Current Refractory Technology and Practices in the Steel Industry

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Steel Production in Numbers

United States 4th largest producer of steel in the world

2016 World Steel Production

United States 4th largest producer of steel in the world

U.S. Production Method, 2016

2015 Steel Shipment by Market Classification

Source: American Iron and Steel Institute
Ironmaking Refractory Technology & Practices

**Blast Furnace** -> Hearth, Tuyere Surround, Bosh, Lower Stack, Upper Stack, Stock Line

**Cast House** -> Trough, Iron Runner, Slag Runner, Tilter

**Blast Furnace Ancillary Equipment** -> Stoves, Bustle Pipe, Tuyeres
Ironmaking Refractory Technology

**Refractory Requirements**

**BF Hearth**
- High Refractoriness
- Resistance to Metal Penetration
- Resistance to Slag Attack
- Higher Thermal Conductivity
- Resistance to Oxidation

**BF Bosh/Stack**
- High Refractoriness
- High Abrasion Resistance
- Resistance to CO Attack
- Resistance to Alkali Attack

**Cast House**
- High Refractoriness
- High Abrasion Resistance
- High Oxidation Resistance
- High Thermal Shock Resistance

**Current Refractory Materials**

**BF Hearth**
- Carbon Brick
- Semi-Graphite Brick
- Graphite Brick

**BF Bosh/Stack**
- SiC Brick
- High Alumina Bricks
- Super Duty Firebricks
- High Alumina Shotcretes

**Cast House**
- Resin/Pitch Bonded Taphole Clays
- High Alumina SiC Monolithic

**Recent Developments**

**BF Hearth**
- Higher mechanical strength, lower porosity-hot pressed carbon bricks
  - 10-15 Years

**BF Bosh/Stack**
- Re-profiling hearth refractory with carbon containing shotcretes
  - 18-24 Months

**Cast House**
- Opportunity exists for improvement of SiC containing high alumina shotcretes for trough applications
  - 3-6 Weeks
Ironmaking Refractory Technology

- Pre-installation Assembly
- Hearth Reline
- Hearth Partial Reline
- Tuyere and Bosh Area
- Shotcrete Repair
- Cast in-situ Repair
Iron Transportation: Torpedo Cars, Iron Ladles

Hot Metal or Torpedo Cars

60% Alumina and 70% Alumina Brick Safety and Working Lining
In some cases, Alumina-SiC-C resin bonded bricks are used

Maintained by 60-65% Alumina Shotcrete
Shotcrete repair done every 50-100,000 tons hot metal

Iron Transfer Ladle

60% Alumina and 70% Alumina Brick Safety and Working Lining OR
70% Alumina Shotcrete Working Lining OR
Alumina-SiC-C Resin Bonded Brick Working Lining

Maintained by 60% Alumina Gun Mixes
~1000-3200 heats/campaign
Iron Transportation: Torpedo Cars, Iron Ladles

Alumina-SiC-C (ASC) Brick vs. High Alumina Brick Lining

Advantages
- Extended campaign life with less gunning maintenance
- Can use thinner lining, increase ladle capacity

Disadvantages
- Need adequate preheating to seal joints in the working lining and prevent breakouts
- Works best if ladles are kept hot “in the run”
Basic Oxygen Furnace (BOF)

MgO-C resin bonded bricks with metallic additions

Mix of fused and sintered high purity MgO

High purity graphite, 5 to 15% by weight Carbon

Lining zoned with various grades of brick to get the desired cost effective lining

Furnace slag aimed to be saturated with MgO by adding dolomitic lime

Slag splashing - a common practice now

Use of laser to measure lining thickness 360°

Lining thickness/profile maintenance with MgO based gun mixes

Campaign Life >35,000 heats achievable
Gun Mix Consumption: 0.70 to 2.0 lb/ton
Steel Ladles

- Slagline: MgO-C resin bonded bricks with or without Al/Si metals
- Barrel: Al₂O₃-MgO-C resin bonded bricks with Al/Si metals
  [Alternatively, high alumina spinel based castables]

Carbon pick-up from Carbon containing refractories an issue for a few shops. Work has been done to lower carbon.

Bottom:
- Al₂O₃-MgO-C resin bonded bricks with Al/Si metals,
  Precast well blocks and nozzles
  Or
  Precast Bottom - high alumina spinel based
Steel Ladle Bottoms:

CFD and Water Modeling to design bottom shapes specific to a ladle geometry and shop practices

Purpose to drain as much steel as possible without draining slag into the tundish, i.e., High Yield Bottoms

Still limited use. Need robust mechanism to control and measure yield benefits. Higher cost than brick bottoms
RH Degasser

Magnesia-Chrome Brick still dominant for degasser linings.

Various grades used depending on wear profile
- Direct Bonded Mag-Chrome
- Semi Rebonded
- Rebonded

Snorkels, Throats, and Lower Vessel lining more frequently relined (250-500 heats)

Efforts are now being made to replace Mag-Chrome bricks.

Magnesia-Carbon bricks or iso-statically pressed pieces are being trialed in snorkels and lower vessel.
Steel Flow Control – Slidegate plates, nozzles, ladle shrouds

Nozzles/Plates:
Alumina-Graphite Resin Bonded
Alumina – Tar Impregnated
Magnesia-Carbon
Zirconia insert in plates

Shrouds:
Zoned with various materials
Alumina-Graphite
Zirconia based slagline area
Fused silica for thermal shock resistance

Material

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<th>Erosion Rate (mm/h)</th>
<th>Al2O3</th>
<th>Al2O3-C</th>
<th>MgO</th>
<th>ZrO2</th>
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<td>CaSi Treated Steel</td>
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<td>6</td>
<td>4</td>
<td>2</td>
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<tr>
<td>Al-Killed Steel</td>
<td>12</td>
<td>8</td>
<td>6</td>
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Ladle Well Block
Ladle Inner Well Nozzle
Ladle Gate Mechanism
Ladle Shroud
Steel Flow Control

Stopper Rods
- Iso-statically pressed, engineered piece
- Shapes/Material requirement vary based on steel grades
- Alumina-Graphite with or without MgO nose, argon injection optional

Submerged Entry Nozzle (SEN)
- Iso-statically pressed, highly engineered
- Different types of materials (up to 5) used to address wear mechanisms
- Alumina-Graphite for body, Zirconia-Graphite for slag line

Failure Modes
- Slag line erosion
- Clogging
- Cracking

Source: T. Yotabun et al., TAIKABUTSU Vol 36, No. 3
**Tundish Lining**
- Calcium silicate board or Micro-porous Insulation
- 65-70% Alumina castable for permanent lining
- 65-85% MgO Based Working Lining Material
  - Gunned
  - Sprayed
  - Dry-Vibrated

Working lining material must
- Withstand temperature up to 2850°F
- Resist tundish slag attack
- Maintain shape at high temperature
- Shrink after cool down
- No interaction with steel (i.e. no Si, H, N, C pick-up)
Reheat Furnaces

- Pusher or Walking Beam Type
- Purpose is to reheat slabs to ~2200°F without any marks or scratches
- Significant energy consumption 1.4-1.7 MMBTU/ton – Pusher type RHF
- **Focus on improving energy efficiency and quality of slabs**
  - using better combustion control equipment
  - Insulating and long lasting refractory designs
  - Study of scale and refractory interaction
Reheat Furnaces

Sidewalls
- Hot Face
  - 60-65% alumina shotcrete
  - 70% Alumina phos bonded plastic
- Back-up lining
  - Insulating Fire Bricks
  - Insulating Gun Mixes
  - Insulating Calcium-Silicate Boards

Roof
- 60-65% alumina castable @ hot face
- 70% alumina plastic @ hot face still common
- Insulating pumpable castables @ cold face

Hearth
- >93% alumina-spinel castable
  - Or
  - >65% alumina castable with ceramic skid rails made of high alumina-spinel castable
Finishing End Refractory Technology

Reheat Furnace
Hearth
Finishing End Refractory Technology

**Amorphous Alumino-Silicate Fibers**

2300°F or 2600°F rated

However, crystallization of fiber starts >1800°F

Excessive shrinkage and loss of mechanical strength- key issue

Limited use in reheat furnace roofs. Used in preheat/ annealing furnace where temperature is low and regular maintenance can be performed

**Polycrystalline Mullite or Alumina Fibers**

2900°F rated

No excessive shrinkage up to 2700°F.

Crystal growth can still occur at higher temperature leading to shrinkage and dust

Uses growing. Higher cost prohibits large scale applications

Some finishing end furnace lining lasting more than 10 years with no maintenance
Polycrystalline Mullite or Alumina Fibers

- Most preferred, if their cost can be justified
- Installed as pre-compressed large size panels
- Offers long service life (>10 years)
- No maintenance required while in service
- Crystal growth observed after long service life or exposure to temperature >2700°F
- Challenge is to lower cost for large scale adoption
• Refractory Materials, as consumables, account for 2-3% of steel production cost. However, they have much greater indirect influence on steel production.

• Selection of refractory lining materials and designs are critical for safe, stable, energy efficient, and cost effective steel production.

• Monolithic preferred due to reduced lead time, and easier installation compared to bricks. However, bricks continue to outperform monolithic in several areas.

• Refractory materials and their application methods have improved continuously. However, there has not been any disruptive change in the last decade or so.

• Changes in steel production process, demand supply of natural resources/energy, environmental regulations, and fundamental understanding of wear mechanisms are the key factors affecting development of refractory technology

• Technological landscape is changing rapidly around us. More collaborative approach is needed between academia, producers, and end-users to advance refractory technology further.
Thank you !