ANALYSIS OF SUB SURFACE OFF CORNER CRACKS IN CONTINUOUS CAST STEEL BILLETS

DITI GARG\textsuperscript{1}, PICHED P\textsuperscript{2}, TEERAPONG B\textsuperscript{2}, NIKORN S\textsuperscript{2}, R B V RAMANA\textsuperscript{1}

SYNOPSIS:

Sub surface off corner cracks in high carbon steel billets (0.60 – 0.85\% C) was a concern at NTS, TSTH. These cracks, 2 to 8 mm beneath the surface, were associated with longitudinal surface depressions. These were found at off corner locations and were usually accompanied by bulging of the billet face. In this work, the influence of operating and metallurgical factors that caused off corner depression and bulging below the mould were examined. Mold water flow rate, casting speed, casting flux, foot roller gap and alignment were identified as major control parameters. With the help of plant trials suitable operating range for the selected parameters could be fixed, reducing the incidences of sub surface off corner crack generation.

Keywords: Crack, Depression, Bulging, Steel, Mold, Billet

1. Tata Steel Limited, Jamshedpur-, India
2. NTS, TSTH, Chonburi, Thailand
1. Introduction

NTS, Tata Steel Thailand, was facing a problem of severe internal cracks which occurred off and on in their High Carbon Steel billets (0.81 – 0.85%C). These sub surface crack were 4 to 8mm beneath the surface, just at off corner of the billet and associated with longitudinal surface depressions, Fig1. These off corner depression were usually accompanied by bulging along the billet face. The macro etched sample revealed sub-surface cracks extending from 12 to 19 mm beneath the depression. Sub surface cracks of severity 3 and 4 were undesirable for high carbon billets, as these cracks could get exposed during subsequent reheating and rolling operations, leading to internal oxidation and causing defects in the final product. This defect, it could be postulated, was caused by bulging of the shell at or near the mould exit. When bulging occurred, a hinging action acted at the colder and stronger corners thus causing the corners to expand slower than the faces resulting in tensile stresses at off-corner locations near the solidification front where the temperature of steel was just below the solidus ~1340°C [1,2,12]. J. K. Brimacombe et.al [2] had reported that at temperatures above 1340 °C the strength and ductility of steel both declined (fig2). Thus, if ever there were generation of tensile stresses within the solidifying billet, the crack would form at the solidification front. It had been reported that the most important parameters that played a critical role in the generation of off corner crack were, the mold taper [2,3,9], casting speed, mould water flow [1,4], foot-roll gap [6,8], casting powder [10,11] and segregating elements [5,7] like phosphorus, sulphur and copper.

If the taper of the mould was loose then the billet would bulge easily causing the cracks to form. For this study though, mould taper was not kept in the scope, as the problem was not pandemic but rather occurred off and on. Casting speed, heat transfer in the mould (mould water flow and casting powder selection) and foot roll gaps had direct bearing on bulging and could affect generation of these cracks. Presence of segregating elements reduced the hot strength of steel, but these were not taken in scope for the present work, as it was found that cracks were observed in some strands and not in complete heat. Also, it was attempted not to cap casting speed unless necessary so as to avoid any restriction on productivity.

Rating methodology:

The rating methodology employed is given in Table1. Cracks were rated based on the distance of the crack from the surface and the length of the crack. The closer the crack was to
the surface and the longer the crack, the higher the rating given. The lowest rating was Zero for a Macro with no cracks and the highest was Four for a Macro in which the crack was within 5mm of the surface and/or was longer than 15mm. Classes 3 and 4 were classified as undesirable.

<table>
<thead>
<tr>
<th>L (mm)</th>
<th>D (mm)</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIL</td>
<td>NIL</td>
<td>0</td>
</tr>
<tr>
<td>&lt;= 5 mm</td>
<td>&gt;= 15 mm</td>
<td>1</td>
</tr>
<tr>
<td>&lt;= 10 mm</td>
<td>&gt;= 10 mm</td>
<td>2</td>
</tr>
<tr>
<td>&lt;= 15 mm</td>
<td>&gt;= 5 mm</td>
<td>3</td>
</tr>
<tr>
<td>&gt;15 mm</td>
<td>&lt; 15 mm</td>
<td>4</td>
</tr>
</tbody>
</table>

2 Experimental Plan

Data Analysis plan

Based on the literature study and observations, the five variables casting speed, mould water flow, increase in mould water temperature (delta T), superheat and mould life were considered for analysis. The data for these parameters were collected for four months. The outliers from the data were removed and the non-outlier range was considered for further analysis. The dependent variable was crack and no crack which was a binary variable, while casting speed, mould water flow, delta T, superheat and mould life were continuous variables. Hence binomial logistic regression was used for the analysis. The null hypothesis was that there was no significant effect of the selected parameters on crack. The results were depicted by the p value. If p value was less than 0.05 (corresponding to confidence level of 95%) than null hypothesis fails for the parameter indicating it to be a significant parameter.

Experimental Plan

Foot roll gap: The effect of foot roll was analysed in one sequence of eight heats with no gap in one strand and gap of 0.3 mm in another strand. The bulging of the strands under both the conditions was used as the control measure.

Casting powder: In one of the sequence casting of eight heat of high carbon, casting powder with lower viscosity was tried to improve the heat flow at corner and off corner location. The trial powder Mold flux 2 was used in three strands while other two strands were run with old Mold flux 1 (Table 2).

<table>
<thead>
<tr>
<th>Strand</th>
<th>Casting powder</th>
<th>Viscosity at 1300°C (poise)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 2</td>
<td>Mold Flux 1</td>
<td>2.5</td>
</tr>
<tr>
<td>3,4 &amp; 5</td>
<td>Mold Flux 2</td>
<td>1.48</td>
</tr>
</tbody>
</table>
3. Results and discussion

Binary logistic regression analysis showed that cast speed, mould flow and mould life were most significant parameters (p value was <0.05) that impacted internal cracks, Fig 3.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Degr. of Freedom</th>
<th>Wald Stat.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>19.02148</td>
<td>0.000013</td>
</tr>
<tr>
<td>Superheat</td>
<td>1</td>
<td>0.876111</td>
<td>0.349270</td>
</tr>
<tr>
<td>Speed 1</td>
<td>1</td>
<td>14.87114</td>
<td>0.000115</td>
</tr>
<tr>
<td>Flow Mould</td>
<td>1</td>
<td>12.69114</td>
<td>0.000367</td>
</tr>
<tr>
<td>Delta T Temp</td>
<td>1</td>
<td>0.60203</td>
<td>0.437804</td>
</tr>
<tr>
<td>Mould Life (total)</td>
<td>1</td>
<td>4.88099</td>
<td>0.027154</td>
</tr>
</tbody>
</table>

Fig 3. Result of binary logistic regression analysis

**Casting Speed:** From the box plot of casting speed when there was crack and when there was no crack, Fig 4(a), it was found that casting speed for no crack condition was lower than that for crack condition. With lower casting speed dwell time in mould increased and hence the heat extraction per unit length of the strand also increases (Fig 4(b)). Thus, shell thickness at the mould exit also increased, improving strength of the shell against bulging. It was observed that defect percentage could be reduced with lower speed but it was not the desired solution. Hence it was attempted to see whether by altering the casting powder and improving foot roll gap the same effect could be had.

**Mould cooling water flow:** From the box plot of mould cooling water flow when there was crack and when there was no crack it was found that the Inter Quartile Range for no crack was lower (1930-2012 l/min) than for (1975-2213 l/min), Fig 5(a). It was also seen that there was a decrease in delta T with increase in mould water flow, Fig 5(b). On calculating it was found
that there was a drop of 5% in the average heat flux in the mould when increasing the mould water flow rate from 1900lpm to 2300lpm. It is possible that the higher MCW flow caused higher heat extraction in the upper half of the mould which resulted in higher shrinkage of the newly formed strand and the formation of gaps in between the shell and mould in the bottom half of the mould. Hence the poor heat transfer. This phenomenon implies a reheating and bulging of the shell within the mould in the bottom half of the mould. As per the data, keeping the MCW flow <1900 lpm, was beneficial.

Trial with loose foot rolls: The eight heats under trial, were cast in 4 different casting speeds, 2.05, 2.18, 2.21 and 2.32 m/min. It was found that at all speeds, the strand with loose foot rolls showed more bulging than the strand with no gap in the foot rolls, Fig6. It was also seen that the slope of the loose foot rolls line was higher than that of the no gap line, i.e. at higher speeds, having loose foot rolls greatly increased the problem. Also, at bulging of 5mm crack can be seen forming with severity of 1 and 2.
Trial with Casting Powder: The eight heats cast with trial powder were cast at speeds from 1.84 to 2.06. A mean plot of the average heat flux in the mould at different speeds for both the powders was plotted, Fig6. It was found that the heat extraction was higher in the strands with Mold flux 2. Also, with the use of low viscosity flux, the heat extraction increased with increasing casting speed. For the existing powder the heat extraction remained almost constant over the entire casting range. It is likely that the lower viscosity flux was draining more easily between the shell / mold interface minimizes the gaps and avoiding local drops in heat flow and steel shell thinning.

![Fig6 Variation in average heat flux in the mould with the casting speed for different mold flux (ref Table 2).](image)

Implementation: The foot roll gap setting was reduced to 0 mm, MCW flow was reduced to 1950 l/min in Aug’13 and casting flux was changed to Mould flux 2 in Oct’13. With the improve measures reduction in rejection was achieved, as shown in Fig7. The cracks in the billet were successfully reduced from 5.22% to 1.61%.

![Fig7. Defect due to sub surface off corner internal cracks of class 3 and 4 in high carbon](image)

4. Conclusion:

The impact of lubrication, casting speed, mould water flow rates and foot roll gaps on the formation of sub surface off corner cracks was studied. It was hypothesised that measures taken to minimise bulging of the strand would help to reduce the extent of the problem. Thus trials were taken and the following were found to be suitable countermeasures:
Decreasing the mould water flow up to 1900 lpm to increase the uniform shell contact and hence the heat extraction in the mould.

Casting powder with lower viscosity. This increased the heat transfer in the mould by decreasing the possibility of formation of low conductivity air gap. Higher heat flux could be achieved at higher casting speeds.

Foot rolls aligned with “no gap” condition allowed significant increase in casting speed and productivity without increase in bulging.

The findings were implemented resulting in significant improvements in the product.

5. References:

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