

A Study on Ultrasonic Vibration's Capability to Enhance the Solidification Process

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Abstract

The purpose of this research is to investigate the role of ultrasonic vibration in the solidification process. According to the review of literature, the solidification process is crucial in increasing the mechanical properties of the material. The use of ultrasonic vibration techniques in the solidification process improves mechanical properties by influencing the casting quality of the material by reducing grain size and providing a more homogeneous microstructure. The ultrasonic vibration process also aids in the reduction of residual stresses and the improvement of wear resistance, all of which contribute to the improvement of mechanical properties.

Keywords: *Solidification, casting, and ultrasonic vibration*

INTRODUCTION

The major goal of this project is to use ultrasonic vibration to improve the solidification process. Vibration treatment is one of the most well-known ways to improve the casting quality of aluminium alloys by lowering grain size and achieving a more uniform and stable microstructure. Normal mechanical vibrations can produce an amplitude of up

to 5 cm and a frequency of up to 10 kHz. Ultrasonic vibration of melts can be undertaken at a greater frequency, such as above 16 kHz.

During the solidification process of metals, flaws such as shrinkage, porosity, pores, discontinuity, hot tears, air or hydrogen are trapped while pouring molten metal into the die cavity during the die casting and

squeeze casting processes. The ultrasonic vibration wave causes more heterogeneous nucleation in the melt. Cavitations occur within the solidification melt, which causes this. This causes degassing, a reduction in hot cracking, a reduction in porosity, and the creation of tiny grains.

Most foundries in this nation anneal alloys to impart workability; this study wanted to see if ultrasonic vibration may improve the workability of these alloys during Solidification for all applications requiring plastic deformation of the cast alloy without actually annealing it.

The ultimate quality of casting products is determined by a variety of elements, one of which is the solidification structure. Casting faults that arise during Solidification will be reflected in the product and have an impact on its service life.

The fundamental difficulty for alloy casting is the incomplete removal of solidification flaws such as coarse columnar, porosity, inclusions, and so on. When ultrasound, a high-energy sound wave, travels through materials, it creates nonlinear processes, including cavitation and acoustic streaming. Many researchers have discovered that introducing

ultrasound into the solidification process can significantly refine the solidification structure for casting; however, research on solidification structure refinement by ultrasonic treatment has primarily focused on light metals such as aluminium, magnesium, copper, and so on. When treating commercial Al-based alloys using a water-cooled ultrasonic resonator, the mean grain size can be reduced, the process distribution may be varied, and the grain size can be reduced and obtain a higher level of material homogeneity. There has been so much talk about ultrasonic vibrations that the vibrations spread throughout the melt, causing massive cavitations due to temperature differences in the melt. Variations in pressure, temperature, and strength produce heterogeneous nucleation and division in the melt, resulting in smaller grains and the formation of globular equiaxed non-dendrite structures.

A fine grain size enables more uniform distribution of secondary intermetallic interphases, in addition to pores that occur from the evolution of the dissolved in the melt. Improvements in mechanical characteristics and pressure stiffness are accompanied by an increase in casting quality.

Objectives and Scope of the Study

The goal of this research is to use ultrasonic vibration to improve the solidification process in order to achieve the following goals:

- To improve alloy casting quality by lowering grain size and achieving a more uniform microstructure.
- To reduce residual stresses by improving mechanical properties.
- To overcome the imperfection of the solidification process as well as to improve wear resistance.

LITERATURE REVIEW

Sahadeva G N et al. clarified that high-intensity ultrasonic vibrations remove coarse grains and form globular grains, demonstrating that grains are refined by improving mechanical properties such as hardness and ultimate tensile strength in relation to nucleation and preservation of small nuclei. The experimental results show that when ultrasonically treated in comparison to pure aluminium AA-356 without ultrasonic treatment, the average effects of hardness and final tensile strength are improved by approximately 13% and 16%, respectively, when compared to pure-356.

Olga Kudryashova et al. [2] investigated vibration intensity of approximately 60 Hz and amplitude of approximately 0.5 mm using experimental research. Under these conditions, the grain size in the ingot is greatly reduced, as is the cast metal's soundness (density). If the pulse is applied above the liquid's temperature, it has no functional meaning. Furthermore, it can be a source of the unfavourable gas capture phenomenon. The vibration can only begin at the beginning of the Solidification begins with the metal's partial Solidification and ends with the metal's complete Solidification.

Aramide Fatai Olufemi et al. discovered that increasing the mould vibration frequency causes grain refining in the alloy during Solidification. This grain refining improves the strength and stiffness of the aforementioned alloy specimens. The maximum values of these mechanical properties increase as the rate of vibration increases. Mechanical mould movements are increasingly improving the mechanical properties of the alloy, with maximum mechanical properties occurring at a frequency of 12Hz.

Rahul Kumar and colleagues the mechanical mould's vibration have a significant impact on the composition and

properties of the casting. More refined and improved mechanical properties can be obtained with mould vibration casting than with standard casting without mould vibration. Grain refining continues to increase from 40 Hz to 150 Hz as the frequency of vibration increases. Casting toughness increases as frequency ranges from 40 to 150 Hz.

According to M.T. Alonso Rasgado et al., piezoelectric translators cannot be located in dies for die excitation. With the right attachment, multi-source vibration is possible. Furthermore, piezoelectric translators can be protected from high humidity and high temperature with suitable cooling arrangements. Although feasibility has been demonstrated, more work is needed to demonstrate the technology in a commercial setting.

G. The research presented by Chirita et al. shows that vibration influences the rates and characteristics of Solidification; vibration has an effect on mechanical properties. Its impact appears to be due to heat transfer aspects; vibration increases heat transfer in liquid; vibration can significantly decrease heat transfer in the metal-wall interface due to contact loss under primarily two hypothetical

mechanisms: high surface tension and wall roughness effect.

Qiang Wanga et al. demonstrated that ultrasonic vibrations could refine grains from 300m to 20m in size. SAC305 grain refinement was more thorough than pure Sn. These segregated greatly in SAC305 ingots and were primarily distributed along the Sn phase boundaries, resulting in a slight decrease in the alloy's hardness. Optimizing the ultrasonic power and cooling rate at the same time can refine the grains and homogenize the microstructures of a solidified alloy.

Wen-qi Zou et al. demonstrated that as the vibration frequency increased, the primary carbides and eutectic colonies became increasingly optimized.

However, as the rate of vibration improves, the hardness increases slightly. The hardness of the as-quenched and as-tempered HCCIs was higher than that of the as-cast HCCIs. The hardness, on the other hand, reflects a little variation as compared to the rise in vibration frequency. In comparison, as the frequency of vibration grew, so did the amount of impact absorbing energy.

In xia Chen and colleagues As the mechanical vibration frequency rises and the filling surface rises, the structure of AZ91D alloy castings is gradually achieved. The casting surface of AZ91D alloy castings has a complete structure and finer profile when the mechanical vibration frequency is 100 Hz. The shape of the casting surface of AZ91D alloy castings gets much more exact as the mechanical amplitude increases, and the filling area gradually expands. The maximum value is reached when the mechanical amplitude exceeds 1.0 mm, according to Crenguța Manuela pîrvulescu et al.

Demonstrated that additional energy infusion in the system results in a modification of the system structure. The application of mechanical vibrations in the liquid phase and during alloy solidification improves the final structure as well as the mechanical characteristics of the cast parts. The use of mechanic vibrations facilitates the formation of gaseous inclusions and their removal from the alloy, resulting in a high degassing of the alloy.

L. Zhang et al. investigated how ultrasonic treatment of molten aluminium alloys can significantly refine the intermetallic.

Furthermore, the results show that the grain refinement of alloys with the addition of an Al-Ti-B master alloy may be related to the particle size of the substrate in the melt during ultrasonic solidification treatment.

Shuo Wang et al. proposed that when the temperature of the ultrasonic treatment was between the alloy's liquidus and solidus, the primary -Sn dendrites were fragmented into smaller grains of 40m. The effective temperature range for ultrasonic treatment is between liquid and solids.

W. Khalifa et al. demonstrate that ultrasonic treatment is effective in controlling the morphology and size of aluminium grains when applied between 619uC and 626uC, where fine non-dendritic grain and/or globular grains form. A 15-second ultrasonic treatment at 623uC and 620uC produced average grain sizes of 60 mm and higher. Higher-temperature samples revealed rosette-like and dendritic grain microstructures.

W. Khalifa et al. explained that ultrasonic vibrations only affect Si particles when the eutectic process occurs in the ultrasonic field, resulting in more compacted particles. This impact was only noticed

near the ultrasonic horn. Treatments at greater temperatures are obviously unsuccessful. The iron inter-metallic phases also changed their morphology from big plate-like particles to a compacted form after being ultrasonically treated at temperatures up to 100°C above the liquid. The shape of the Fe-intermetallic phases is only slightly affected by higher temperatures. These findings are general and apply to all of the alloys examined.

Xiaopeng Zhang et al. [15] proposed that ultrasonic introduction can obviously increase the melt temperature, which rises with increasing ultrasonic power; ultrasonic treatment decreases the melt temperature gradient in the horizontal direction, resulting in a more uniform temperature distribution in the melt. Under ultrasonic treatment, the profile of isothermal lines is altered; they become flatter. The Solidification is apparently slowed by ultrasonic processing; the higher the power, the slower the Solidification; both the liquidus and solidus are arc-shaped without ultrasonic treatment, but the liquidus becomes nearly straight under ultrasonic treatment, indicating that the temperature gradient in the horizontal direction is apparently reduced.

Mukkollu Sambasiva Rao et al. [16] investigated the effect of a cooling slope combined with ultrasonic cavitation casting on the microstructure and mechanical properties of an Al-4wt% Cu-2wt% Mg alloy. It was discovered that the Cooling slope casting has globular grain rather than a dendritic structure. If a cooling slope is combined with ultrasonic acoustic cavitation, a refined microstructure can be obtained.

S. Gencalp et al. [17] concentrated on the casting of the cooling slope while subjected to ultrasonic melt vibration. This has resulted in more homogeneous grains and the formation of non-dendritic microstructures. Furthermore, the authors believe that the frequency of vibration and the temperature of the pouring can influence the formation of the microstructure. As a result, it is suggested that this research can be expanded.

Yao Lei et al. [18] determined that the Mg-8Li-3Al alloy has a dual-phase structure and phases, with the morphology of the phase changing from coarse rosette-like to finely globular with the use of ultrasonic vibration. The finely globular structure is obtained, especially when the power is 170 W, and the refining effect improves as the ultrasonic treatment time

is extended. With ultrasonic vibration, the mechanical properties of the alloy significantly improve. The tensile strength of the alloy with 170 W of an ultrasonic vibration for 90 s increases by 9.5 percent when compared to the alloy without ultrasonic vibration, and the elongation improves by 45.7 percent.

E. Riedel et al. [19] discovered that continuous Solidification of the aluminium casting alloy A356 accompanied by U.S.T. results in increased homogenization of the castings, structure modifications, and mechanical property improvement. A new adjustable numerical model for predicting the U.S.T. of liquid and solidifying aluminium was presented and partially validated in this context. The model can simulate the aforementioned homogenization mechanisms and thus has a high potential for numerical considerations of other ultrasonic melt treatment applications. More work is needed to extend the model so that the Influence of U.S.T. and cavitation on alloy microstructure and mechanical properties can be calculated.

T.V. Atamanenko et al. [20] discovered that the efficacy of ultrasonic treatment grows with treatment time. For 0.18 kg of Ti alloy, 7 to 10 seconds are enough to

significantly refine the structure. The effect of ultrasonic treatment is quite stable: 2 minutes between ultrasonic treatment and casting results in only marginal grain coarsening.

According to J. B. Ferguson et al. [21], the theoretical mechanisms generally proposed to account for ultrasonic grain refining in Al and Mg alloys are a cavitation-induced increase in melting temperature predicted by the Clausius-Clapeyron equation and cavitation-induced wetting of otherwise unwetted insoluble particles. Grain size, on the other hand, is known to be affected by cooling rate and casting temperatures, and there is no evidence to differentiate the potential impact of temperature and cooling rate effects on grain size. The studies using Al-A356 ultrasonic cavitation treatment revealed that ultrasound provided significant grain refining, but the treatments also significantly cooled the liquid, lowering the temperature of pouring.

According to G. M. Swallow et al. [22], "Quantitative investigations on the application of ultrasonic to solidifying melts have clearly revealed grain refinement to occur from a spectrum of mechanisms involving both the shattering of existing crystals and the production of

new ones near locations of cavitation." The findings show that the dominating mechanism in weld pools will be the rupture of existing crystals, whose melt flow pathways will be governed by electromagnetic forces and thermal gradients rather than the acoustic forces shown in this study. The creation of large numbers of stable bubbles in the liquid demonstrates a second advantage of using ultrasonic to degass the melt.

According to Xinbao Liu et al. [23], the microstructure of materials is usually determined by the nucleation stage and the subsequent growth condition. Sufficient nuclei are required for grain refinement. The final grain size, however, is determined not only by nucleation but also by the growth condition. If latent heat dissipation is slow, the initial nuclei are unstable and re-melt during later Solidification. As a result, only a small percentage of them mature into final grains. As a result, rapid extraction of latent heat as well as sufficient nuclei is required for microstructure refinement.

According to Gui Wang et al. [24], acoustic streaming generates enough sustained convection to create a uniform thermal environment throughout the melt. The low-temperature gradient and the

undercooled region beneath the colder do not generate a location for continuous nucleation and improve the survival of newly formed crystals as they are transported through the melt while U.S.T. is applied. Aside from the cavitation-enhanced heterogeneous nucleation mechanism, it is also possible that crystals are formed through a continuous process of nucleation on the sonotrode's surface, growth of these crystals, and detachment of those crystals formed directly on the sonotrode's radiating surface. Once crystals form on or near the sonotrode as a result of either of the above mechanisms, the new crystals are swept into the melt by the high degree of convection caused by acoustic streaming.

When no ultrasonic vibration was used, the morphology of eutectic silicon changed from a coarse acicular plate-like form to a finely dispersed rosette-like form, according to X. Jian et al. [25]. As a result, the size of eutectic silicon was reduced by ultrasonic treatment. Review of Literature Findings:

- Ultrasonic vibration solidification refines the grain structure of the alloy.
- The mechanical properties of an alloy, such as hardness, ultimate tensile

strength, and yield strength, are influenced by ultrasonic vibration.

- Ultrasonic vibration creates a more uniform structure.
- According to the above literature review, the vibration should begin at the beginning of the solidification process and continue until the metal is completely solidified.
- The main grain was gradually polished as the vibration frequency was increased. In addition, as the vibration frequency increased, the hardness increased slightly.

CONCLUSIONS

The review of optimizing the solidification process utilizing ultrasonic vibration yielded the following significant conclusions:

- The use of ultrasonic vibration in the solidification process has an impact on the mechanical properties of the alloy, such as hardness, ultimate tensile strength, and yield strength.
- During the solidification process, ultrasonic vibration refines the grain of the alloy.

- Ultrasonic vibration produces a structure that is more stable and homogeneous.

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