Journal of Process Control 29 (2015) 1–10

Contents lists available at ScienceDirect

Journal of Process Control

journal homepage: www.elsevier.com/locate/jprocont

# Novel mold breakout prediction and control technology in slab continuous casting

Fei He*, Li Zhou, Zhi-hao Deng

*School of Metallurgical Engineering, Anhui University of Technology, Ma'anshan, Anhui, 243002, China*

ARTICLE INFO

*Article history:*
Received 19 September 2014
Accepted 3 March 2015
Available online 29 March 2015

*Keywords:*
Continuous casting
Mold
Sticking-type breakout
Logic judgment model
Recovery behavior
Breakout prevention

ABSTRACT

To realize smooth and high speed continuous casting, the urgent problem is to control the sticking-type breakout efficiently. In addition to improving casting process conditions of inducing stickers, the key is to develop active and accurate breakout prediction and healing control technology. In this paper, a novel logic judgment model for predicting stickers is presented, which is designed for more rows of thermocouples (TCs) in high density, and uses temperature change rate and vertical and horizontal detections to well recognize sticker propagation. Simulation results indicate that new model can accurately and timely detect all stickers, and has a good robustness. After sticking alarm, dynamic control strategies of casting speed according to the location of alarmed thermocouples are proposed for breakout prevention, by investigation on formation mechanism and recovery behavior of sticking-type breakout. The proposed model and control strategy have been validated through its application on a steel plant. The results show that the detection ratio for stickers and frequency of false alarm are 100% and 0.15% times/heat respectively, and the healing rate of the stickers has reached 100%. The case in which breakout still occurs after alarm has been eliminated. The present technology has achieved better performance in prediction and control of the sticking-type breakout and satisfies the requirement for field application.


## 1. Introduction

In slab continuous casting, the breakout is a serious quality accident which occurs when strand surface defects (such as sticking and cracks) develop to a certain extent. It will not only disturb stable production pace, but also damage the devices of the caster, and result in huge economic losses. In the actual production, the sticking-type breakout is the most frequent type among all kind of breakouts, which accounts for about 70% to 80%. Especially with the development of modern continuous casting technology with high-efficiency, stable and high speed casting has become important tendency. However, the increase of casting speed leads to a more complex mold heat transfer, friction and lubrication, and other issues, which increases greatly the occurrence of the sticking-type breakout. So reducing the sticking-type breakout is the key to realize stable slab quality and high production.

Formation mechanism of sticking-type breakout has been widely studied. A comprehensive explanation is that formation of sticking-type breakout includes formation and propagation of sticker [1,2]. The original sticking initiates near the meniscus. When the forces acting on initial solidified shell exceed its shear strength due to larger mold level fluctuation or poor lubrication between mold and shell, etc., the shell is easier to be torn and stick to the mold. As shown in Fig. 1, at the beginning of positive period, the shell is torn, and when mold moves upward, the rupture increases and hot liquid steel inflows, and new shell is quickly solidified due to cooling of copper plates. And then, with the vibration of mold and downward movement of slab, the shell is torn and re-solidified again and again, and the tear line moves downward. This is propagation behavior of sticker. When the tear moves to mold exit, a breakout will happen. So the direct cause of the sticking-type breakout is the rupture of initial solidified shell at the meniscus. Here, the typical appearance of a sticker breakout shell is V-shaped tear line.

An interesting issue about inducing factors of stickers has been discussed strongly [3–9]. The factors include steel grade, degree of superheat of liquid steel, casting speed, mold level fluctuation, mold powder, heat flux, etc. Improving casting conditions of inducing the sticker can avoid the sticking phenomenon at the source. But the sticking-type breakout is still difficult to be completely avoided in the actual production process owing to their complexity. At present, effective method is to detect and predict actively potential sticking phenomenon by measuring mold temperature change by means of thermocouples embedded in mold's copper

* Corresponding author. Tel.: +86 18255565957.
*E-mail address:* hf2573546@sina.com (F. He).

http://dx.doi.org/10.1016/j.jprocont.2015.03.003
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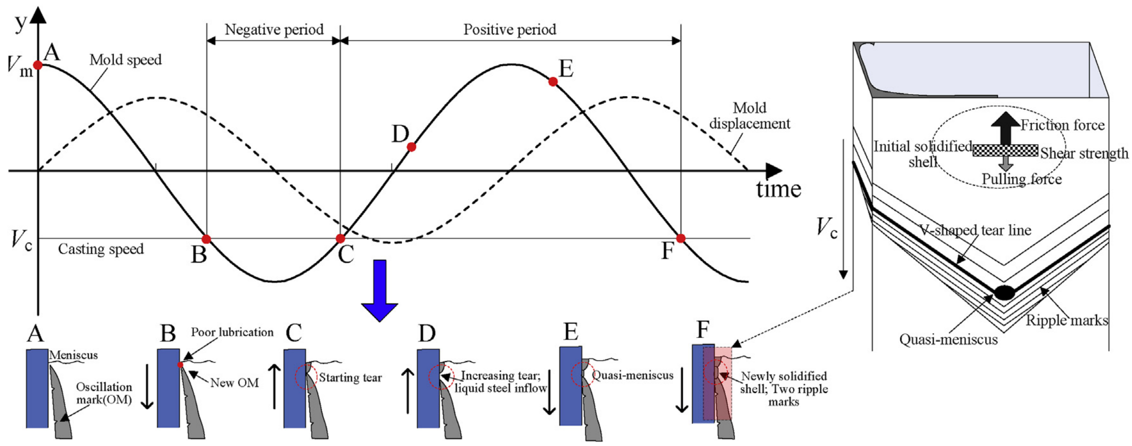


**Fig. 1.** Formation mechanism of sticker.

plates, and then prevent a breakout by reducing casting speed or other measures.

Many breakout prediction technologies have been developed, which can divided into two types: logic judgment method [2,10–16] and intelligent method [17–22]. Although the intelligent method has better prediction accuracy and fault tolerance for solving actual nonlinear problems, it depends on the learning data excessively and lacks the technological guidance, and it is seldom applied in practice successfully. Logic judgment method has been widely used for breakout prediction. But the logic algorithms and arrangement of the thermocouples (such as one row, two rows, three rows or multiple rows) are different. The logic algorithms play an important role in reducing sticking-type breakouts. However, in practical application, they still have high false alarm rate and poor robustness, due to thermocouples' failures or uneven growth of shell, etc. High false alarm rate also affects slab quality and stable production. The issues must be considered for design of logic algorithms.

After sticking alarm, reducing casting speed is main method of the recovery of the sticker and breakout prevention. Many researchers [10,23–26] have investigated recovery behavior of stickers and deduced recovery conditions by mathematical equations, such as the minimum casting speed and holding time, etc. However, propagation behavior of sticking point isn't considered numerically in the derivation of recovery conditions for sticking-type breakout, and recovery conditions don't combine the alarm conditions. In actual production, due to late alarm or improper control strategies of reducing casting speed, breakout still occurs after alarm. So the alarm time as soon as possible and effect of casting speed on recovery of sticker breakout should be investigated elaborately.

In this paper, a novel mold breakout prediction and control technology has been presented for slab continuous casting. To improve breakout prediction performance, a logic judgment model for arrangement of more rows of thermocouples has been developed. The model has been given adequate consideration to characteristics of actual mold temperature change following sticking. And most important of all, vertical and horizontal detections to well recognize two-dimensional sticker propagation behavior, have been adopted in the model. The strategy can reduce false alarm rate and improve robustness of the model to noise. After sticking alarm released by new model, a healing control technology has been used for breakout prevention. The control strategies of casting speed and relative alarm conditions have been discussed in detail. It is proposed that strategies of reducing casting speed are selected automatically according to the location of alarmed thermocouple. Then the present technology has been applied to an actual steel plant. And its application effect is evaluated and discussed.

## 2. Investigation of mold temperature

### 2.1. Mold instrumentation

The subject of the study is carried out in two slab continuous casters of H steel plant in China. Each caster has two strands, an arc radius of 9.5 m, and the casting slab section size is $(230/250) \times (900–2150)$ mm$^2$. The operation casting speed is 0.80–2.03 m/min. The casting steelgrades in the caster are various and complex, such as ULC, LC, MC, peritectic, peritectic-HSLA, MC-HSLA, pipe grades, etc.

The corresponding mold in the caster is a combined straight mold, which is comprised of four copper plates: broad face copper plate fixed side, broad face copper plate loose side, narrow face copper plate left and narrow face copper plate right. The arrangement of thermocouples embedded in copper plates of the mold is shown in Fig. 1. 6 rows of 12 columns, a total of 72 thermocouples are embedded in each broad face. 6 rows of 2 columns, a total of 12 thermocouples are embedded in each narrow face. In total, 168 thermocouples are installed in the four copper plates. And these thermocouples are marked according to Fig. 2, as for example, 6G denotes the thermocouple in the 6th row of column G. The installation of thermocouples in mold copper plate is shown in Fig. 3. The measuring temperature with thermocouple depends on the type of the thermocouple and embedding depth in mold copper plate. In this study, high-precision K-type thermocouple is

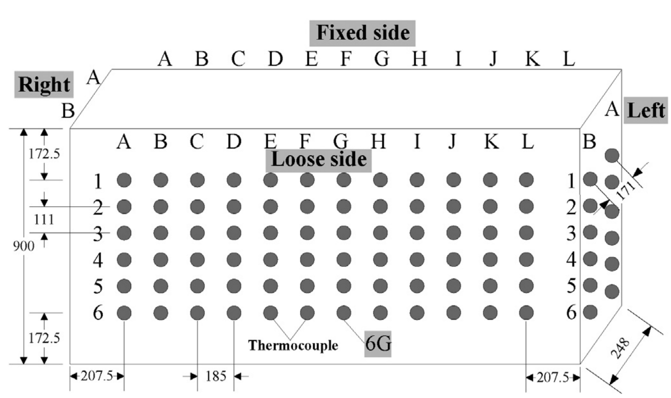


**Fig. 2.** Arrangement of thermocouples embedded in mold copper plates [mm].