Effect of Stopper Rod Movement on Mould Fluid Flow and Sliver Formation (at ArcelorMittal Dofasco No. 1 Continuous Caster)

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Objectives

Overall: To study detailed effect of transient flow phenomena on defect formation, to enable better methods to predict & improve product quality

Plant Measurements:
To correlate the change of stopper rod position with sliver defects on ULC steel coils by analyzing:
- Validated ASIS™ images of slivers after downstream processing  
- SEM Images of cross-sections of sliver samples  
- Process data from corporate databases

Computational Models:  
- Develop accurate transient models of 3-D flow to simulate specific measured mold events, in order to quantify conditions for defect formation
Methodology

Obtain Sliver Samples

SEM Analysis
1. Determine sliver type by EDS
2. Determine depth of entrapment (coil)
   - Calculate depth of entrapment (slab)
   - Calculate entrapment location in mould

ASIS Data
- Determine sliver location from validated images
- Calculate corresponding slab segment location

Corporate Process Databases

Compare sliver type with occurrence of stopper rod movement

Verify whether sliver is related to stopper rod movement or not

Sliver Sample Population

N = 78 (Random)

Samples with SEM data and linked to Stopper Rod movement
N = 28 (35%)

Sliver samples were obtained from coils processed at Dofasco’s HDG Lines & analyzed at Global R&D Hamilton
Estimation of Depth of Particle Entrapment

**Typical Sliver SEM Micrograph**

Composition of Entrapped Particle determined by EDS

\[ d_{\text{slab}} = \text{Depth of entrapment in slab (mm)} \]

\[ T_{\text{coil}} = \text{Coil thickness (mm)} \]

\[ d_{\text{coil}} = \text{Depth of entrapment in coil (mm)} \]

\[ T_{\text{slab}} = \text{Slab thickness (mm)} \]

\[ T_{\text{scale}} = \text{Scale thickness (mm)} \]

Assumed to form in Hot Mill Reheat Furnace based on Dofasco’s historical data

**Depth of entrapment in slab after casting is given by: (in mm)**

\[ d_{\text{slab}} = \frac{T_{\text{slab}} \cdot d_{\text{coil}}}{T_{\text{coil}}} + T_{\text{scale}} \]

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Estimation of Particle Entrapment Location in Mould

**Figure Courtesy: Prof. B. G. Thomas**

\[ z = \text{Distance of entrapment from meniscus (mm)} \]

\[ d_{\text{slab}} = \text{Depth of entrapment in slab (mm)} \rightarrow \text{from SEM} \]

\[ V_c = \text{Casting speed (mm/min)} \rightarrow \text{from Process Database} \]

\[ k = \text{solidification constant (mm/min}^{0.5}) \rightarrow \text{from CON1D} \]

**Location of entrapment in mould is given by: (in mm)**

\[ z = \frac{V_c \cdot d_{\text{slab}}^2}{k^2} \]

\[ d_{\text{slab}} \text{ (estimated from SEM)} \]
Estimation of Defective Slab Segment

Slabs are divided into segments for storing process information in Level II.

Note: Accuracy of sliver location on slab: ± 1 slab segment

- $L_{\text{coil}}$ = Coil length (m)
- $Y_{\text{start}}$ = Sliver start position from Coil Start (m)
- $L_{\text{silver}}$ = Sliver length (m)
- $L_{\text{slab}}$ = Slab length (m)
- $S_{\text{start}}$ = Defect slab segment (start)
- $S_{\text{end}}$ = Defect slab segment (end)
- $\Delta L$ = Slab segment length (m)

Start and End Slab Segments “containing” the sliver given by:

- $S_{\text{start}} = \frac{Y_{\text{start}}}{L_{\text{coil}}} \cdot \frac{L_{\text{slab}}}{\Delta L}$
- $S_{\text{end}} = \frac{Y_{\text{start}}}{L_{\text{coil}}} + \frac{L_{\text{silver}}}{L_{\text{coil}}} \cdot \frac{L_{\text{slab}}}{\Delta L}$
Definition of Stopper Rod Index

1.0  2.0  3.0  4.0  5.0
Throughput (tonne/min)

Stopper Rod Opening (mm)    

RODSTROKE = REMSTROKE - \Delta TSRITSRITSRI

Stopper Rod Opening at Constant Throughput

Top of Stopper Rod Stroke

Stopper Rod

RODSTROKE

REMSTROKE

\Delta TSRITSRITSRI

Start (Closed) Position

Actual Position

Bottom of Stopper Rod Stroke

Upper Nozzle

TSRI

TSRI

A stopper rod movement caused spikes in mould level and subsequent mould powder entrapment.

Example 1: Mould Powder Sliver

A stopper rod movement caused spikes in mould level and subsequent mould powder entrapment.
Process Data & Defect Entrapment

Example 2: Multiple Mould Powder Slivers

Multiple stopper rod movements caused several mould powder entrapments.

Example 3: MP & Alumina Sliver following a Washout Event

A “wash-out” event caused mould powder & inclusion entrapments.
Summary

• Sliver formation on ULC coils for has been correlated with stopper rod movement at No. 1 CC under constant throughput casting conditions
• In some cases, a stopper rod movement was associated with mould level fluctuation under constant throughput conditions
  ➢ Both mould powder and alumina type slivers were associated with stopper rod movement in above cases
• In other cases, slivers were associated with stopper rod movement + factors such as, speed change etc.

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