# ANNUAL REPORT 2005

**Meeting date: June 1, 2005**

## *Continuous Casting Consortium Annual Meeting*

**Brian G. Thomas, Director**

***Department of Mechanical & Industrial Engineering***
**University of Illinois at Urbana-Champaign**

# OBJECTIVES

- To develop computational models of continuous casting of steel and related processes
- To apply these models to problems of practical interest to the steel industry

# Tentative Attendees

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|---|---|
| Nucor Steel, Decatur, AL: | *Ron O'Malley & Jay Watson* |
| Accumold / SMS Demag: | *Don Lorento* |
| Algoma Steel: | *Bart Thompson & Troy Murray(?)* |
| LWB Refractories: | *Don Griffin, & Rob Nunnington* |
| Mittal Riverdale: | *Gary Norgren, Clint Graham, Steve Fiegle & Michael Okelman* |
| LaBein: | *Claudio Ojeda* |
| Corus: | *?* |
| Postech: | *Ho-Jung Shin* |
| Fluent Inc.: | *Ashwini Kumar & Hossam Metwally* |
| University of Illinois: | *Brian G. Thomas, Joseph Bentsman, Lifeng Zhang, Joydeep Sengupta, Kun Xu, Seid Koric, Kai Zheng, Claudio Ojeda, Jun Aoki, Bret Reitow, Ho-Jung Shin, Sami Vapalahti, Sana Mahmood, Zaher Hashisho & Albert Liu(?)* |



# Day 1: Morning Session

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|---|---|---|
| *8:00am* | *Breakfast & Introductions* | 143 Mech. Eng. Bldg. |
| 8:15 | B.G. Thomas: | Overview of projects |
| 8:30 | L. Zhang: | Multiphase flow, inclusion nucleation, growth, removal and entrapment – in molten steel and continuous casting |
| 9:30 | BGT / Q. Yuan: | Continuous Casting Defects from Transient Flow and Inclusion Entrapment |
| *10:00* | *Break* | |
| 10:05 | BGT / Z. Hashisho: | Argon gas flow through nozzle refractories |
| 10:25 | J. Aoki: | Ladle mixing and inclusion removal by bubbles |
| 11:15 | B. Rietow / S. Mahmood | Fluid flow in a funnel mold thin-slab caster<br>Measuring mold top surface velocities using nailboards |
| 11:50 | BGT / ME470 team: | Measuring mold surface velocities using deflecting rod |
| 12:05 | Discussion of flow projects | |

# Day 1: Afternoon Session

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| *12:30pm* | *Lunch* | 143 Mech. Eng. Bldg. |
| 1:00 | BGT / S. Vapalahti: | Calibration of CON1D in mold using 3-D FEM model |
| 1:10 | K. Zheng: | Online control of spray cooling using CON1D |
| 1:40 | K. Xu: | Modeling of nitride precipitate formation during secondary spray cooling |
| 2:00 | *Break* | |
| 2:05 | H.-J. Shin: | Investigation of oscillation marks and hook formation in ULC steels using metallurgical analysis and models |
| | J. Sengupta: | Application of CON2D to meniscus behavior<br>Mechanism for oscillation and hook formation |
| *3:35* | *Break* | |
| 3:40 | C. Ojeda: | Modeling Meniscus fluctuations during oscillation |
| 4:00 | S. Koric: | Solidification Stress Modeling using ABAQUS |
| 4:20 | L. Zhang: | Continuous Steelmaking – development of a new process to continuously melt, refine, and cast high quality steel |
| 5:00 | Discussion of future projects and directions | |
| *5:30* | *Adjourn meeting* | |
| *6:00* | *Dinner* | Illini Room A, Union Building |



# Day 2

8:00 am-? *B.G. Thomas: 356 Mech. Eng. Bldg.*
Informal discussions on future projects

8:00 am-? *Research group: 345 Mech. Eng. Bldg.*
Informal discussions
Further details on current projects and software
CON1D and CON2D operation
Questions

# Research Summaries

## Flow Dynamics and Inclusion Transport in Continuous Casting of Steel

*B.G. Thomas,* S.P. Vanka,* and L. Zhang*
National Science Foundation GOALI # DMI-0115486 & CCC**

Computational models of transient, multiphase fluid flow are being developed, validated, and applied to improve understanding of transient flow, inclusion transport and defect formation in the mold region during the continuous casting of steel slabs. Process parameters, such as nozzle geometry and gas injection rate, which are easy to change and yet profoundly influence both flow and product quality, are being optimized. Models to compute the transport and entrapment of inclusion particles are being tested through water model experiments, steel plant trials, and metallographic measurements at several steel companies who are cosponsoring this research.

## Thermal Stress Analysis of Solidifying Steel Shells

*B.G. Thomas,* S. Koric, J. Sengupta, K. Xu, and C. Ojeda*
Continuous Casting Consortium**

A coupled, two-dimensional, transient finite-element model has been developed to predict temperature, shrinkage, and stress development in both horizontal and vertical sections through the solidifying shell as it moves down through the caster. The model includes the effects of the volume change during phase transformation, ferrostatic pressure, the generalized plane strain stress state, the constraining influence of the mold, creep plasticity, and the dynamic effect of solidification shrinkage on heat transfer across the interfacial gap between the mold and the shell. The model is being applied to simulate the early stages of solidification, ideal taper for different steel grades, maximum casting speed to avoid excessive bulging, and understanding crack formation.



# Research Summaries

## Initial Solidification and Meniscus Hook Formation in Continuous Slab Casting

*B.G. Thomas,* S.-H. Kim,* H.-J. Shin, Y. Meng, L. Zhang, J. Sengupta, and C. Ojeda*
Continuous Casting Consortium**, POSTECH, Korea, and Labein, Spain

The first few seconds of solidification at the meniscus create the final cast product surface, and may include defects such as deep oscillation marks, surface depressions, and subsurface hooks in the microstructure, if conditions are not optimal. Computational fluid flow, heat flow and stress models of the meniscus region are being developed and applied to simulate these phenomena. Plant measurements such as mold temperature, liquid surface shape, and metallographic examination of oscillation marks and hooks are being conducted on slabs cast at POSCO. Together, ways to optimize casting conditions such as speed, level control, superheat, mold oscillation practice, and mold powder composition are being investigated to minimize meniscus hook depth.

## Online Dynamic Control of Cooling in Continuous Casting of Thin Steel Slabs (ongoing)

*B.G. Thomas,* J. Bentsman*, Y. Meng, K. Zheng, and S. Vapalahti*
Continuous Casting Consortium** and National Science Foundation

*Temperature variations during cooling cause quality problems such as cracks, especially under transient conditions such as caused by changes in casting speed. Setting the spray water flow rates to maintain optimal temperature profiles during process changes becomes increasingly difficult when the casting speeds are high and response times must be fast. This project aims to develop a fundamentally-based online system to dynamically control the water flow rates in order to continuously optimize and stabilize cooling conditions in the thin slab casting process. The system will use model-based predictive control, incorporating both online measurements of mold heat removal and on a high-speed finite-difference model of heat conduction and solidification during the process.*

# Research Summaries

## Fluid flow, Heat transfer and Interfacial Phenomena in Nozzle Refractories (ongoing)

*B.G. Thomas,* and Z. Hashisho*
Continuous Casting Consortium**

Dolomite nozzles differ from conventional nozzles in having higher resistance to alumina clogging but are more easily eroded. Fundamental modeling studies are being performed to understand and characterize the behavior of these nozzles, to compare them with conventional nozzles, and to optimize their use in service. Specific studies include an analysis of the flow of argon gas within the porous refractory walls to learn the gas distribution upon entering the molten steel. Heat transfer through the refractory walls is being modeled for a variety of realistic conditions, to understand the role of steel skulling on clogging for different refractory properties. Finally, the interfacial behaviors which govern the clogging attachment, the dissolution of the refractory, and the thermodynamic reactions are being studied.

## Thermal Stress and Surface Crack Formation in Continuous Casting (starting)

*B.G. Thomas,* J. Sengupta, and K. Xu*
Continuous Casting Consortium**

Thermal stress in the steel shell as it moves down through the mold and below between the rolls in the secondary cooling zones contributes to many different problems, including transverse cracks, slab shape problems, and support roll wear. Mathematical heat flow and stress models are being developed to predict the temperature, and the associated distortion, stresses and strains, both in and below the mold. In addition, criteria for crack formation will be developed, based on steel ductility measurements and a model of grain size and nitride, oxide, and sulfide precipitation to track the susceptibility of different steel grades to ductility problems. Results will be compared with experience prior to establishing cracking criteria and applying the models to understand and explore ways of preventing cracking problems.



# Research Summaries

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

*B.G. Thomas, L. Zhang, and J. Aoki*
Department of Energy; University of Missouri – Rolla; Continuous Casting Consortium**

Many operational problems and costs are associated with feeding the continuous casting process from the continuous electric furnace steelmaking operation using via batch ladles. A multifaceted project combining plant experiments, lab experiments, and computational modeling aims to design a fully continuous process using a series of intermediate vessels where alloy addition and refining occurs at steady state. The UIUC role focuses on the computational modeling aspects of the project. Three-dimensional models of multiphase turbulent fluid flow, mixing, and particle motion are being developed to assist with the design calculations. The results will help to design a feasible process, while identifying and solving possible problems prior to the pilot plant stage.

## Investigation of Steel Cleanliness during Ingot Teeming

*B.G. Thomas,* L. Zhang*, and B. Rietow*
Ingot Metallurgy Forum

Inclusions trapped during bottom-poured static-cast ingots lead to quality problems in the final product. Computational models of transient, multiphase fluid flow in this process are being developed and applied to improve understanding of inclusion transport and capture. Process parameters, such as teeming rate and runner geometry are being optimized. Plant experiments to measure inclusion locations, refractory wear, and other relevant phenomena are being conducted for additional insight and model validation.