THERMAL DISTORTION OF SOLIDIFYING SHELL NEAR THE MENISCUS

CASE STUDY: EFFECT OF SUDDEN FLUCTUATION OF LIQUID LEVEL

PRELIMINARY RESULTS

JOYDEEP SENGUPTA
NSERC (Canada) Postdoctoral Fellow

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INTRODUCTION

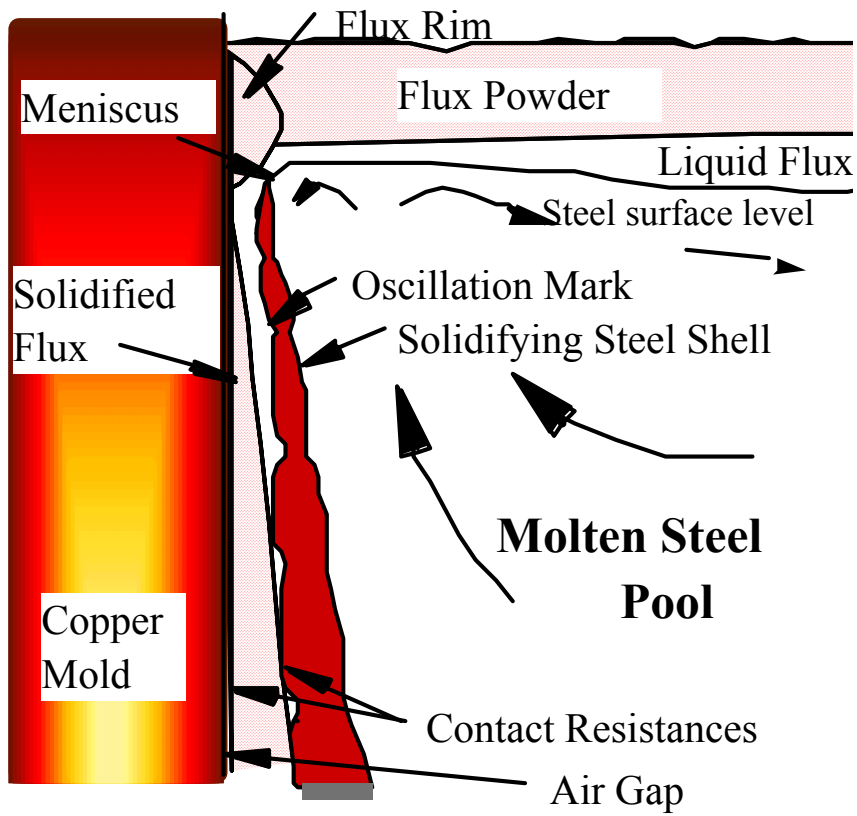
Initial solidification phenomena in the mold is complicated by:

Heat Transfer Effects
- **Solidification & conduction in shell**
- **Gap and flux layer resistances**
- **Superheat delivery from turbulent flow**

Mechanical Effects
- **Pressure build-up in the flux channel**
- **Interaction between shell and flux rim**
- **Meniscus freezing**

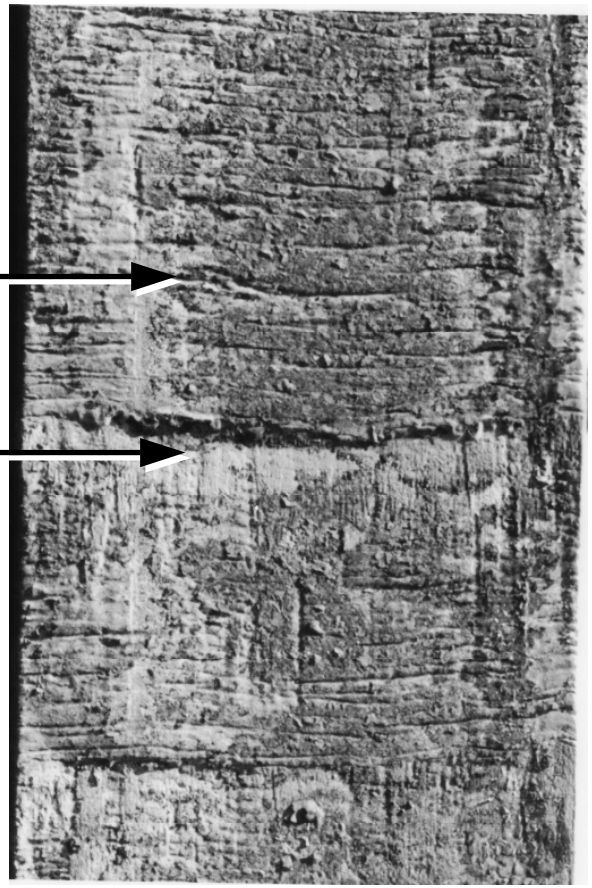
Metallurgical Effects
- **Large shrinkage: δ ferrite to austenite**
- **Higher $T_{coherency}$: stronger shell**
- **Segregation: liquid film at G.B.**

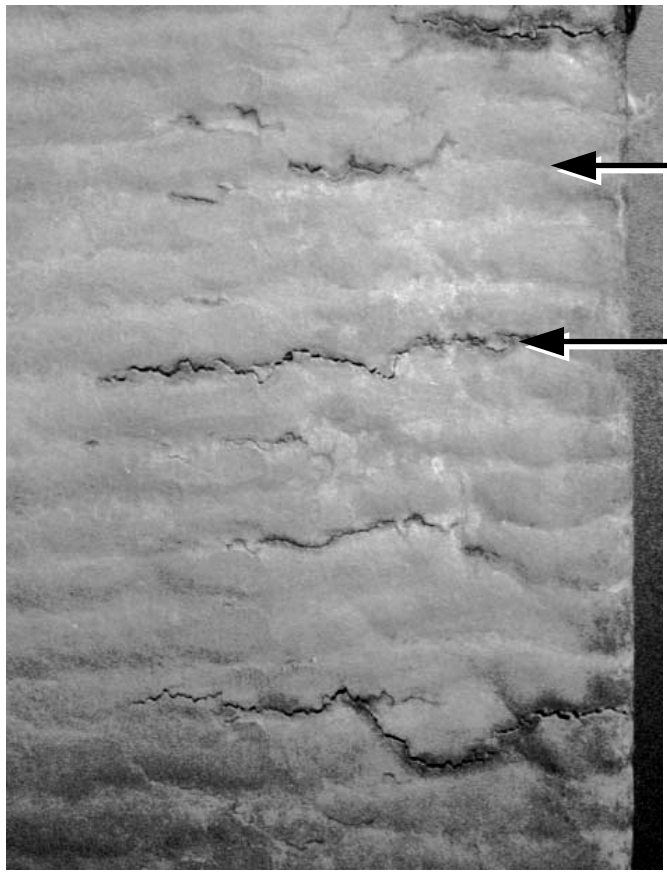
Transient Effects
- **Fluctuation of meniscus (surface level)**
- **Oscillation of the mold**



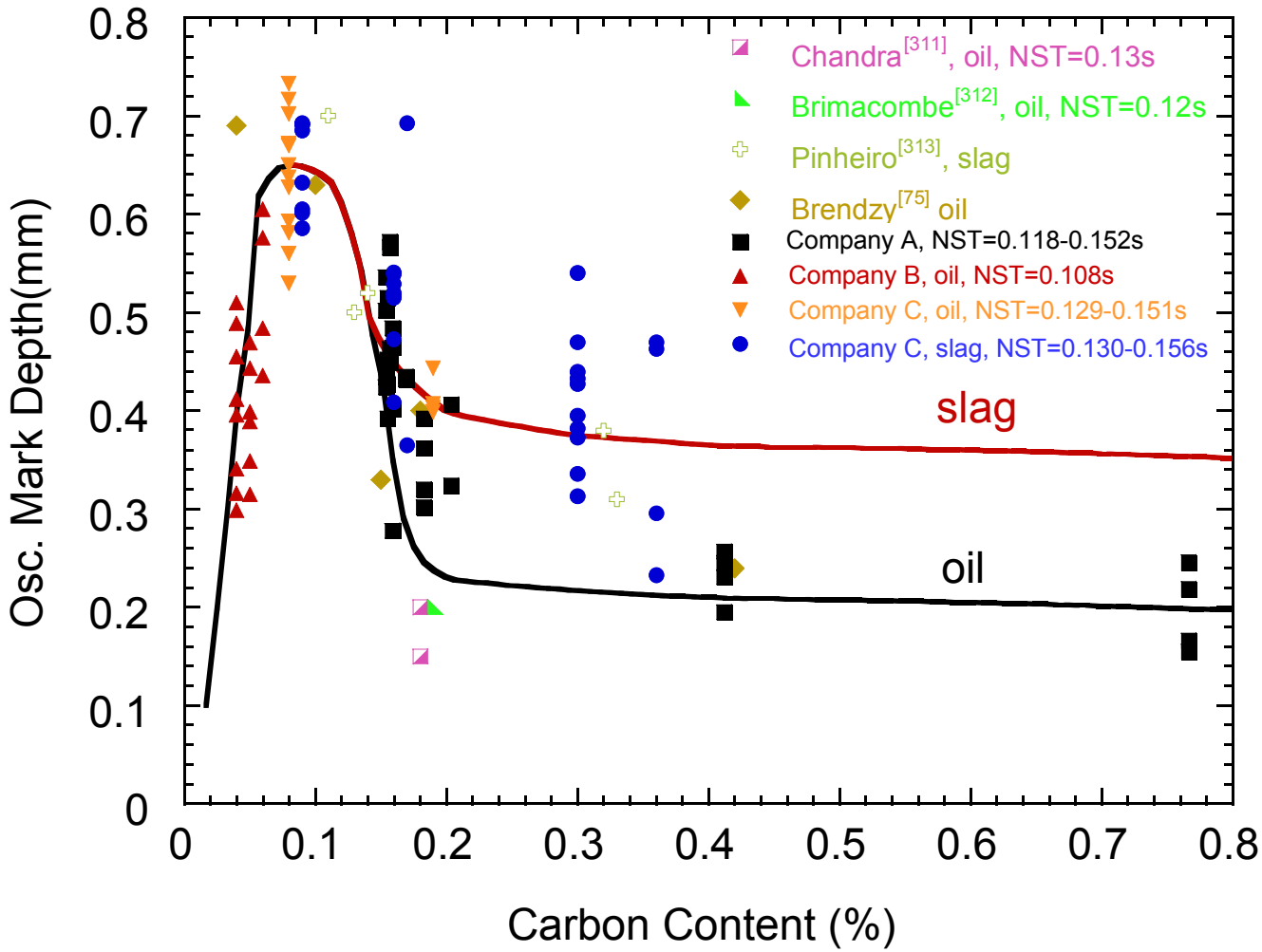
QUALITY ISSUES

Thermal stresses generated during initial solidification can cause shell deformation, distortion, which lead to defects:
Surface depressions, Deep oscillation marks, Hooks, &Transverse cracks





EFFECT OF STEEL COMPOSITION ON OSCILLATION MARK DEPTH

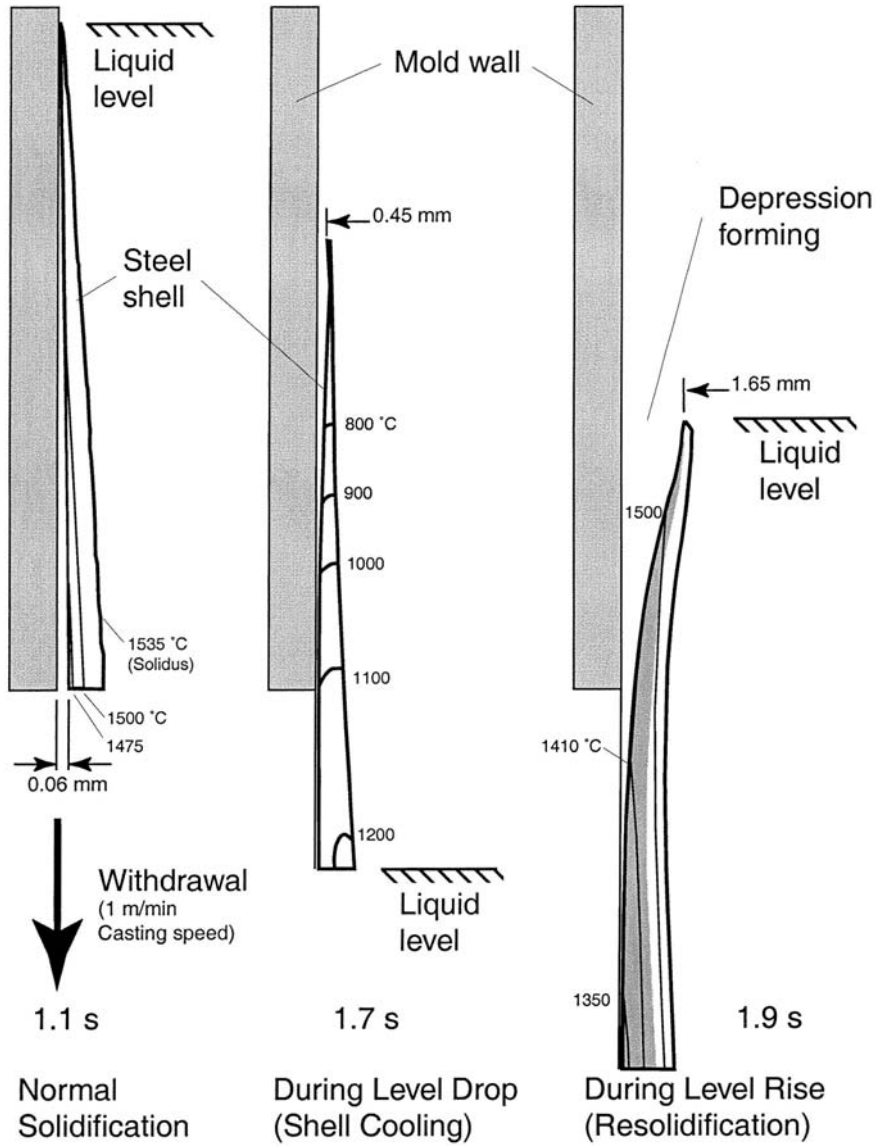


PHENOMENA DURING A LEVEL DROP

First studied by:
B.G. Thomas and H. Zhu in 1996

Sudden drop of meniscus level can cause bending of the solidifying shell away from mold

Can directly initiate transverse surface depressions and longitudinal cracks



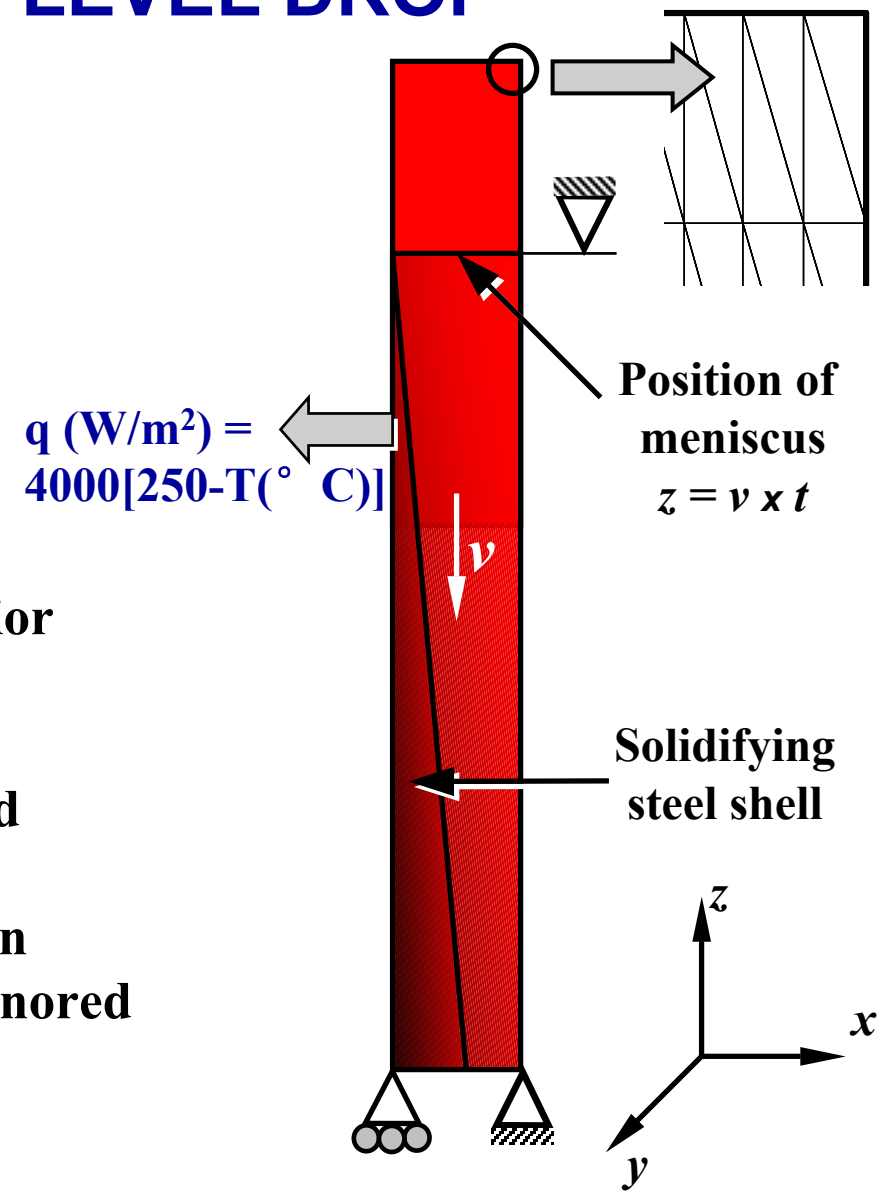
USING CON2D TO STUDY LEVEL DROP

General Features

- Coupled thermal and stress analysis
- Generalized Plane Strain
- Domain Size: 3 mm x 30 mm
- Fixed Lagrangian grid
- 6 noded triangular elements
- Mesh resolution: 0.05 mm x 0.25 mm
- Temperature dependent k, c_p, ρ, ΔH
- Elastic-viscoplastic constitutive behavior

Assumptions:

- Effect of ferrostatic pressure is ignored
- No constraint at the mold edge
- No mold taper, slag, oscillation, friction
- Drop in heat transfer due to air gap ignored
- Level is assumed to drop suddenly
- No kinetics & undercooling effects



TREATMENT OF LIQUID ELEMENTS

Ideally liquid elements should not exhibit any stiffness and strength

- **Thermal strain = 0**
- **Elastic strain = 0**
- **Viscoplastic strain = 0**

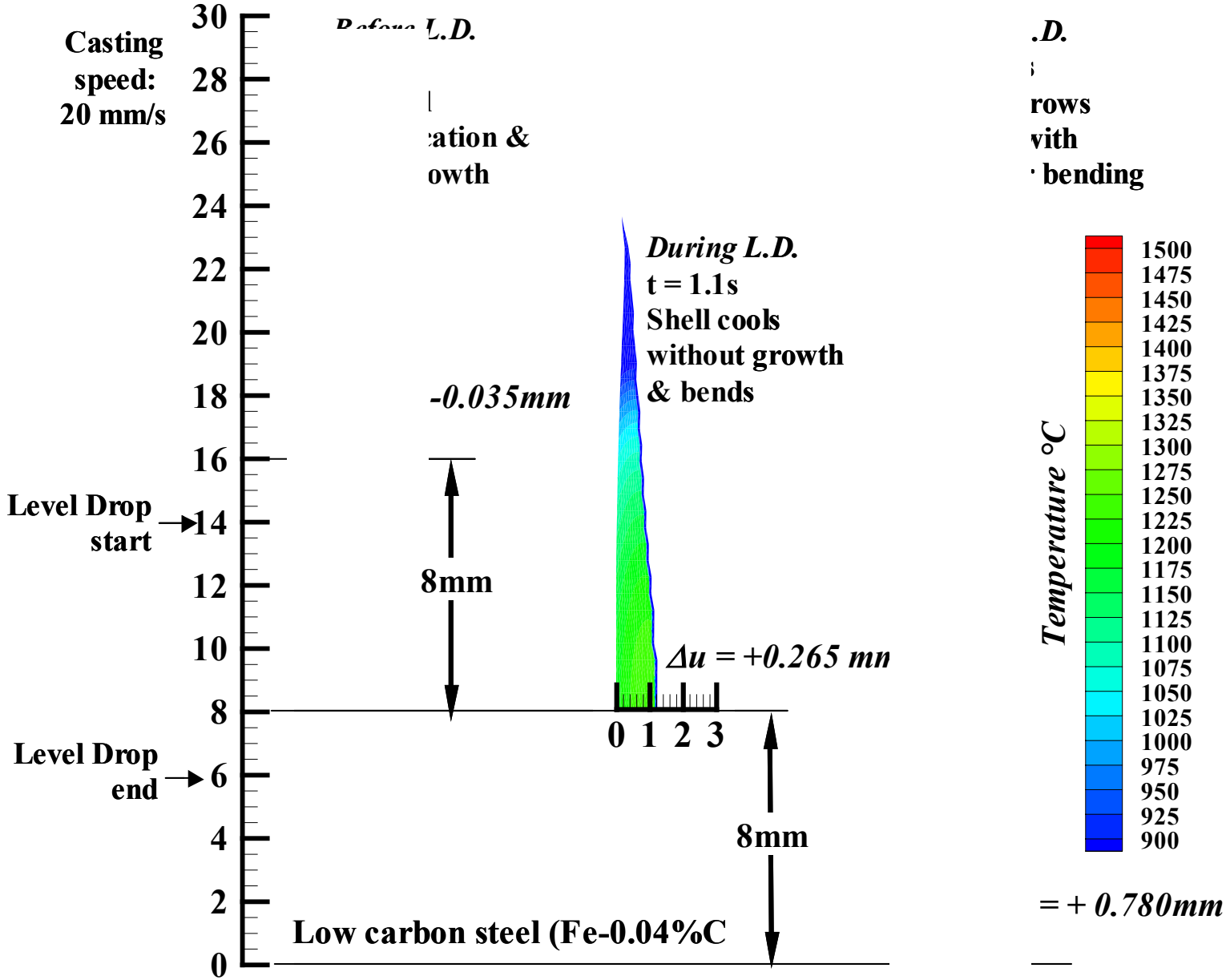
During Level Drop:

- **Temperature of the nodes above $T_{solidus}$ are set to 35 ° C (air)**
  (equivalent to sudden drop in the meniscus level)
- **Constitutive behavior remains that of liquid**

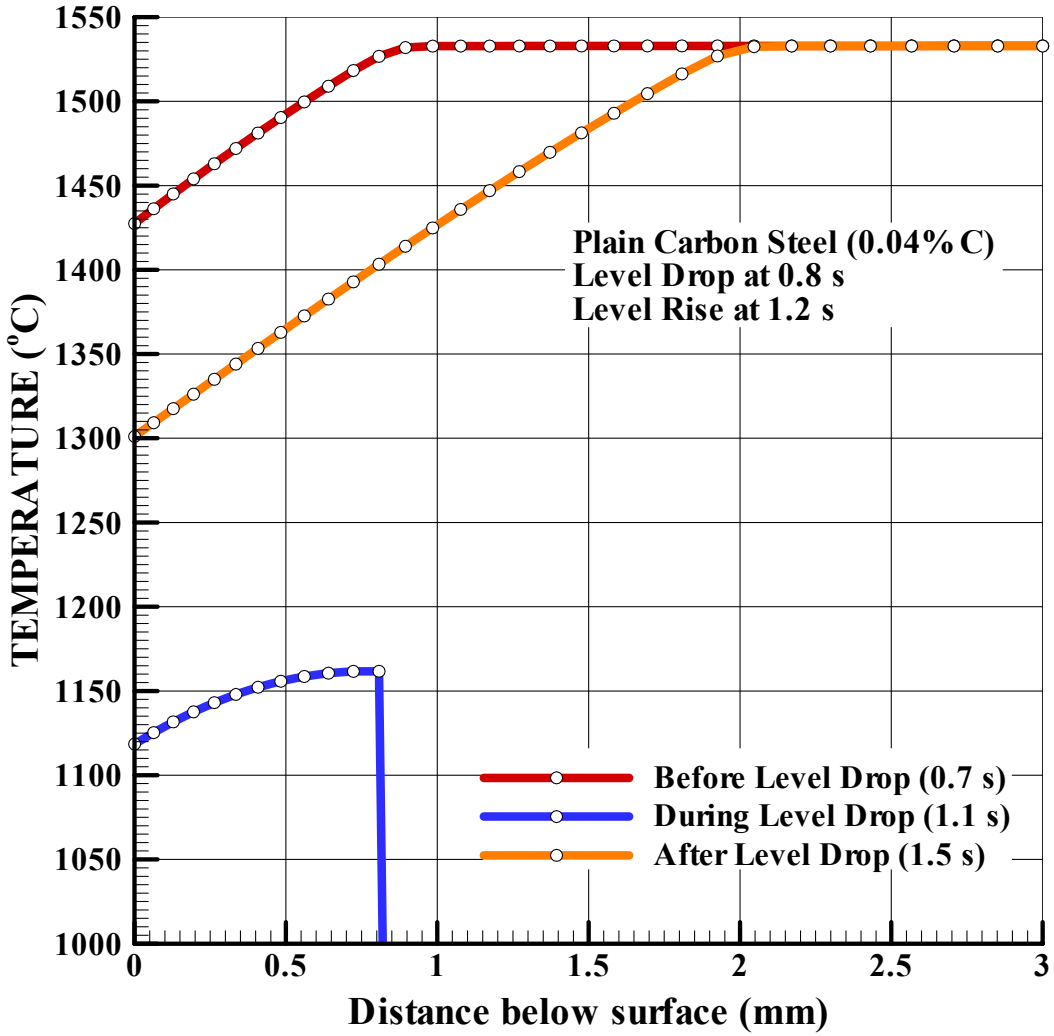
SIMULATION CONDITIONS

Grade	Low C	Peritectic	High C
%C	0.04	0.13	0.47
$T_{solidus}$	1518 ° C	1495 ° C	1444 ° C
$T_{liquidus}$	1533 ° C	1526 ° C	1499 ° C
ΔT	15 ° C	31 ° C	55 ° C
$\Delta T_{superheat}$	10 ° C		
Cast Velocity	20 mm/sec (1.2 m/min)		
T_{mold}	250 ° C		
$T_{ambient}$	35 ° C		
Level drop time	0.8 s		
Level rise time	1.2 s		
Total time	1.5 s (0.001 s time step size)		

RESULTS: Level Drop Simulation



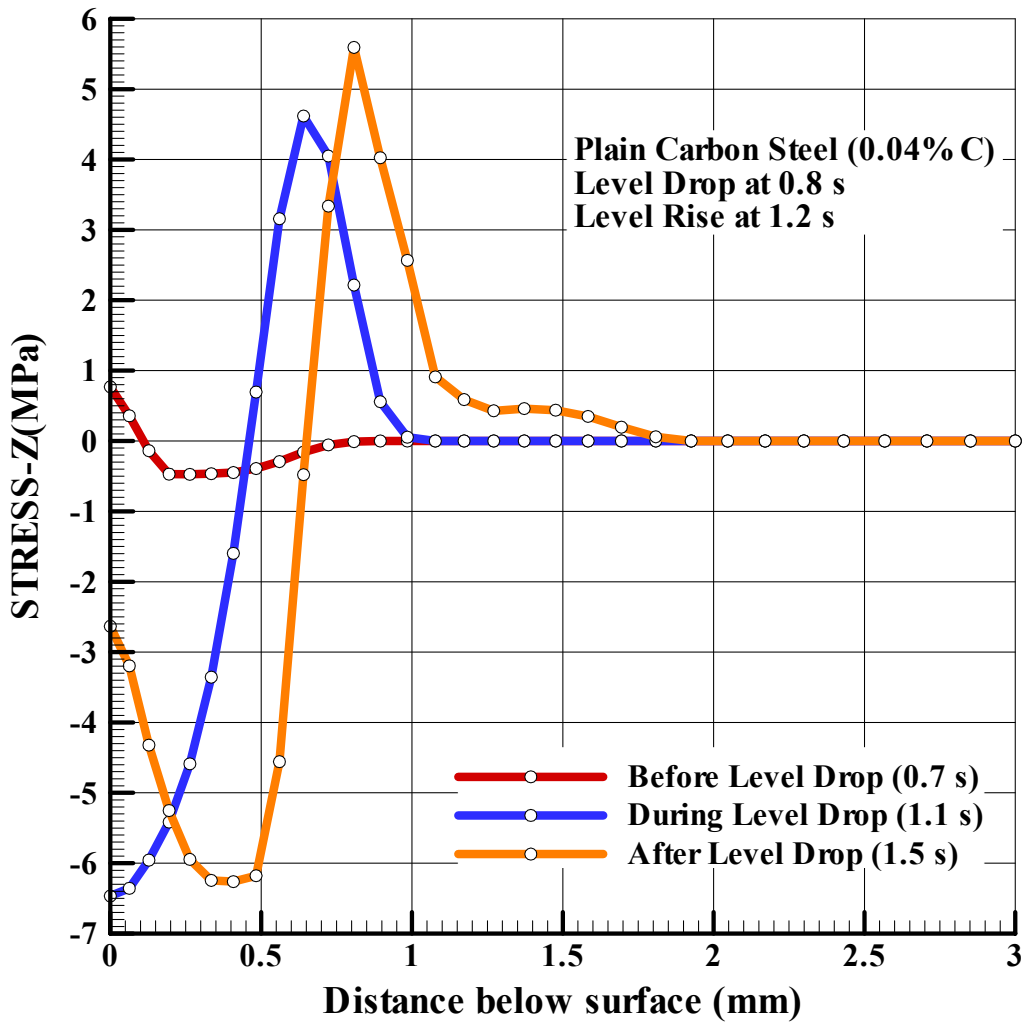
RESULTS: Temperature Profiles Across Shell



6mm from domain bottom

- **Temperature and its gradient across the shell decreases during level drop**
- **Re-establishing contact with the liquid causes solidification to continue**

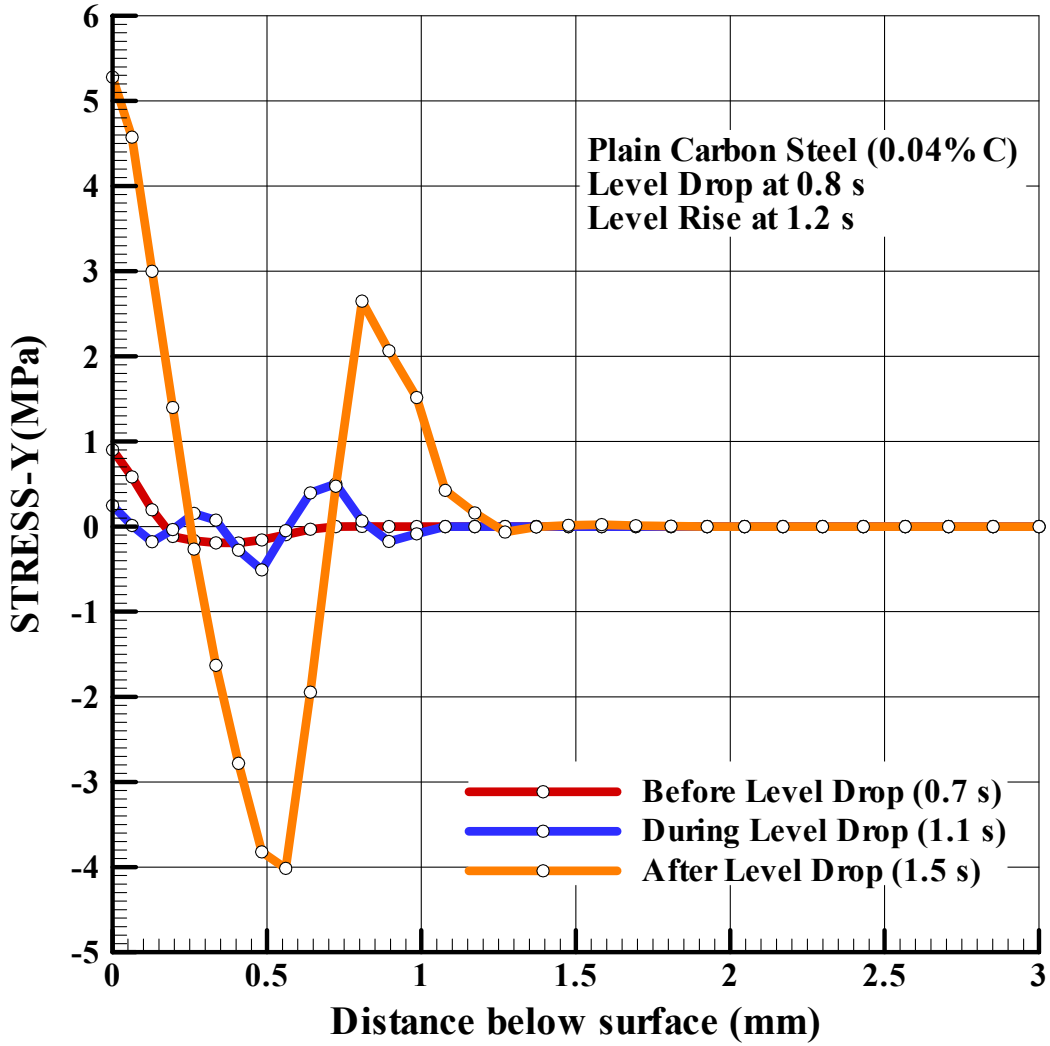
RESULTS: Z-Stress Profiles



6mm from domain bottom

- **In absence of external forces, stress profiles across the shell equilibrate**
- **Large internal tensile stress due to continuous shell bending**

RESULTS: Y-Stress Profiles

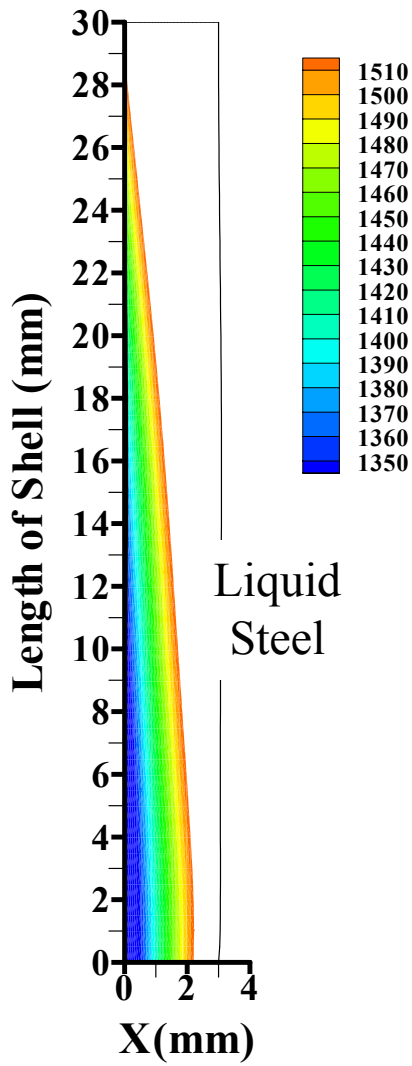


6mm from domain bottom

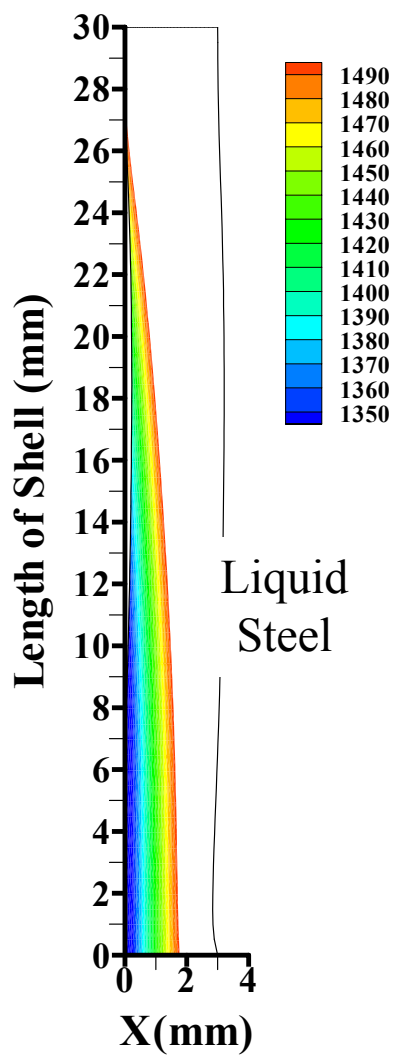
Large tensile stress at the surface after level drop – may lead to longitudinal surface cracking

RESULTS: Before Level Drop

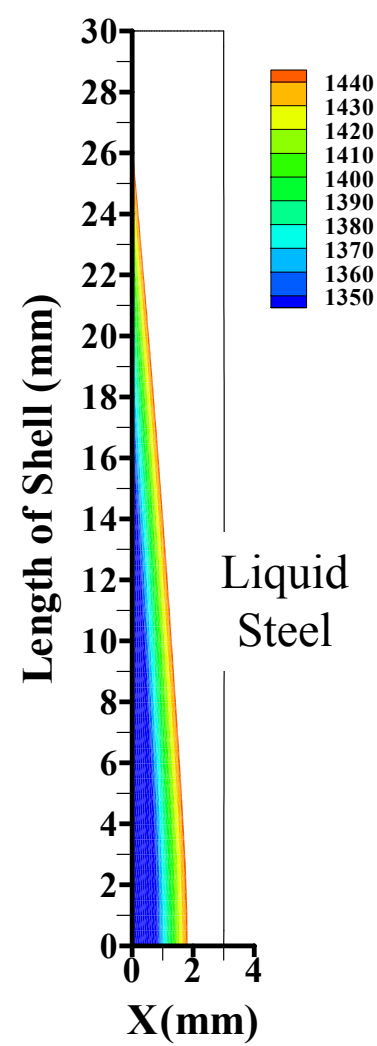
Fe-0.04% C
***Δu* = 0.10 mm**



Fe-0.13% C
***Δu* = 0.42 mm**

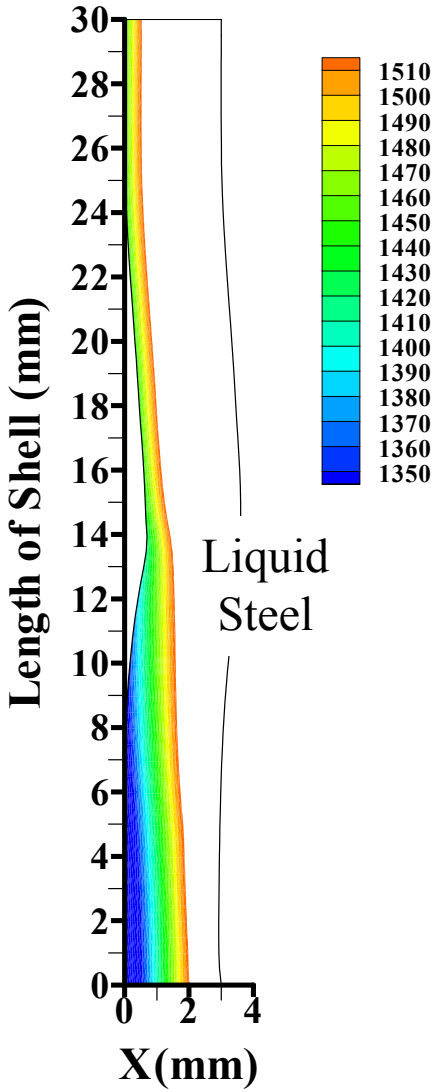


Fe-0.47% C
***Δu* = 0.02 mm**

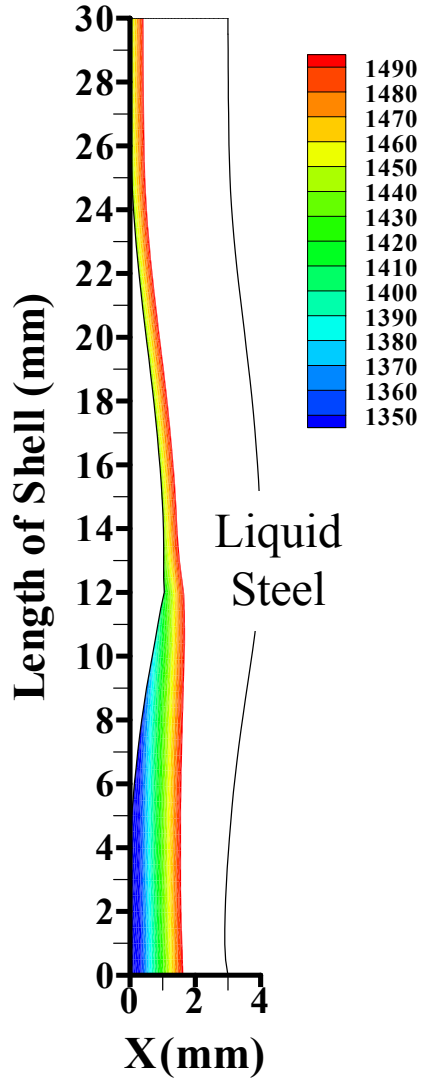


RESULTS: With Level Drop

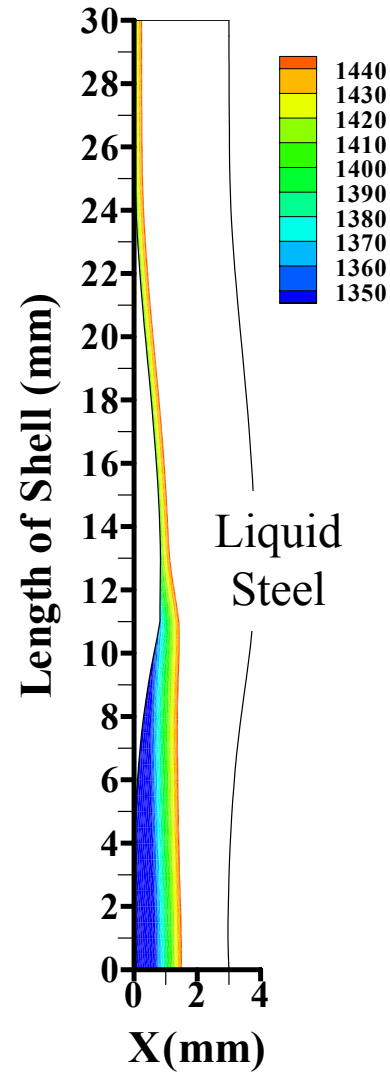
Fe-0.04% C
***Δu* = 0.78 mm**



Fe-0.13% C
***Δu* = 1.19 mm**



Fe-0.47% C
***Δu* = 0.91 mm**



CONCLUSIONS

CON2D is a powerful fundamental tool that can be used to study initial solidification phenomena.
However, further work is required.

Thermal stresses generated in the solidifying shell due to level fluctuations in the mold can lead to transverse surface depressions and longitudinal surface cracks.

Peritectic steels have been demonstrated to exhibit the most shell bending.

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