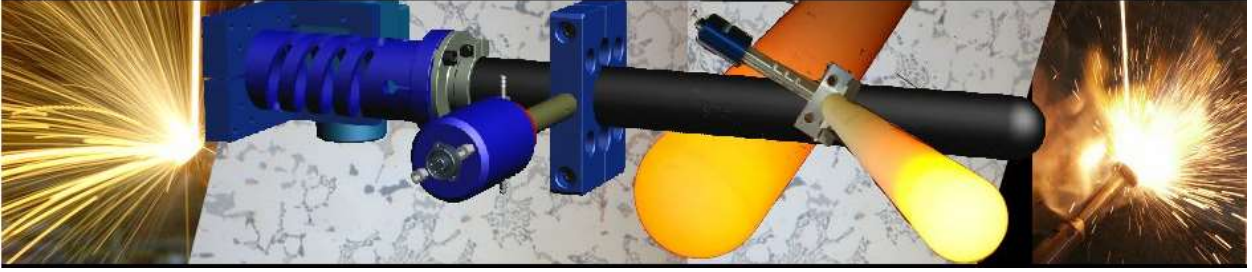

Ultrasonic vibrations in metallurgy…

with **MMM** Technology

Degassing of Al and Mg alloys

Grain refinement of Al and Mg alloys

Prepared by Hélder Puga and Miodrag Prokic

June 2022

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Patent

European Patent Application (related to MMM technology): EP 1 238 715 A1. Multifrequency ultrasonic structural actuator
Applicant**: Prokic Miodrag**, MP Interconsulting, 5.03.2001 – 11.09.2002

…summary

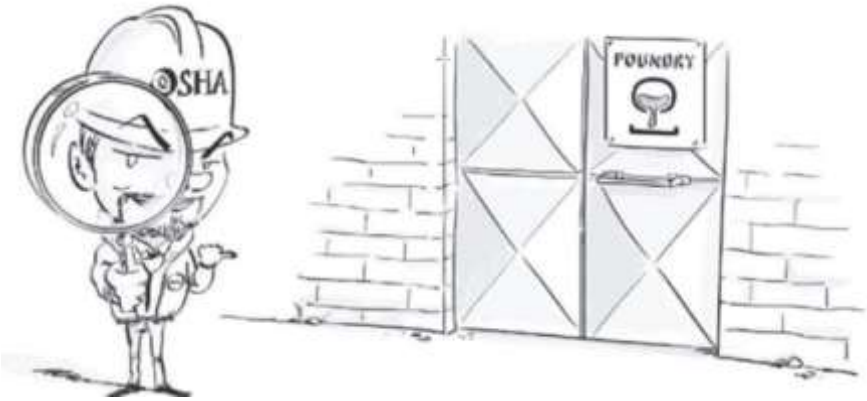
1. ***MMM technology what is it?***

2. ***Basic equipment set up in foundry environment***

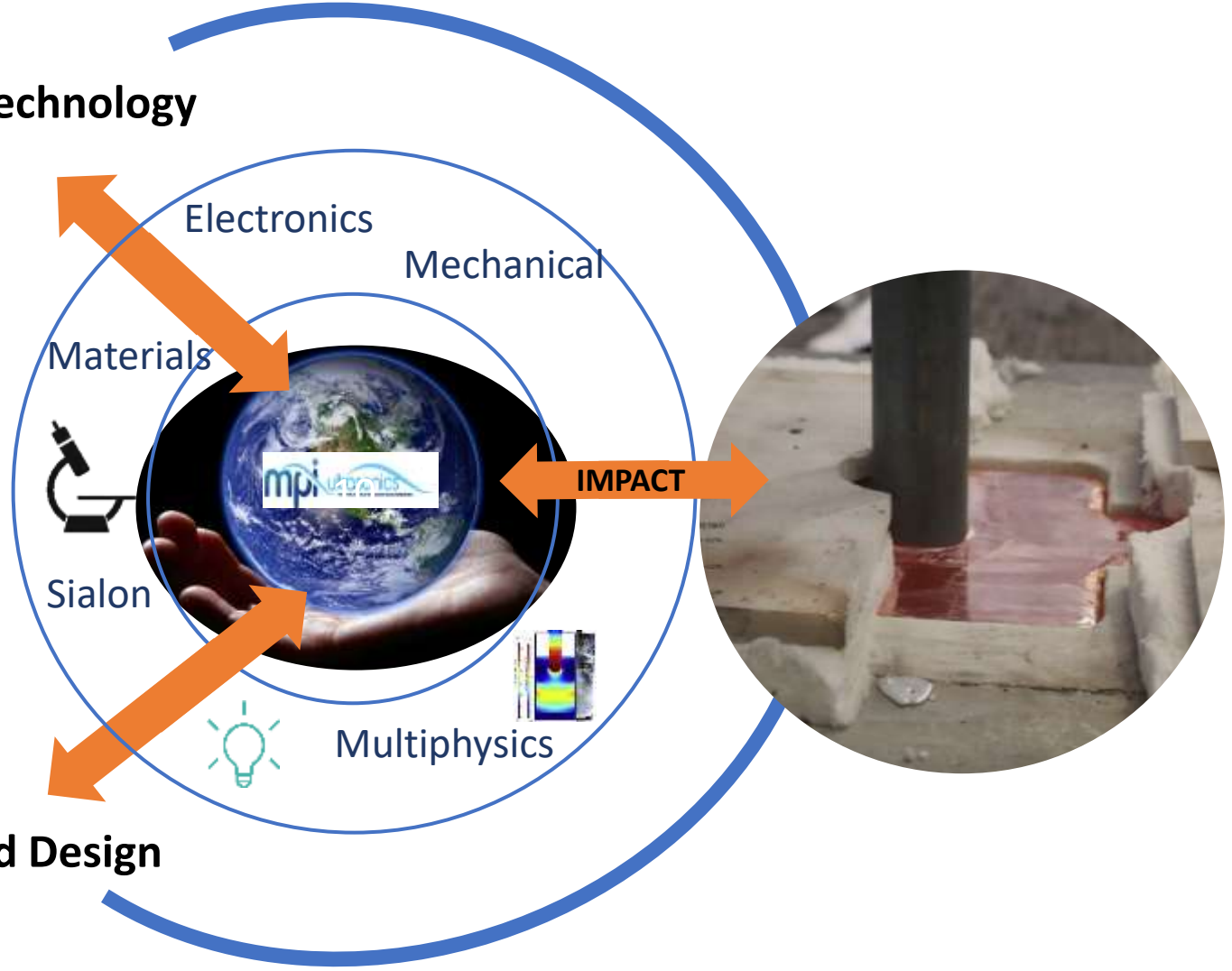
3. ***What have we done with it in Al, Mg and Brass?***

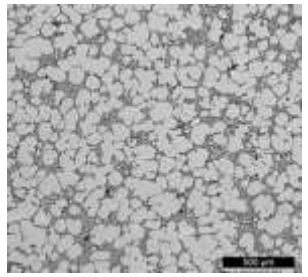
4. ***How is MMM technology different than Southwire's offering***

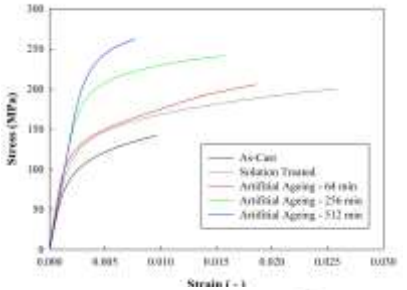
5. ***5th generation of MMM technology and its readiness for industrial application in foundries***



… Ultrasonic vibrations in metallurgy… with MMM Technology





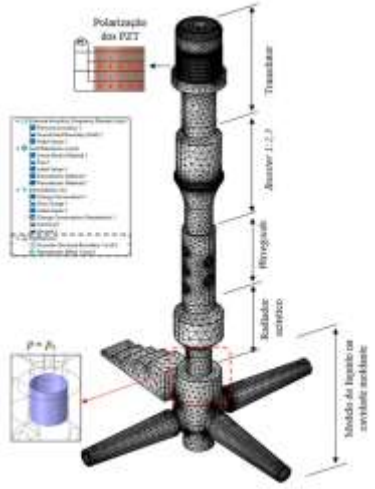


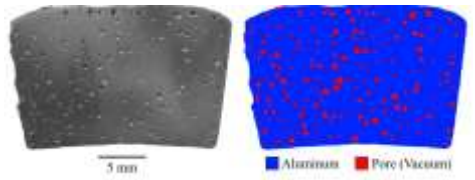
Degassing

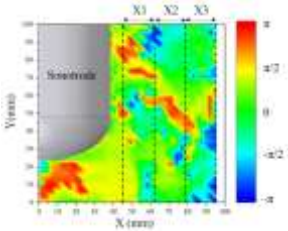
Refining

Modification

Cleanness







… MMM technology what is it?

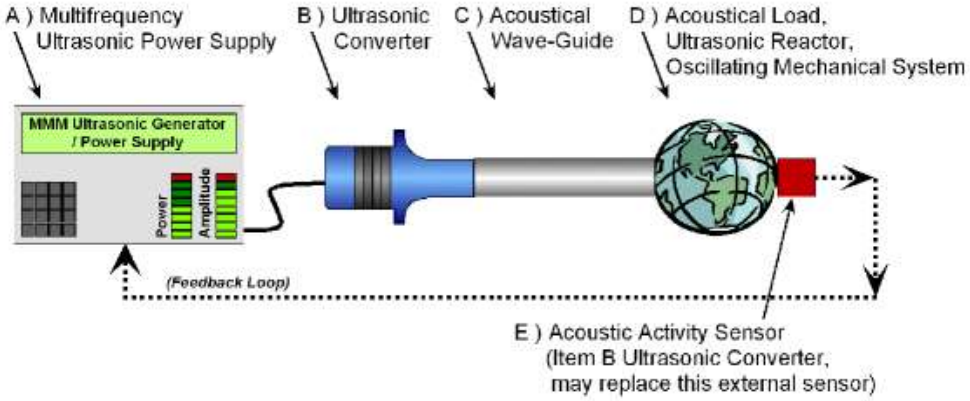
MMM technology (or **M**ultifrequency, **M**ultimode, **M**odulated sonic and ultrasonic agitation) is the methodology how to **vibrate**, almost **spatially uniformly**, **arbitrary shaped masses**, **without creating standing waves**.

We realize **synchronous excitation** of many **resonant modes**, by **modulating operating frequency** and signal amplitude of sonic and ultrasonic waves.

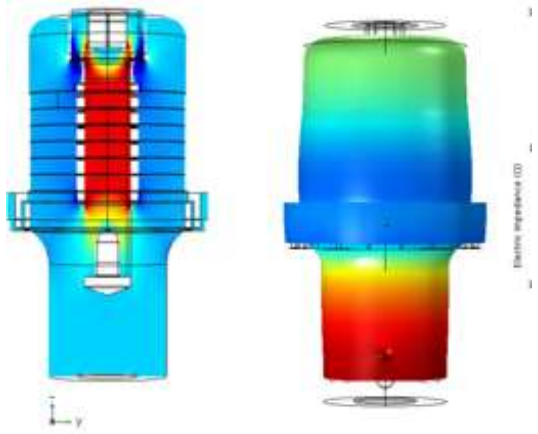
We **create non-stationary**, **repetitive**, **dynamic** and **variable excitation** of different natural resonant modes of certain body (in this case we agitate liquids, or liquid metals).

MMM technology and related equipment design still has its (acoustic, mechanical, or ultrasonic) limits, but anyway there is an exact design and optimization methodology (practiced by MPI) leading to efficient ultrasonic processing tools.

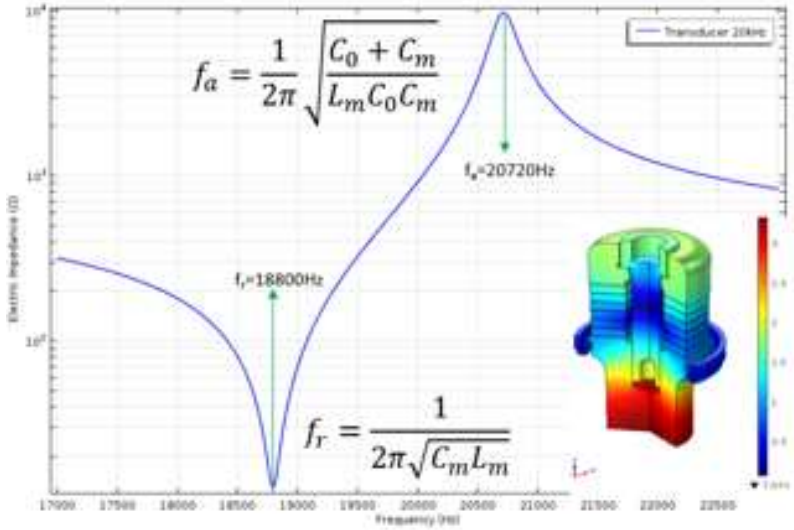
Please, read more about matter waves, oscillations, vibrations … here:
https://mastersonics.com/documents/revision_of_the_particle-wave_dualism.pdf
www.UltrasonicMetallurgy.com
www.MPI-Ultrasonics.com
www.Mastersonics.com



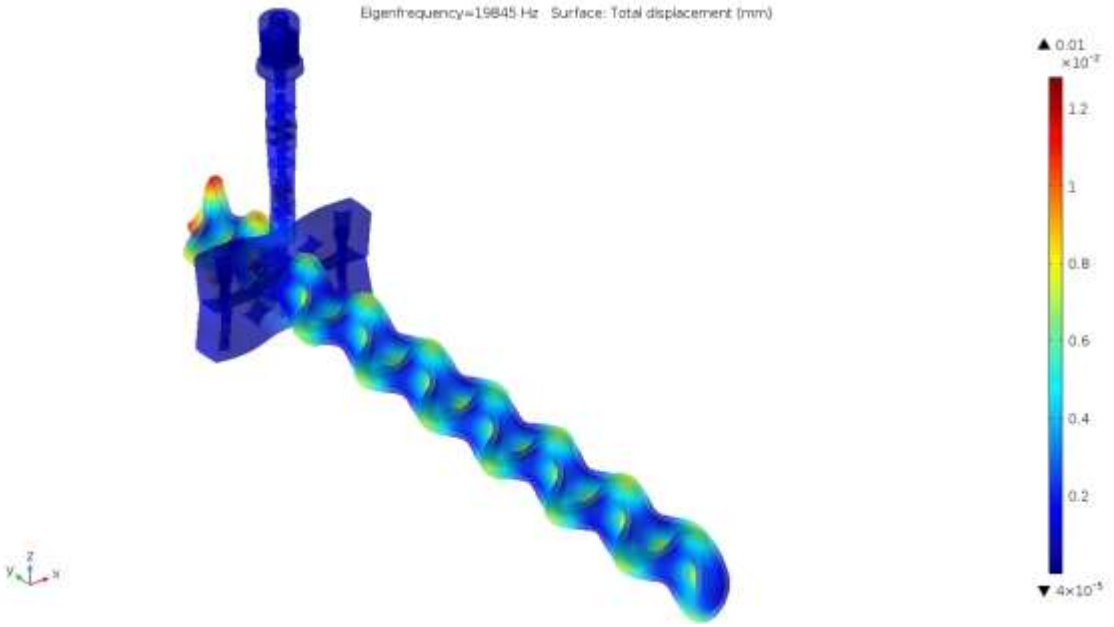
… Basic equipment



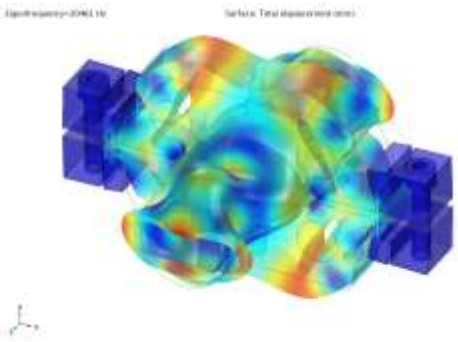
Selection of vibration mode shapes: **Axial modes**

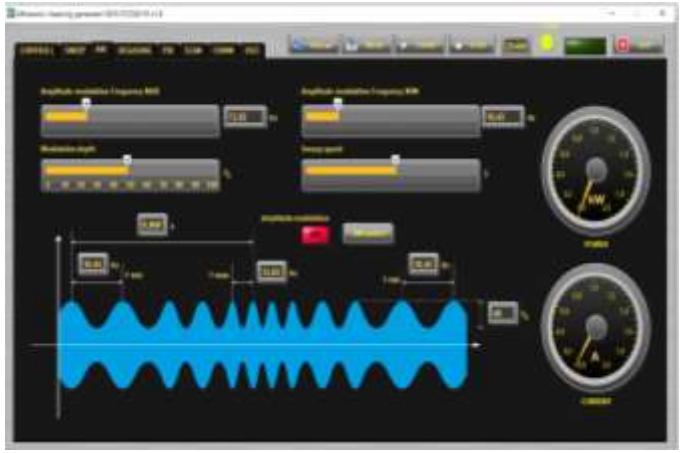


$$\frac{\partial}{\partial x}\left(EA(z)\frac{\partial \omega(z,t)}{\partial z}\right) = \rho A(z)\frac{\partial^2 \omega(z,t)}{\partial t^2}$$



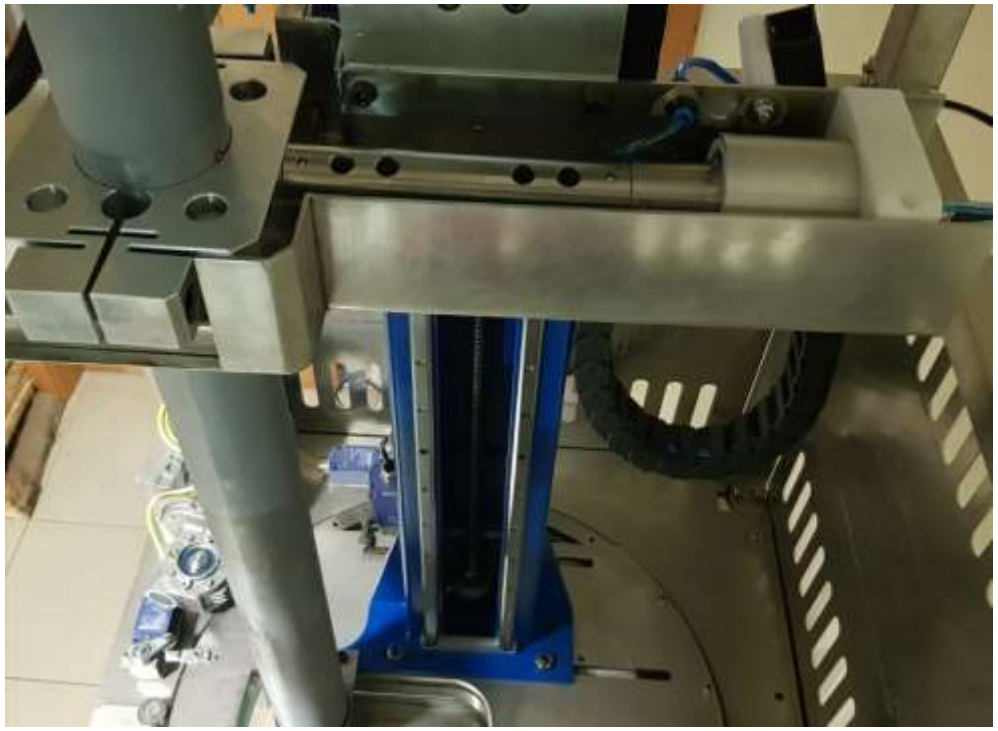
… Basic equipment



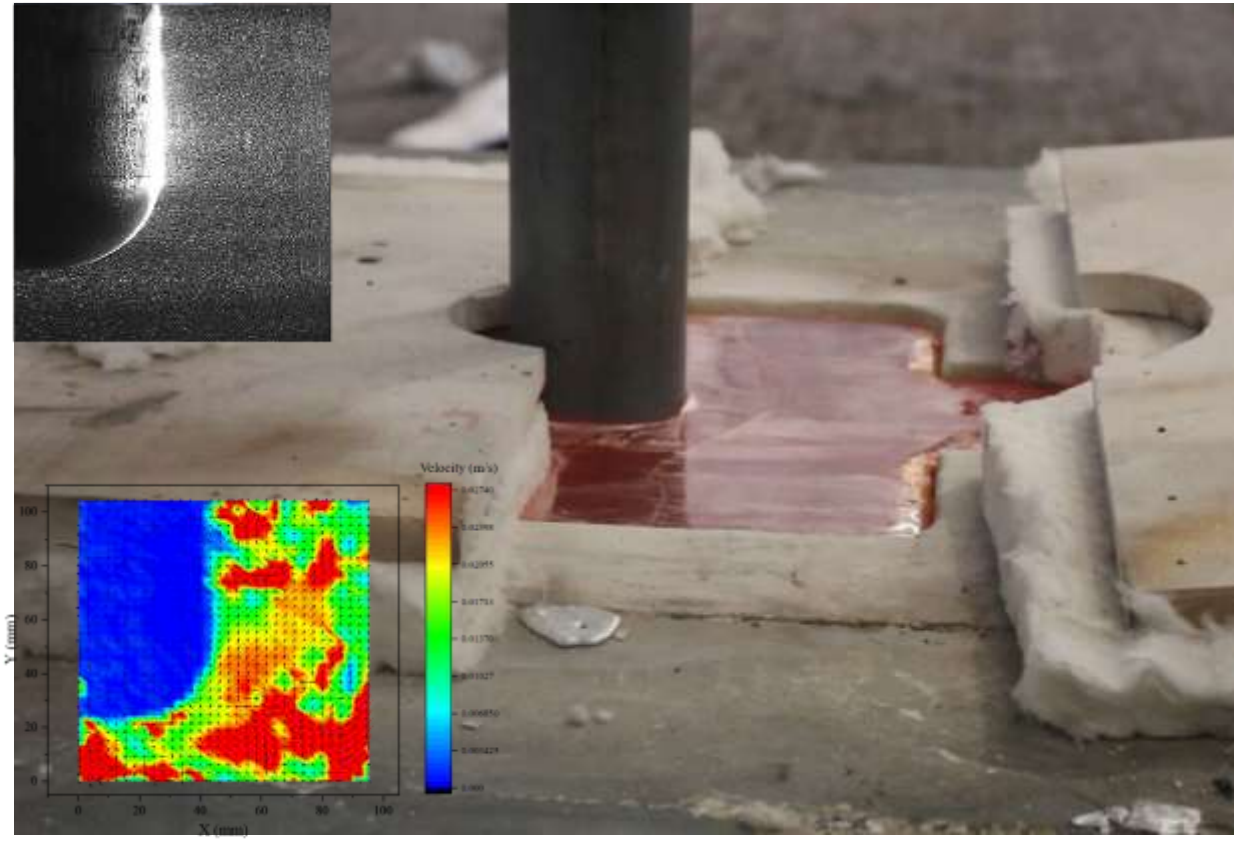


… Basic equipment

New Prototype for Aluminum alloy processing

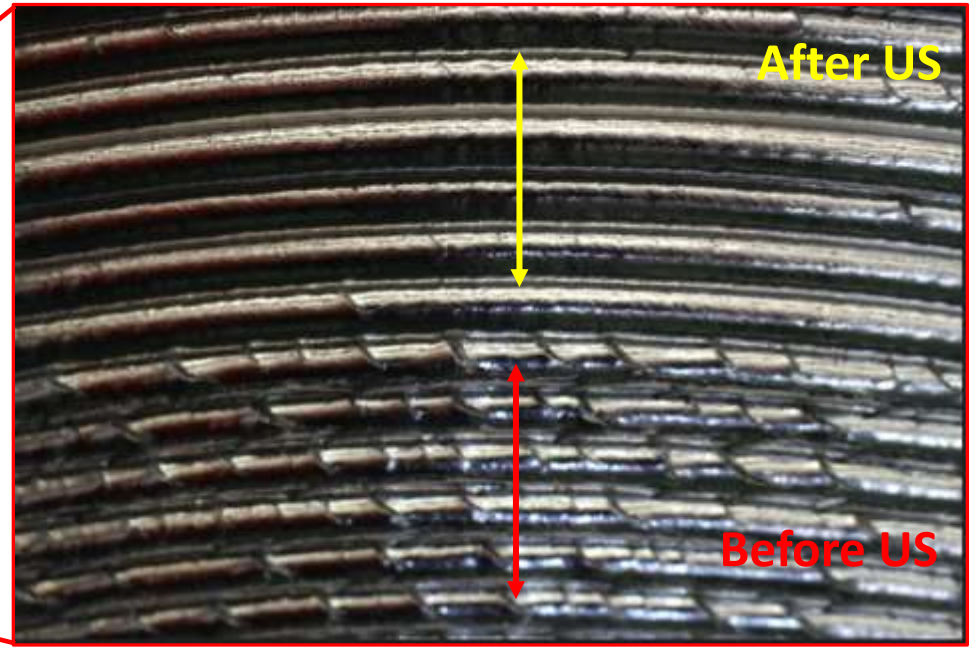


… Basic equipment set up in foundry environment



Spatial distribution of acoustic from the transducer radial sonication of SiAlON tube.

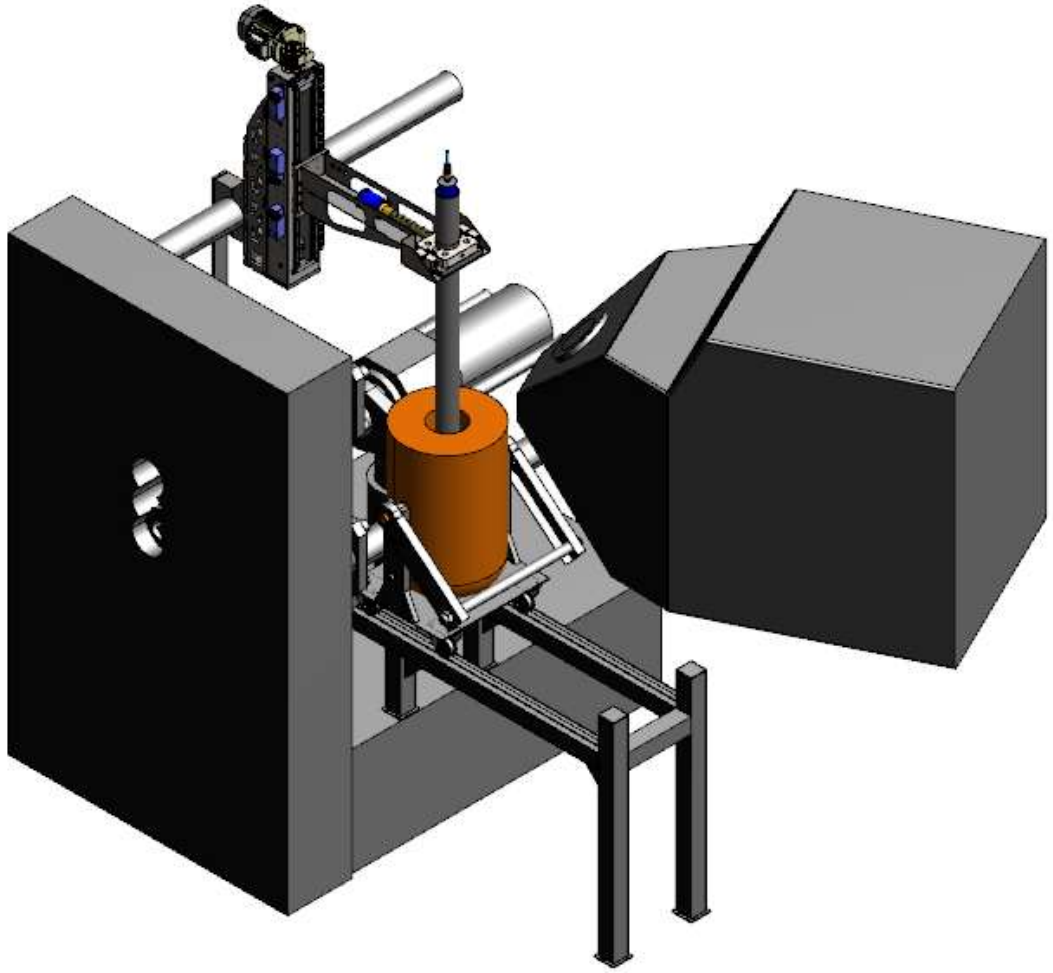
… Basic equipment set up in foundry environment

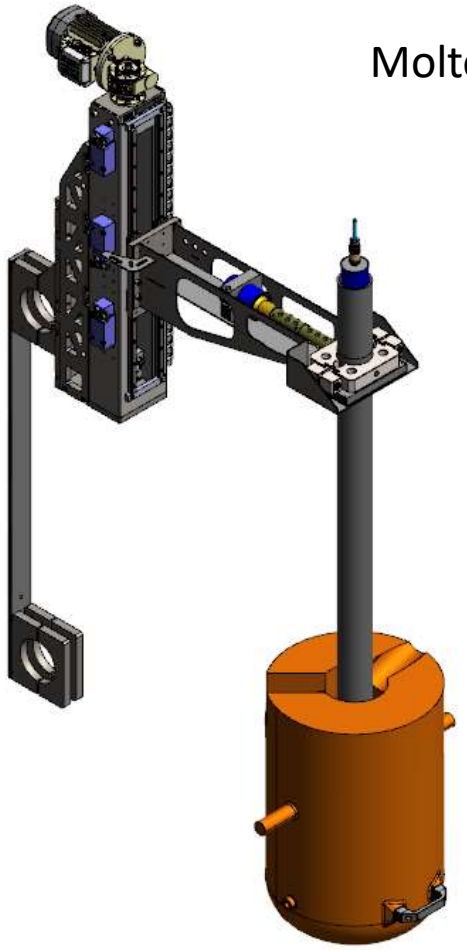


… Basic equipment set up in foundry environment

Regular production (Aluminum alloy processing – A356 alloy)

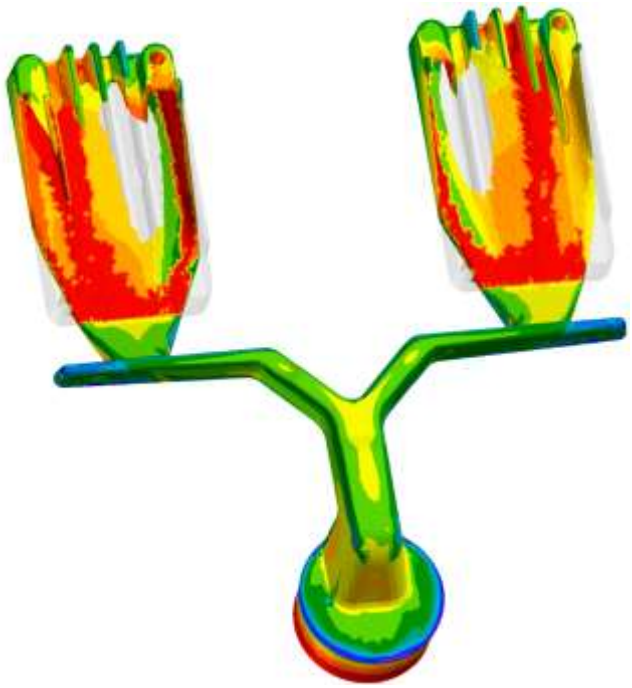
…MMM technology applied in HPDC: a novel approach





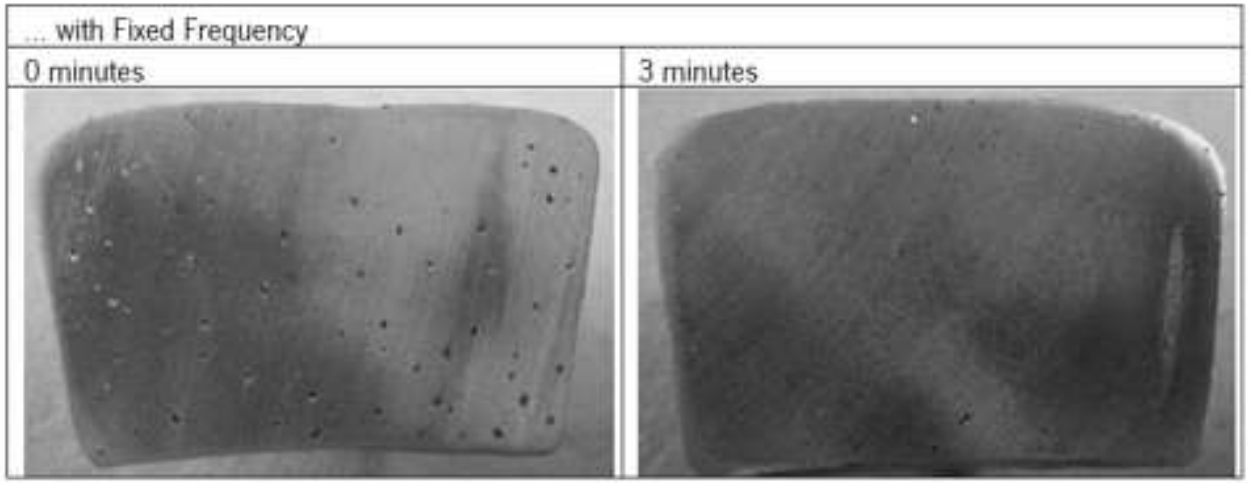
Molten Metal Treatment Cycle-by-Cycle

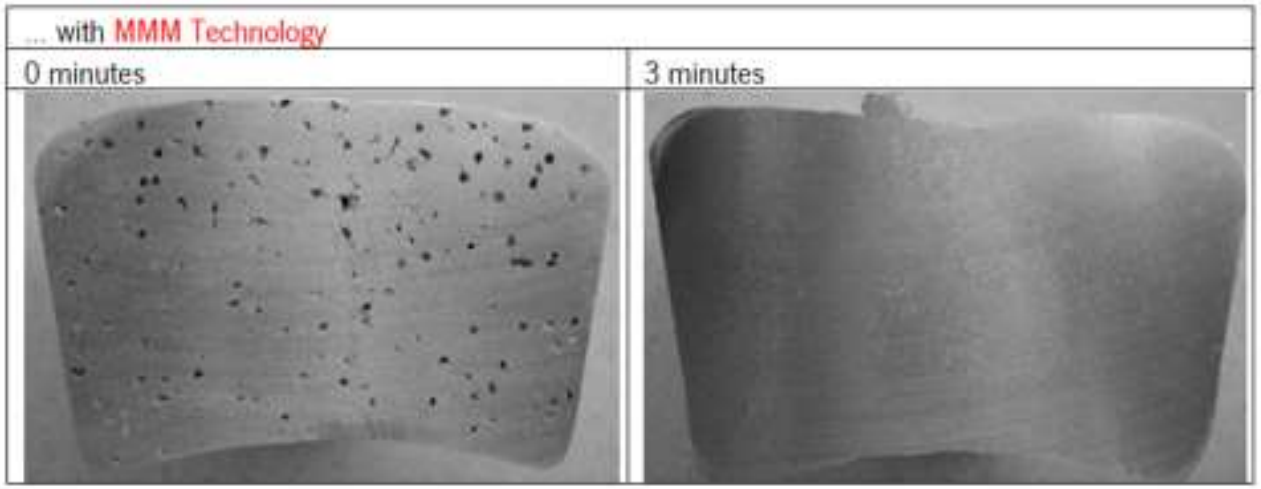
From few grams to 5 kg



…What have we done with it in Al? Degassing

… based on the **cavitation mechanism** promoting the **nucleation of bubbles** inside of molten metal at a range of temperature, which will cause coalescence and **rise to the surface of the melt carrying with it the dissolved hydrogen as non-metallic material present inside.**





Ultrasonic degassing can be an efficient process to degas molten non-ferrous alloys. For melting charges in static conditions (industrial scale) acceptable degassing is achieved 3 times faster than with argon degassing.

When compared with most common fixed-frequency ultrasonic sources MMM ultrasonic technique seems to improve significantly ultrasonic degassing process by increasing the final alloy density and shortening degassing time (Density Index < 1%).

…What have we done with it in Al? Degassing

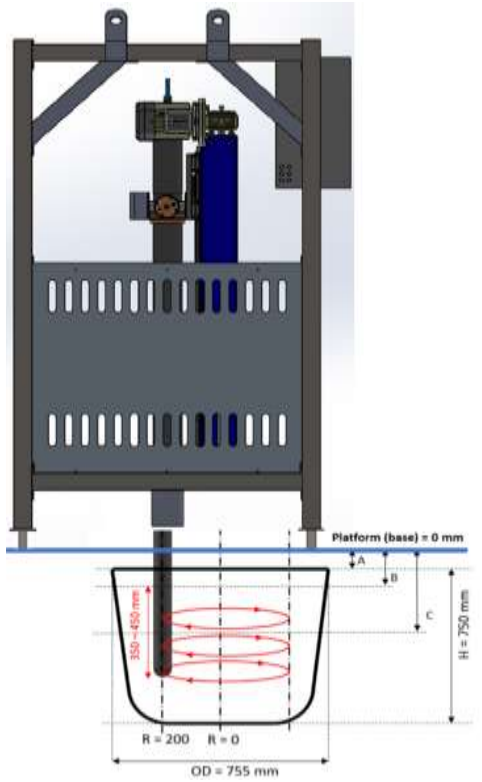
In an ideal liquid, viscosity and thermal conductivity are the two main factors of acoustic attenuation.

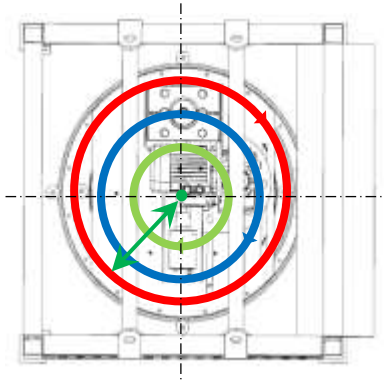
Because of acoustic attenuation, the cavitation phenomenon decreases with increasing distance from an acoustic radiator, creating a threshold volume regarding sonication efficiency. To overcome such challenges, we combine two complementing systems: **(i) MMM concept**; and **(ii) Dynamic Stirring rotation,** (using the same sonotrode).

(i) MMM concept

dedicated Software (an advantage compared to the competition, here we have full control of degassing process)

(ii) Dynamic Stiring rotation

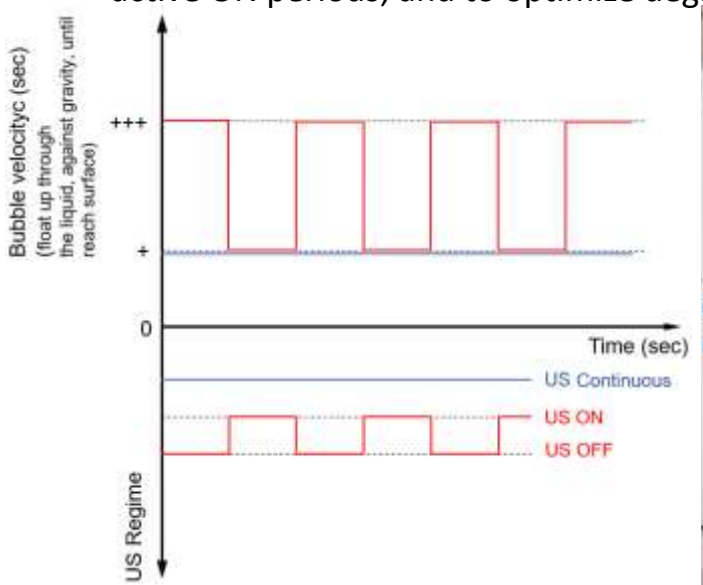


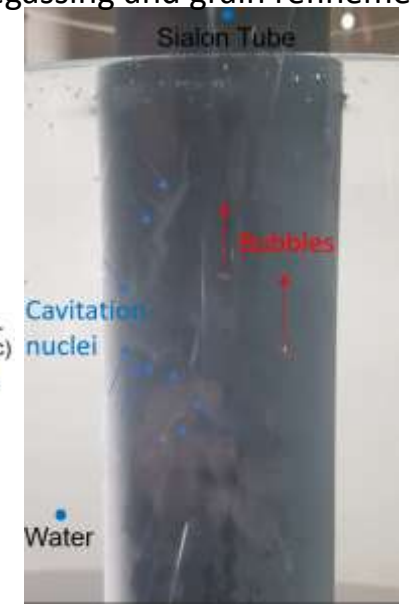


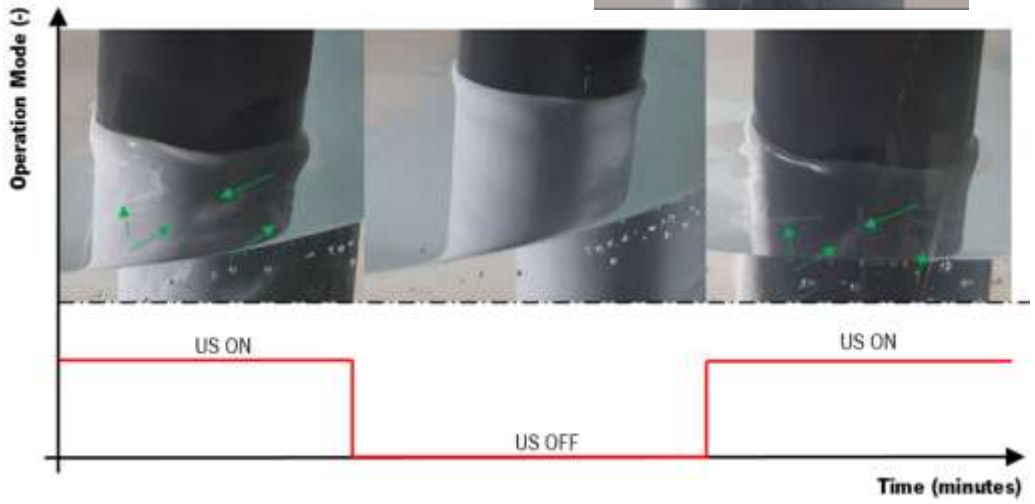
Dynamic stiring rotation degassing system creates a circular helix, 3D motion of ultrasonic cavitation, overcoming the acoustic attenuation issues.

…What have we done with it in AI? Degassing

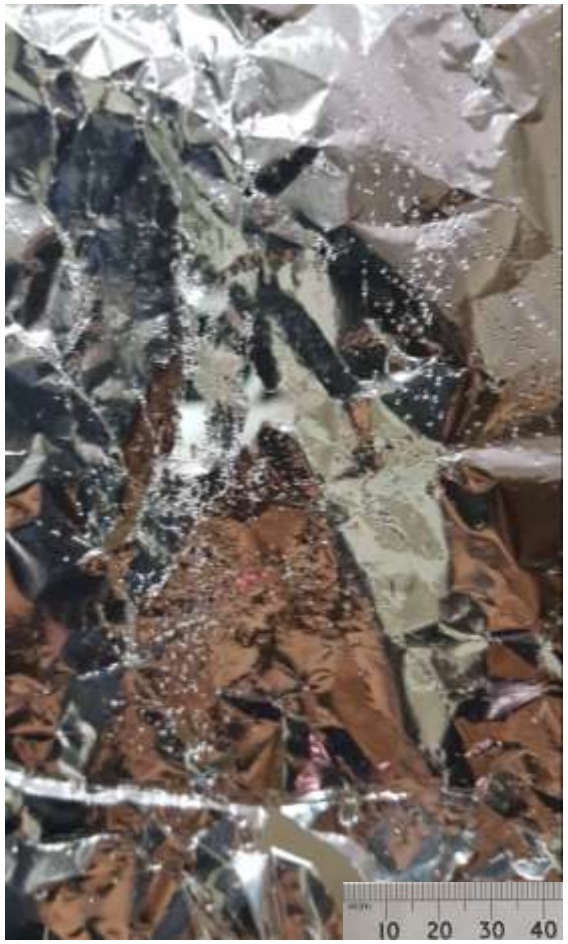
What is beneficial for ultrasonic liquid processing is to make sonication by sending **periodical ultrasonic pulse trains** (**with defined ON and OFF time intervals**), this way involving molecular relaxation during OFF time intervals, for enabling transient and time-evolving processes to happen between active ON periods, and to optimize degassing and grain refinement effects.

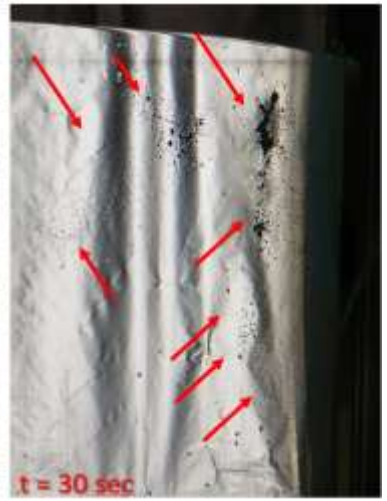




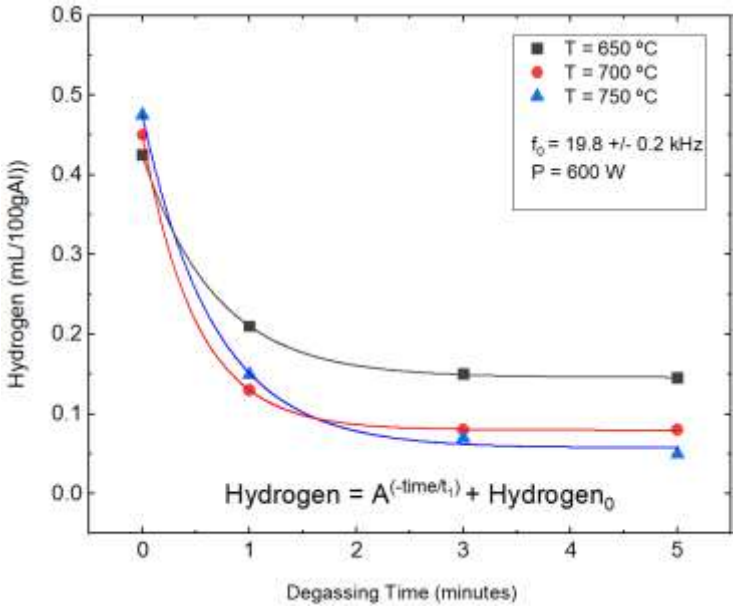


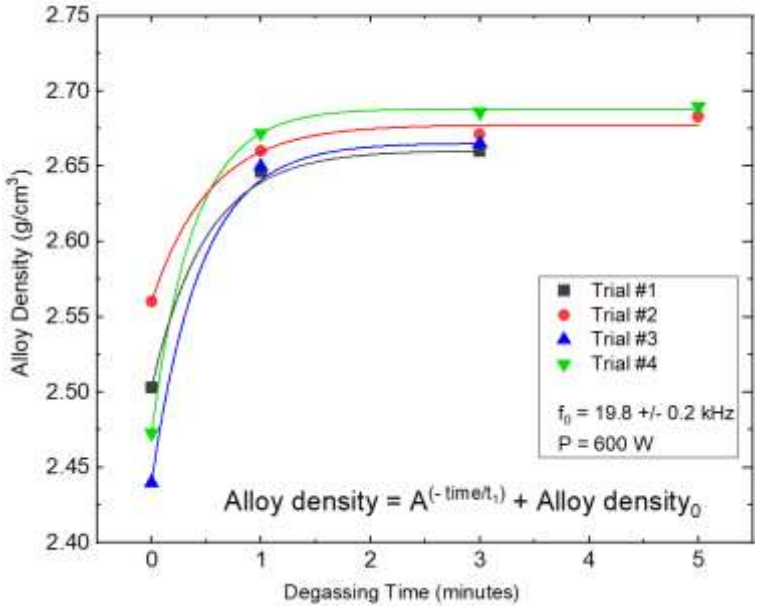
We are using the capabilities of the software that comes with all our ultrasonic generators

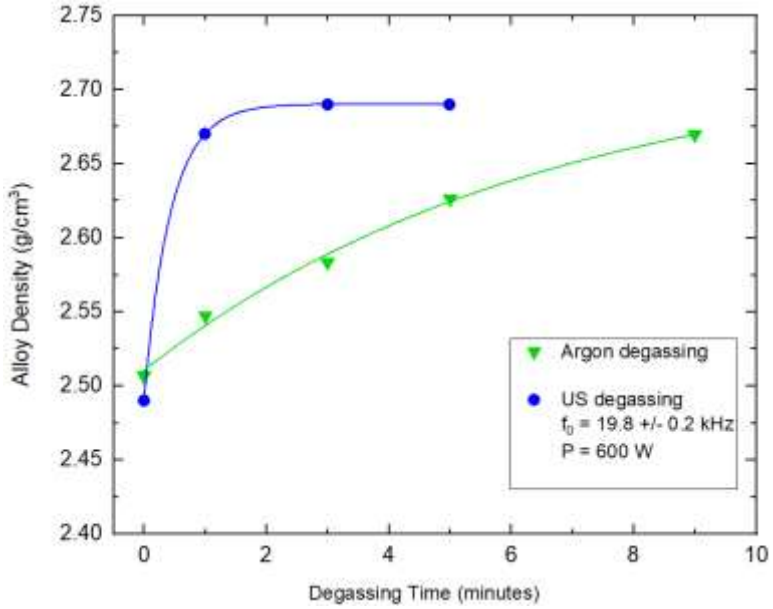




…What have we done with it in Al? Degassing







Conditions:

Alloy A380 (AlSi9Cu3)

Temperature of degassing 700 ºC

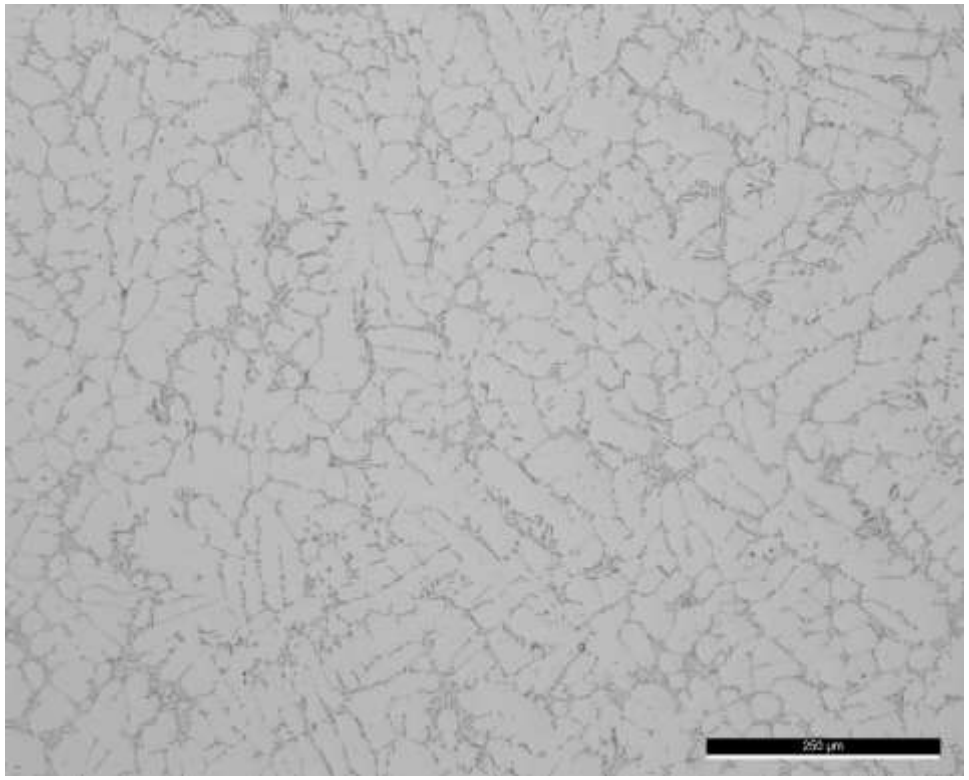
Volume processed 5 kg

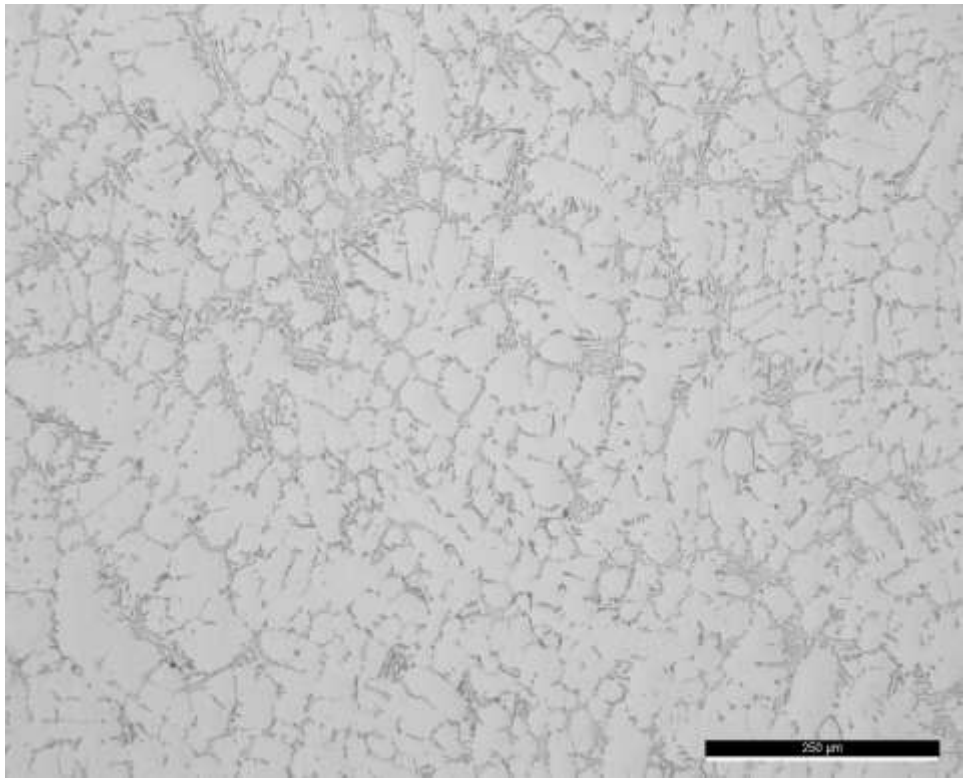
…What have we done with it in Al? Degassing + Refinement

With the application of **MMM technology**, it is possible to acoustically "activate" the liquid and create metallurgical conditions for refinement of alloy during solidification. Experimental results show that the certain acoustic activity inside the molten melt can remain active from 10 to 15 minutes (after stopping external ultrasonic agitation).

A moderate grain refinement (globular and rosette-like α-Al grains) can be observed in alloys solidified after ultrasonic melt treatment.

Liquids are manifesting "structural or spatial memory effects" when being acoustically or ultrasonically agitated.

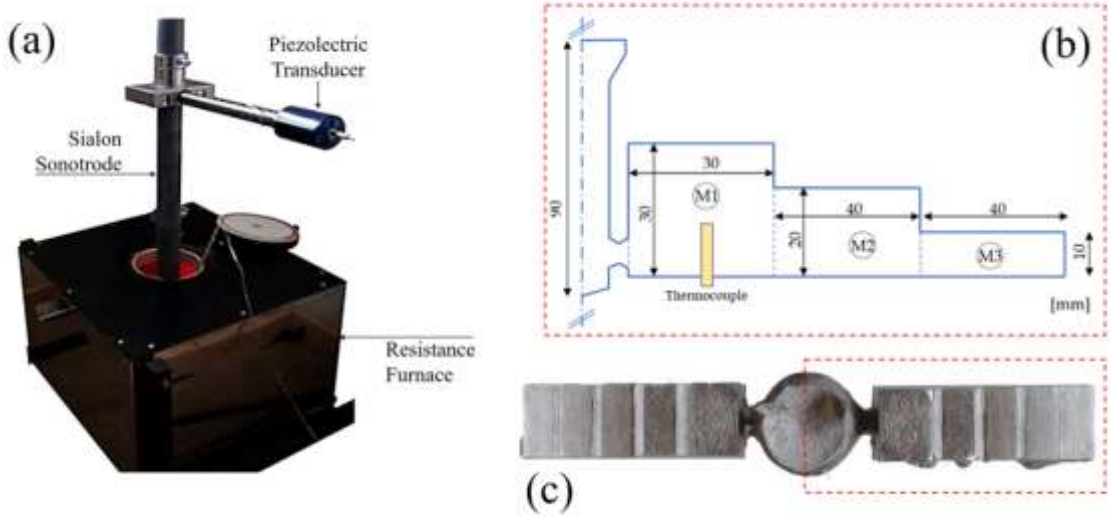




Conditions:
Alloy A356 (AlSi7Mg0.6)
Temperature of degassing 700 ºC
Processing Time 6 minutes
Processed Volume 15 kg

… What have we done with it in Al?

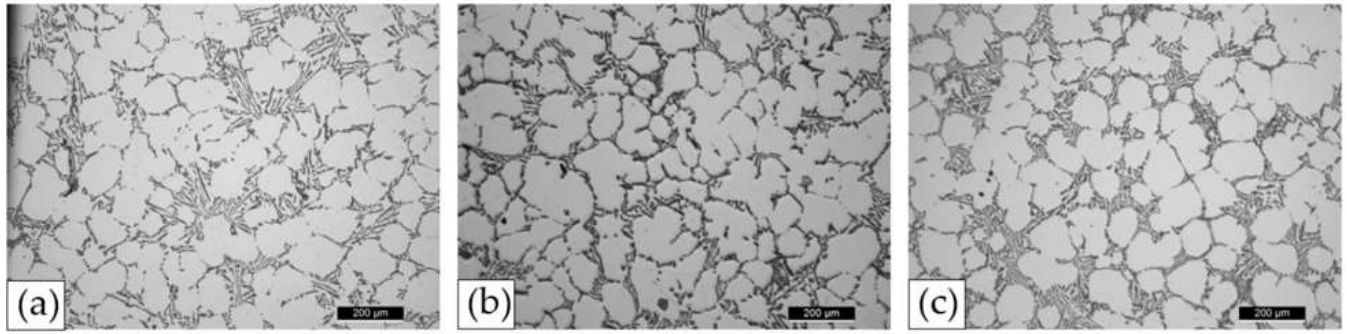
Refinement



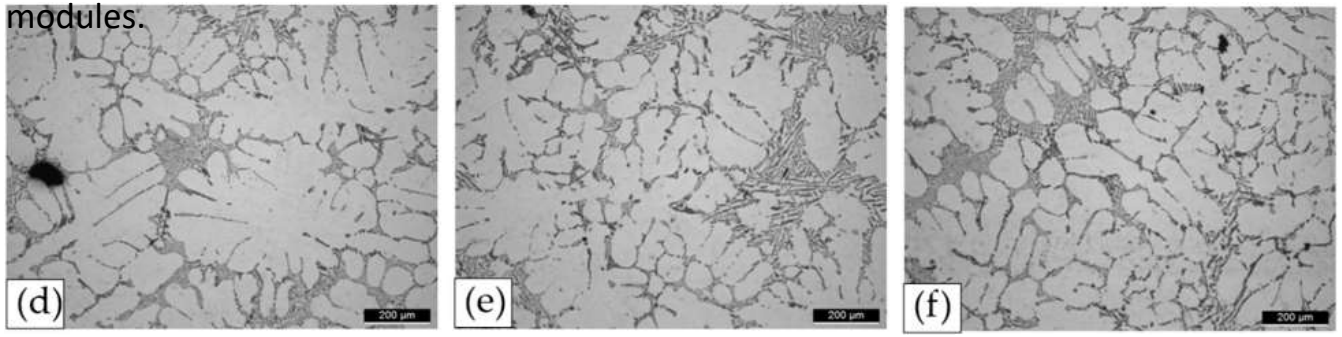
(a) SiAlON sonotrode in the melt, (b) mold design (c) cast specimen

Conditions:
Alloy A356 (AlSi7Mg0.6)
Volume processed 5 kg

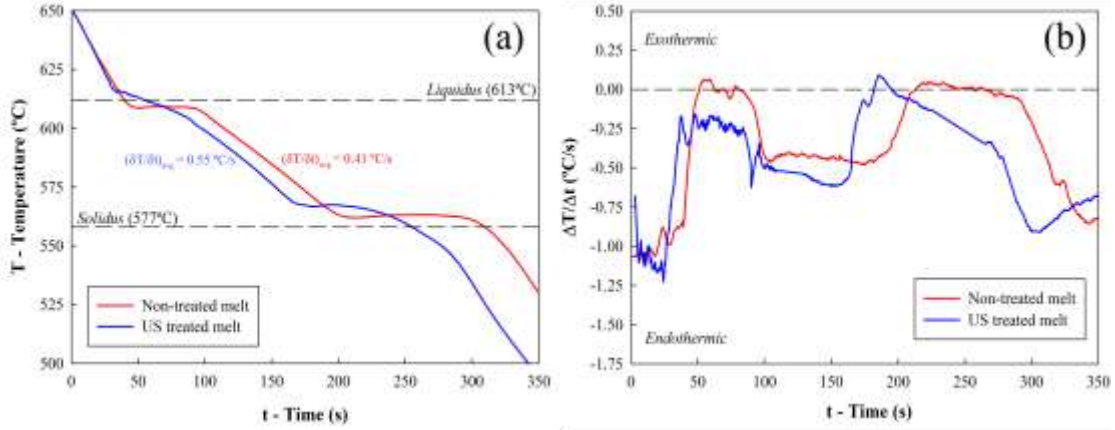
f = 20.2 ± 0.4 kHz
Sweeping On/Off (4 s/2 s)
P = 600 W
t = 300 s
Temperature of treatment 680 ± 5 °C



Microstructures in ultrasonic treated melts in the (a) M1, (b) M2 and (c) M3 modules.



Microstructures in non-treated melts in the (d) M1, (e) M2 and (f) M3 modules.



Solidification in M1 module: (a) cooling curves and (b) dT/dt.

…What have we done with it in Al? Degassing + Refinement

Ultrasonic degassing attracts a great deal of interest due to its cleanliness, and reduced dross formation.

Compared to the argon degassing process, the ultrasonic technique significantly reduces the slag weight resulting from the operation.

This difference proves that the absence of turbulence, conservation of the oxide film on the bath's surface, and the processing time during ultrasonic degassing are decisive factors in reducing the weight of formed slag.

Degassing Technique	Alloy	Density (g/cm³)		Treatment Time (min)	Slag (%)
		Initial	Final		
Impeller Rotary	AlSi8Cu3	2.51	2.65	9	2 (per 1 Ton)
Ultrasound		2.44	**2.68**	**3**	-
Impeller Rotary	AlSi7Mg0.6	2.43	2.61	9	2.6 (per 1 Ton)
Ultrasound		2.42	**2.64**	**3**	-

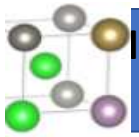
…What have we done with it in Al? Refinement

Aluminium Alloy Recycling

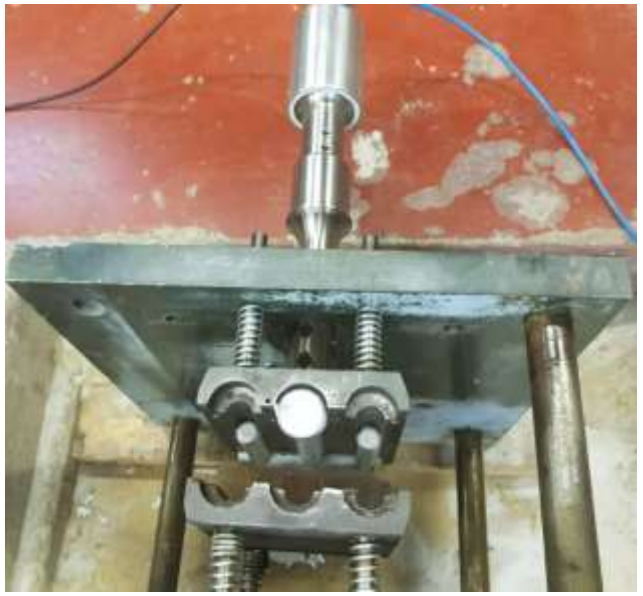
Degassing by Ultrasound at 700 ºC

Solidification under Ultrasonic Vibrations (applied to the mold)

Ultrasonic intermetallics refinement



locky, polyhedral structure that appears as hexagonal crystals.



Conditions:

Scrap of car parts (Alloy A380)

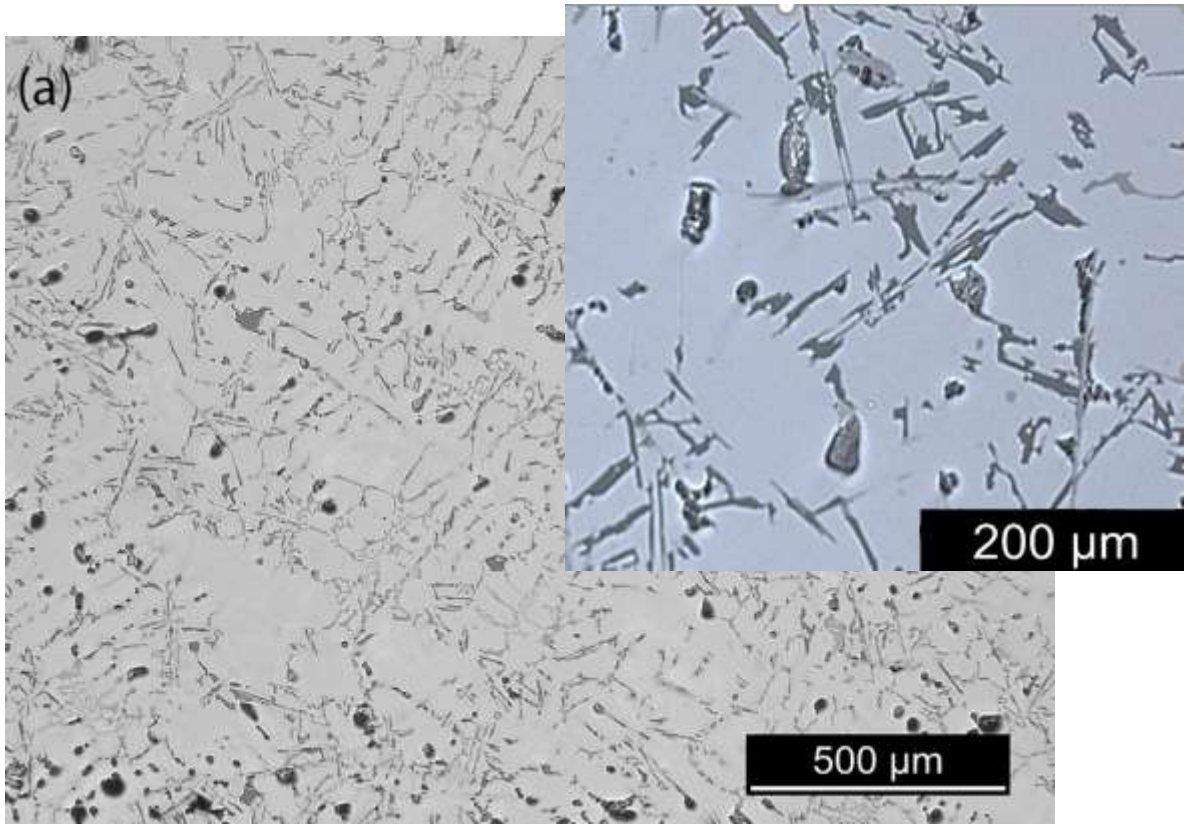
Temperature of pouring 700 ºC

Volume processed 15 kg

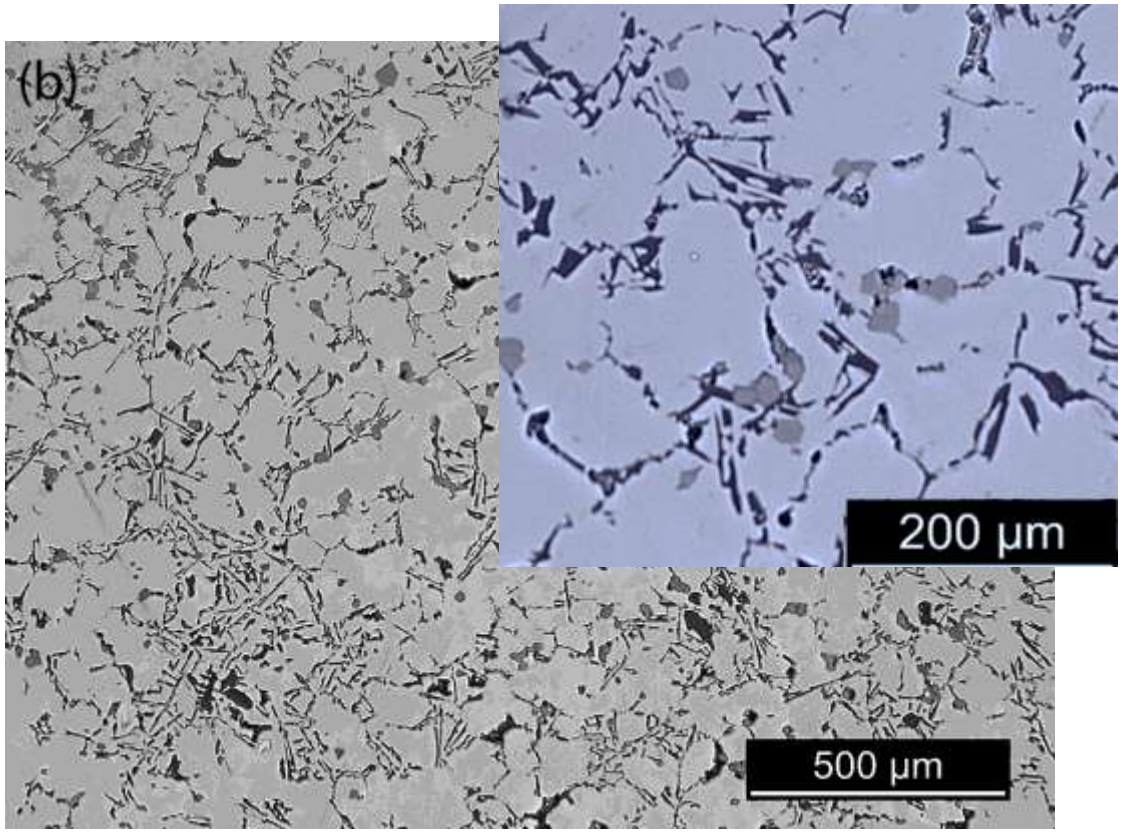
Ultrasonic Molten Metal **Processing**

…What have we done with it in Al? Refinement

Aluminium Alloy Recycling



Usual Molten Metal **Processing**



Ultrasonic Molten Metal **Processing**

Conditions:

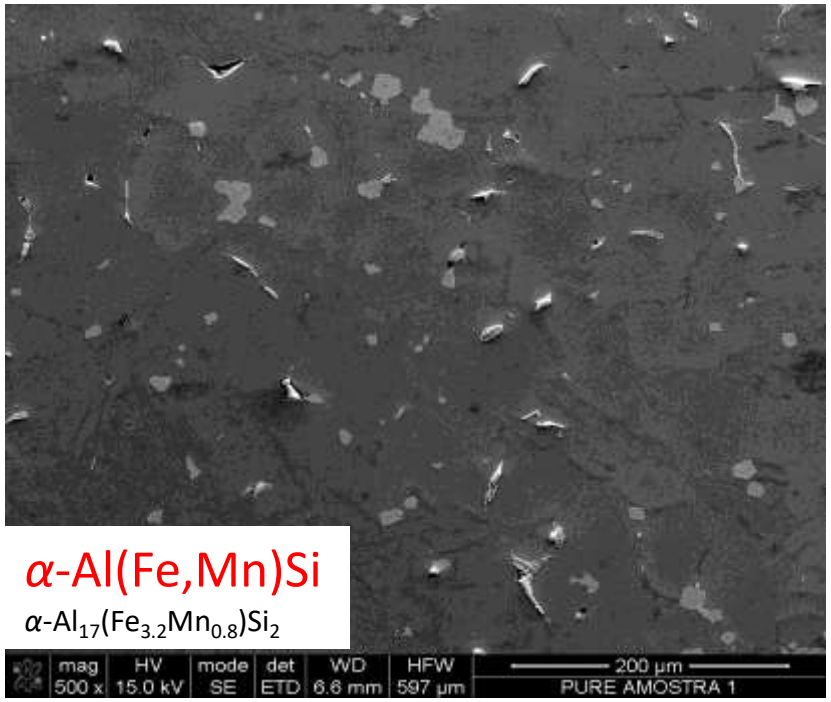
Scrap of car parts (Alloy A380)
Temperature of pouring 700 ºC
Volume processed 15 kg

…What have we done with it in Al? Refinement

Aluminium Alloy Recycling

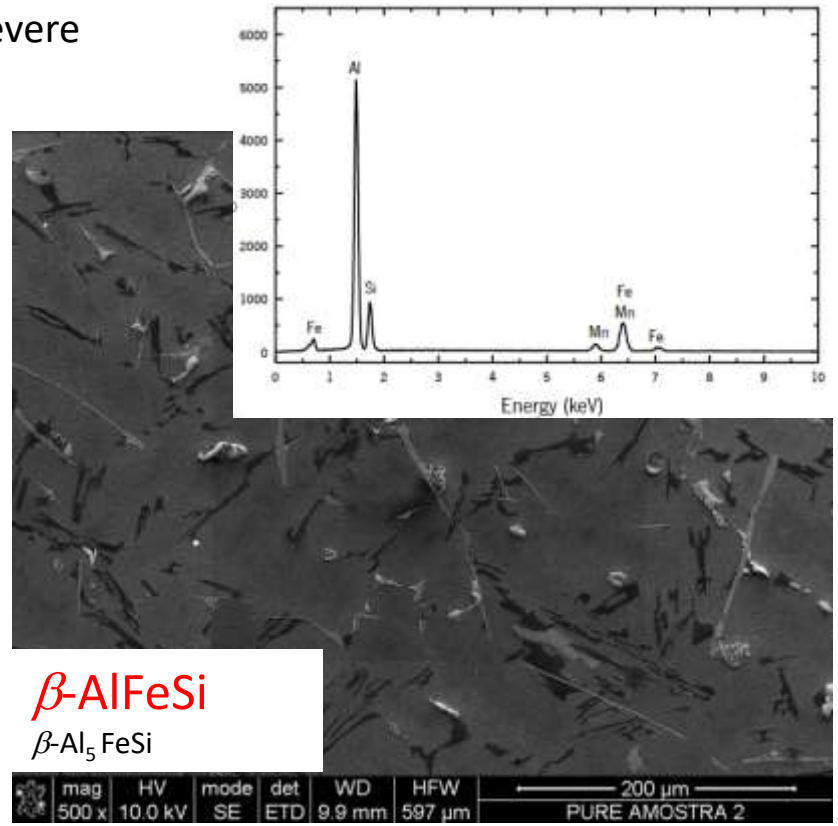
Secondary aluminium processing (or recycling), should treat impurities and intermetallics (Fe – IMCs) being in a scrap metal. Such non-desirable impurities are influencing solid microstructure being often detrimental to properties of produced alloys.

Needle-like, or plate-shaped, brittle β – IMCs allow easy to crack nucleation and defects propagation leading to severe loss of ductility in Fe-containing Al-Si alloys



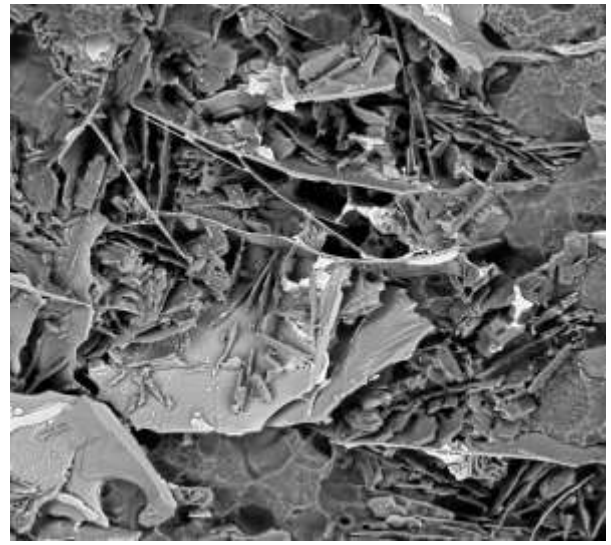
α-Al(Fe,Mn)Si

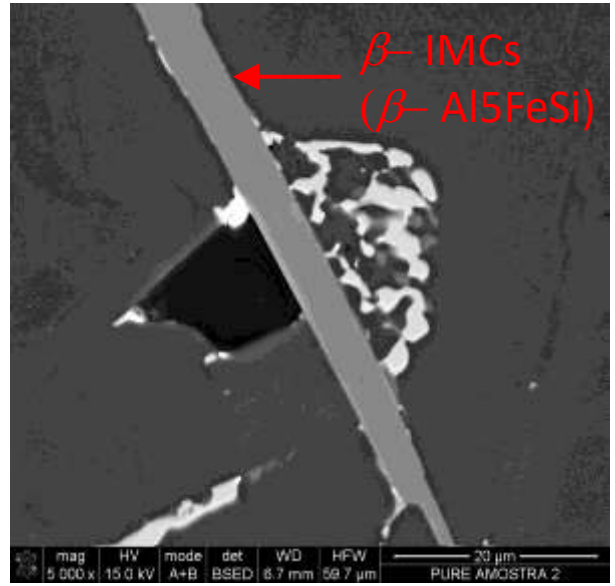
α-$Al_{17}(Fe_{3.2}Mn_{0.8})Si_2$



β-AlFeSi

β-Al_5 FeSi





…What have we done with it in AI? Refinement

In **brief conclusion**, our **equipment/design** can produce spatially **uniform and frequency-wideband** ultrasonic field and maximize ultrasonic **activity in liquids**, if we apply **different frequency and amplitude modulating** techniques on ultrasonic signals (what is known as **MMM technology**).

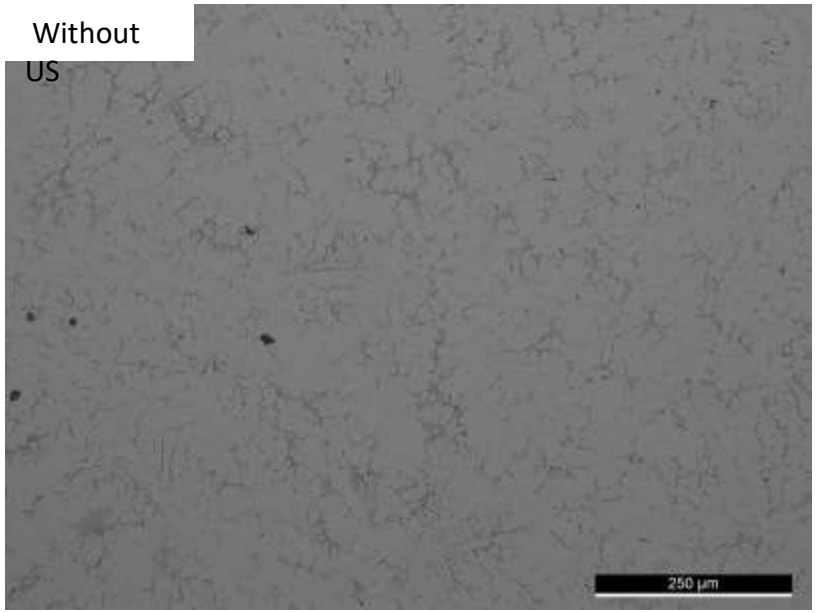
MMM technology also means that by applying complex acoustic vibrations, we can make an artificial conditioning of liquid properties. For instance, material properties (of liquids and solid masses), being on certain stable temperature, can be characterized with number of lumped or fixed parameters and constants. When we apply complex-acoustic-field of MMM ultrasonic vibrations, mentioned lumped or fixed and constant-values metal-parameters state will spread or transform to some new liquid or solid state, having "*by-intervals-defined parameters*" during MMM processing.

Also, beneficial for **ultrasonic liquid processing is to apply certain macro-mechanical motion of ultrasonic source during sonication** (for instance circular, helix and up-down, 3D motion), this way making "spatial sweeping" and processing a bigger liquid mass. Such ultrasonic processing is generating "spatially and by frequency modulated quantity of motion, or modulation of linear and angular mechanical moments" of involved liquid state participants.

…What have we done with it in Mg?

Ultrasonic Magnesium Mg-Al-Zn treatment

Without US



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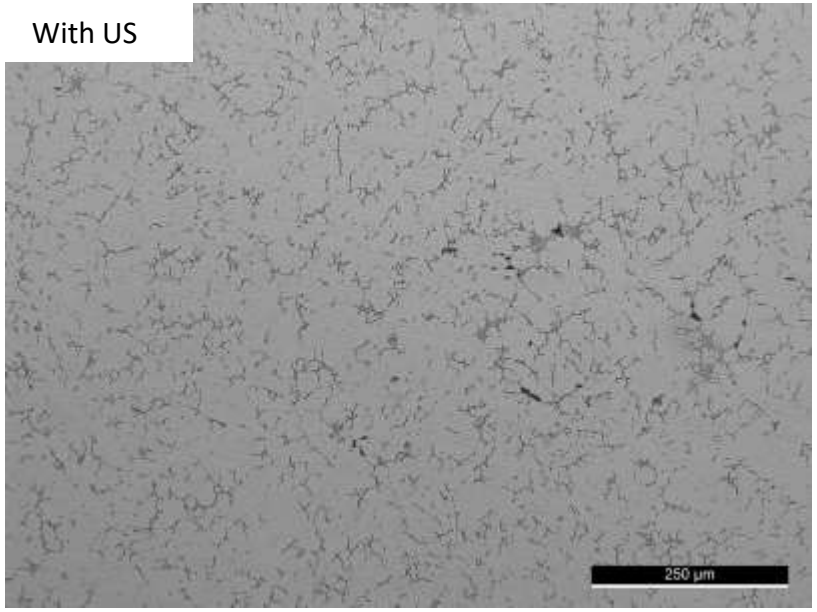
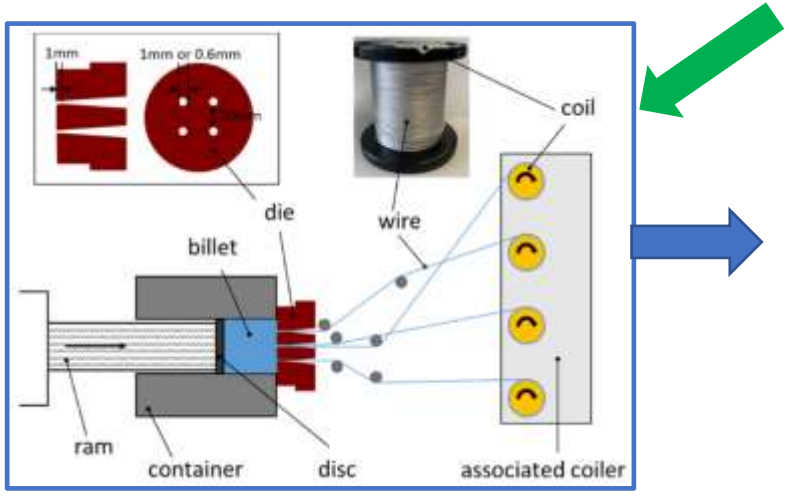
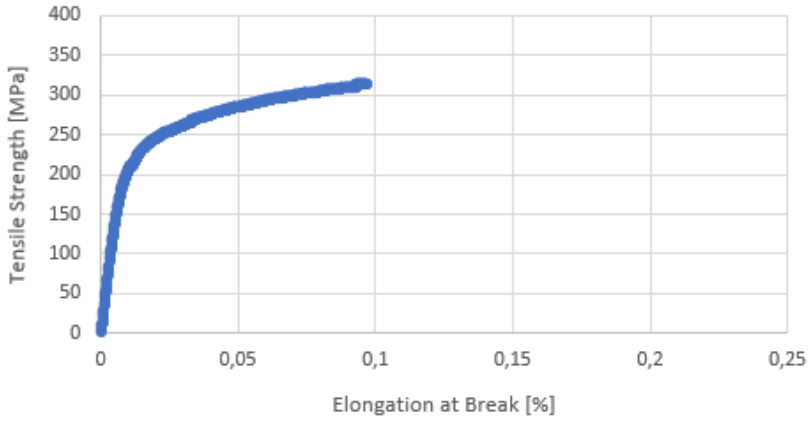
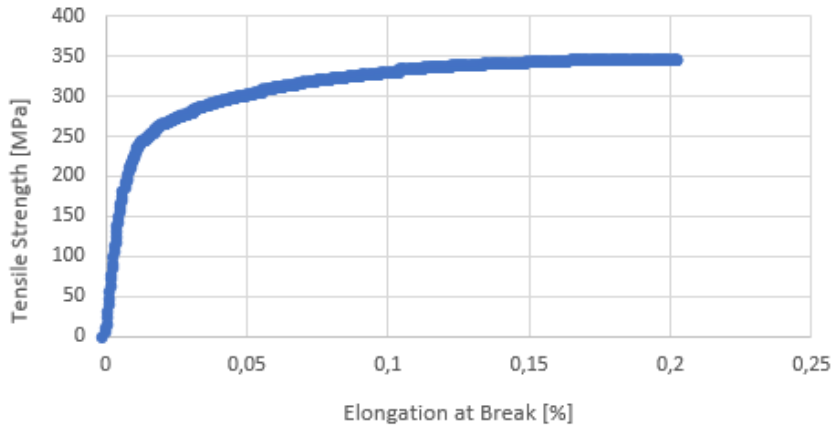


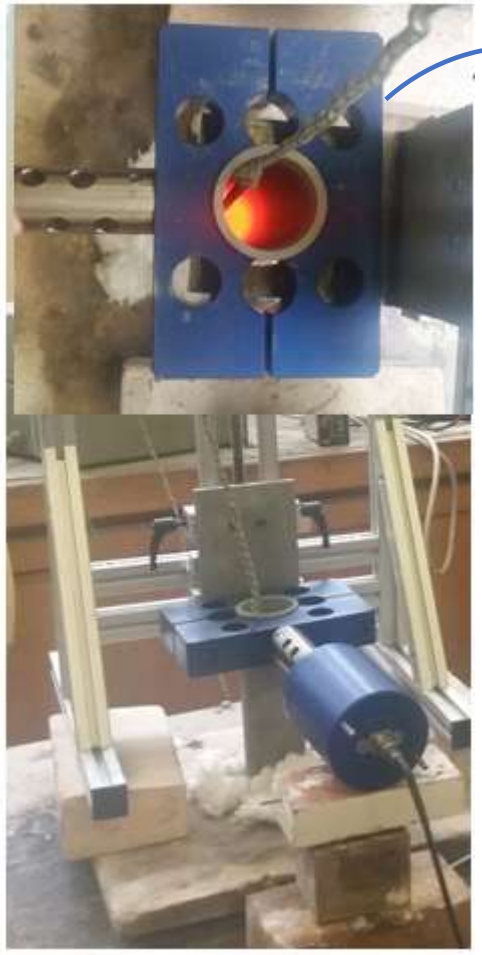






Direct Extrusion of Magnesium Wires from Mg-Al-Zn Series Alloys

…What have we done with it in Brass?

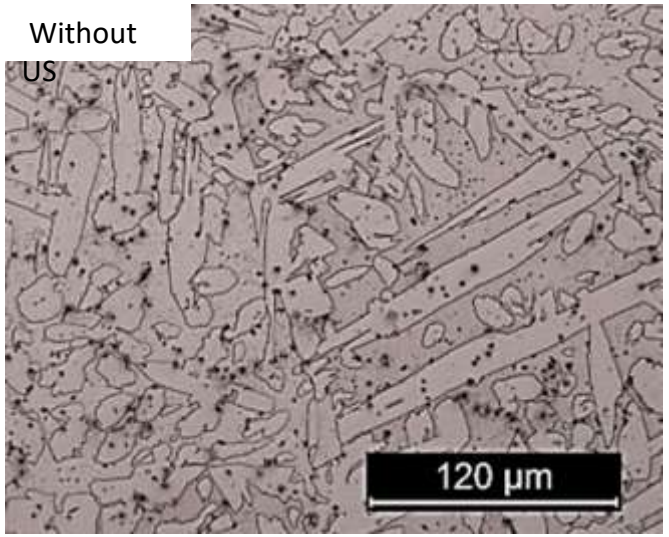


Ultrasonic Brass treatment

After US Treatment → Pouring

Refinement technique	Tensile Stress (MPa)	Yield Stress (MPa)	Elongation (%)
Not refined	282 (± 30)	178 (± 14)	4.3 (± 1.00)
Chemical refinement	310 (± 15)	181 (± 11)	5.0 (± 0.70)
Ultrasonic refinement at 900°C	345 (± 15)	183 (± 10)	6.9 (± 0.50)
Ultrasonic refinement at 920°C	367 (± 12)	187 (± 7)	9.4 (± 0.60)
Ultrasonic refinement at 940°C	386 (± 10)	192 (± 7)	11.5 (± 0.60)

Without US



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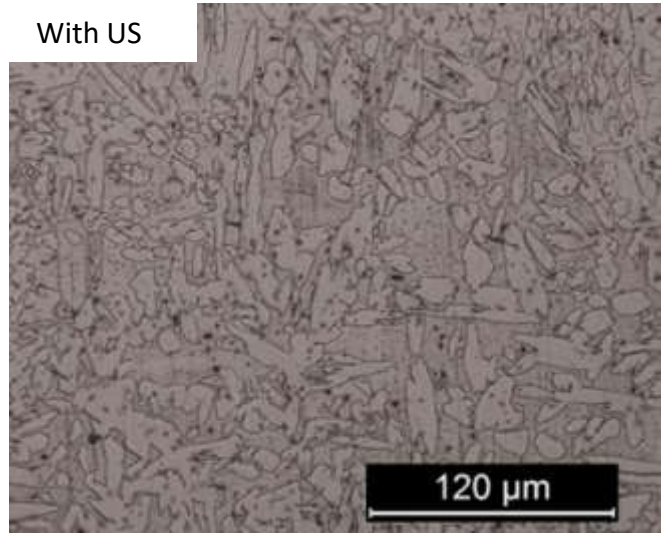


…How is MMM technology different from Southwire's offering

Southwire is offering **fixed ultrasonic frequency**, liquid metal agitation using high intensity probe sonication. That means, **producing spatially not uniform "ultrasonic-jet or ultrasonic-torch" agitation**.

Southwire patented **design** is convenient for **injecting argon or nitrogen** for stimulating degassing (in parallel with ultrasonic activity). Anyway, high intensity "ultrasonic-jet or ultrasonic-torch", and presence of injected gas in front of ultrasonic probe are mutually contra-productive and could reduce expected degassing effects.

Every fixed frequency ultrasonic probe sonication can also inject big quantity of environmental gasses in liquids, if not properly applied (that means, degassing with probe-sonication is not reliable).

…5th generation of MMM technology and its readiness for industrial application in foundries

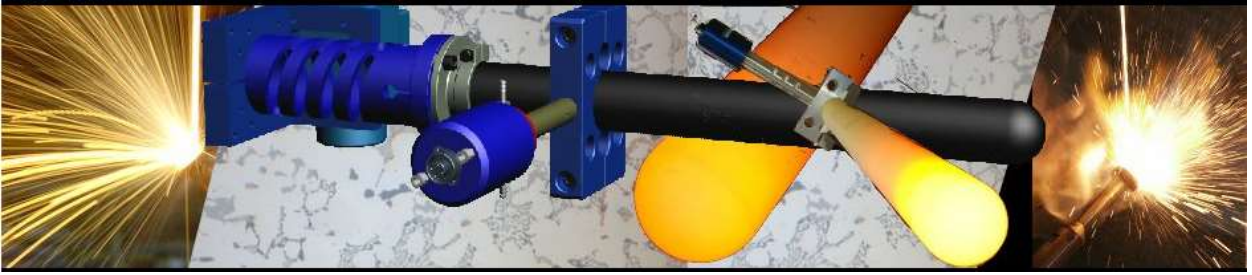
MMM technology is becoming the ***symbol for Macro Ultrasonic Engineering***, meaning that arbitrary-shaped, small, and big objects or masses can be ultrasonically and uniformly agitated with high power. MMM, high power, sonic and ultrasonic technology is much different and stronger when compared to very high frequency and very low power NDT (Non-Destructive Testing).

…Conclusion

As we know, nobody integrally formulated such simple, generally valid (for all liquids) conclusions in one place, related to ultrasonic liquid processing, or to an efficient ultrasonic energy transfer, degassing, cavitation, explaining influence of operating temperatures, acoustic coupling, and decoupling between ultrasonic sonotrodes and treated liquids, linear and non-linear behaviors of liquids during ultrasonic processing.

This what is summarized here is essential for understanding Sonochemistry and Ultrasonically assisted Metallurgy, or Sonometallurgy. Without knowing considerations and facts, as here summarized, we will not have a basic conceptual understanding about what is happening during ultrasonic processing of liquids, and we will struggle explaining multi-parameter and time evolving processes. Of course, all that what exposed here, is separately and sporadically known until certain level, and on some incomplete way stated or published, but nobody made such generally valid and mutually related comments and conclusions, integrally formulated in one place. Anyway, we still need to address such problematic much better and systematically.

This, what is briefly elaborated here, is our competitive advantage regarding Ultrasonic Metallurgy and applications of our **MMM Technology**



… the future of Metallurgy starts here, with MMM Technology.

Thank You.