REVAMPING OF THE NO. 2-3 SLAB CASTER AT POSCO GWANGYANG: DESIGN, START-UP AND INITIAL OPERATION RESULTS

S.m. Lee, J.Y. Hwang, S.H. Lee, G. Shin

One of the purposes of revamping the No. 2-3 caster was to have annual production capacity of 3.5 million tonnes per year for automotive application. Under a given caster length of 47m, the basic requirement under this value is to achieve 2.7 m/min casting speed for 250mm x 1600mm in slab section. In order to ensure stable operation for this high casting speed, many technologies were newly developed and implemented during the revamping process. The roller geometry was designed to minimize mould level hunting due to unsteady bulging. The concept of Intensive secondary cooling was applied to shorten crater end position as well as to decrease corner transverse cracking by applying the concepts of surface structure control [1]. A movable multi-mode electromagnetic system was designed to control mould flow to meet diverse operation conditions. An Automatic Ar control system was applied at the caster nozzle to minimize nozzle clogging. This caster was started in Nov. 2007 and went up to 2.7m/min in casting speed very quickly. This paper discusses the behaviour of mould level, mould surface flow and secondary cooling temperature to the directions of slab width and thickness experienced during casting speed increase and in particular at 2.7m/min maximum casting speed. Initial productivity and slab-quality results are also presented.

KEYWORDS: continuous casting, caster design, revamping, initial operation, high speed casting, high productivity, roller geometry, secondary cooling

INTRODUCTION

During the recent revamping of the No 2-3 caster at Gwangyang, it was decided to change caster type from curved to vertical bending to produce ULC and LCAK steels in 3.5 million ton per year for the automotive exposed application. Tab. 1 shows the main features of No. 2-3 caster at Gwangyang.

Because there was limitation of caster length and caster width, a maximum casting speed of 2.7m/min was needed to satisfy the target productivity of the revamping project. This casting speed is similar to that of Fukuyama caster [2] that has a 3.0m/min maximum casting speed for 220mm of slab thickness when different slab thickness is compensated.

Differently from the previous caster revamping project performed at POSCO, design concepts such as roll geometry, electromagnetic mould flow controlling device and secondary cooling system were performed by POSCO. This is because there are many risk-taking items such as mould level fluctuation due to unsteady bulging, uneven meniscus shape and strong surface velocity in mould, temperature profiles in strand and crater end position when the casting speed of 2.7m/min for 250mm slab thickness was considered.

After revamping, this caster reached a casting speed of 2.7m/

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	Before revamping	After revamping
Tundish capacity (ton)	60	80
Caster type	Curved	Vertical bending
Slab section size (mm^2)	1600 x 230	1600 x 250
Vertical length (m)	-	2.8
Mould length (mm)	900	950
Machine radius (m)	12	9
Metallurgical length (m)	41	47

Tab. 1 **Main features of the No 2-3 caster at Gwangyang before/after revamping.**
Caratteristiche principali dell'impianto No 2-3 di Gwangyang prima e dopo il revamping.

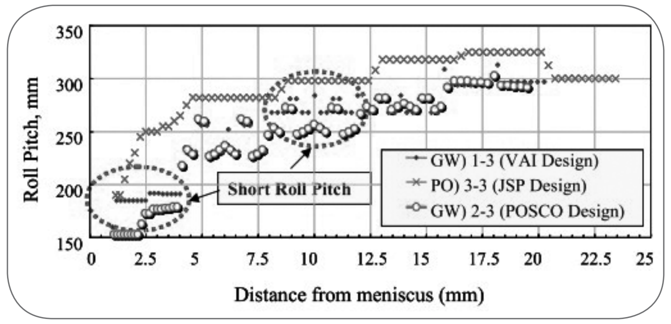

Fig. 1 ***Roll geometry (roll pitch) applied at No. 2-3 caster of Gwangyang.***
Roll geometry (roll pitch) messa in atto nel impianto No 2-3 di Gwangyang.

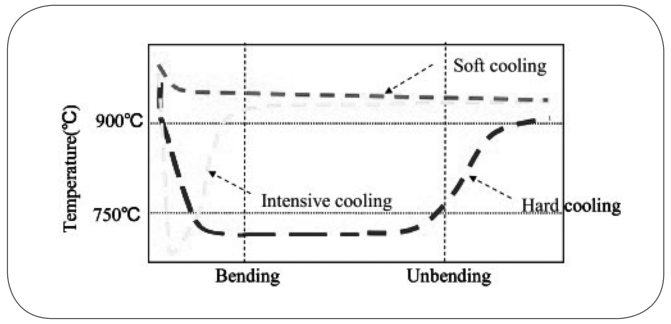

Fig. 2 ***Secondary cooling concept.***
Progetto del sistema di raffreddamento secondario.

min for LCAK, 2.5m/min for ULC and 1.8m/min for MC smoothly. In this report, the design concepts, initial operation results during casting speed increase and in particular at 2.7m/min maximum casting speed will be presented and discussed.

NEW TECHNOLOGIES APPLIED FOR THE CASTER

Roll geometry to reduce unsteady bulging

A table mould level is necessary to avoid mould powder entrapment in high speed casting.
However, because solidified shell thickness is thin as casting speed increases, the possibility of mould level fluctuation due to unsteady bulging possibility is increased.
In POSCO, severe mould level fluctuation due to unsteady bulging phenomena was experienced at one of the slab casting machines. After changing bender and upper segments, mould level fluctuation due to unsteady bulging phenomenon fully disappeared. This result gives us insight to understand unsteady bulging.
A mathematical model that can predict unsteady bulging was developed. Based on this model, roll geometry for the No. 2-3 caster at Gwangyang was designed as shown in Fig. 1. The short roll pitch concept was applied and in particular very short roll pitch was applied at bender part. The non-constant roll pitch concept was applied to minimize interference between sprays that is changed with different spray height and roll surface at the segment where spray width adjustment system is installed.

Secondary cooling system

Fig. 2 shows the cooling concepts of soft cooling, intensive cooling and hard cooling generally used to avoid crack sensitive temperature region. Even if high speed casting needs hard cooling practices, some crack sensitive steel grade still needs soft cooling and intensive cooling practices.
Secondary cooling system was designed to cover these three cooling practices. For this, air-mist cooling that has a high turn down ratio of 15 was applied.
In order to suppress the occurrence of unsteady bulging and shorten the length to the crater end position, heat should be effectively extracted from the slab surface. The concept of low head and wide angle nozzle was applied as shown in Fig. 3. Because there is space between rolls, if the nozzle tip is positioned below a roll then the spray impact area can be greatly increased. The basic experimental results of heat transfer characteristics showed that more than 20% of heat can be extracted by using this concept.
Slab corner temperature control is important to prevent corner transverse cracking for high speed casting. This is because the possibility of slab corner overcooling is increased with the intensity of secondary cooling. In order to control slab corner temperature, technologies of spray margin control and slab corner temperature measurement are necessary.
As a spray margin control system, spray width adjustment system was applied as shown in Fig. 4. Because nozzle position is changed with slab width, very precise control of spray is possible.

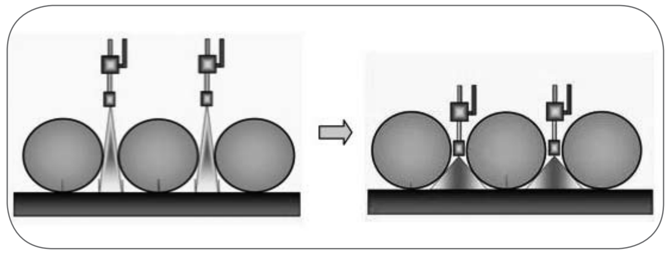

Fig. 3 ***Schematic showing the concept of low head and wide angle nozzle.***
Schema che riporta la soluzione of low head and wide angle nozzle.

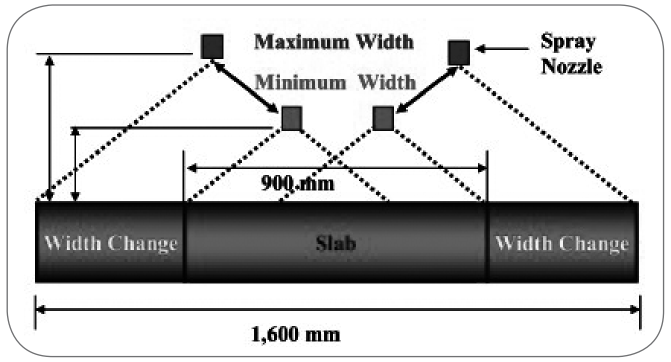

Fig. 4 ***Schematic showing the concepts of spray width adjustment system.***
Schema che riporta le caratteristiche of spray width adjustment system.

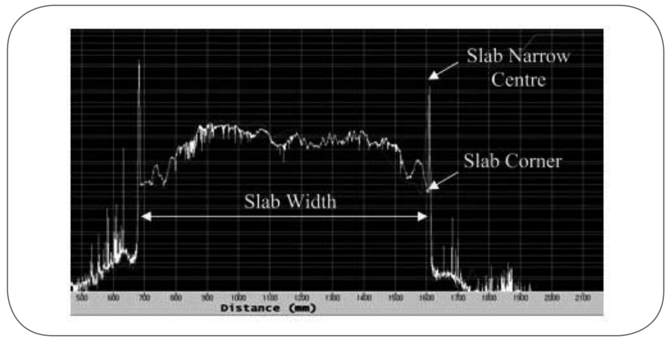

Fig. 5 ***Measured example from the temperature scanning device.***
Esempio di misura ottenuta con l'apparecchiatura di scansione della temperatura.

For slab corner temperature measurement, a temperature scanning device [3] developed by POSCO was applied. Because the distance from pyrometer to slab surface is constant during scanning, very reliable temperature measurement can be obtained. Fig. 5 shows measured example. It can be seen that slab corner temperature is easily discerned by using this device.

Stabilization of mould flow

Stabilization of mould flow under high speed was considered. The strong upward flow, especially near mould narrow face during high speed casting, makes lubrication difficult. Sometimes, this flow influences mould level movement. Mould flux is easily entrapped into the mould under the strong meniscus flow occurred under high speed casting. It is reported that the use of slowing-down mode of multi-mode electromagnetic system (MM-EMS) is useful to suppress upward flow for making flat meniscus [4] and to decrease meniscus flow.
Some steel grades need rotating mode of MM-EMS for the purpose of detaching bubbles and inclusions at the solidification front and for making uniform solidification. However, previous MM-EMS had problems with interference between rotating flow induced by stirrer and jet flow from SEN when rotating mode is applied, because the stirrer centre location is nearly the same as that of SEN port.
In order to meet high casting speed and to solve this interference problem, a movable multi-mode system (MM-EMS) was developed to control mould flow. The position of

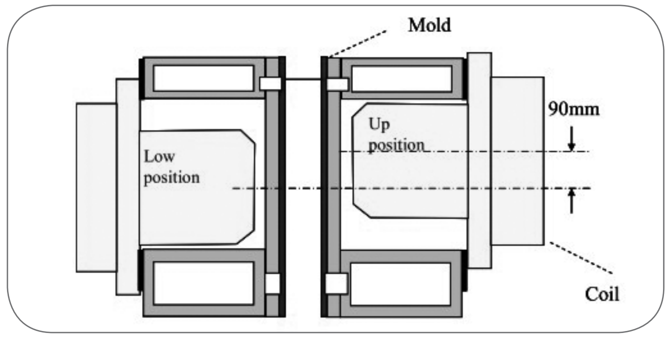

Fig. 6 ***Schematic of movable multi-mode EMS system.***
Schema del sistema mobile MM-EMS.

EM position	Mode	Sub Mode
Upper position	Rotating	Rotating direction change
Lower position	Slow-down and Accelerating	Left/Right independent control

Tab. 2 ***The relationship between position of movable MM-EMS and its function.***
Relazione tra la posizione dell' MM-EMS mobile e il suo funzionamento.

the stirrer could be changed in mould as shown in Fig. 6, and acceleration,deceleration, rotation, and other modes are supported by new movable MM-EMS.
Tab. 2 shows the relationship between position of MM-EMS and its function. Because MM-EMS has movable function, several combinations of EMS mode and position are possible.
Nail board method [4] was used to check the stabilization of mould flow by measuring meniscus shape, flow direction, flow velocity and slag pool thickness.

INITIAL OPERATIONAL RESULTS AND HIGH SPEED CASTING TRIALS

Hot test was successfully finished in Nov 2007. Fig. 7 shows the change of production after hot-test.

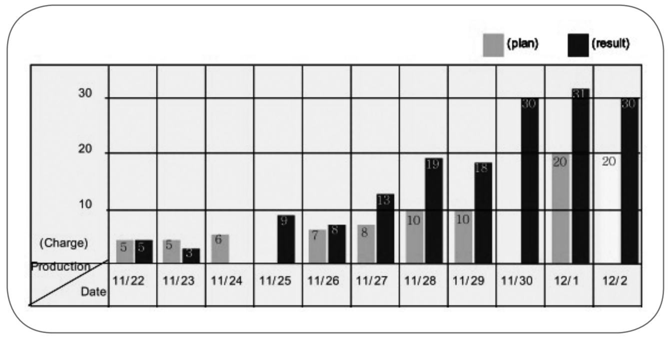

Fig. 7 ***Schematic of movable multi-mode EMS system.***
Schema del sistema mobile MM-EMS.

Within 10 days from start-up, the production rate of 30 heats/day was achieved for three consecutive days.
High speed casting tests have been performed very carefully. In order to avoid any troubles and quality loss during the high casting speed tests, many operation parameters were analyzed after finishing one high casting speed test for specific steel grades.
Mould level signal was analyzed to find specific frequency. Powder pool thickness and consumption amount were checked. The meniscus flow conditions were checked by nail board method. The heat removal of mould was also checked to determine whether this value was increased with casting speed. Strand temperature profiles to the direction of slab width and thickness were checked for cold spots on the slab surface. The pin shooting test was performed to find crater end position. The heat transfer model was updated after every test by using the measurement results of surface temperature profiles and solidification profiles.

Steel Grade	Date	Casting speed (width)	Remarks
LCAK	'08.12.18	2.5 m/min (1,180 mm)	
	'08.01.17	2.6 m/min (1,240 mm)	- Throughput: 6.5 ton/min/strand
	'08.02.01	2.6 m/min (1,000 mm)	
	'08.02.14	2.7 m/min (930 mm)	- 3 consecutive charge
ULC	'08.02.29	2.3 m/min (1,049 mm)	
	'08.03.18	2.5 m/min (1,000 mm)	
MC	'08.03.06	1.8 m/min (1,140 mm)	

Tab. 3 **Details of high speed casting test for LCAK, ULC and MC.**
Dettaglio delle prove di colata ad alta velocità per LCAK, ULC and MC.

Tab. 3 summarizes test details for high speed casting for LCAK, ULC and MC. For LCAK, casting speed of 2.4 m/min was achieved immediately after start-up. The maximum casting speed of 2.7 min was achieved for 3 consecutive charges on Feb. 14 2008. High throughput of 6.5 ton/min/strand was also achieved after 60 days from start-up.
For ULC, casting speed to 2.5m/min was achieved immediately after finishing high casting speed test of LCAK. For MC, the high speed test is performing with the development of mould powder.

RESULTS FOR HIGH SPEED TEST

Results of maximum casting speed of 2.7m/min for LCAK

Fig. 8 shows the trends of casting parameters monitored by the POSCO CCMS system during maximum casting speed test of 2.7m/min. The x-axis is time after casting start. In the figure, Vc is casting speed and S/N open is opening ratio of sliding gate. After 2.5m/min, casting speed of 2.7m.min was reached and maintained for three consecutive charges. During high speed casting test at 2.7m/min, any troubles and any quality loss did not occur. It can be seen that mould level is well controlled and there is no problem with SEN nozzle clogging.

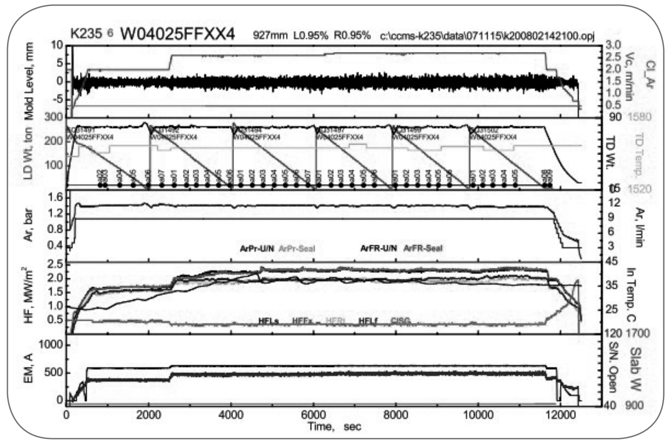

Fig. 8 **Trends of casting parameters monitored by POSCO CCMS system during maximum casting speed test of 2.7 m/min.**
Andamento dei parametri di colata rilevati con il sistema POSCO CCMS in occasione delle prove di massima velocità a 2.7 m/min.

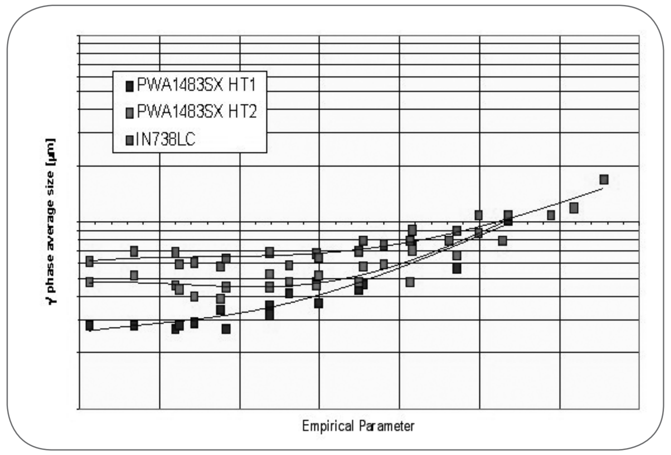

Fig. 9 **RMS value of mould level according to casting speed.**
Valore RMS of mould level in funzione della velocità di fusione.

Fig. 9 shows RMS value of mould level according to casting speed. It can be seen that the mould level is controlled within ±2mm and there is no tendency of increasing mould level deviation with casting speed and steel grade.
This stable mould level seems to be related to roll geometry and cooling conditions. Before making the high speed test, the calculation model predicted unsteady bulging.. Fig. 10 (a) shows FFT results predicted under the casting condition of 2.7m/min. Even if a specific peak appeared at 0.15Hz, the amplitude of this frequency was very small. It means that unsteadybulging did not occur under the current roll geometry and cooling conditions. Fig. 10 (b) shows FFT results of mould level obtained under the actual casting condition of 2.7m/min. There is very good agreement between the predicted and the measured values.

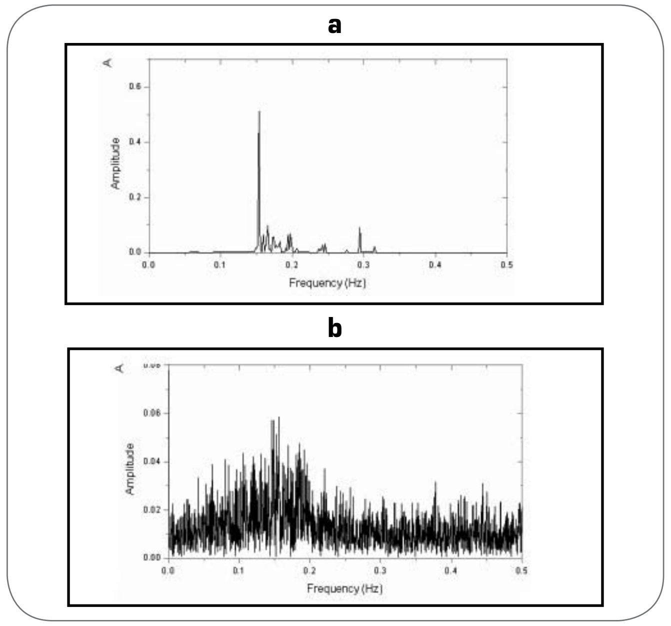

Fig. 10 **Comparison of FFT results of 2.7 m/min between predicted and measured. A9 The predicted; b) the measured.**
Confronto tra i risultati FFT a 2.7 m/min calcolati e misurati.

Meniscus flow conditions were checked by nail board method under the casting conditions of 2.7m/min. Fig. 11 shows the slag and steel profiles. It can be seen that meniscus profiles are very flat. The use of braking mode of movable multi-mode system seems to be effective to make flat meniscus.
Fig. 12 shows strand surface temperature profiles to the direction of slab width measured by a temperature scanning device located near straightener method under casting conditions of 2.7m/min. The slab centre temperature appeared to be about 810 degrees C. This low strand surface temperature near the slab centre seems to be effective to suppress strand bulging. Slab corner temperature was well discerned because of a sharp peak appearing at both ends. Slab corner temperature was about 780 degrees C. These sharp peaks are due to slab narrow face temperature.
Sharp peaks mean that slab temperature at slab narrow face centre is high and there is bulging.
Actually, 15mm bulging occurred at slab narrow face centre.
During high casting speed test of 2.7m/min, crater end position was measured by pin shooting method. Fig. 13 shows specimen in which pins were shot. Because crater end position was approximately predicted by computation, two positions near the segment were selected as pin shooting position. Here, Seg.18 is final segment for this caster. It can be seen that after segment 18, melted flow did not appear on pin surface. It means that this position is fully solidified. However, in the case of the pin shot before segment 18, melted flows did appear. Based on this result, the solidification calculation model was calibrated. This model predicted the crater end position as 45.5m, that is 1m before caster exit. This result says that 2.7m/min is the maximum casting speed that can be obtained for this caster.
Based on crater end position according to casting speed, the solidification factor was calculated as shown in Fig. 14. Here, the value of solidification factor for 3m/min was calculated based on Fukuyama caster2). At the casting speed of 2.7m/min, the solidification factor appeared to be 30.8 m/min.
Casting speed (m/min)Slab quality had been checked during high speed casting test of LCAK. Quality problems related to inclusions and cracks did not appear. This seems to be because stable meld level is maintained, nozzle clogging does not appear and slab surface temperature profiles were well controlled during high speed casting.

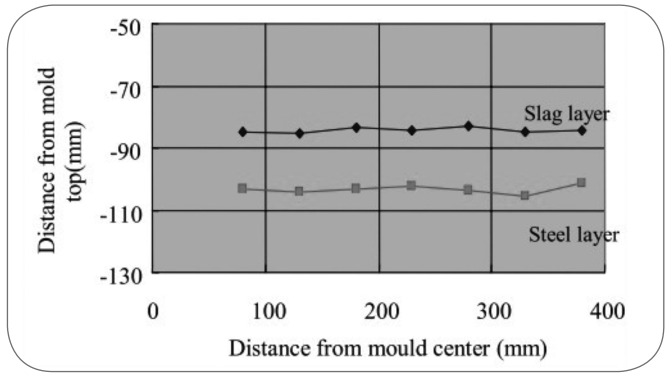

Fig. 11 **Steel and slag profiles at meniscus measured by nail board method.**
Profili dell'acciaio e della scoria al menisco, misurati col metodo nail board.

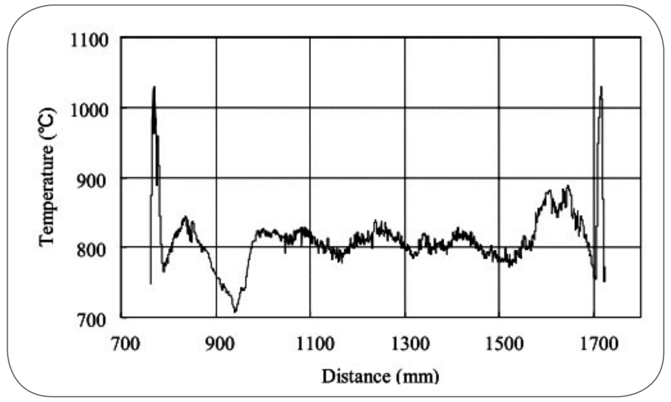

Fig. 12 **Strand surface temperature profiles to the direction of slab width obtained by temperature scanning device.**
Profilo termico in direzione dello spessore della bramma ottenuto con l'apparecchiatura di scansione di temperatura.

Results of high speed casting test for ULC

After reaching the maximum casting speed for LCAK steel, a similar high speed casting test was performed on ULC. Casting speed to 2.5m/min was easily achieved under similar casting conditions to LCAK. Because there was a possibility of narrow face bulging for ULC, narrow slab face cooling intensity was

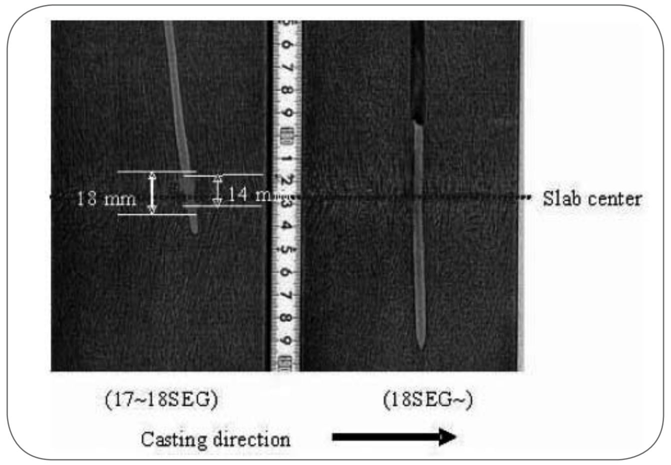

Fig. 13 **Specimen in which pins were shot.**
Campione in cui vengono disciolte le linguette.

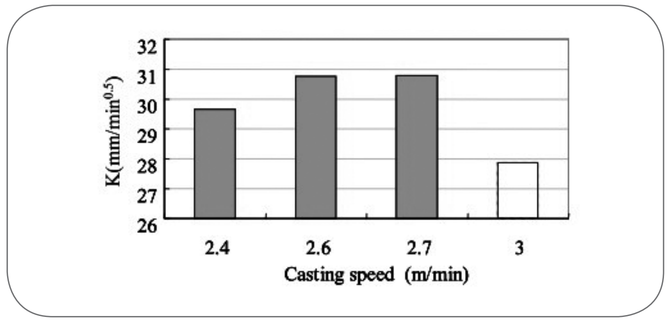

Fig. 14 **Solidification factor according to casting speed.**
Fattore di solidificazione in funzione della velocità di colata.

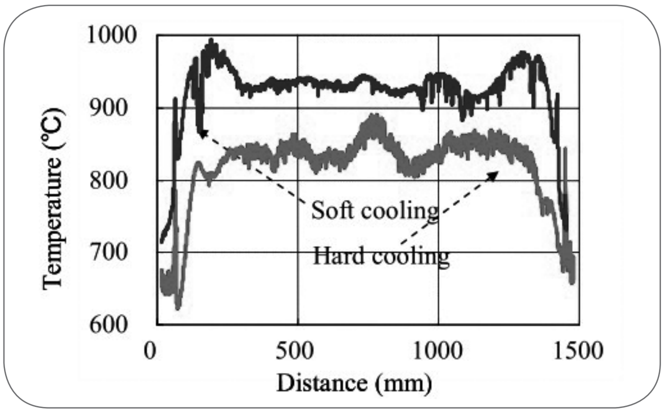

Fig. 15

Comparison of temperature profiles between soft cooling and hard cooling.

Confronto dei profili di temperatura nel caso di soft cooling and hard cooling.

increased. Due to optimization of narrow side cooling, narrow face bulging appeared to be similar to that of LCAK. During the high speed casting test of ULC, meld level was controlled within ±2mm and nozzle clogging did not appear. The use of Ar automatic control system was useful to control Ar amount precisely for ULC. Inclusion problems related to mould flux and Al2O3 were not observed under high speed casting.

Results of high speed casting test for MC

Stable meld level of No.2-3 caster at Gwangyang was very useful to make high speed casting test for MC. In order to avoid corner transverse cracking of MC, two different cooling practices were compared as shown in Fig. 15. One is soft cooling that has 850 degree C and 920 degree C as corner temperature and slab centre temperature respectively. The other is hard cooling that has 620 degree C and 830 degree C as corner temperature and slab centre temperature respectively. The latter case gave good results regarding corner transverse cracking under high casting of MC.
Due to hard cooling strategy and precise control of slab corner temperature, increase of casting speed for MC was possible. The high speed casting for MC is performing with the development of meld powder.

CONCLUSIONS

In order to produce 3.5 million tonnes per year of the automotive steel grades, many technologies for high casting speed have been developed and implemented during revamping of the No.2-3 caster at Gwangyang. High casting speed tests for LCAK, ULC and MC have been performed. The following conclusions were made.
1) High speed casting to 2.7m/min for LCAK was achieved. Quality problems related to inclusions and cracks did not appear. This seems to be because stable meld level is maintained, nozzle clogging does not appear and slab surface temperature profiles were well controlled during high speed casting of 2.7m/min.
2) During high speed casting, mould level deviation did not increase with casting speed. The newly designed roll geometry and the application of hard cooling were very effective for maintaining stable mold level.
3) The use of slowing-down mode of MM-EMS was useful to make flat meniscus under the casting speed of 2.7m/min
4) Solidification factor appeared to be 30.8m/min at the casting speed of 2.7m/min.
5) With the use of spray width adjustment systems and temperature scanning devices it can be possible to control slab temperature very precisely. The use of hard cooling for slab corner is effective to avoid corner cracking of MC of high speed casting.

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ABSTRACT

AMMODERNAMENTO DELLA LINEA NO. 2.3 DI COLATA DI BRAMME PRESSO LO STABILIMENTO POSCO DI GWANGYANG: PROGETTAZIONE, AVVIAMENTO E PRIMI RISULTATI OPERATIVI

Parole chiave: colata continua, tecnologie, acciaio

Uno degli obiettivi del piano di ammodernamento della linea di colata n ° 2-3 presso lo stabilimento Posco di Gwangyang era quello di avere una capacità di produzione annuale di 3,5 milioni di tonnellate/anno, per l'applicazione nel campo automobilistico. Data una lunghezza della linea di colata di 47 m, il requisito di base è quello di raggiungere una velocità di colata di 2,7 m/min per bramme con sezione di 1600 mm x 250 mm. Al fine di garantire un'operatività stabile per questa linea di colata ad alta velocità, nel processo di rinnovamento sono stati recentemente sviluppati e attuati diversi interventi tecnologici. La geometria del rullo è stata progettata per ridurre al minimo la le oscillazioni del livello della lingottiera dovute a fenomeni di rigonfiamento instabile.
E' stata applicata la soluzione del Raffreddamento Secondario Intensivo per diminuire la dimensione del cratere finale, e per diminuire la criccatura trasversale agli spigoli applicando i concetti di controllo della struttura della superficie [1]. Un sistema elettromagnetico mobile multi-mode è stato progettato per condizionare il flusso della lingottiera per soddisfare diverse condizioni operative. Un sistema di controllo automatico dell'argon è stato applicato all'ugello di colata per ridurne al minimo l'otturazione.
La linea di colata è stata avviata nel novembre 2007 ed ha permesso di raggiungere la velocità di colata di 2.7 m/min molto rapidamente. Questo documento esamina il comportamento del livello della lingottiera, il flusso superficiale e la temperatura di raffreddamento secondario in relazione a larghezza e spessore di bramme che sono stati sperimentati in occasione dell'aumento della velocità di colata e in particolare allorché si raggiunge la massima velocità pari a 2.7 m/min. Vengono anche presentati i risultati iniziali relativi a produttività e qualità delle bramme prodotte.