Sonication Pilot in High Pressure Die Casting

Pilot production in foundry by MPI Ultrasonics

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Contents:

1) Introduction

This is the second report on the metallurgical impact of MMM-Ultrasound on the alloy 46000 (AlS9Cu3) used by GALJA.
The results from the ultrasonic metal treatment and metallurgical investigation at MPI's metallurgical lab were reported in January, 2024.

This report covers the pilot trials conducted in a high pressure die casting foundry in Europe.
This research was contracted by:

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Tax ID: PL 682-176-87-68

2) MMM Ultrasound

Figure 1 illustrates the principles of acoustic cavitation in liquid metals. When ultrasonic waves are applied to the melt, the alternating compression and expansion caused by the acoustic peaks induce the formation and oscillation of gas bubbles within the liquid. This cavitation process results in the collapse of these bubbles, generating shockwaves that create local pressures higher than 2 MPa and temperatures reaching up to 5000°C. The intense collapse and agitation also lead to acoustic streaming, which facilitates the movement of particles and improves the degassing of the melt by helping to expel dissolved gases (hydrogen), and non-metallic particles to the surface of the liquid. These combined effects contribute to the refinement of aluminium alloys, promoting finer grain structures and enhancing the overall quality of the material.

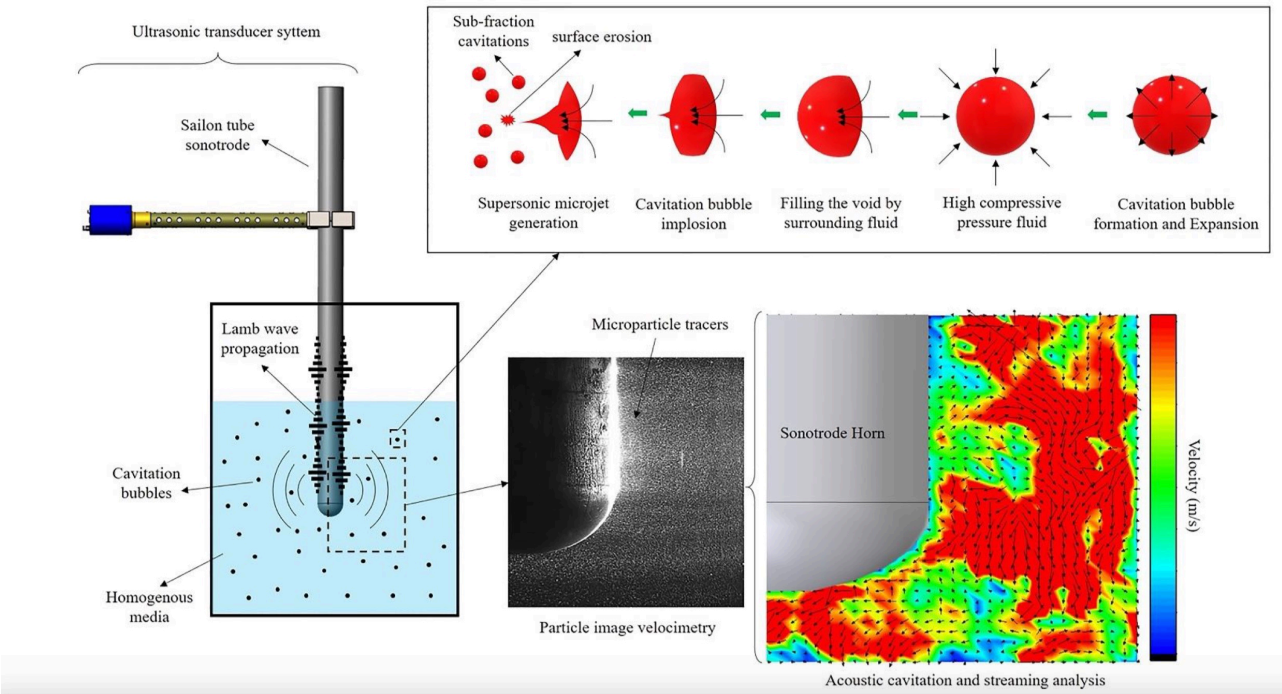

Fig. 1 - MMM-Ultrasonic treatment (courtesy MPI-ultrasonics)

This process of ultrasonic agitation and acoustic streaming create shock waves and increase mass transport due to the turbulence of cavitation. The sonication process has several effects in aluminium and the dominant effect depends on the metal temperature during sonication:

- Degassing
- Grain refinement
- Intermetallic modification
- Enhanced fluid flow during mould filling

At high temperatures, above the liquidus, degassing primarily occurs through the rise of cavitation bubbles, which transport soluble hydrogen to the surface of the melt. The MMM-Ultrasound technique induces homogeneous cavitation throughout the molten material. During bubble expansion, the bubbles absorb energy from the melt, creating localized undercooling at the bubble-liquid interface. This leads to nucleation on the bubble surface. When the bubbles collapse, acoustic streaming is generated, which enhances the distribution of these newly formed nuclei throughout the surrounding liquid. As a result, a significant number of nuclei are introduced into the molten alloy, promoting heterogeneous nucleation and facilitating in-situ grain refinement.

Cavitation also influences the formation and morphology of the first solidifying phases, while contributing to the fragmentation of oxide particles, which can act as additional nucleation sites. Ultimately, the ultrasonic energy injected into the melt alters the shape and size of intermetallics, improving the overall microstructure of the alloy.

Lab scale testing on AL 46000 (AlSi9Cu3)

A short summary of the lab scale trials conduced by MPI-ultrasonics. For further details, see report from January 2024. The foundry ingots for the experiments were provided by GALJA. The chemical composition according to the certificate is shown in Table 1:

Si	Fe	Mg	Cu	Mn	Zn	Sn	Al
9.15	0.66	0.18	2.25	0.26	0.47	0.1	Bal.

Table 1 - Chemical composition

The lab scale results based on 3kg cast samples, clearly showed an increase of both Ultimate Tensile Strength (UTS), as well as elongation in the ultrasonically treated samples. The duration of ultrasonic treatment was kept constant at 15s.
The lower the metal temperature during the ultrasonic treatment, the bigger the impact on mechanical properties. At the lowest temperature of the range, the UTS increased by 30% and the elongation by 250%.

The microstructure showed smaller grains and significantly lower Secondary Dendrite Arm Spacing (SDAS), which explains the increase in the ductility.

The alloy also showed intermetallic modifications, where the three principle intermetallics: $CuAl_2$; α-$Al_{15}(Fe,Mn)_3Si_2$ and β-Al_5FeSi were smaller in seize. Moreover, the β-phase had a different morphology, which significantly contributes to the increase in ductility (s. Figure 2).

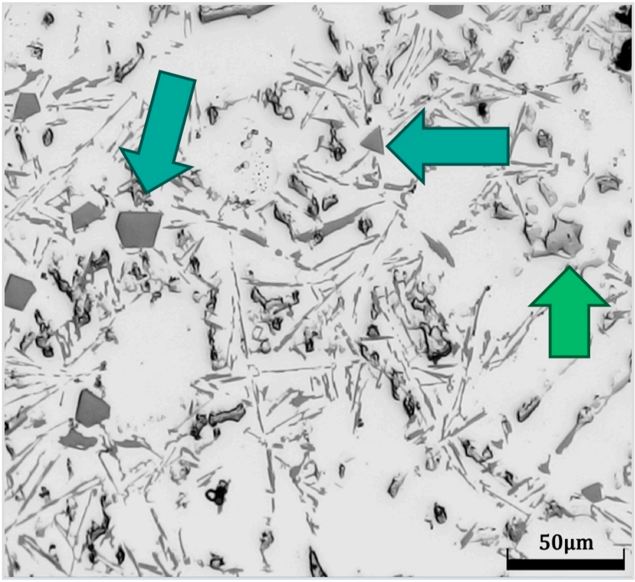

Fig. 2 - Block shaped β-Al5FeSi

Pilot installation at High Pressure Die Casting facility

Based on the lab results, it was decided to ultrasonically treat a fixed volume of metal (20kg) prior to high pressure die casting, at 690°C, for a fixed period of the time.
Therefor a special ultrasonic metal treatment unit was designed, built and placed in between the holding furnace and the shot sleeve feeding of a high pressure die casting machine (s. Figure 3).

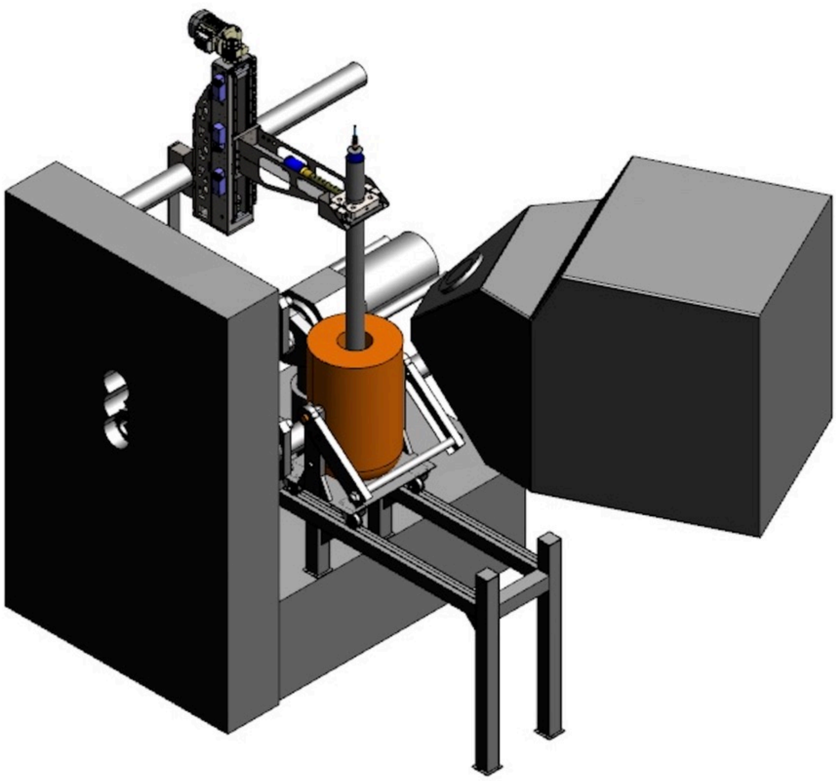

Fig. 3 - CAD design of MMM-Ultrasonic metal treatment unit

The ultrasonic treatment unit holds 20kg of aluminium and the sonotrode is submerged in the metal, see figure 4.

The AlSi9Cu3 alloy is kept at a temperature of 690°C in the holding furnace.
In each cycle, the holding furnace transfers the required amount of molten metal to produce the casting. This molten metal volume is transferred to the US treatment unit and treated for a specific time.
At the end of US treatment, the sonotrode is lifted, and the molten metal is discharged into the shot sleeve of the casting machine and subsequently injected into the mould cavity with the pre-set parameters in the machine.
The ultrasonic metal treatment occurs during the casting cycle, without increasing the cycle time of the machine. In the case of the pilot, the machine cycle time is 45 seconds, the molten metal treatment corresponds to 30 seconds.
The entire process is synchronized with the processing unit of the high pressure die casting machine.

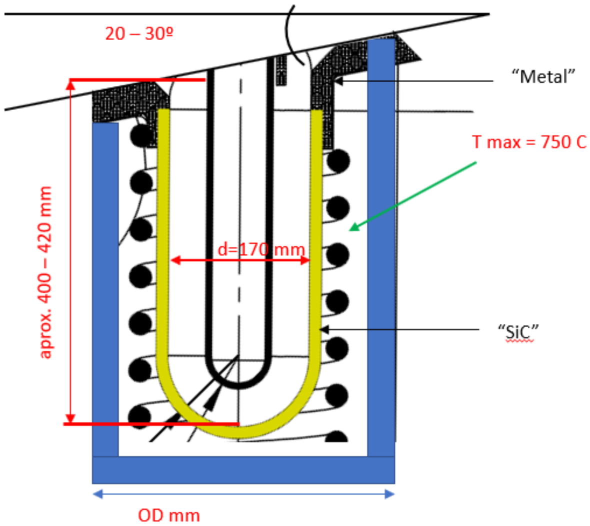

Fig. 4 - US Metal treatment unit

For pilot casting a standard part was chosen and tensile properties were taken form three different positions. Figure 5 shows an example taken from the tests. In "red" the values without ultrasonic treatment, and in "black" the values with ultrasonic treatment. The data shows a strength increase of ca. 30% and an increase of elongation of ca. 70%. Ultrasonic treatment was done at 690°C for 30s.

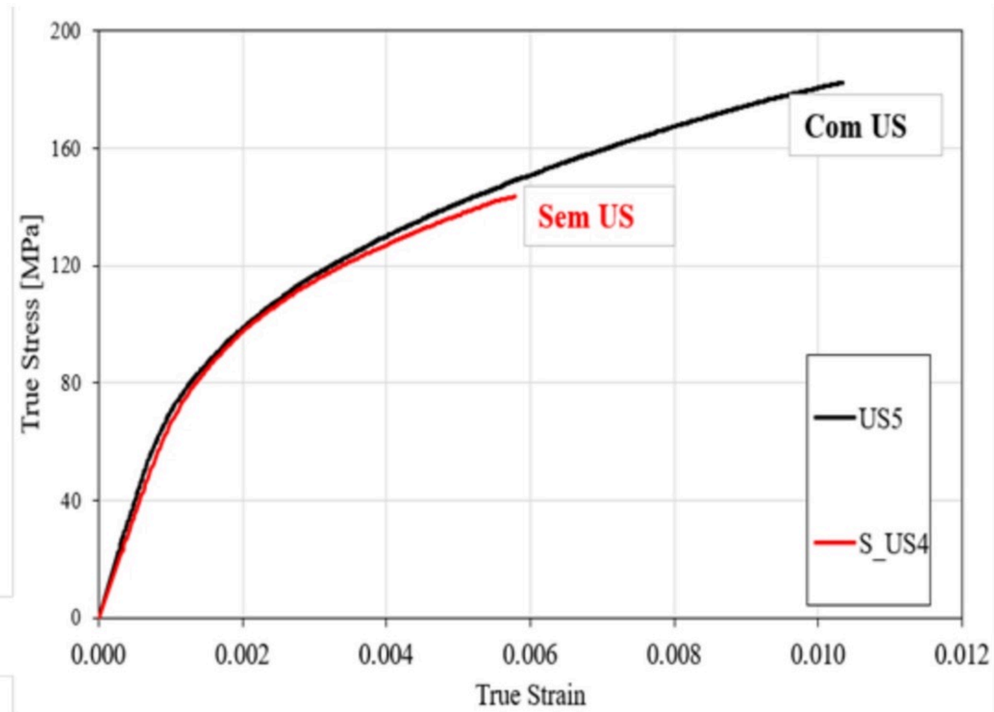

Fig. 5 True stress strain curves - AlSi9Cu3 (US @ 680°C)

A top view of the sonotrode inside the MMM-US metal treatment unit is shown in figure 6, and the unit is shown in operation in figure 7.

Fig. 6 Sonotrode submerged in US metal treatment unit

Fig. 7 - Industrial set-up MMM-Ultrasonic Treatment in Foundry

For consistent mechanical properties the following parameter control is required:
- Melt temperature during sonication
- Sonication time
- Time between sonication and casting
- Ultrasonic generator settings
- Sonotrode position (depth) in the melt

The foundry practice at the pilot confirms that improvements in strength and elongation of the AlSi9Cu3 alloy are obtainable under real life conditions, with ultrasonic treatment of 20kg of aluminium, prior to high pressure die casting of parts.
The sonication process is robust and could be applied to any kind of casting process, not only to high pressure die casting.

The high pressure die casting cell had enough space to accommodate the ultrasonic metal treatment unit between the holding furnace and the shot sleeve feeding. In compact machine configurations this is not always the case, and therefore MMM-Ultrasonic treatment shall be part of the machine design and cell layout from the start.
Several design configurations for a MMM-ultrasonic metal treatment unit in high pressure die casting are conceivable, while considering: receiving shot volume of metal / sonication / feeding metal into the shot sleeve. It is advisable to develop a standard design concept of the unit, as part of the high pressure die casting machine, using standard MMM-ultrasonic components (generator, transducer, sonotrode, clamps, etc).

Conclusions

- MMM-Ultrasonic treatment has a significant effect on the mechanical properties and the microstructure of the cast samples. During the pilot production strength increased in the range of 30% and elongation in the range of 70%.
- A robust sonication process was designed and tested in a high pressure die casting cell under series production conditions. The MMM-Ultrasonic metal treatment unit performed well and is ready to be tested further in series production.
- The MMM-sonication unit shall contain a fixed volume of metal (=shot volume) and must be placed between the holding furnace and the feeding into the shot sleeve of the machine. The sonication process should be considered during the layout of the high pressure die casting cell and engineered from the onset. Post installation is not always possible due to space limitations.
- At the pilot, the sonication occurred during the casting cycle, without slowing down the casting machine. The casting cycle determines the time available for sonication in this case.
- The mechanical properties impact is highest at the lowest possible sonication temperature, this should be considered during the development of the casting process.

Suggestion for further work and production trials

After the successful pilot it is recommended to continue testing of the MMM-Ultrasonic Treatment System in a production environment and gather more data about endurance, cooling conditions, operating temperatures, and equipment uptime.

As mentioned earlier, a standard design of a MMM-Ultrasonic Treatment Unit (in collaboration with a foundry equipment manufacturer).

Testing the limits of the system. How much metal can be treated with a single sonotrode? Current data shows ca. 300kg - 400kg, however with continuous sonication. Shot volumes in high pressure die casting are limited to 150kg (“Gigacasting”). However sonication times at higher metal volumes require more investigations.

Testing new sonotrode materials and design, as possible alternatives to ceramic tubes.

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