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Modeling Of CC Secondary Cooling Sprays: An Experimental Study

Sami Vapalahti (Ph.D. Student)*,

Prof. Humberto Castillejos, Prof. Andres Acosta**, Prof, Brian G. Thomas*** & Prof. Seppo Louhenkilpi***

****Laboratory of Metallurgy, Helsinki University of Technology, Finland***
*****Laboratory of Process Metallurgy, CINVESTAV, Mexico***
******Department of Mechanical & Industrial Engineering, University of Illinois at Urbana-Champaign***

Acknowledgements

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  - DMI 05-28668 (Sensor); GOALI DMI 05-00453 (Online)
- National Center for Supercomputing Applications (NCSA) at UIUC
- Fluent, Inc., CFX, UIFLOW (P. Vanka)
- Other Graduate students, especially J. Sengupta

Introduction

- Motivation
- Goals
- Unsteady state measurements
- Steady state measurements
- Surface oxidation
- Conclusions
- Future work

Motivation

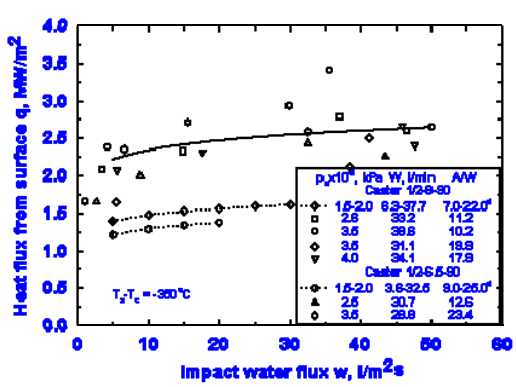
- Used mathematical models fundamental and accurate boundary conditions crucial
- Literature information on air-mist insufficient for accurate modeling
  - Water quality (used plant (oil, powder) vs. dwell water)
  - Surface roughness (as-cast vs. cut surface)
  - Spray characteristics (flow rate, impact pressure, droplet size, droplet velocity, etc.)
  - Time scales
- Information very valuable also for basic understanding at plant about prevailing conditions in the caster

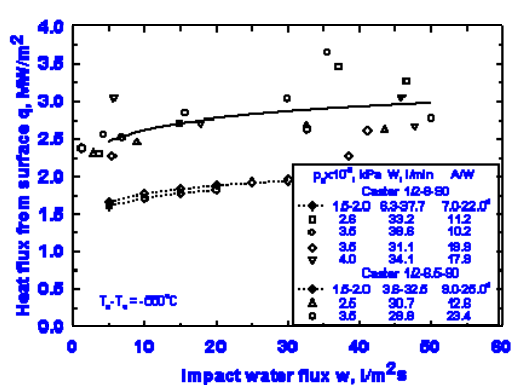
Earlier Work At Cinvestav

- Laboratory measurements, heat transfer modeling and plant results indicate that secondary cooling in thin slab casting occurs under the transition boiling regime. The corresponding heat transfer rate is larger than that obtained under the film boiling regime, the prevailing regime in conventional slab casting.
- Above 4.2 m/min the mold heat flux reaches a limit and the heat extraction bestowed by the secondary cooling system can not maintain the same growth rate of the slab shell, despite increases in water flow rate.
- In a recent laboratory work, we found that an increase in the nozzle air pressure from 200 to 250 kPa, improved the heat flux for a given water impact density. The study indicates that a higher air pressure produces finer droplets which have a higher cooling efficiency.

Earlier Work At Cinvestav

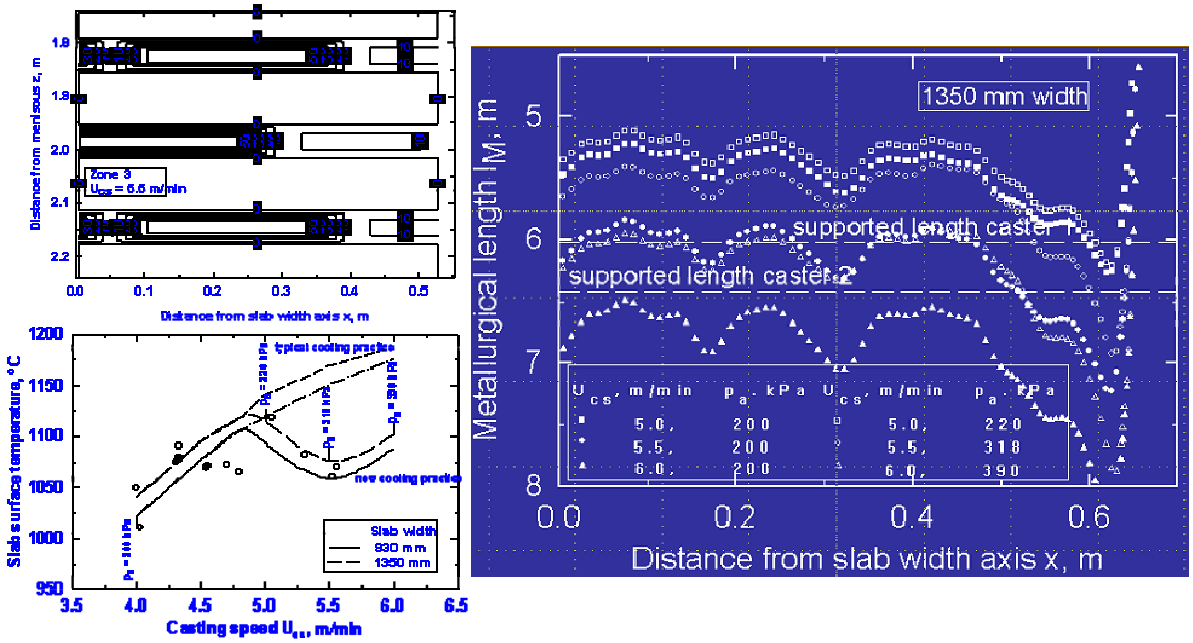
- Initial (surface) temperature has a noticeable effect on heat removal rate (Castillejos et. al. 2005):





Earlier Work At Cinvestav

- Mathematical modelling based on experiments (Castillejos et. al. 2005):



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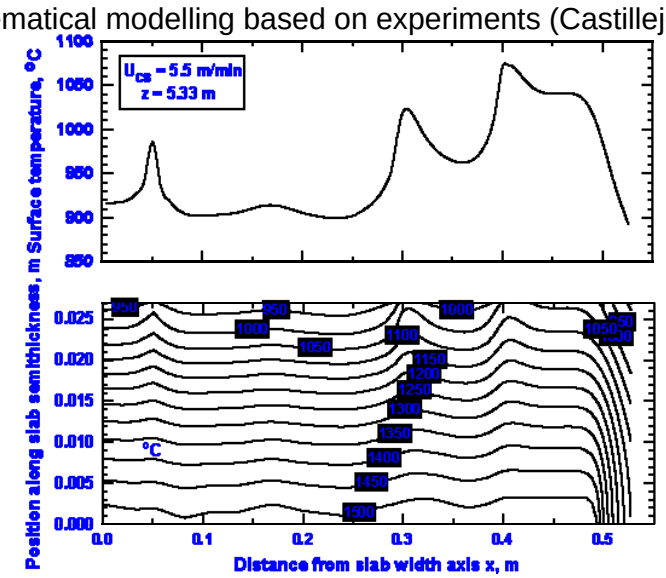


- Conclusions for thin slab casting (Castillejos et. al. 2005):
  - Casting speed could be increased and previously occurred bulgings could be avoided without modifications to the caster with only changing cooling praxis

Goals

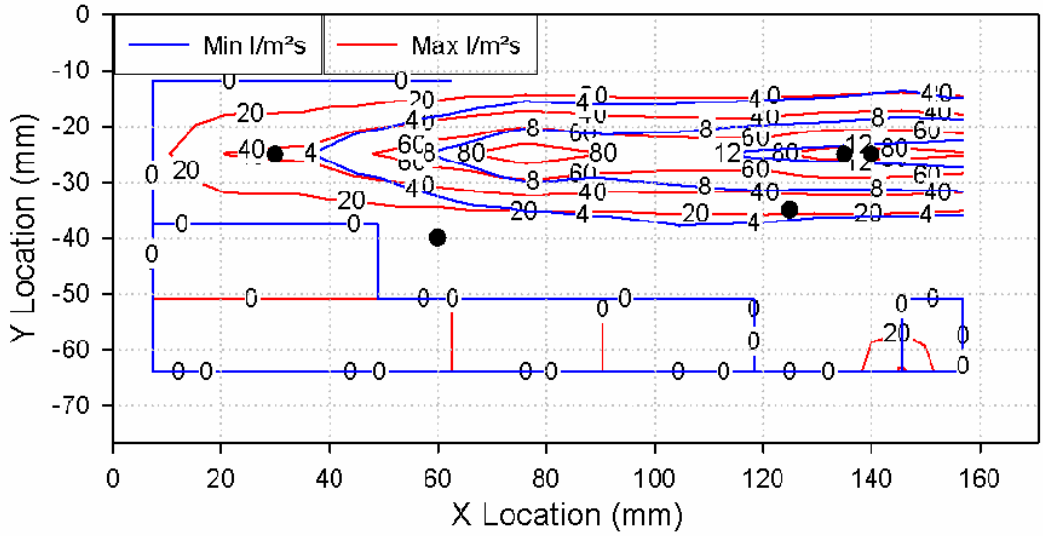
- Find a method to predict heat transfer coefficients for air-mist
- Measure efficiency of typical nozzles (e.g. used by Nucor Decatur) by unsteady state measurements
- Perform unsteady and steady state experiments and compare results with earlier results obtained by Prof. Castillejos and Prof. Acosta at CINVESTAV
- Find the effect of surface roughness and water quality on heat transfer characteristics of air-mist
- Find time dependencies in cooling under steady state conditions

Nozzle Characterisation

- Currently only available characterisation is ”foot print”
- Future work will have to include pressure maps and droplet size and velocity analysis
- Is used for determining thermocouple locations and flow rates basis for current heat transfer boundary conditions

Foot Prints

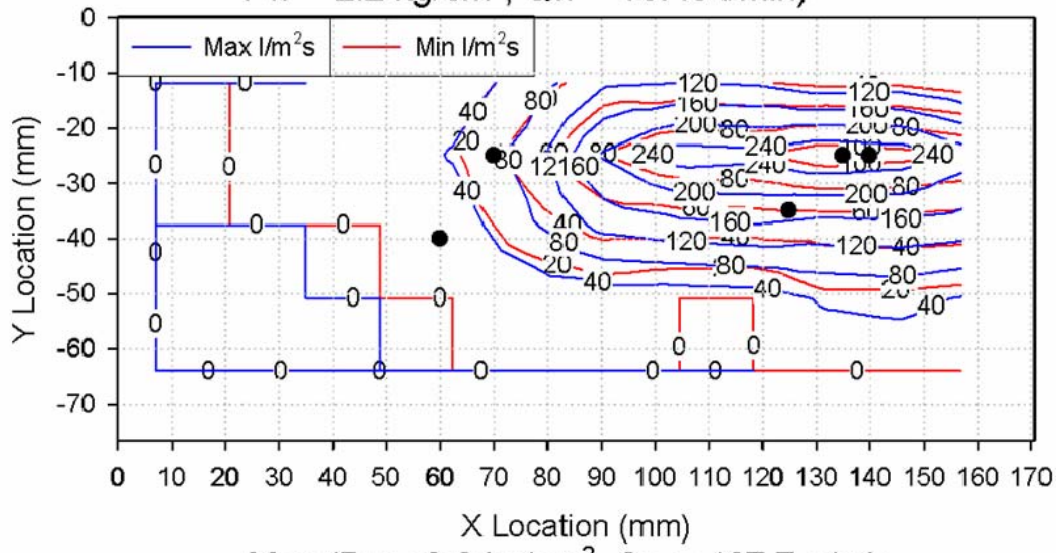
Max (Pa = 4.6 kg/cm², Qa = 126 g/min, Pw = 5.8 kg/cm², Qw = 10.45)



Min (Pa = 0.5 kg/cm², Qa = 161.03 g/min, Pw = 1 kg/cm², Qw = 1.2 l/min)

Foot Prints

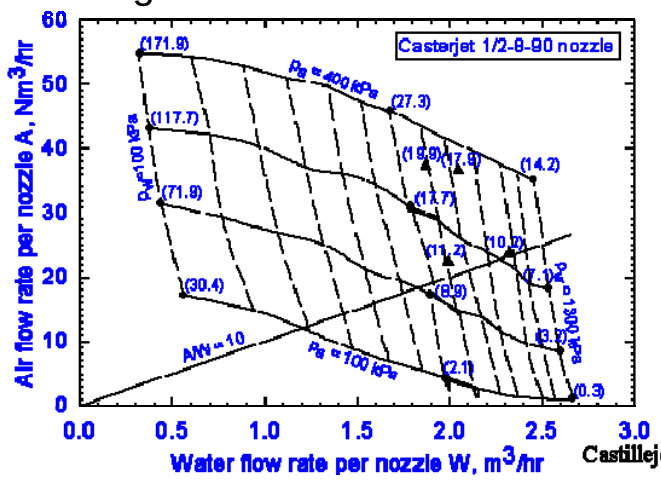
Min (Pa = 2.0 kg/cm², Qa = 747.12 g/min, Pw = 2.2 kg/cm², Qw = 16.45 l/min)



Max (Pa = 3.8 kg/cm², Qa = 467.7 g/min, Pw = 4.5 kg/cm², Qw = 39.47 l/min)

Operation Diagram

- To be able to use the results from measurements it is necessary to understand the behavior of the nozzle when flows are changed and that is why operating diagram of each researched nozzle must be obtained
- A/W ratio is a good measure

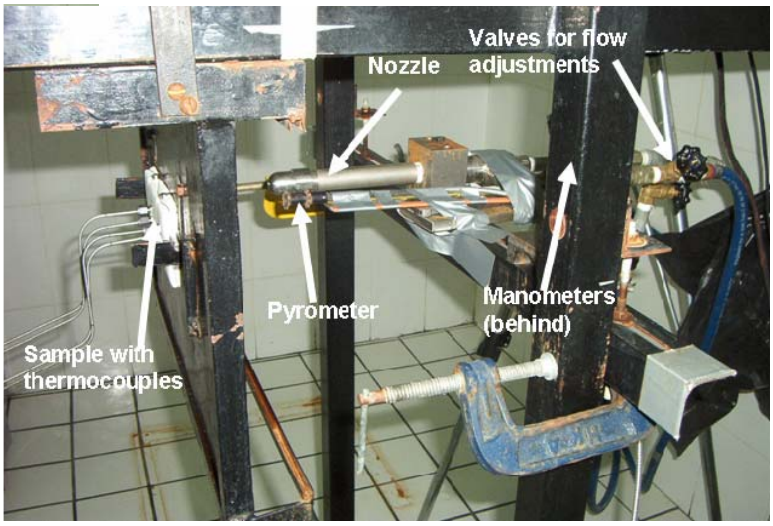


Castillejos et. al. 2005

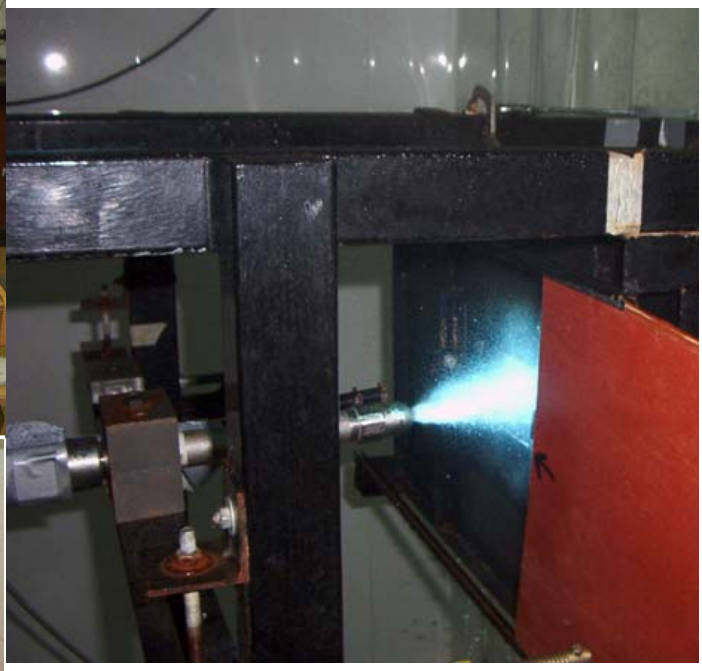
Unsteady State Measurements

- Heating actual as-cast steel samples from Nucor Decatur in a furnace to a desired temperature and cooling them down to room temperature under selected spray conditions
- Both as-cast and smooth surfaces
- 1D inverse model used for calculating heat fluxes at the surface from measured temperatures

Unsteady State Equipment



Unsteady State Equipment



Unsteady State Measurements

The plates will be produced and measured for actual locations of the thermocouples and the thermocouples are attached

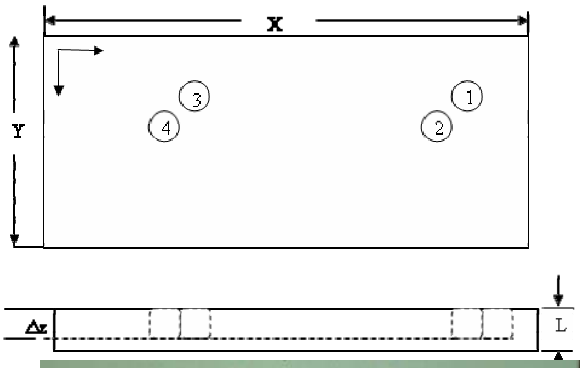
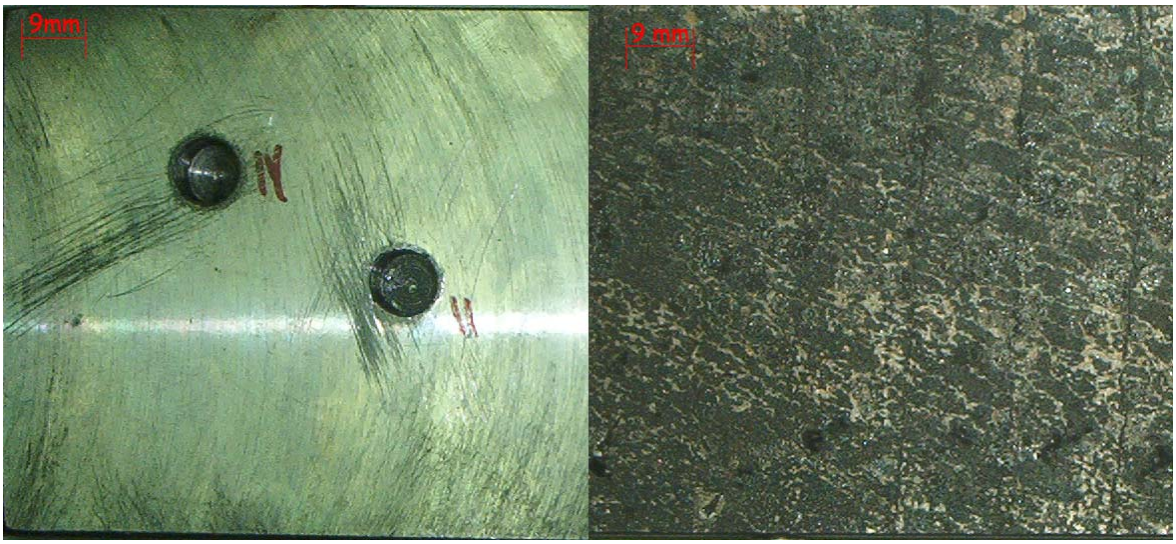


PLATE 3	lxl	lyl	dz	X	Y	L	L-dz
1	133.6	26.2	11.6	168.5	76.6	12.95	1.45
2	123.4	35.8	11.5				1.45
3	70.0	26	11.6				1.45
4	60.3	41.6	11.5				1.45

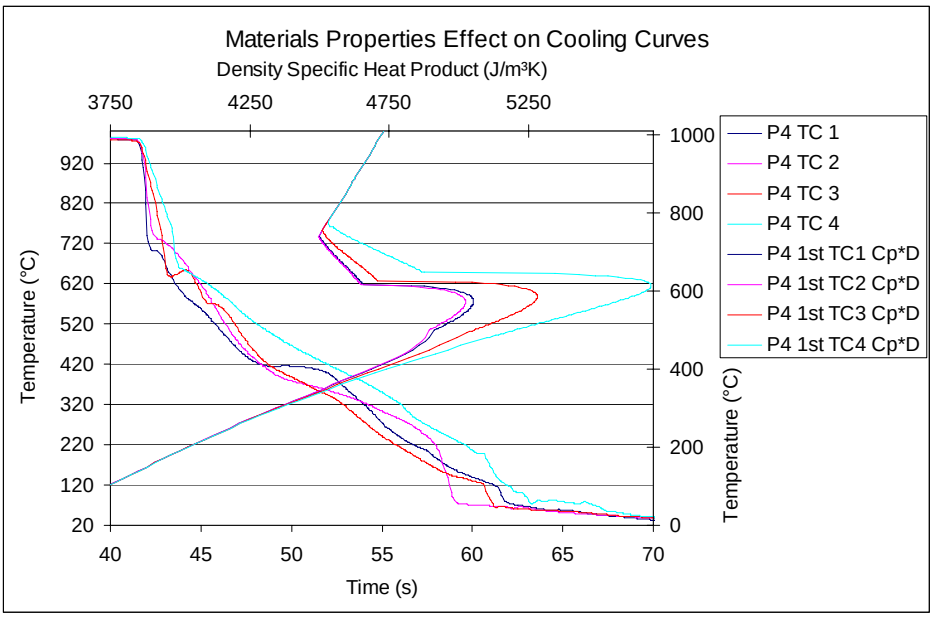
PLATE 4							
1	134.6	25.6	11.8	168.5	77.0	12.95	1.15
2	123.9	34.9	11.8				1.15
3	69.9	28.0	11.6				1.35
4	60.5	38.9	11.6				1.35

PLATE 5							
1	134.4	25.7	12.1	168.0	76.0	12.85	0.75
2	123.5	35.9	11.9				0.95
3	69.6	25.3	11.8				1.05
4	59.3	40.6	11.9				0.95

Sample Surfaces

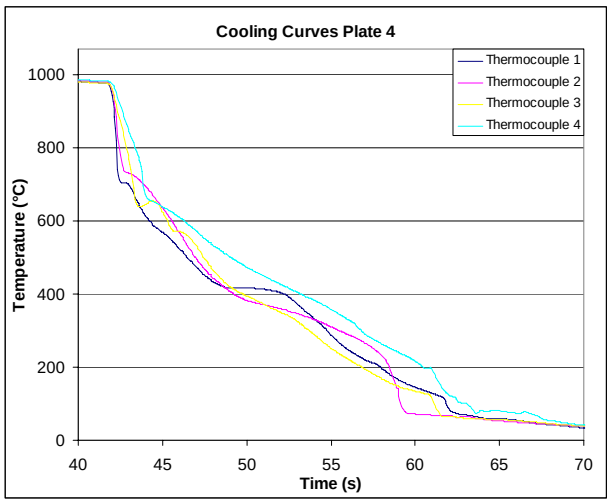


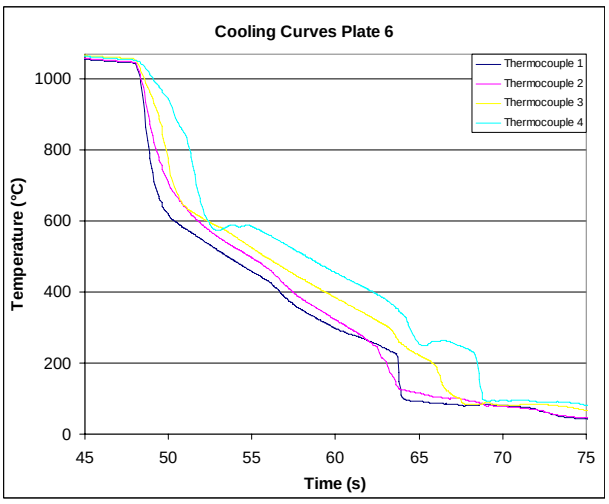
Materials Properties And Cooling Curves



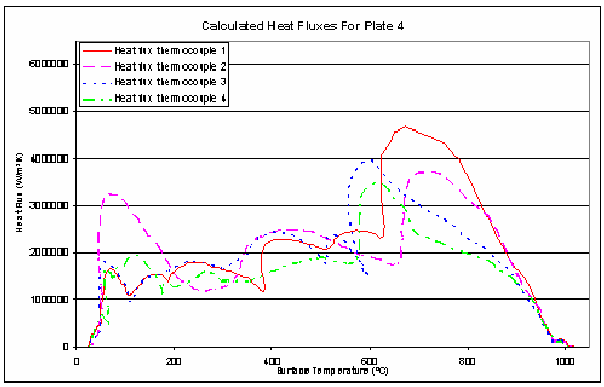
Surface Roughness

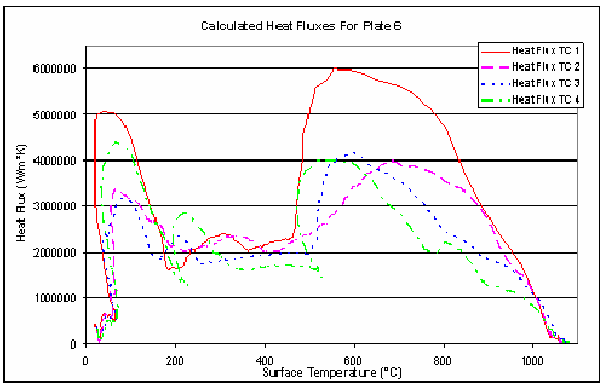
Plate	To (°C)	Pa (kg/cm²)	Pw (kg/cm²)	Qa (grams/min)	Qw (l/min)	Water T (°C)	Note
4	975	3.5	3.8	625.11	30.75	22	
6	1050	3.6	3.8	625.8	30.78	24	Smooth



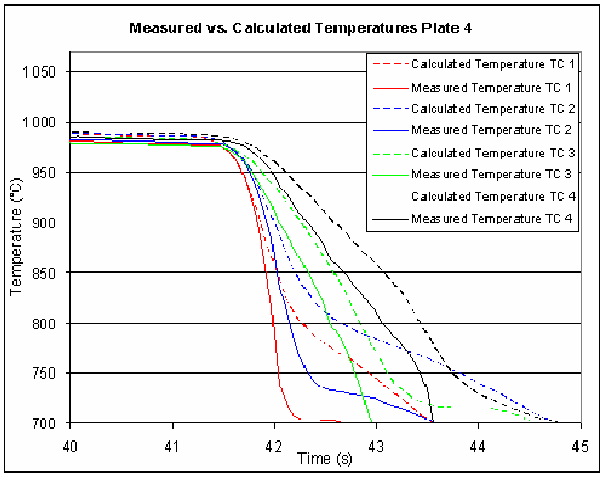


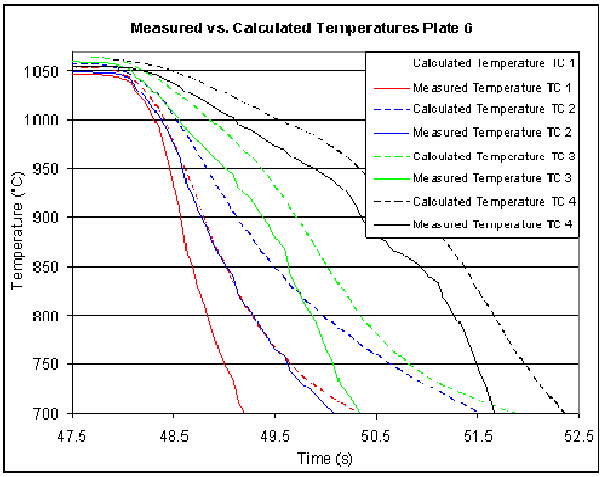
Surface Roughness





Surface Roughness

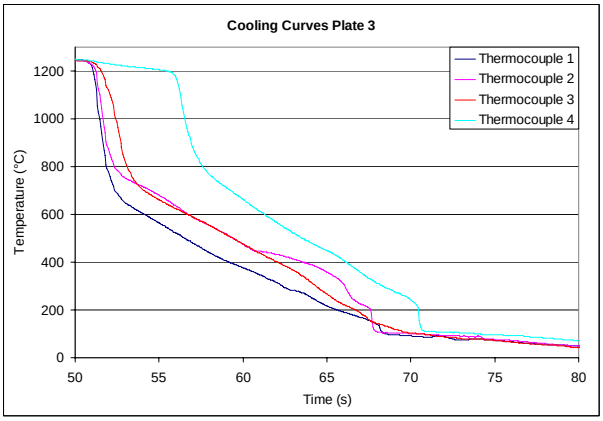


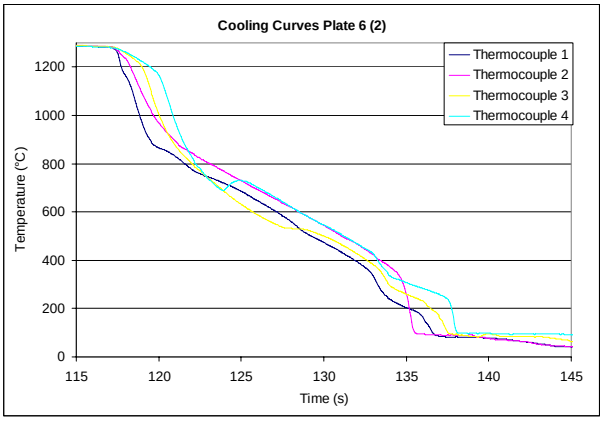


Surface Roughness

Repeatability

Plate	To (°C)	Pa (kg/cm²)	Pw (kg/cm²)	Qa (grams/min)	Qw (l/min)	Water T (°C)	Note
3	1245	3.8	4.0	530	32.60	24	2mm up
6(2)	1276	3.5	4.0	545	32.30	24	





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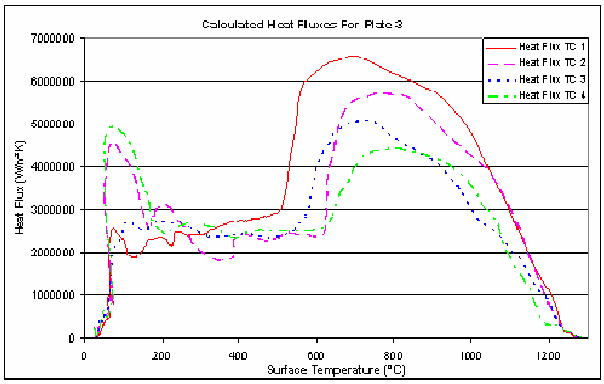
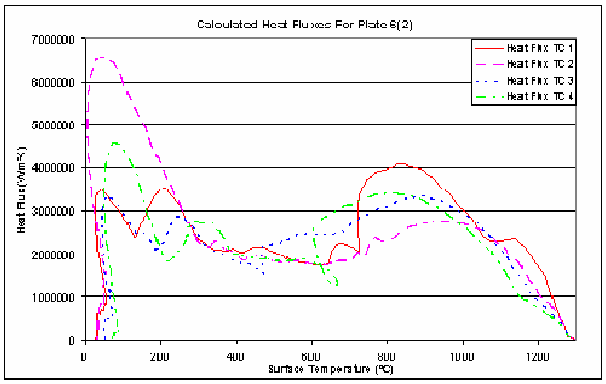
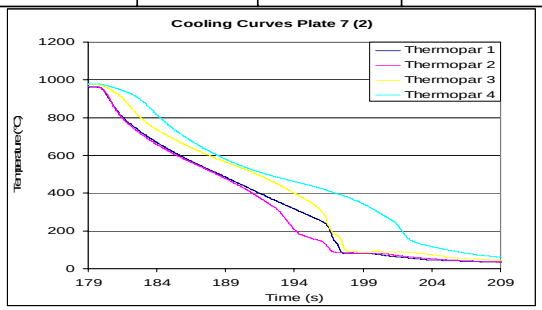
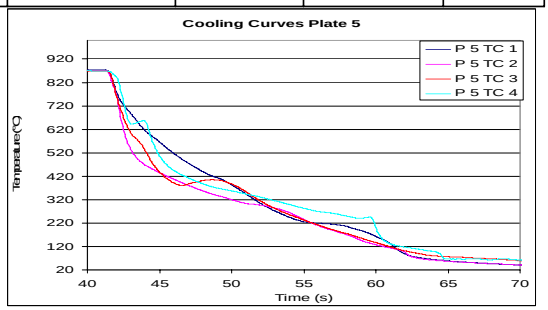


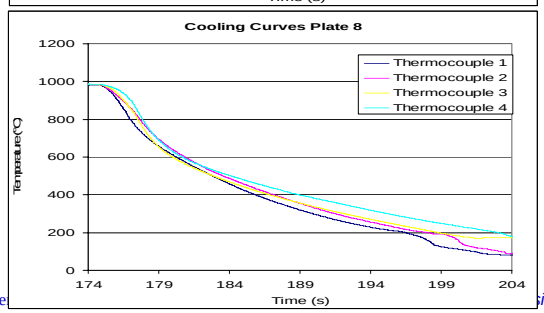


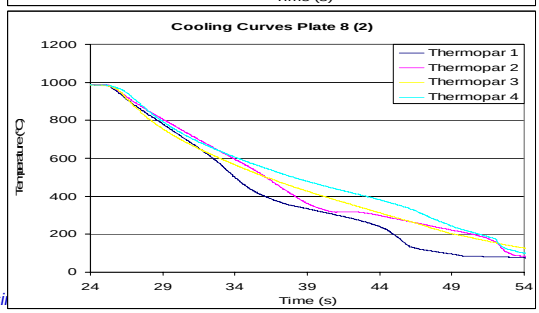
Steel Grade

Plate	To (°C)	Pa (kg/cm²)	Pw (kg/cm²)	Qa (grams/min)	Qw (l/min)	Water T (°C)	Note
5	870	3.5	4.0	545.70	32.48	19	Smooth
7(2)	960	3.5	4.0	549.9	32.45	24	
8	980	3.5	4.0	540.6	32.56	24	Stainless
8(2)	980	3.5	4.0	520.3	32.78	24	

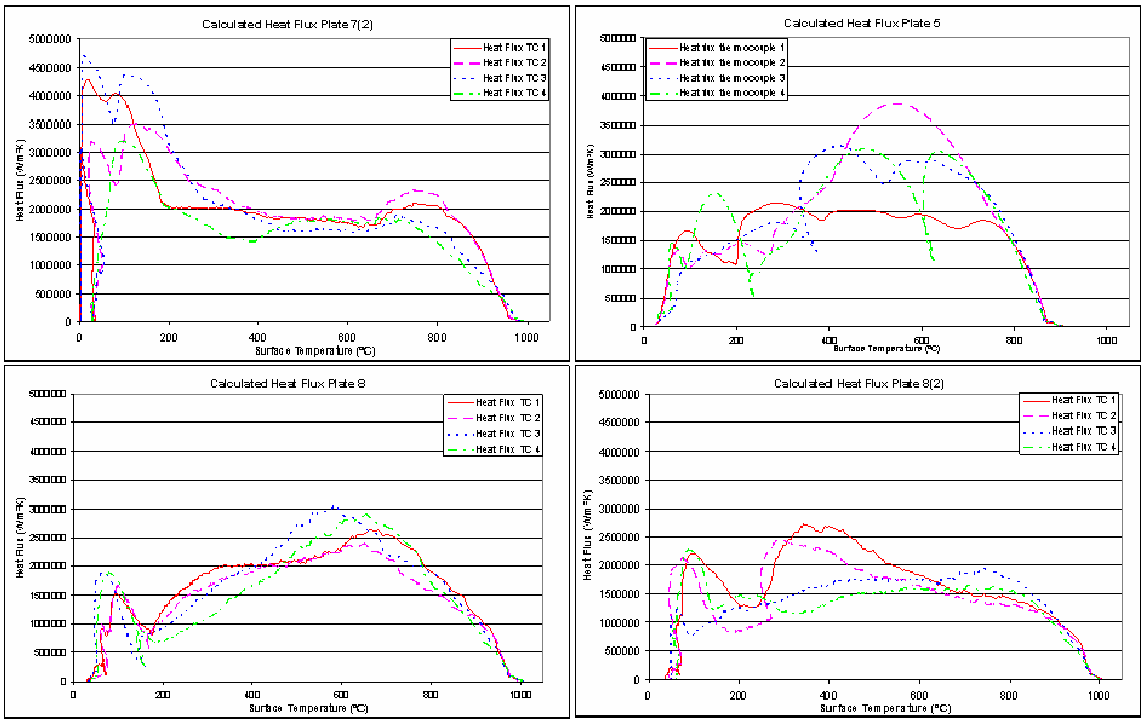




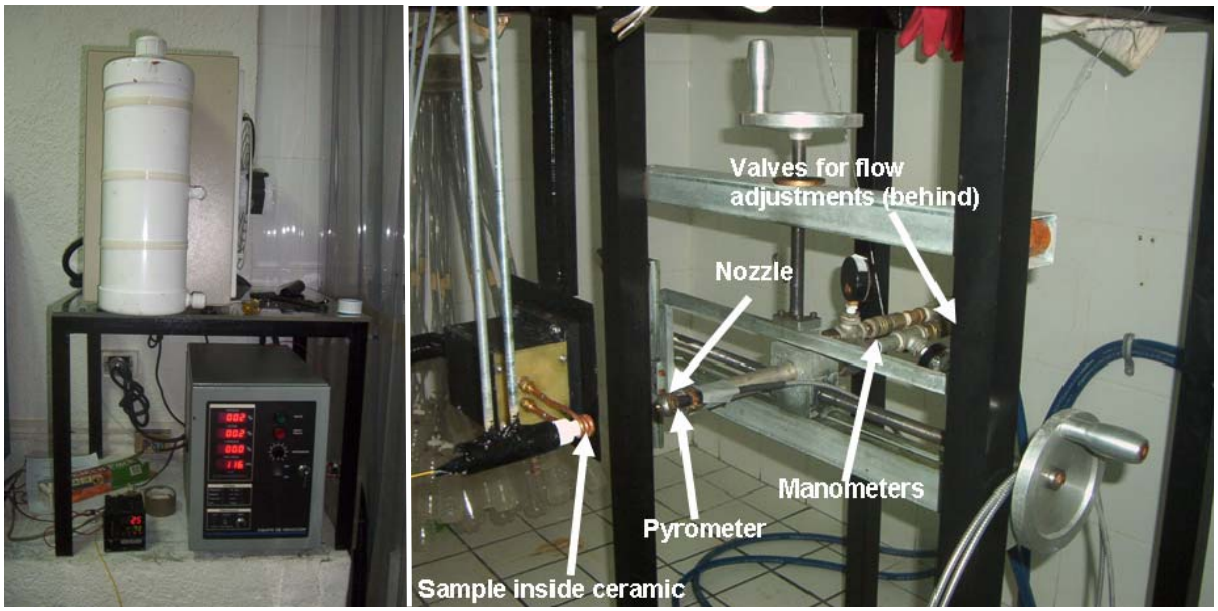




Steel Grade



Steady State Equipment



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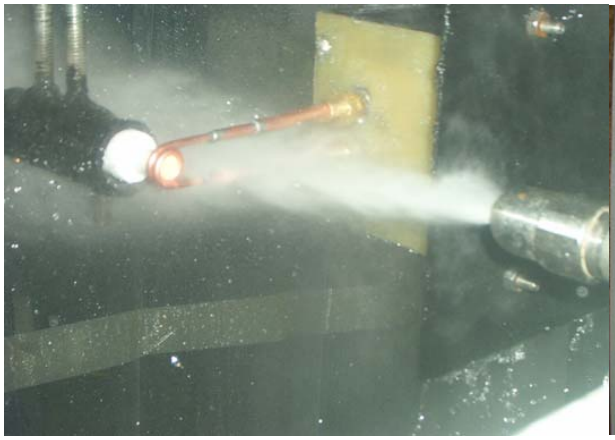
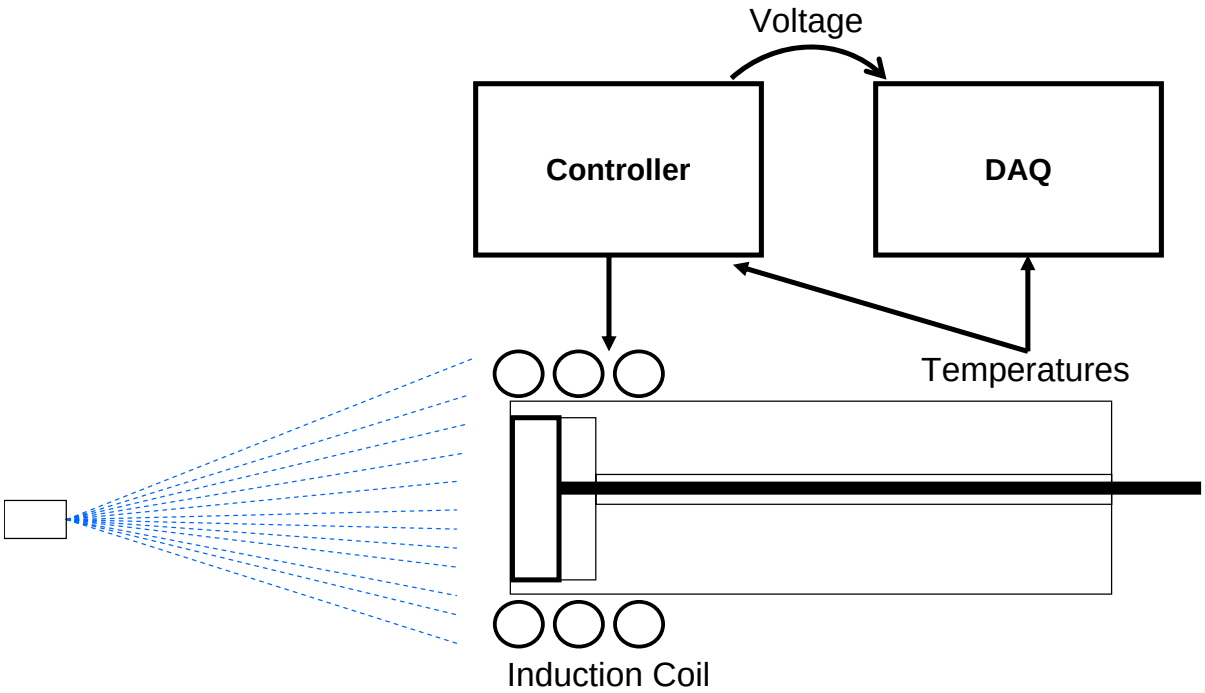


Steady State Measurements



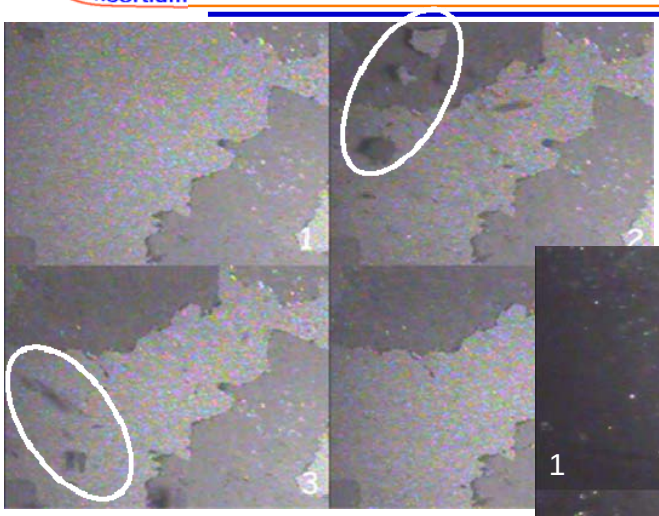
Steady State Measurements

- Works with heat flux values < 5 MW/m²
- Problems keeping surface hot under high cooling rate -> thinner sample
- Delayed by electric grounding and signal noise promblems and equipment delivery

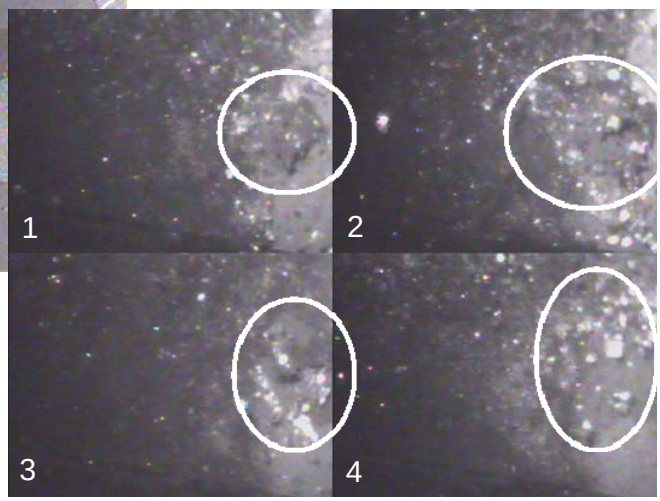
Oxidation

- Oxidation was investigated using an intense xenon strobe light with a high shutter speed camera during air cooling and air-mist cooling
- Oxilayers peeled of by the cooling were measured
- Thickness af the sample plates was measured after the trials

Oxidation



Stainless steel surface during air cooling



Stainless steel surface during spray cooling. Time scale (1-4) ~3 secs.

Oxidation

- Oxide layer thickness is a function of the time in furnace but also the cooling rate since in spray cooling the plate has no time to oxide more
- Average oxide layer thickness in boron steel in the experiments is 0.72 mm at 1300°C and 0.36 mm at 1000°C based on measurement of removed oxide from samples and plate 3 where the thermocouples were exposed after two experiments at ~ 1300°C
- After spray cooling there is rarely any oxide left on the surface of the sample with used boron or stainless steel grades but more often with boron steel

Conclusions

- Unsteady state
  - Results show used nozzles much more efficient that previously tested pneumatic and hydraulic nozzles
  - Reproduceability not very good with current experimental setup -> small effects impossible to detect
  - Comparison results for steady state
- Steady State
  - Promising results although break through not yet done
  - Currently 8 mm sample diameter with 1.5 mm thickness
  - Work will continue by graduate student during summer and under this project in September
- Oxidation
  - Results indicate it is not important to take into account oxide build up in secondary cooling zone with used steel grades
  - Stainless steel oxide ”explosive” and thinner than boron steel oxide
  - Thickness is a function of furnace holding time and cooling rate

Future Work

- Improve data aquisition by adding accuracy and aquired signals
- Finalize steady state measurement procedure as accurate and efficient as possible
- Compare results with unsteady state measurements
- Test different water chemistries using steady state
- Build a mathematical model to describe cooling rate of air-mist
- Characterize sprays by pressure foot print, droplet size distribution, and velocities