Continuous Casting of Steel

Mechanical & Industrial Engineering Department

ME8109 – Casting and Solidification Materials

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Outline

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Introduction & Objective

- Slabs, Billets, Blooms depending on dimensions of the strand
- Higher capital cost and lower operating cost, less deformation
- The most efficient process and energy

1843
- Start practicing on new process of continuous casting

1936
- Start to develop the commercial continuous casting of steel by Siegfried Junghans

1940
- Several methods have been tested.

1950
- First vertical type continuous casting machine into operation by Mannesman

1957
- Alfred Wettli start to work on his first horizontal caster machine
Continuous Casting of Steel

Continuous Casting Methods

* Vertical Casting

- Mold axis and fluid flow are in vertical position
- Casting non-ferrous alloys such as Aluminum
- Produce ingots as a row material for Extrusion, Forging or Rolling
- Stop periodically to remove the cast ingot
- Speed is slow to avoid internal cracks and metallurgical length shorter

* Horizontal Casting

- Mold axis and fluid flow are in horizontal position
- Casting Steel or Copper alloys
- Withdrawal the strand through the hot rolling after spray chamber
- Produce ingots as a row material for Extrusion, Forging or Rolling
- Hot condition to pre-shap the final strand
- Cut the strand into different size by gas torches
Continuous Casting Methods

* Strip Casting
  - Casting Steel or other metals
  - Solidify thin layer of steel by passing the molten steel through large rotating rollers

* Curved Casting
  - Mold axis and fluid flow are in curved (V & H) position
  - Casting steel alloys
  - Semi-finished products such as Slabs, Billets and Blooms
  - Molten steel pours into the mold through a ladle and tundish
  - Speed is Fast and continuously, metallurgical length longer

* Other Continuous Casting
  - Electro-Slag Re-melting (ESR) or Vacuum Arc Re-melting (VAR) to cast supper-alloys (aerospace application)
Continuous Casting of Steel

Steel Casting Process

1. The steel heated above liquidus temperature in the furnace (Superheating degree)
2. Carry molten Steel (below 1600°C) by ladle into tundish
3. Enters molten steel into the mold through Submerge entry nozzle (SEN)
4. A solidified shell is formed during casting (1540°C)
5. Cooling continuous by quenching with water spray along the whole of the strand
6. The steel is still solidified all the way through when it’s cut into Slab by oxygen lances (1000°C)

Steel: Iron + Carbon (0.2% - 2.1%)

Entering liquid steel into the mold can cause unbalances and clogging and possibly break out
Melting Point of steel: 1370°C

http://www.youtube.com/watch?v=d-72gc61-E
**Fluid Flow & Solidification**

**Initial Solidification**

- The time-dependent shape of the meniscus
- Liquid flux flow into the shell-mould gap
- Local superheat contained in the flowing steel
- Conduction of heat through the mould
- Liquid mold flux and re-solidified flux rim
Fluid Flow & Solidification

Superheat Molten Steel and Level Fluctuation

Superheat = Steel Temperature Entering – Steel Melting Point

- Hottest, area midway between SEN and narrow face
- Coldest area, at the meniscus cause freezing meniscus and lead to:
  - To avoid Freezing Meniscus, reach the metal flow to the surface quickly
  - To avoid breakout, no gap between shell and mold
  - Level Fluctuation can reduce by flow pattern
  - Increase casting speed impact on transient turbulent fluctuation
  - Surface velocity keep under the critical value

Mold Powder

- Act as a lubricant between strand and mold
- Improve heat transfer from strand to mold
- Protect liquid steel against reoxidation
- Absorb inclusions that rise to the metal surface
- Provide thermal and chemical insulation of the top surface

Temperature and super heat distribution in the mould

1) Turbulence, 2) Level Fluctuation, 3) Vortexing, 4) Emulsification
Fluid Flow & Solidification

Clogging at SEN

- Dislodged Clogs or change the flux composition and leading to defect on molten steel
- Change the nozzle flow pattern (Asymmetrical) leading to slag entrainment and surface defect
- Clogging interferes with mold level control

* Using control device (stopper rod or slide gate) to compensate for the clog and ensure a smooth flow pattern

Caster Curvature

- Vertical Caster (at least the top 2.5 m section)
- Less Particle defects
Fluid Flow & Solidification

Argon Gas Injection

- Reduce nozzle clogging
- Influence and control the flow pattern in the mold
- Generating serious top surface fluctuation
- Capturing inclusions
- Capture solid oxide particles and lead to surface slivers

Electromagnetic Forces

AC electromagnetic fields of high or low frequencies:

- Oscillation marks
- Lateral cracks
- Entrapment of inclusions and bubbles
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Porosity Sources

Air Entrainment
• Failure to eliminate all air in the mold cavity

Oxides
• Re-oxidation inclusion (porosity remains when inclusion material removed by blasting)
• High level of oxygen reduce surface tension that must become to form a bubble

Shrinkage
• Shrinkage occurs when liquid metal becomes denser solid
• Drop the pressure in the liquid metal below atmospheric

Heat Treatment and Casting Speed
• Lower casting speed, higher metallurgical length
• Higher casting speed, higher temperature in SCZ
• Higher casting speed, consequently temperature distribution on the Walls
• Cast Speed depends on Product type & size
  * Regular: 0.5 – 4 m/min
  * High speed: 1.5-2.8 m/min
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Heat Treatment and Casting Speed

Mould Lubrication

- Helping to avoid breakout in high speed casting
- Occurs by influence of slag into the strand

\[
fi = \eta \left( V_m - V_c \right) / dl
\]

\[
f_s = \eta_s H
\]

- \( V_m \) = mould speed
- \( V_c \) = casting speed
- \( \eta \) = viscosity of liquid slag film
- \( dl \) = thickness of slag film.

- \( \eta_s \) = coefficient of solid friction
- \( H \) = ferrostatic pressure of molten steel
Primary & Secondary Cooling Zoon

* Passing the molten steel through the water-cooled tank

- Temperature of solid
- Casting speed
- Solidification time
- Cooling rate

Good quality & Thickness of the crust

* Key factors affecting on quality of strand in SCZ area

- Cooling water spray rate
- Metallurgical Length consideration
- Superheat of liquid steel
Conclusion

Quality of final product depend on:

- Liquid level in the mold
- Powder feeding rate
- Casting speed
- Gas injection
- Slide gate opening
- Nozzle position
- Cooling water rate

Benefit of continuous casting of steel:

- Considerable energy saving
- Less scrapped produced
- Improved labour productivity
- Improved quality of steel
- Reduced pollution
- Reduced capital costs, time saving, casting process
- Increased use of purchase scraps when output is maximized
- A highly productive process that can be fully automated
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Thank You