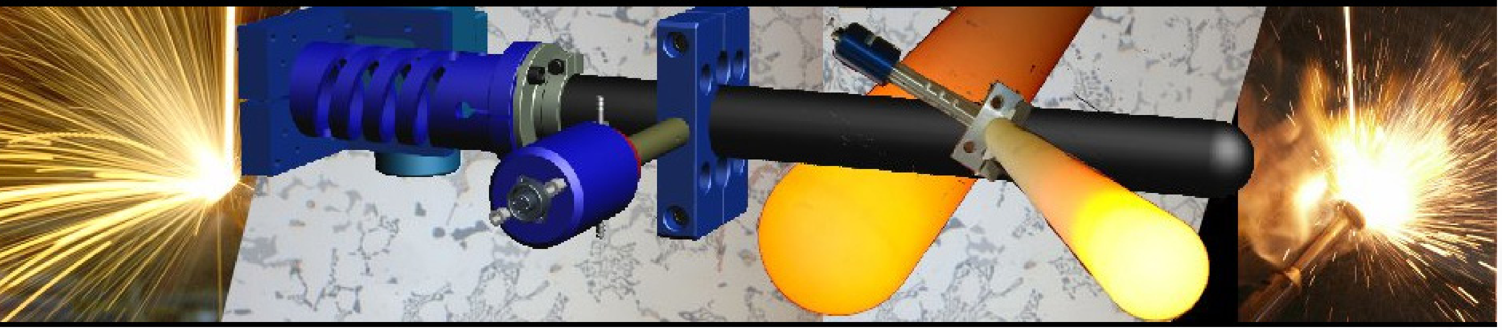

www.UltrasonicMetallurgy.com

Ultrasonic vibrations in metallurgy…

Technology, results, difficulties…

MP Interconsulting
Marais 36,
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Summary

Part 1

History of Ultrasonic Processing in Metallurgy – Ultrasonic Treatment of Light Alloy Melts

Theoretical foundations

- Cavitation, temperature, amplitude, frequency…

Reality & Practice

- How can I control the process?
- Can I control the process with my equipment?
- What the best characteristics of "*Ultrasonic Activity*" are?
- Design solutions applied in treatment of Light Alloy Melts

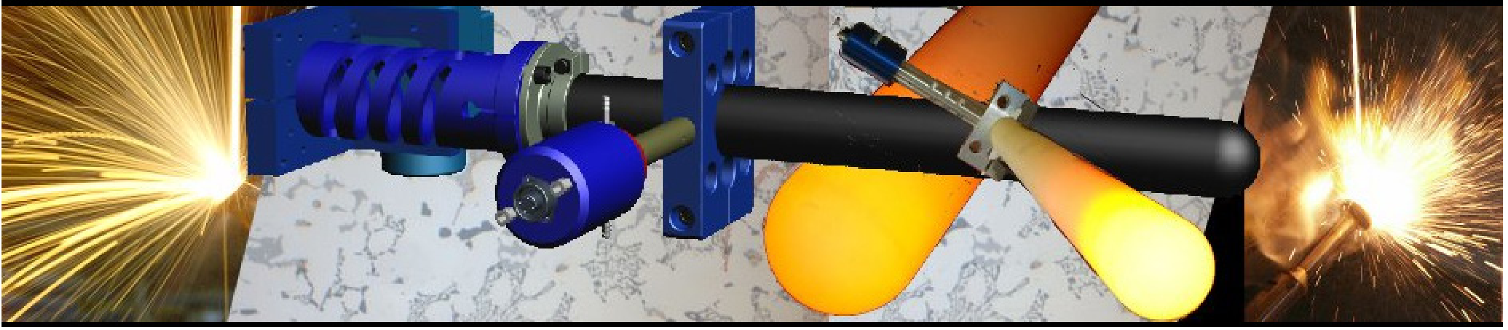
✓ Results of MMM technology applied in processing of aluminum alloys

Part 2

Some ideas/proposals

Part 3

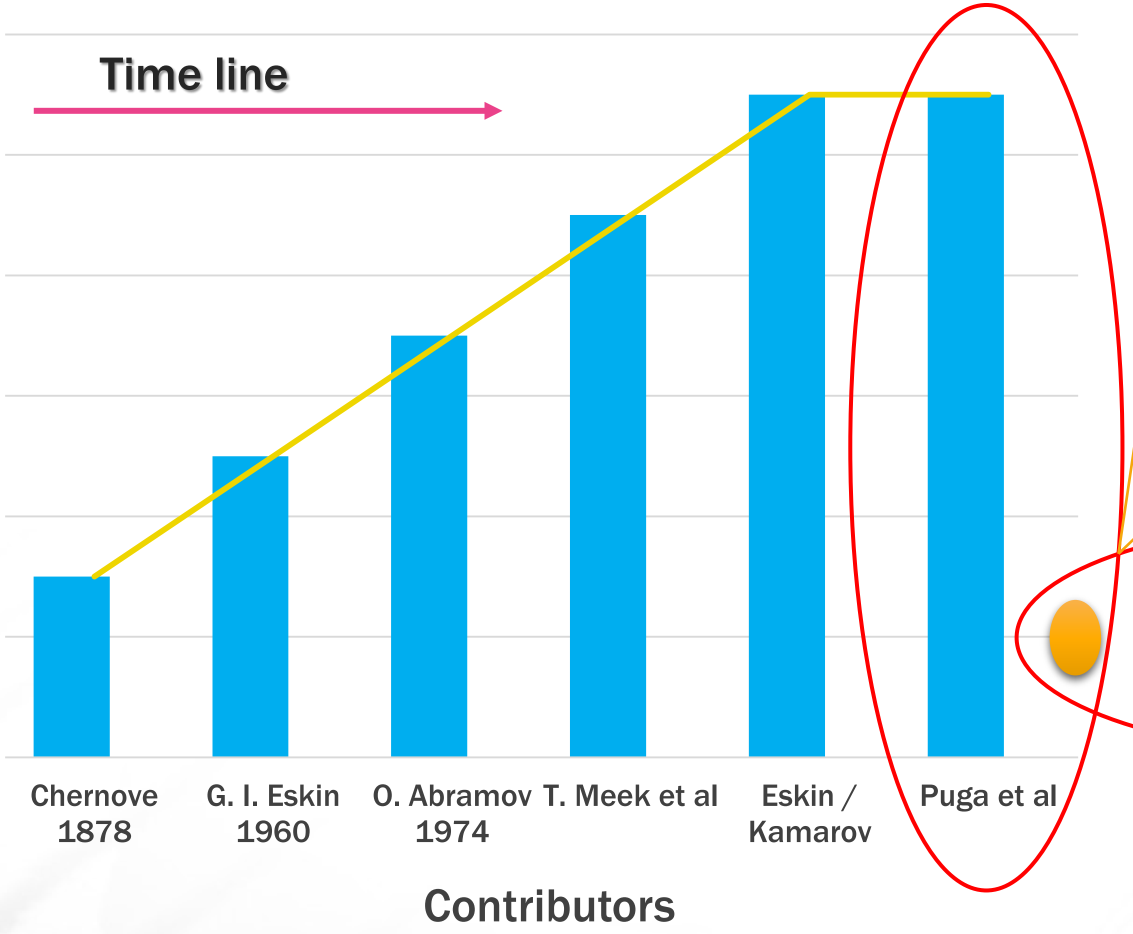
How can I control the cavitation?



Ultrasonic vibrations in metallurgy…

Part 1

History of Ultrasonic Processing in Metallurgy – Ultrasonic Treatment of Light Alloy Melts



Suggestions!

Questions ?

Ideas
Designs
Lab Trials.
...

CAD

FEA

CT2M
Center for Mechanical and Materials Technologies

Aim

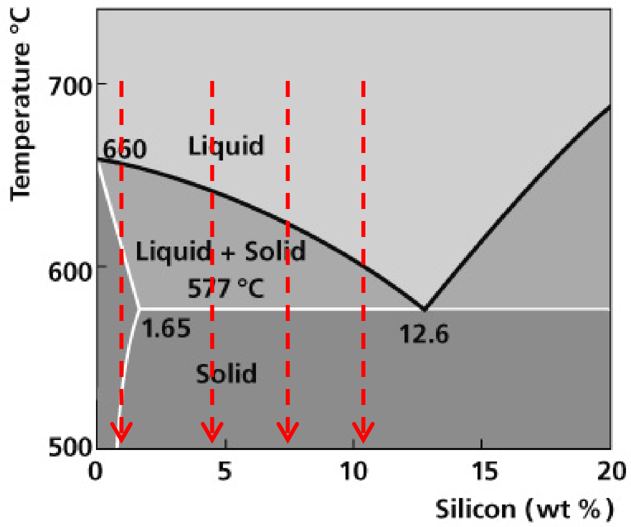
Quality of casting
Mechanical properties
Understand the mechanisms involved
Industrial applications

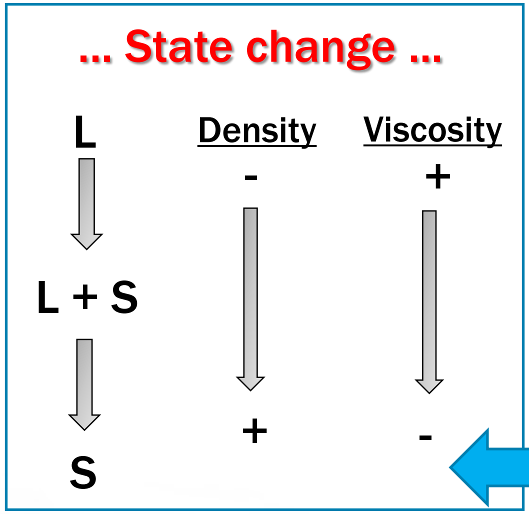
History of Ultrasonic Processing in Metallurgy – Ultrasonic Treatment of Light Alloy Melts

What the differences between us and Others are?

Fixed frequency sound waves

Others Standing waves break ceramic sonotrodes, while creating spatial zones of very high and very low acoustic activity.





MMM (=) Multi-frequency, Multi-Mode, Modulated sound waves.

we Multi-frequency, pulse-repetitive, frequency, phase and amplitude modulated, bulk-wave excitation.

Elimination of ultrasonic standing waves gives spatially uniform processing of liquid metals.

Capability to drive ultrasonically any arbitrary solid body shape, or large mechanical system at high energy, if needed.

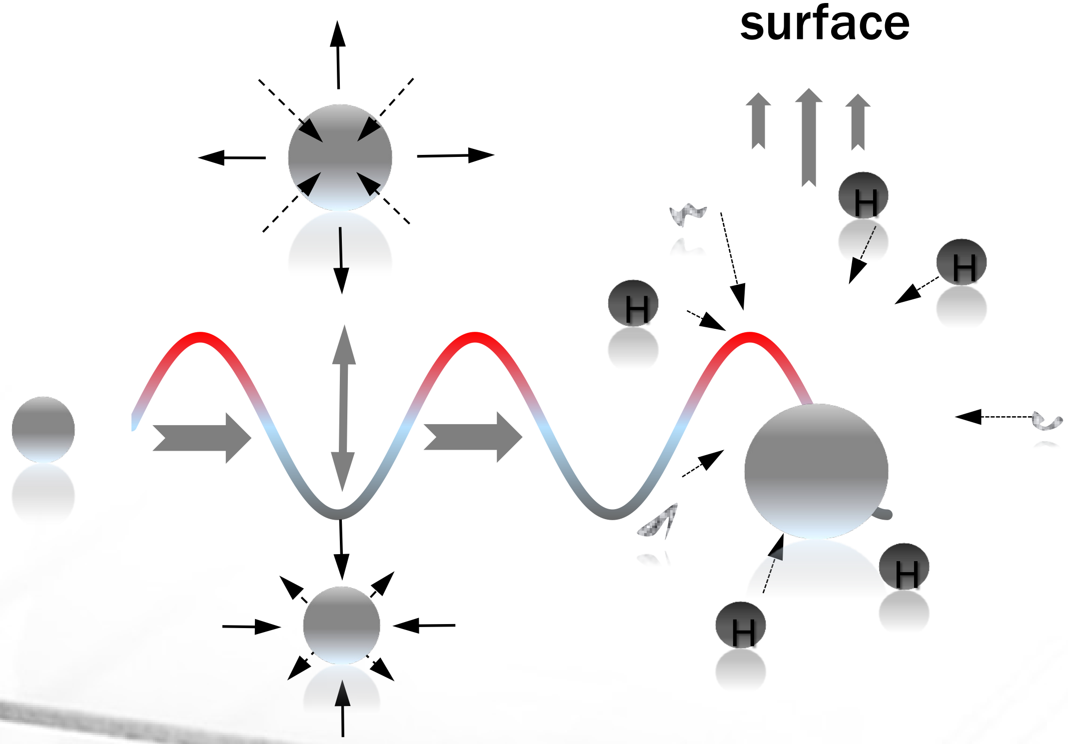
To solve:
Multifrequency, Multimode, Modulated sound waves.

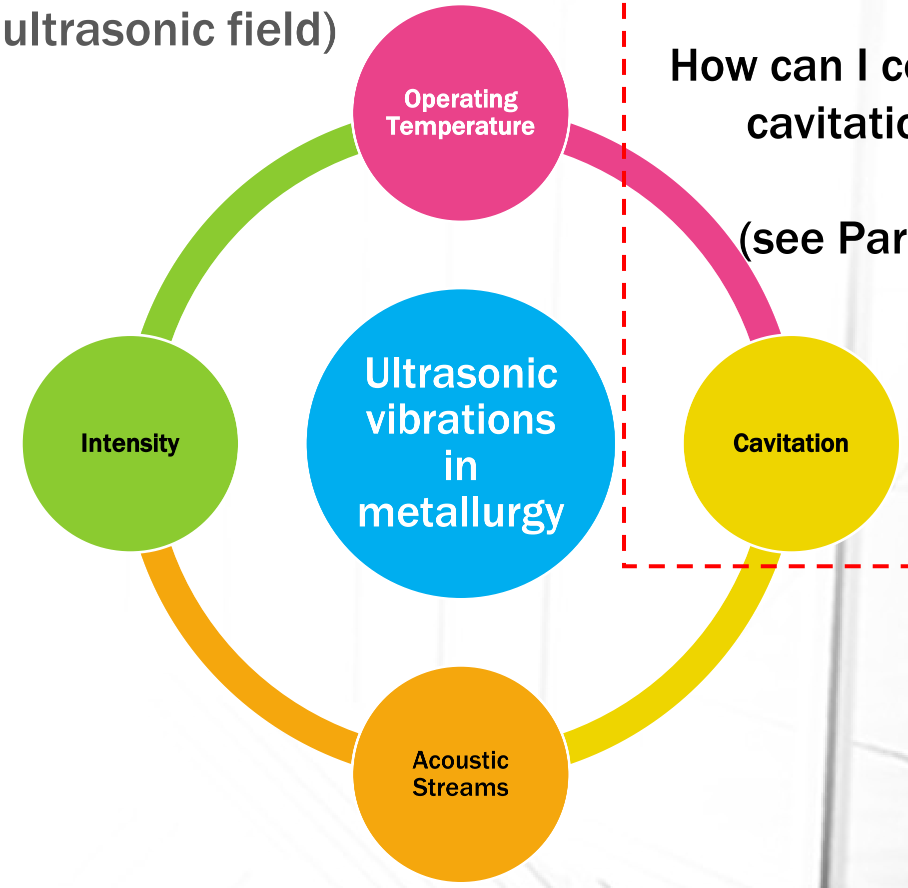
Theoretical foundations

- Cavitation – consequence of an external action (in this case ultrasonic field)
- Acoustic streaming

$$I = \frac{P}{S} \ (\frac{w}{cm^2})$$

Escaping toward surface





How can I controle cavitation?

(see Part 3)

Theoretical foundations

$$I = \frac{P}{A}\left(\frac{W}{cm^2}\right)$$

Advantages of Acoustic Processing

• Grain refinement with significantly improved and 3D uniformly distributed micro-crystallization.

• Disintegration, elimination, wetting and dissolving of non-metallic and metallic inclusions, making smooth intermetallic transitional areas.

• Alloys mixing with nano-particles, increasing density of alloys, varying percentages of alloy ingredients.

• Improving chemical, mechanical and physical properties and corrosion resistance, e.g. in Al-Li alloys and other aerospace alloys.

• Alloys' density increase until theoretical limits.

Theoretical foundations - Continuous and Static Casting with Ultrasound

Ultrasonic solidification

Degassing

Principle:
Supplying acoustic energy to a melt, in order to induce cavitation and initiate Sonocrystallization:

(i) A great number of small cavities developed inside the liquid.

(ii) Diffusion of hydrogen from the melt to developed bubbles

(iii) Large bubbles coagulate and float to a surface of liquid pool

Refinement of α-Al

Besides degassing, the development of cavitation promotes significant undercooling and formation of numerous solidification nuclei.

Si and Intermetallics modification

Grain refinement exerts a positive influence on several properties of cast aluminum, namely: porosity, shrinkage distribution, intermetallics distribution and mechanical properties.

Improve Mechanical Properties

Application of acoustic waves in treating of melt aluminum alloys.

A promising future

What is the role of casting / foundrymen in improving the properties of aluminium alloys?

- Control of melting process.
- Melt treatment: degassing, microstructure refinement and modification.
- Assessment of variables which could contribute to improved castings.

and…

Application of acoustic waves in treating of melt aluminum alloys.

A promising future

Ultrasound above the threshold of acoustic cavitation can be introduced into a molten metal (e.g. during the continuous casting process), this way promoting:

<u>Degassing of liquid metals using high intensity ultrasonic activity.</u>

<u>Ultrasonic grain modification technology (improving micro crystallization).</u>

<u>Ultrasonic filtering and refining of molten metal.</u>

<u>Ultrasonic mixing and homogenizing of liquids is exceptionally efficient.</u>

Liquids and liquid metals that do not mix in normal conditions can also be mixed in number of combinations, **homogenized and/or alloyed in high intensity ultrasonic reactors, or in certain ultrasonically optimized casting process.**

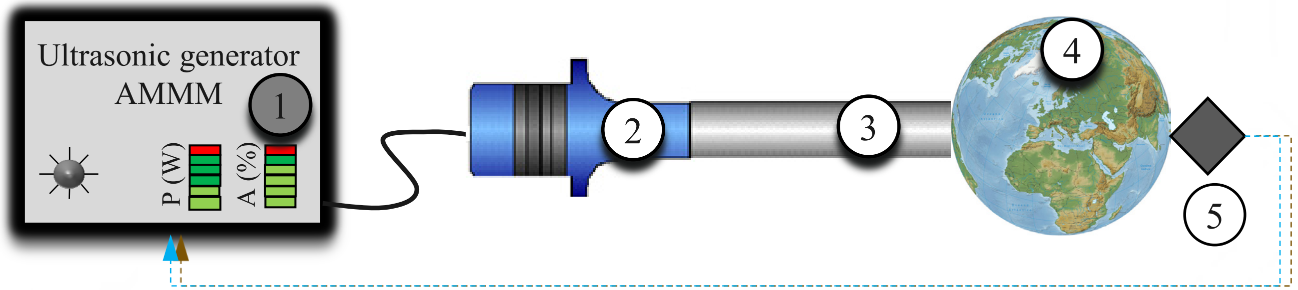
Reality & Practice

?

How can I control the process…
Using the MMM Technology

Can I control the process with my equipment…
Yes, using MMM Technology (cavitation control)

What are the best characteristics of "*Ultrasonic Activity*"…
Depends, but using MMM Technology you can chose



1 High frequency Ultrasonic generator

2 Ultrasonic Transducer

3 Waveguide

4 Load (medium…)

5 Sensor

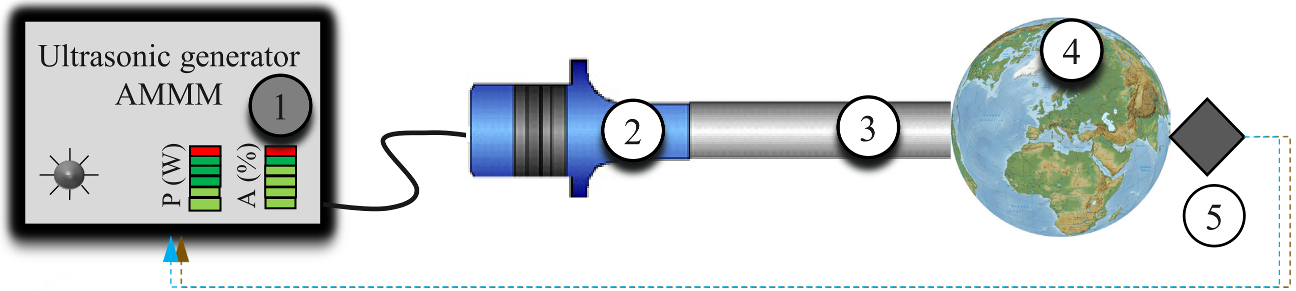
MMM Technology was developed by MPInterconsulting.

Based in Switzerland MPI has clients around the world.

MPI offers products, R&D services and consultancy in high power Ultrasonics, a range of top quality ultrasonic cleaning and sonochemistry equipment and special equipment development for new applications

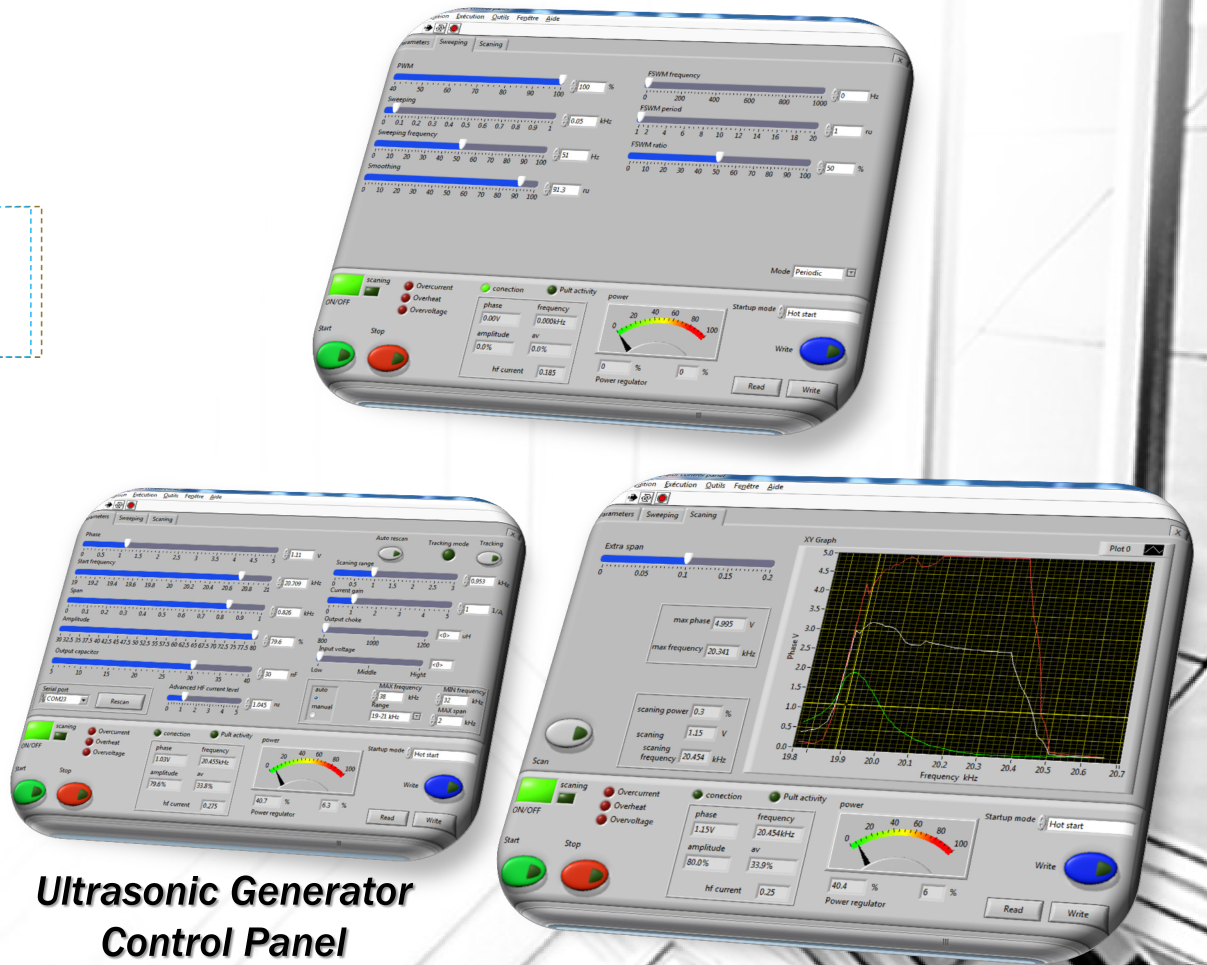
Reality & Practice – Control Options

Based on specific Lab View, multi-windows monitoring software (where we can monitor several of significant parameters related to cavitation in a time and frequency domains).



1 High frequency Ultrasonic generator 2 Ultrasonic Transducer

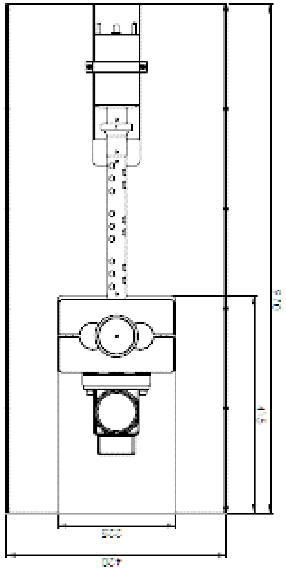
3 Waveguide 4 Load (medium...) 5 Sensor

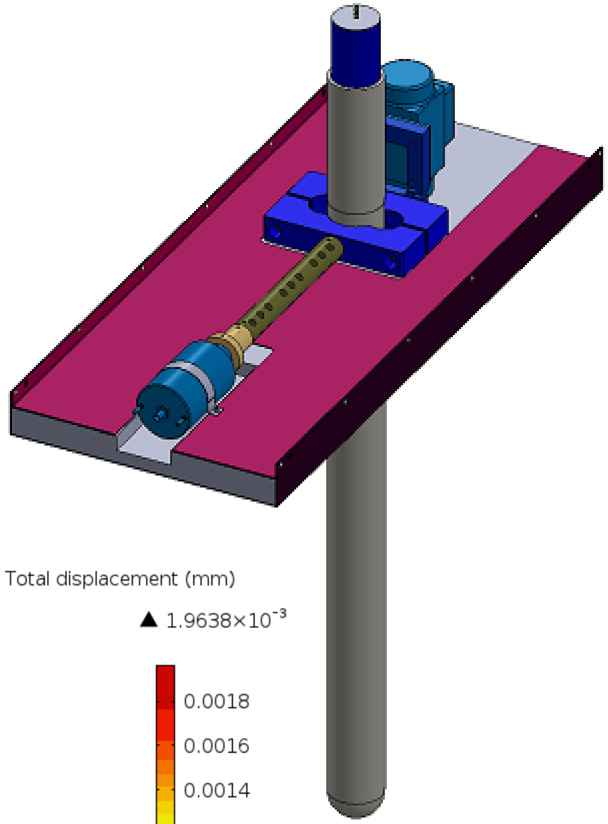


Ultrasonic Generator Control Panel

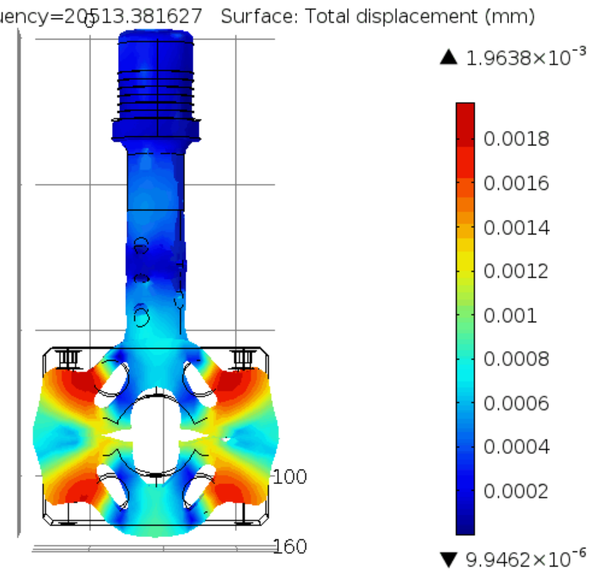
Design options
applied in processing of Light Alloy Melts

CAD

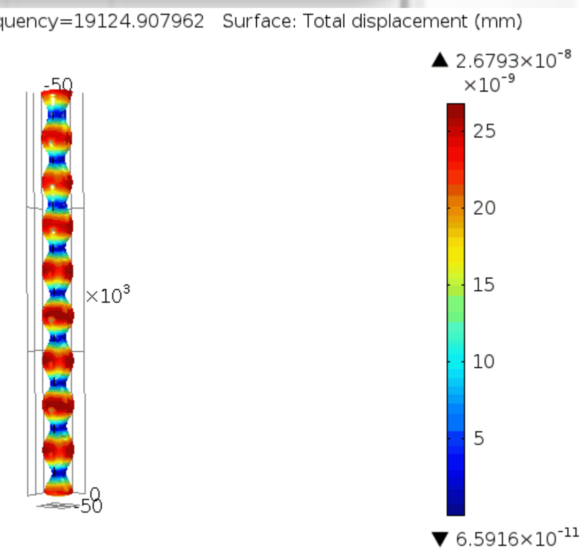




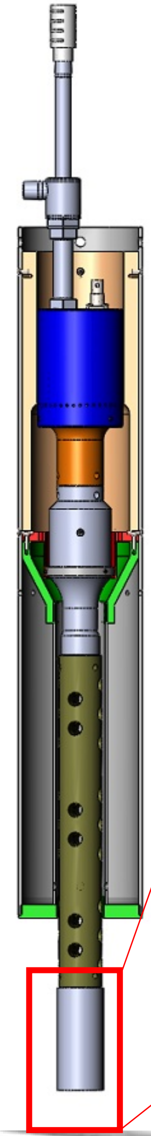
FEA

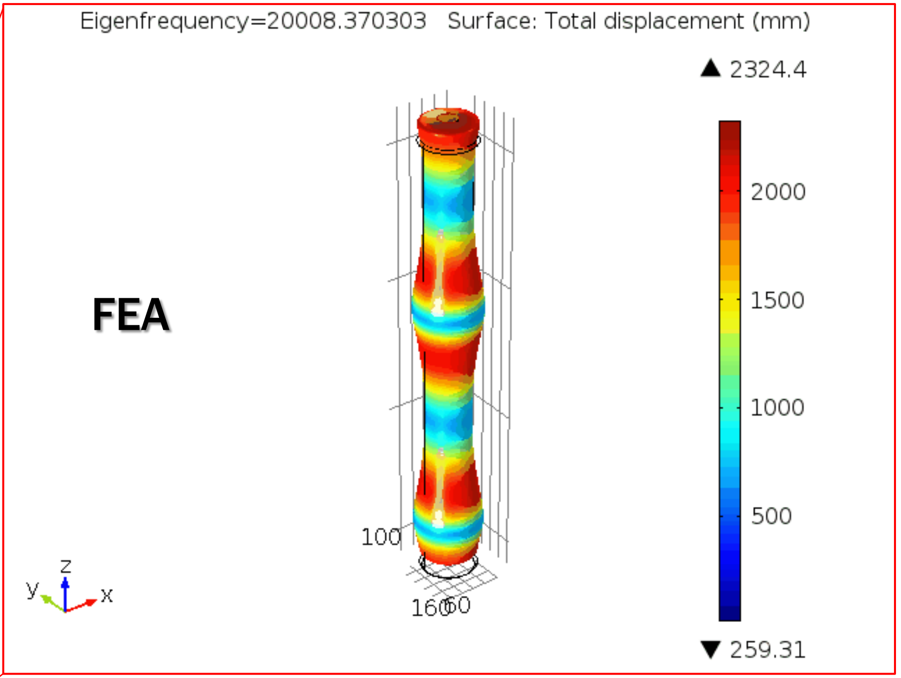


FEA



Design options
applied in processing of Light Alloy Melts

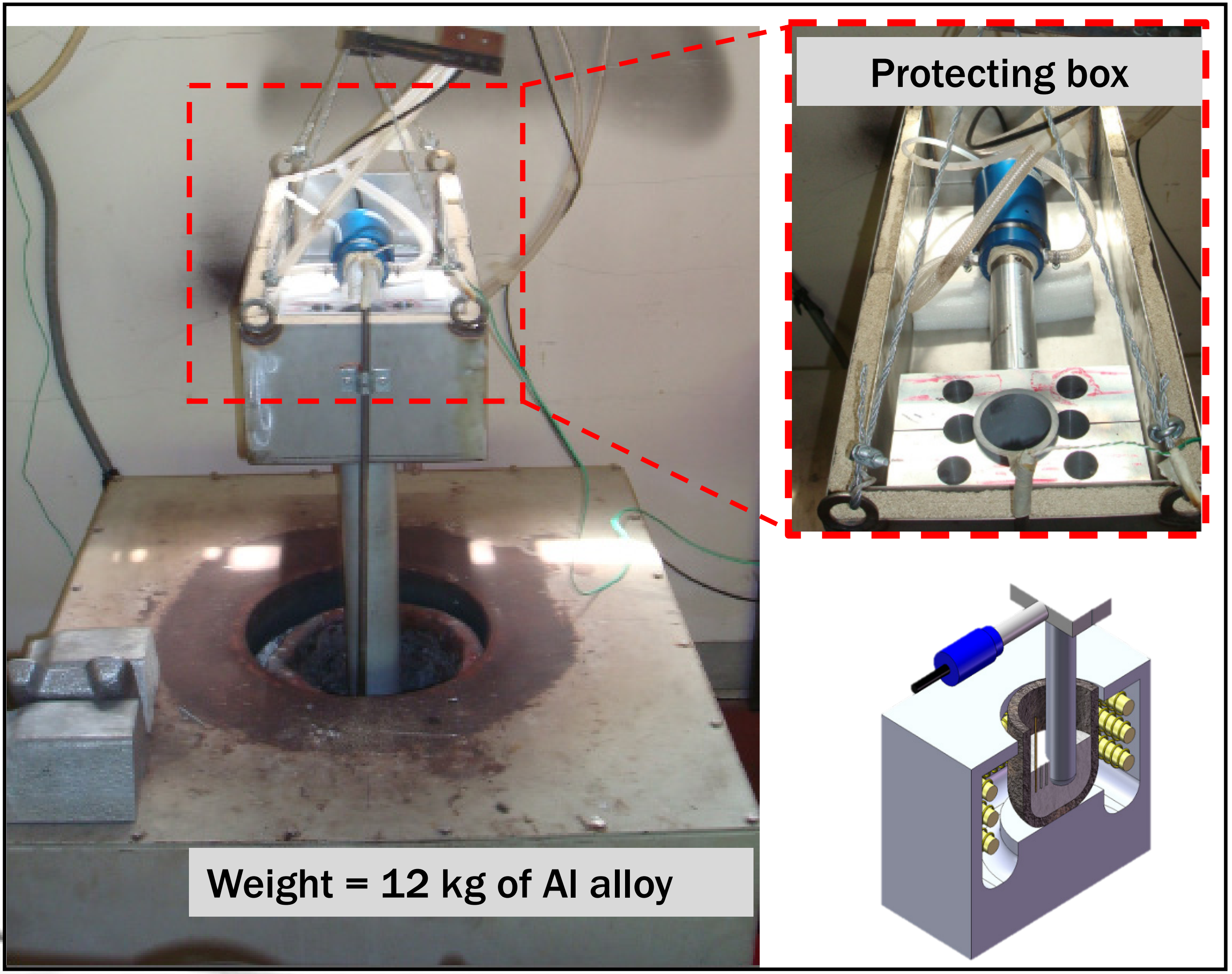




Diameters from 35 to 60mm.
Length from 1HWL to 4HWL.

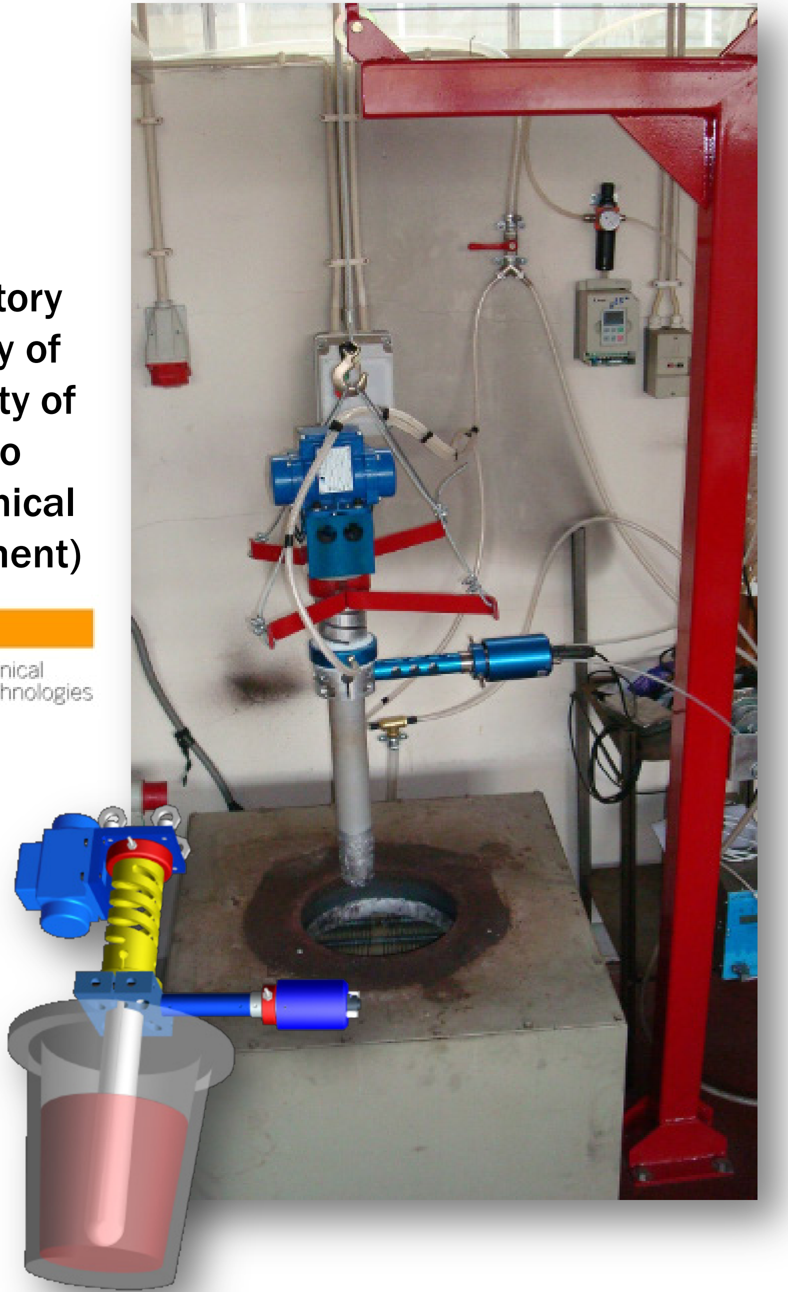
Sonotrode material:
Special Alloy resistant to wear with high amplitudes of vibration.

Different Design options
applied in processing of Light Alloy Melts



Laboratory Foundry of University of Minho (Mechanical Department)

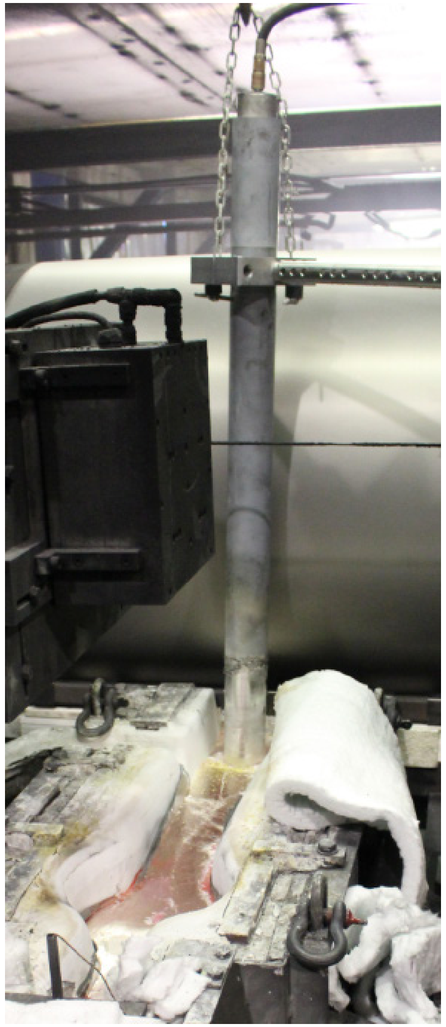
CT2M
Center for Mechanical and Materials Technologies



Different Design options
applied in processing of Light Alloy Melts

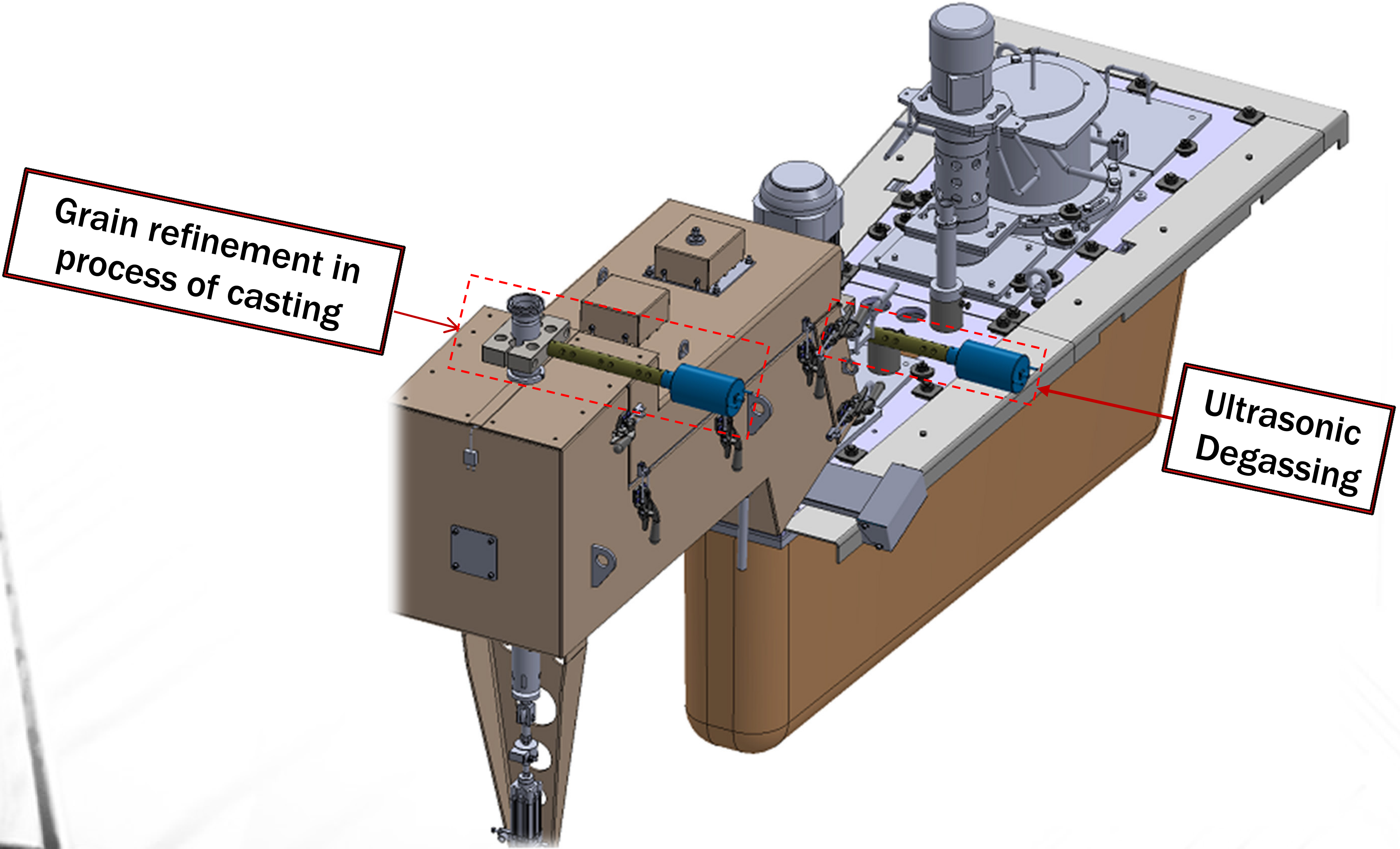
in Industrial environment

Degassing treatment

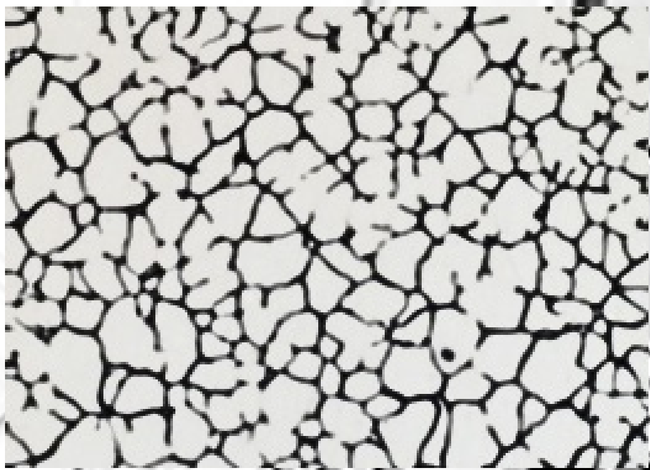


Grain refinement

Design options applied in processing of Light Alloy Melts

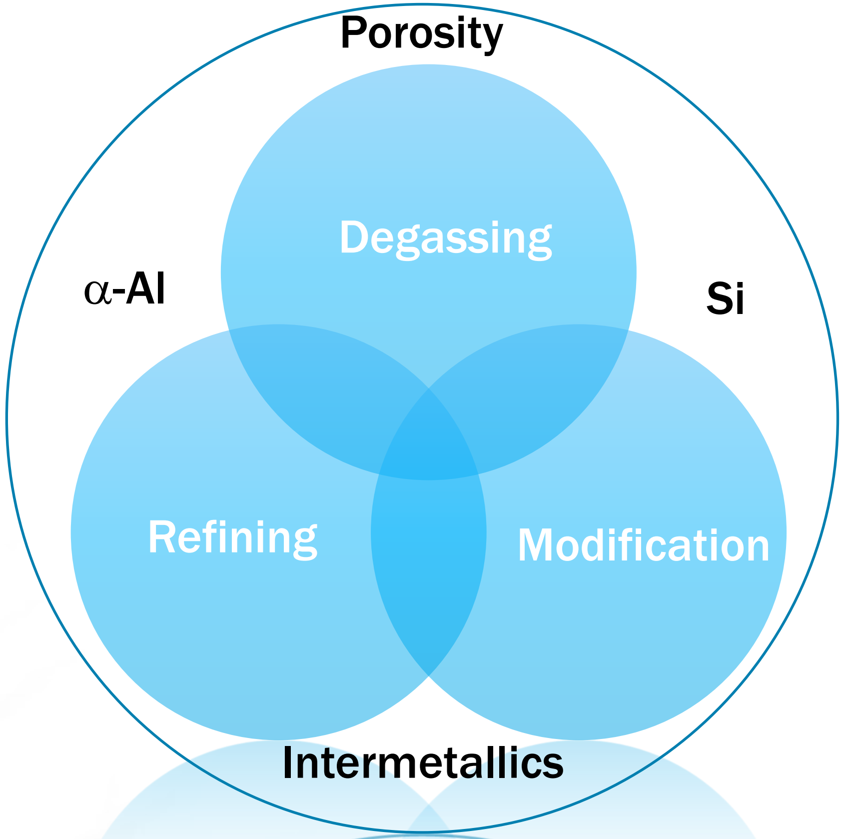


Light Alloys Furnace Ultrasonically optimized



*If we really understand the problem,
the answer will come out of it,
because the answer is not separate
from the problem.*

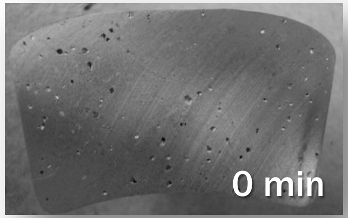
Results of MMM technology in processing of Aluminum alloys

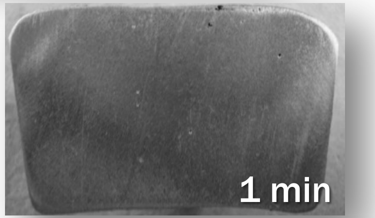


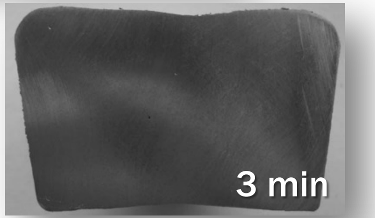
Results obtained with MMM Technology

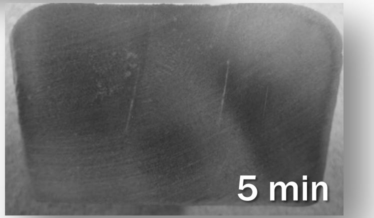
Static Casting, Ultrasonically Assisted

Some of our experimental results



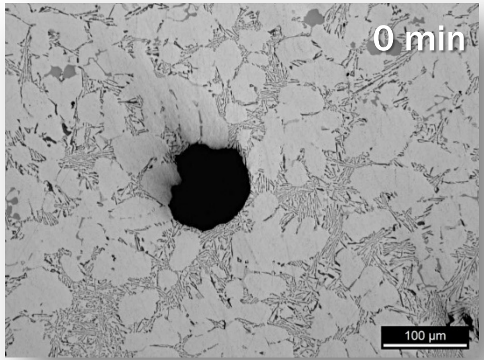


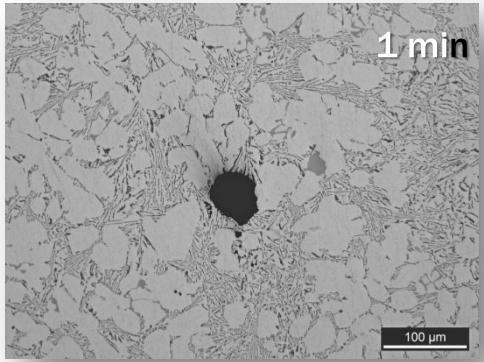




Samples

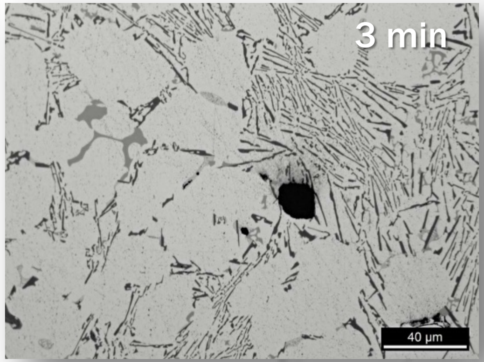
RPT tests

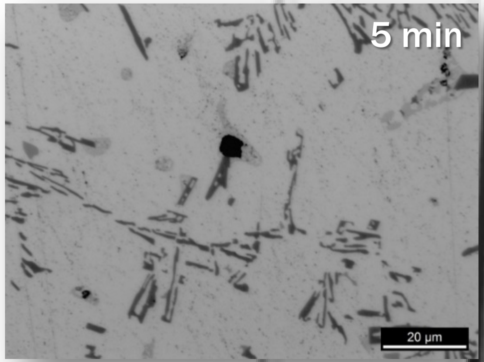




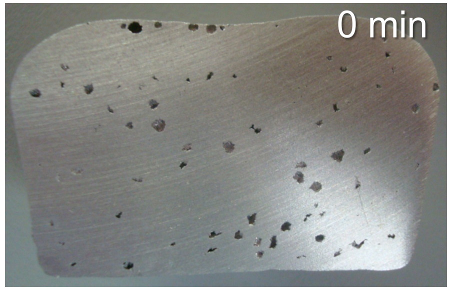
Samples

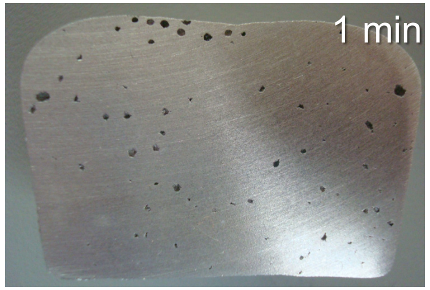
Porosity



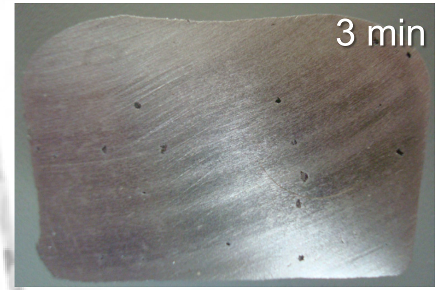


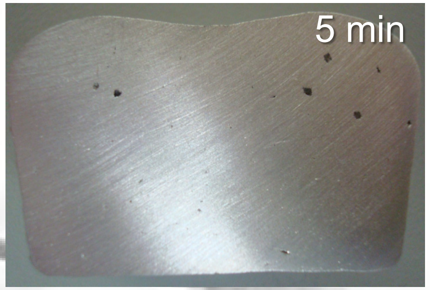
Static Casting, Ultrasonically Assisted



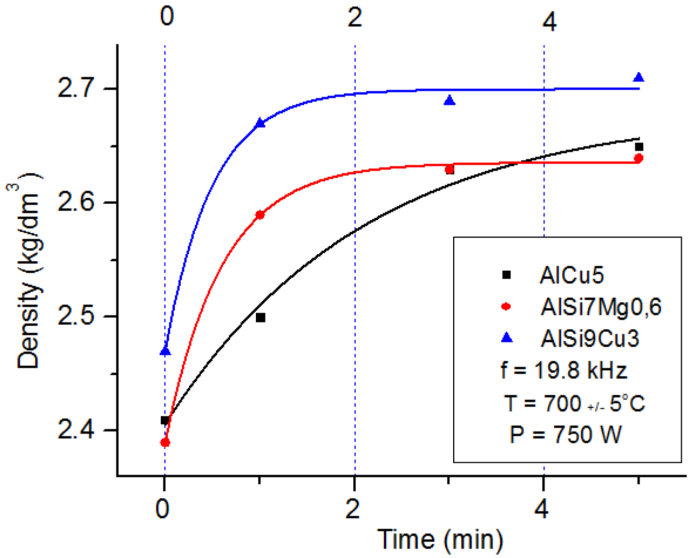


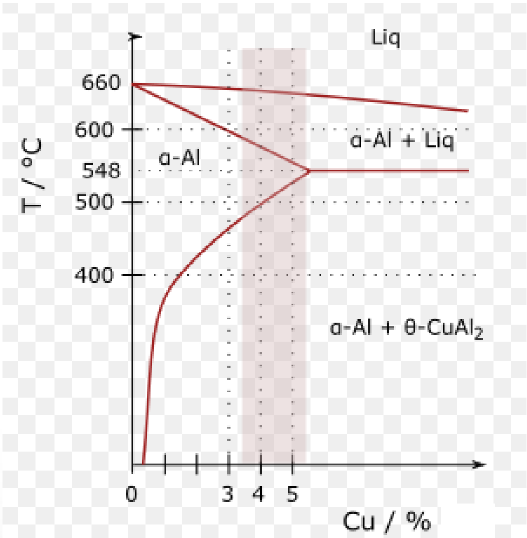
Al-Cu

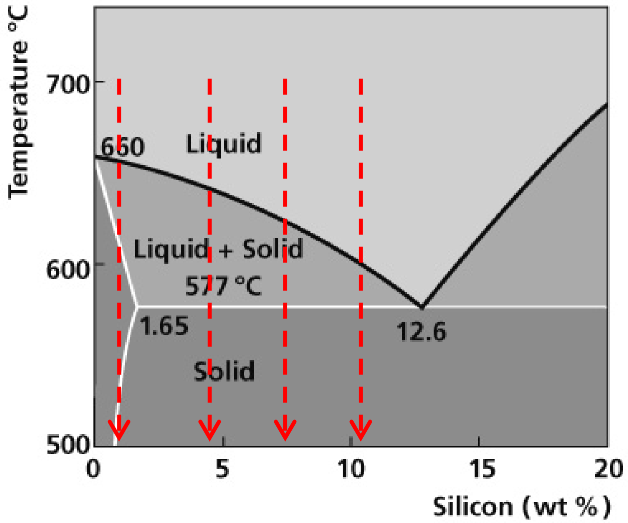


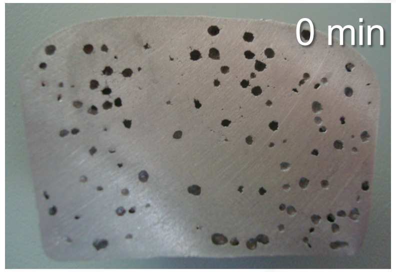


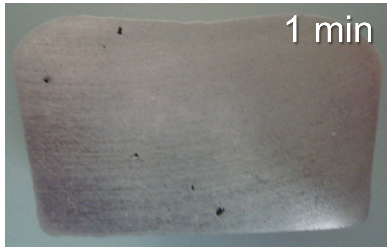
Some of our experimental results

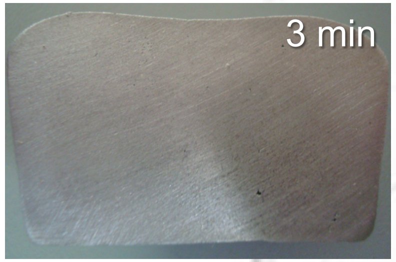








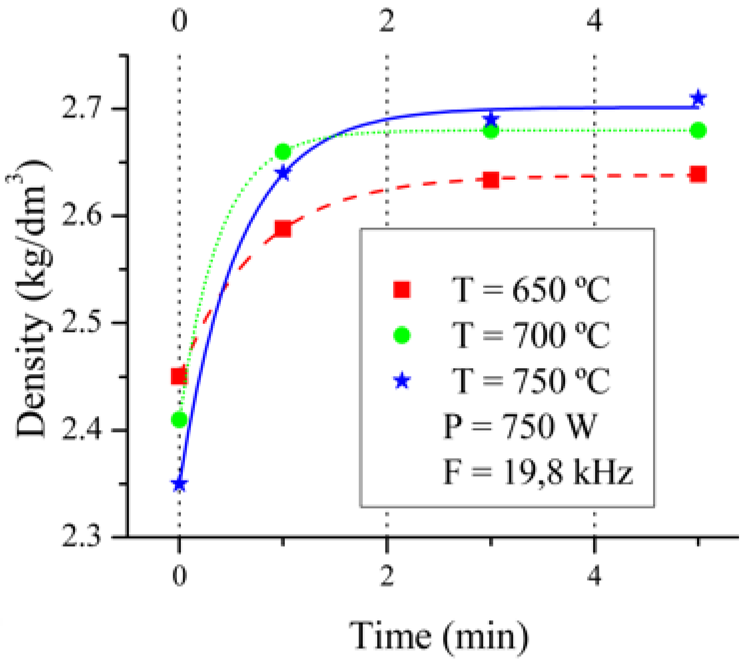


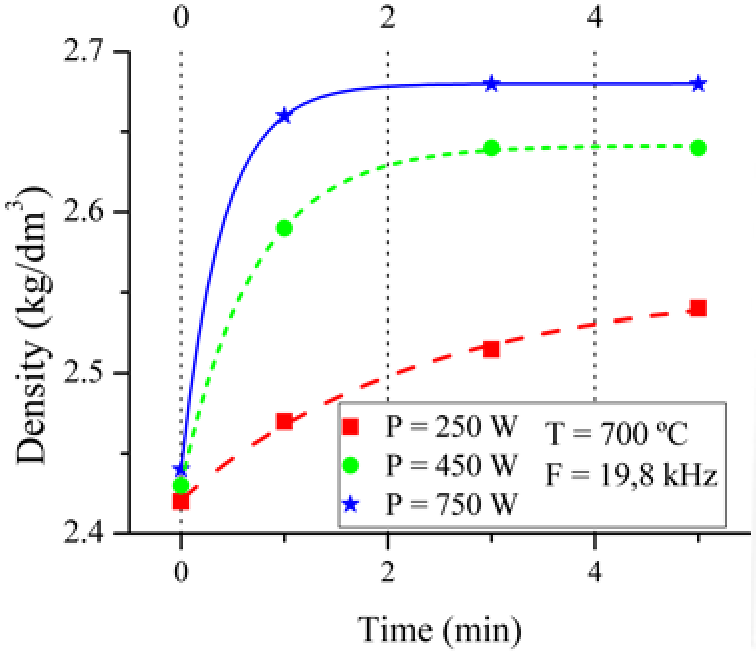


Al-Si-Mg

Static Casting, Ultrasonically Assisted

Some of our experimental results





6.63 W/cm^2

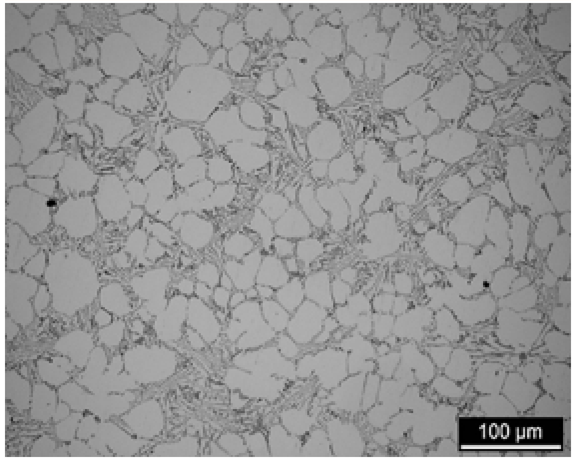
3.97 W/cm^2

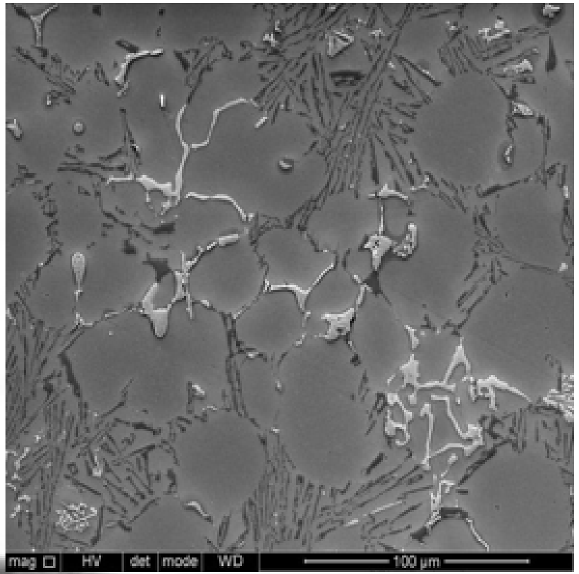
2.20 W/cm^2

Effect of temperature and ultrasonic power in Al-Si-Cu processing

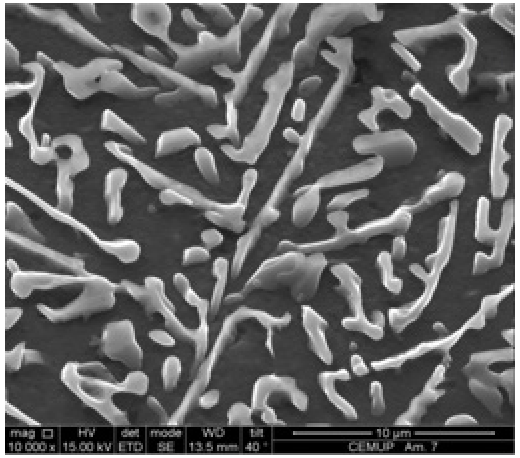
Static Casting, Ultrasonically Assisted

Some of our experimental results





Al-Si-Cu after ultrasonic processing

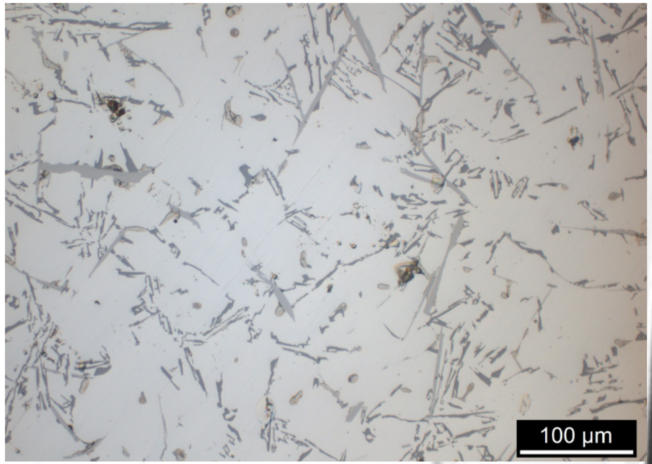


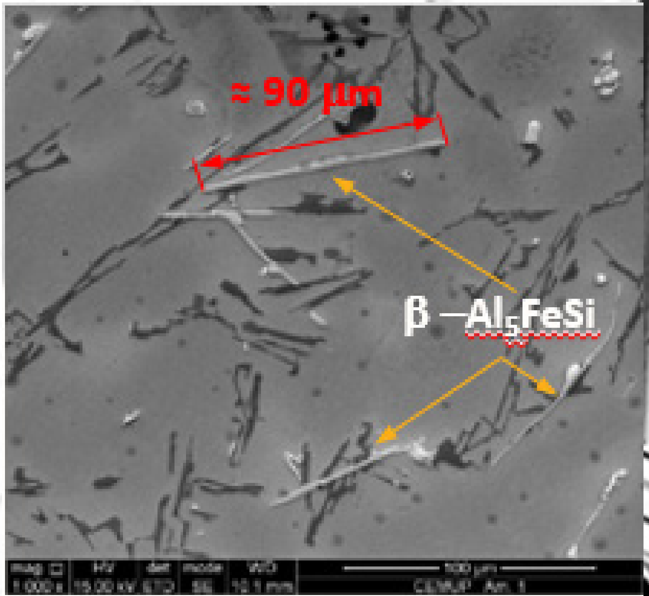
Samples

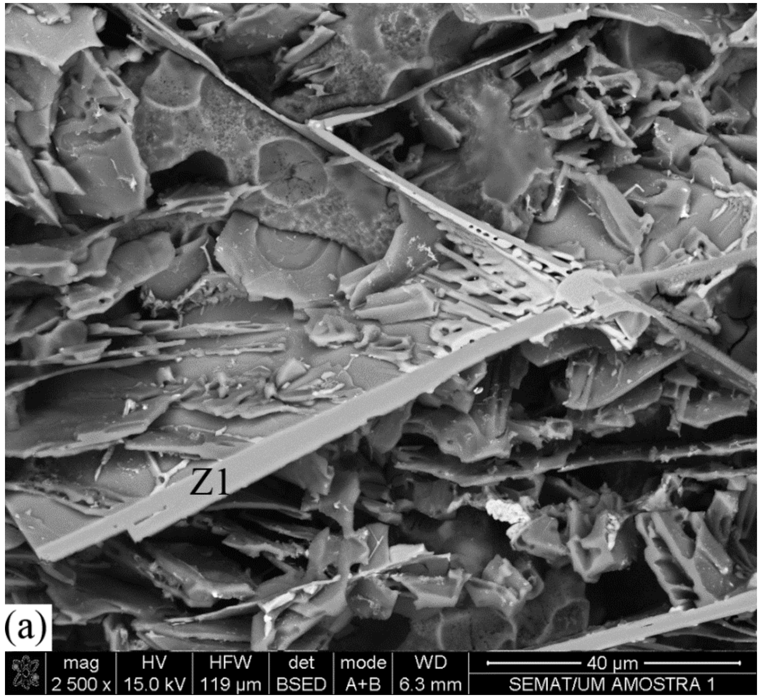
Refinement
Modification

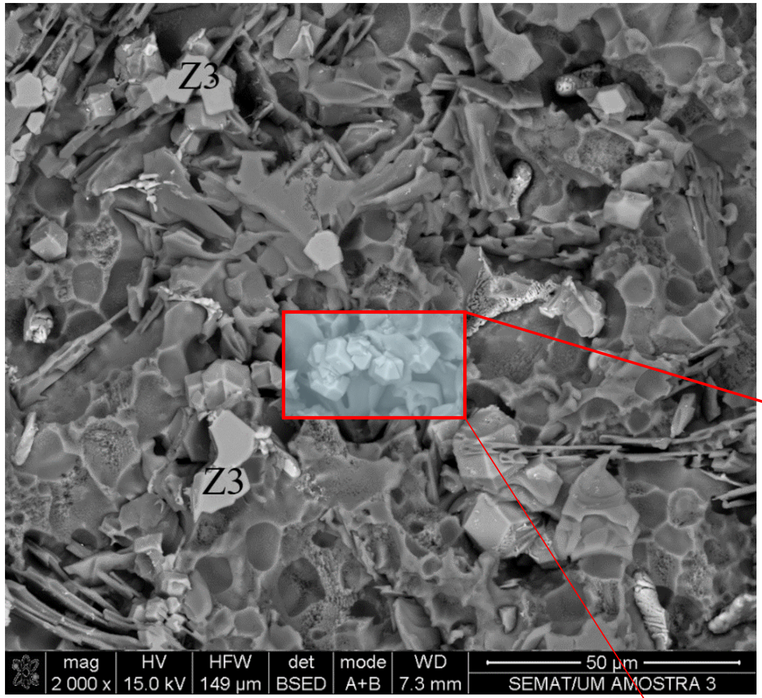
Optical microscope (OM) and Scanning Electron Microscope (SEM) with quantitative metallographic analysis capability were used to evaluate the shape and grain size of constituents

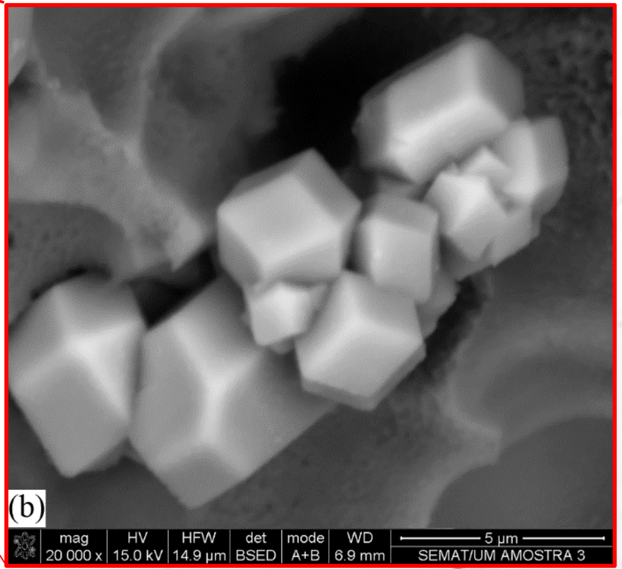
Al-Si-Cu before ultrasonic processing



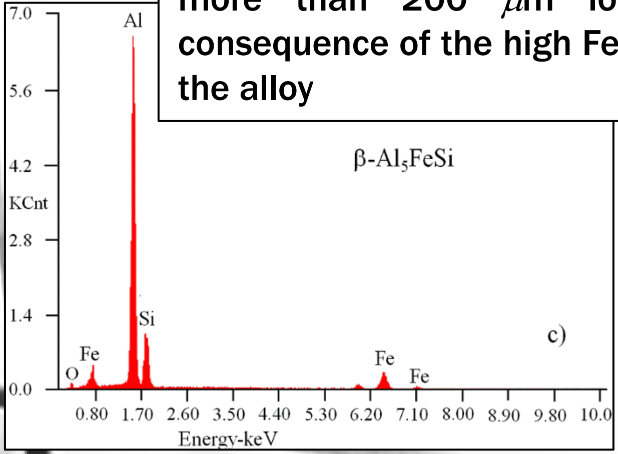


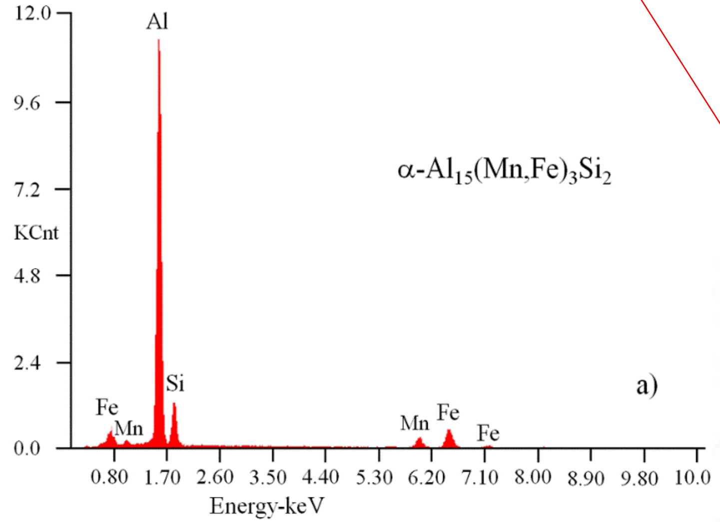






The long needles of β-Al5FeSi (light grey needles uniformly distributed in Figure 5 (b)) were, in some cases, more than 200 μm long, as a consequence of the high Fe content in the alloy





Static Casting, Ultrasonically Assisted

Static Casting, Ultrasonically Assisted

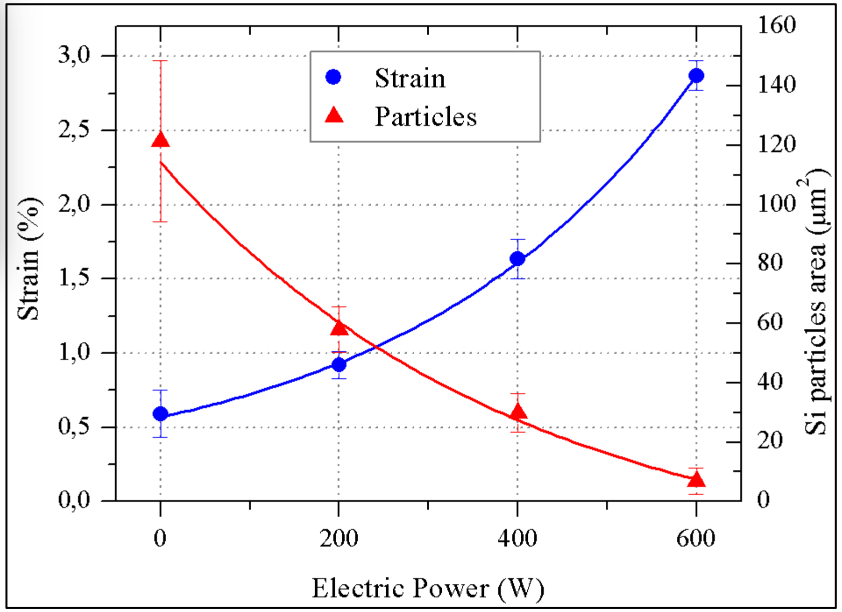
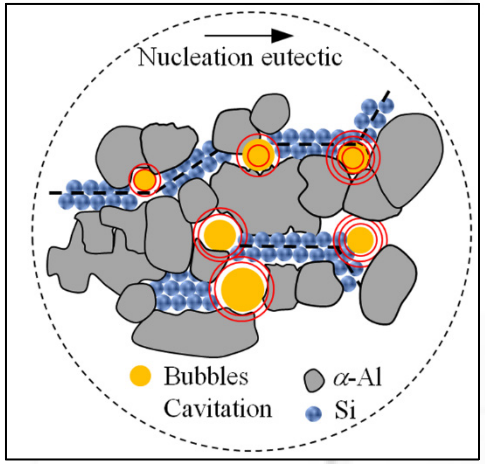


Fig. 1

According to the microstructures shown in Fig.1, it appears that the supply of acoustic energy to the melt during the stage of solidification has a high potential to change the morphology of eutectic silicon. In fact, the silicon lamellar/acicular morphology, typical for unmodified alloys (Fig.2) was transformed into a fibrous structure with rounded edges, compact and shaped polygons (Fig.3), of ultrasonically modified alloys.



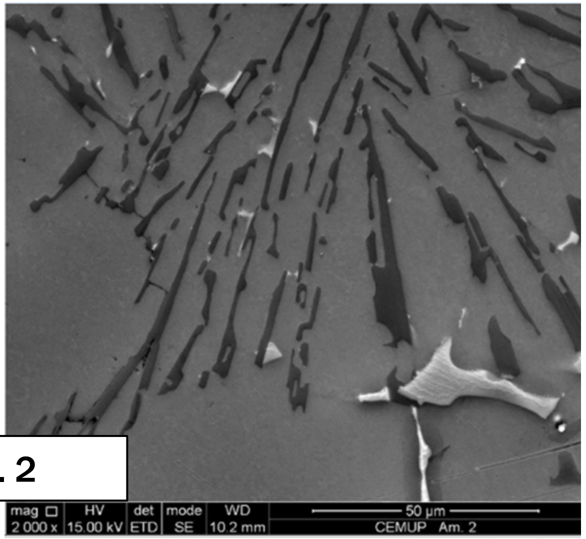


Fig. 2

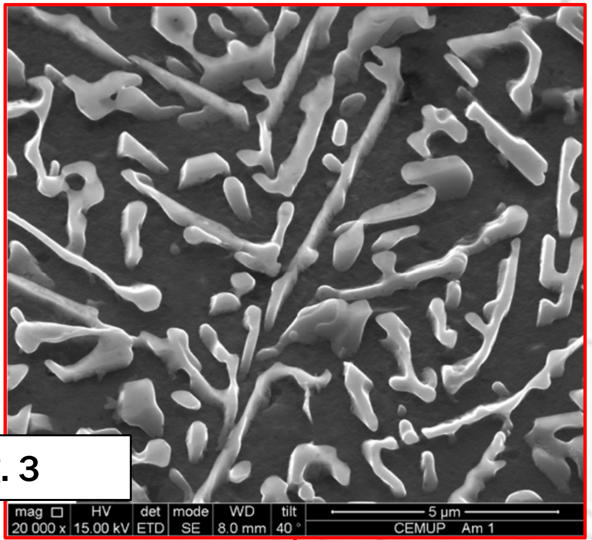
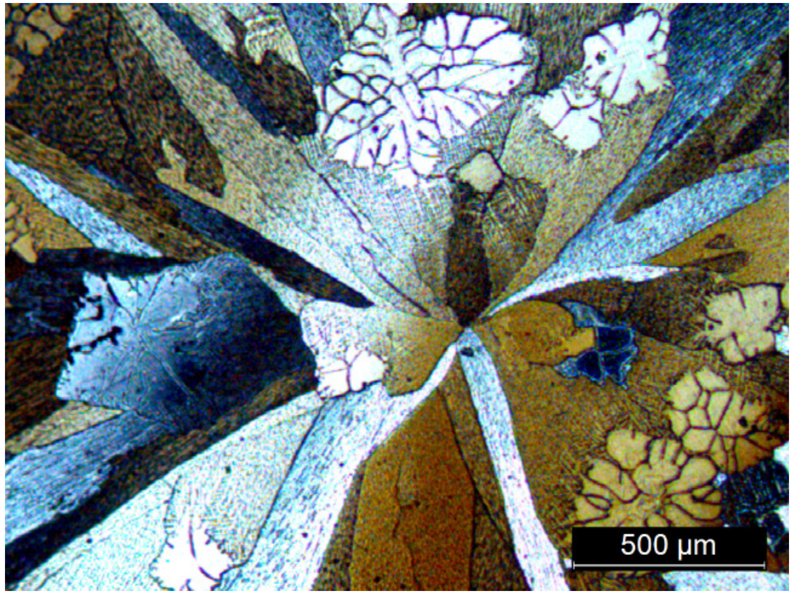


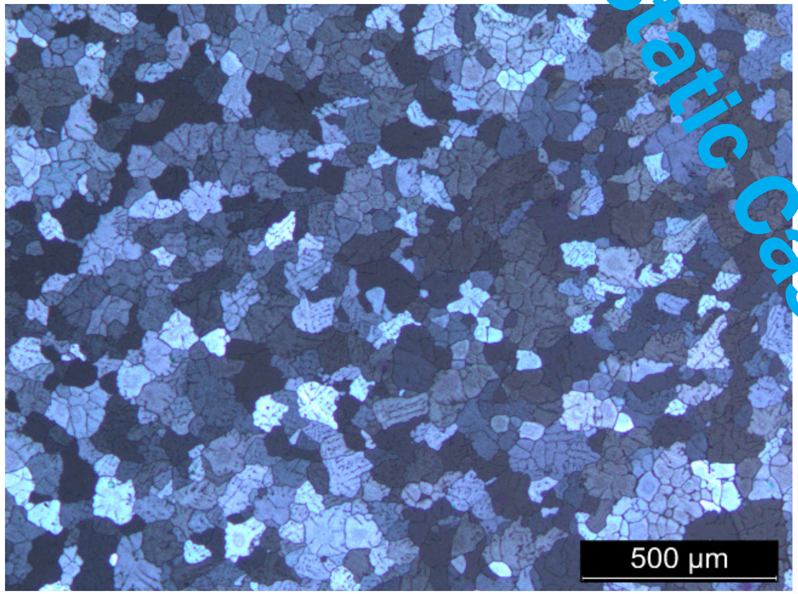
Fig. 3

Static Casting, Ultrasonically Assisted

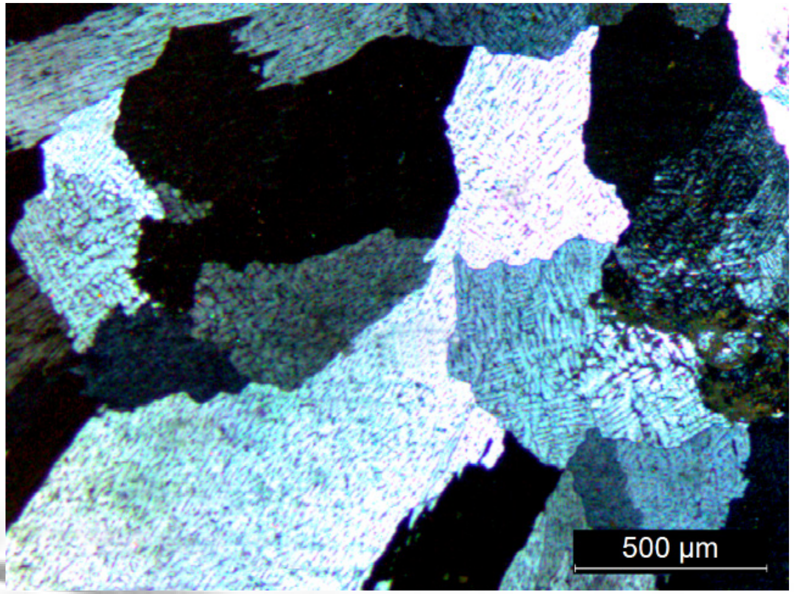
AlSc



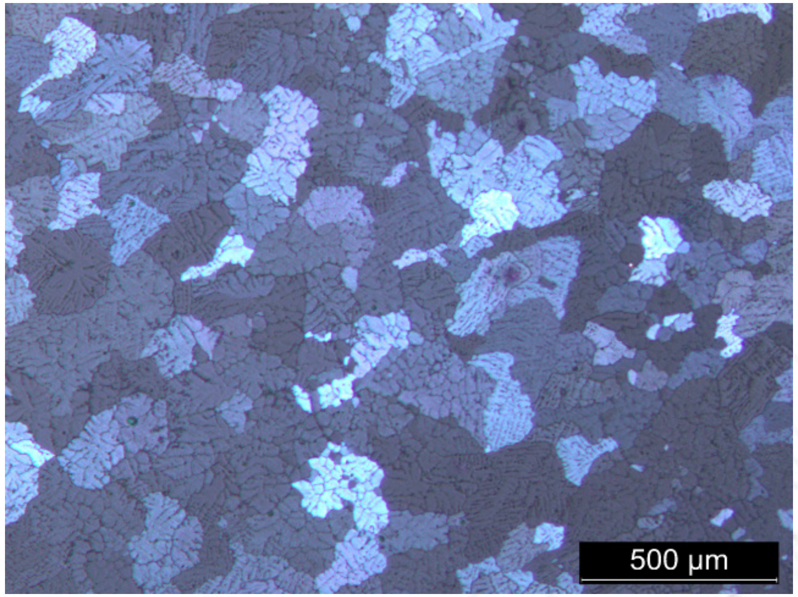
AlSc+US



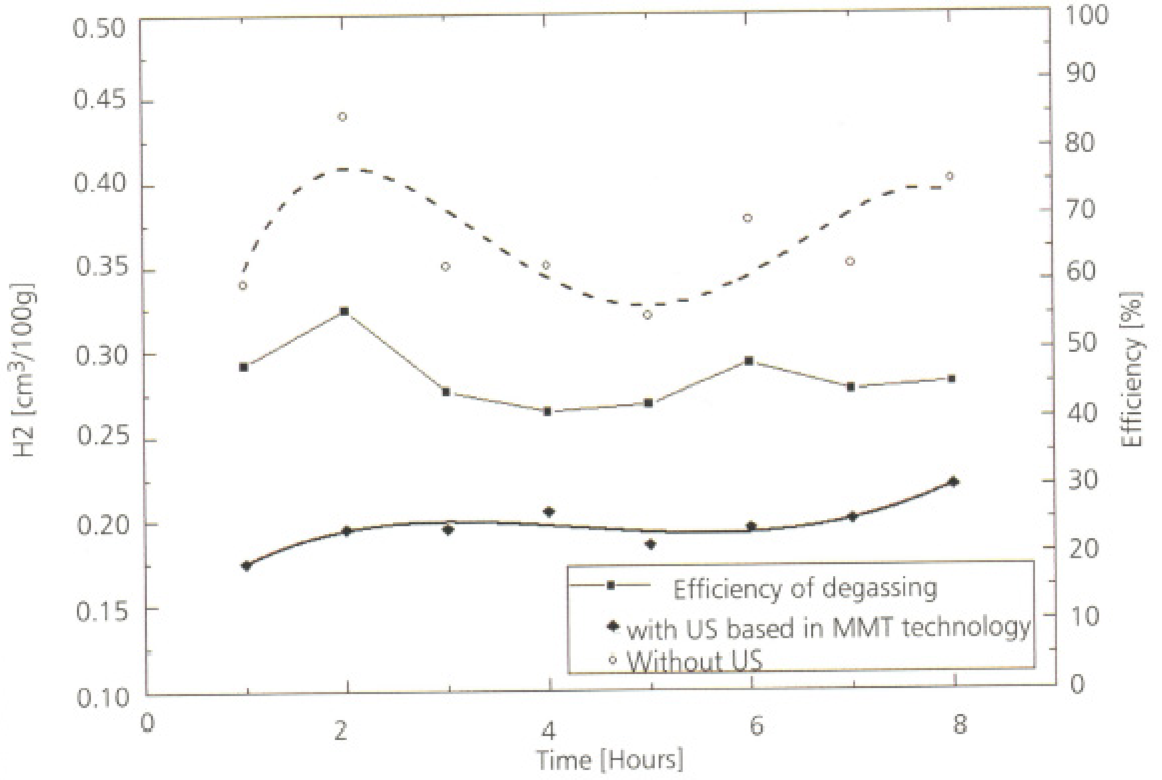
AlScMg



AlScMg+US



Continuous Casting, Ultrasonically Assisted

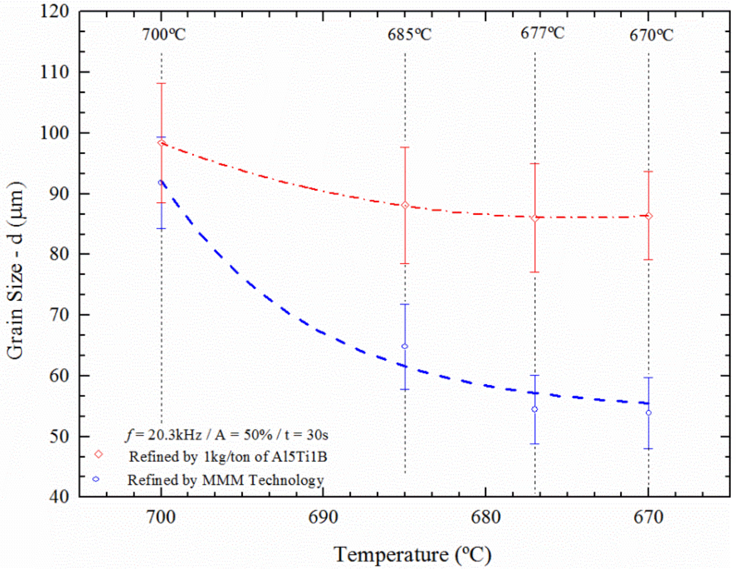


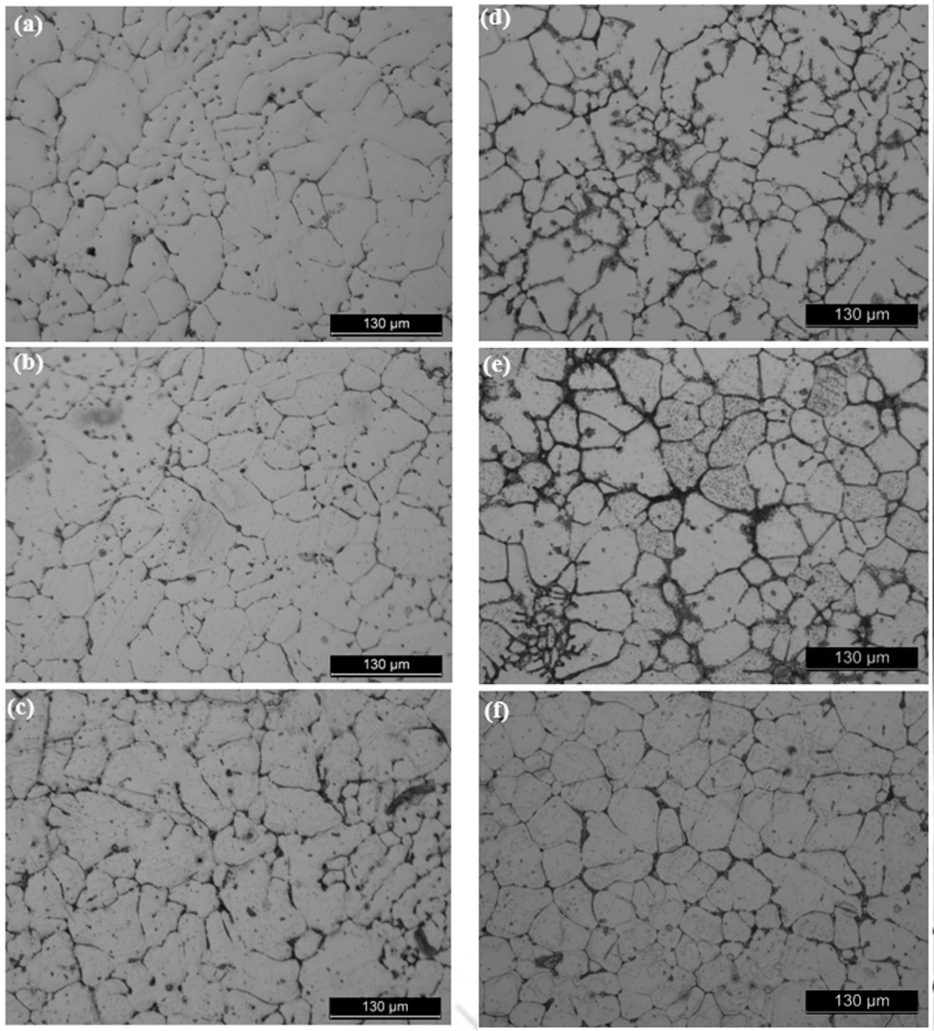
Hydrogen content in the melt of alloy of the series 3xxx along of time in Continuous casting

Continuous Casting, Ultrasonically Assisted

The efficiency of ultrasonic treatment (UST) depends on many factors, namely the ultrasonic parameters, such as amplitude and frequency of vibration, the degassing conditions (melt treatment temperature and processing time), the alloy composition, the material purity, and volume, all of great importance in the obtained results.

The Figure presents the as-cast microstructure of the Al-Mg-Mn alloy processed by different refinement techniques at different temperatures. From Figure it is clear that ultrasonic treatment had a significant effect on the microstructure morphology of the as-cast alloys and the final microstructure depends on the US treatment temperature, when compared with microstructure obtained after conventional treatment (refinement with 1kg/ton of Al5Ti1B).

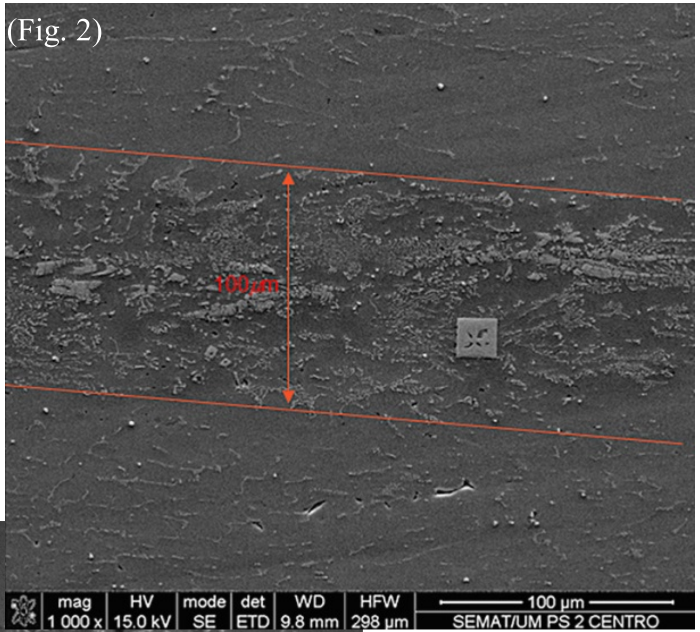




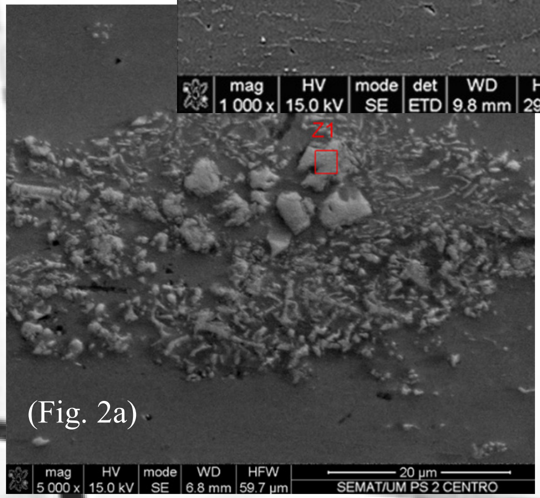
Effect of liquid temperature on the microstructure after casting Al-Mg-Mn: (a-c) with 1kg/ton of Al5Ti1B; (d-f) with MMM Ultrasonic Technology. (a) and (d) casting at 700C; (b) and (e) casting at 685ºC; (c) and (f) casting at 670ºC.

Continuous Casting, Ultrasonically Assisted

Trial was conducted on an industrial scale using the same alloy, according to the experimental results obtained in laboratorial scale. The Figure shows the contrasts of electronic microscopy microstructure of samples processed by traditional process (degassing by argon and refinement by addition of 1kg/ton of Al5Ti1B) (Fig. 1) and processed by MMM technology (regarding degassing and refinement) (Fig. 2). Fig. 1 shows the microstructure of the cross-section of alloy in which is clearly observed center zone segregation.

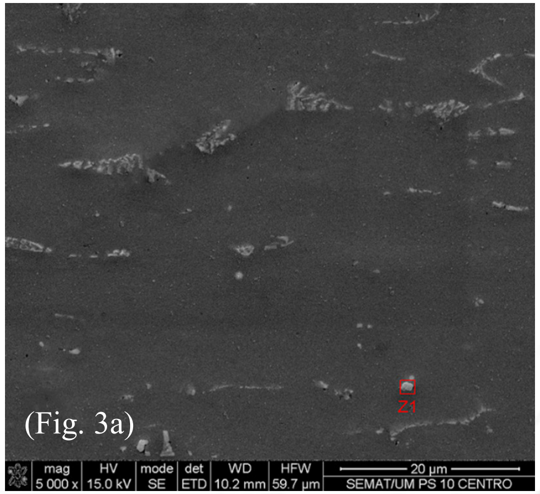


(Fig. 2)



(Fig. 2a)

Microstructures of strips of Al-Mg-Zn alloy after twin-roll casting



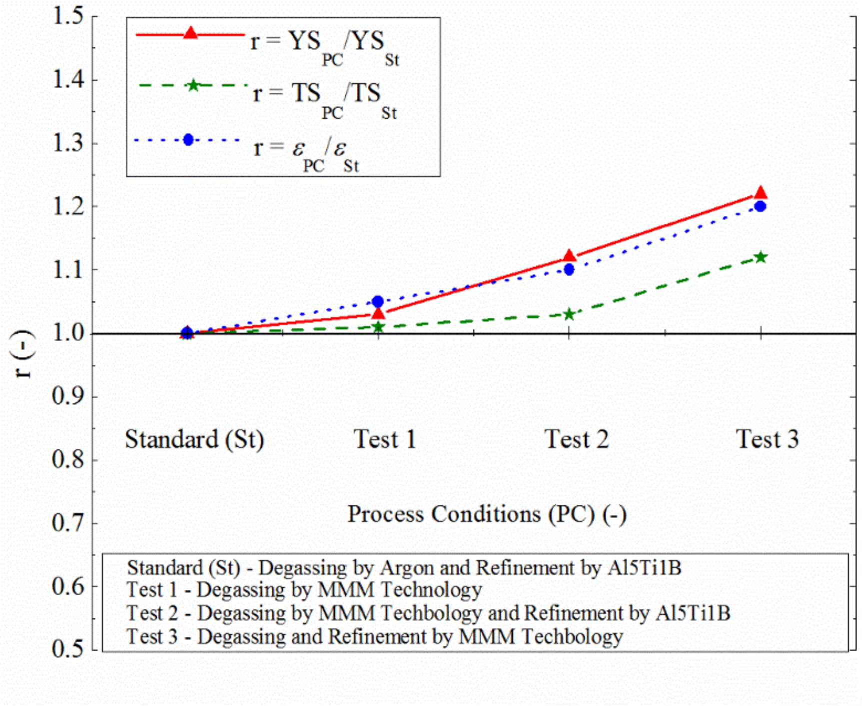
(Fig. 3a)

Besides the strong chemical segregation at the centre of the strip (Fig. 2) and the crystals homogeneously distributed (Fig. 3), the SEM analysis revealed the co-existence of other intermetallic phases, as presented in Fig. 2a and 3a, which morphology, EDS X-ray spectra suggest presence of the composition of AlMnFeSi.

When compared with the microstructure of the non-US processed samples (conventional process), the phases present in the US-treated samples (Fig. 3a) revealed a more uniform distribution, and their morphologies were significantly different.

Continuous Casting, Ultrasonically Assisted

According to trial results is clear that is possible to increase alloy mechanical properties with a correct melt treatment, especially when ultrasonic treatment with MMM technology is applied (Test 3 – see Figure). These results are according to good homogenization of microstructure morphology and low level of porosity verified in the samples tested. Also, this results are according to bibliography where is mentioned that mechanical properties of Al alloys depend on several factors, namely to microstructure morphology and size and distribution of porosities.

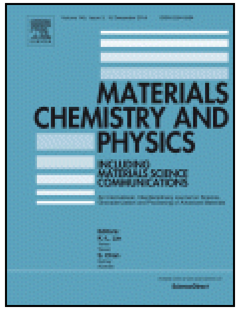


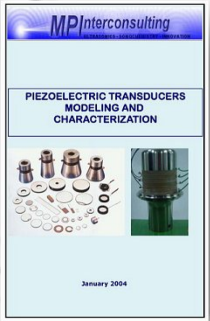
Relation of mechanical properties of strips of Al-Mg-Zn alloy after twin-roll casting

In what concerns to microstructure refining and modification by ultrasound, the main conclusions to be drawn from the experimentation are:

- Ultrasonic degassing can be an efficient process to degas molten aluminium alloys.
- The degassing efficiency depends on the electric energy that is converted into acoustic energy, which affects the degassing rate and the final alloy density, but it is not affected by the resonant frequency;
- US processing is an external supply of energy – physical process – environmentally clean and efficient that promotes refinement of the α-Al and eutectic Si phases, and decrease of porosity.
- US processing promotes the change of α-Al dendritic morphology, which is typical in die-castings, into globular morphology, which size depends on applied ultrasonic power and the distance from ultrasonic radiation emitting surface.
- US processing promotes the amelioration of mechanical properties.
- Elimination of traditional argon degassing and replacement with ultrasonic degassing (savings in argon and electricity for mixing).
- Better alloying, wetting, disintegration, homogenization and integration of all metallic and non-metallic ingredients and impurities into a metal mass (we get: more homogenous, harder, no defect, no intermetallic long needle).

Publications





<u>Physical modification of intermetallic phases in Al-Si-Cu alloys</u>
J. Barbosa, **H. Puga**, J. Oliveira, A. S. Ribeiro, **M. Prokic**
Materials Chemistry and Physics 148 (2014) 1163–1170

<u>Influence of indirect ultrasonic vibration on the microstructure and mechanical behavior of Al-Si-Cu alloy</u>
H. Puga, J. Barbosa, S.Costa, A.M.P.Pinto, S. Ribeiro, **M. Prokic**
Materials Science & Engineering A 560 (2013) 589–595

<u>Influence of ultrasonic melt treatment on microstructure and properties of AlSi9Cu3 alloy</u>
H. Puga, S.Costa, J. Barbosa, S. Ribeiro, **M. Prokic**
Journal of Materials Processing Technology 211 (2011) 1729-1735

<u>The combined effect of melt stirring and ultrasonic agitation on the degassing efficiency of AlSi9Cu3 alloy</u>
H. Puga, J. C. Teixeira, J. Barbosa,E. Seabra, S. Ribeiro, **M. Prokic**
Materials Letters 63 (2009) 2089-2092

<u>The influence of processing parameters on the ultrasonic degassing of molten AlSi9Cu3 aluminium alloy</u>
H. Puga, J. Barbosa, E. Seabra, S. Ribeiro, **M. Prokic**
Materials Letters 63 (2009) 806-808

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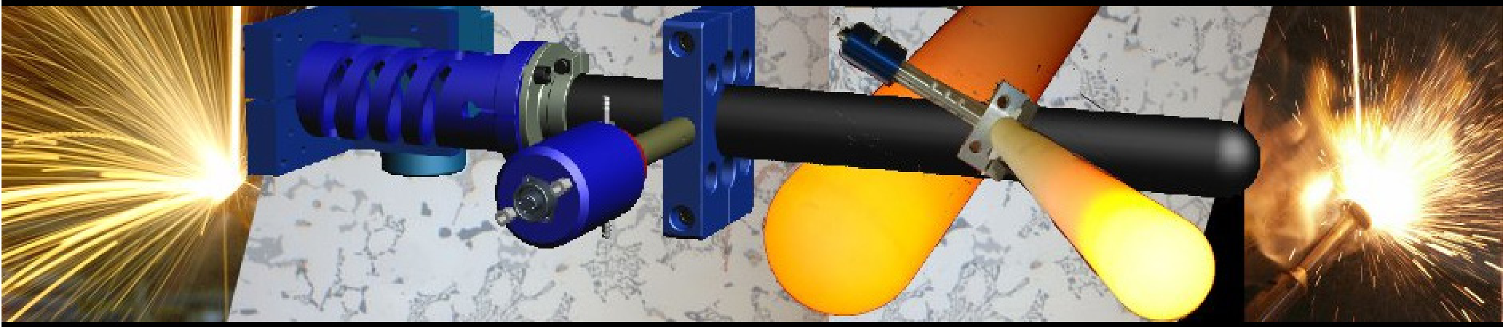
<u>Piezoelectric Transducers Modeling and Characterization</u>
Miodrag Prokic, 240 pages, January 2004
MPI, Le Locle, Switzerland,
www.mpi-ultrasonics.com

Patents

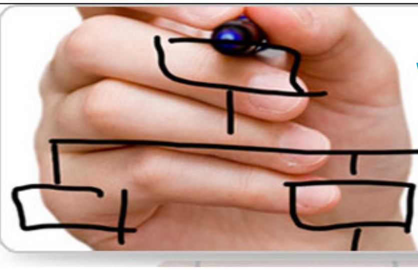
<u>European Patent Application (related to MMM technology): EP 1 238 715 A1</u>
Multifrequency ultrasonic structural actuator
Applicant: **Prokic Miodrag**, MP Interconsulting, 5.03.2001 – 11.09.2002



Ultrasonic vibrations in metallurgy…

Some ideas/proposal

Part 2



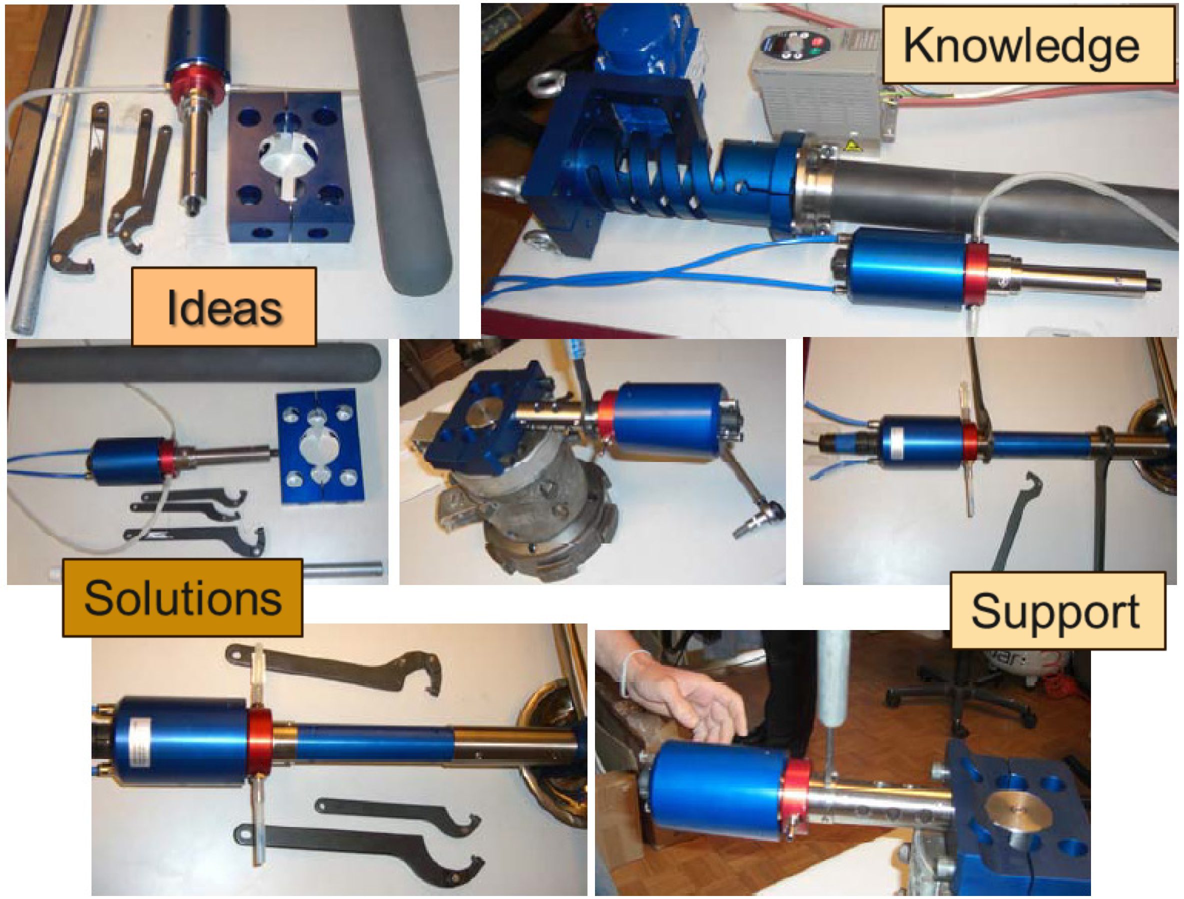
Solutions..

What we need?

-Improve the quality of products

-Save processing energy

Thanks to MMM technology



Remarks

Traditionally available ultrasonic equipment for liquid metals treatment is still not compatible with high-volume, in-line metal processing (single frequency is creating standing waves and dead zones).

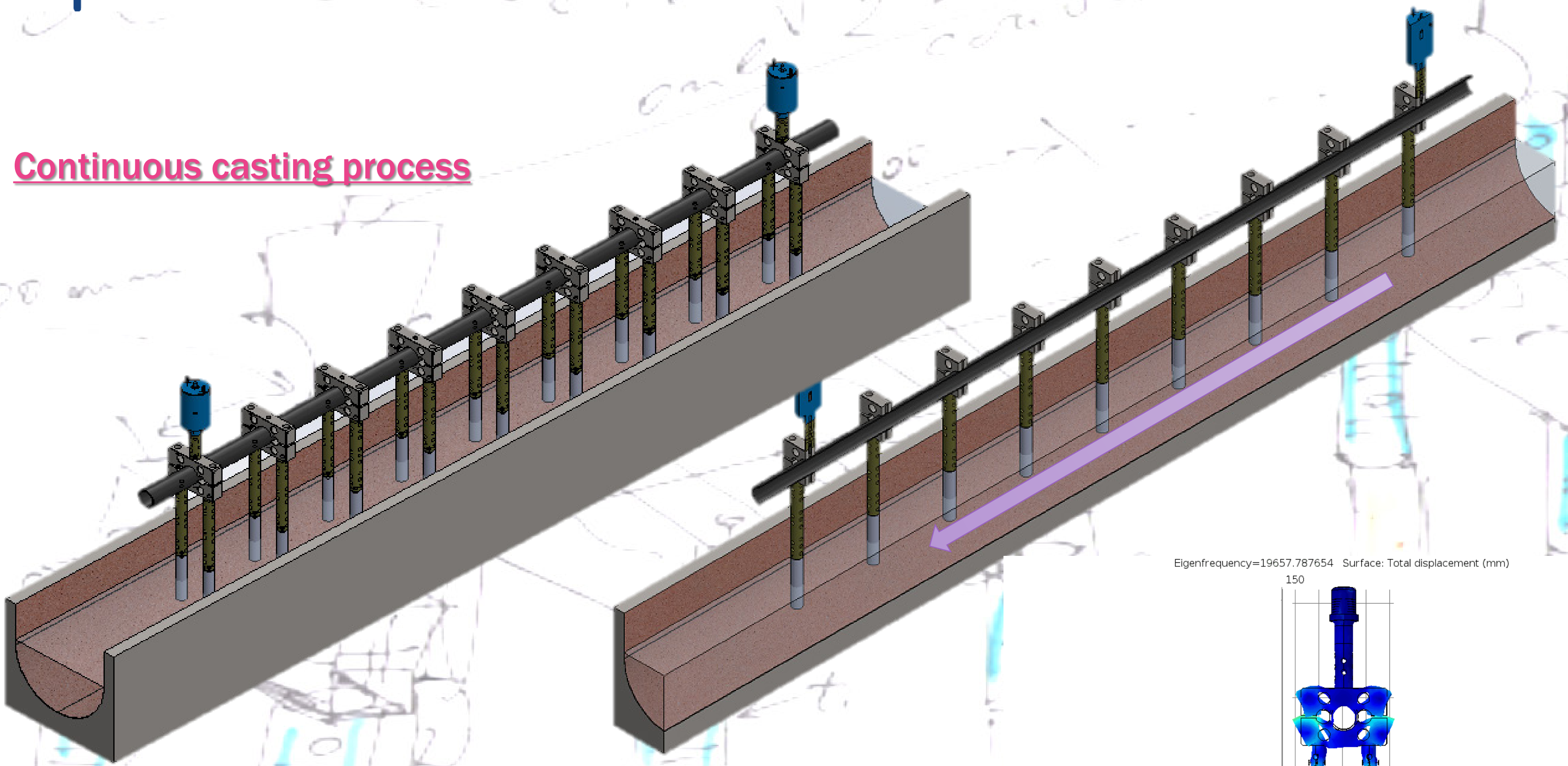
High temperature of liquid metals presents an enormous problem to continuous operation of ultrasonic transducers.

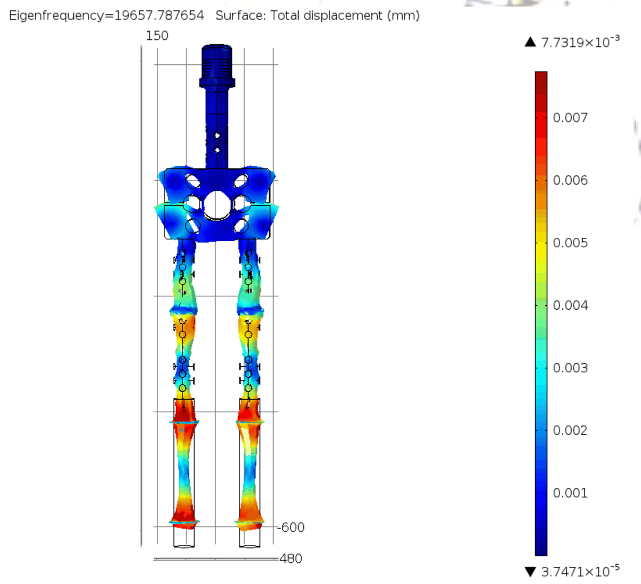
We can now separate the ultrasonic transducers from the liquid metal using long metal waveguide rods, yet still introduce high ultrasonic power into liquid metals.

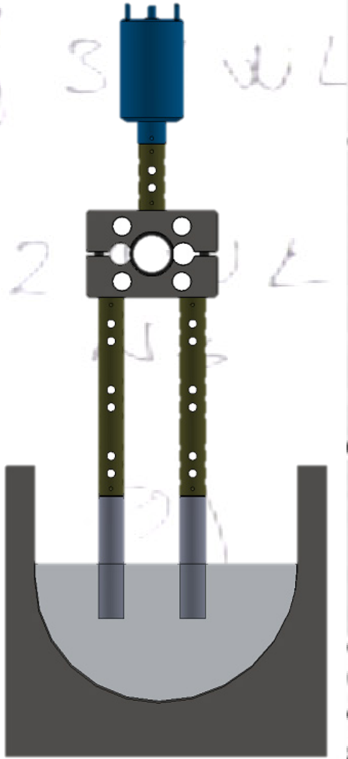
proposal for your factory

*Inventing is mixing brains and materials.
The more brains you use, the less materials you need.*

Continuous casting process







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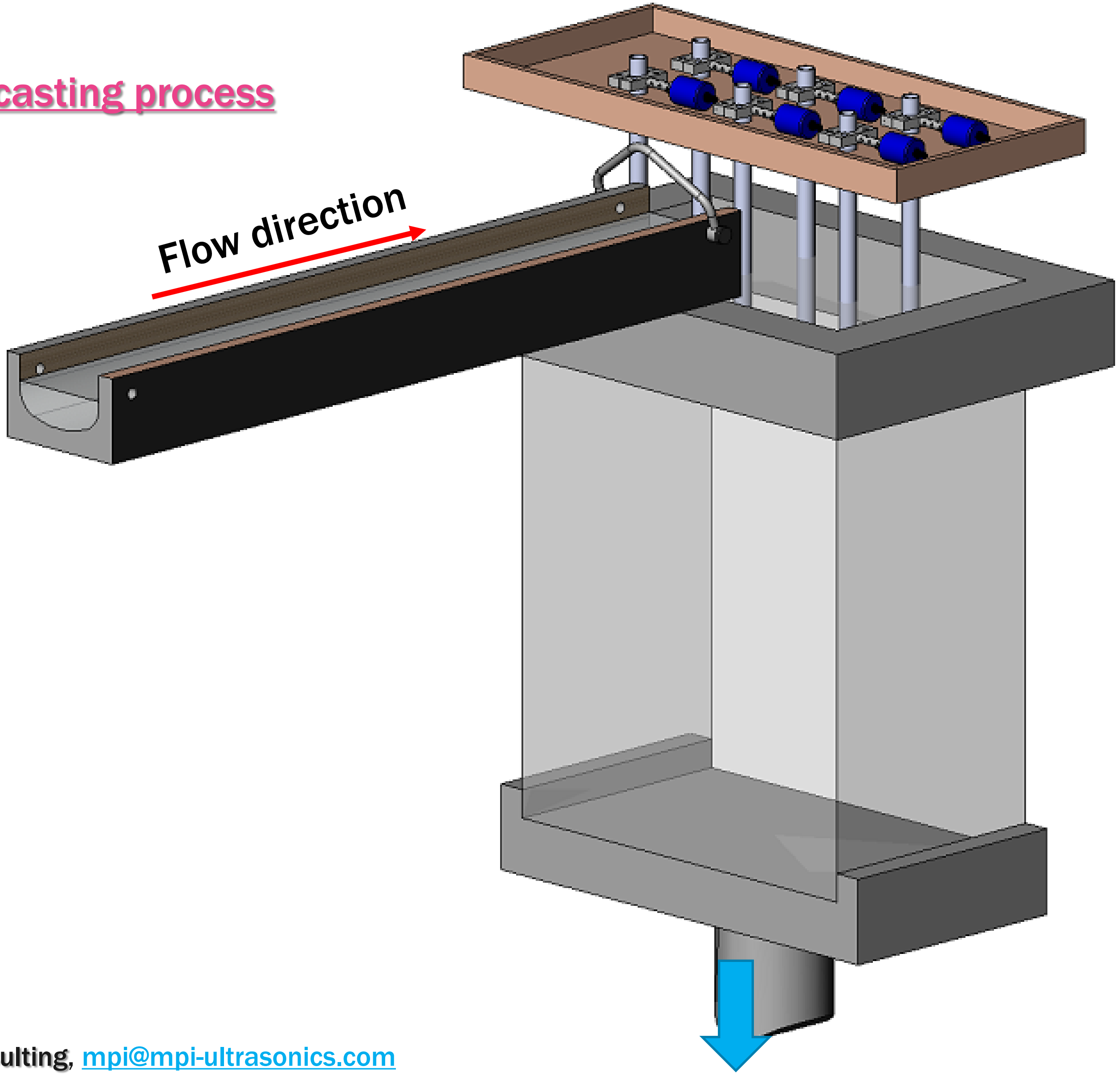

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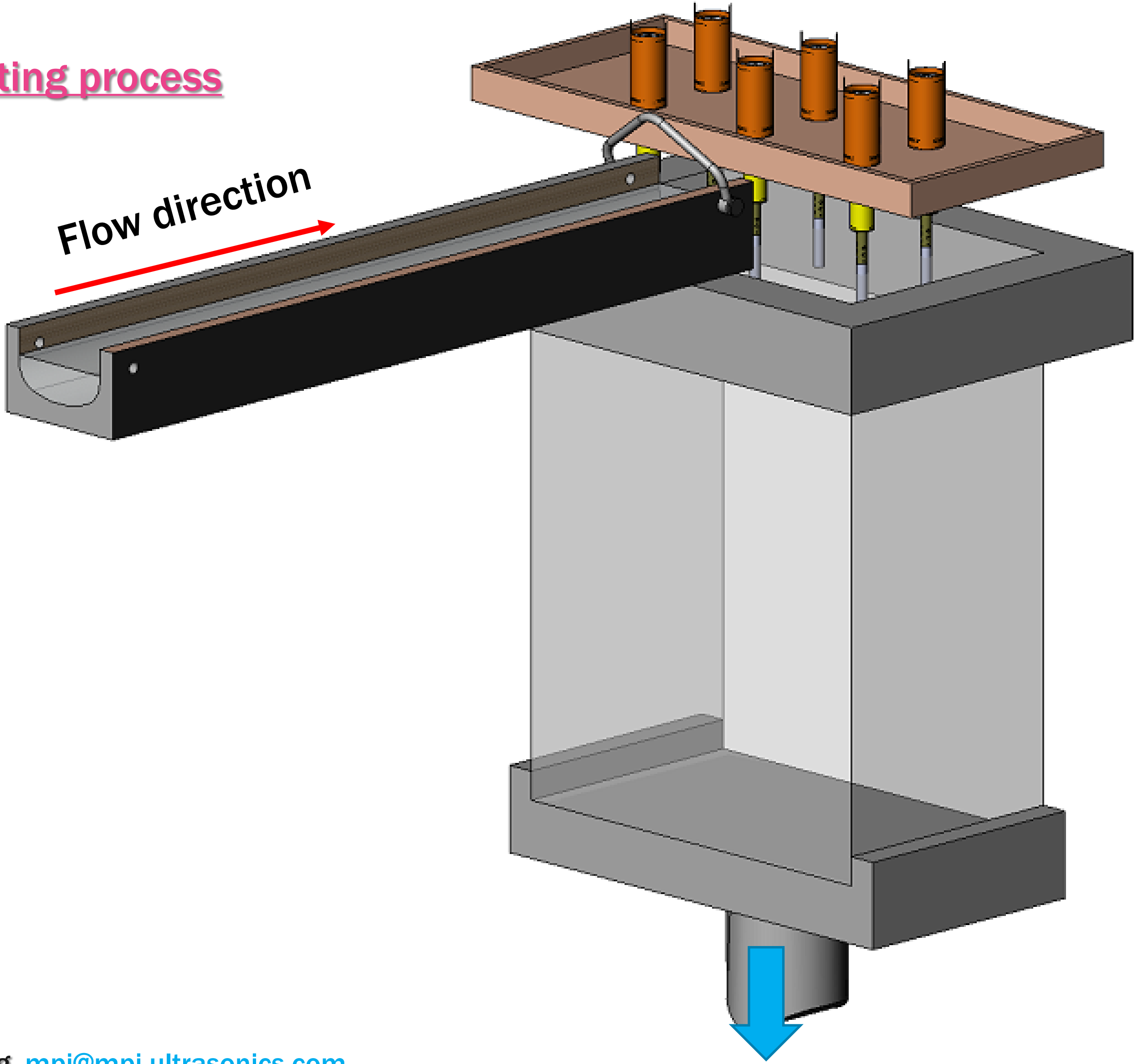

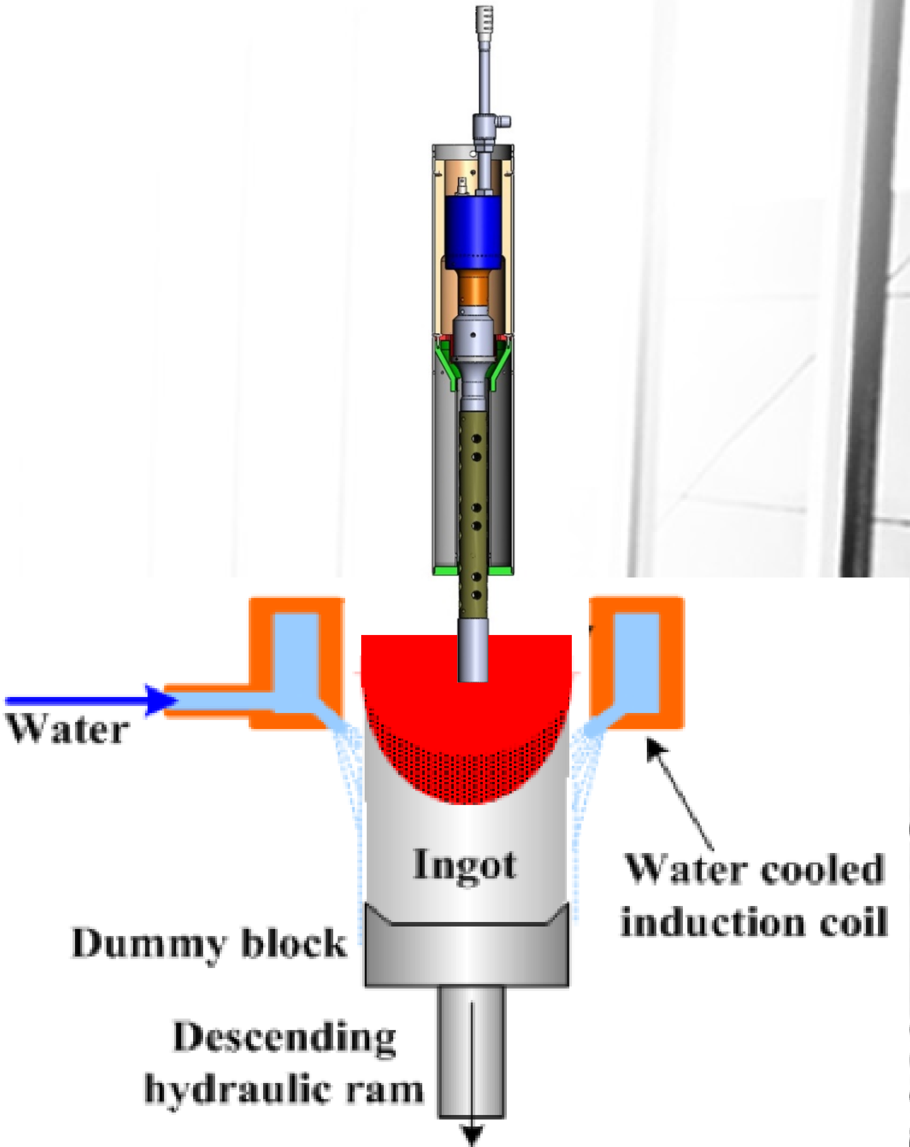

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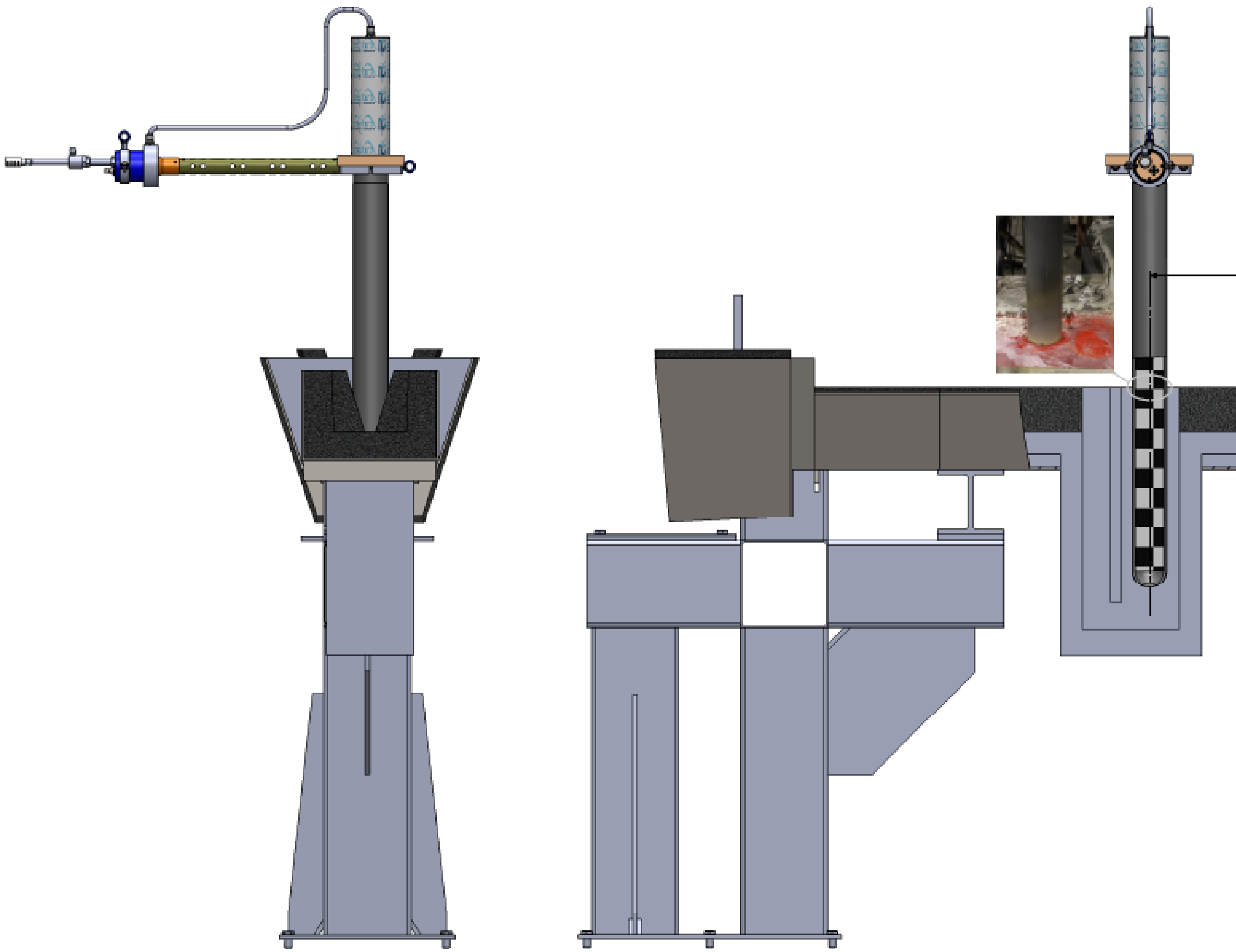
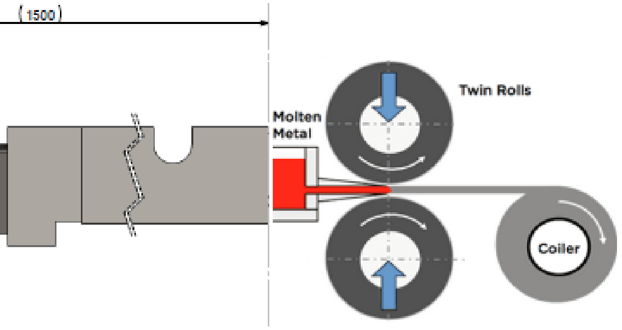
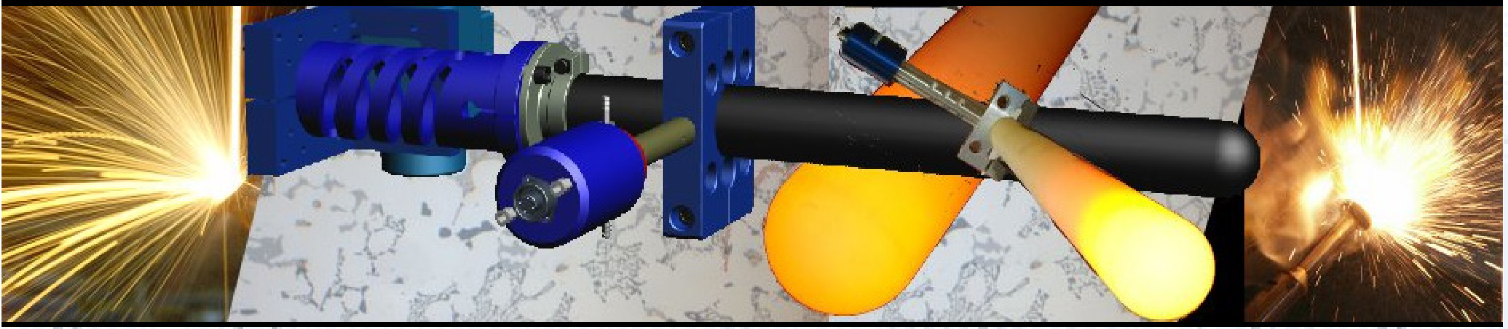






mpi ultrasonics

ENTER THE WORLD OF ULTRASONICS MACRO ENGINEERING

Ultrasonic vibrations in metallurgy…

Cavitation

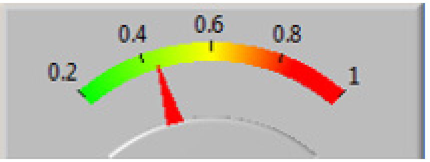
Part 3

No man…can choose to do what he never heard of doing or never thought of doing. In this sense, the ultimate measure of freedom is knowledge and we learn in order to be free.

Controlling Cavitation in Metallurgy

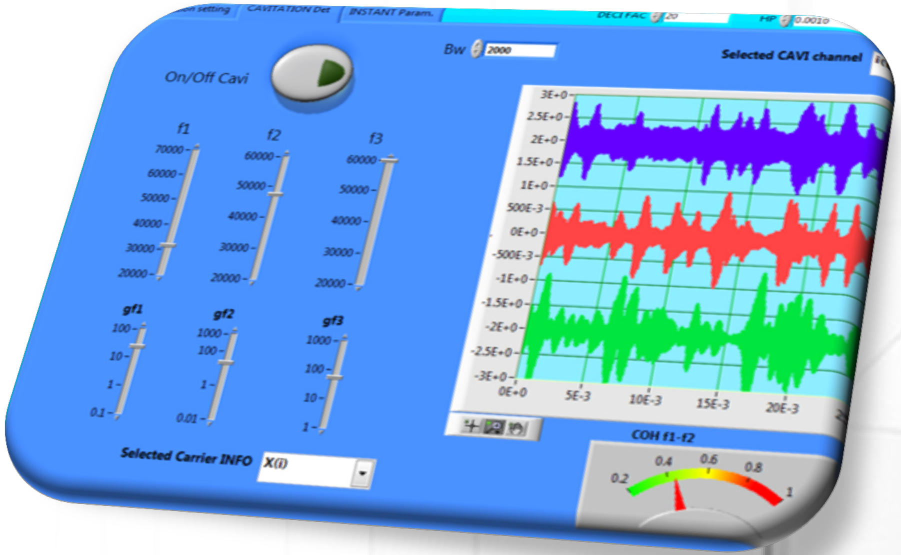
As a very powerful tool for ultrasonic liquid metals processing, we mastered real-time monitoring and measurements related to Cavitation, which is the most significant active factor for realizing number of metallurgical processing such as:

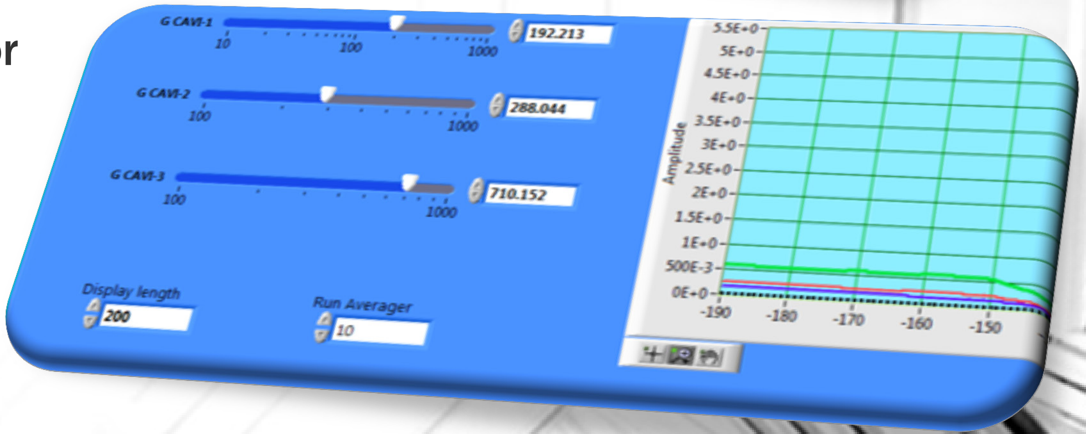
- ✓ Degassing and density increase,
- ✓ Micro alloying,
- ✓ Total surface wetting of all kind of inclusions, including blind and micro-capillary holes
- ✓ Uniform grain refinement, based on sonocrystallization,
- ✓ Extending the natural limits in alloying, mixing, homogenizing and playing with different percentages of almost arbitrarily selectable liquid ingredients.



Controlling Cavitation in Metallurgy

Our expertise in “self-sensing techniques” developed from other ultrasonics-related ***applications has opened new ways to address the cavitation measurement challenge***. Thus, we are now able “***to see***”, ***measure and control the cavitation in real time*** (**<u>without submersing sensors for cavitation in a liquid metal</u>**). We know what the essential parameters of ultrasonic waves are in order to create and control cavitation. We know what to change, or implement during ultrasonic agitation for producing and controlling certain level of cavitation in liquids.

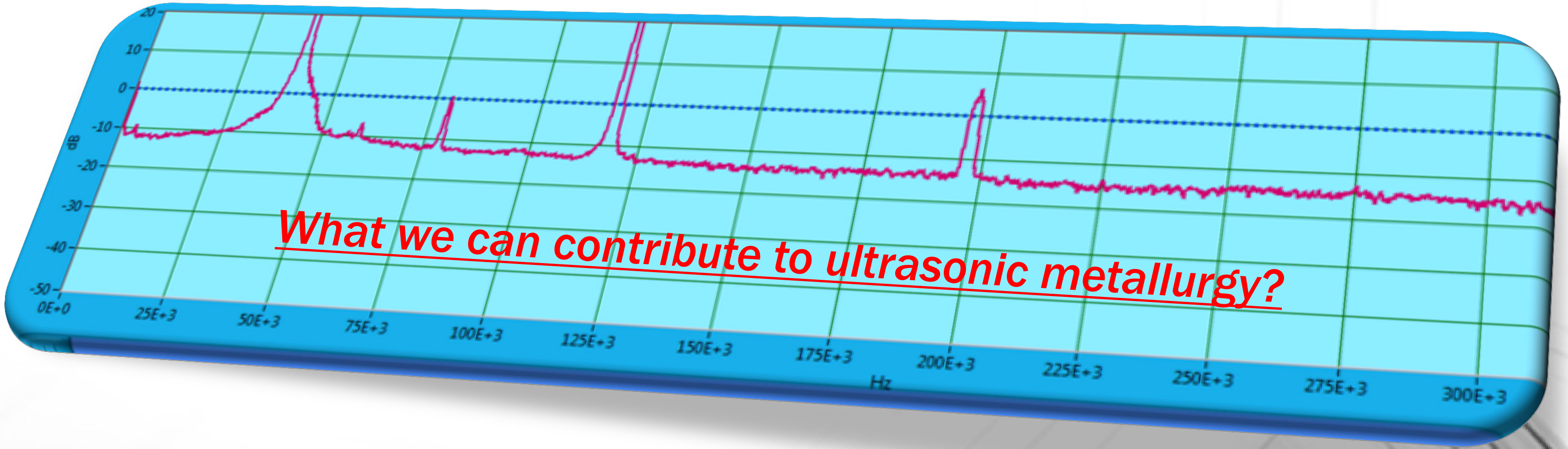




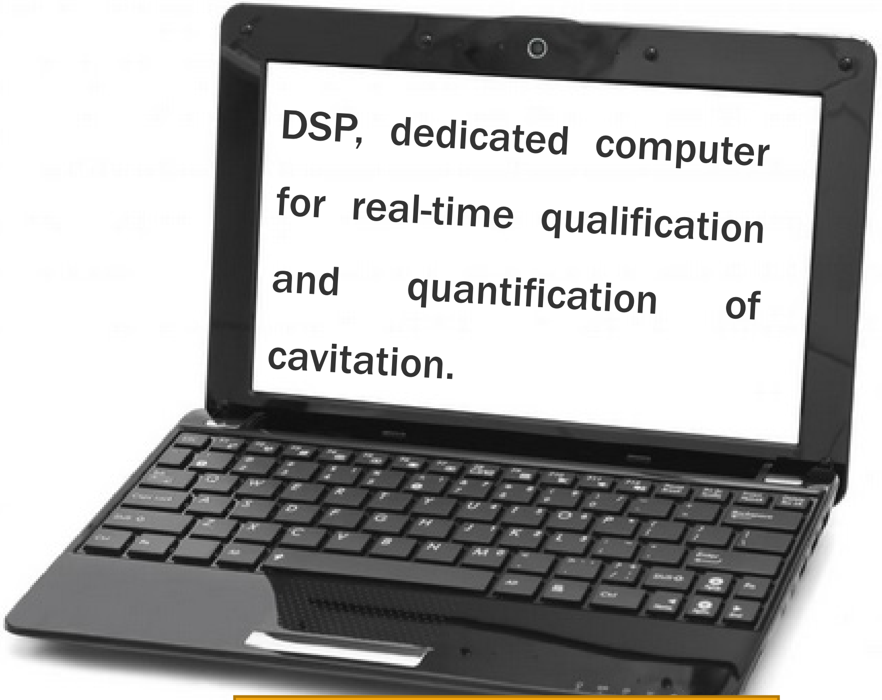
Controlling Cavitation in Metallurgy

The active power dynamics of ultrasonic transducers is continuously monitored with modern signal processing techniques.

This involves a novel signal processing approach which is very rarely available in standard monitoring systems.



Controlling Cavitation in Metallurgy



Based on specific Lab View, multi-windows and real time monitoring software.

Self-sensing technique

We can make diagnostic and measurements of cavitation without submersing any kind of sensor, where the ultrasonic source (sonotrode and ultrasonic converter) is in the same time emitter of ultrasonic waves, and active sensing element for acoustic activity and cavitation related signals.

Controlling Cavitation in Metallurgy

We know **exactly and precisely which signal processing** and modulating parameters should be applied to a carrier ultrasonic signal (from ultrasonic power supply) in order to control certain level of cavitation in a liquid metal.

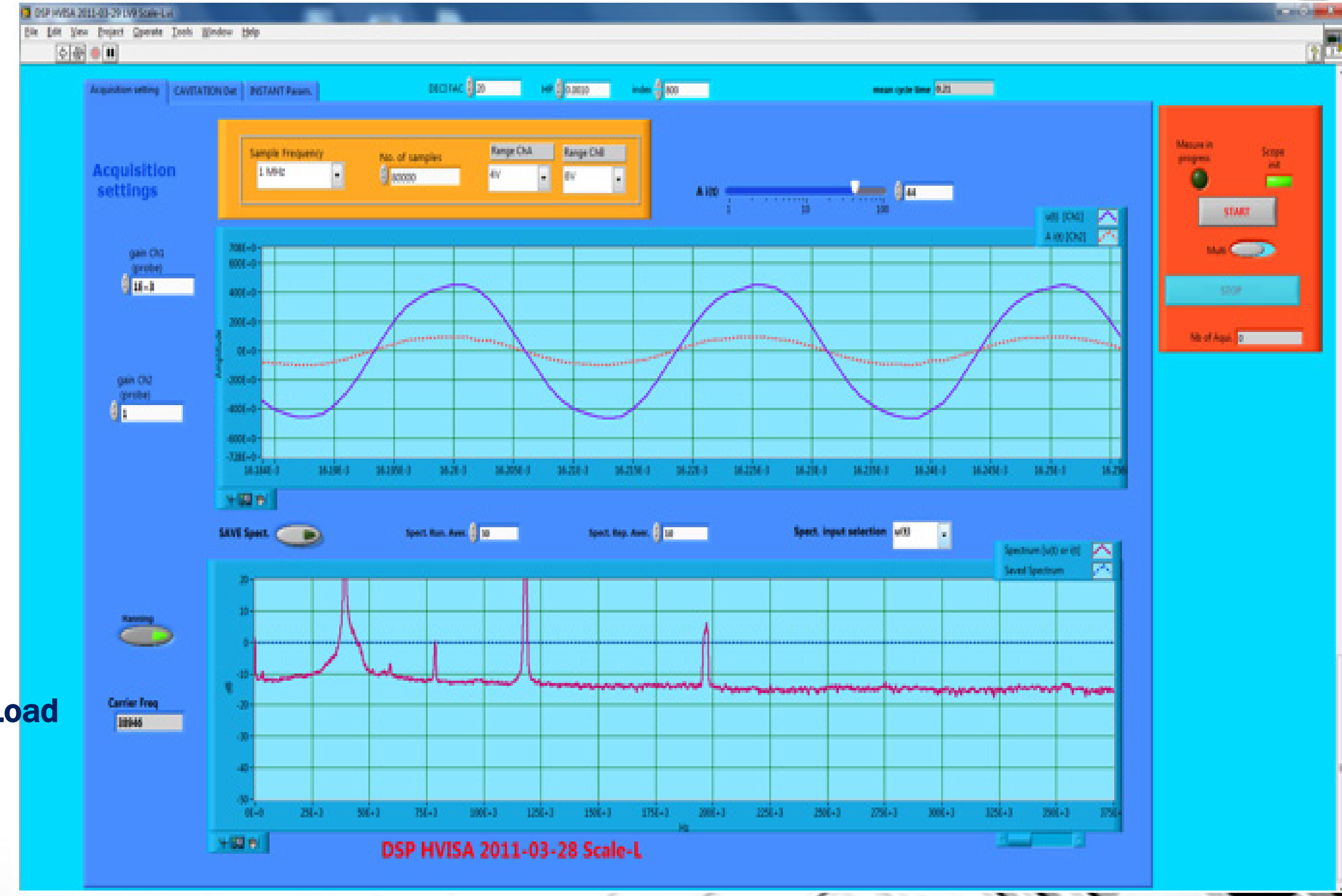
We achieved to **extract pure acoustic** (and electric) signals related only to cavitation, from overall and mixed acoustic field activity (apart from high amplitude carrier ultrasonic signal, separated from surrounding mechanical, low and higher frequency harmonics, which are not related to cavitation). We can monitor power of cavitation, and different amplitude and phase, real-time and frequency dependent parameters, as well as values based on complex mathematical calculations, and based on such parameters we can actively control ultrasonic power supply (generator) in order to keep desired level of cavitation continuously (during ultrasonic processing of liquid metal).

Controlling Cavitation in Metallurgy

Computerized station with specific software performing advanced signal processing methods that are applicable in acoustics and ultrasonic technologies for detection and characterizations of multilevel modulated (ultrasonic) signals.

Visualize and measure real-time and frequency dependent plots of immediate

- ✓ active and apparent (ultrasonic) power,
- ✓ different signal amplitudes (vs. time & frequency)
- ✓ immediate signal frequency versus time,
- ✓ Actual, high power, load impedance.

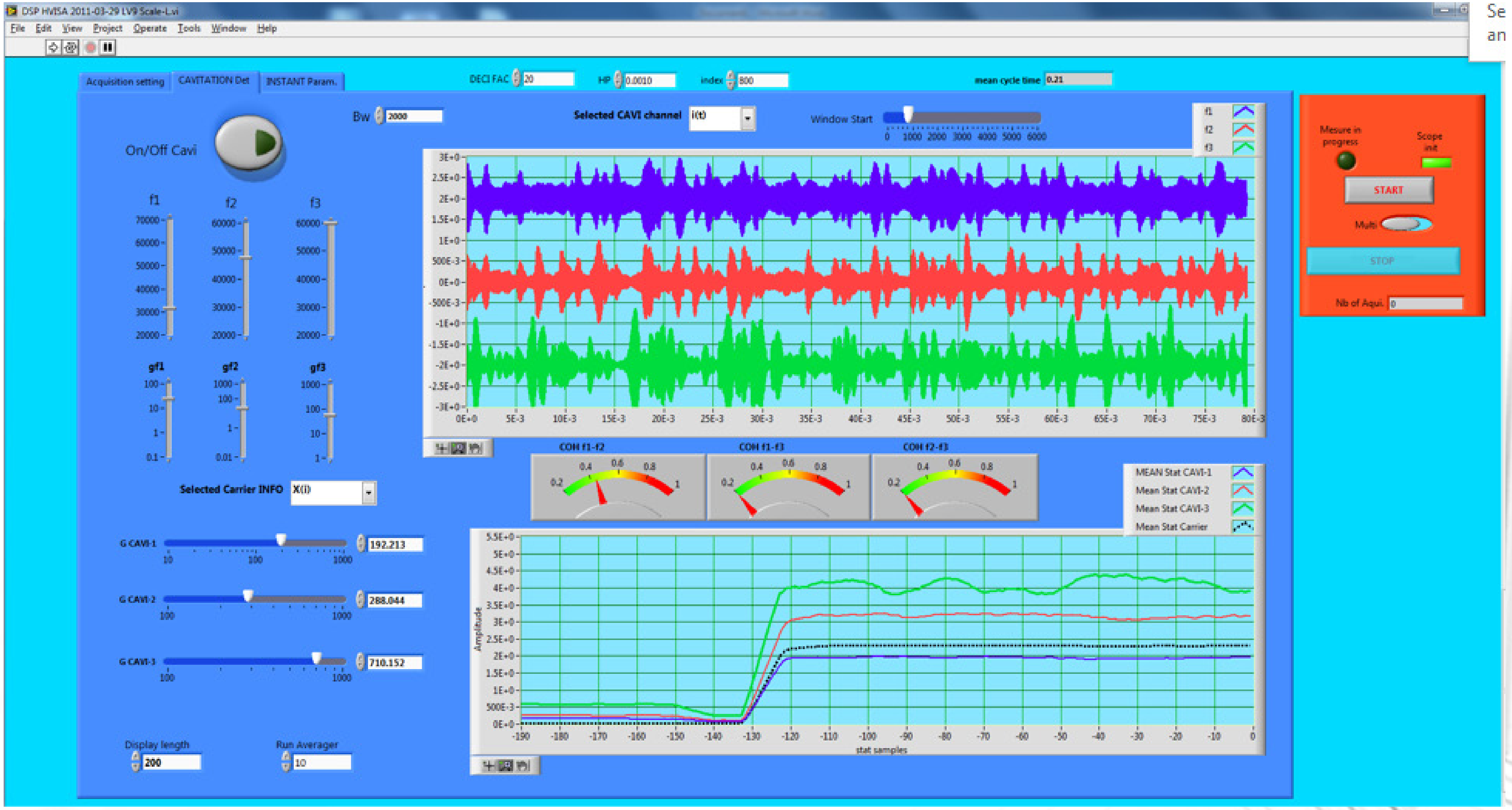


Amplitude – Frequency Spectrum (of Load current and voltage signals during ultrasonic processing)

Controlling Cavitation in Metallurgy

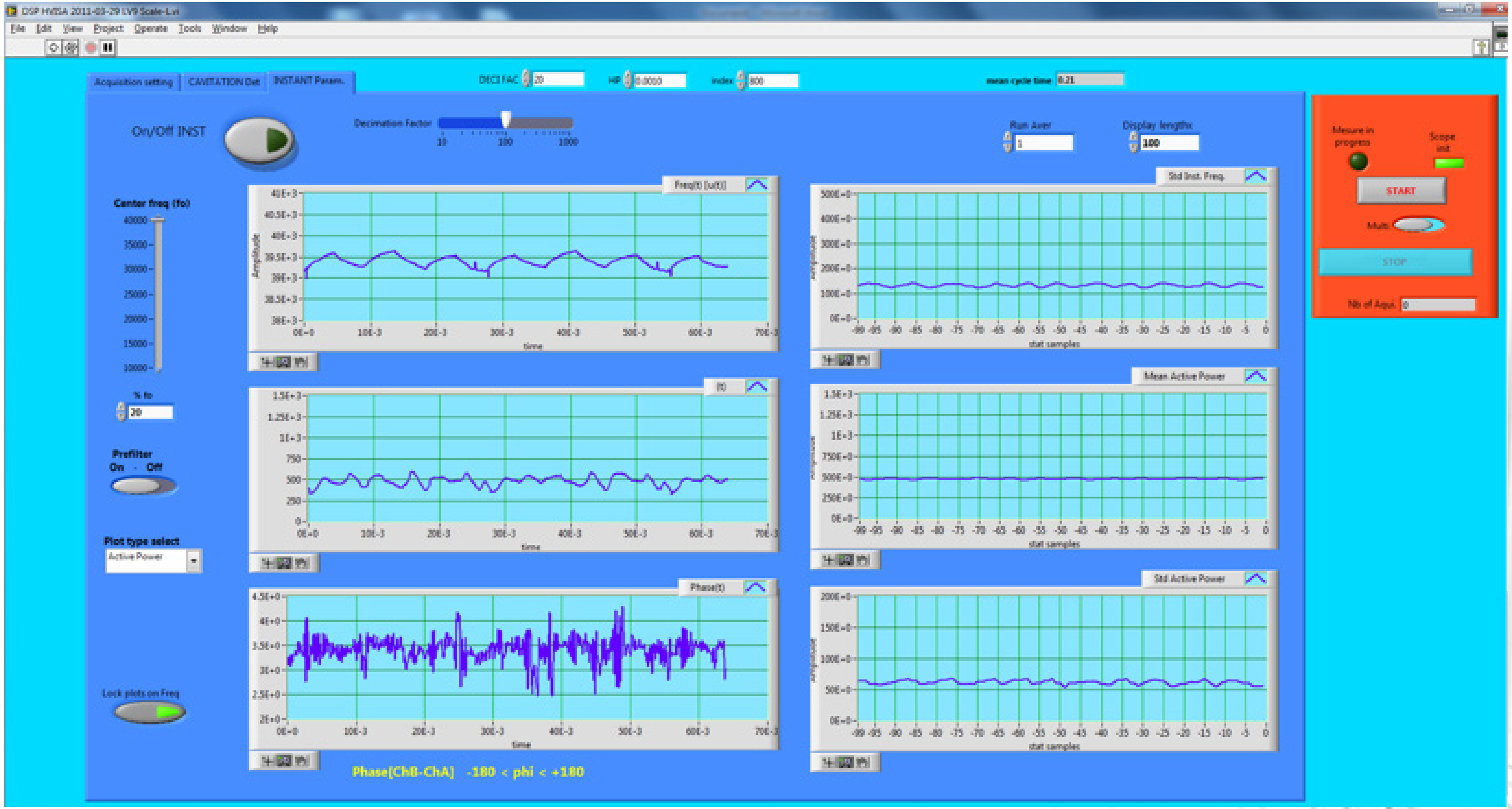
Another significant message is that present measurements related to ultrasonic liquids processing (known from literature, and industrial practices) are far below from what is enough, if we would like to master, qualify and quantify what modern ultrasonic liquids processing is (applicable to Sonochemistry, liquid metals processing, degassing, Sonocrystallization). **Our approach is giving chances to generate real-time feedback** (during ultrasonic processing) and to **stimulate the most important time and frequency domain parameters of ultrasonic field** (based on knowing what is really happening in acoustically agitated media, and what should be maximized in real time)… what nobody is presently addressing.

Controlling Cavitation in Metallurgy



Measured amplitudes of Cavitation in a time domain, and after averaging

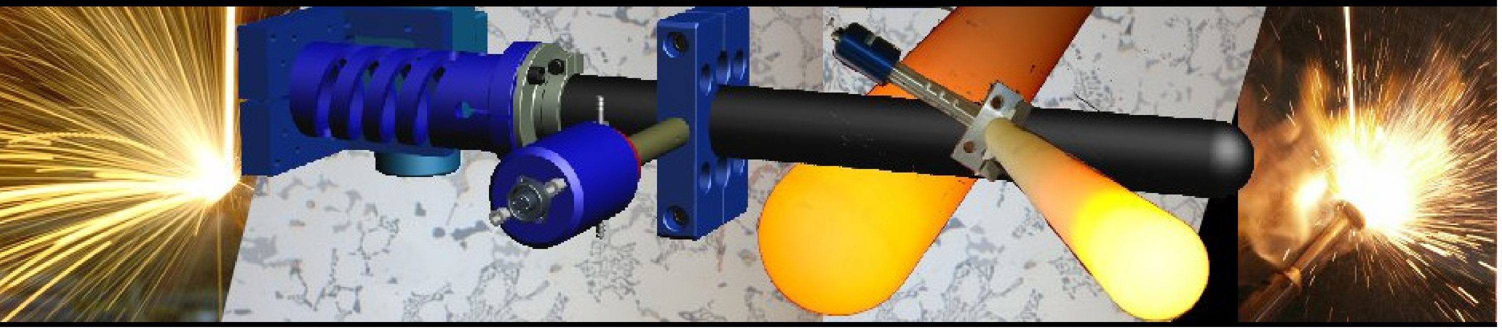
Controlling Cavitation in Metallurgy



Operating Frequency, Power and Phase in a time domain (left) and after averaging (right)

Controlling Cavitation in Metallurgy

- ✓ Our development in this domain took almost 10 years of work.
- ✓ Looks that there is nothing comparable to what we are offering as an integrated package of multilevel signal analysis (for acoustics and complex ultrasonic signals analysis… and with much wider fields of future applications).
- ✓ Dynamic, almost non-stationary, randomized and time-variable, pulse-repetitive, and phase-frequency modulated ultrasonic waves are producing strongest effects of cavitation and realizing spatially uniform, ultrasonic liquids processing.



www.UltrasonicMetallurgy.com

Thank You.

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