ANNUAL REPORT 2012

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Cononline Implementation Issues

Bryan Petrus
(Ph.D. Student)

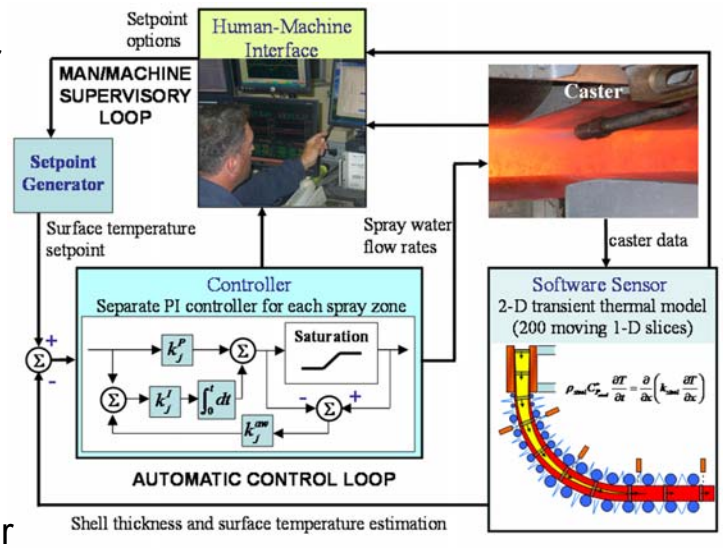
Department of Mechanical Science and Engineering
University of Illinois at Urbana-Champaign

Overview

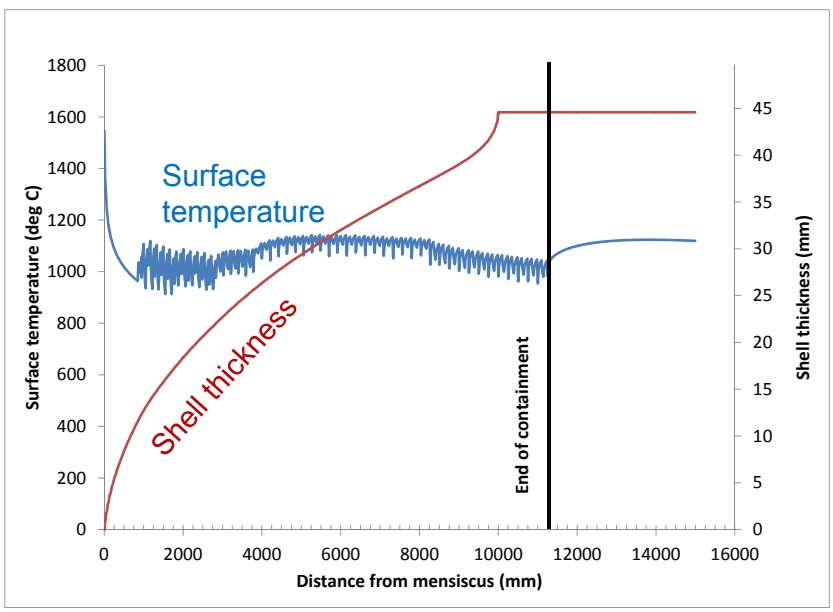
- Overview of Cononline
- Method for determining metallurgical length
  - Overview of method
  - Use in calibrating and validating Cononline
- Cononline trial / transverse cracking investigation

Cononline

- Online control system for secondary cooling water sprays in caster
- Real-time model ("Consensor") of heat transfer and solidification in the strand predicts surface temperature.
- Control algorithm ("Concontroller") tries to keep the Consensor prediction constant

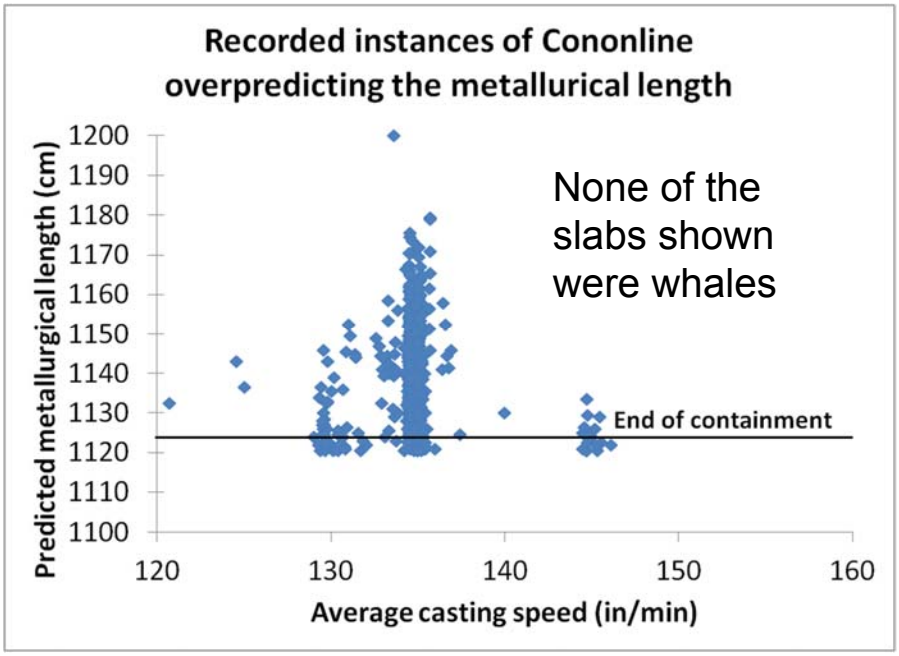


CON1D – Thermodynamic model predictions



Results depend on spray-heat transfer coefficients

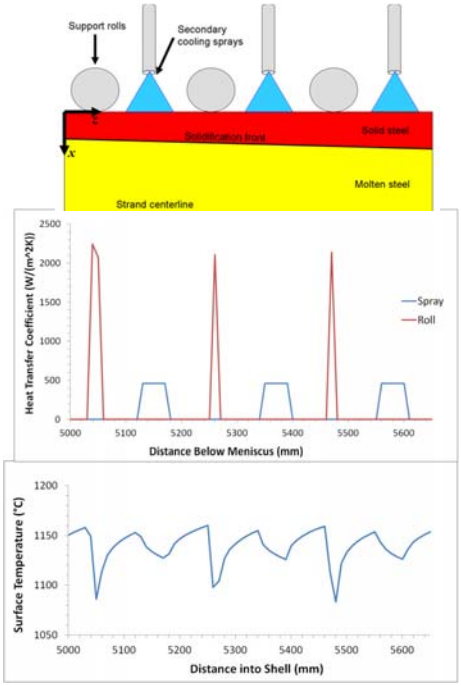
CON1D Calibration



Calibrating CON1D – Heat removal in the secondary cooling region

- Mold heat removal can be measured by temperature drop in mold cooling water
- However, we can't directly measure heat loss due to spray cooling

- Empirical correlations relate heat flux to water flux (flow rate divided by impacting area) based on experiments are fairly accurate
- But, there is still some significant variation between casters
  - Relative amounts lost due to sprays versus rolls?
  - Uneven distribution of spray water under nozzle?
  - Effect of air mist versus hydraulic nozzles?
- These factors can be adjusted through parameters in the CON1D input file:
  - "Spray coefficient" : increases effect of spray cooling
  - Shape of spray footprint
  - "Roll fraction" : increases effect of roll cooling



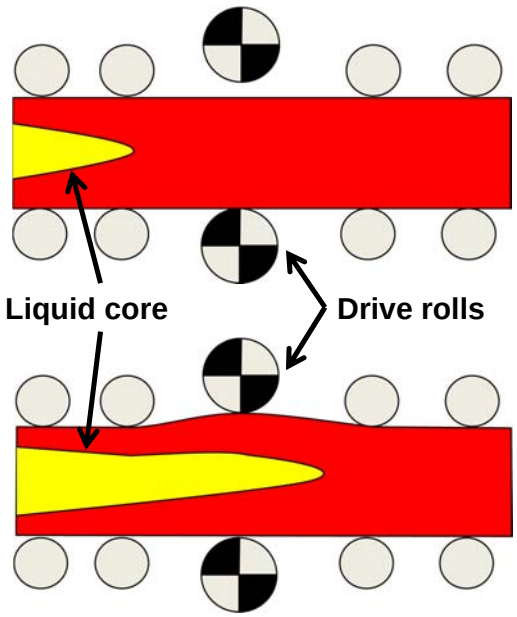
Calibrating Con1d – Metallurgical Length

- Historical whale cases provide a minimum value for metallurgical length
- Shell thickness for accidental crushed slab incident does not necessarily equate to shell thickness for containment
- How can we get a better idea of the metallurgical length?

Nucor Hertford Metallurgical Length Trial

- Test for containment devised by Toshi Hirose
  - Takes advantage of dynamic soft reduction
  - Increase gap in last segment until rolls lose contact with strand surface (~ 0.04 inches) and stop turning
  - Slowly increase speed until metallurgical length moves into the zone and then ferrostatic forces cause bulging. This forces the strand surface back into contact with the roll, causing them to turn.

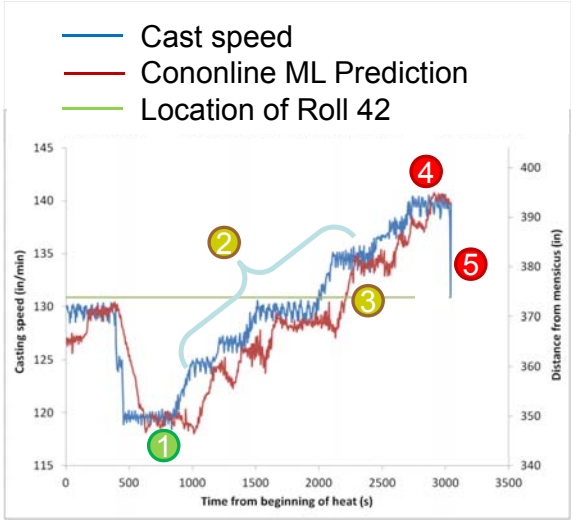
- Decatur caster does not have dynamic soft reduction ability
- But, they can lift their drive rolls ~ 0.02 inches away from the slab surface to let the SARCLAD through.
- Decatur version:
  - Lift the drive roll using the strand tracking screen in the pulpit
  - Cut the power to the drive roll (pull the fuse)
  - Increase speed until the roll stops turning



Nucor Decatur Metallurgical Length Trial

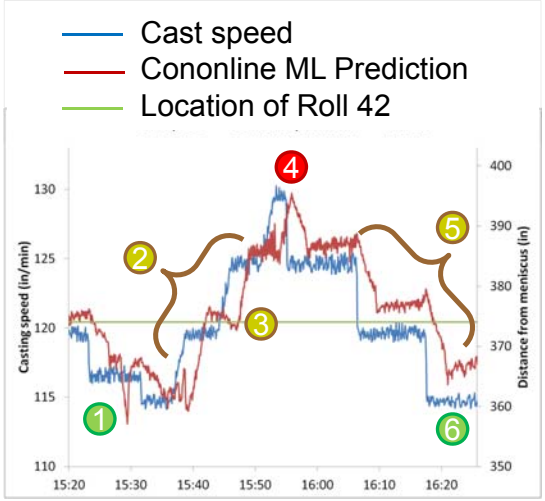
Nucor Decatur Metallurgical Length Trial 1

- North caster, heat SB3794
  - 0.18% Carbon, 48.5" wide, spray curve 4
- Observations
  1. Speed was reduced to 120 ipm, drive roll was lifted and de-powered
  2. Between 125 and 135 ipm, roll shifted when speed was increased, then came to a stop
  3. At 135 ipm, still no turning. But, Consensor starts to predict ML exceeds "containment"
  4. At 140 ipm, the roll began turning, Consensor predicted ML 10 inches longer than roll position
  5. Cobble at finishing mill, caster tailed out
- Conclusions
  - ML should be at or near 374 inches at 140 ipm under these conditions
  - Cononline was overpredicting ML (so had an excessive safety factor)
  - **DON'T ATTEMPT THIS TRIAL ON LIGHT GAUGE MATERIAL** (this was ≤ 0.100 gauge) because it is more sensitive to temperature variations along cast slab length, which are caused by this method

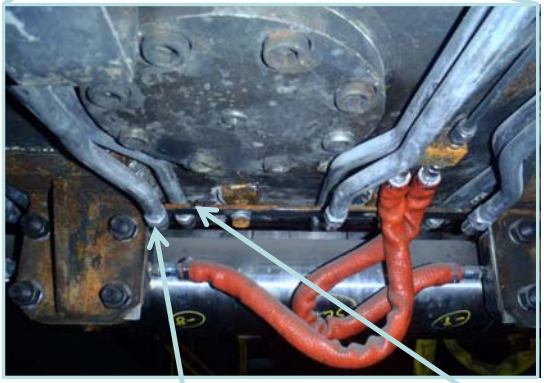


Nucor Decatur Metallurgical Length Trial 2

- North caster, NB4085 and Nb4089
  - 0.04% Carbon, 62.5" wide, spray curve 4
- Observations
  1. Slowed down to 115 ipm before beginning trial, drive roll would shift occasionally
  2. At 120-125 ipm, roll would turn and stop repeatedly, never turning continuously
  3. At 120 ipm, Consensor starts to predict ML exceeds "containment"
  4. At 130 ipm, drive roll began turning continuously, so speed was slowed down again
  5. During slowdown, roll showed same behavior as during the speed-up (so no hysteresis)
  6. Ended trial after reaching 115 ipm again
- Conclusions
  - ML should be above 374 inches at 130 ipm under these conditions
  - Cononline is again overpredicting ML



Roll Cooling in Foot Rolls and Bender



Roll spray

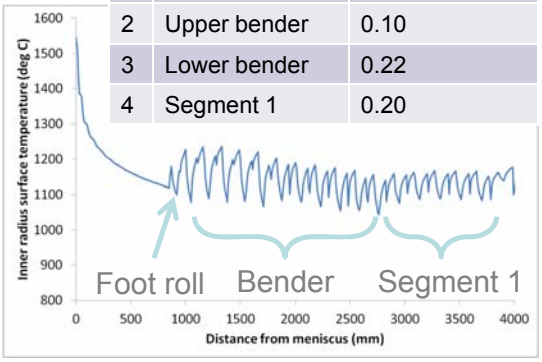
Slab spray

Internally cooled rolls

CON1D Calibration

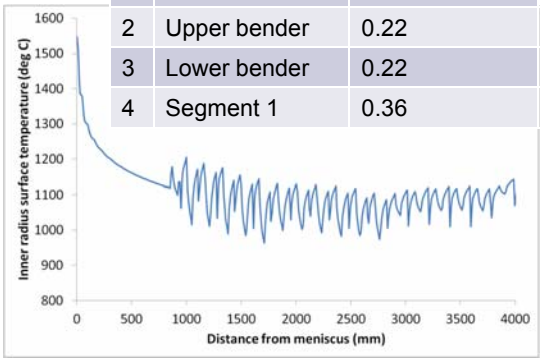
Original heat transfer coefficients

	Zone name	Roll fraction
1	Foot roll	0.08
2	Upper bender	0.10
3	Lower bender	0.22
4	Segment 1	0.20



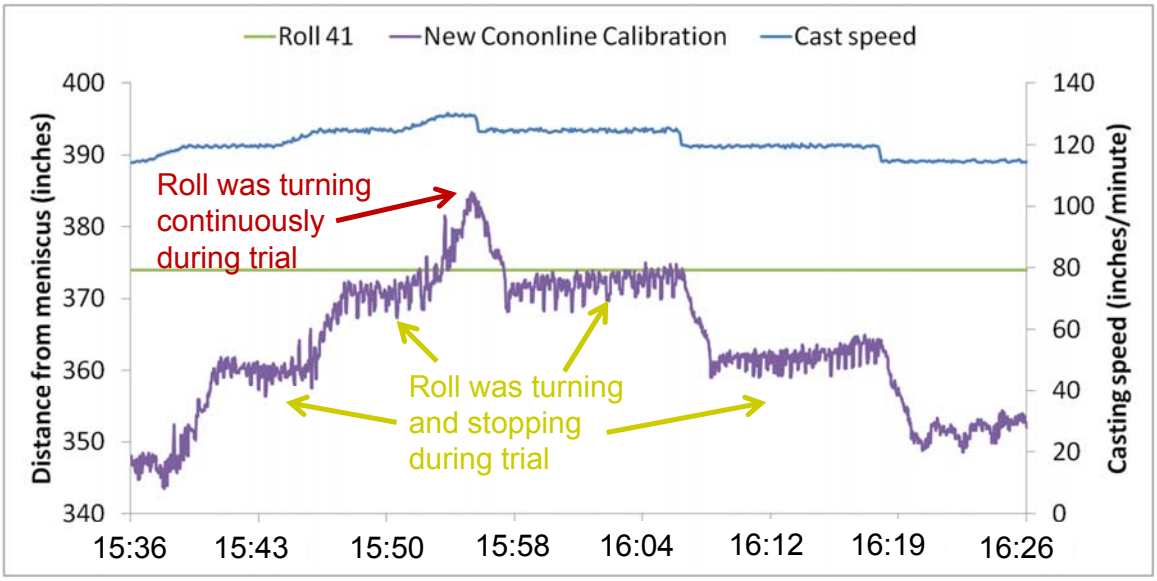
Increased roll heat transfer in upper spray zones

	Zone name	Roll fraction
1	Foot roll	0.22
2	Upper bender	0.22
3	Lower bender	0.22
4	Segment 1	0.36



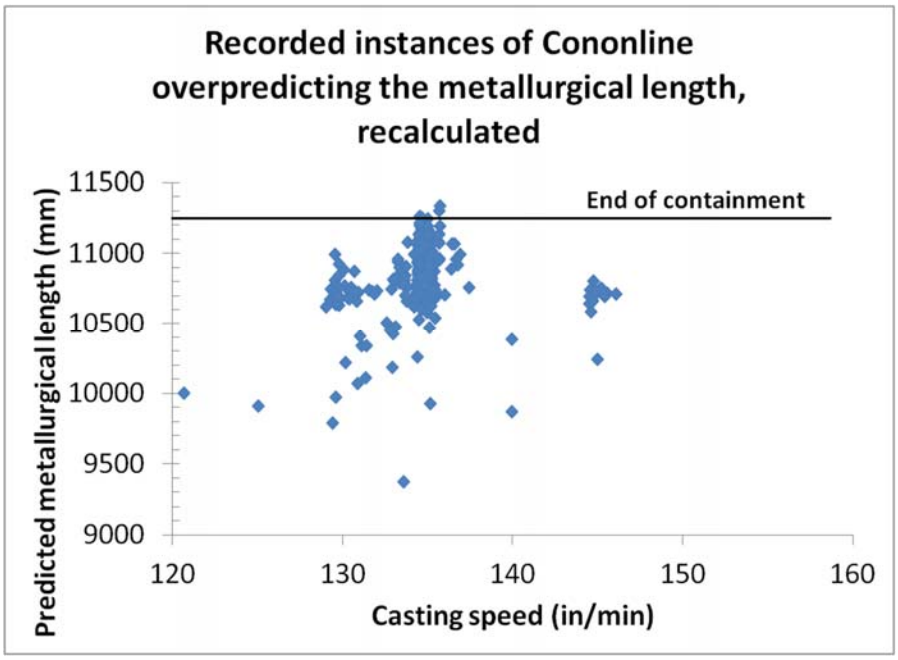
Increased roll cooling in foot roll and upper bender to be same as lower bender, and increased roll cooling in segment 1 to be same as rest of segments.

Offline "Replay" of Metallurgical Length Trial 2



With changed roll fractions, Cononline prediction matches better with the trial.

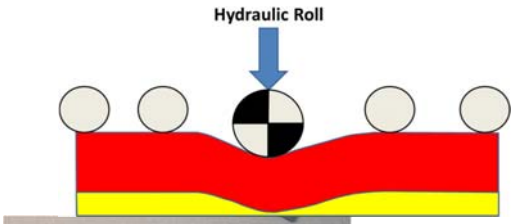
CON1D Calibration



Calibrating Con1d – Shell thickness measurements

- Whales
  - 2004 – predates Level 2 database, so casting conditions are not available
  - 2006
  - 2008 – flow meter for spray water in upper bender was broken, so measurement is not reliable
- Cracked slab
  - Hydraulics misfired on a drive roll, causing strand to be crushed from 90 mm down to 70 mm
  - Segregate bands are visible where the steel was almost completely solid
  - This gives a good measurement of the shell thickness at the location of the drive roll
    - 34 mm thick at 6.8 m from meniscus

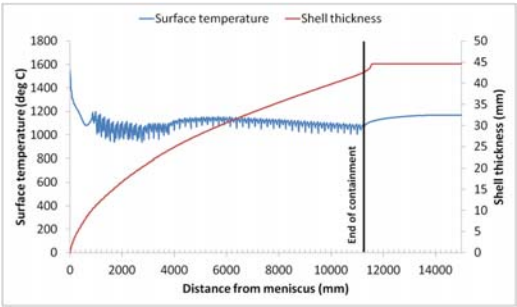
Thick slab caster



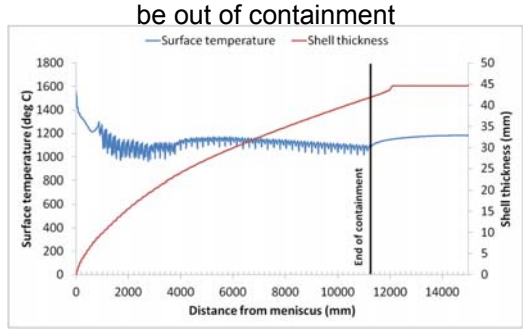
Nucor Decatur, (thin slab) Oct. 2008

New Cononline performance for Historical Whale Cases

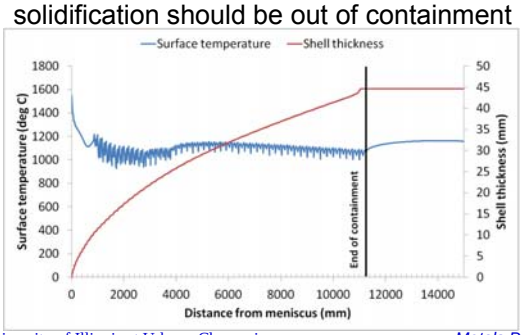
2004 Whale – final solidification should be out of containment



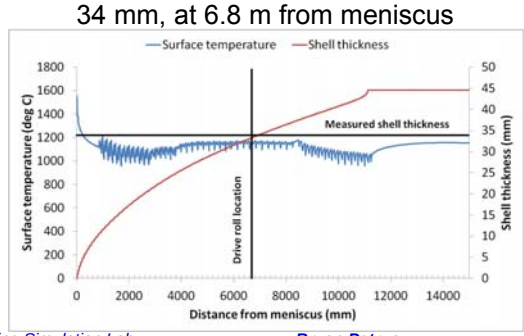
2006 Whale – final solidification should be out of containment



2008 Whale (broken flowmeter) – final solidification should be out of containment



Crushed slab – shell thickness should be 34 mm, at 6.8 m from meniscus

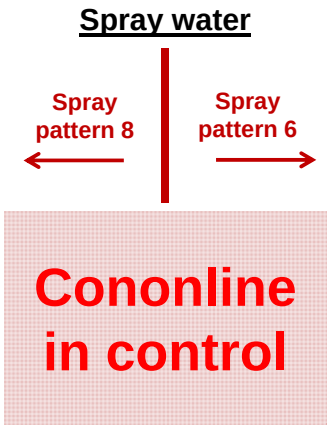


Transverse Cracking Investigation

Trial (August 25, 2010)

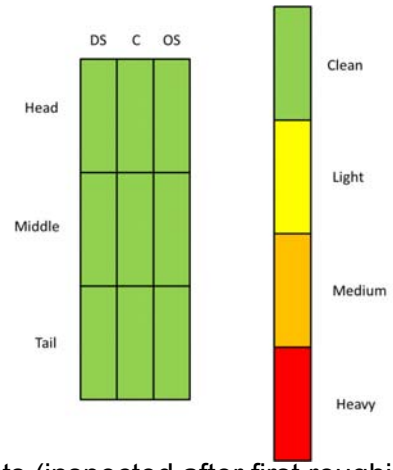
Early version of Cononline was put in control of secondary cooling sprays for several slabs of a Niobium-bearing grade

Spray water



Look up recorded spray rate histories and other conditions

Roughing mill inspection report

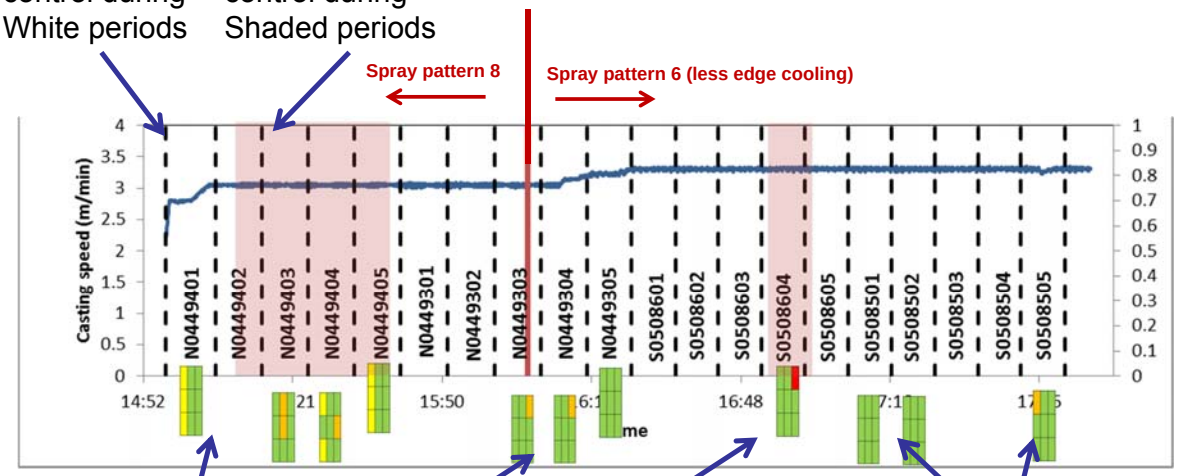


Slab Defects (inspected after first roughing mill roll)

Transverse cracking observations

Spray Table control during White periods

Cononline was in control during Shaded periods

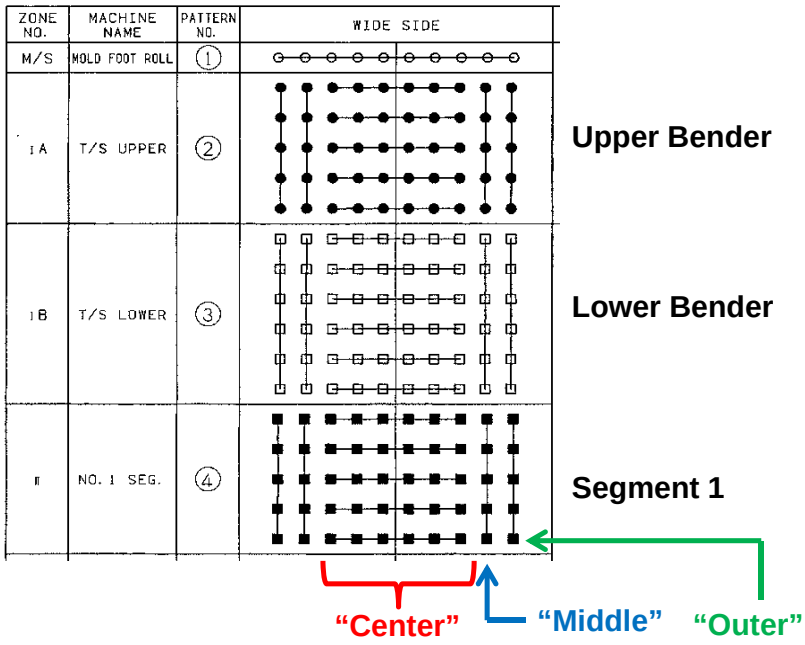


Light to medium transverse cracks reported

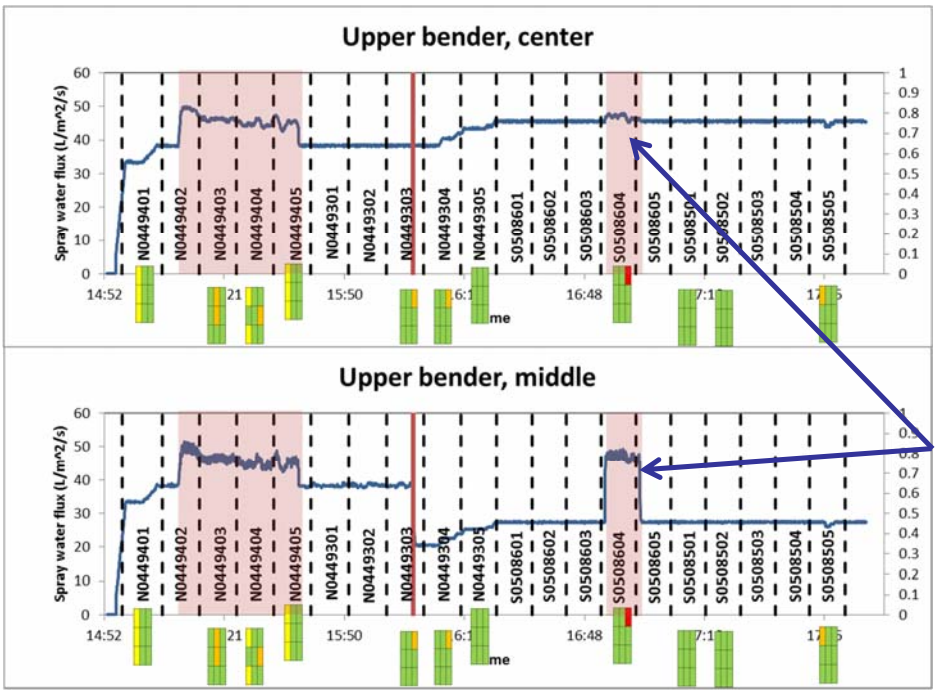
Medium to heavy transverse cracks, mostly at edges

Transverse cracking frequency reduced

Spray zone configuration



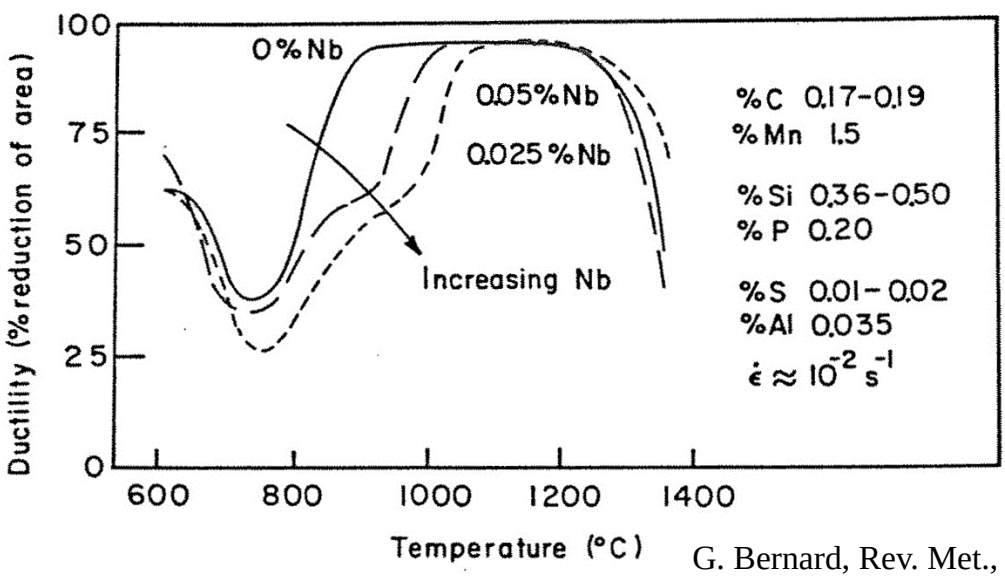
Spray water flow rate Details



Time periods with higher spray water flow have more defects

Note: unexpected lack of decrease in water flow rate towards slab

Niobium Effect on Ductility Trough

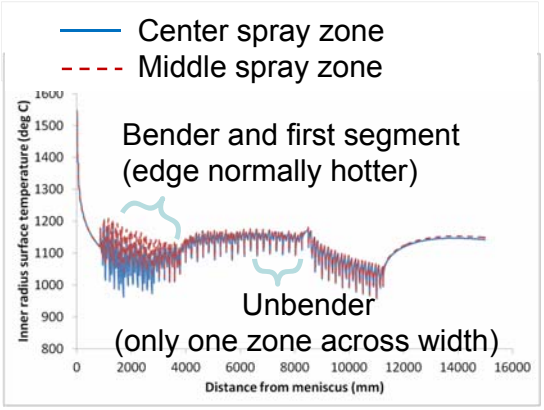


G. Bernard, Rev. Met., 1978

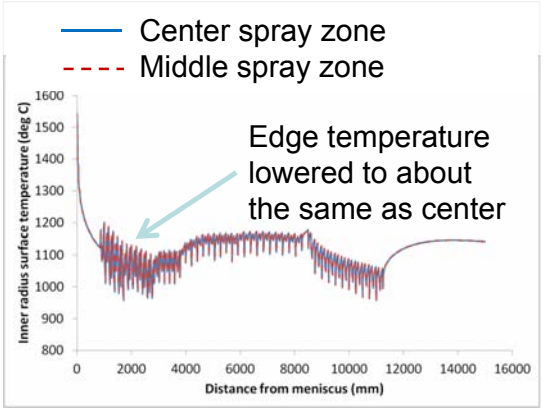
Effect on surface temperature

CON1D predictions

Normal spray practice
(Spray table pattern 6)



Heavy edge cooling
(Cononline trial)

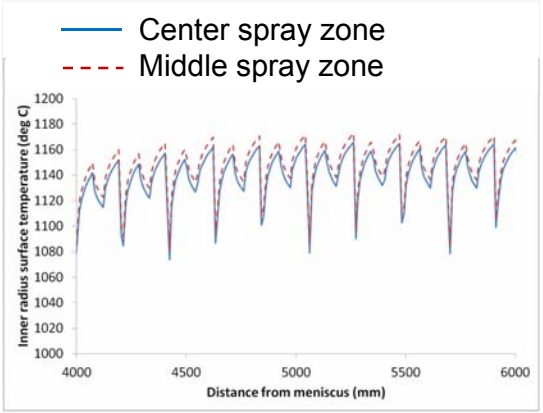


Center spray zone temperature profile stays almost equal

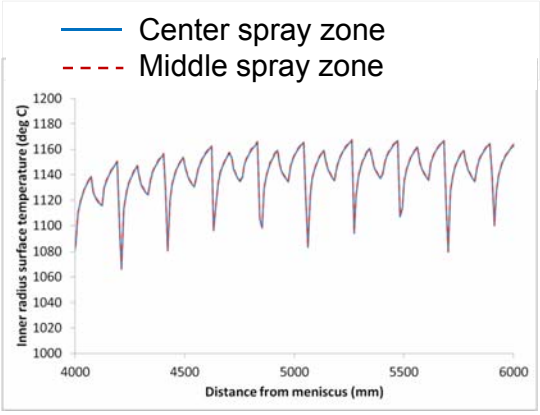
Effect on Surface Temperature: unbending region

CON1D predictions

Normal spray practice
(Spray table pattern 6)



Heavy edge cooling
(Cononline trial)

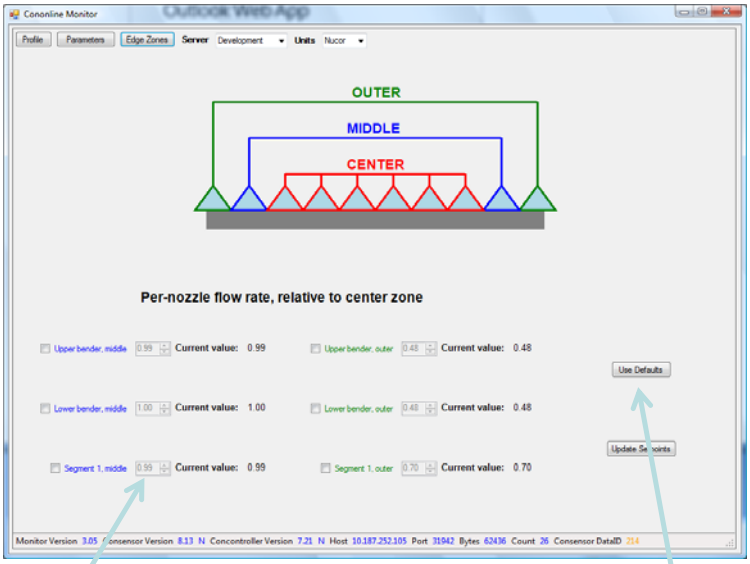


Lower temperature at edges persists into unbending
(but is only ~10C)

Transverse cracking - analysis

- Cracks were caused by excessive cooling on slab edges.
- At time of this trial, Concontroller only suggested flow rates for the center spray zones.
- Outer spray zones were controlled separately to deliver equal flow rate in each nozzle across the zone.
- Spray curve 6 uses gentler edge cooling (designed to prevent transverse cracks)
- Conclusion: Concontroller was modified to ensure variable edge cooling by spray pattern, slab-width, and casting speed.

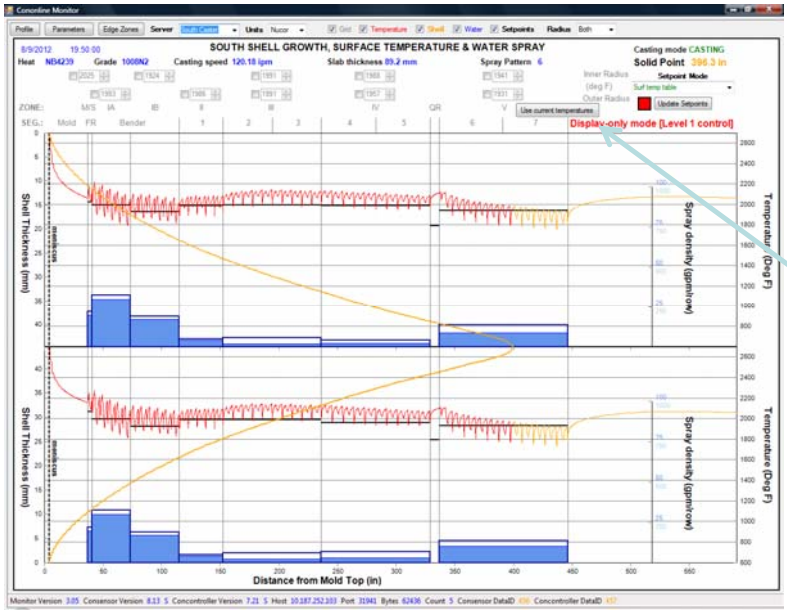
Edge cooling setpoints



Manually override edge cooling ratios

Base edge cooling ratios off of values in Level 1 spray table

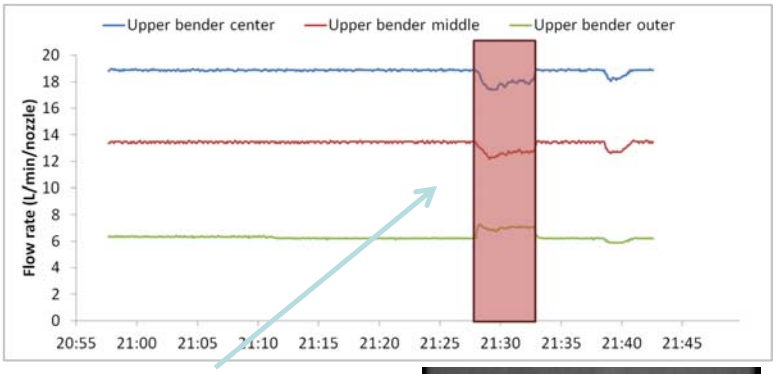
Temperature setpoints



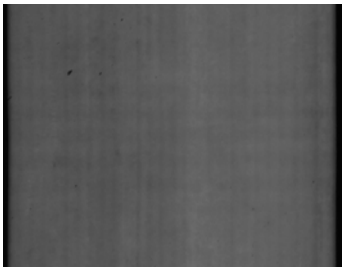
Set Concontroller temperature setpoints to match current operating conditions.

Cononline – current performance

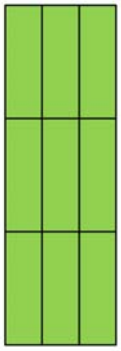
Trial data from August 9, 2012



Note flow rates are more similar



Inspected at roughing mill, finishing mill, and backspin: clean!



Result: no cracks

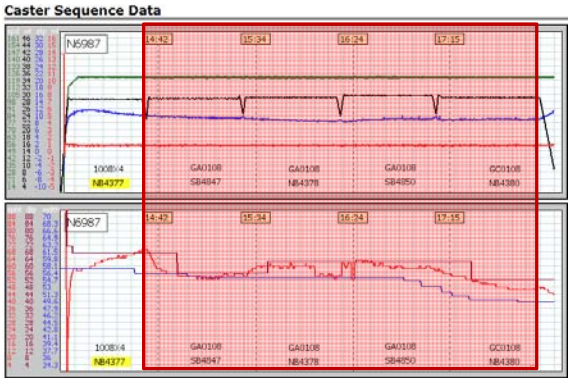
Conclusions

- Cononline is “ready to go”
  - Prediction of metallurgical length is more accurate, but possibly still conservative
  - Transverse cracking in first trial was due to method used by Level 1 to assign flow rates to off-center spray zones. The issue has been resolved by adding turn-down ratios to Concontroller.
  - Ready for extended trials!

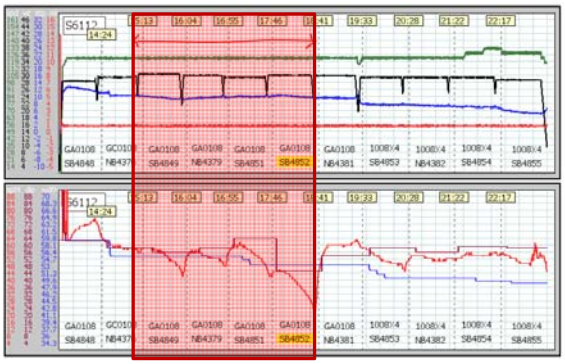
Extended Trials

<u>August 15, 2012</u>

North caster



South caster



Acknowledgments

- Continuous Casting Consortium Members (ABB, Arcelor-Mittal, Baosteel, Tata Steel, Magnesita Refractories, Nucor Steel, Nippon Steel, Postech, Posco, SSAB, ANSYS-Fluent)
- Hemanth Jahsti and Xiaoxu Zhou, former grad students in CCC, further developed Con1d
- Nucor Decatur
  - Ron O'Malley, Bob Williams, Megan Miller, Adam Zewe, Caster Green, Rodney Thrasher, Mike Langley, Wes Waddell, Steve Wallace, Kris Sledge, Rob Oldroyd, Terri Morris, and many, many others