A Review on Optimize the Solidification Process using Ultrasonic Vibration

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Abstract

This study is concerned with the influence of ultrasonic vibration in the solidification process. According to the literature review, Solidification process plays main role in increasing the mechanical properties of the material. From implementation of ultrasonic vibration technique in solidification process enhances the mechanical properties by influencing the casting quality of the material from reducing the grain size and gives more homogenous microstructure. The ultrasonic vibration process also help in reducing the residual stresses and improvement of wear resistance which all leads to enhancement of the mechanical properties.

Keywords: - *Ultrasonic vibration, Solidification, casting*

INTRODUCTION

The main aim of this project is to improve the solidification process by using ultrasonic vibration. Vibration treatment is one of the known methods of improving the casting quality of aluminium alloys through reducing the grain size and obtaining a more uniform and stable microstructure. An amplitude up to 5 cm and a frequency up to 10 kHz can be achieved with the normal mechanical vibrations. At a higher frequency, e.g., above 16 kHz, ultrasonic vibration of melts can be performed [2].

In die casting and squeeze casting process it consists of such a large number of defects like shrinkage, porosity, pores, discontinuity, hot tears, air or hydrogen is trapped while pouring the molten metal in to the die cavity throughout the solidification process of metals. More heterogeneous nucleation in the melt is produced by wave of ultrasonic vibration. This is due to cavitations phenomena occur within the solidification melt. This leads to degassing, reduce in hot cracking, porosity reduction and formation of small size grains [1].

Alloys are typically subjected to annealing in most foundries in this country to impart their workability; this research aimed to determine the possibility of enhancing the workability of these alloys during solidification by using ultrasonic vibration for all applications requiring plastic deformation of the cast alloy without actually subjecting it to annealing [3].

The ultimate quality of casting products is connected to so many factors, with the solidification structure being one of the most significant ones. In casting products, casting defects developed during solidification, will be reflected and affect service life. Incomplete removal of solidification defects, such as coarse columnar, porosity, inclusions, etc., is the key issue for alloy casting. Ultrasound, a high-energy sound wave, when propagated in materials, causes a variety of nonlinear effects, such as cavitation and acoustic streaming. Many researchers found that when introduced into the solidification process, ultrasound can significantly refine the solidification structure for casting; however, research on solidification structure refinement by ultrasonic treatment focuses primarily on light metals such as aluminium, magnesium, copper, etc. Using a water-cooled ultrasonic resonator to treat commercial Al-based alloys may reduce the mean size of the grain, vary the distribution of the process,and achieve greater homogeneity of the material.

There has been so much discussion about ultrasonic vibrations that the vibrations spread through the melt that the temperature differences in the melt often create cavitations of large forces. This variation in pressure, temperature and strength cause heterogeneous control of nucleation and division in the melt with decreased grain size and globular equi- axed non-dendrite structure creation. In addition to pores that develop from the evolution of the dissolved in the melt, a fine grain size provides a more uniform distribution of secondary inter-metallic interphases. Improvements in both mechanical properties and pressure stiffness are matched by the corresponding improvement in casting quality [1].

OBJECTIVES AND SCOPE OF THE STUDY

The objective of this study is to improve the solidification process by using ultrasonic vibration in order to achieve following objectives:

- To influence the casting quality of alloys through reducing the grain size and obtaining a more uniform microstructure.
- To reduce the residual stresses with the enhancement in mechanical properties, and the improvement of wear resistance.
- To overcome the imperfection of the solidification process.

LITERATURE REVIEW

Sahadeva G N et al. [1] clarified that ultrasonic vibrations of high intensity remove coarse grains and form globular grains, which shows that grains are refined by enhancing mechanical properties such as hardness and ultimate tensile strength in relation to nucleation and preservation of small nuclei. The experimental result shows that when ultrasonically treated relative to pure aluminium AA-356 without ultrasonic treatment, the average effects of the hardness and final tensile strength are improved by approximately 13 percent and 16 percent respectively compared to pure AA-356.

Olga Kudryashova et al. [2] investigated by experimental research, with a vibration intensity of approximately 60 Hz and an amplitude of approximately

0.5 mm. Under such conditions, the grain size in the ingot is greatly decreased, as is the increased soundness (density) of the cast metal. The pulse, if applied above the temperature of the liquid, has no functional meaning. In addition, it can serve as a source of the undesirable capture phenomenon of gas. The vibration can only begin at the beginning of solidification and end with the full solidification of the metal.

Aramide Fatai Olufemi et al. [3] revealed that increased mould vibration frequency causes refining of the grain in the alloy during solidification. This grain refining results in an improvement in the strength and stiffness of the said alloy specimens. Increasing the rate of vibration leads to higher maximum values of these mechanical properties. Increasingly, the mechanical mould movements enhance the alloy's mechanical properties, with maximum mechanical properties occurring at a frequency of 12Hz.

Rahul Kumar et al. [4] The vibration of the mechanical mould has a major impact on the composition and properties of the casting. With mould vibration casting, more refined and improved mechanical properties can be obtained than with standard casting without mould vibration. While the frequency of vibration increases, grain refining continues to increase from 40 Hz to 150 Hz. Casting toughness also increases as frequencies vary from 40 Hz to 150 Hz.

M.T. Alonso Rasgado et al. [5] explained that the piezoelectric translators cannot be located in di es for die excitation. Multi-source vibration is possible with an appropriately designed attachment. And also piezoelectric translators can be protected from high humidity and high temperatures with appropriate cooling arrangements. Although feasibility has been established, further work is required to demonstrate the technology in a commercial environment.

G. Chirita a et al. [6] Presented research shows that vibration influences the rates and characteristics of the solidification; vibration has an effect on mechanical properties. Its impact appears to be due to aspects related to heat transfer; vibration increases heat transfer in the liquid; vibration can significantly decrease heat transfer in the metal-wall interface due to contact loss under mainly two hypothetical mechanisms: high surface tension and wall roughness effect.

Qiang Wanga et al. [7] proved that the Ultrasonic vibrations can refine grains from larger than 300µm to 20µm. The grain refinement for SAC305 was deeper than that for pure Sn. The segregation of these was tremendous in the SAC305 ingots and mainly distributed along the Sn phase boundaries, resulting in some decrease of the alloy’s hardness. Simultaneously optimizing the ultrasonic power and the cooling rate may both refine the grains and homogenize the microstructures of a solidified alloy.Wen-qi Zou et al. [8] clarified that the primary carbides and eutectic colonies were increasingly optimised with an improvement in the vibration frequency.

However, with an improvement in the rate of vibration, the hardness shows a small rise. Compared with that of the as-cast HCCIs, the toughness of the as-quenched and as-tempered HCCIs was increased. However, considering the increase in vibration frequency, the hardness represents a slight variance. In comparison, with an increase in the frequency of vibration, impact absorbing energy was increased.

Inxia chen et al. [9] Revealed that the structure of AZ91D alloy castings is gradually achieved with the increase in the mechanical vibration frequency, and the filling surface is increasing gradually. The casting surface of AZ91D alloy castings has a more complete structure and a finer profile when the mechanical vibration frequency is 100 Hz. The shape of the casting surface of AZ91D alloy castings becomes much more accurate with the increase in mechanical amplitude, and the filling area increases progressively when the mechanical amplitude is 1.0 mm, the maximum value is obtained.

Crenguţa Manuela pîrvulescuet et al.[10] presented that by further energy infusion in the system, a modification of the system structure is obtained. The treatment with mechanic vibrations aplied in the liquid phase and during the alloys solidification leads to the final structure improvement and to the improvement of the cast parts mechanic characteristics. The treatment with mechanic vibrations makes easier the formation of the gaseous inclusions and their removal from the alloy, a high de-gassing of the alloy is obtained.

L. Zhang et al. [11] worked on the Ultrasonic treatment of molten aluminum alloys can refine the intermetallic dramatically. And also the results show that the grain refinement of alloys with addition of an Al–Ti–B master alloy may also be related to the substrate particle size in the melt under ultrasonic solidification treatment.

Shuo Wang et al. [12] proposed that the primary β-Sn dendrites were fragmented into smaller grains of 40µm when the temperature of the ultrasonic treatment was in between liquidus and solidus of the alloy. The ultrasonic treatment effective temperature range is between is between liquid and solidus.

W. Khalifaet al. [13] prove that Ultrasonic treatment has shown to be effective in controlling the morphology and size of aluminum grains when applied from 619uC and 626uC, where fine non-dendritic grain and/or globular grains are formed. Ultrasonic treatment of 15 second at 623uC and 620uC produced average grain sizes smaller than 60 mm and higher. Rosette-like and dendritic grain microstructures were found in the samples treated at higher temperatures.

Inhomogeneous microstructures in terms of grain size and morphology were seen by those treated at lower temperatures.

W. Khalifa et al. [14] clarified that the ultrasonic vibrations only impact the Si particles when the eutectic reaction takes place under the ultrasonic field, where more compacted particles are formed. Only near the ultrasonic horn was this effect detected. Obviously, treatments at higher temperatures are ineffective. And also, through ultrasonic treatment at temperatures up to 10oC above liquid, the iron inter-metallic phases modified their morphology from large plate-like particles to a compacted form. Higher temperature treatments have a limited effect on the morphology of the Fe-inter-metallic phases. Such results are universal and relate to all of the alloys tested.

Xiaopeng Zhang et al. [15] proposed that the Ultrasound introduction can obviously increase the melt temperature, which rises with the increasing of ultrasonic power; the melt temperature gradient in the horizontal direction is decreased by ultrasonic treatment, leading to more uniform temperature distribution in the melt. The profile of isothermal lines is modified; they become more flat under ultrasonic treatment. The solidification is apparently slowed down by ultrasonic processing, the higher the power is, the slower the solidification will be; both the liquidus and solidus are arc-shaped without ultrasonic treatment, however, the liquidus turns to be nearly straight under ultrasonic treatment, indicating that the temperature gradient in horizontal direction is apparently decreased.

Mukkollu Sambasiva Rao et al. [16] carried out research on the effect of cooling slope integrated with ultrasonic cavitation casting on the microstructure and mechanical properties of Al-4wt%Cu- 2wt%Mg alloy. It showed that the Cooling slope casting shows globular grain than dendritic structure. Refined microstructure can be obtained by if cooling slope integrated with ultrasonic acoustic cavitation.

S. Gencalp et al. [17] focused on the casting of the cooling slope under ultrasonic melt vibration. This has caused more homogeneous grains and the development of non-dendritic microstructures. And the authors also assume that the frequency of vibration and pouring temperature can influence the formation of the microstructure. Therefore, it is indicated that it is possible to expand this research.

Yao Lei et al. [18] evaluated that the Mg-8Li-3Al alloy consists of a dual phase structure of Į and ǜ phases, the morphology of Į phase is modified from coarse rosette-like structure to finely globular one with the application of ultrasonic vibration. The finely globular structure is obtained especially when the power is 170 W, and the refining effect is also getting better with prolonging the ultrasonic treatment time. The mechanical properties of the alloy with ultrasonic vibration increase significantly. Compared with the alloy without ultrasonic vibration, the tensile strength of the one with 170 W of ultrasonic vibration for 90 s increases by 9.5%, and the elongation improves by 45.7%.

E. Riedela et al. [19] identified that an ongoing solidification of the aluminum casting alloy A356 accompanied by UST results in an increased homogenization of the castings, structure modifications, and the improvement in their mechanical properties. In this context, a new adjustable numerical model for making predictions on the UST of liquid and solidifying aluminum was presented and partly verified. The model can simulate the aforementioned mechanisms of homogenization, and thus has high potential for the numerical considerations of other applications of ultrasonic melt treatments. Further developments are necessary to extend the model so that the influence of UST and cavitation on microstructure of alloys and their mechanical properties can be calculated.

T.V. Atamanenko et al. [20] found that the effect of ultrasonic treatment increases with treatment time. For 0.18 kg of mass Ti alloy, 7 to 10 seconds are sufficient to refine the structure considerably. The effect of ultrasonic treatment is quite stable: 2 minutes between ultrasonic treatment of the same volume and casting result in only marginal grain coarsening.

J. B. Ferguson et al. [21] Stated that a cavitation-induced increase in melting temperature expected by the Clausius- Clapeyron equation and cavitation-induced wetting of otherwise unwetted insoluble particles were the theoretical mechanisms generally suggested to account for ultrasonic grain refining in Al and Mg alloys. Grain size, however, is known to be affected by cooling rate and casting temperatures, and there is no evidence from which to distinguish the potential impact of temperature and cooling rate effects on grain size. It was observed from the studies using Al-A356 ultrasonic cavitation treatment that ultrasound provided considerable grain refining, but the treatments also significantly cooled the liquid and thus reduced the temperature of pouring.

G. M. Swallowe et al. [22] explained that the Qualitative experiments on the application of ultrasonic to solidifying melts have clearly shown grain refinement to arise from a range of processes involving both the disruption of existing crystals and the formation of new ones near sites of cavitation. The evidence suggests that the dominant mechanism in weld pools will be the disruption of existing crystals whose flow paths in the melt will probably be dominated by electro-magnetic forces and thermal gradients rather than the acoustic forces evident in this work. The formation of quantities of stable bubbles in the liquid illustrates a second advantage in the application of ultrasonic as a means of degassing the melt.

Xinbao Liu et al. [23] discussed that the microstructure of materials usually depends on the nucleation stage and on the subsequent growth condition.The sufficient nuclei are essential to the grain refinement. However, the final grain size is determined not only by the nucleation, but also by the growth condition. If the dissipation of latent heat is slow, the initial nuclei are unstable and re melt during the later solidification. Consequently, only a small portion of them grow into the final grains. Therefore, a rapid extraction of latent heat as well as the sufficient nuclei is necessary for refining the microstructure.

Gui Wang et al. [24] proposed that acoustic streaming generates sustained convection sufficient to create a uniform thermal environment throughout the melt. The low temperature gradient and the under cooled region beneath the colder sonotrode establishes a location for continuous nucleation, and enhances the survival of newly formed crystals as they are transported throughout the melt while UST continues to be applied. Apart from the cavitation enhanced heterogeneous nucleation mechanism, it is also possible that crystals are generated by a continuous process of nucleation on surface of the sonotrode, growth of these crystals and detachment of those crystals formed directly on the radiating surface of the sonotrode. Once crystals form by either of the above mechanisms on or near the sonotrode, the new crystals are then swept into the melt by the high degree of convection caused by acoustic streaming.

X. Jian et al. [25] experienced that the morphology of eutectic silicon was modified from a coarse acicular plate-like form when no ultrasonic vibration was used, to a finely dispersed rosette like form when ultrasonic treatment was employed. And it result in Ultrasonic treatment reduced the size of eutectic silicon.

Findings of Literature Review:

- Ultrasonic vibration solidification causes refinement of the grain in the alloy.
- Ultrasonic vibration influences the mechanical properties of alloy like hardness, ultimate tensile strength and yield strength.
- Ultrasonic vibration gives more homogeneous structure.
- Above literature review shows that the vibration should be started just at the

beginning of solidification and finish with the complete metal solidification.

- With an increase in the vibration frequency, the primary grain was refined gradually. And, the hardness showed a slight increase with an increase in the vibration frequency.

CONCLUSIONS

The following major conclusions are drawn from the review of optimize the solidification process using ultrasonic vibration:

- By implementing Ultrasonic vibration in the solidification process influences the mechanical properties of alloy like hardness, ultimate tensile strength and yield strength.
- Ultrasonic vibration in solidification process causes refinement of the grain in the alloy.
- Ultrasonic vibration gives more stable and homogeneous structure.

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