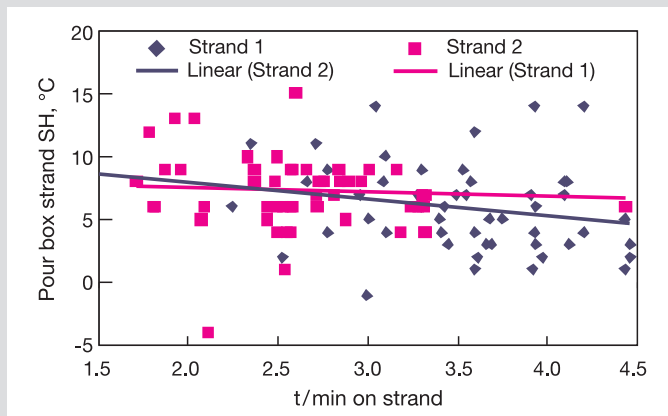


6 First sequence measured using CasTemp at slab caster No. 1
Erste Sequenz, gemessen mit CasTemp an der Stranggießanlage Nr. 1



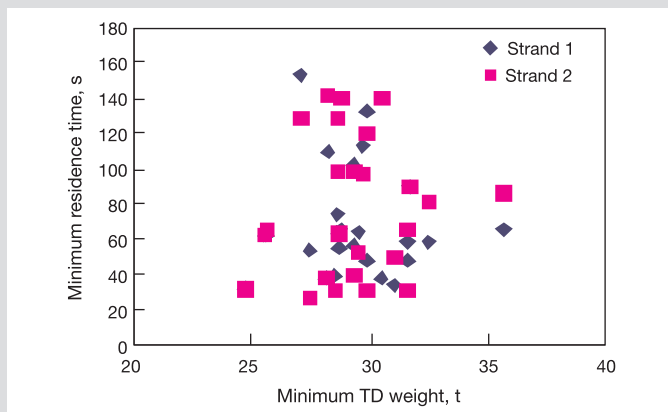
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Drop in superheat from pour box dip test to strand CasTemp
 Überhitzungsabfall von Gießkammertauchmessung zu Strangmessung mit CasTemp



8

Relationship superheat measurement between 0 – 8 min ladle open and strand throughput
 Relation der Überhitzungsmessung nach 0 – 8 min zum Strangdurchsatz



9

Relationship between minimum tundish weight and residence time
 Verhältnis zwischen geringstem Verteilergewicht und Verweilzeit

Continuous temperature data analysis at Mittal Steel

At Mittal Steel's Indiana Harbor Steel Production No. 4, slab caster No. 1 has a product mix of approximately 45 % ultra-low carbon steels, 12 % cold-rolled lamination steels, and the balance LCAK grades. Steel Production No. 4 has a single two-strand casting machine and produced 3.2 million t of slabs in 2004. Primary customers for product from slab caster No. 1 include automotive (with a high percentage of exposed critical parts), appliance and electrical steel applications. The caster was originally built as a Mannesmann-Demag machine in 1972. The caster has a central turret, with two independent ladle arms and two independent tundish cars. In 1989, the caster was rebuilt by Hitachi-Zosen, with the tundish size increased to 44 t. In 2000, the caster was modified by SMS-Demag from a curved-mould to a straight-mould caster, resulting in the strands moving slightly away from the central turret, but the full tundish weight was virtually unchanged at 43.5 t. At the time of the 2000 conversion, the tundish was redesigned from a rectangular shape to a modified V-shape [3]. Tundish internal flow control consists of a bowl-shaped pouring pad and a short dam between the pouring pad and the strand exit well nozzles.

To better optimize casting operation, the CasTemp system was installed at slab caster No. 1. Initial installations of the CasTemp sensor in Europe were installed through the tundish bottom as shown in figure 3, but this was not possible at slab caster No. 1 due to the configuration of the tundish bottom. During the fall of 2004, initial modifications to the tundish back-walls were made to safely accommodate sensor installation. Initial trials showed good sealing around the refractory joints and the outer-wall metal locking plates. The position of the sensor tip is approximately 30.5 cm above the well nozzle entry and halfway between the vertical axis of the well nozzle and back-wall of the tundish. Operation over the past 12 months showed the sensor provides reliable, accurate, on-line data. Casting analysis from CasTemp data at slab caster No. 1 is summarized in the following figures.

Figure 4 shows the distribution of tundish pour box dip probe superheat values compared to CasTemp superheat values over each tundish well nozzle. The downstream well nozzle positions have a similar distribution of superheat values, offset due to the temperature loss as the steel resides in the tundish for a period of time.

Based on continuous measurements of superheat, a model of pouring box superheats can be constructed from multiple linear regressions of tundish flow characteristics. This permits the superheat values from the

References

- [1] Gass, R. T.; Skoczylas, G. W.: Reduction of Breakouts at Ispat Inland Inc., Proc. ISS Steelmaking Conf., 25 - 28 March 2001, Baltimore, USA, Vol. 84 (2001), pp. 41/52.
- [2] Lagerberg, J. L.; Oldenburg, W. W.; Huisman, R. S.; Yardy, J.; Kendall, M.: Experience with a novel approach to continuous tundish temperature measurement, Proc. AIS-Tech Conf., 15 - 17 April 2004, Nashville, USA, Vol. 2 (2004), pp. 781/86.
- [3] Gass, R.; Knoepke, J.; Moscoe, J.; Shah, R.; Beck, J.; Dzierzawski, J.; Ponikvar, P.: Conversion of Ispat Inland's No. 1 slab caster to vertical bending, Proc. ISSTech Conf., 27 - 30 April 2003, Indianapolis, USA, Vol. 1 (2003), pp. 3/18.
- [4] Lowry M. L. and Sahai, Y.: Modeling of thermal effects in liquid steel flow in tundishes, Proc. ISS Steelmaking Conf., 16 April 1991, Washington D.C., USA, Vol. 74 (1991), pp. 505/11.

CasTemp data to be directly compared with existing superheat-speed patterns. Separate regression formulas were developed using continuous temperature measurements from either strand, and are of the form:

$$PBCalcSH1 = a(SH1) + b(ROLLQ1) + c(ROLLQ2) + d(QRATIO1) + e(PRIORSH1) + f(RESIDTIME1) + g(RESIDTIME2) + h$$

where the following terms are defined:

SH1: superheat on strand no. 1 as measured from CasTemp liquidus for current slab

ROLLQ1: a rolling average strand 1 throughput from current and prior slab

ROLLQ2: a rolling average strand 2 throughput from current and prior slab

QRATIO1 = (t/min on strand 1) / (t/min on strand 2)

PRIORSH1: superheat on strand No. 1 as measured from CasTemp-Liquidus for prior slab

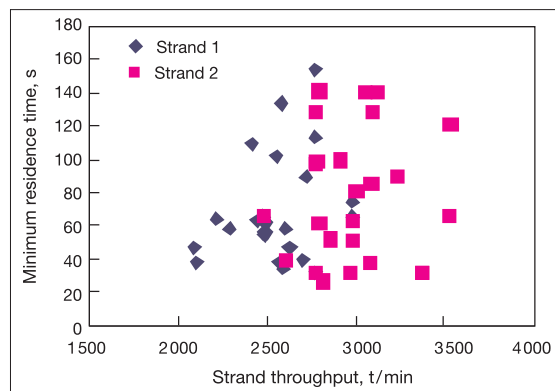
RESIDTIME1 = average tundish weight / ROLLQ1

RESIDTIME2 = average tundish weight / ROLLQ2.

A corresponding equation was also developed using the superheat from strand No. 2 as measured from CasTemp-Liquidus. Figure 5 shows the comparison of estimated pour box temperatures versus actual dip probes for steel grade A. Regression results for the relationship in Figure 5 have an $r^2 = 0.81$ for strand 1 and $r^2 = 0.78$ for strand 2.

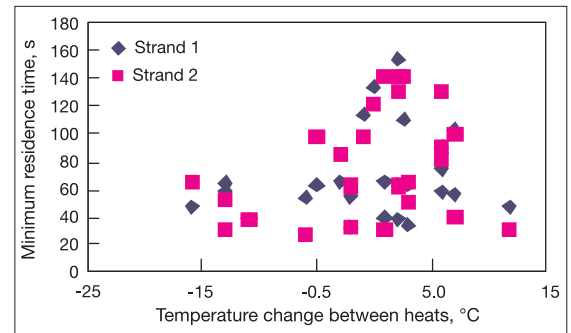
If the drop in pour box to strand superheat is significantly larger than expected, there will be an opportunity to increase the casting speed pattern without increased risk of breakout.

Figure 6 shows the first sequence measured using CasTemp at slab caster No. 1. The top two trend lines clearly show the temperature difference between the two strands with non-symmetrical throughputs; the higher throughput being the hotter strand. The data suggests the narrower strand can operate at increased casting speeds during some portion of the casting time. The lower trends show the temperatures



10 Relationship between strand throughput rate and minimum residence time

Verhältnis zwischen Strangdurchsatz und kürzester Verweilzeit



11 Effect on minimum residence time and ladle temperature
Auswirkung von geringer Verweilzeit und Pfannentemperatur

measured within the tundish sidewall refractories during the same cast.

Figure 7 shows the drop in superheat from pour box dip test to strand CasTemp is roughly dependent upon strand throughput rate (t/min), when the time from ladle open to superheat measurement is greater than 8 min. When the superheat measurement is between 0 and 8 min after ladle opening, the relationship to strand throughput rate is much weaker, as shown in figure 8, due to the intermix between the prior and current heat. For this reason, continued dip probe measurement of the initial superheat of each heat after opening is recommended, even with the good correlation between the continuously measured superheat and the model estimated pouring box superheat value.

Previous water modelling and mathematical modelling by Lowry and Sahai [4] has predicted that the inter-mixing behaviour of hot to cold compared to cold to hot steel will produce very different minimum residence times for the steel mixing in the tundish. A minimum residence time can be defined for temperature and superheat change between heats as:

- Residence time for hot heat to cold heat temperature at ladle exchange is dropping, but when new heat reaches the continuous sensor then temperature drops at an increased rate.
- Residence time for cold heat to hot heat temperature at ladle exchange is dropping, but when new heat reaches the continuous sensor, then temperature stops dropping (before increasing).
- Residence time for new heat about the same temperature as old heat temperature at ladle exchange is dropping, but when new heat reaches the continuous sensor, then temperature stops dropping (before increasing).

Using the above criteria, ladle exchange superheat trends were analyzed for the minimum residence time until the new superheat reached the continuous sensor near the strand. Figure 9 shows that there is no

obvious relationship between the minimum tundish weight and the residence time. Figure 10 shows a very weak relationship between strand throughput rate and minimum residence time. However, figure 11 shows that there is a substantial effect on minimum residence time due to whether the temperature change between heats was hot to cold, or cold to hot. This is roughly consistent with the predicted results from Lowry and Sahai [4], that a new, much colder heat will short-circuit steel flow across the tundish bottom (even when a short dam is present) rather than mixing as expected if there was no change in temperature between the two heats.

There are several long-term opportunities possible from continued use of CasTemp for slab caster No. 1:

- maximization of casting speed and throughput
- better control of steel residence time has the opportunity to better control alumina transfer during ladle exchanges
- model of continuous temperature on the opposite strand, based on continuous probe at one tundish exit and pour box dip probes
- potential for manpower reductions by elimination of most dip probe measurements.

Conclusions

The CasTemp system has been successfully implemented at Mittal Steel, Indiana Harbor's slab caster No. 1, with sensors mounted over each strand in every tundish. The system has demonstrated never seen before industrial accuracy (± 1 °C) with its ability to measure the liquidus of the steel freezing in the tundish.

The sensors have shown that when the system is properly maintained they can accurately measure a complete tundish sequence including pre-heat, the casting sequence and even the tundish cooling period on an accurate real-time basis.

These continuous measurements have allowed development of a model for steel entry into the tundish, as a step toward modification of superheat speed patterns to optimize cast speed of individual strands.

Continuous CasTemp data can be used to measure steel residence times in the tundish, to help verify tundish flow conditions during unsteady-state casting conditions. This new accurate measurement will allow the plant to maximize casting speed and afford better superheat control thus maximizing steel throughput.

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