

Research Article

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Influence of processing parameters on slab stickers during continuous casting

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Abstract: In this study, the parameters of 44 sticker breakout samples were analysed. The research mainly focused on the steel grades and slab thickness of stickers. Other processing parameters, such as slab width, casting speed, mould fluctuation, heat flux and operation, were also discussed. The results show that the number of stickers of low carbon steel and low alloy steel was 16 and 28, respectively. The stickers of low carbon steel were less than those of low alloy steel regardless of the thickness and width. The ratio of stickers per 1,000 casting heats of 220, 260 and 320 mm thickness slabs was 2.5, 0.5 and 0.6, respectively. The higher casting speed of 220 mm thickness slabs made the casting status unsteady and caused more stickers. From the perspective of width, the stickers were gradually increased along with the increase in width due to the worse mould slag. This study provides a foundation to reduce slab stickers and is helpful for a more efficient technology of continuous casting.

Keywords: sticker breakout, steel grade, thickness, casting speed, heat flux

1 Introduction

Breakout is a serious accident during continuous casting. The liquid steel overflowed from the slab shell not only decreases the quality of the slab product but

also destroys the second cooling equipment and stops the productive process [1–3]. A sticker between mould and slab shell is the main cause of breakout, which accounts for 70% to 80%. In recent years, the problem caused by slab sticker breakout is more obvious along with the casting speed increase and development of effective continuous casting technology, which hinders the further increase in casting speed and decreases slab quality [4].

In order to avoid breakout, some metallurgical researchers carried out many meaningful studies. On one hand, some breakout prediction systems (BOPSs) were developed to detect the sticker breakout [5–7], such as mould thermocouple monitoring, thermal image monitoring [8,9], heat flux monitoring and friction monitoring [10]. Although BOPS could prevent breakout by reducing casting speed, this operation also decreased the slab quality due to the decrease in casting speed. If the causes of sticker breakout could be found before its formation, the stickers would be eliminated at the beginning. Therefore, some influence parameters, such as pouring temperature, mould slag, casting speed, mould fluctuation and heat flux, were investigated [11–15]. However, steel grades, slab thickness and operation have not been studied, which are the important influence parameters to sticker breakout.

This research was based on the data of wide and thick slab casters from 2015 to 2017. A total of 44 sticker breakout samples were confirmed. The main casting parameters of sticker breakout were investigated, such as steel grade, slab thickness, slab width, casting speed and mould fluctuation. The research results can provide a foundation to prevent sticker breakout.

2 Experiment

The radius of the arc continuous caster was 10.75 m, whose metallurgical length was 28.8 m. The mould length was 0.9 m and the standard mould level was 0.8 m. The slab thicknesses were 0.22, 0.26 and 0.32 m and the width was 1.8–2.7 m. The maximum and minimum casting

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Table 1: Arc continuous caster parameters

Item	Parameters
Strand	1
Slab width	1.8–2.7 m
Slab thickness	0.22, 0.26, 0.32 m
Radius	10.75 m
Metallurgical length	28.8 m
Mould length	0.9 m
Mould level	0.8 ± 0.003 m
Drive	Hydraulic drive
Oscillation frequency	40–400 times/min
Casting speed	0.75–1.2 m/min

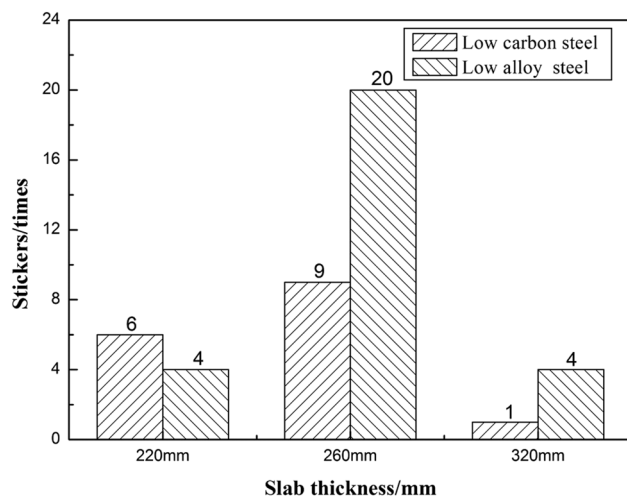
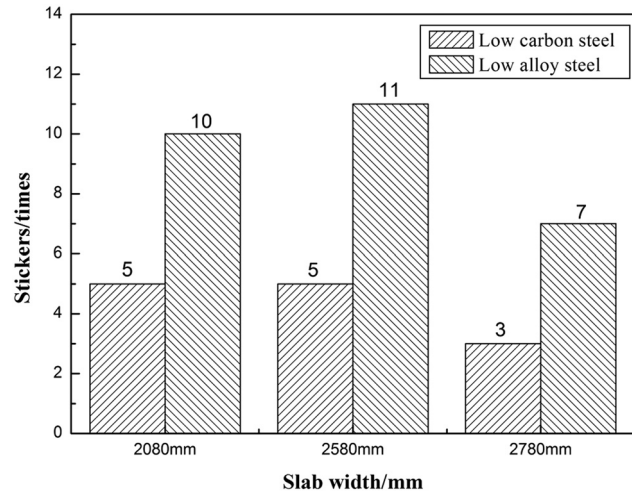
speeds were 1.2 and 0.75 m/min. The main parameters are shown in Table 1.

3 Influence of processing parameters

3.1 Steel grade

From 2015 to 2017, more than 10,000 slabs were casted with about 50 steel grades. The 44 stickers were mainly of the Q235, Q345 and Q420 steel grades, which could be divided to two main types: carbon steel and low alloy steel.

Figure 1 shows stickers of different steel grades with the same thickness. There were ten stickers in 0.22 m thickness slab, which contained six stickers of low

**Figure 1:** Stickers of different steel grades with the same thickness.**Figure 2:** Stickers of different steel grades with the same width.

carbon steel and four stickers of low alloy steel. The casted 0.26 m thickness slabs had the most stickers, which of low carbon steel and low alloy steel were 9 and 20, respectively. The 0.32 m thickness slabs contained only one sticker of carbon steel and four stickers of low alloy steel. Although low carbon steel stickers of 220 mm slabs were more than those of low alloy steel, it can be seen that the total stickers of low alloy steel are more than those of low carbon steel.

Figure 2 depicts stickers of different steel grades with the same width. The stickers of low carbon steel with width 2,080, 2,580 and 2,780 mm were 5, 5 and 3, respectively, whereas the stickers of low alloy steel with width 2,080, 2,580 and 2,780 mm were 10, 11 and 7. It is noticeable that the stickers of low alloy steel are more than those of low carbon steel about two times.

From the above data, it can be concluded that stickers of low alloy steel were more than those of low carbon steel regardless of the same thickness or width. On one hand, low alloy steel had more alloy elements, such as Mn and Si, which were used to reduce the amount of O and S elements. This also made the shrinkage of the slab shell become larger and non-uniform. Then, the thin slab tended to have a micro-deformation due to liquid steel pressure [16]. When the deformation was big enough, the slab shell would be stuck to the mould copper plate. On the other hand, the addition of rare earth elements was a routine process of low alloy steel production. Although it improved the quality of slab, it also produced some oxides or inclusions with high melting point. Those were easily to be captured by mould liquid slag, which increased the viscosity and melting point. Then, liquid slag would be

harder to flow into the gap between mould and slab shell, which made the lubrication worse and sticker occur [17,18]. Therefore, the sticker between mould and slab easily formed when low alloy steel was casted.

3.2 Slab thickness

All 44 sticker samples were from 220, 260 and 320 mm thick slabs, which were 10, 29 and 5, respectively. Figure 3 represents the casting heat and sticker percentage with different slab thicknesses. The casting heats of 260 mm thickness slab were more than those of 220 mm thickness slab about 71.6%, and the increase in sticker percentage was about 43.3%. The stickers increased along with the casting heat increase. While 320 mm slabs were casted, the percentage of casting heats and stickers both decrease. Table 2 shows stickers per 1,000 casting heats of different slab thicknesses. It can be seen that 220 mm thickness slab had 2.5 stickers per 1,000 casting heats, which was higher obviously than those of 260 and 320 mm thickness slabs. Therefore, the continuous casting process of 260 and 320 mm slabs was more stable and the

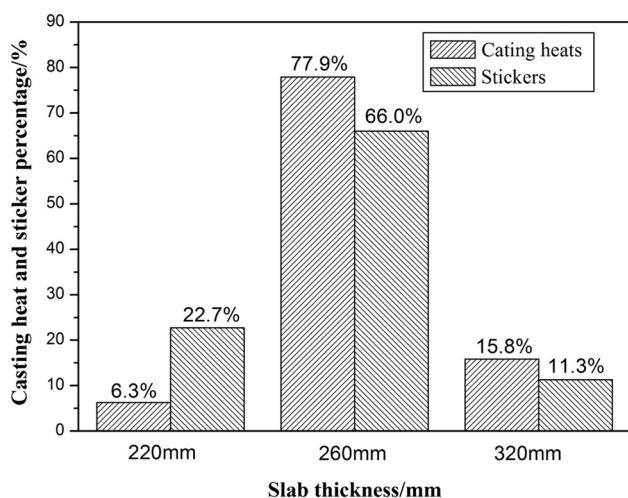


Figure 3: Casting heat and sticker percentage with different slab thicknesses.

Table 2: Stickers per 1,000 casting heats of different slab thicknesses

Slab thickness	220 mm	260 mm	320 mm
Stickers per 1,000	2.5	0.6	0.5

sticker's probability was smaller. The reason was that the 220 mm slab usually had a higher casting speed, which required a larger amount consumption of mould slag. Then, the thickness of liquid slag became more nonuniform along with the increase in casting speed, which made sticker breakout occur more easily. Therefore, the 220 mm thickness slabs should be paid more attention about the casting speed and mould powder.

3.3 Slab width

As 260 mm thick slab had the most stickers, casting heat and sticker breakout percentage of different width were calculated. In Figure 4, the casting heat percentages of 2,080 and 2,580 mm were 59% and 26.1%, which showed a decreased trend. But the sticker breakout percentage of 2,580 mm was 6.9% higher than that of 2,080 mm. The 2,780 mm thick slab had the lowest percentage of sticker breakout, since the casting heat percentage was only 14.9%. The stickers per 1,000 casting heats of 2,080, 2,580 and 2,780 mm were 0.4, 1.1 and 1.2, respectively, which obviously increased along with the increase in slab width. With the increase in slab width, the meltdown and inflow of the mould liquid slag probably became uneven and the larger dimension may have less slag consumption for strand shell. It is one of the main reasons for the slab sticker. On the other hand, the wider slab had a larger sticking area. Under the shrinkage force and ferrostatic pressure acting on the wide face, the comprehensive force may push the strand shell to

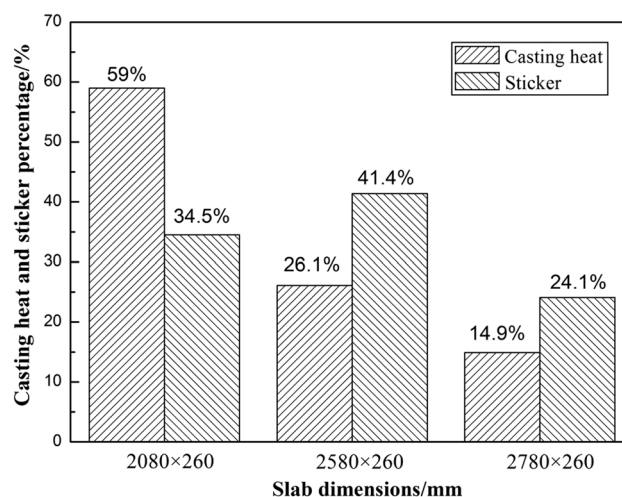


Figure 4: Casting heat and sticker breakout percentage of 260 mm thick slab.

contact with the mould copper plate, which produced a sticker breakout directly. Therefore, while the wider and thicker slabs are casted, the slag meltdown, inflow of mould slag and operation of pushing slag should be given appropriate attention.

3.4 Casting speed

Figure 5 shows sticker breakout of different slab dimensions along with casting speed increase. There was one sticker when the $260 \times 2,580$ mm slabs were produced at the casting speed 0.6 and 0.7 m/min. The increase in casting speed did not bring the increase in stickers. However, there were ten stickers while the casting speed was 0.75 m/min. Therefore, 0.6 and 0.7 m/min were the steady casting speeds and the casting speed 0.7 m/min was preferable due to the higher production efficiency. In the same way, the $260 \times 2,080$ mm slabs were more suitable for production at 0.8 m/min. The stickers of 220 mm thick slabs increased along with the increase in casting speed first, and it decreased when 220 mm thick slabs were casted at 1.25 m/min. According to the casting records, 1.25 m/min was not the normal casting speed and the slabs were not produced at this speed very much. Overall, the 320 and 220 mm thick slabs had a similar trend and the steady casting speeds were 0.6 and 0.8 m/min, respectively. Although the high casting speed can enhance the productive effectiveness of continuous casting, it also needs more consumption of mould slag, cooling water

and liquid steel, which makes the process of continuous casting more complicated. Once the mould lacks the liquid slag, the sticker occurs. From this point, the 220 mm thick slabs have more stickers per 1,000 casting heats as shown in Table 2. Therefore, to avoid sticker breakout and obtain a continuous production, the slabs produced at higher casting speed need more attention.

3.5 Mould level fluctuation

In steady state casting, the mould level is required to be constant and its fluctuation is controlled at less than 3 mm. However, the mould level usually has fluctuation due to the difference in steel grades. Figure 6 represents the mould level fluctuation of stickers with different steel grades. There was only one sticker with the mould level fluctuation less than 3 mm, and another sticker's mould level fluctuation was 3–5 mm. The total 26 stickers of mould level fluctuation 5–10 mm included 15 low alloy steel grades and 11 low carbon steel grades. The total nine stickers of mould level fluctuation 10–20 mm included five low alloy steel grades and four low carbon steel grades. The whole six stickers of mould level fluctuation more than 20 mm were all casted with low alloy steel grades. It can be concluded that the mould level fluctuation of low alloy steel is more than that of low carbon steel, which is another reason that the stickers of low alloy steel are more than those of low carbon steel. The reason is that the strand shell of low alloy steel is more uneven than that of low carbon steel,

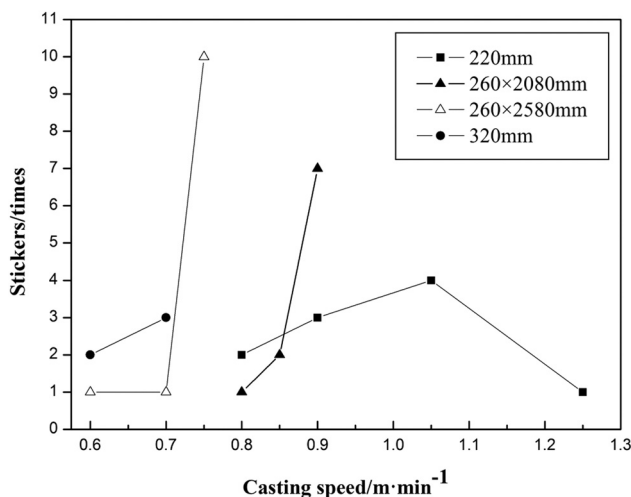


Figure 5: Sticker breakout of different slab dimensions along with casting speed increase.

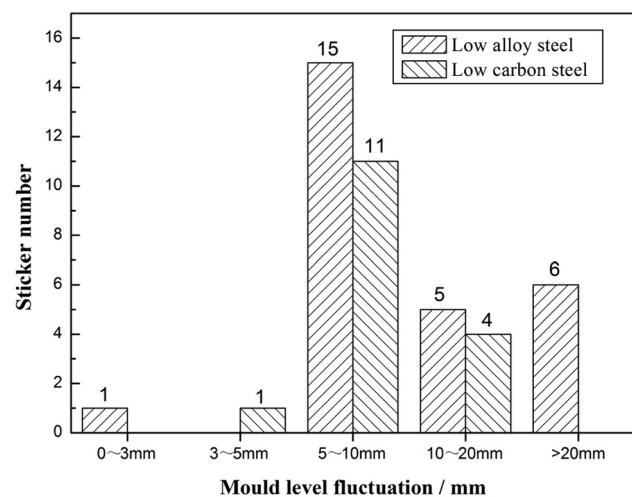


Figure 6: Mould level fluctuation of stickers with different steel grades.

which is likely to produce the bulging. While the rollers of second cooling section press the strand shell, the mould level will be a larger up and down. The thin strand shell around meniscus is easily broken and stuck to the mould copper plate, such as a sticker of $220 \times 2,580$ mm occurred on 22 July 2015, which was caused by a large mould level fluctuation of 28 mm. On the other hand, the low alloy steel is easy to have submerged entry nozzle (SEN) clogging, which disturbs the flowing of liquid steel and produce a large mould level fluctuation. The liquid slag was broken by the large mould level fluctuation, and a sticker occurred. Therefore, the mould level should be controlled strictly to avoid sticker breakout, especially producing low alloy steel.

3.6 Sticker position

Of the 44 sticker samples, 43 cases occurred on the wide faces. Figure 7 shows the sticker positions on the inside and outside radius of slabs with different slab widths. Of 43 cases, 29 stickers occurred on the centre zone. Of these, of 5 cases in 320 mm thickness slabs, 4 stickers occurred on the centre zone, accounting for 80%; of 28 cases in 260 mm thickness slabs, 19 stickers occurred on the centre zone, accounting for 67.9%; and of 10 cases in 220 mm thickness slabs, 6 stickers occurred on the centre zone, accounting for 60%. It can be concluded that the stickers tend to take place on the centre zone more, and this probability grows up along with the increase in slab width.

On one hand, the strand shell of the centre zone is thinner than that of mould corner and narrow face, as these have two dimensions heat transfer. Under the liquid steel pressure, the thinner shell is closer to the mould copper plate, which makes liquid slag inflow harder to the gap. So the centre zone has more stickers than those of other two zones. On the other hand, along with the increase in slab width, the contractility of the mould edge and narrow faces makes the strand shell of wide faces be stretched largely. Under this tensile force, the strand shell with a larger thickness is closer to mould copper plates more. Meanwhile, the tensile force makes the thinner strand shell broken easily.

3.7 Cooling water temperature

Table 3 shows the stickers and root mean square (RMS) of cooling water temperature of different seasons. The Q3 and Q4 have the maximum 19 stickers and the minimum 7 stickers. The cooling water temperature of Q3

Table 3: Stickers and RMS of cooling water temperature of different seasons

Item	Q1	Q2	Q3	Q4
Stickers	8	10	19	7
RMS	2.25	1.4	2.62	0.4

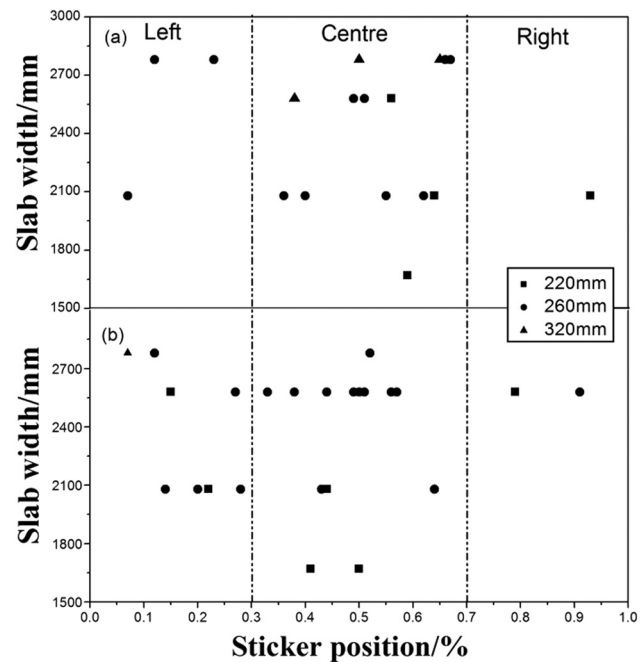


Figure 7: Sticker positions on (a) inside and (b) outside radius of slabs with different slab widths.

is higher than other three seasons and the temperature ranges from 28.8 to 36.8°C, as shown in Figure 8. The temperature fluctuation of cooling water is very obvious. Table 3 also represents the RMS of cooling water temperature. The Q3 has the highest RMS value of 2.62, and Q4 has the least RMS value of 0.4. The reason is that the environment temperature of Q3 is very high in this steel plant, and the consistent temperature of cooling water is not easily controlled. The change in cooling water makes the uniformity of strand shell worse, and the thinner strand shell is close or stuck to the mould copper plate. Therefore, while slabs are casted at the Q3, the temperature cooling water and its fluctuation should be given more attention.

3.8 Operation

As shown in Table 4, the stickers of operation groups A, B, C and D are 9, 11, 13 and 10, respectively. The group C

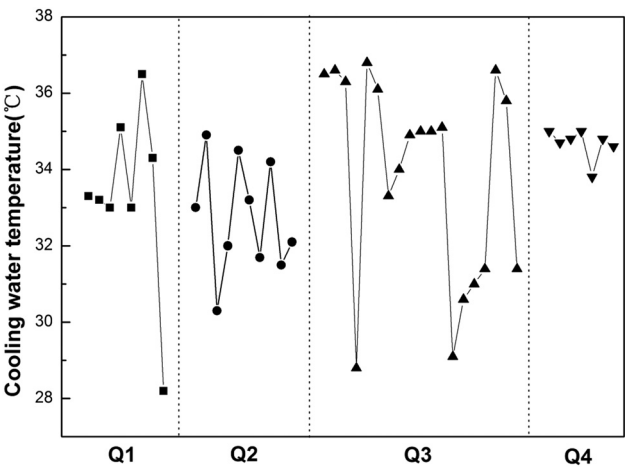


Figure 8: Cooling water temperature of four seasons.

Table 4: Stickers of different operation groups

Group	A	B	C	D
Stickers	9	11	13	10

has the most stickers. The number of stickers of four groups is close, so it means that they have the similar level of operation. But 20 stickers occurred within 1 h around the shift time (8:00, 16:00 and 24:00), as shown in Figure 9. The ignorance of mould power supply and the difference in pushing mould powder operation are the main problems of shift change. Once the local strand shell is in the lack of mould power, the sticker will occur at this position. So the fore and after operation groups should keep the mould power enough and do the same operation of pushing mould power during shift change.

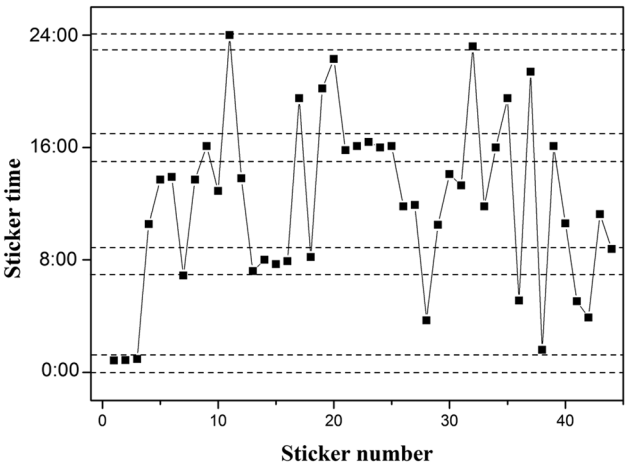


Figure 9: Sticker time out of a total of 24 h.

4 Heat flux

4.1 Heat flux of wide copper plates

Figure 10 depicts the average and difference of heat flux of wide copper plates. From Figure 10a, the heat fluxes increase with the increase in casting speed. The 2,080 mm wide slabs casted at the speed 0.9 m/min had the most stickers, and the heat fluxes range from 1.07 to 1.21 MW/m². The value of heat flux fluctuation is 0.14 MW/m². The values of heat flux fluctuation of 2,580 and 2,780 mm slabs are 0.21 and 0.25 MW/m² at casting speeds 0.7 and 0.75 m/min. It can be seen that the wider slab has a large fluctuation of heat flux. From Figure 10b, the difference in heat flux of 2,780 mm range from −0.12 to 0.06 MW/m², which is larger than those of the 2,580 and 2,080 mm slabs. Along with increase in slab width, the average and difference of heat flux increase obviously, which increases the difference in shell

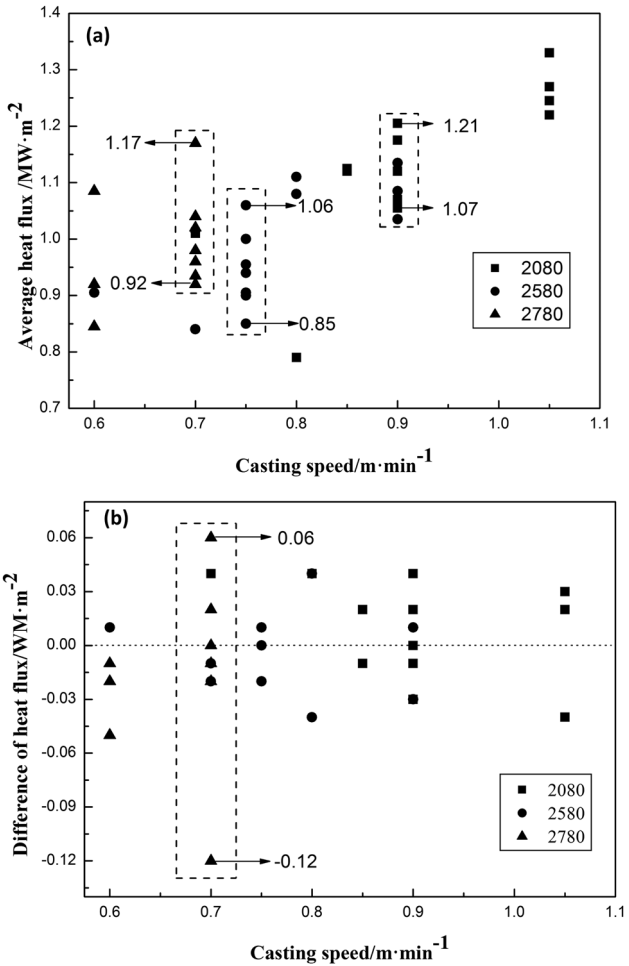


Figure 10: The average (a) and difference (b) of heat flux of wide copper plates.

thickness and thermal stress. The sticker or other defects take place at the thinner position easily [20]. Therefore, while the wider slabs are casted, the consistent heat fluxes are helpful to avoid stickers and decrease surface defects.

4.2 Heat flux fluctuation

Figure 11 depicts heat flux of mould copper plates compared with that of steady state. It can be seen that the 90.91% heat fluxes are less than 5%. It demonstrates that the heat flux is rather steady in most cases before stickers. The reason is that the local heat flux caused by sticker is less compared with the heat flux of the whole copper plate, therefore, the fluctuation of heat flux is not obvious. So, heat flux is not sensitive enough for use as one of the criteria in a BOPS.

4.3 Heat flux of narrow face

In the actual production, the heat flux of the narrow face is supposed to be lower than that of the wide face, which is about 70–90% of that of the wide face [19]. In Figure 12, only two stickers occurred in this range. In most cases, the percentages are over 90%, and the highest is 122%. It can be concluded that the high heat flux of the narrow face is another reason of stickers. In practice, the cooling water of the narrow face should be controlled in an appropriate volume.

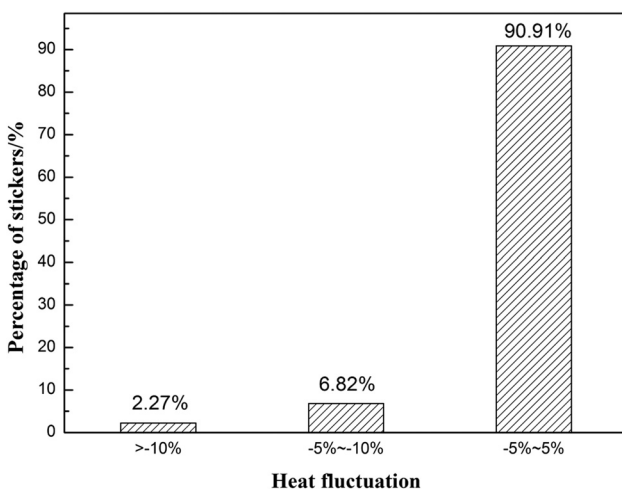


Figure 11: Heat flux of mould copper plates compared with that of steady state.

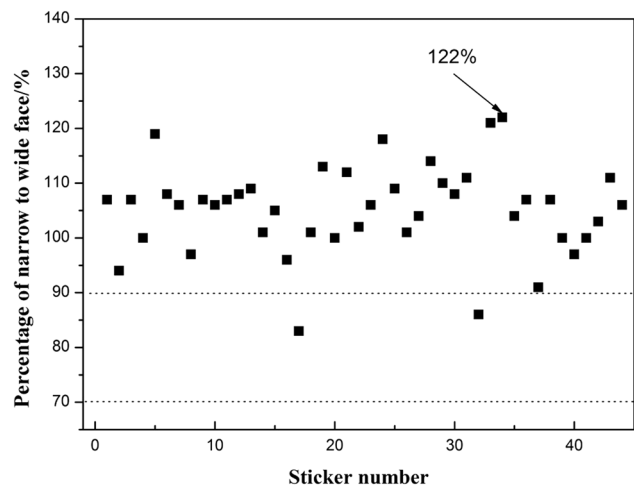


Figure 12: Percentage of heat flux of narrow face to wide face.

5 Conclusion

1. The stickers of low alloy steel were more than those of low carbon steel regardless of the thickness and width due to the added Mn, Si and rare earth elements, which made the strand shell non-uniform and changed the viscosity and melting point mould slag. Meanwhile, the mould level fluctuation of low alloy steel was usually larger than that of low carbon steel, which increased the risk of slab stickers. Therefore, the slabs of low alloy steel should be given more attention on mould slag and strand uniformity.
2. From the perspective of width, the stickers increased with the increase in slab width due to the more consumption of mould slag when 260 mm thick slabs were casted. However, from the perspective of thickness, the 220 mm thickness slab had the largest ratio of 2.5 stickers per 1,000 casting heats. The reason is that 220 mm slabs were always produced at higher casting speed and casting status was more unstable than that of other thickness slabs. Therefore, while the slabs are casted at higher casting speed or larger width, the worse status of mould slag should be given more attention.
3. The 90.9% stickers have less than 5% fluctuation of the heat flux, which shows that the heat flux fluctuation is not sensitive enough for use as one of the criteria in a BOPS. But the fluctuation of heat flux usually increases with the increase in slab width. Therefore, while the wider slabs are casted, the heat fluxes should be consistent and have less fluctuation.
4. The maximum steady casting speeds of $260 \times 2,080$ mm and $260 \times 2,580$ mm slabs are 0.7 and

0.8 m/min. Meanwhile, the stickers are influenced by operation and cooling water temperature.

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