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Fundamental understanding of mechanisms affecting clinking and reheat cracking mechanisms in as-cast structure

2nd Postgraduate Research Symposium on Ferrous Metallurgy

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Introduction

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Reader in Solid Mechanics

Dr. Didier Farrugia
Scientific Fellow Tata RD&T

- PhD Start: July 2016
- PhD Finish: December 2019 (~1 year left)

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Contents

- Introduction to the research
- Background to Clinking (as we understand it!)
- Approach
- Testing
  - Macro Approach
  - Micro Approach
  - Replicating Clinking
- Conclusion

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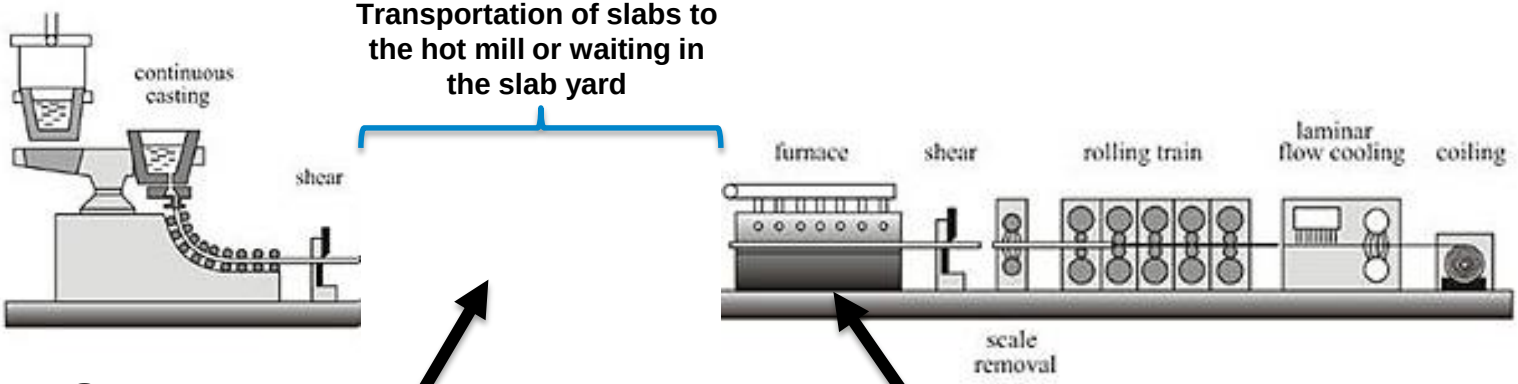
Background to Clinking

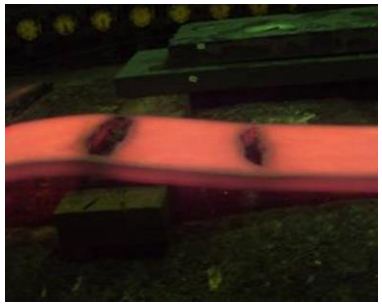


Concast

Hot Mill

Clinking can occur in the slab yard upon cooling after casting…

…Or in the furnace upon entry into the reheat furnace



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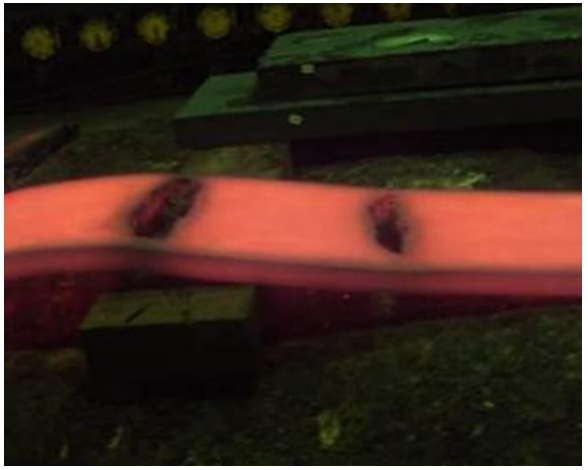
Background to Clinking

- Transverse cracks
- Loud, fast cracking
- Occurs more frequently when left for extended cool down
  - Hot charging employed to reduce frequency
- Influence of stacking sequence
- Kumowicz Clinking Index
  - Function(composition)
  - Higher alloying composition = higher clinking sensitivity
- **High Silicon Steels**



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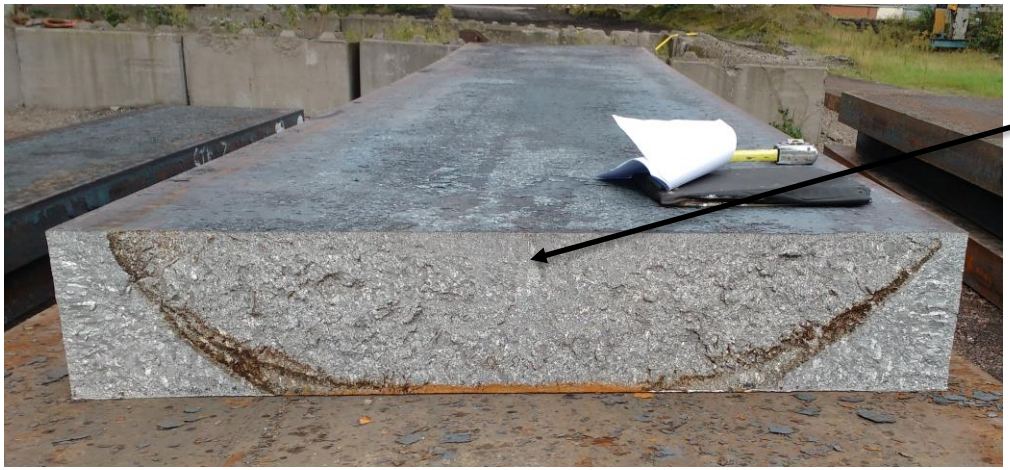
Background to Clinking – ‘Smiler’ Crack



Flat fracture surface – point of initiation

- Fracture occurs from the centre propagating towards the edges
- Band of rust forming

- Surface cracks propagated
- Occur at regular intervals along slab length

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PhD Approach

1. Macro-Approach

- Finite Element Analysis of stress state
  - Investigate stacking/route
- Fracture mechanics to determine critical crack length for failure
  - C(T) specimens
  - Charpy specimens
  - Tensile Tests
- LEFM or J-Integral

2. Micro-Approach

- How does the microstructure vary through the as-cast slab?
- How to account and predict the influence of microstructure and stresses on global response

3. Replicating Clinking

- Obtain stress state through FE
- Design component to replicate bi-axial stress state
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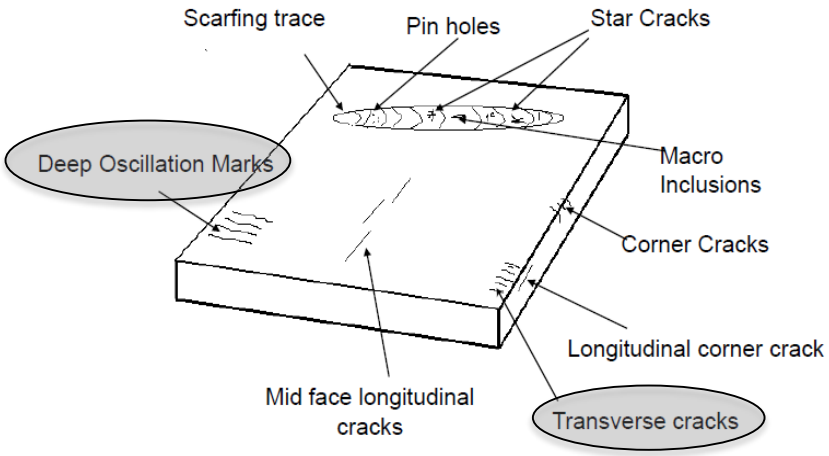
1. Macro Mechanisms of Clinking

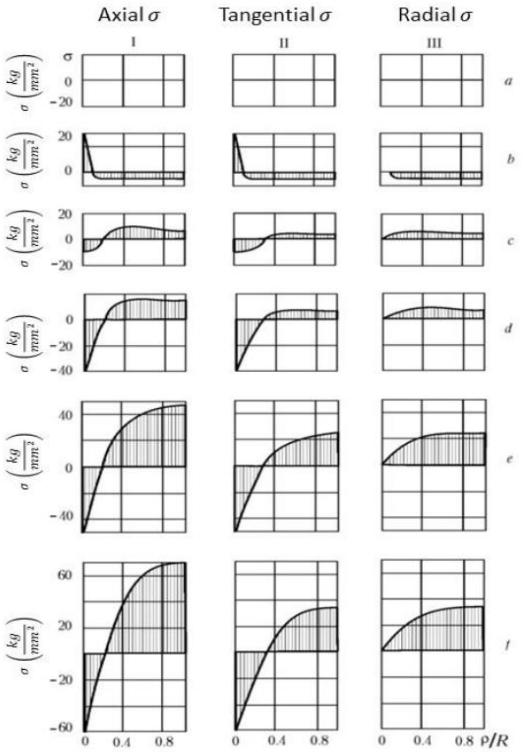
- Large longitudinal residual stresses
  - Non-uniform cooling
  - Transformation stresses
  - Mechanical stresses
  - Process route through plant

- Oscillation marks can form transverse cracks

- Transverse cracks can act as site initiators

- Propagated by longitudinal cracks





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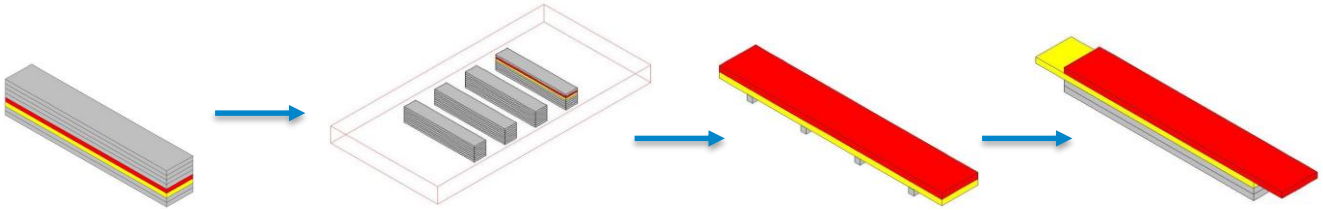
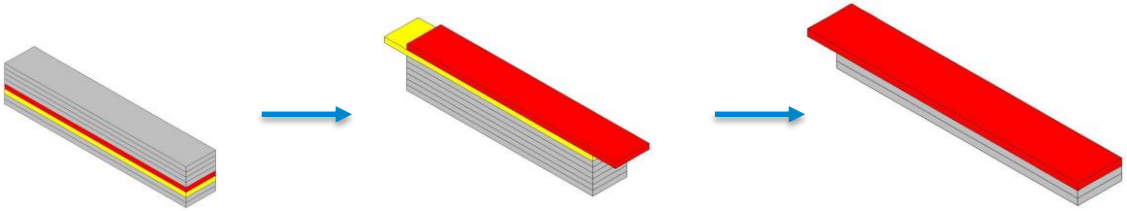
1. Macro Approach

Case 1



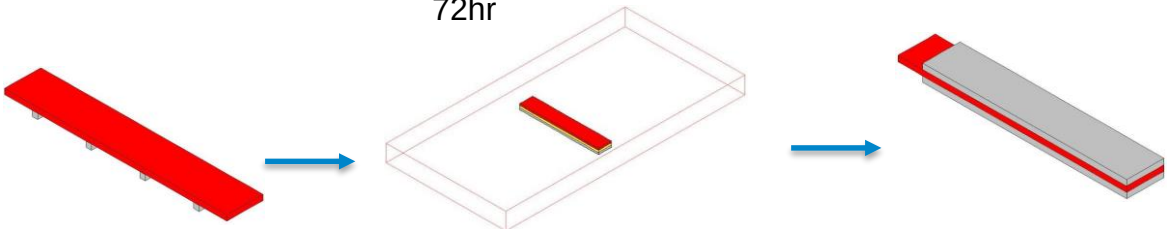
Transport: 4 hrs → Hot box: 36 hrs → Grid: 1 hr → Scheduled: 4hr

Case 2



Transport: 2hr → Storage: hot stack, 72hr → Scheduled: 5hr

Case 3



Grid: 2hr, rain → Hot box: 400 hr → Scheduled: 3 hr

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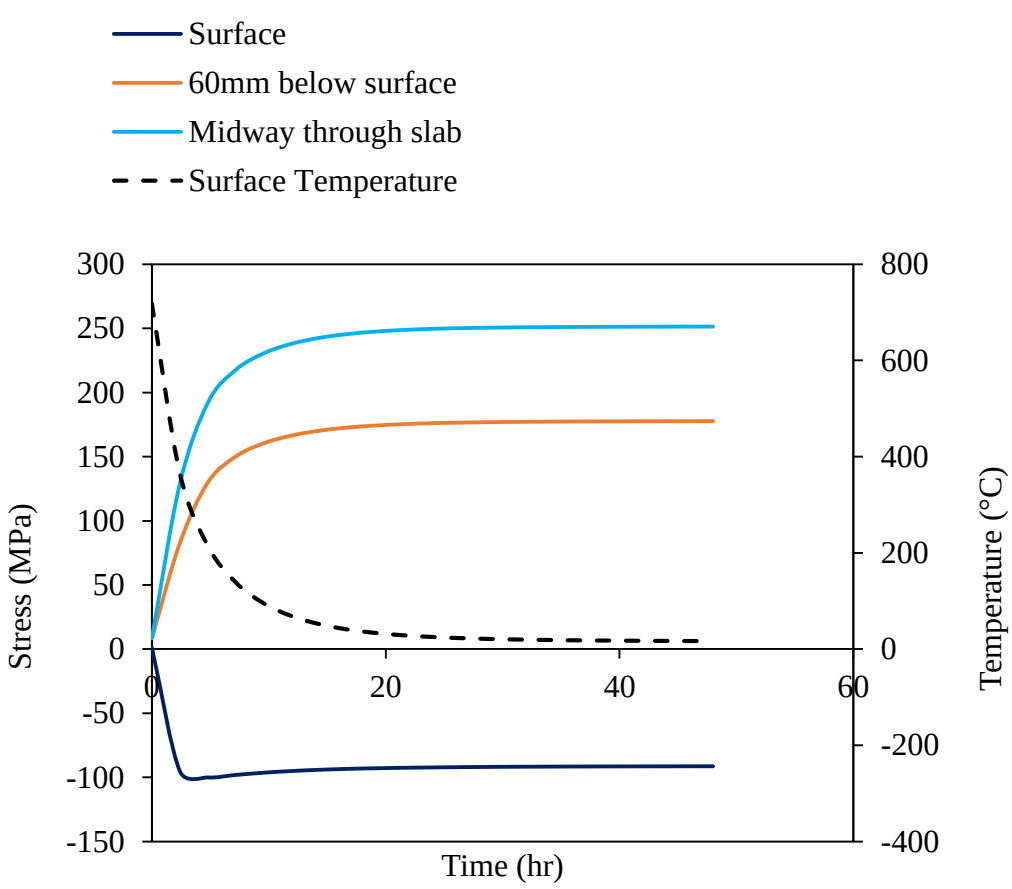
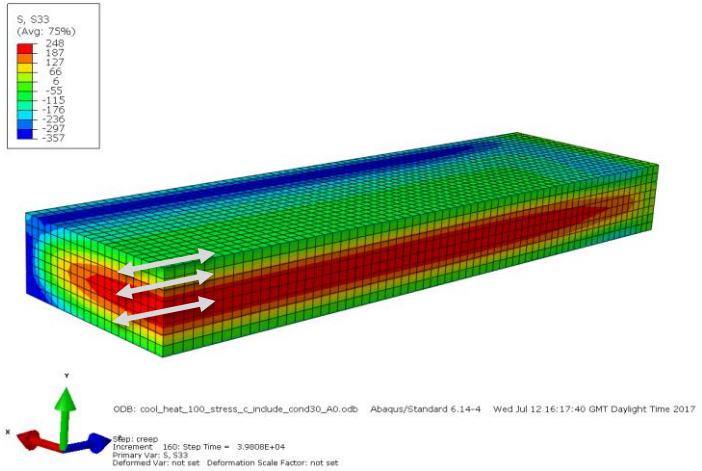
1. Macro Approach – FE Analysis (Case 4)





- Simulations for:
  - Thin slab cast – 70mm
  - Thick slab cast – 225mm
- Simulated material properties
- Case 4 – baseline case: air cooling with no route/process after casting

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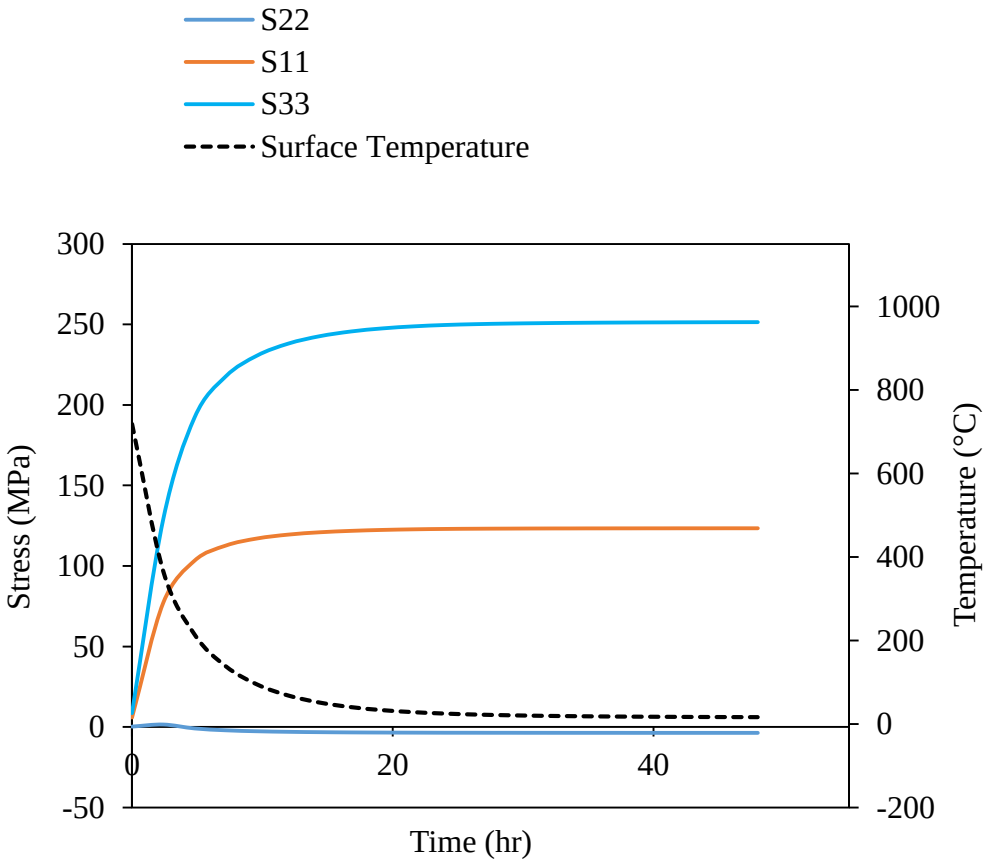
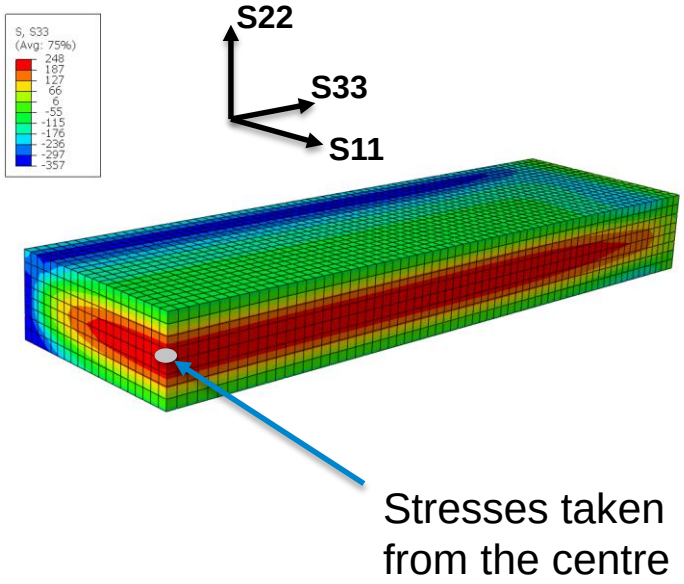
1. Macro Approach – FE Analysis (Case 4)





Stresses taken from the centre

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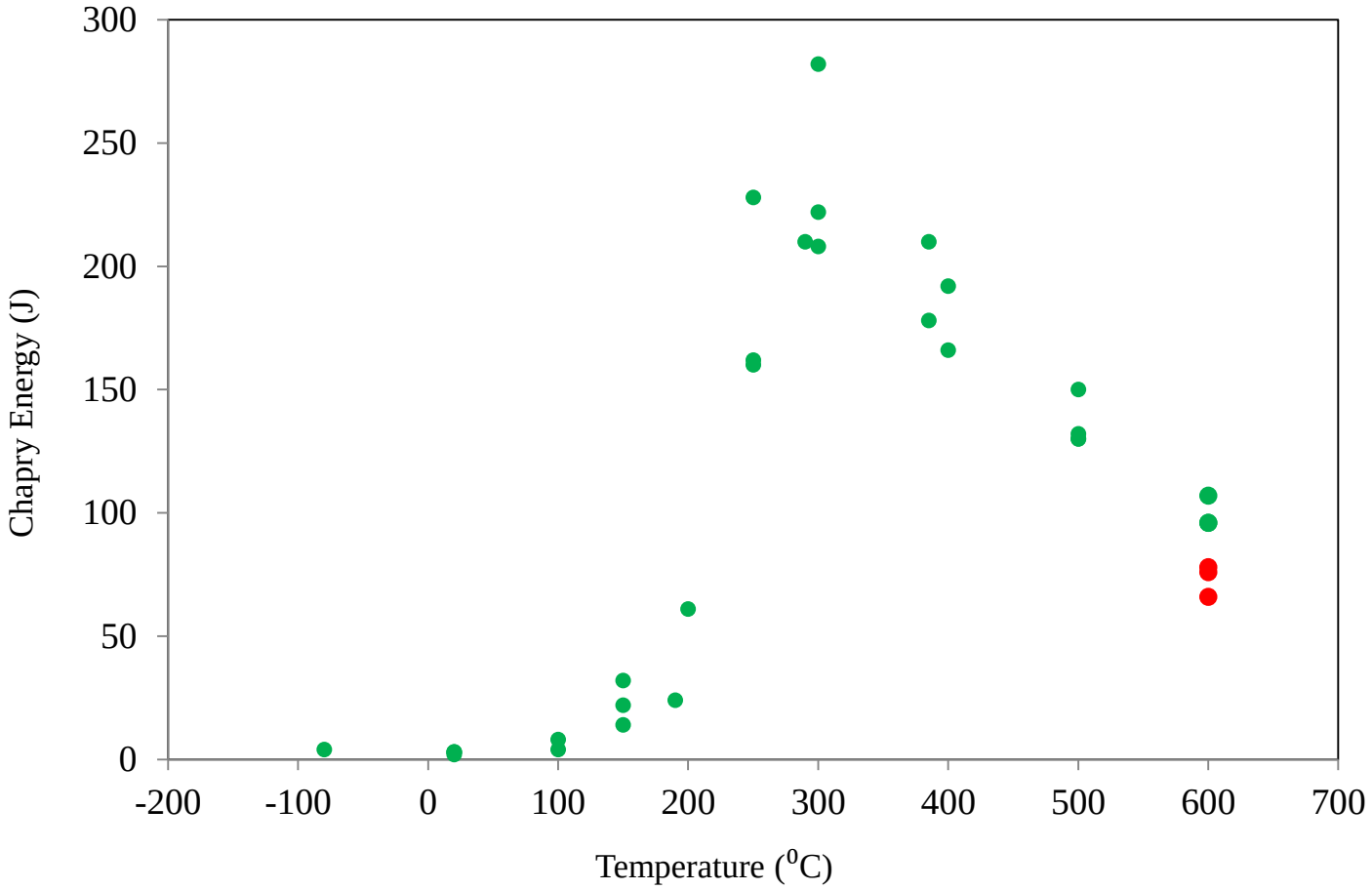
1. Macro Approach: Charpy Assessments



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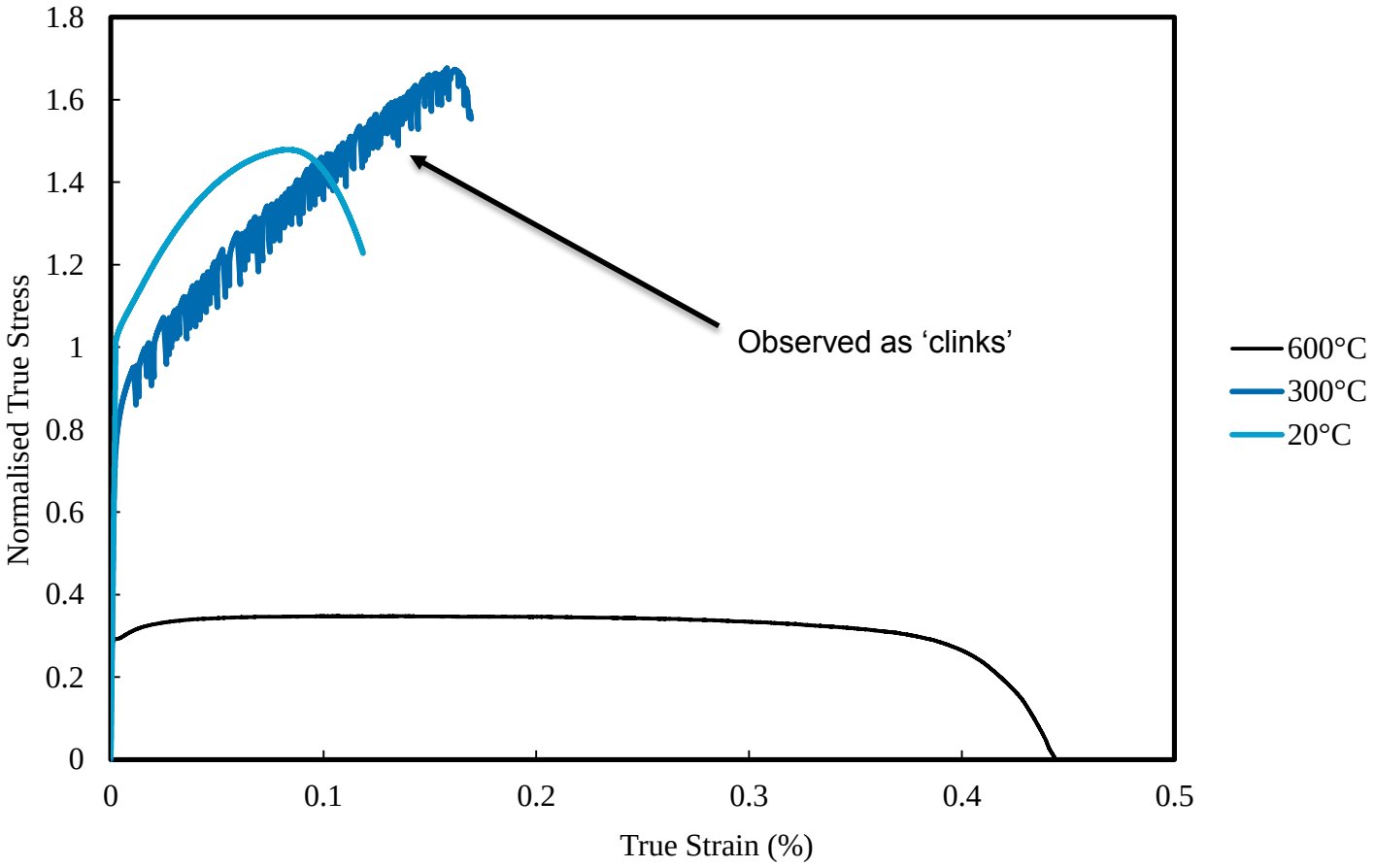
1. Macro Approach: Tensile Tests



*Normalised against room temperature yield stress

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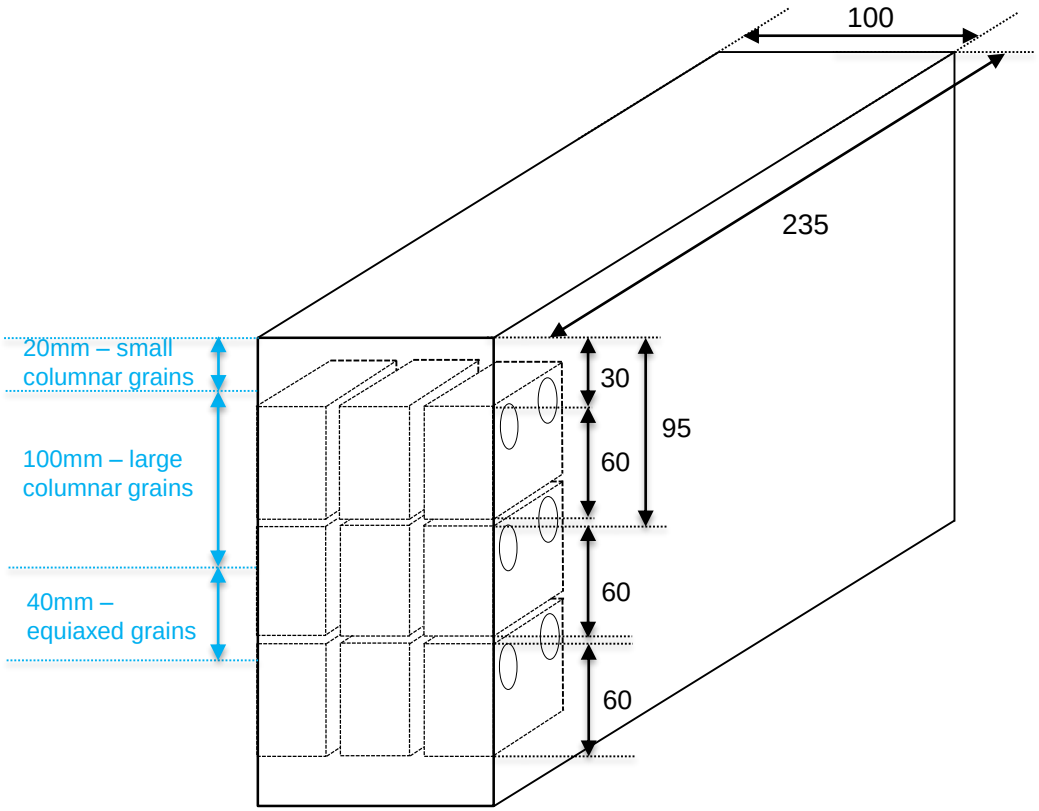
1. Macro Approach: Fracture Assessments

- K_{IC} test being completed using as-cast specimens through the thickness



Applied stress

$$K_{IC} = Y\sigma\sqrt{a}$$

Fracture toughness

Shape factor

Critical crack length

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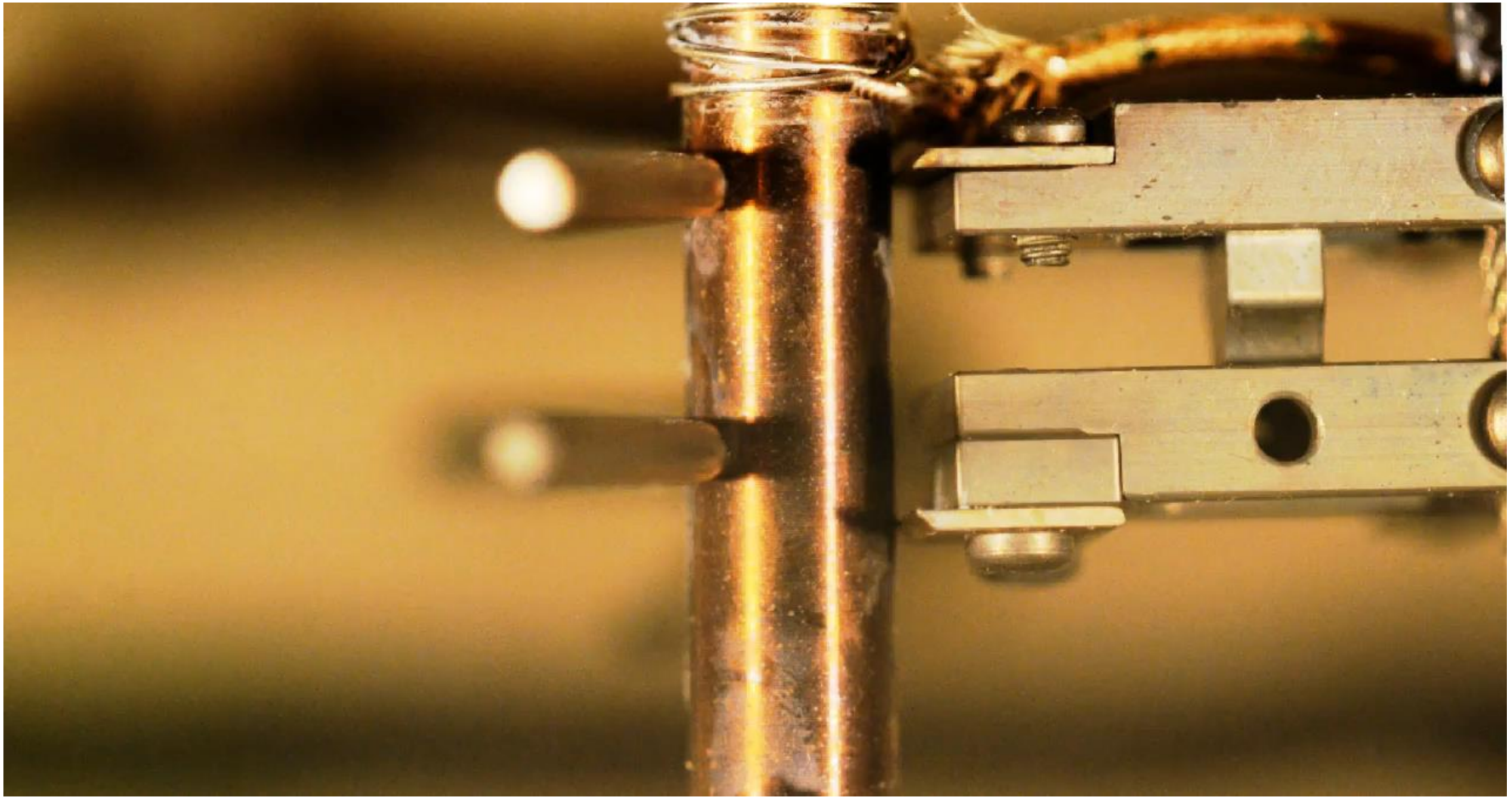
1. Macro Approach: Tensile Tests



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PhD Approach

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2. Micro Approach – As cast microstructure

Small columnar grains propagating from the surface

Large columnar grains propagating from the surface

Equiaxed grains in the centre

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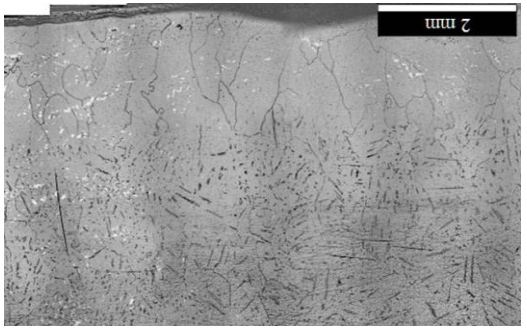
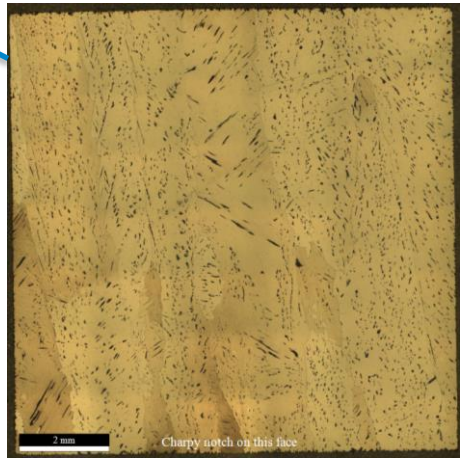
2. Micro Approach – Microstructural Features

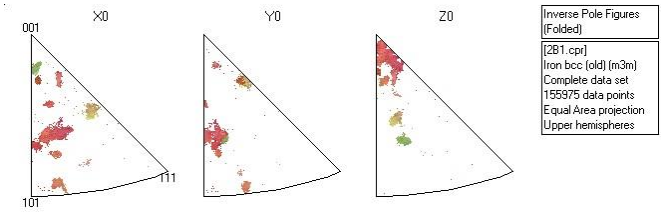
1. Decarburised zone



2. Large cementite laths



2. Columnar grains grow in the <100> direction from top of the slab



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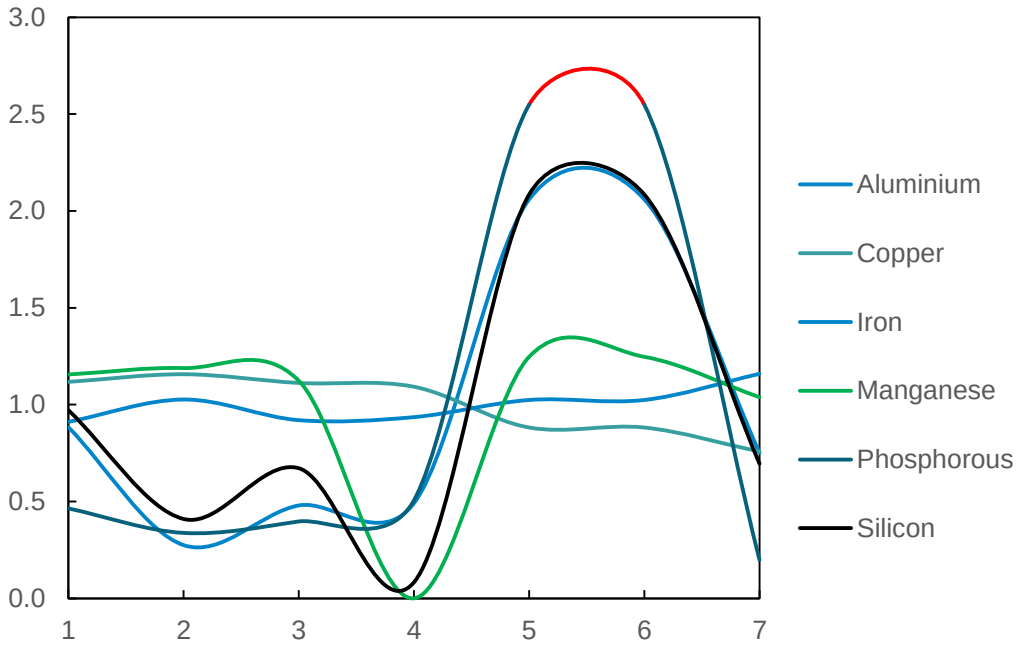
2. Micro Approach – Segregation (XRF)



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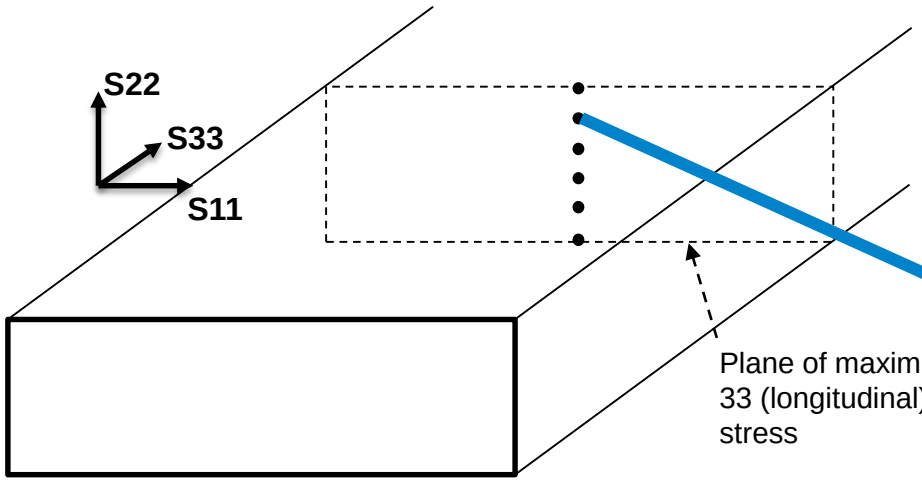
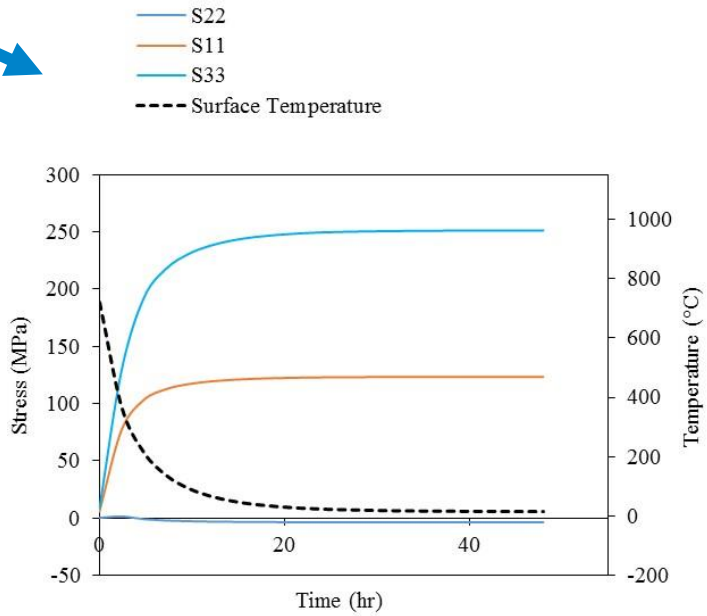
3. Replicating Clinking



Outputs

1. How does fracture behaviour depend on location (and grain stucture) in slab?
2. How does temperature effect the fracture
3. Does the grain orientation have a large impact on the strains accumulating in the grains?
4. Do the samples reflect the low strain fracture observed in clinking



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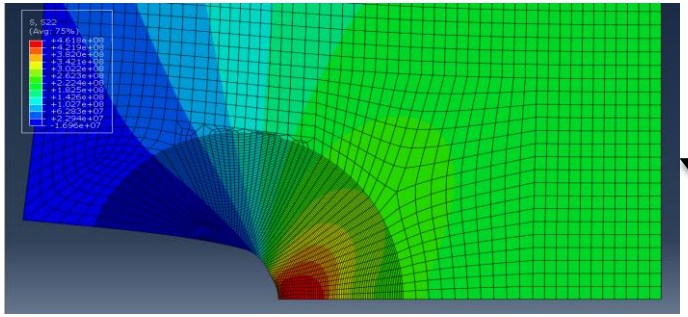
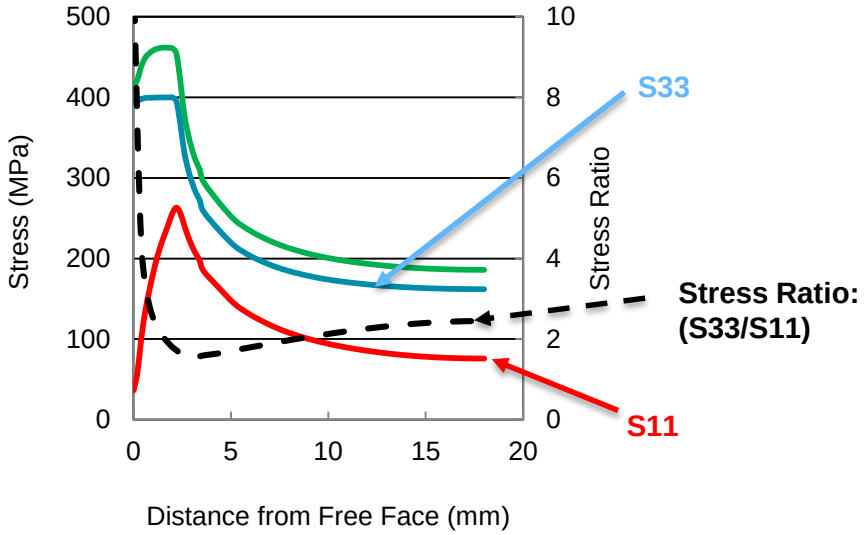
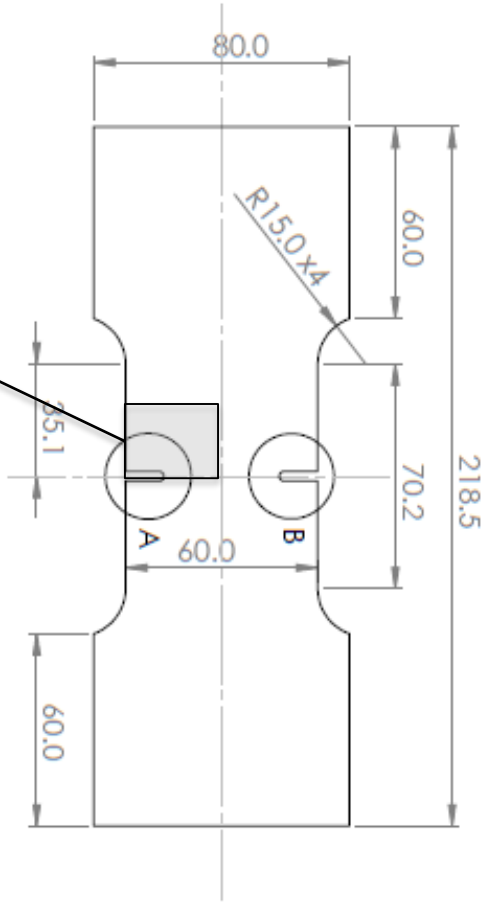
3. Replicating Clinking: Specimen Design



S33

S11





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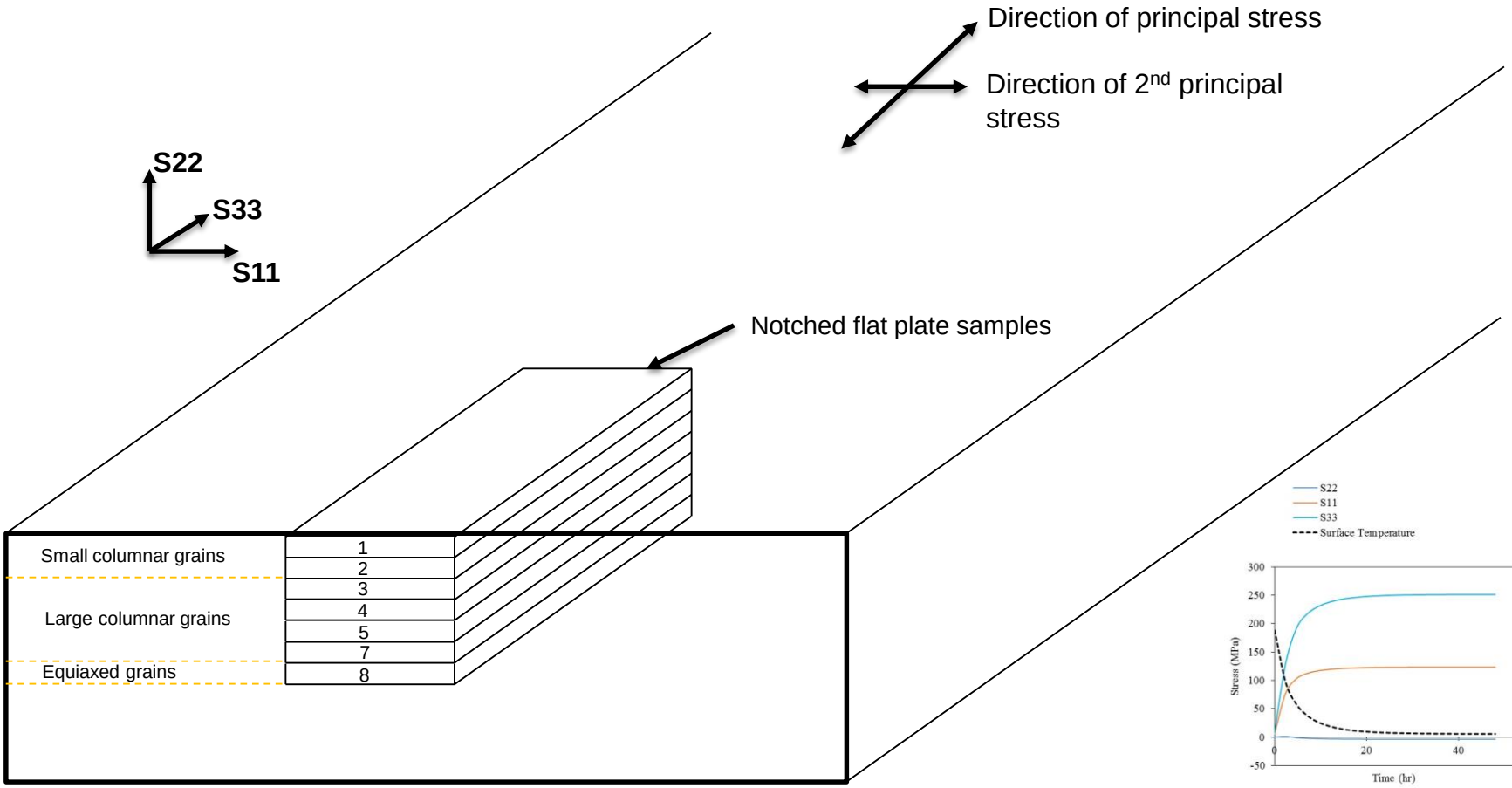
3. Replicating Clinking: Specimen Extraction



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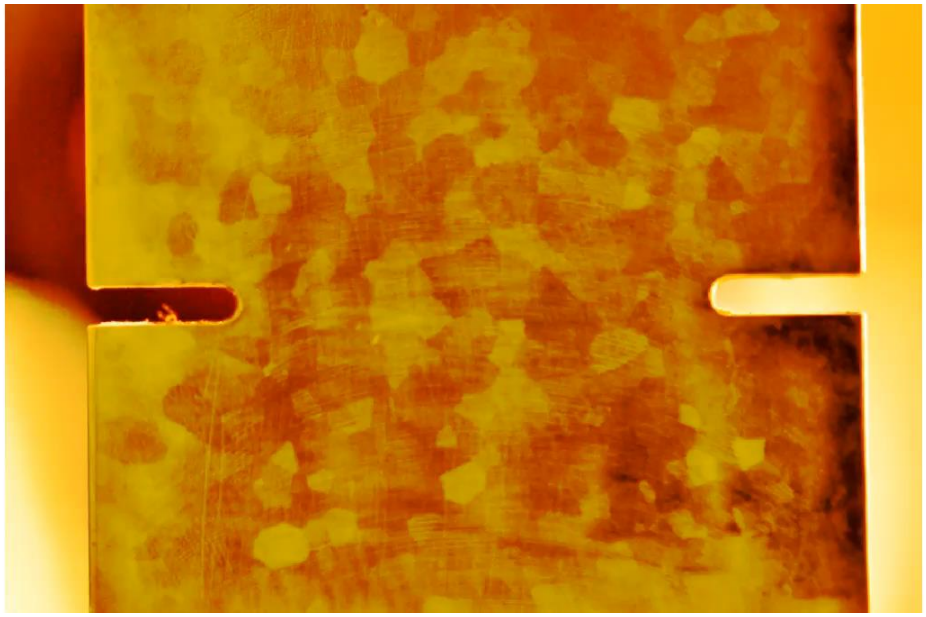
3. Replicating Clinking: Fracture Video



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Summary

- Clinking is loud audible transverse failure causing catastrophic failure
  - Wide range of compositions and alloys
- Undertaking a macro and micro approach, with the end goal of replicating clinking
- Macro Approach Results
  - Material becomes brittle at around 100°C
  - Significant drop in tensile properties between 300°C and 600°C
  - Clinking occurs during these tensile tests, likely due to micro crack propagation and arrest during fracture
- Hoping to obtain a greater understanding of **underlying causes**