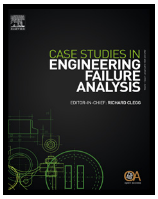
Case Studies in Engineering Failure Analysis 5–6 (2016) 15–22

Contents lists available at ScienceDirect

Case Studies in Engineering Failure Analysis

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



Case study

# Case study of severe strip breakage in rolling mill of Thin Slab Casting and Rolling (TSCR) shop of TATA Steel, Jamshedpur

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ARTICLE INFO

*Article history:*
Received 1 October 2015
Accepted 9 November 2015
Available online 1 December 2015

*Keywords:*
Inclusion
Slag
Roll separating force
XRF spectrometry

ABSTRACT

In this paper, a case of severe strip breakage in rolling mill of Thin Slab Casting and Rolling (TSCR) shop of TATA Steel, Jamshedpur is presented. Visual observation revealed complete splitting with material missing along the central axis of the strip. Presence of defects in form of white stringers, white patches and holes were observed along the same axis just ahead of split location. Metallurgical analysis revealed association of these defects with slag type foreign materials in the rolled strip. The entrapments of un-deformable materials like slag in slab resulted in the formation of surface discontinuities on the strip on account of differential rolling. The discontinuities manifested in form of holes at lower strip thickness in the later stands of the mill. Inhomogeneous deformation about such holes also resulted in material overlapping. In summary, the breakage of the strip was found to have a strong correlation with the presence of heavy chunk of foreign inclusions from secondary steelmaking sources.

## 1. Introduction

Strip breakages in steel rolling mills result in loss of production due to mill stoppage and may also cause damage to equipment. The magnitude of loss is even higher in the case of integrated processes like Thin Slab Casting and Rolling (TSCR) where all the processing stations are interlinked [1]. In such a case, mill stoppages may affect upstream processes and can also lead to unplanned abort of casting and steelmaking operations. Rolling of defective strips in the final stands may also affect work roll surfaces with an adverse impact on the surface quality of the hot rolled strips. Additional time and cost is sometimes invested in premature changing of work rolls in the rolling mill.

In TSCR shop of TATA Steel Jamshedpur, thin slabs of 50–70 mm thickness are cast a high speeds and directly charged to tunnel furnaces where they are reheated to 1150–1170 °C and soaked for 15–25 min for homogenization. The slabs are then delivered to the six-stand finishing mill and hot rolled into strips of desired thickness.

A severe strip breakage was experienced in the finishing mill of TSCR while rolling a slab of low-C low-Mn grade. Preliminary investigations revealed no abnormality in casting and reheating parameters of the slab experiencing the breakage during its rolling. The slabs were also free from shape related defects like wedge or camber. Mechanical failures like

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http://dx.doi.org/10.1016/j.csefa.2015.11.002

hydraulic leakages, looper failures, strip and roll cooling system malfunctions, etc. did not occur during rolling of the slab. Even systems like Automatic Gauge Control and Automatic Profile Control were found to be properly functioning. Also, no operational errors related to mill balancing or CVC shifting was observed corresponding to this slab. Thus, an in-depth study was required to understand the root cause of the breakage. This paper reports the findings of this investigation based on which the mechanism of strip breakage could also be hypothesized.

## 2. Visual observation of cobbled slab

Strip breakage was observed in between F5 and F6 stands of the finishing mill. The processing details of the low-C low-Mn slab under study are represented in Table 1. Visual observation of the stock piece around the breakage location is schematically represented in Fig. 1. A white stringer like defect was observed at location 1 (Fig. 1) as shown in Fig. 2. At location 2 (Fig. 2) of the stock, heavy amount of whitish patches were noticed as seen from Fig. 2. Through thickness cracks in the strip were also observed at the location of the white patches. Large holes (location 3) were found at close vicinity to the white patch (~3 m) as shown in Fig. 2. Finally, complete splitting (location 4) was noticed with material missing from the central portion of coil behind the holes as shown in Fig. 2. It is at this location that the mill was stopped on emergency. The white stringer, heavy white patches, holes and complete separation were noticed along the same axis of the coil: 630 mm from its drive side. It may be noted that no anomalies were observed in stock portions remaining in the mill behind the F5 stand.

## 3. Sampling procedure

Samples were retrieved from location 1–4 of the stock for metallurgical analysis. Transverse microsample was prepared from locations 1 to analyze the composition of the stringer. Sampling at location 2, as represented photographically in Fig. 3, was aimed to understand the nature of white patch. The portion of stock around the first hole (location 3) from the head end of the strip was separated. This is represented in Fig. 4. Transverse microsample was prepared from the crack like defect at the corner of the hole as indicated in Fig. 4. Similar sampling procedure was employed for another hole about 3 m away from the first hole which may be noticed from Fig. 5. Finally, a longitudinal sample was prepared along the split edge from the location of complete strip separation (location 4) as shown in Fig. 6.

## 4. Microscopy

SEM micrograph of unetched transverse microsample prepared from location 1 revealed entrapment of non-metallic inclusions (NMI) as shown in Fig. 7. Optical microscopic observation (Leica, model: DMRX, Germany) of the strip at the

**Table 1**
Slab and coil processing parameters (ideal vs. actual).

| Parameters | Plan (Ideal) | Actual (Before breakage) |
|---|---|---|
| Coil width | 1250 mm | 1252 mm |
| Coil thickness | 2.5 mm | 2.52 mm |
| Slab thickness | 56 mm | 56 mm |
| Casting speed | 5 m/min | 5.1 m/min |
| Superheat | 20–30 °C | 28 °C |
| Tundish weight | >30 T | 35 T |
| Ladle weight | >15 T | 40 T |
| Finishing mill entry temperature | >1000 °C | 1080 °C |
| Finish rolling temperature (FRT) | 910 °C | 910 °C |

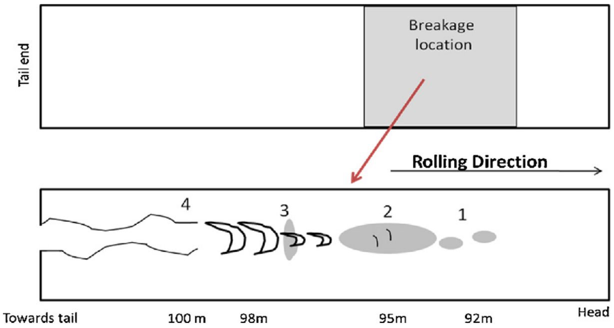


**Fig. 1.** Visual observation around strip breakage portion collected from mill between F5 and F6 stands (Schematic representation).

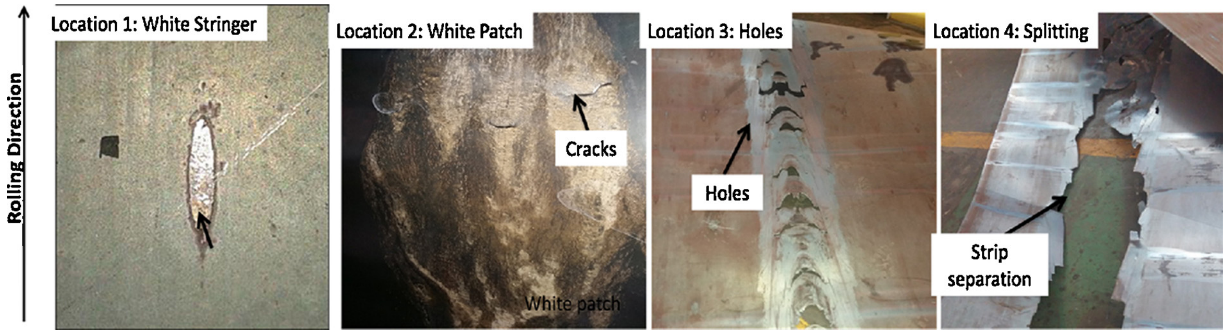


**Fig. 2.** Location 1 – White stringer; Location 2 – Large white patch; Location 3 – Chevron holes; Location 4 – Complete separation along the central location of coil.

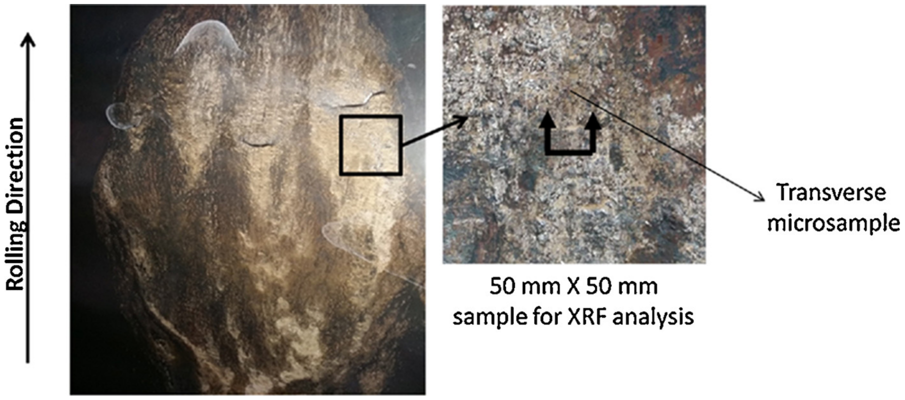


**Fig. 3.** Sampling procedure from the location of white patch.

location 2 is shown in Fig. 8(a). It revealed an undulated top surface with a loose layer of foreign material of 35 μm thickness in its close vicinity. Such undulations or foreign layer are not observed at the bottom surface of the strip at this location as shown in Fig. 8(b). Since the white patch was also observed on the top surface of the strip, it may be believed that the loose foreign layer in the microstructure is nothing but the white patch.

The crack like defect at the edges of the first hole reveals the entrapment of similar foreign entrapments at the tip of the crack as shown in Fig. 9 [2].

Stereo observation of longitudinal specimen prepared from the other hole as shown in Fig. 6 reveals three different layers. These are shown in Fig. 10(a) and indicate material overlapping. The inter-layer region in the longitudinal microsample also shows the presence of foreign materials as seen in Fig. 10(b). The same microsample on etching revealed a gradient of ferrite

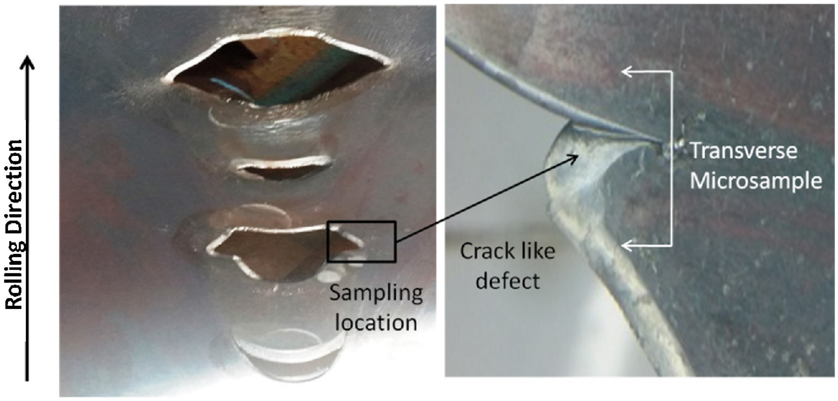


**Fig. 4.** Sampling at the first chevron-type hole location.

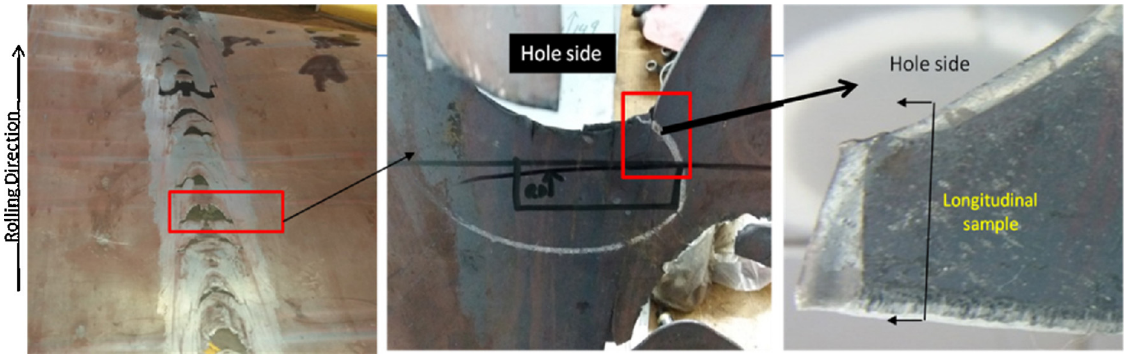


**Fig. 5.** Sampling location at another hole away from the first observed hole.

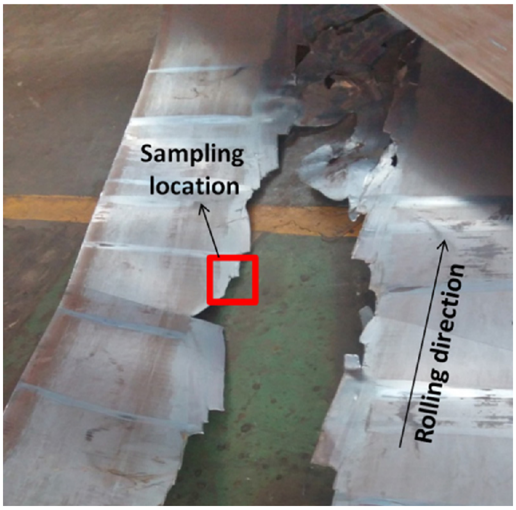


**Fig. 6.** Sampling location from split edges at breakage portion of strip.

grain size along the rolling direction as seen from Fig. 11. Material adjacent to the hole is seen to have a much finer microstructure and locations away from the hole are observed with coarse grains as observed from Fig. 12.

The longitudinal microsample prepared from location 4 revealed foreign materials along the separated edge of the strip as shown in Fig. 12.

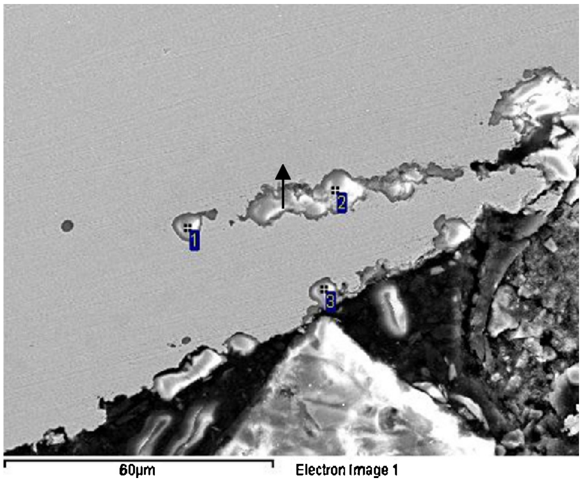


**Fig. 7.** SEM observation at the location of white stringer revealing inclusions.

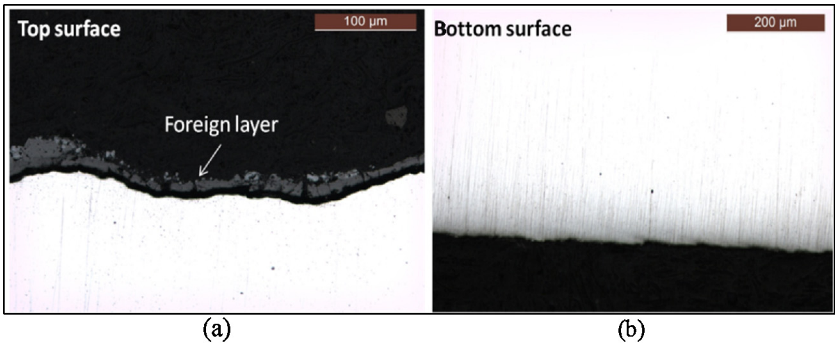


**Fig. 8.** Optical microscopic observation of (a) top surface revealing undulations and loose foreign layer and (b) bottom surface without undulation and foreign layer.

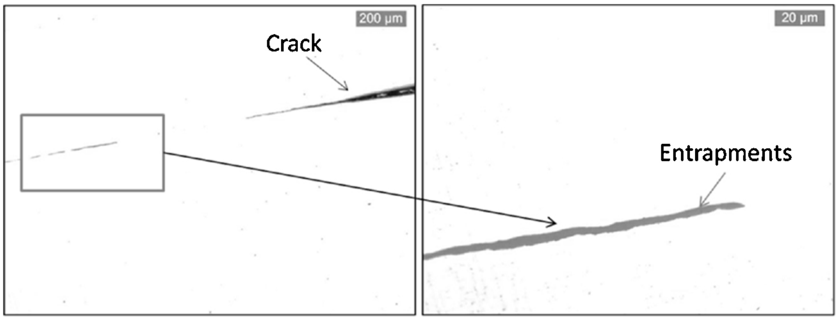


**Fig. 9.** Optical microscopic observation revealing entrapments at the tip of the crack.

## 5. SEM-EDS and XRF spectroscopy

Energy dispersive X-ray spectroscopy (EDS) was carried out extensively using high magnification scanning electron microscope (SEM) to note composition of the NMI type entrapment observed at location 1, loose foreign layer in location 2 and entrapments at the interlayer and crack tip in location 3. The consolidated results are displayed in Table 2. The composition of the entrapments being similar at all locations, it can be understood that same material is present at all the anomalous locations. The composition indicates slag type chemistry due to the presence of Ca, Mg, Si, Al in the foreign material.

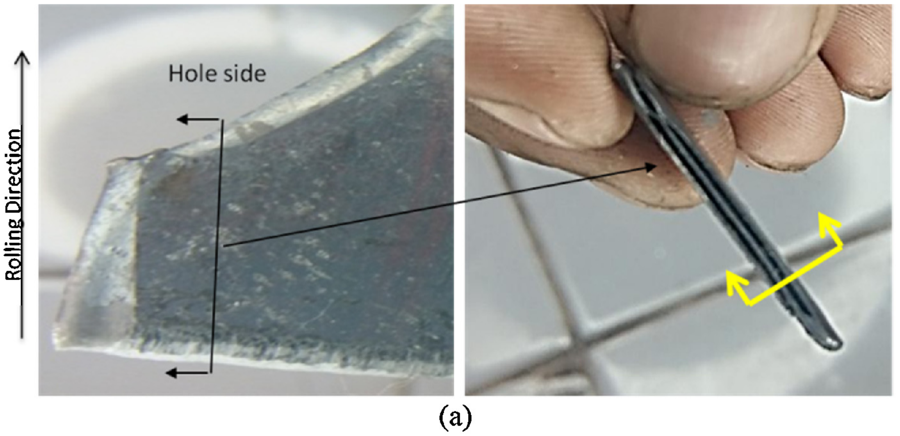
In order to confirm whether the same material is the white patch in location 2, X-Ray Fluorescence (XRF) analysis was done on the white patch. The result is shown in Table 3. It indicates similar slag like chemistry. In order to identify the exact source of slag, the composition was matched with that of mould slag, tundish slag and ladle slag. Presence of sulphur clearly indicates the slag to be of secondary steelmaking origin. [3].

## 6. Discussion

The Level-2 automation system recording of roll separating forces experienced by F4–F6 stands during rolling of the strip under study are represented in Fig. 13 [4]. It can be observed that roll force of F4 stand was fairly stable. However, the roll force profile of F5 stand was anomalous, showing a sudden drop followed by a sharp rise. The drop of roll separating forces indicates the presence of discontinuities in the stock entering F5 stand. Therefore, it may be believed that such discontinuities (holes) may have formed during rolling in F4 stand.

On investigating the discontinuities, foreign materials in form of slag were observed associated with it. Such inclusions were entrapped in the subsurface location of the slab during casting. Rolling of the slab exposed these foreign materials to the surface. This is clearly indicated from the investigation at location 2 of the strip. Since slag has no deformability, it led to inhomogeneous straining, resulting in the formation of cracks or discontinuities at the slag/steel matrix interface [5–7]. This may be understood from the presence of cracks on white patch in location 2.

At the locations of heavier concentration of such foreign material, rolling to lower thicknesses may have exposed the material on both the surfaces. The material ultimately gets removed due to their low deformability, leaving behind holes. Remnants of such foreign materials at the crack like defects at the corner of the holes in location 3 clearly relate the origin of these holes to these foreign materials. The hypothesized mechanism of formation of holes is represented in Fig. 14.



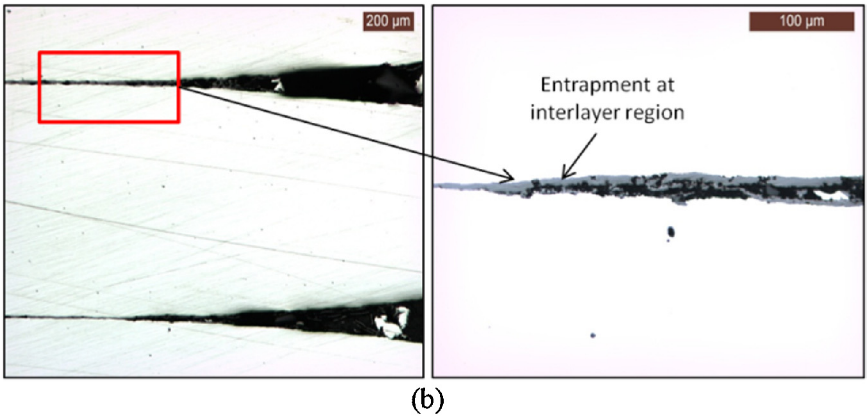


**Fig. 10.** (a) Observation of multi-layer in the longitudinal sample from the hole. (b) Optical microscopic observation revealing entrapments at the inter-layer region.

Once defects like holes are formed in a stock, the material suffers non-uniform deformation about these discontinuities. This is clearly indicated from the grain size variation as observed in the longitudinal direction. The surrounding of the hole reveals the finest grain sizes indicating highest deformation at these locations. Also since deformation about the holes is unconstrained, overlapping of material is caused during rolling such stock at F5. The increase in roll forces may be accounted to the greater reduction required for the overlapped material to be rolled to the target thickness.

Optical microscopic observation reveals traces of such foreign materials left behind along the split edges of the strip at the breakage location. Since, no material was observed at the centre of the strip at the split location, it can be hypothesized that this location had the heaviest chunk of this foreign material. The stock with its missing central portion will create a lower roll

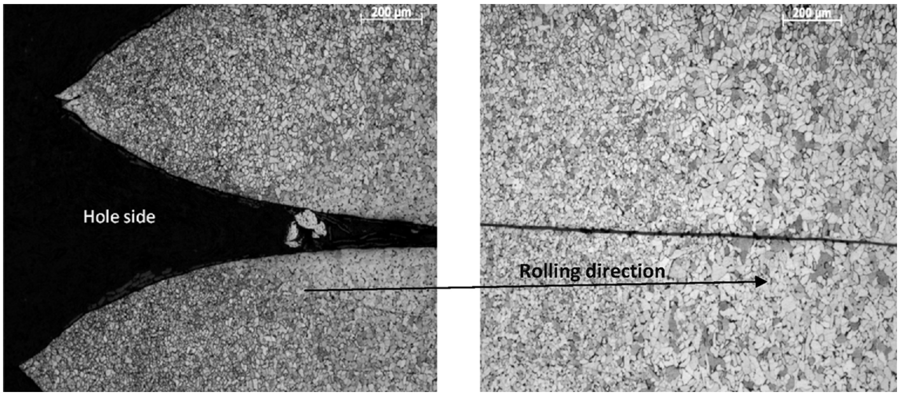


**Fig. 11.** Optical microstructure (longitudinal) revealing grain size variation along longitudinal direction at the chevron-crack location.

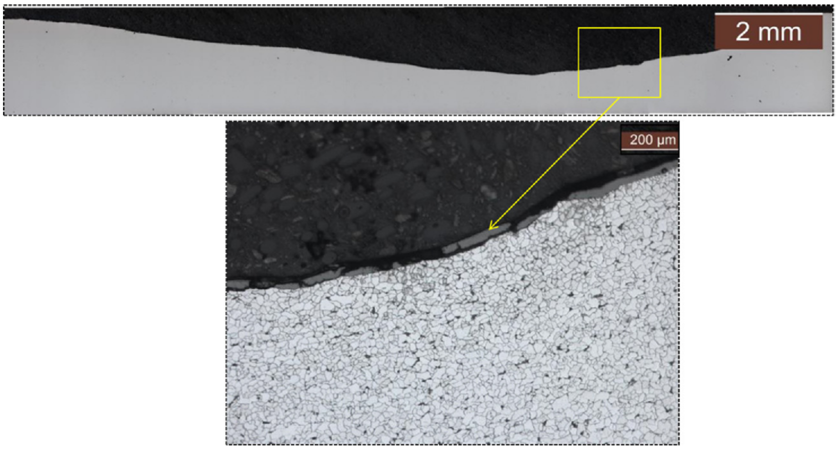


**Fig. 12.** Longitudinal microstructure along split edge of strip showing the presence of foreign material.

**Table 2**
SEM-EDS analysis results indicating foreign material (non-metallic inclusion) at locations at various locations.

| Location | Ca | Mg | Al | Si | S |
|---|---|---|---|---|---|
| Non-metallic inclusion (Fig. 7) | 19.25 | 4.35 | 1.4 | 2.10 | 0.69 |
| | 28.02 | 5.0 | 1.85 | 2.36 | 0.51 |
| | 28.25 | 4.5 | 1.2 | 2.58 | 0.57 |
| Loose foreign layer on top surface (Fig. 8) | 25.50 | 4.2 | 0.49 | 2.51 | 0.55 |
| | 26.95 | 4.2 | 0.59 | 2.53 | 0.54 |
| | 27.59 | 4.25 | 0.46 | 4.55 | 0.51 |
| Foreign inclusion entrapped in crack (Fig. 9) | 28.01 | 4.4 | 1.05 | 2.63 | 0.55 |
| | 28.9 | 4.65 | 0.8 | 2.68 | 0.51 |
| | 27.98 | 4.25 | 1.2 | 3.0 | 0.54 |
| Inter-layer region in overlapped location (Fig. 10) | 25.1 | 4.69 | 0.8 | 2.1 | 0.56 |
| | 28.0 | 4.8 | 0.39 | 2.18 | 0.54 |
| | 26.4 | 4.5 | 0.4 | 3.68 | 0.55 |
| | 28.1 | 5.25 | 0.78 | 2.9 | 0.52 |
| | 27.0 | 5.1 | 0.4 | 2.5 | 0.59 |
| | 26.8 | 4.3 | 0.45 | 3.6 | 0.53 |

**Table 3**
XRF analysis results indicating NMI (slag) at locations at various locations.

| Elements | Ca | Mg | Al | Si | S |
|---|---|---|---|---|---|
| Conc. (wt.%) | 18.08 | 4.58 | 0.42 | 2.58 | 0.52 |

separating force as observed, explaining the subsequent drop in the roll forces of F5. The roll forces of F6 show a drop before the stoppage of mill, indicating the same discontinuities passing through it. No such rise in the roll separating forces of F6 stand is observed. This clearly indicates that the overlapped material at F5 is rolled to its target thickness, further validating the reason for the rise of roll forces of F5.

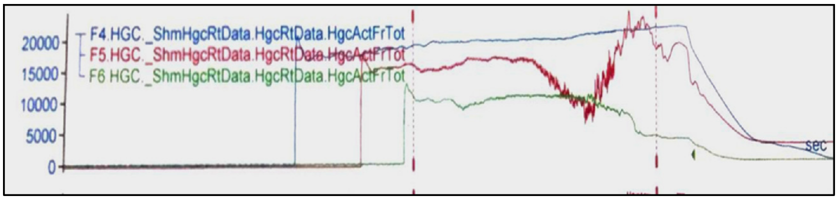


**Fig. 13.** Profile of roll separating force in F4 and F5 rolling stands.

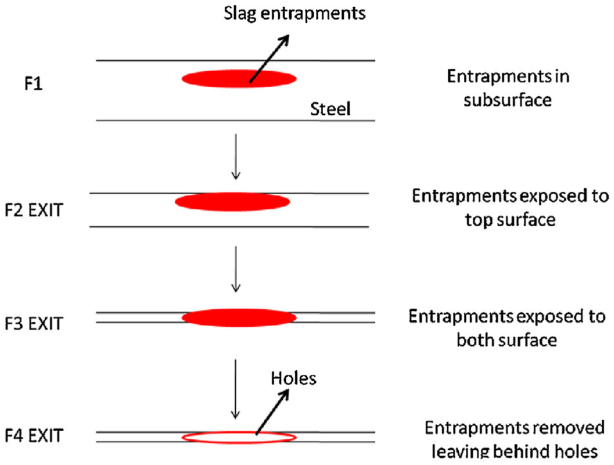


**Fig. 14.** Mechanism of hole formation in strips during rolling.

## 7. Recommendations

The presence of foreign materials leads to differential rolling which is the root cause of the strip breakage. The foreign material is identified to be of secondary steelmaking type slag. It is known that ladle slag can be drawn into the tundish towards the end of teeming from the ladle. To prevent slag from entering the tundish, a slag detection system is installed in the slide gate of the ladle. Slag detecting systems like AMEPA® detects the presence of slag through electrical resistivity method, based on which feedback is received by the slide gate mechanism to continue or block the flow of liquid steel. The slag detection system generally gets activated when 15– 20 T liquid steel is remaining in the ladle, below which chances of entrapments increases. Since in thins slab casting, there is a practical constraint of slab inspection or scarfing, it is recommended that such slag detection systems must remain activated throughout the duration of casting from a ladle. In case any slag entrainment is noticed, such slabs should be rolled into thicker sections in order to avoid such breakages.

## 8. Conclusions

Following conclusions can be drawn from this study:

(1) Presence of foreign materials in form of secondary steelmaking slag is observed at the strip breakage site in the strip.
(2) Rolling strips to low thickness exposed the foreign materials complete which get removed subsequently because of lack of deformability forming holes.
(3) Material overlapping occurred due to the presence of holes in the strip which allows unconstrained deformation.
(4) The splitting at the centreline is related to the presence of heavy chunk of such foreign slag in this location.
(5) It is recommended to keep the slag detection system activated during ladle teeming in order to avoid slag carryover. If such cases accidentally occur, it is recommended to roll slabs to lower thicknesses.

## Acknowledgement

The authors wish to acknowledge the support from the operations team of LD3&TSCR, TATA Steel, Jamshedpur in carrying out the investigation.

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