Pacific Northwest
NATIONAL LABORATORY

Ultrasonically-Induced Microstructural Refinement to Improve Strength of an Al-Si-Mg Casting

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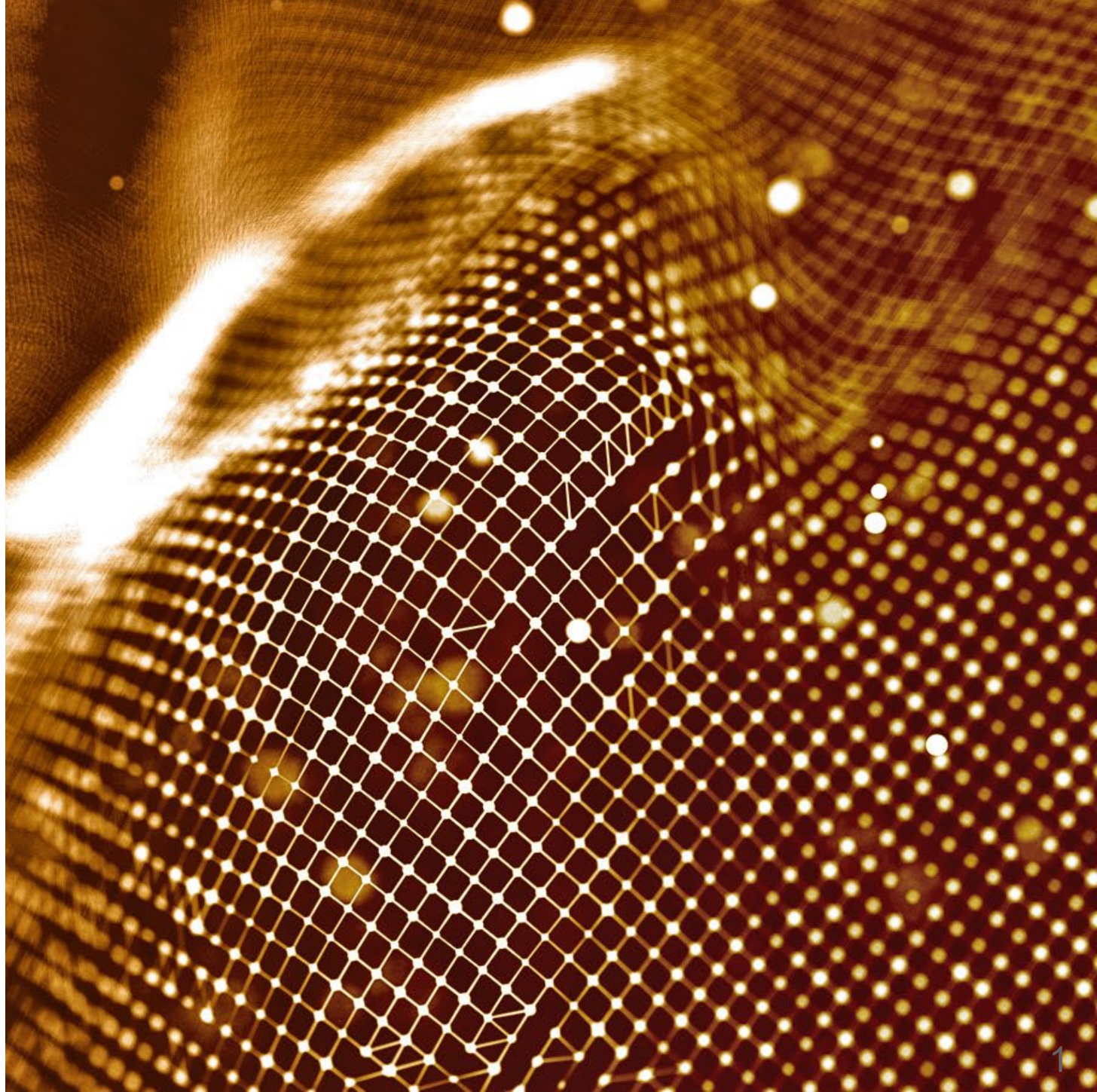
Katherine Rader, Jens Darsell, Jon Helgeland, Nathan Canfield, and Aashish Rohatgi (project PI)



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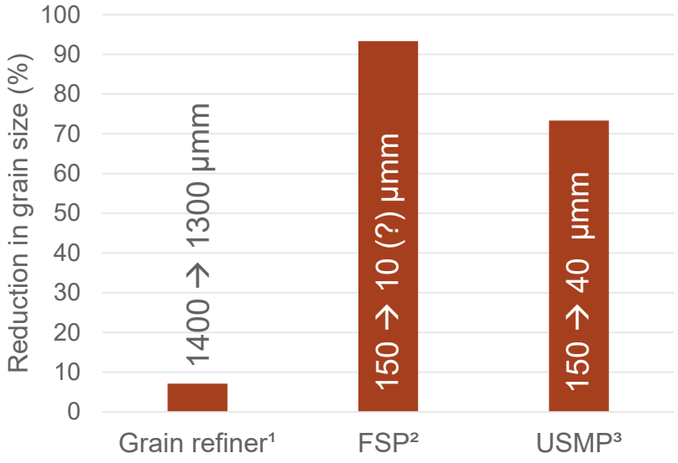
Lightweight Metals Core Program

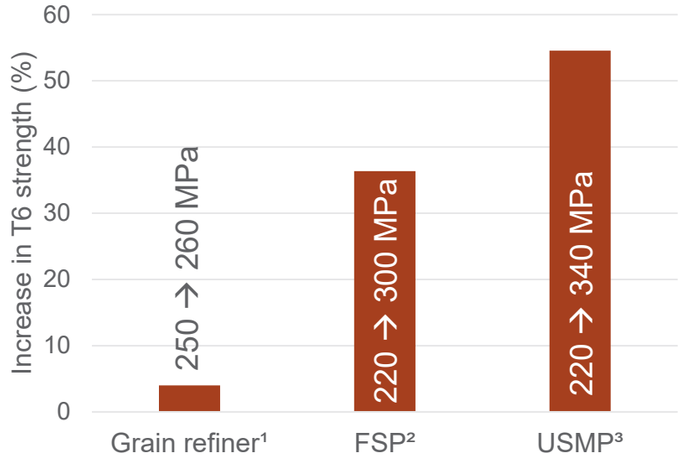
- Funded by the Department of Energy Vehicle Technologies Office
  - Collaboration between multiple DOE labs

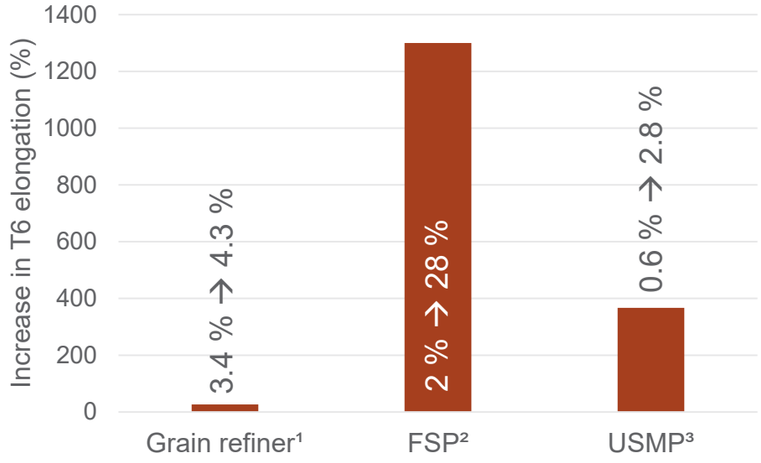
- Objective: Selective processing of lightweight metals
  - Local modification → Satisfy varying property requirements at different locations
  - “Put the right property in the right place”

Motivation

- Cast aluminum alloys typically have poor mechanical properties
  - Large, dendritic grains
  - Porosity
  - Heterogeneity
- Ultrasonic melt processing: transform dendritic grains → globular grains
  - Enhanced nucleation and fracture of dendrites
  - Higher strength and increased ductility



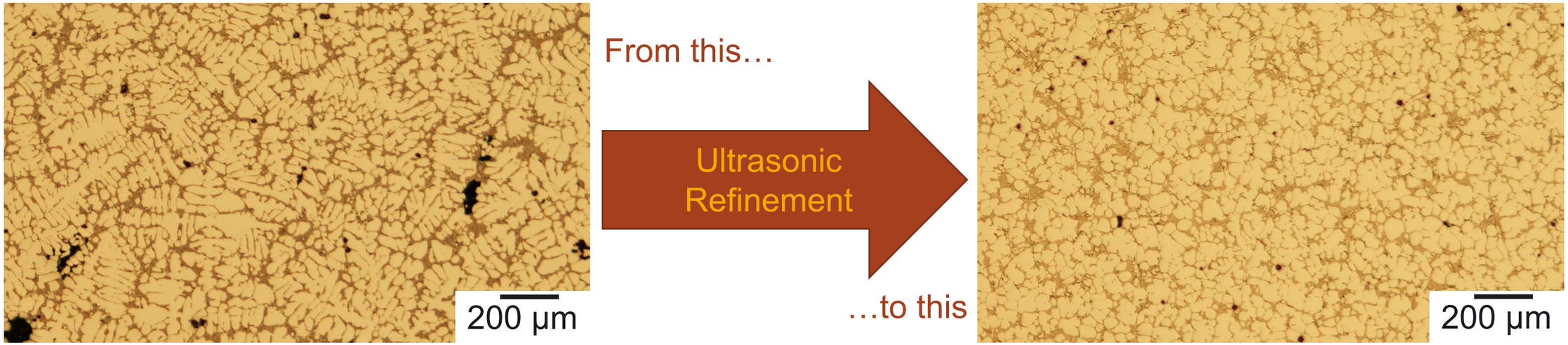




[1] L. Yu *et al*. 2005. *J. Mater. Sci.*, 40, p. 3865-3867 [2] Z. Y. Ma *et al*. 2006. *Metall. Mater. Trans. A*, 37, p. 3323-3336.
[3] H. Puga *et al.* 2013. *Mater. Sci. Engr. A*, 560, p. 589-595.

Local Ultrasonic Intensification

- Apply local ultrasonic intensification to aluminum during casting as it is solidifying in the mold
  - Target ultrasonically-induced refinement to key locations
- How is this different from other grain refining technologies?
  - No chemical additions or additional post-processing steps
  - Ultrasound applied via a probe in the mold

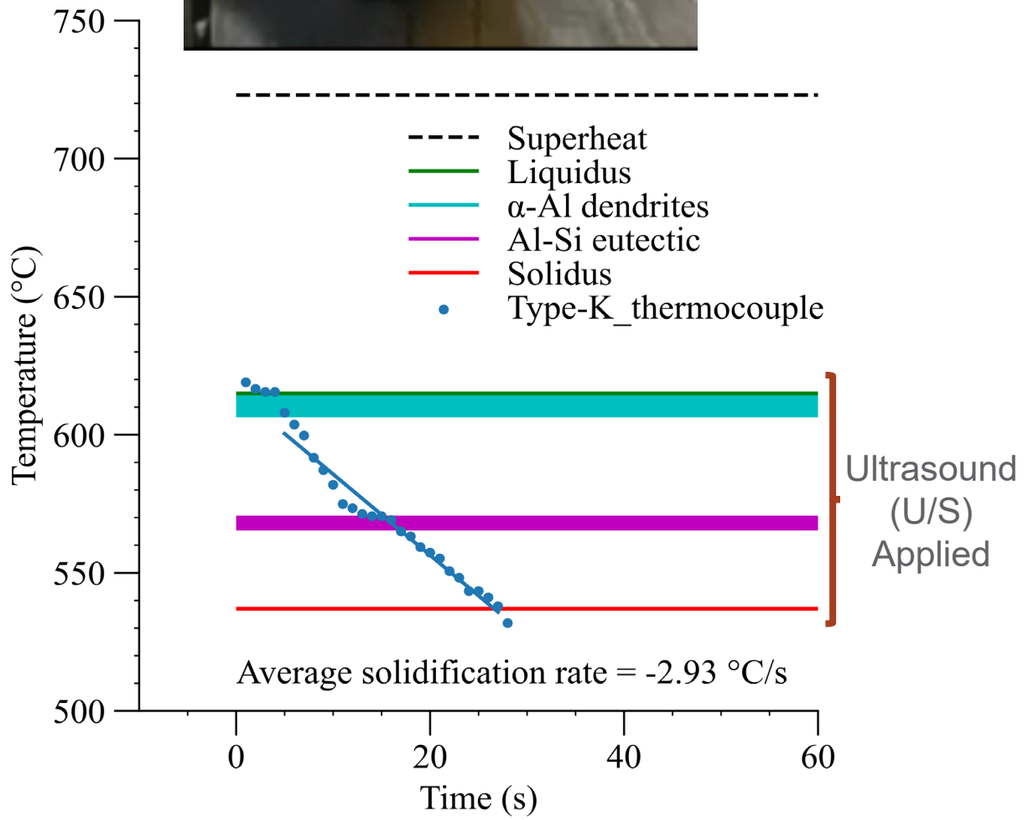


Casting Experiments

- Material: A356 aluminum alloy + Fe
  - Composition in wt. %:

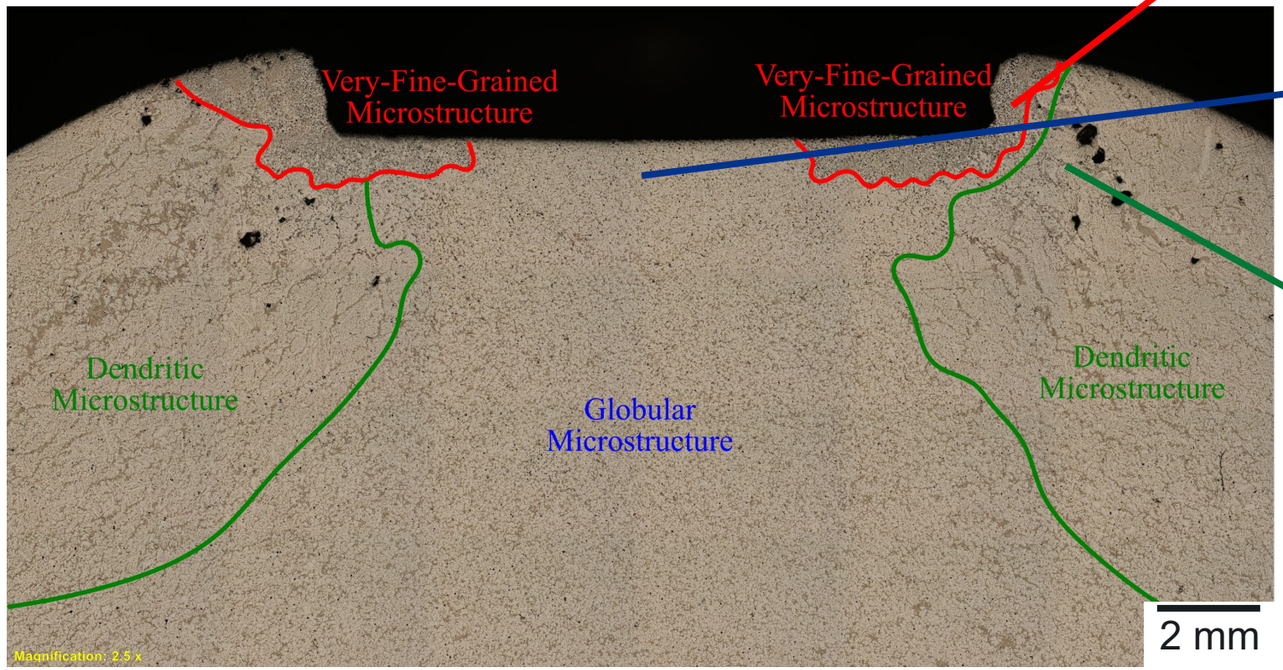
Al	Si	Mg	Fe
91.8	6.78	0.35	0.91

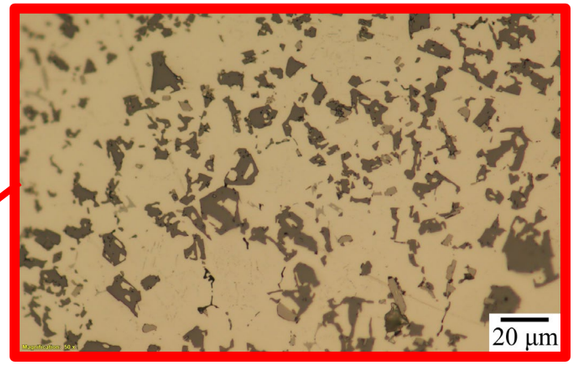
- 200 g of aluminum cast in a graphite mold
  - Simulate cooling rates of permanent mold casting techniques
- Ultrasound was applied to the aluminum as it cooled and solidified in the mold
  - 13-mm-diameter Ti6Al4V probe
  - Frequency of ultrasound = 20 kHz

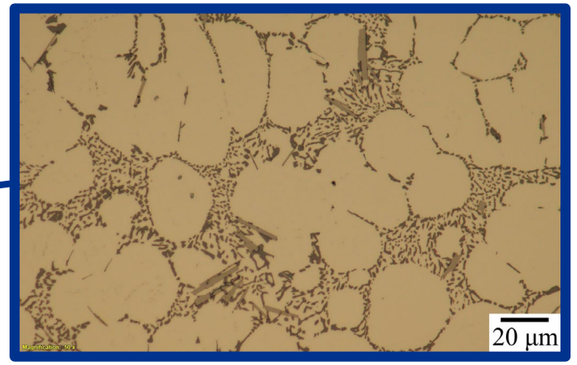


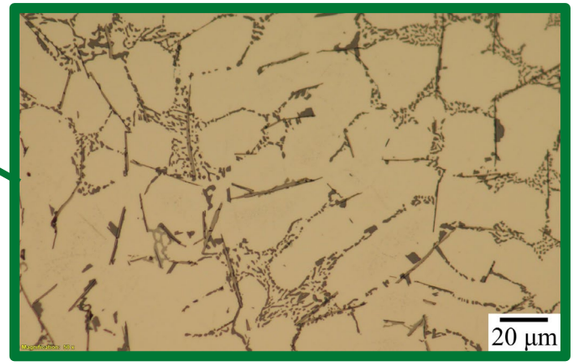
As-Cast Microstructure with Ultrasound

- Casting without ultrasound → dendritic morphology
- Casting with ultrasound → 3 morphologies
  - Very-fine-grained
  - Globular microstructure
  - Dendritic microstructure

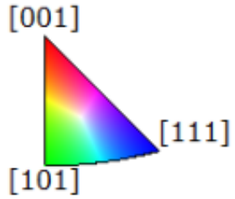




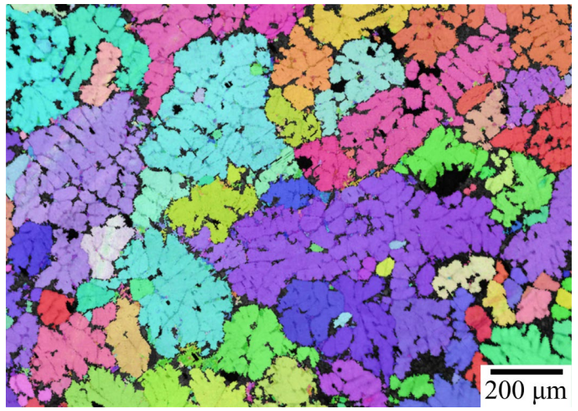




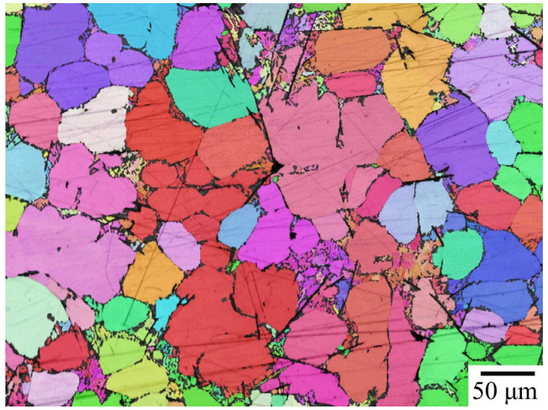
Ultrasonically-Induced Refinement: Primary Aluminum Grains



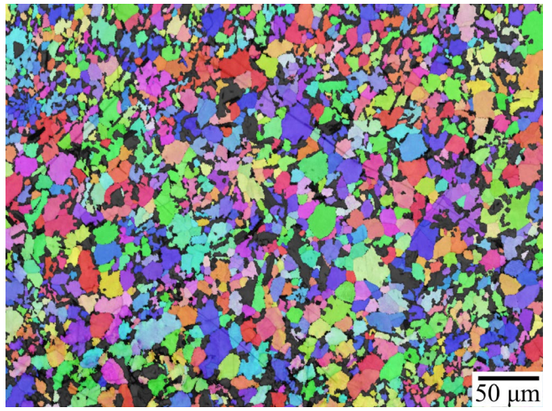
No Ultrasound



With Ultrasound



With Ultrasound

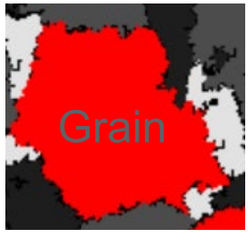


	Dendritic Morphology	Globular Morphology	Very-Fine-Grained Morphology
Equivalent Grain Size (µm)	140	36	9.3
Sphericity	0.39	0.48	0.56
Aspect Ratio	1.8	1.5	1.8

$$\text{Equivalent Grain Size} = \sqrt{4A/\pi}$$

(*i.e.,* Grain diameter if it was a perfect circle)

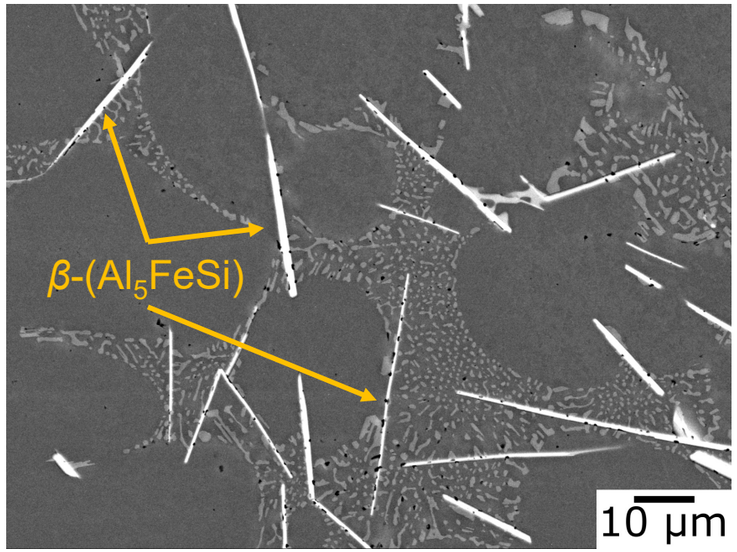
A = Grain area



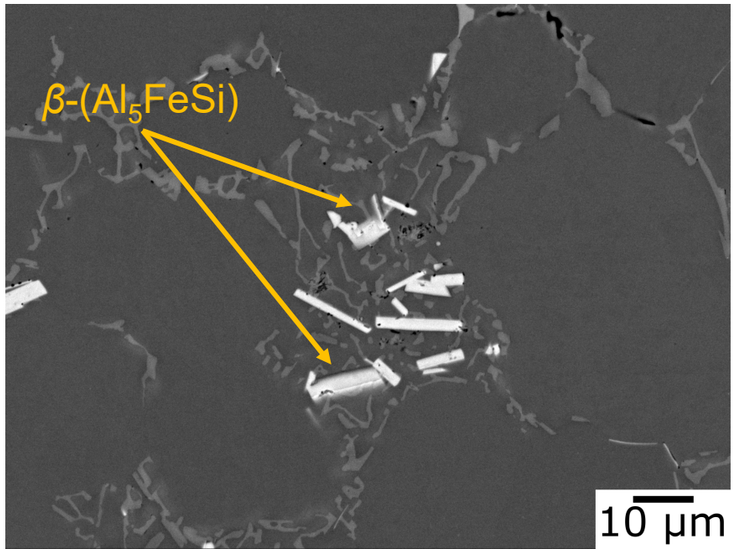
Ultrasonically-induced grain refinement is equivalent to or better than other grain refining methods without the need for chemistry modification or post-processing steps.

Ultrasonically-Induced Refinement: Brittle Intermetallic Phase (β-Al_5FeSi)

No Ultrasound



With Ultrasound

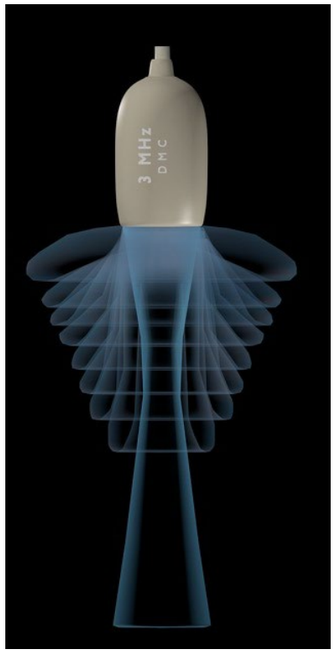


	Needle-Shaped Morphology	Rectangular Morphology
Equivalent Grain Size (µm)	3.3	2.5
Sphericity	0.16	0.27
Aspect Ratio	14	5.7

Ultrasound may enable greater use of secondary Al alloys by reducing aspect ratio of brittle intermetallics, thereby potentially improving the mechanical performance of the casting.

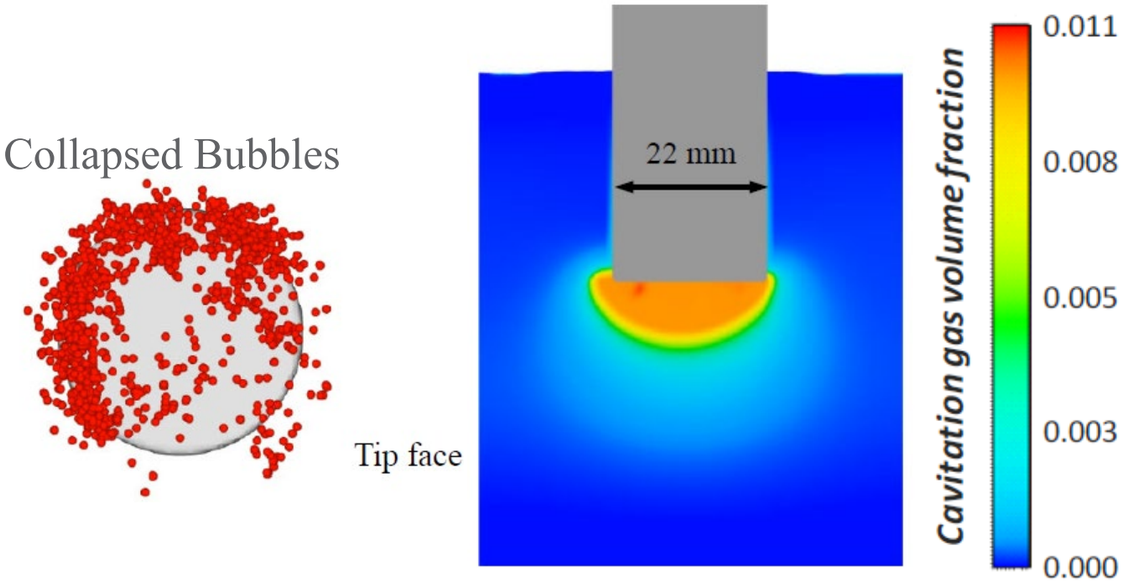
Potential Mechanisms for Very-Fine-Grained Morphology

- Increased concentration of collapsing cavitation bubbles
  - Increased pressure near outer circumference of ultrasound probe tip face
  - Enhanced nucleation
- Side lobes of ultrasound probe
  - Enhanced mixing



Note: Not to scale

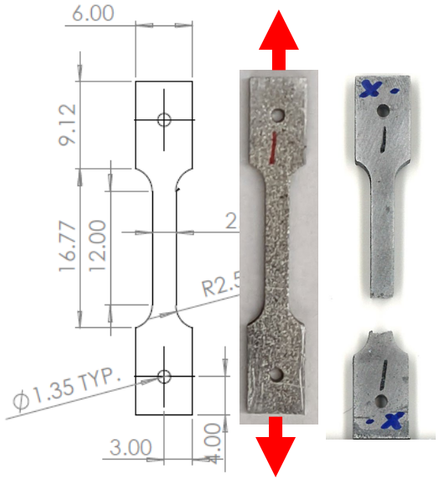
Image from McGrath & Murphy (2022) *Radiopaedia.org* https://doi.org/10.53347/rID-47372

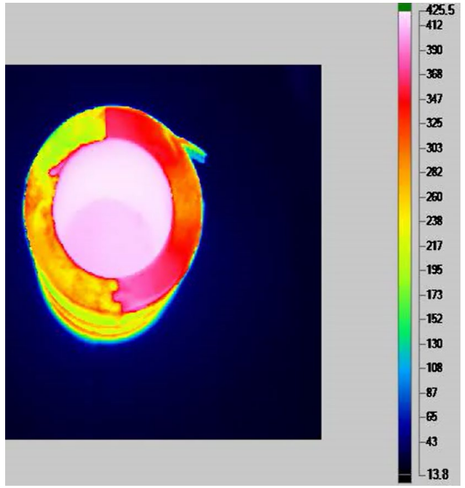


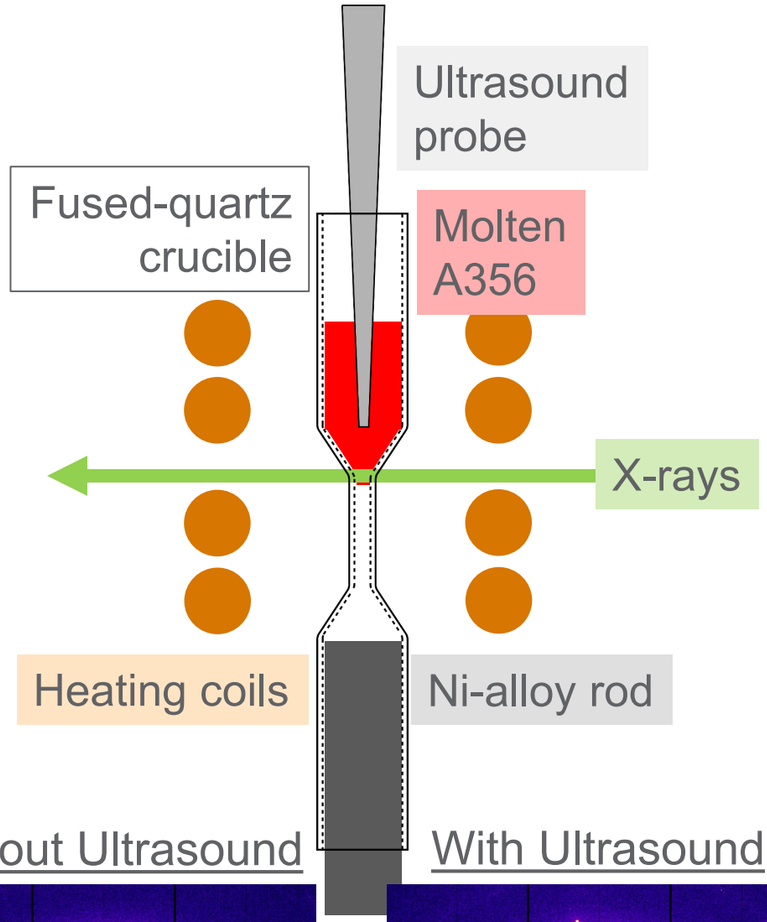
Images from Riedel et al. (2020) *Metals* 10(47): 1-22

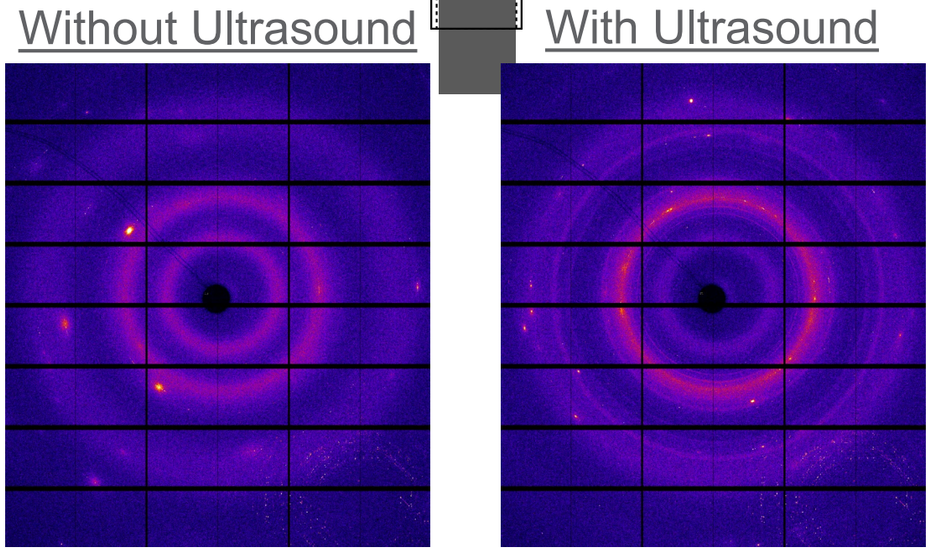
Ongoing Work

- Mechanical testing
- Demonstrate local ultrasonic intensification during casting in a preheated steel mold
- In-situ solidification experiments at the Advanced Photon Source
  - Conducted in-situ diffraction and radiography experiments at beamlines 1-ID-E and 32-ID-B









Conclusions

- Casting with the application of local ultrasonic intensification produced non-dendritic microstructures with two distinct morphologies: (1) globular grains, and (2) very-fine grains
- The primary aluminum grains of the globular morphology are 74 % finer than the dendritic grains of the control casting.
- The primary aluminum grains of the very-fine-grained microstructure are 93 % finer than the dendritic grains of the control casting.
- The application of local ultrasonic intensification during casting changed the morphology of β-Al_5FeSi phase particles from needle-shaped to rectangular without changing the mean equivalent grain size.

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Thank you

Katherine Rader: Katherine.Rader@pnnl.gov
Aashish Rohatgi: Aashish.Rohatgi@pnnl.gov