LIBRARY SEARCH ON INFLUENCE OF OSCILLATION PARAMETERS ON SURFACE QUALITY OF BILLETS & BLOOMS

Number of references: 15

1) **Amplitude-modulated Magnetic Field Coupled with Mold Oscillation in Electromagnetic Continuous Casting.** Z. Lei, Z. Ren, K. Deng, W. Li, Y. Zhong. ISIJ International, Vol. 46 (2006), No. 5, pp. 680–686

Molten metal meniscus profile and mold flux channel width were measured under high frequency magnetic field by model experiments, then the dynamic pressure in mold flux channel were calculated during one mold oscillation period. It is found that the high frequency magnetic field can decrease the dynamic pressure greatly, which may be one mechanism of improving the billets surface quality by the soft-contact mold electromagnetic continuous casting. Based on this study, a novel technology named Amplitude- Modulated Magnetic Field (AMMF) coupled with mold oscillation in electromagnetic continuous casting was proposed in order to balance the dynamic pressure caused by mold oscillation with a varied electromagnetic force inducted by AMMF. Based on the calculation of mold flux channel dynamic pressure, a model to optimize design of AMMF was proposed. Then continuous casting experiments under AMMF coupled with mold oscillation were carried out. It is shown that AMMF is effective in reducing the friction force during continuous casting and improving the billets surface quality.

2) **Cold Model Experiment on Infiltration of Mould Flux in Continuous Casting of Steel: Simple Analysis Neglecting Mould Oscillation.** T. Kajitani, K. Okazawa, W. Yamada, H. Yamamura. ISIJ International, Vol. 46 (2006), No. 2, pp. 250–256

A new cold model of continuous casting is developed to clarify the infiltration of mould flux into channel between a mould and a solidifying shell. In the experiment, silicone oil is poured and infiltrated down into the channel between an acrylic plate and a moving belt. In contrast with most of the previous analyses that assumed a fixed thickness of the liquid flux film, this model is based on an idea that the thickness can be varied depending on the balance of forces acting on the shell: static pressure in the molten steel pool, and dynamic and static pressure in the mould flux channel. Furthermore, a linear gauge sensor that is in contact with the acrylic plate monitors the film thickness of oil, while in continuous casting the thickness of mould flux cannot be measured during the operation. Simple experiments without oscillating motion clearly reveal that the infiltration behavior is largely dependent on the profile of channel: In the channel that becomes narrower in downward direction, the infiltration of oil is enhanced with the increase of both belt velocity and oil viscosity. In contrast, for the channel that becomes wider along the downward direction, the increase of the velocity and the viscosity reduces the oil infiltration. In continuous casting operation, the increase of both casting velocity and viscosity of mould flux decreases the mould flux consumption.

Those observations indicate that the infiltration of mould flux is strongly governed by the channel that becomes wider in casting direction.

3) **Dynamic pressure in mould flux channel during mould non-sinusoidal oscillation** H. Wang, G. Li, Y. Zhao, H. Zhao. Ironmaking and Steelmaking 2010 VOL 37 NO 6

Based on the lubrication theory of mould flux, a mathematical model of dynamic pressure in mould flux channel was developed, and the distribution of dynamic pressure and its variation during non-sinusoidal oscillation were investigated. The effects of casting speed and nonsinusoidal oscillation parameters, including the degree of non-sinusoidal operation (nonsinusoidal factor), amplitude and frequency of oscillation on the dynamic pressure in the mould flux channel, were studied. The results indicate that the maximum negative pressure is decreased, and the maximum positive pressure is increased with increasing non-sinusoidal factor. The optimum value of non-sinusoidal factor is ,0?2. With increasing amplitude and frequency of oscillation, both the negative and positive pressure are increased; moreover, the increment of positive pressure is obviously greater than that of negative pressure; especially when the oscillation frequency is increased, the increment of negative pressure is very little. When the casting speed is enhanced, the negative pressure is increased, but the positive pressure is decreased. Therefore, if the casting speed is increased, the oscillation amplitude needs to be increased, as well as the oscillation frequency needs to be decreased properly. With these adjustments, the positive pressure in mould flux channel is nearly unchanged. The actions of strand demoulding and cracks welding are kept effective. Moreover, the negative pressure in mould flux channel is increased properly, which causes the flux consumption to increase, so the mould lubrication is improved. Finally, the strand surface quality is improved greatly, and breakout can be avoided. The applicability of the optimised non-sinusoidal oscillation parameters for the two kinds of casting speed has been proven by industrial practice.

4) **Effects of oscillation waverform on the surface quality of SBQ billets.** W. Fuchs, S. Lemgen, H. Roelofs, C. Tercelli.

Von Moos Stahl AG in Emmenbrücke, Switzerland, produces 470,000 tpy of wire, rods and bars mainly for the automotive industry. Von Moos operates a three-strand Convex Technology caster installed in 1998. In August 2001, one strand of the caster was fitted with hydraulic oscillation and a comprehensive series of tests aimed to determine what, if any, advantages hydraulic oscillation might have over the existing system. During the trials, several differently shaped oscillation curves have been tested, together with different modes of varying frequency and stroke depending on the casting speed. The paper presents the results of this test campaign, focusing on the effect of the oscillation parameters on surface quality, as well as on operational aspects.

5) **Experimental study of the formation of oscillation marks in continuous casting of steel billets.** J. Elfsberg, B. Widell, H. Fredriksson. KTH/Casting of Metals, S-100 44 Stockholm, Sweden

The initial solidification is very important for the surface quality of the material from continuous casting processes. The liquid metal forms a meniscus and a metal shell starts to solidify in the upper part of the oscillating mold. During the first stage of solidification, surface marks called oscillation marks are formed. The formation mechanism of the oscillation marks needs to be known to optimize the process. An experimental study of the formation of oscillation marks on steel billets has been performed. For each steel grade, the sulphur content was varied within the limitations of the alloy. The contents of other alloying elements were kept as constant as possible. A number of charges were cast with constant casting rate and varying oscillation frequency. The cast surface profile was measured using a surface profilometer. From the profiles the distance between the oscillation marks could be determined. The depth of the oscillation marks varies in a periodic way. There are about two to ten more shallow marks between deeper ones. Our results indicate that there is, for a given casting speed, an optimal oscillation frequency. The frequency depends on the interfacial tension between steel and slag. Using this optimal frequency, the appearance of the marks will be more regular. In our future work we will include the convective movements of the melt and the oscillation of the mould in the model.

6) **Experimental study on mould oscillation-less continuous casting process under high frequency amplitude-modulated magnetic field.** Z. Lei, Z. Ren, K. Deng, W. Li, H. Wang. ISIJ International, Vol. 44 (2004), N$_0$. 11, pp. 1842-1846

In order to investigate the influence of high frequency magnetic fields on surface quality billets in the soft-contacted electromagnetic continuous casting, several kinds of high frequency Amplitude-Modulated Magnetic Field (AMMF), that is, triangle and sine wave AMMF, were adopted in this experimental research. The magnetic field flux in the mould and the intermittent contacting distance were measured. The experiment of Mould Oscillation-Less Electromagnetic Continuous Casting (MOLECC) of tin under the three wave kinds of AMMF were carried out. Ot is shown that: (1) During the MOLECC process under the rectangle, triangle and sine wave AMMF, when the modulated wave frequency is a little lower than the intrinsic frequency of the experimental system the intermittent contacting distance is the greatest, the mould flux lubrication is the best, the continuous casting withdrawing resistance is the least and the surface quality of billets is the best. (2) Among the three kinds of AMMF, sine wave is the best in deducing the withdrawing resistance and improving the billets surface quality.

7) **Improvement of surface quality of continuously cast billet by high cycle mold oscillation.** H. Yasunaka, T. Mori, T. Kominami, Y. Onoe, S. Harada.

The influence of mold oscillation conditions on the oscillation mark depth and surface quality of continuously cast billets were investigated using a billets continuous casting machine. The oscillation mark depth was reduced by increasing the mold oscillation cycle. The number of transverse cracks formed at the bottom of the oscillation mark can also be reduced by increasing the mold oscillation cycle. Additionally, transverse crack formation can be prevented at an oscillation cycle over 6 Hz.

8) **Mold oscillation monitoring – operational and maintenance tool.** J. Williams.

As competition increases within the steel industry, it is crucial for organizations to operate with the most efficiency and yield high quality products. The mold oscillator is a key component in the steel making process and its malfunction directly impacts the surface quality of the product. For either a value added or low grade commodity producer, a mold oscillation monitoring system can reduce operating and maintenance costs typically incurred for premature equipment replacement.

9) **Mould oscillation monitoring in continuous casting.** J. Ciriza, G. de Toledo, J. Laraudogoitia, M. Carboni, J. Bolota. XXXV Seminário de Fusão, Refino e Solidificação dos Metais, 2004 **(in Portuguese)**

Abnormal performance of critical operational elements of the continuous casting machine (CCM) can produce surface defects on continuous casting (CC) products or even break-outs. Moreover, surface and sub-surface defects in the CC semis are not usually along all the semis length, but only in some places, highlighting the existence of transitory phenomena. Those facts have shown the importance of reaching stable CC operation conditions and the need of knowing when transient conditions are happening during casting. To achieve that involves several things: to identify relevant CC parameters, to monitor them, to identify abnormal transient values and to relate transient values to semis quality. Both, off-line and on-line, mould monitoring techniques have been employed by SIDENOR I+D including mounted sensors (accelerometers, linear voltage displacement transducers (LVDT), strain gauges) and instrumented moulds. This paper pays special attention to the assessment of the friction between billet and mould and its application for breakout forecasting using advanced on-line monitoring techniques. An index for billet-mould friction assessment has been defined using strain gauges installed in the cam rod of the oscillation mechanism. Through the study of the information related to casting parameters prior to fifty-eight breakouts it was concluded that almost 50% of them could have been forecast through the behaviour of the monitored parameters prior to the breakouts. A monitoring program called SIROL has been developed to judge on-line the CCM performance. Another index for billet-mould friction assessment, using accelerometers placed in the oscillating mould cassette, has been recently obtained; and in this paper the preliminary results are presented. It can be said that the mould monitoring is a useful tool to improve the system operation and product quality as well as to optimise the predictive maintenance work.

10) **Mould-strand interaction in continuous casting of steel billets. Part II Lubrication and oscillation mark formation.** J. Brendzy, I. Bakshi, I.V.

Samarasekera, J.K. Brimacombe. Ironmakign and Steelmaking, 1993, Vol. 20, No. 1

Load cells, placed between the mould assembly and the oscillator table, have been employed to measure load variations during mould oscillation and to evaluate the performance of three different lubrication oils. During the upstroke of the mould oscillation cycle, the compressive load detected by the load cells is a maximum and is characterized by a plateau with numerous small peaks, provided there is no sticking or binding. A smooth decompression of the load occurs when the mould is moving down faster than the strand. These results indicate that oscillation marks during the negative strip period, resulting decoupling between the shell and strand, which reduces mould load. It has been found that the role of oil is to prevent sticking between the newly forming shell and the mould. At low flowrates, depending on the type of oil, sticking can commence and is manifested as an increase in maximum load during the upstroke period. The maximum load also increased when casting low carbon steels, particulary with carbon contents in the range 0.035-0.05 % carbon billets, and to a lesser extent the 0.09-0.10% carbon billets, had transverse surface depressions and cracks. The large variation in maximum load recorded when casting these grades is related to binding in the mould, which in turn is responsible for the formation of transverse depressions and cracks.

11) **Triaxial system to control the mold oscillation: impact, applications and benefits in the brazilian iron and steel industry.** N. Tozato **(in Spanish).** 14th IAS Steelmaking Conference, 2003, San Nicolas, Argentina

A portable system based on triaxial accelerometers has been used to monitor the performance of mold oscillation in several Brazilian casters. The system employs triaxial accelerometers to measure the acceleration of the mold in the vertical direction (Yaxis), in the two horizontal directions, perpendicular to the narrow face (X-axis) and to the wide face (Z-axis). Through the acceleration signals, collected by a portable computer, the speed and the mold displacement in the three axes are calculated, using frequency analysis techniques. Furthermore, the system is capable of calculating the following parameters:
· Frequency and primary amplitude of mold oscillation in the vertical address (Y-axis).
· Amplitude (displacement) of the mold movement in two horizontal directions (X-axis and Z-axis).
· Frequency and amplitude of oscillation originated in external sources (undesirable) in the three axes.
· Positive and negative time and ratio phase, residual displacement, mold lead, friction, mold asymmetry, low, medium and high frequency vibrations.
These features converted the system in an excellent tool for the monitoring of the mold oscillation, adapted to process control and for the maintenance of the Brazilian casters.

12) **Trials for reducing depth of oscillation marks in continuous casting.** M. Kudoh, Y. Itoh. Steel Research 74 (2003) No. 3 pp. 147-152.

Improvement of surface defects in continuously cast slab or billet is important for saving surface scarfing and for carrying out direct rolling. Deep oscillation marks, one type of the surface defects, sometimes cause surface cracking and positive segregation. In this study, the mechanism by which oscillation marks are formed was investigated by using a continuously cast simulator, which is a billet type machine. Then attempts were made to reduce the depth of oscillation marks by two methods in which electromagnetic force, which is the most effective means for reducing depth, was not used. The two methods were use of an adiabatic board for preventing solidification of a meniscus and the use of a board for suppressing the flow of flux. Overlapping of a molten metal on a meniscus resulted in formation of oscillation marks in tin. On the other hand, bending of a solidified shell also resulted in formation of oscillation marks in a tin lead alloy. The depth of the oscillation marks formed by the overlapping mechanism was greater than that formed by the bending mechanism. Both mechanisms depended on the strength of the solidified shell. Therefore, two trials to reduce the depth of oscillation marks formed by the overlapping mechanism were carried out. In one trial, an adiabatic board was inserted into the molten metal. Reduction in depth of the oscillation marks reduced up to about 86% was achieved when high viscosity flux was used. However, the adiabatic boar was not effective when low viscosity flux was used. In the other trial, a board was inserted into a molten flux layer with a depth of 10 mm in depth in order to suppress the flow of the flux and to change the direction of flux flow, and the depth of oscillation marks was reduced by about 33 %. Therefore, both of these methods are effective for reducing the depth of oscillation marks in a continuously cast billet.

13) **Use of a multi-sensor technique to monitor the mould oscillation in a continuous billet caster.** P. P. Sahoo, S. Basu. ISIJ International, Vol. 46 (2006), No. 2, pp. 219–225.

Producing a defect free product is most important in the process of continuous casting as the defect may propagate to the end product and also can increase the downgrading. Inadequate oscillation parameters as well as a defective oscillation may greatly affect the surface quality of the cast product. So monitoring friction along with the oscillation profile of the oscillator can lead to take corrective action when there is an increase in friction between the mould and strand or if there is any wear and tear in the machine components. In the present work a multi-sensor based mould oscillation monitoring system was developed to monitor the mould health as well as the friction between the mould and strand of a billet caster. Friction force was calculated for different carbon composition, type of lubrications and was co-related with the surface quality of billets. Also monitoring the mould health was able to detect problems in the machine and corrective action could be taken care of in time.

14) **Effect of transverse depressions and oscillation marks on heat transfer in the continuous casting mold.** B. G. Thomas, D. Lui, Ho. The Minerals, Metals, & Materials Society, Warrendale, PA., 1997. pp. 117-142.

Results from mathematical models and plant experiments are combined to quantify the effect of transverse depressions and oscillation marks on heat transfer in the continuous casting mold. A heat transfer model has been developed to calculate transient heat conduction within the solidifying steel, coupled with the steady-state heat conduction with the continuous casting mold wall. The model features a detailed treatment of the interfacial gap between the shell and mold, including mass and momentum balances on the solid and liquid powder layers. The model predicts the solidified shell thickness down the mold, temperature in the mold and shell, thickness of the resolidified and liquid powder layers, heat flux distribution down the mold, mold water temperature rise, ideal taper of the mold walls, and other related phenomena. The important effect of non-uniform distribution of superheat is incorporated using the results from previous 3-D turbulent fluid flow calculations within the liquid cavity. Results from plant experiments confirm that transverse surface depressions and oscillation marks form at the meniscus and move down the mold. Measurements of mold thermocouple temperatures and breakout shell thickness were used to calibrate the models. The results indicate that the surface depressions and oscillation marks are filled with mold flux, but still have a significant effect on decreasing heat transfer. The predicted mold temperature fluctuations are consistent with measurements. If the depressions become filled with air, their effect is greatly increased. These results should be useful in the difficult task of interpreting transient mold thermocouple signals for on-line quality monitoring.

15) **Investigation of strand surface defects using mould instrumentation and modelling.** B. Thomas, M. Jenkins, R. Mahapatra. Ironmaking and Steelmaking 2004 VOL 31 NO 6

The surfaces of continuously cast steel blooms exhibit a variety of surface features and defects, which were investigated to reveal the interactions at the meniscus between the steel shell and interfacial flux layers that caused them. One such defect formed at periodic intervals along the surface of first and second blooms in a sequence. It was characterised by gradually deepening oscillation marks, followed immediately by longitudinal striations or ‘glaciation marks’. In severe cases, deep depressions were clearly visible within the glaciated region. These defects were investigated through plant trials and both physical and mathematical modelling. The defects were found to exhibit a characteristic temperature history: temperature troughs that move down the mould at the casting speed. These defects may be monitored in much the same way as sticker breakouts, thereby allowing existing thermocouple based breakout detection systems to be modified to include a quality alarm. This study attributes these defects to high amplitude, low frequency, mould level fluctuations. A mechanism is proposed which ascribes the generation of these defects to the interaction of the meniscus with the slag rim at peaks in the mould level cycle. Installing an improved mould level control system eliminated the defects.

16) **Optimum design and operation of moulds for the continuous casting of steels billets.** J.K. Brimacombe, I.V. Samarasekera, R. Bommaraju.

The mould employed for the continuous casting of steels billets is simple in design; but its behaviour during operation is complex and its impact on billet quality is profound. A research programme spanning nearly a decade has been conducted at UBC to elucidate the thermomechanical behaviour of the mould and to link mould design and operation to billet quality and operating problems. This work, much of it done on operating casting machines, has revealed that quality problems such as off-squareness (ovality in rounds) and off-corner internal cracks, together with casting problems like breakouts and hanging in the mould, frequently originate close to the meniscus. It is in this region that the mould is hottest and distorts due to differential thermal expansion. The distortion, coupled with mould oscillation, causes the mould to interact mechanically with the newly solidified shell to form oscillation marks on the surface of the billet. This in turn affect the width of the mould/billet gap which governs the local heat extraction by the mould. The achievement of billet quality depends fundamentally on controlling the uniformity of the oscillation marks and minimizing their depth ie. achieving uniform mould heat extraction around the periphery of the billet and maximizing local heat transfer.