Physics of Ultrasonic Treatment of Metals & Applications

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December 12th, 2023

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Fundamentals of Ultrasonic Treatment of Aluminum Alloys

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ABSTRACT

High integrity cast Aluminum (Al) components require the use of molten metal processing technologies prior to casting. These include processes such as degassing to reduce porosity, filtration to reduce inclusion content, addition of grain refiners to refine the grain structure, and the addition of chemical modifiers to alter the morphology of eutectic phases. Ultrasonic Treatment (UST) is a novel processing method through which ultrasonic energy is introduced into molten metal for the purpose of degassing as well as modifying the cast microstructure. To optimize the use and applications of UST, it is necessary to examine the fundamental mechanisms and the limiting values of controlling parameters. The mechanisms of ultrasonic energy imparted within molten metal will be discussed as well as the benefits of UST during molten metal processing.

Keywords: Ultrasonic treatment, degassing, grain refinement, intermetallic morphology modification, aluminum, ultrasonic equipment, MMM technology

Outline

1. Ultrasonic Treatment (UST) & Applications
2. Fixed & Variable Frequency Modalities
3. Experimental Procedure
4. Results
5. Next Steps

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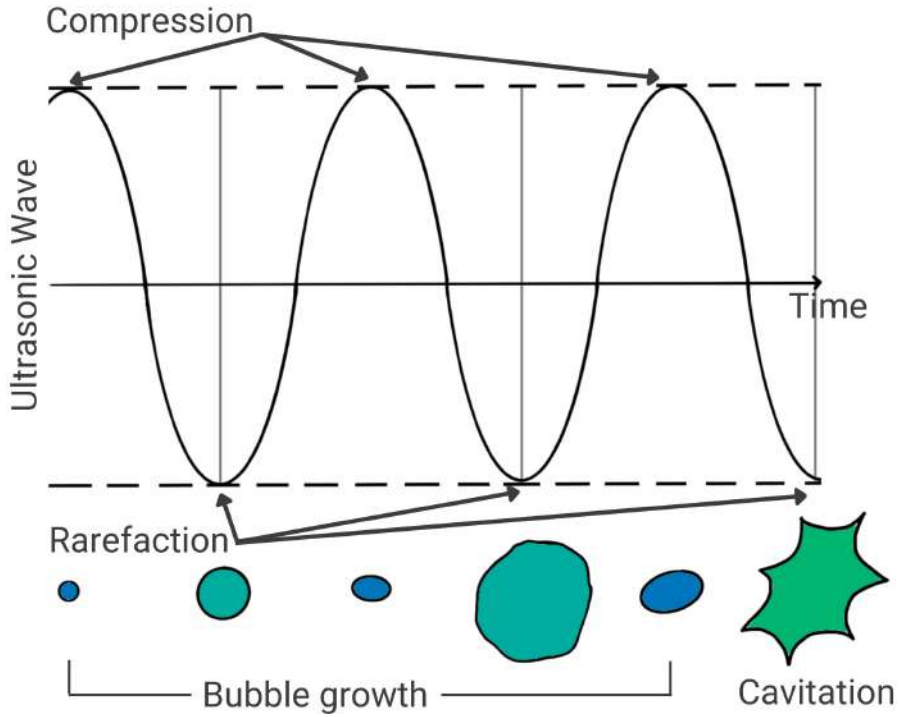
Ultrasonic Treatment (UST)

Applying ultrasonic waves to the molten state metal for changes in cast aluminum quality

Acoustic Cavitation



Acoustic Streaming

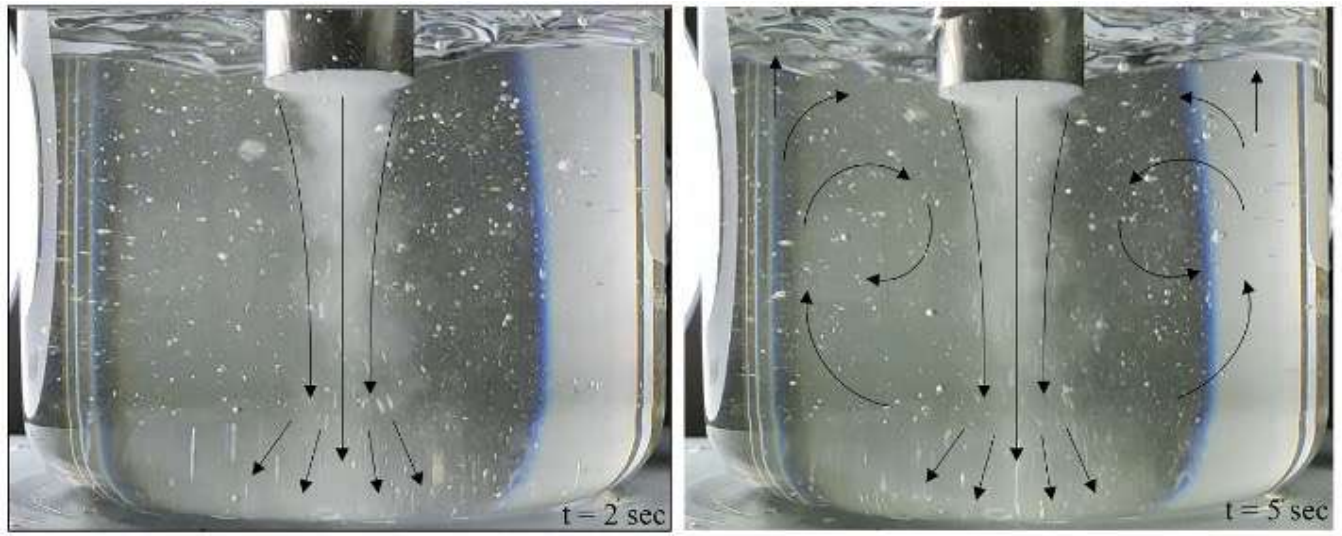
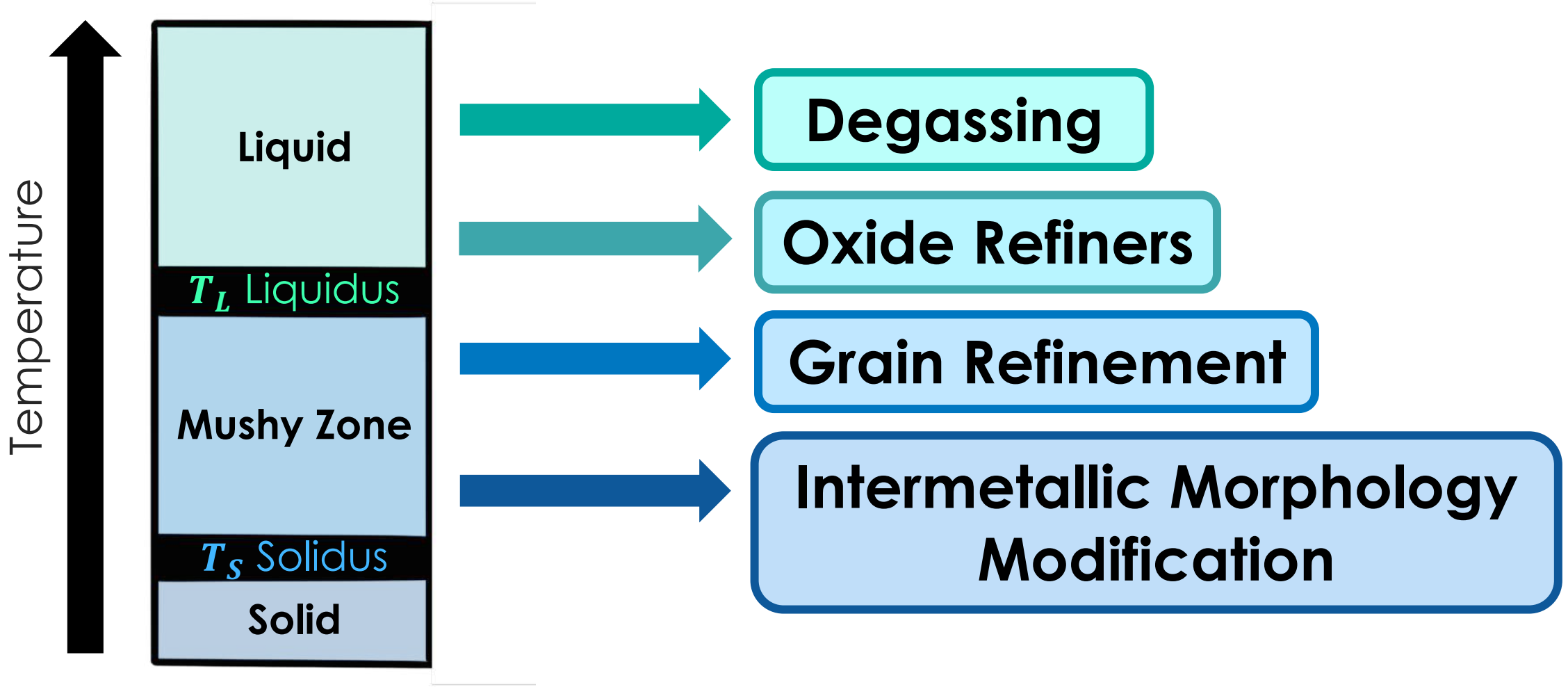
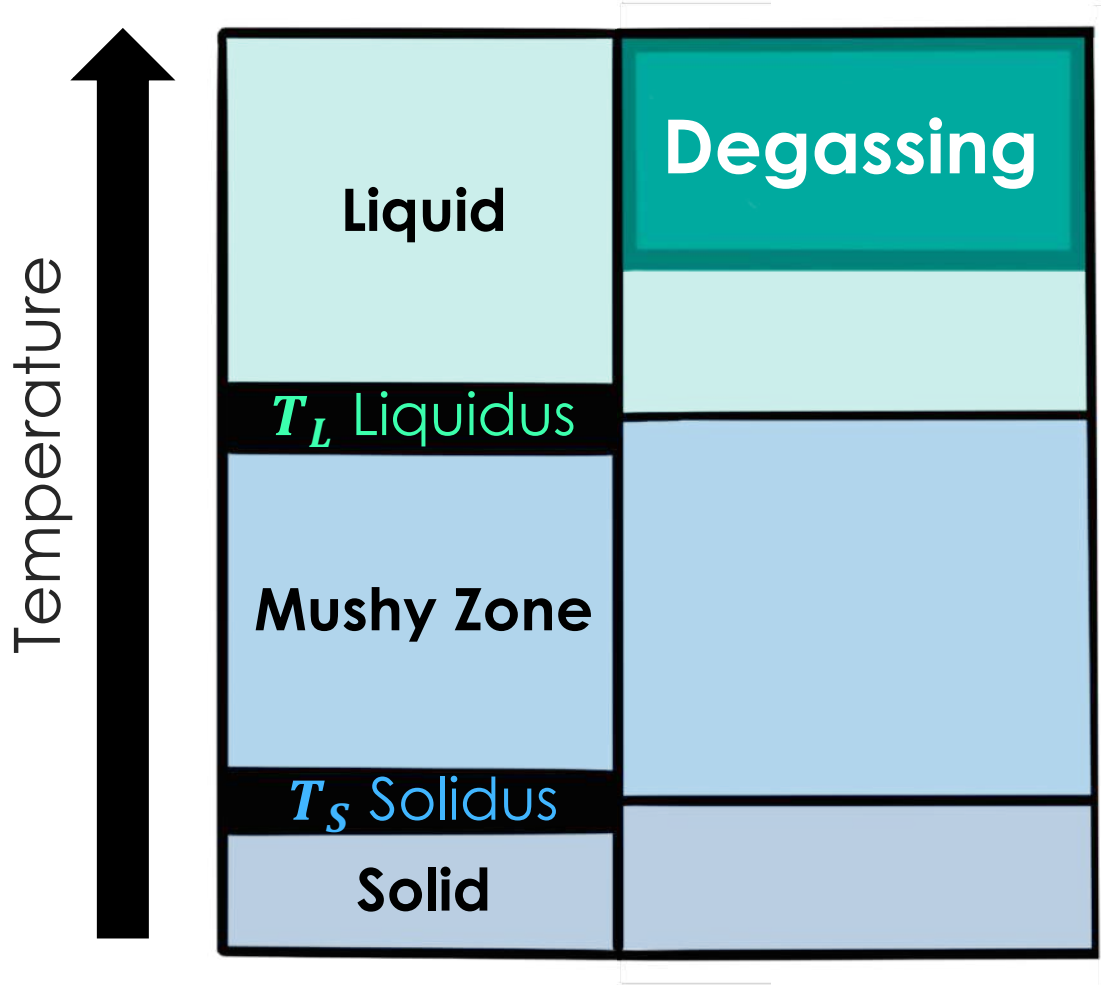


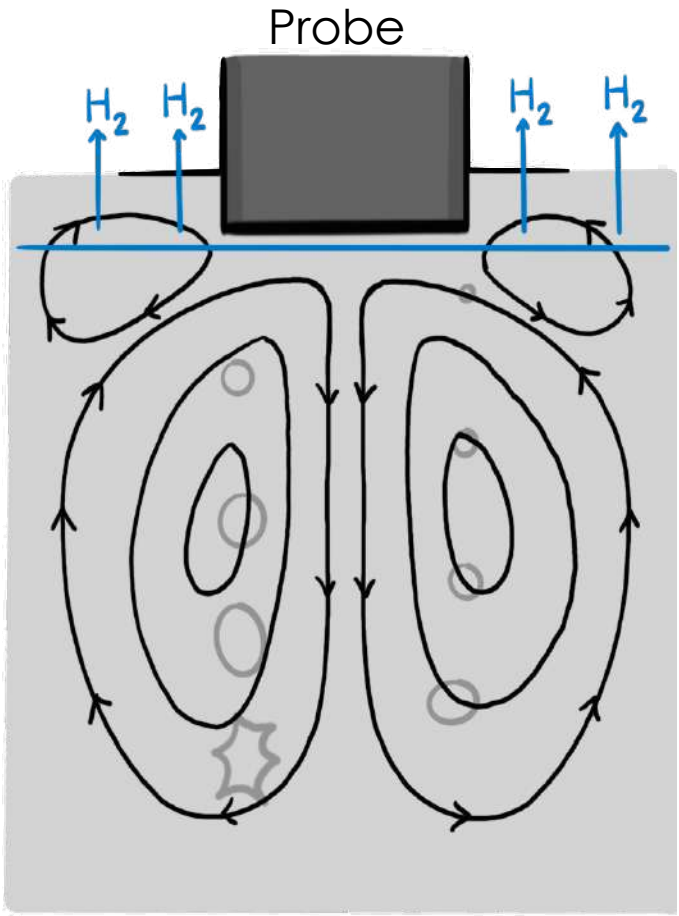
Photo Courtesy H. Puga

UST Applications

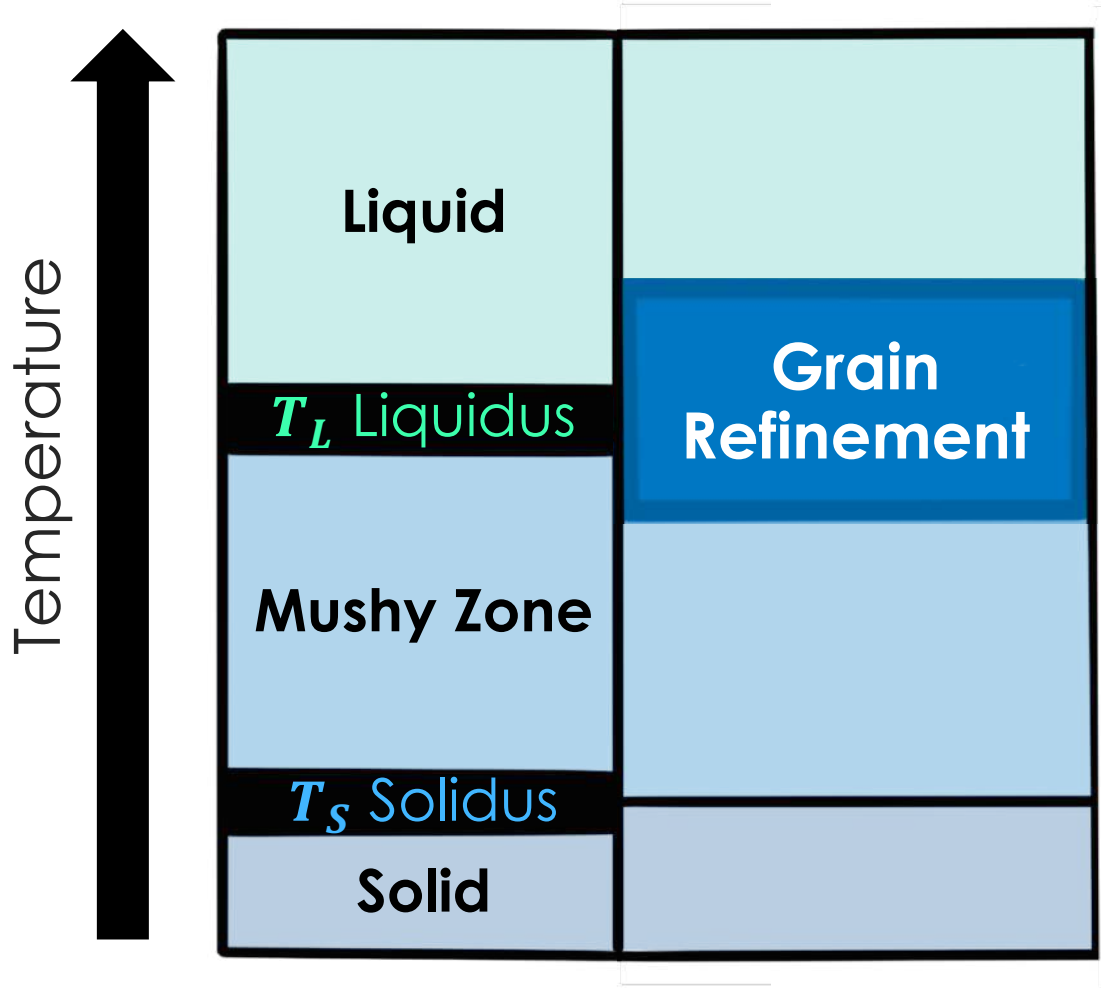


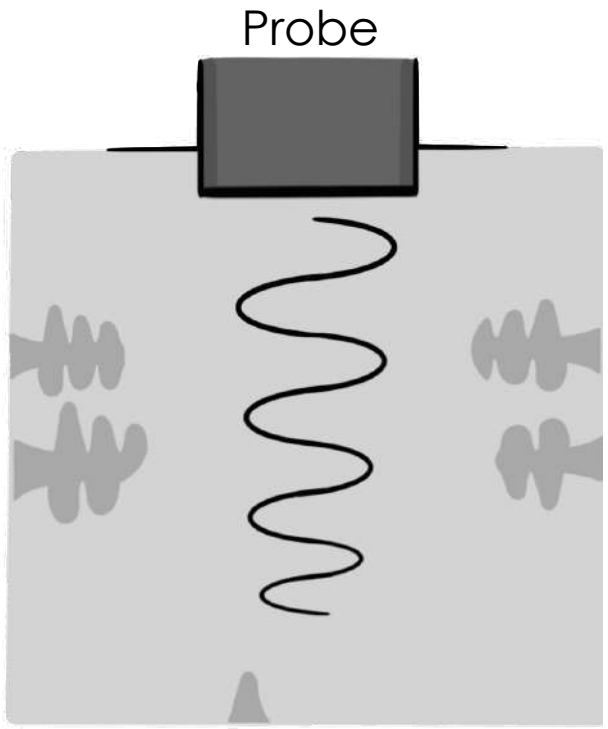
Mechanisms of UST Degassing



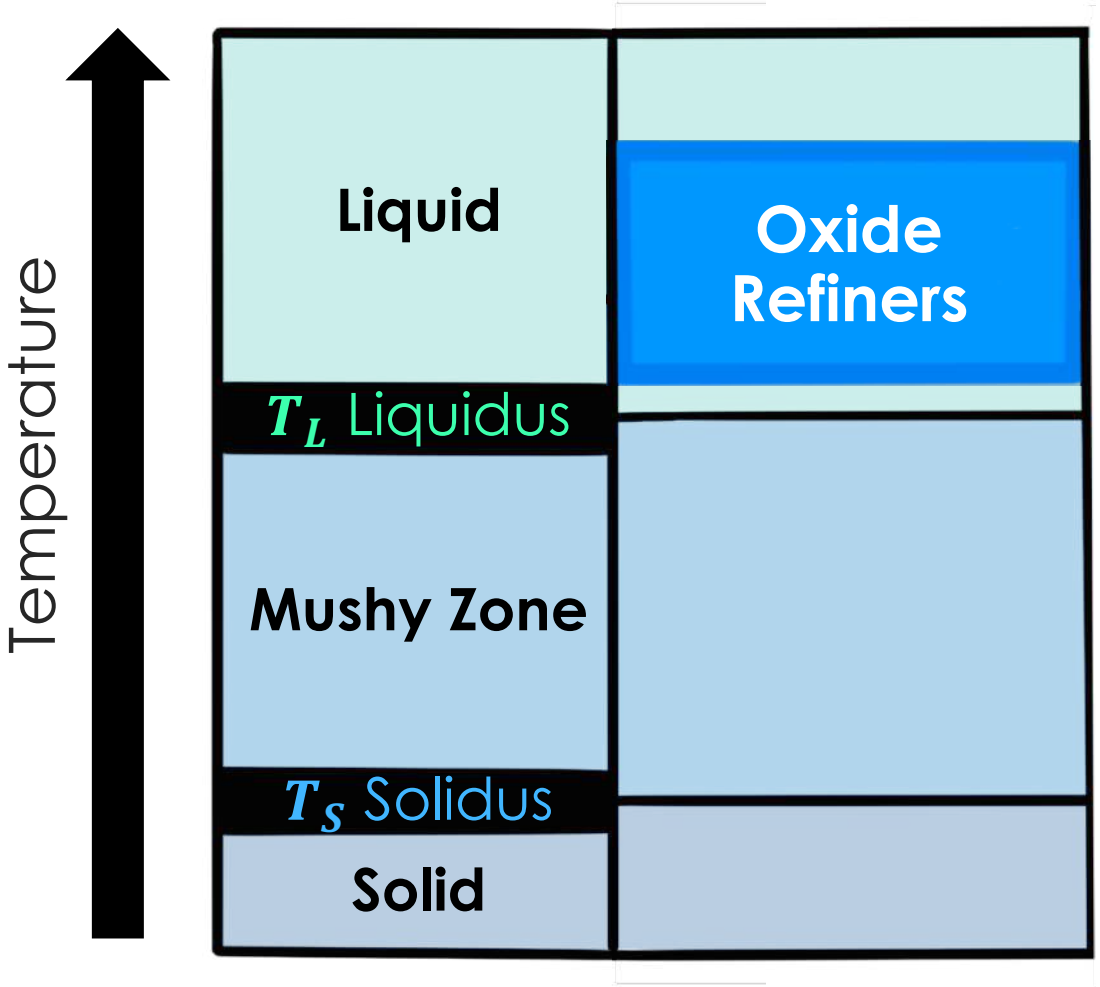


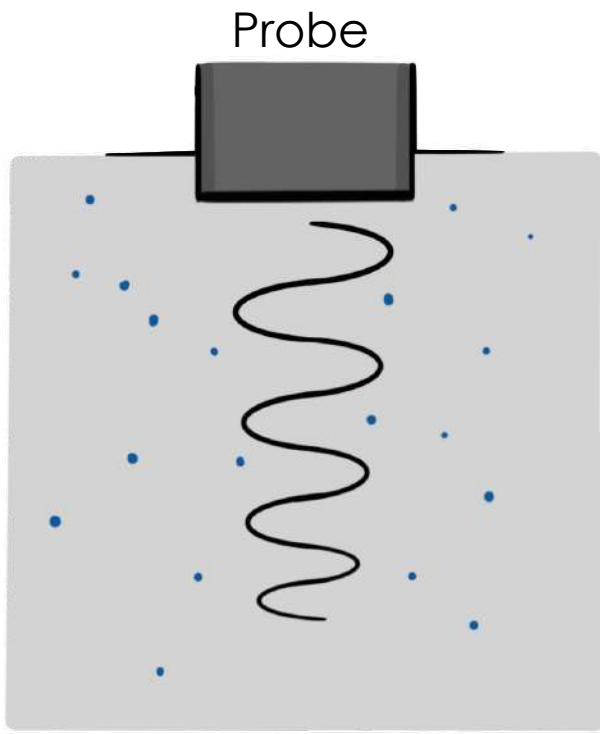
Mechanisms of UST Grain Refinement

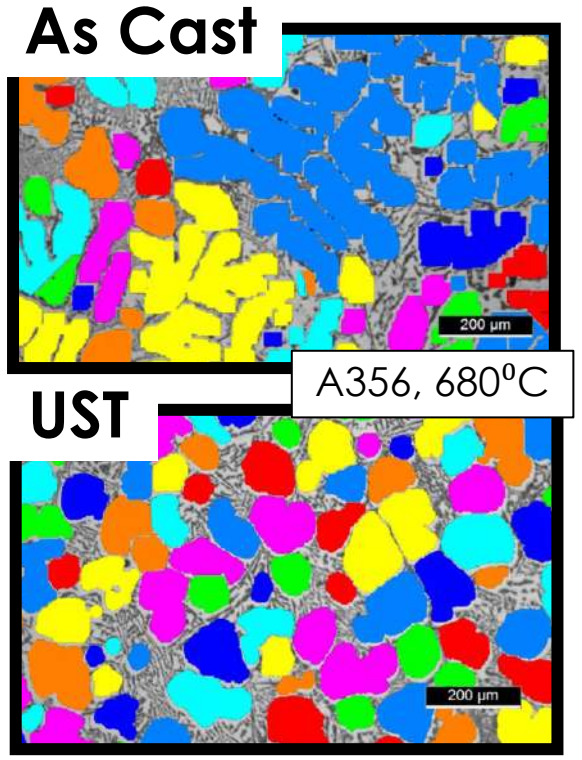




Mechanisms of UST Oxide Refiners

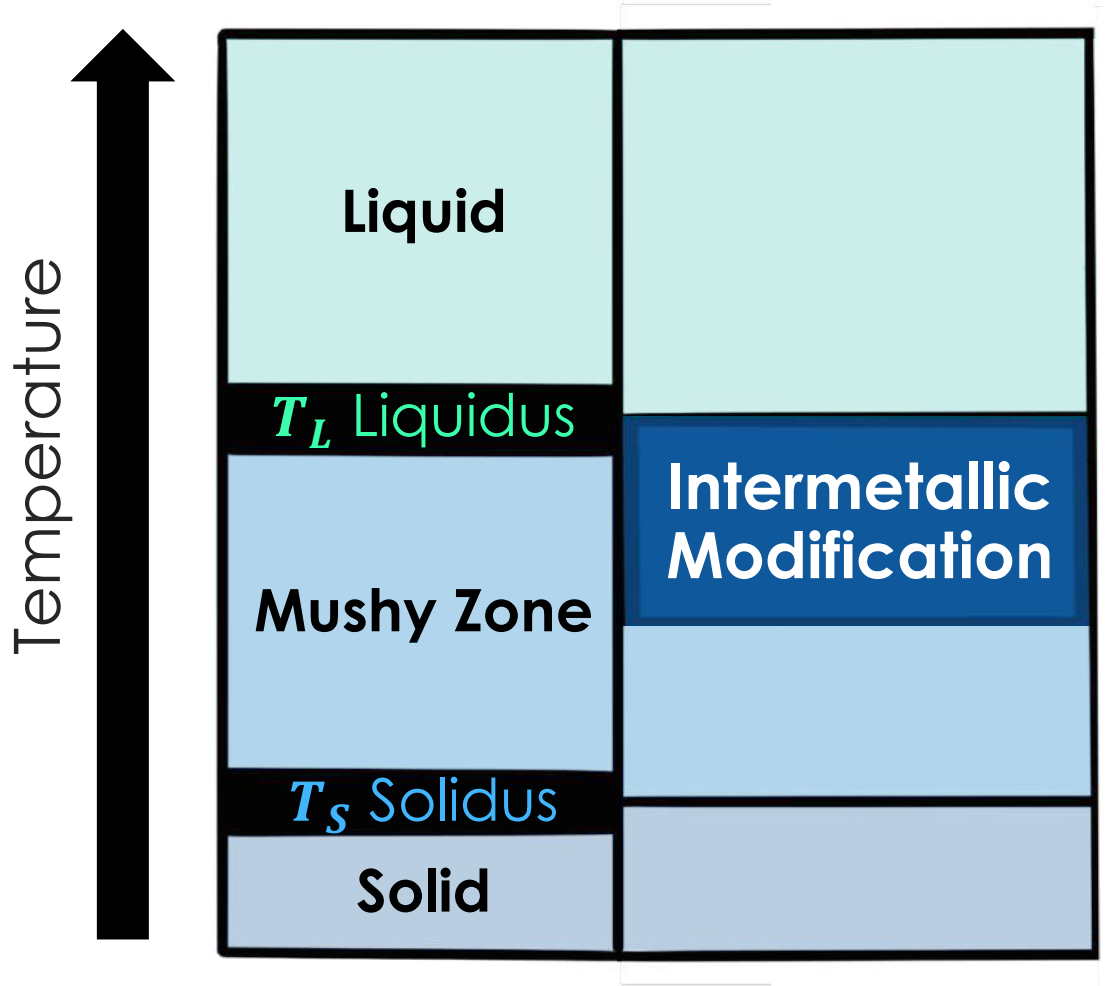


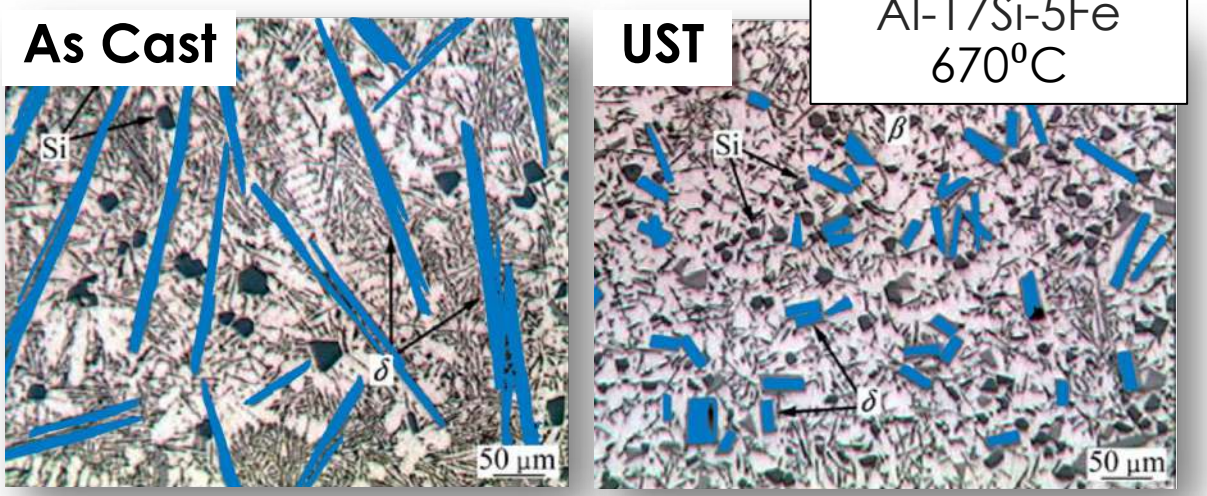




H. Puga et al. AFS, 2020

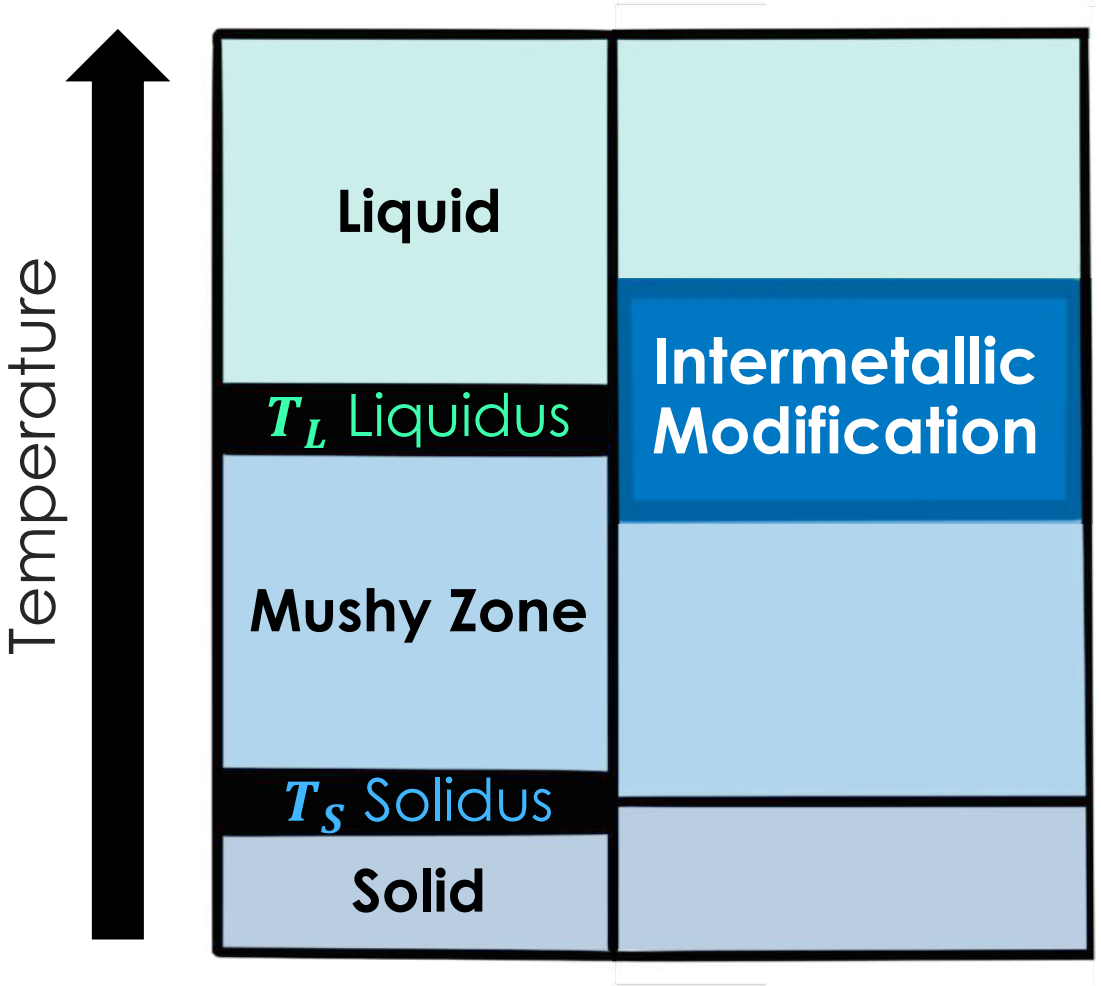
Mechanisms of UST Intermetallic Mod.

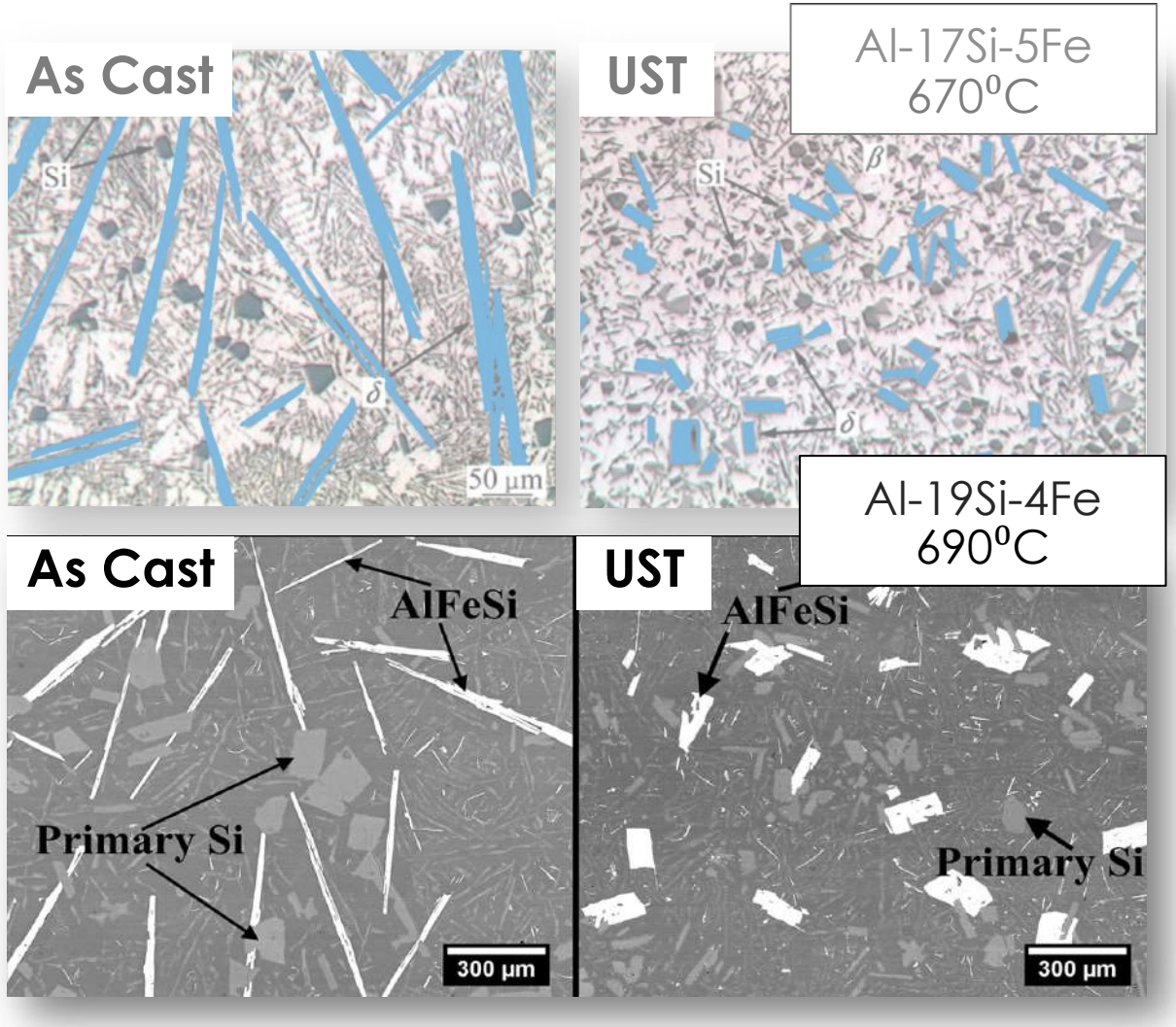




C. Lin *et al* Trans. Nonferrous Met. Soc. China , 2013

Mechanisms of UST Intermetallic Mod.





C. Lin *et al* Trans. Nonferrous Met. Soc. China , 2013
C.J. Todaro *et al* TMS, 2017

Outline

1. Ultrasonic Treatment (UST) & Applications
2. **Fixed & Variable Frequency Modalities**
3. Experimental Procedure
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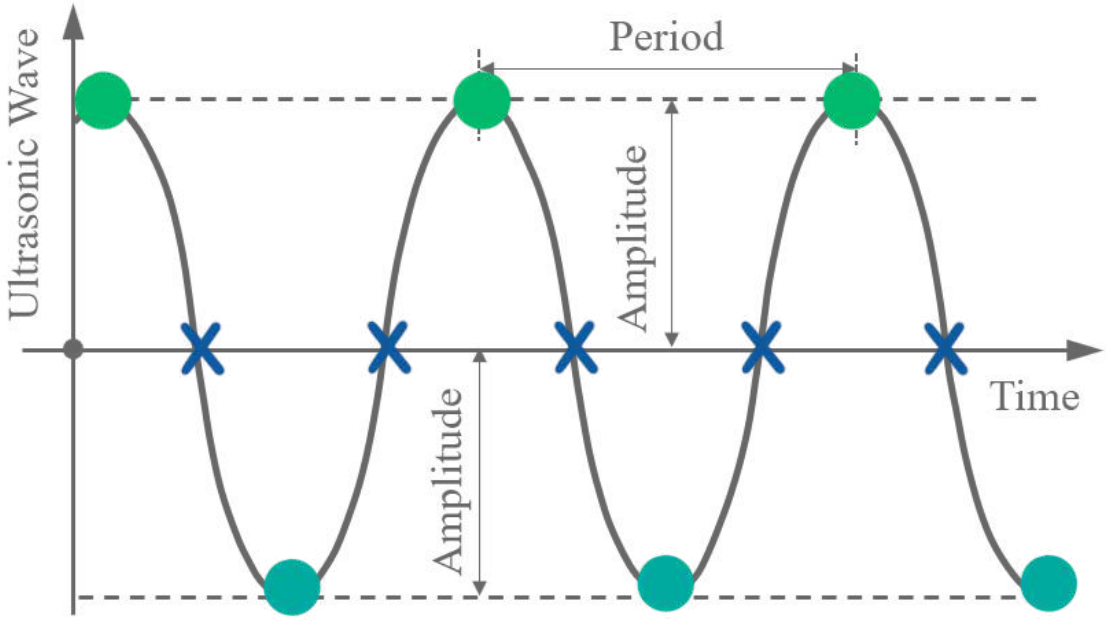
Ultrasonic Systems & Modalities

Mechanism & efficiency dependent on equipment parameters

Ultrasonic output method influences:

- Amplitude/intensity
- Depth of treatment
- Optimization

Fixed Frequency



- Fixed f = 19-22kHz
- Most commonly used

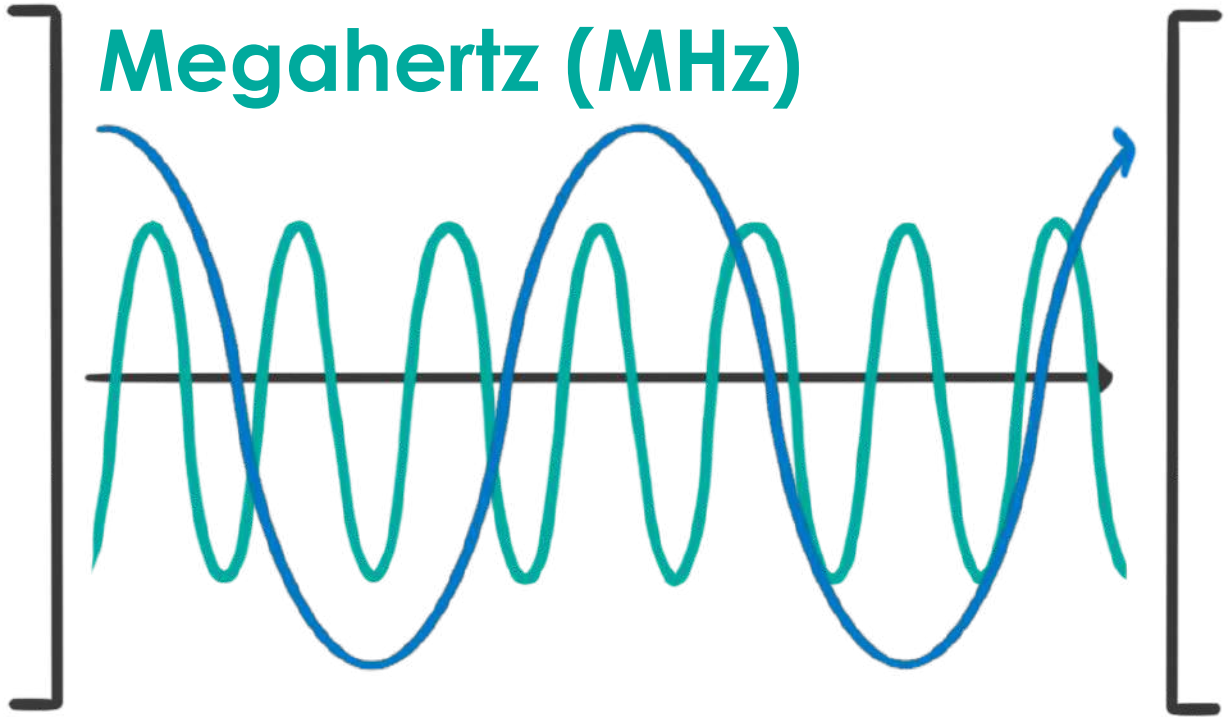
Acoustic Cavitation

- Mode of high pressure
- Mode of low pressure

Nodes

- ✗ Non-uniform treatment
- ✗ Inefficient

Variable Frequency



Multifrequency Concept

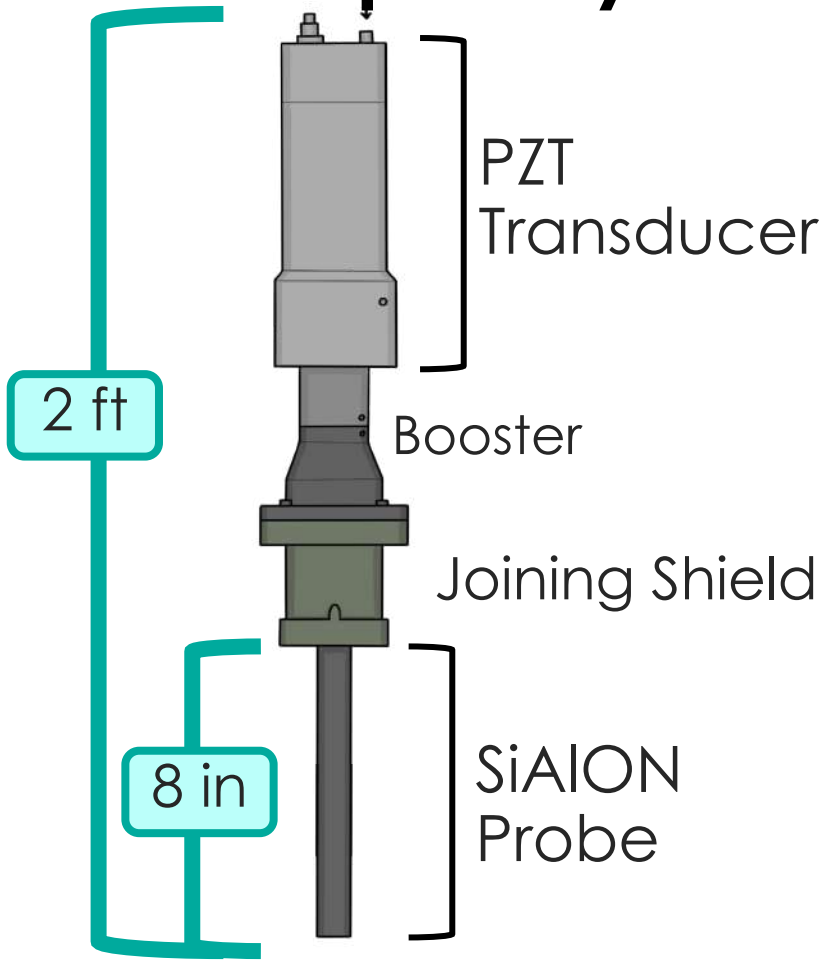
- Two or more *f*
- *High-kHz + low-MHz*
- Superpostion increases amplitude
- Eliminates nodes

Current uses:

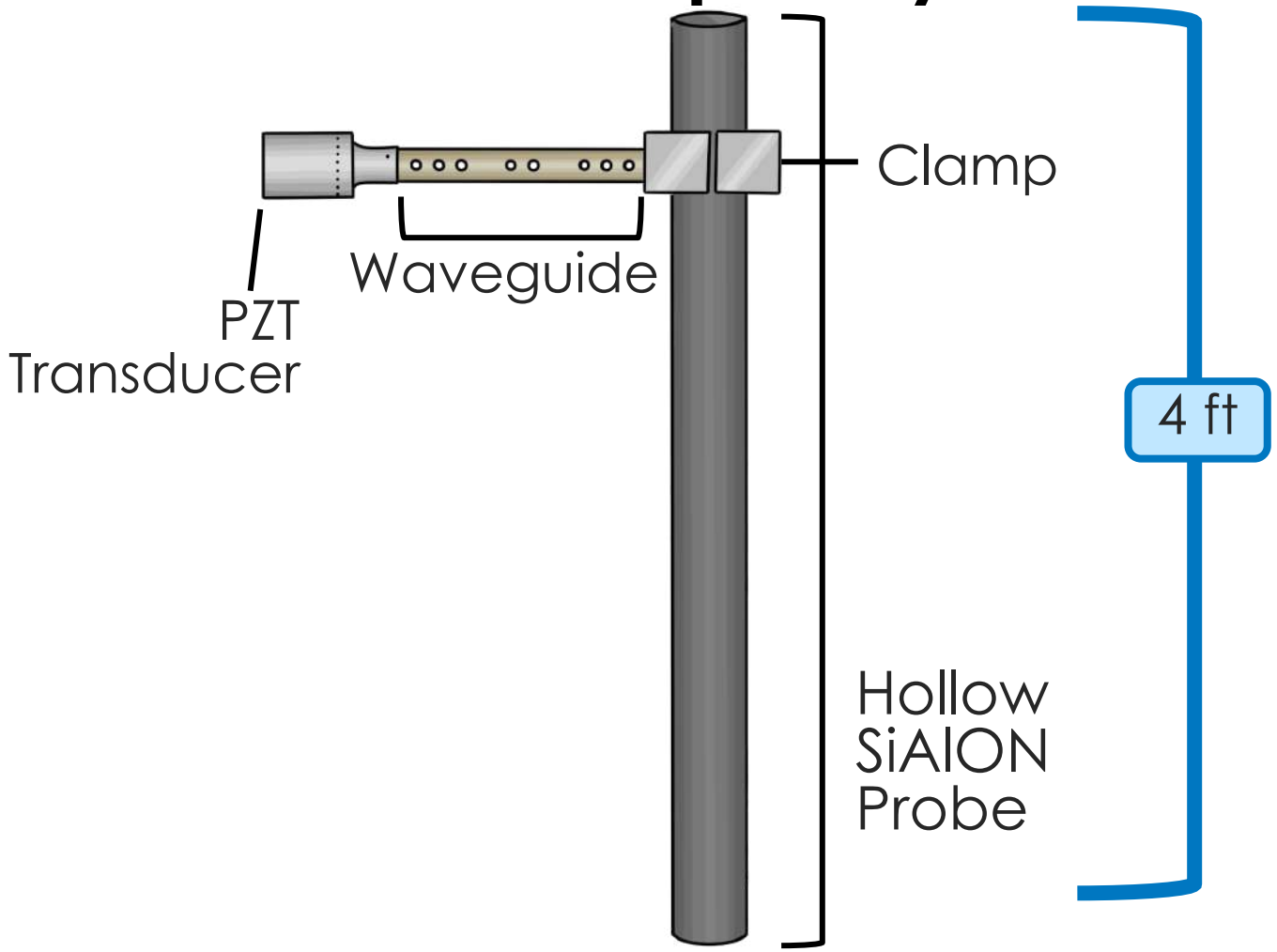
- Food Sanitation
- Polymer Science
- Medical applications

Equipment Types

Fixed Frequency:

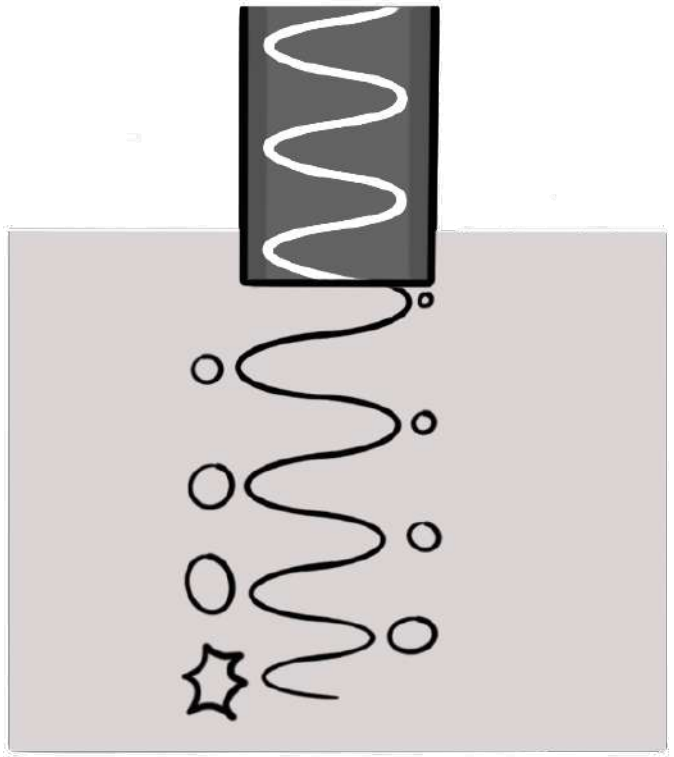


Variable Frequency:



Ultrasonic Radiation

Fixed Frequency:
Longitudinal Expansion



Variable Frequency:
Radial Expansion

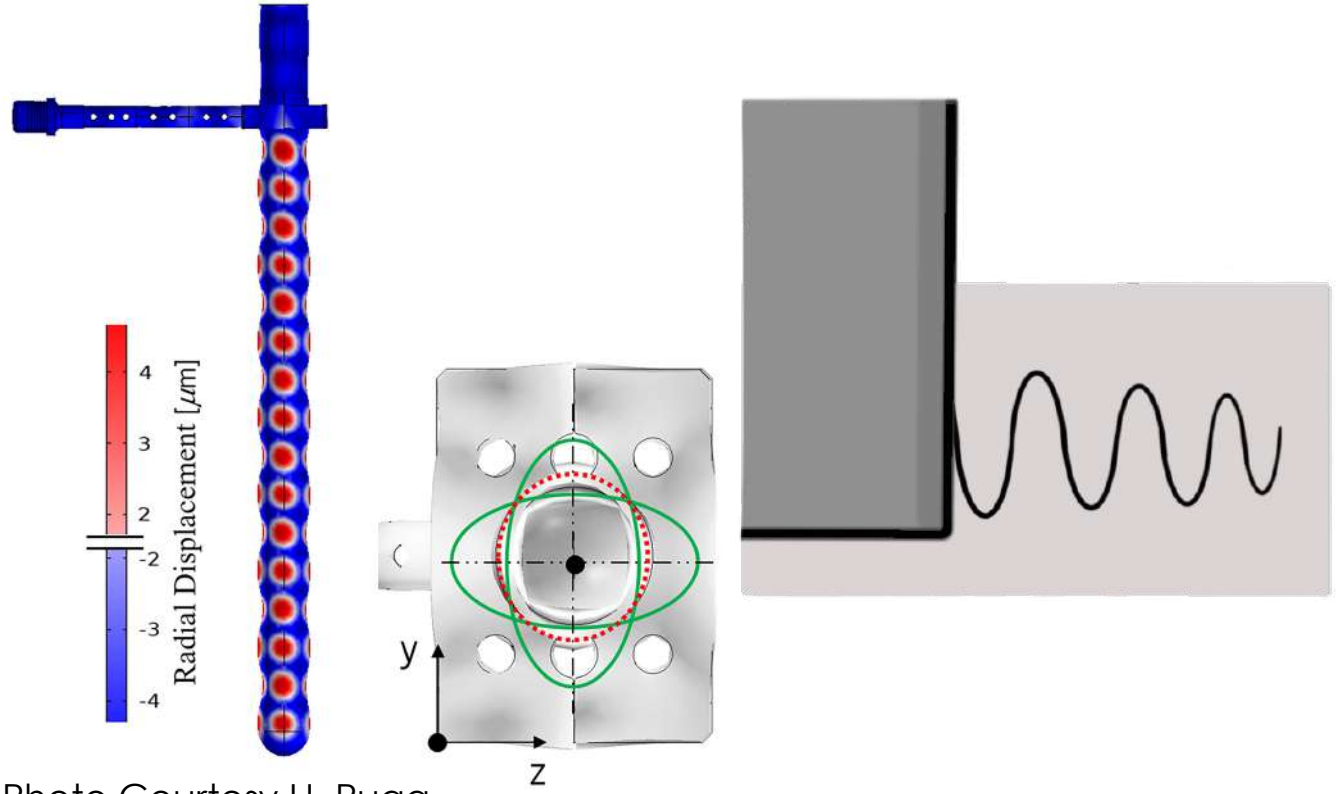


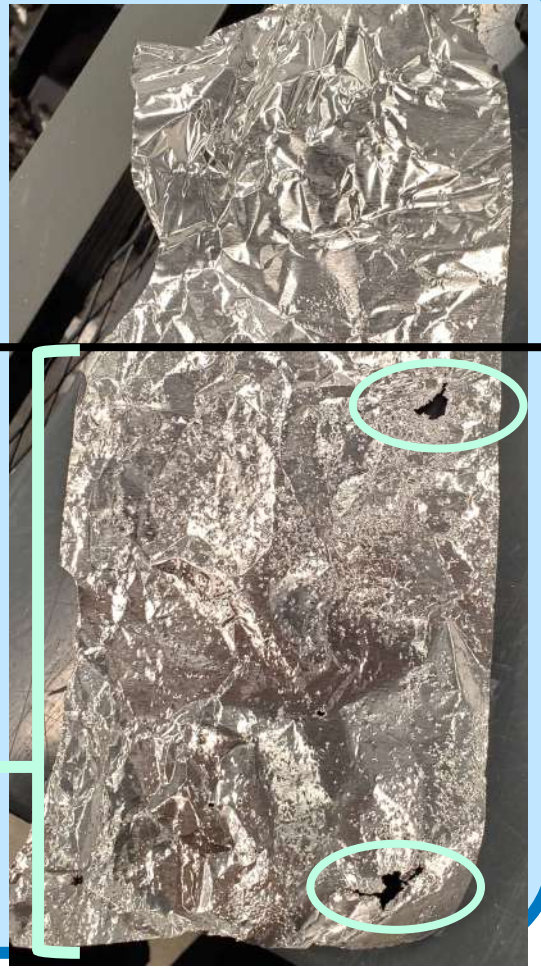
Photo Courtesy H. Puga

Treatment in Water

Pulse cycle: On 5s, Off 3s

Fixed Frequency:

Variable Frequency:

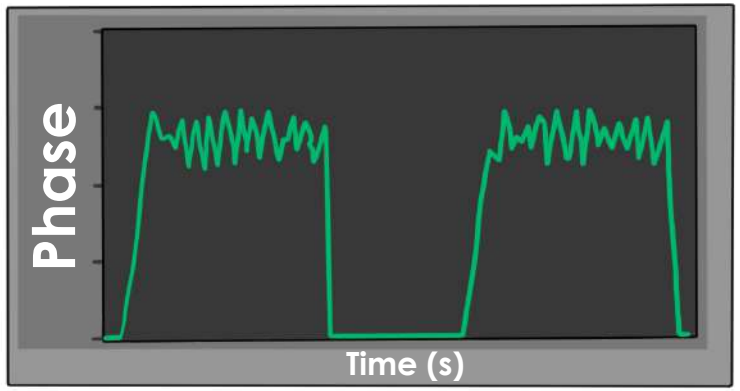


Foil placed in water for 10 seconds

Variable Frequency Modulation

Multifrequency Multimode Modulation (MMM)

- Phase Locked Loop (PLL)
  - Negative feedback loop: f
- Pulse Width Modulation (PWM)
  - Acoustic power control



Combine PWM & PLL to monitor power delivery

Outline

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Big Picture: Experimental Plan

Degassing

1. *Performance review: Fixed and Variable ƒ UST degassing*

Oxide Refiners/Grain Refinement

2. *Treatment temperature: liquid or some fraction solid*

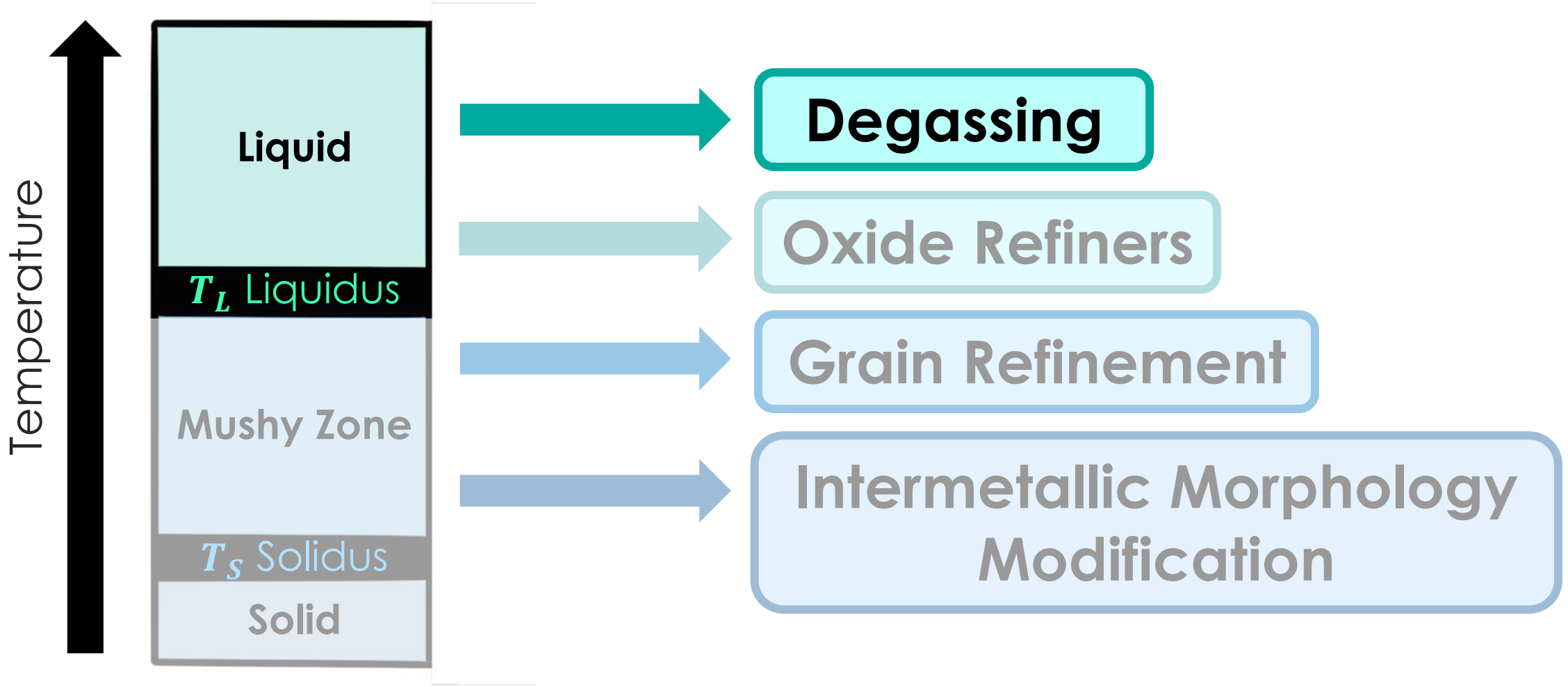
3. *Oxide content for UST grain refinement during liquid state*

Intermetallic Modification

4. *Variable frequency equipment parameters*

5. *Treatment temperature: liquid & some fraction solid*

UST Applications



Experimental Procedure

Practice each degassing method in the foundry furnace

Traditional Rotary Degasser | **Variable f UST** | **Fixed f UST**

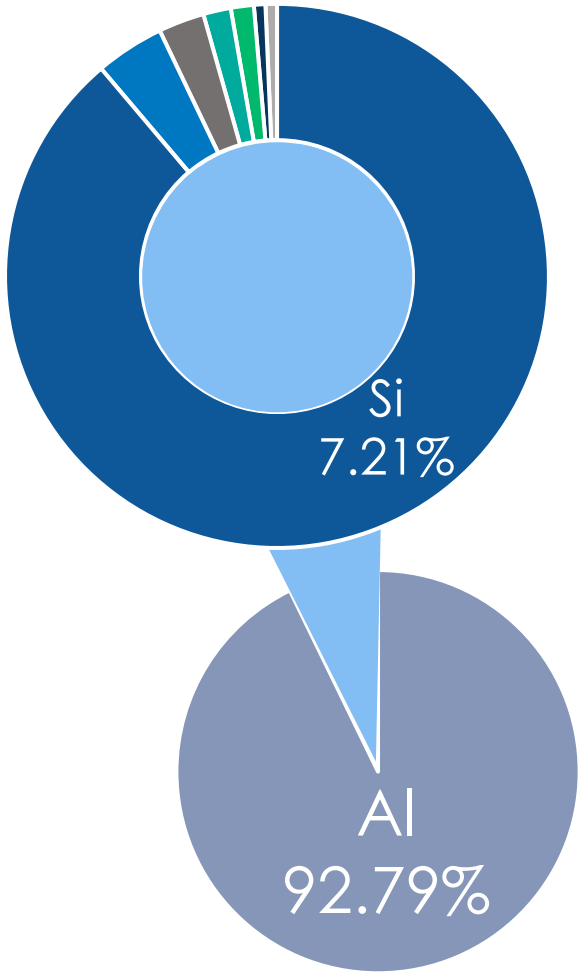
- Determine equipment capabilities, develop procedures
  - Parameters:

All	Ultrasonics	Purging
✓ Temperature ✓ Time	✓ Frequency ✓ Power	✓ Gas flow rate

Examine preliminary data, proceed from there

Starting Material

Composition



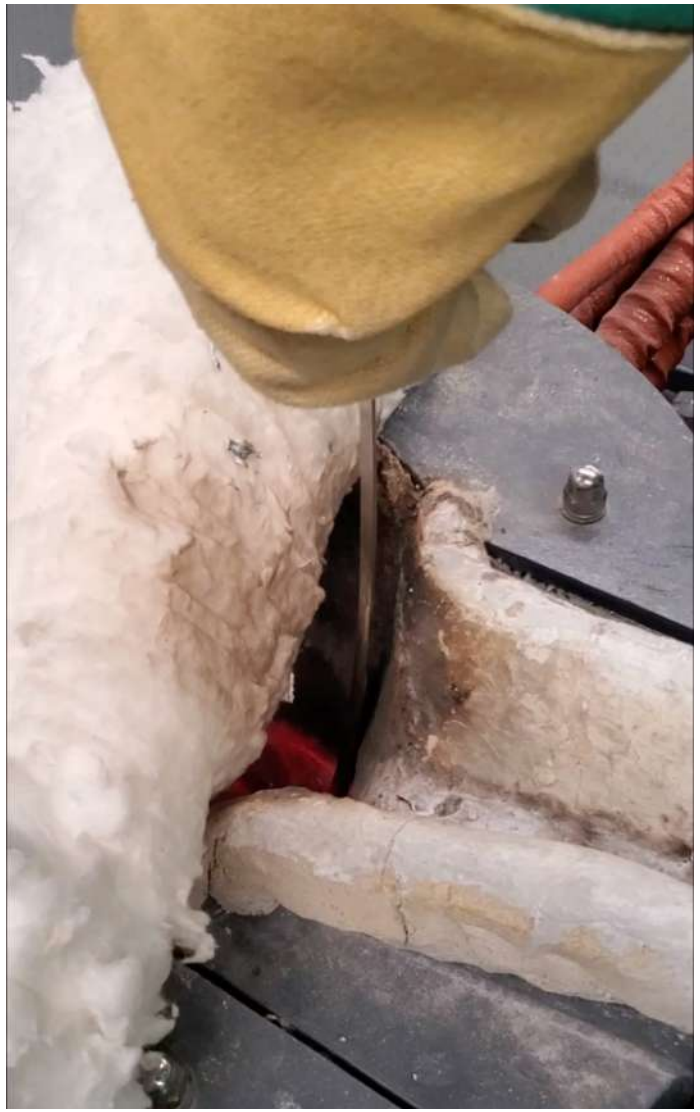
	wt %
Si	7.210
Mg	0.297
Ti	0.112
Fe	0.112
Cu	0.003
Zn	0.010
Mn	0.007

A356.2

✓63 ± 1 lbs
✓Upgassed

Upgassing

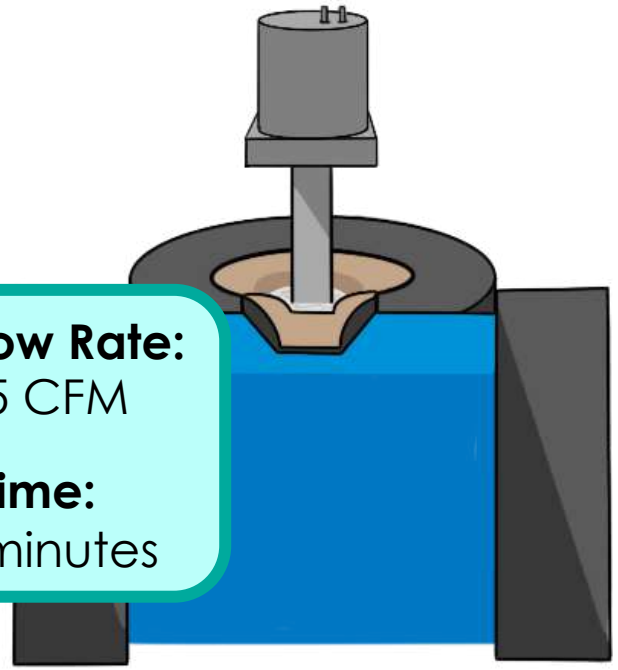
Hydrogen Addition
✓½ Potato
✓~ 200 grams



Degassing Procedures

Treatment Temperature: 710 ± 2 °C

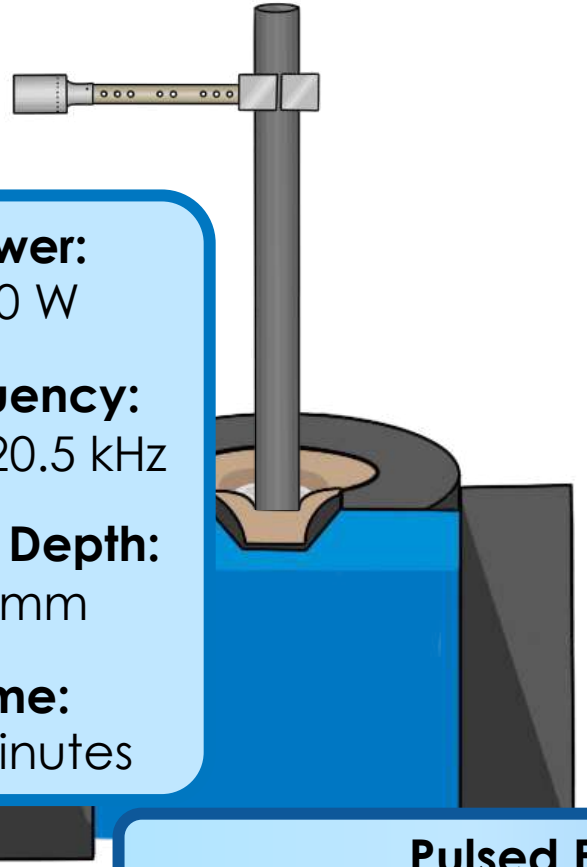
Traditional Rotary Degasser



Ar Flow Rate:
0.5 CFM

Time:
15 minutes

Variable *f* UST



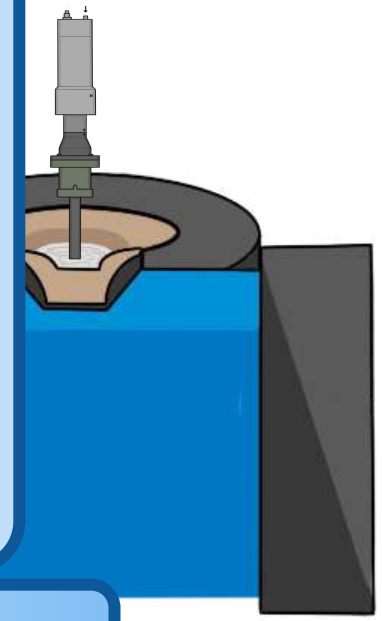
Power:
200 W

Frequency:
Main 20.5 kHz

Probe Depth:
80 mm

Time:
10 minutes

Fixed *f* UST



Ar Flow Rate:
CFM

Power:
1500W, 60% A

Frequency:
20 kHz

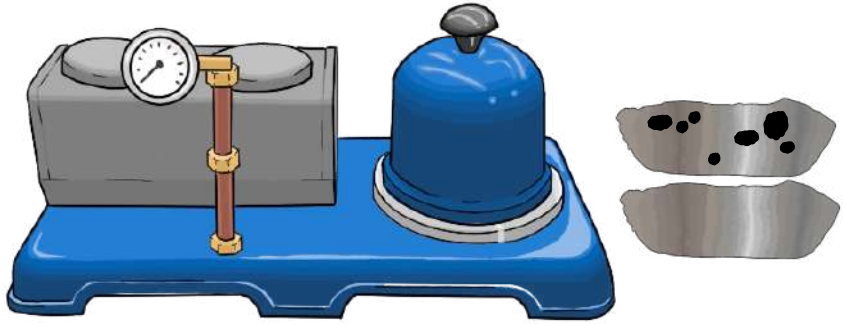
Probe Depth:
10 mm

Time:
10 minutes

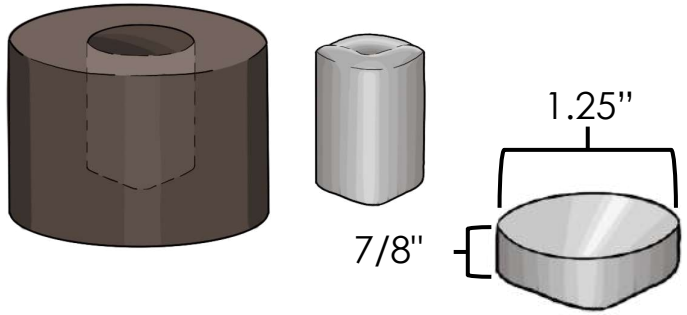
Pulsed Frequency:
On 5 seconds, Off 3 seconds

Data Outcomes

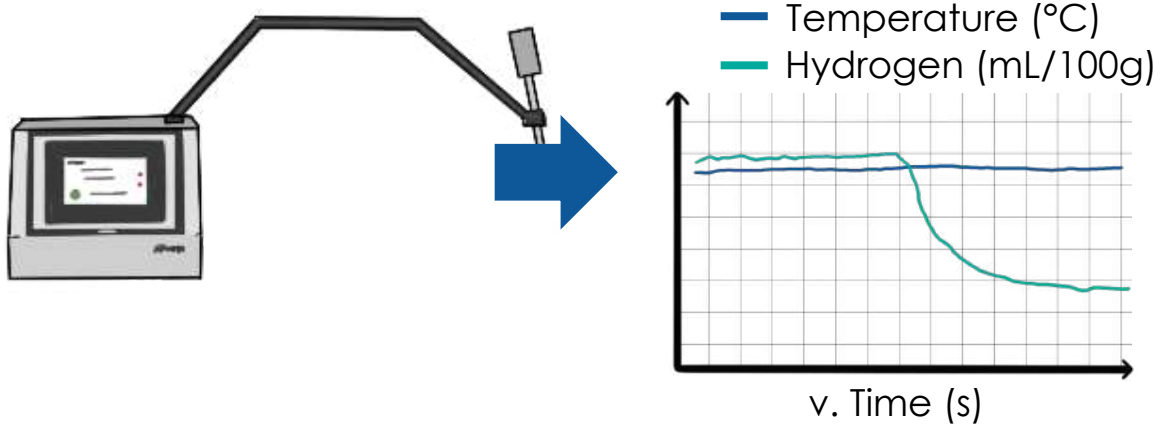
Reduced Pressure Test (RPT)



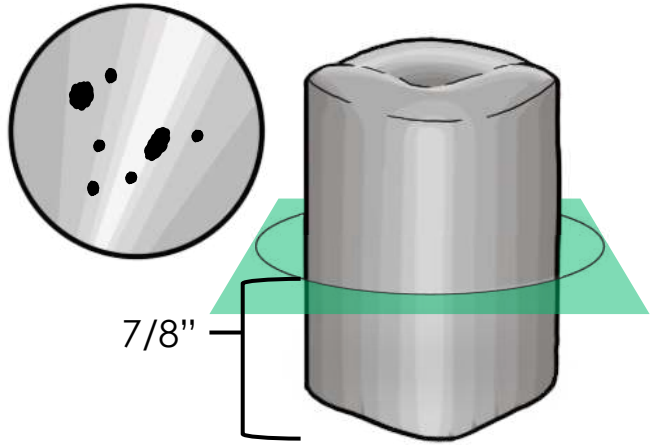
Universal Casting



In-Melt Hydrogen Analyzer



CT Scan & Porosity



Variable f UST Setup

Fixed f UST Setup

Fixed f Issues

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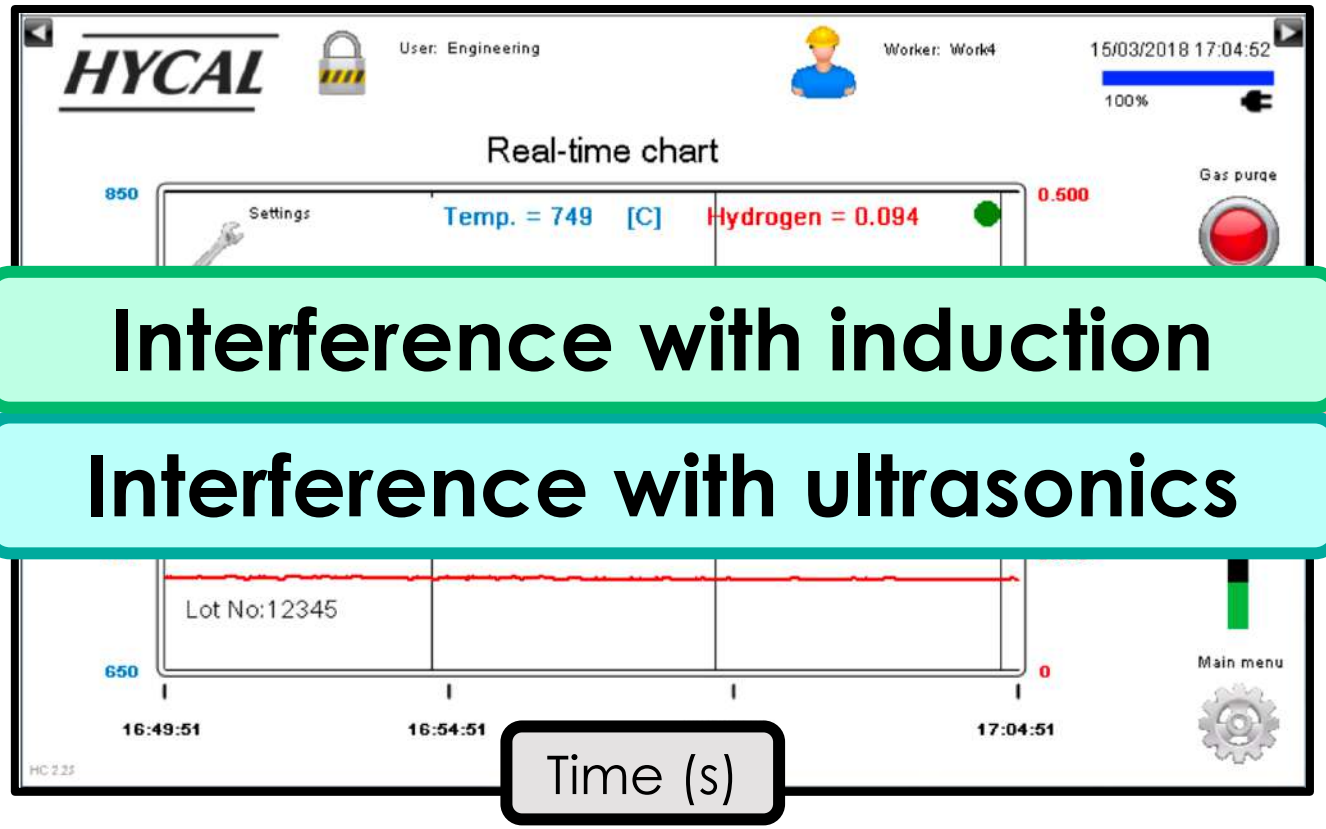
HYCAL: Hydrogen Content Data

Hydrogen Content Analysis



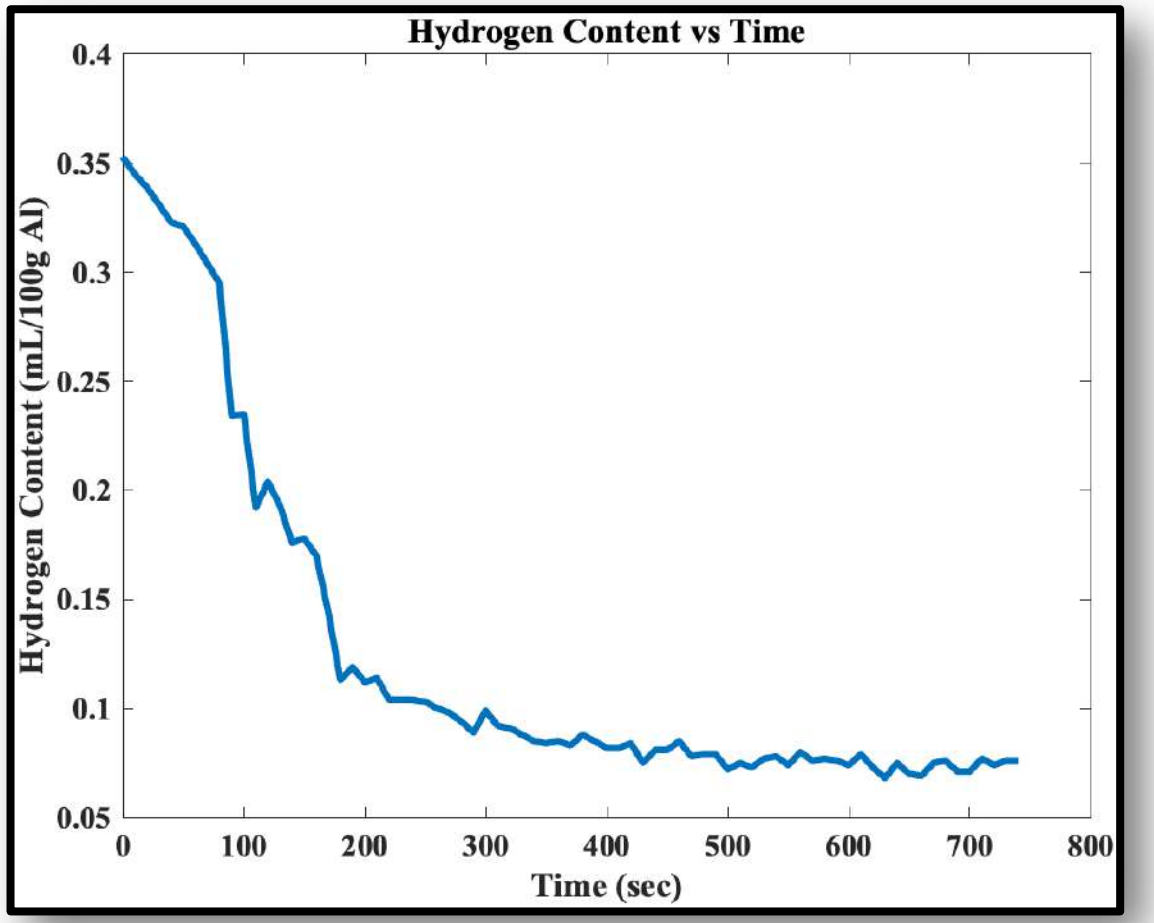
Interference with induction

Interference with ultrasonics

Photos Courtesy EMC Hycal

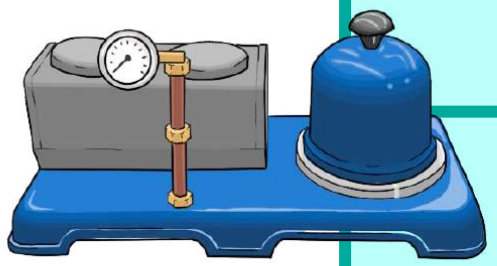
HYCAL: Live Hydrogen Content

Traditional Rotary Degasser



Hydrogen Content	
0 minutes	0.3530 mL/100g
15 minutes	0.0736 mL/100g

RPT: Hydrogen Visualization



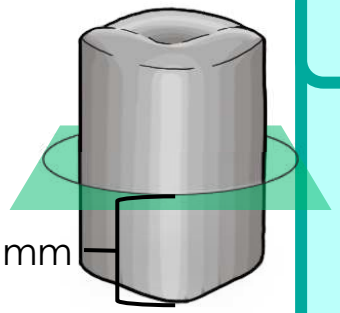
Rotary

Treatment: (15 min)

Variable f

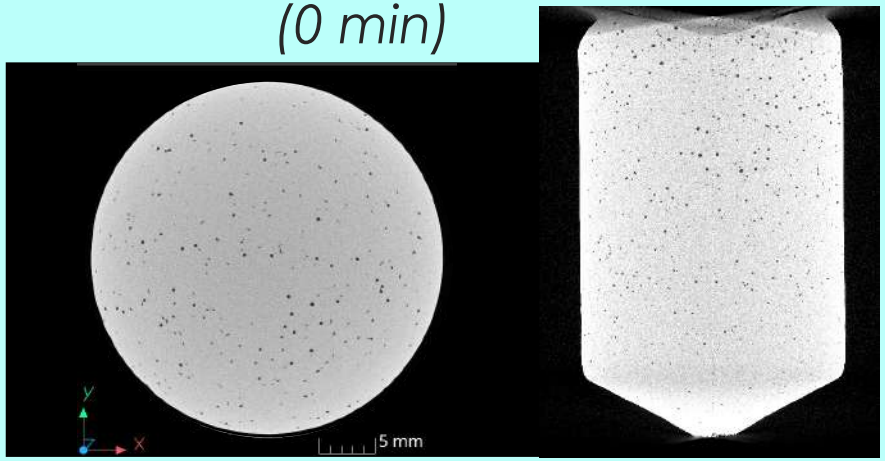
Treatment: (10 min)

CT Scan: Porosity Distribution

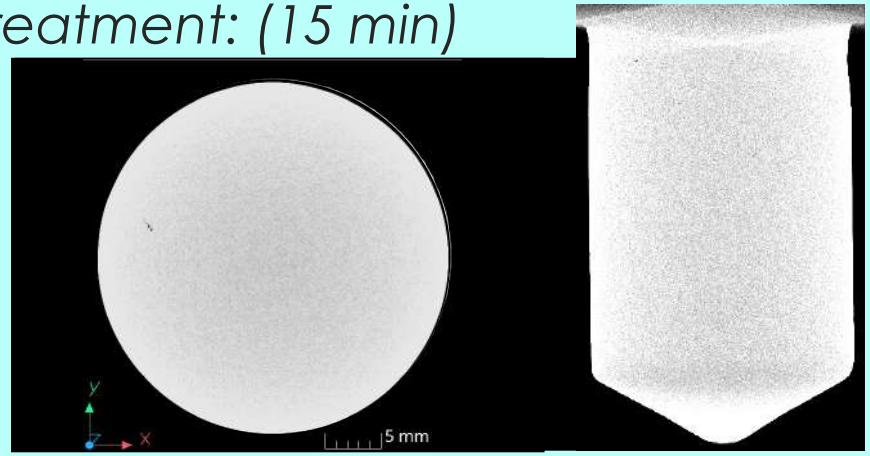


Rotary

(0 min)

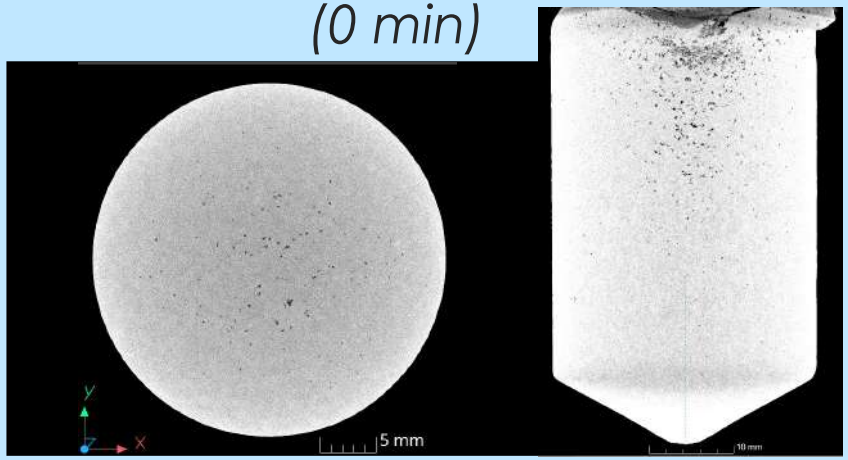


Treatment: (15 min)

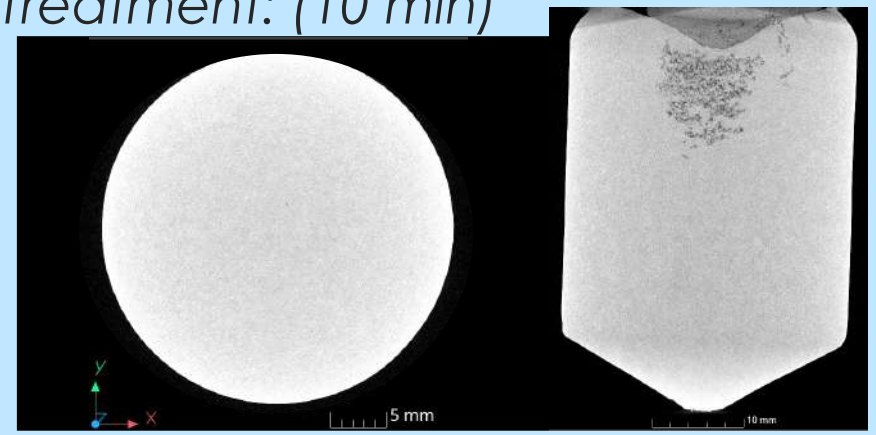


Variable *f*

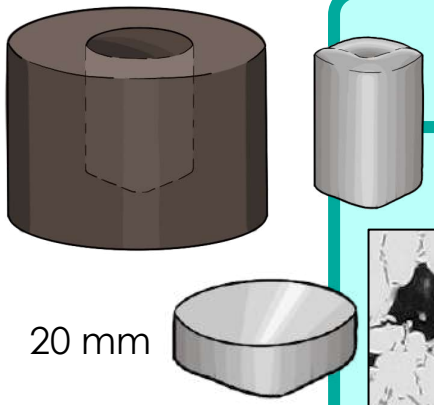
(0 min)



Treatment: (10 min)

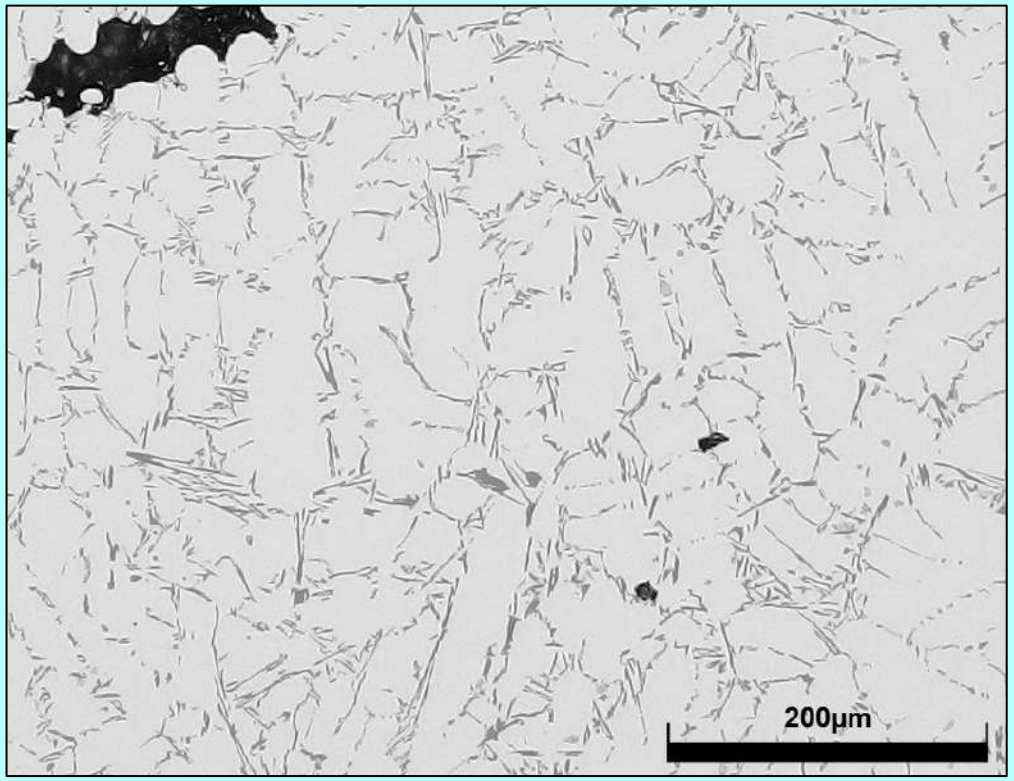


Grain Refinement Preliminary Data



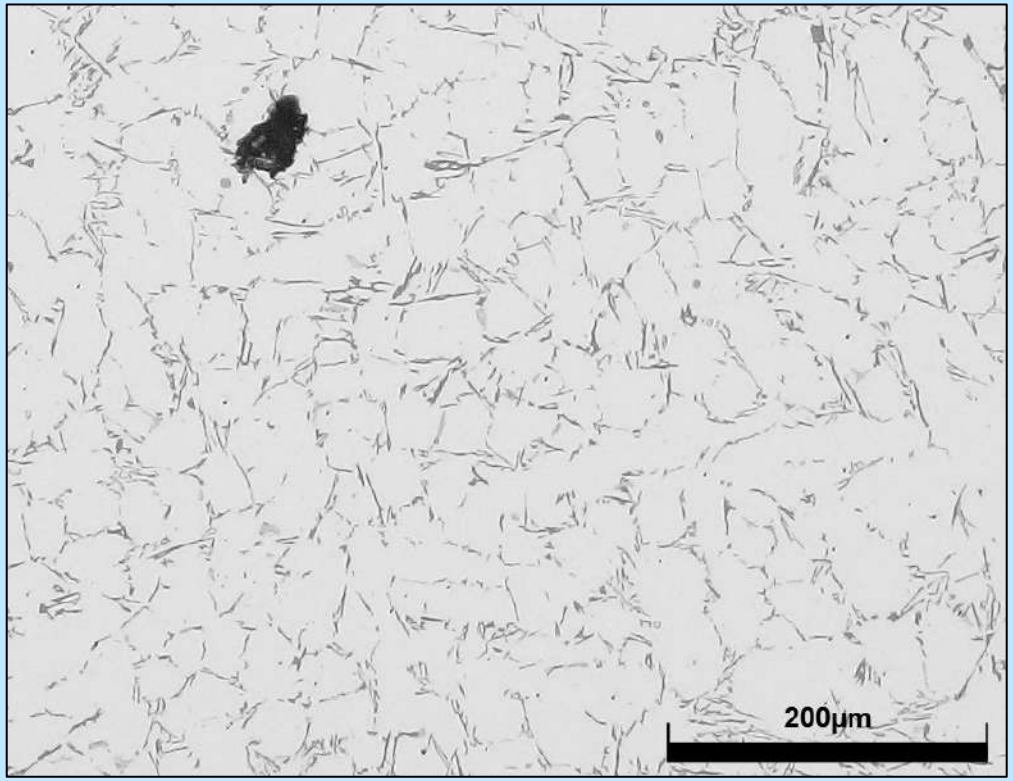
No Treatment

(0 min)

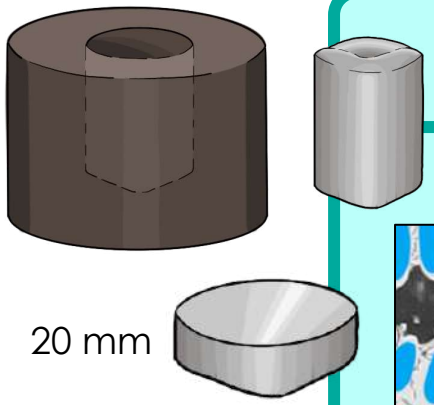


Variable *f*

Treatment: (10 min)

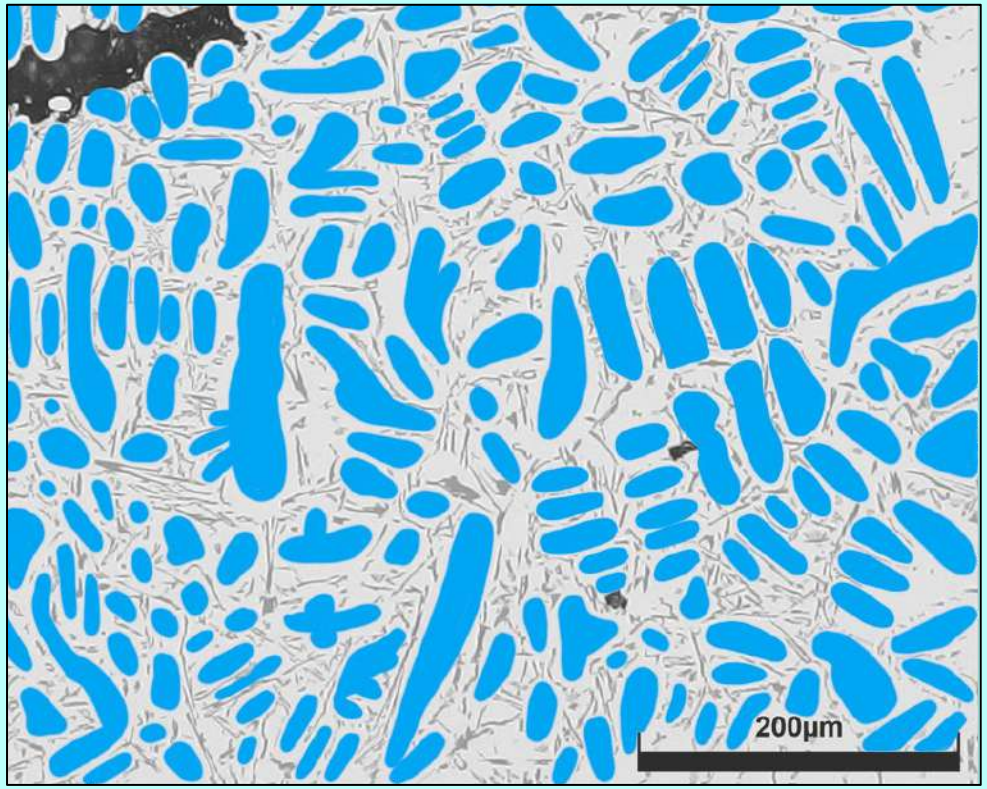


Grain Refinement Preliminary Data



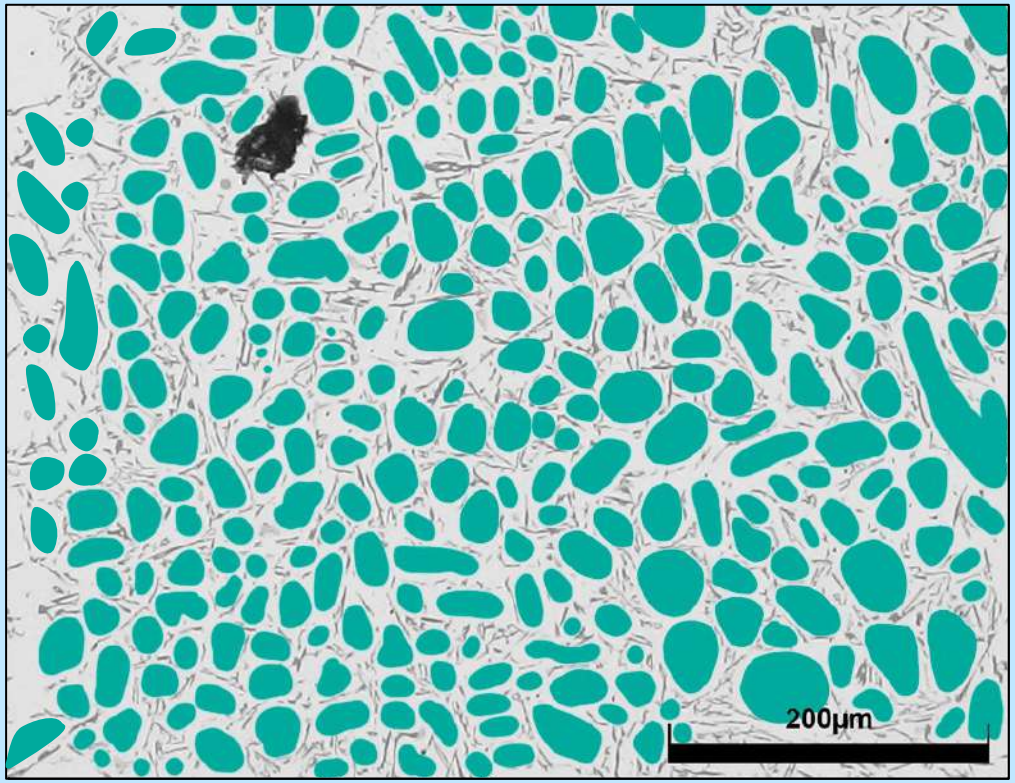
No Treatment

(0 min)



Variable *f*

Treatment: (10 min)



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Degassing Performance Review

HYCAL

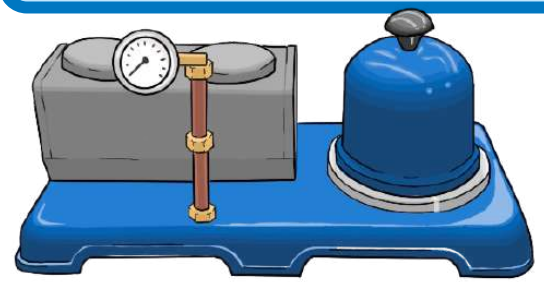
- Troubleshooting *HYCAL + Ultrasound + Induction*

Fixed f

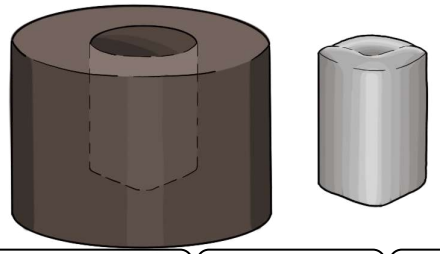
- Small reactor alternative to furnace

Data Collection

1)



2)



Microstructure | Density | CT Data

ELTRA oxide analysis

3) Tensile Data, Fracture Surface

4) Dross Comparison

5) Hydrogen Analysis

ACRC Ultrasonic Project

Points of Discussion

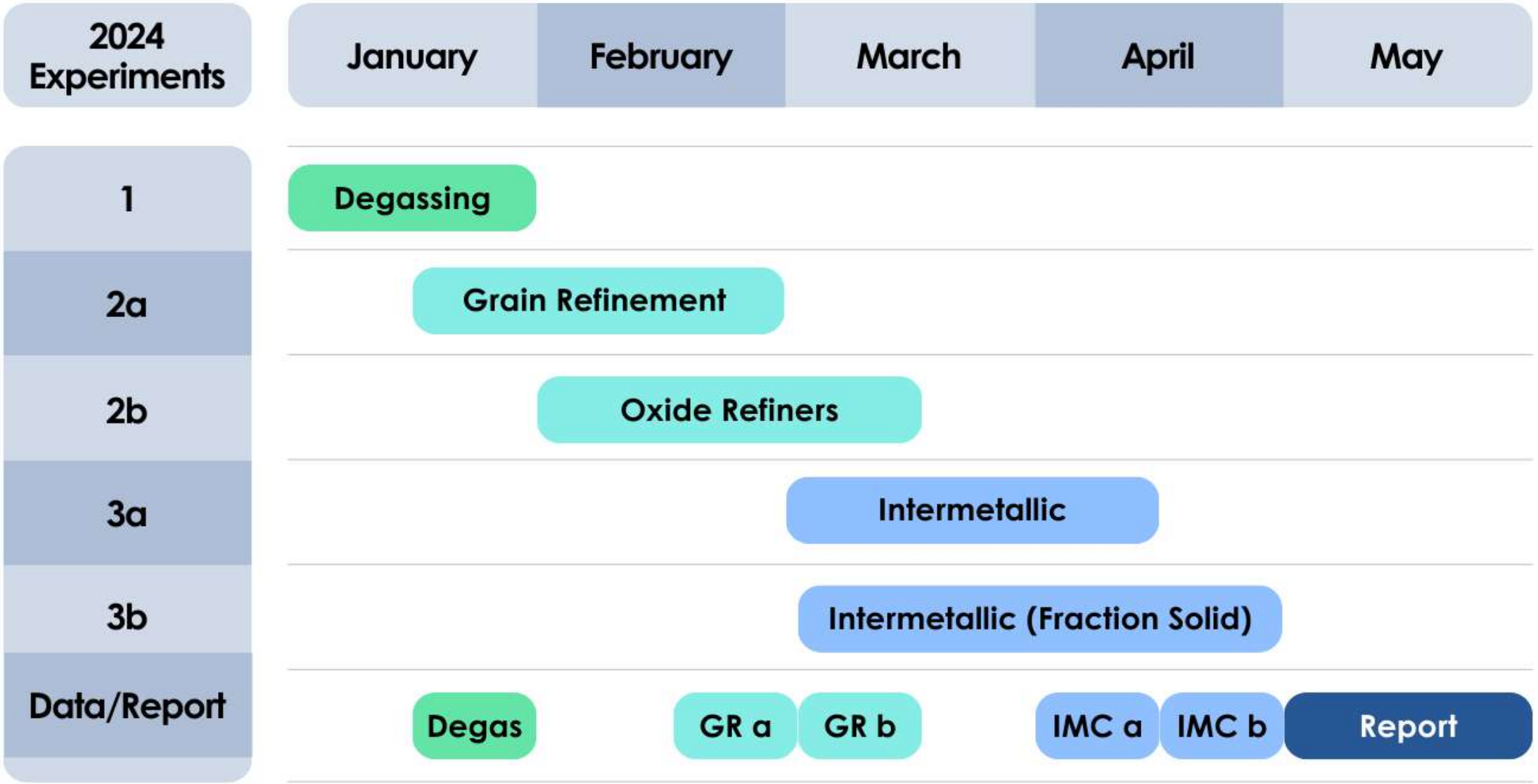
1. **Generating quantitative data for degassing**
   - Hydrogen content - *HYCAL*
   - Oxide/Inclusion content

2. **Upgassing**
   - Necessary for visual results in degassing

3. **Troubleshooting equipment**

4. **Questions for future experiments**
   - Treatment with some fraction solid
   - Grain refinement, oxide refiners
   - Intermetallic morphology modification

Timeline



Acknowledgements

Thank you!

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