Development of a Process to Continuously Melt, Refine, and Cast High-Quality Steel

Research Conducted by:
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Research Team

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  - Metallurgical Engineering Students
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- **University of Illinois at Urbana-Champaign**
  - Mechanical and Industrial Engineering Faculty
    - Brian Thomas, Lifeng Zhang
  - Graduate student (fluid flow modeling)
    - Jun Aoki

- **Consortium of Eight Steel Companies**
  - Nucor, Nucor-Yamato, Gerdau Ameristeel, SMI, TXI-Chaparral, Bayou

- **Consortium of Three Engineering / Know-how Suppliers**
  - Corefurnace (Techint), Proware-Metsim, Heraeus Electronite

Development of a Process to Continuously Melt, Refine, and Cast High-Quality Steel
Overview of presentation

- General aspects of continuous steelmaking
- Examples of previous research
- Introducing a new conceptual process
  - Conceptual layout of process
  - Some information about each unit
    - Including unit that was modeled by Lifeng Zhang
Goal of Project

- Conduct R & D to design a continuous steelmaking process that starts with scrap and delivers high quality steel to the casting mold in one process.

FEATURES OF THE CONCEPT

- Fully continuous
- Scrap-based
- Continuous stirring of vessels (Bottom – blowing)
- Separated vessels
- Enclosed process

=> POTENTIAL BENEFITS

- High productivity, maximum automation
- Less Refining required
- Rapid mixing, high reaction rates near equilibrium
- No backflow
- Safer & environmentally friendly
Continuous Steelmaking

Benefits/Advantages

- Lower capital cost
  - Smaller vessels
  - Less cranes
- Higher capital utilization
- Less labor
- Easier to automate
- Less conversion time
- Better energy utilization
- Less off-gas (less KO61)
- More consistent quality
- Safer & healthier workplace
  - Enclosed process
  - Less batch processing

Risks/Challenges

- Logistics
  - Start-up / Shut-down
- Matching to casting speed
- Changes or upsets to system
  - Grade change
  - Delays
  - Off-specification
- Connectors
- Deslagging
- Elevation of Vessels
- Refractories
- Previous problems
- Difficult to run a pilot plant
- Lack of real operational data
Previous Research in Continuous Steelmaking

- Several processes were researched
  - Types of vessels:
    - CSTR - Completely Stirred Tank Reactor
    - Counter-current Reactor
    - Con-current Reactor
    - Emulsion / Spraying
  - Starting material
    - Hot metal
    - Scrap
  - Types of processes:
    - Continuous operating and periodically tapping (e.g. Consteel)
    - Continuous operating and tapping into ladle
    - Fully continuous operation (never tested)
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PFR: WORCRA cont. steelmaking

- Australia, Sweden, Britain, USA
  - 1961 – 1990’s
  - Countercurrent flow
  - Different versions
  - 10 tph Oregon ‘72

Problems/Critics
- Backmixing = NO CONTROL
- Refractory wear
- Heat loss
- Unsatisfactory productivity

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Emulsion CSTR: IRSID cont. st.

- **France**
  - 1963 – 1970’s
  - Emulsion & separation
  - FAST KINETICS

- **Problems/Critics**
  - Unknown mechanism = NO CONTROL
  - Low iron yield
  - Long settling times
  - Refractory wear


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Equilibrium CSTR: AISI cont. st.

- USA
  - 1980’s - 1990’s
  - Equilibrium CSTR

- Problems/Critics
  - Kinetic limits
  - Low iron yield
    - High initial carbon and low final carbon
    - Clogging of connectors transporting FeO

The AISE Steel Foundation “The Making, Shaping and Treating of Steel” 11th edition, Steelmaking and Refining Volume, 1998, p. 748, Fig. 13.4

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UMR’s Continuous Steelmaking Concept

- Processing time ≈ 1 ¼ hr
- Total liquid metal ≈ 130 t

- 4 Units - 100% scrap based
- Melting Unit
  - EBT AC (or DC) EAF melting
  - Consteel preheating & continuous feed
  - Remove P
- Oxidation Unit
  - CSTR to remove C
- Reduction Unit
  - CSTR to remove O & S
  - Alloying
- Enhancement Unit
  - Homogenization
  - Flotation

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Heated holding ladle (for EAF or tundish), or pig the steel

0.15%C

Heat and hold (40-50 t)

Measure

2890°F

2910°F

2980°F

2880°F

2870°F

2830°F

012 3456 78 9 10 11 12 13 14 15 16

Conceptual layout for 110 tph process

Top view
Looking at steel surface

Side view

Melt

O₂ + Ar

Oxidize

Rede

Reduce

Alloys

Deoxidizer, CaO, MgO

CaO, MgO

Measure

Heating rods

Wire feeding adjustment

Mold

Measure
Consteel preheater and EAF

- Preheat tunnel (~100 ft)
  - Continuously transports and preheats scrap to ~800ºF
- Near-equilibrium EAF
  - Less FeO in the slag, higher Fe-yield
  - Continuously foaming slag
  - Electrode heats liquid - Liquid melts scrap
- Proven technology

http://www.corefurnace.com/meltshop_01.html
Preliminary Concepts – Melting Unit

- **Consteel preheater**
  - Post-combustion of CO from EAF and oxidation vessel
    - More efficient = gas composition consistent
    - Estimated scrap (and lime) temperature entering unit (800ºF)

- **Melting similar to current EBT AC (or DC) EAF**
  - ~50 tons of metal capacity
  - 40 MW of power (50 MW transformer)
  - ~30 minutes residence time for 110 tph
  - Continuous charging and tapping
  - Continuous oxygen blow
    - De-P and De-C (below 0.15%C) continuously
  - Carbon/oxygen injection for continuous foamy slag
  - Continuous de-slagging

- **Continuous Tapping**
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- De-C
- Similar to continuous Q-BOP
  - Fruehan model
- Continuous de-slag

![Diagram of Oxidation Unit]

- 45 scf CO / t
- 32 scf Ar / t
- 111 t / hr
- 2890°F
- C = 0.15%
- 18 lbs flux / t
- 30 lbs slag / t
- 110 t / hr
- 2910°F
- C = 0.08%
- 54 scf O₂ / t
- 32 scf Ar / t

Steel weight = 20 t
Time = 12 min
Fluid flow in vessel

"Mix":
- Homogenize composition & temperature
- Mass transport (→ kinetics)
  - Bulk
  - Create interface (turbulent energy)
- Support floatation

Zhang, Lifeng “internal document”
UIUC, August 2003
Preliminary Concept for Reduction Unit

- **De-O & De-S**
- **Continuous de-slag**
- **Alloying**
  - Bulk (small pieces)
- **Temperature control**
  - Resistant heating
  - Avoid cooling
- **Calcium treatment**

- **110 t / hr**
  - 2910°F
  - O = 550 ppm
  - S = 300 ppm

- **12.4 lbs slag / t**
- **Deoxidizer, CaO, MgO**
- **2.2 lbs Al / t**
- **8.4 lbs flux / t**
- **64 scf Ar / t**
- **9.4 lbs SiMn / t**
- **5.2 lbs FeSi / t** (other alloys)
- **~1 kWhr / t**
- **110 t / hr**
  - 2880°F
  - O = 6 ppm
  - S = 35 ppm

- **64 scf Ar / t**
- **3.4 lbs CaSil / t**

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Preliminary Concept for Final Unit

- Final Alloying
  - Wire injection adjustments
- Homogenization
- Inclusion floatation
- Minimize reoxidation
- Continuous transfer to mold

- Small alloy additions
- 110 t / hr 2880°F
- 2.2 lbs flux / t
- 32 scf Ar / t
- 32 scf Ar / t
- 2.4 lbs slag / t
- 110 t / hr 2830°F
- Steel weight = 34 - 50 t
  - Time = 20 - 30 min
  - 1 – 3 strands

Development of a Process to Continuously Melt, Refine, and Cast High-Quality Steel
Continuous Monitoring

- Con®Cept: Temperature & Chemistry
  - Laser – lens – spectrometer (LMF & EAF, etc.)
- Inclusion sensor*
  - Size & Number

Temperature  Chemistry

Ramaseder et al. “Continuous chemical analysis of liquid steel” Steel Times International, Nov 02, p. 30

Pillwax et al. “VAI-ConCept – A Performance Package for AOD converters” AISE Steel Technology, Vol. 80, No. 9, Sept 03, p. 93
Summary

- Continuous steelmaking has the potential to increase profits
- Extensive previous research exists
- New conceptual process is scrap based and fully continuous
- Fluid flow modeling is crucial during the design of the vessels