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EFFECT OF ULTRASONIC VIBRATION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ADC12 ALUMINUM ALLOY BY PERMANENT MOLD CASTING

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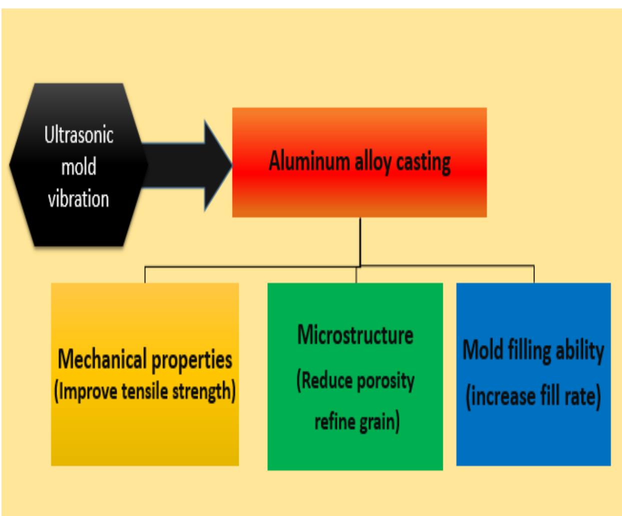
Graphical abstract



Abstract

In this study, the effect of ultrasonic vibration on mold filling ability, microstructure, and mechanical properties of the aluminum alloy during solidification is investigated. Microstructure and mechanical properties were compared with casting without ultrasonic. Grain refinement and an increase in mechanical properties were obtained due to the ultrasonic vibration. The material used for the research was ADC12 aluminum alloy, and the frequency of ultrasonic vibration was 20 kHz. The casting was carried out in SKD11 steel molds. It was found that the ultrasonic mold vibrated casting has less porosity , fine grain and improvement in mechanical properties as compared to the casting without ultrasonic mold vibration. Where the tensile strength increased by about the tensile strength increased by 20% at 660°C and 9% at 700°C while the hardness changed insignificantly.

Keywords: Ultrasonic vibration, aluminum casting, permanent mold casting, grain refinement, ADC12

1.0 INTRODUCTION

Aluminum alloy ADC12 has suitable qualities such as easy casting, is researched, and is widely used, especially for casting technique in gravity die casting and high-pressure casting. This kind of alloy has components similar to the eutectic alloy, which has a melting temperature in the range of 516-582°C. Microstructure involves the α-Al phase containing 1,65 - 12,6% Si and eutectic structure contains silicon-rich aluminum and pure silicon.

Ultrasonic transmission into alloys is used to refine the structure, reduce segregation, and improve the formation and distribution of other phases in the material. Ultrasonic processing applies for metallurgy generally, emerging from 20 and being widespread studied [1, 2, 16]. Many works have been published globally that have demonstrated that ultrasonic vibrations associated with the metal solidification process lead to structural changes, including grain structure refinement, removal of columnar grain structures, dendrites, increased uniformity, and decreased segregation [3, 4].

Several successful studies were carried out with high-frequency ultrasound during casting by Eskin [3, 16, 17, 18] and Abramov [4]. Under the action of high-intensity ultrasonic vibrations on liquid metals, the structure of columnar dendrites is broken, co-axial particles are refined, in some conditions also produces some spherical particles, increases uniformity and reduces segregation and also degases in liquid metals. The effect of ultrasonic processing in enhancing the mechanical properties of cast metal depends on parameters such as melting temperature, range, and frequency of waves, ultrasonic timing, and processing capacity [4]. Besides, ultrasonic vibrations can be used to invade and degas liquid metals [5]. Xu et al. [6] found that ultrasonic processing was an effective method of degassing melted aluminum. Also, Jian has discovered that ultrasonic vibrations can be used to refine eutectic Si in hypoeutectic Al-Si alloys [7].

Many studies on high-power ultrasonic applications in metal casting have been carried out with the most common effect is grain refinement [1, 2, 4]. Several studies have reported that when ultrasonic processing in liquid or semi-liquid metals, the particles become significantly finer, as well as suppress the columnar structure and form a spherical particle structure [1, 2, 4]. Proposed mechanisms include the influence of nucleation through local cooling and wetting (activation) of metal substrates, fragmentation, and transport of dendrite or intermetallic structure. Ultrasonic processing is also used to refine other structures, such as the refining of eutectic structures in Al-Si alloys [8-10], and change the distribution and the form of Al_3Ti / TiB_2 phases in Al-Ti-B alloy [11]. Ultrasonic degassing is another effect in metallurgy. Eskin reported that the ultrasonic treatment resulting in erosion halved the hydrogen content from 0.6 to 0.3 cm^3 per 100g in Al-6% Mg alloy [5]. Similar results were found by Abramov [4], Puga et al. [12], NajiMeidani et al. [13], and Xu et al. [14].

Therefore, the efficiency of ultrasonic degassing depends greatly on the ultrasonic processing temperature, the volume of the treated liquid metal, and the ultrasonic capacity [12, 19, 20]. Besides, there are also studies on the combination of other degassing technologies with ultrasonic degassing, such as combined with vacuum treatment or argon degassing, resulting in a better degassing effect in aluminum alloys than with the single degassing method [3, 15].

This paper presents some results when vibrating the mold at ultrasonic frequencies during aluminum alloy casting. The research was performed on aluminum alloy ADC 12 (A384) with the gravity die casting method. The ultrasonic frequency used to study of 20kHz. The degree of filling ability of the sections in the mold, the mechanical properties of casting material was investigated in this study.

2.0 MATERIALS AND METHODS

The material selected in the present work is the cast aluminum alloy ADC12. The chemical composition of ADC12 is presented in Table 1. The ultrasonic system used for this research involves the ultrasonic source of 1.5 kW and the piezoelectric transducer of 20 kHz. The ultrasonic vibration probe is designed as shown in Figure 1 and made of steel SKD11. The practical oscillation amplitude (peak-peak) is about 100µm. The oscillating parts are fixed on a set of frames and fitted with a casting mold (Figure 2).

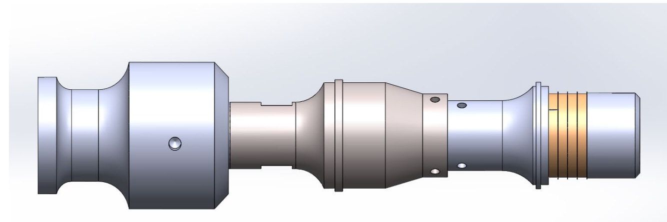


Figure 1 Model of 20 kHz ultrasonic vibration probe

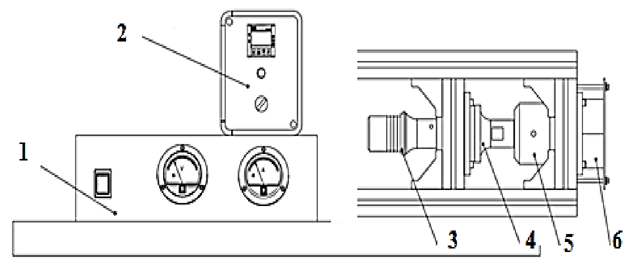


Figure 2 A casting metal system using ultrasonic vibrations

Where (1) is an ultrasonic source, (2) is a timer, (3) is a transducer, (4) is an oscillation amplifier, (5) is an ultrasonic vibration probe, and (6) is a metal mold.

Table 1 Chemical Composition of ACD 12 (wt%)

Si	Fe	Mg	Mn	Zn	Cu	Al
11.38	0.83	0.20	0.17	0.95	1.90	The rest

Casting Mold

A casting mold is designed to satisfy the criteria to achieve the best effectiveness (Figure 3). The cavity includes different sections to evaluate the degree of metal filling ability in the mold under ultrasonic vibration. The parting line is vertical and the direction of vibration of the ultrasound is horizontal. In the method of gravity die casting, a vertical die is preferred to allow the gas in the mold to escape easily when pouring liquid metal. Ultrasonic with horizontal impact will cause the mold walls to oscillate perpendicular to the direction of gravity, thereby affecting the friction between metal and the mold wall and the crystallization direction of the cast metal. Large cross-sections of the mold are used for microstructure analysis and mechanical tests such as tensile strength and hardness measurements. The mold is made of steel SKD11. For the requirement of the impact range of ultrasound on the metal in the die, the mold size is designed so that the cast aluminum mass can be contained in the cavity between 250-300g.

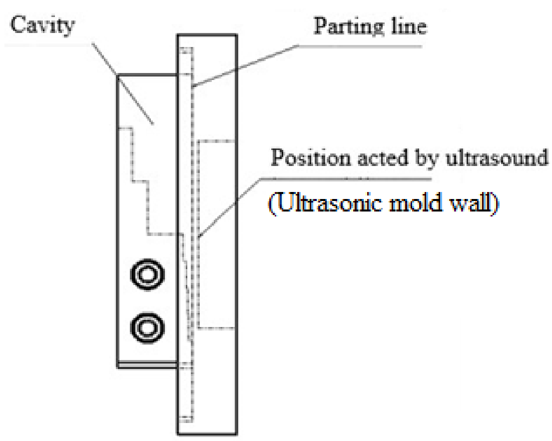


Figure 3 The casting mold

Analysis of macrostructure and microstructure

Microstructure analysis samples were obtained from castings. The samples were cut axially, then the sample was ground with grit sandpapers from P180 to P2500. The samples then were electrolytically polished in a 10% volumetric solution of H_3PO_4 in distilled water at a voltage of 20V and a current of 2A for 60 seconds. The sample surface was cleaned with distilled water and 70° alcohol and then dried before etching. Samples were etched with Keller solution (95 ml distilled water, 2.5 ml HNO_3 85%, 1.5 HCl, 1 ml HF) with an etching time of 20 seconds. The sample was cleaned with 90° alcohol and dried. Optika microscopes with magnifications from 50x to 500x were used to observe macrostructure and microstructure.

Hardness measurement

The hardness was measured using a Vicker-hardness tester with the HV3 scale with a load of 30 kgf and a holding time of 10 seconds. To ensure the reliability of the measurement, 15 positions are measured per sample (Figure 4) including 5 positions which are far 4 mm from the ultrasonic mold wall, 5 positions on the central axis (8 mm from the wall), and 5 positions which are far 12 mm from ultrasonic die wall, the distance between two measuring marks is 6mm. The measured values are used to determine the mean hardness and standard deviation, and the hardness values that vary by region per mold are evaluated.

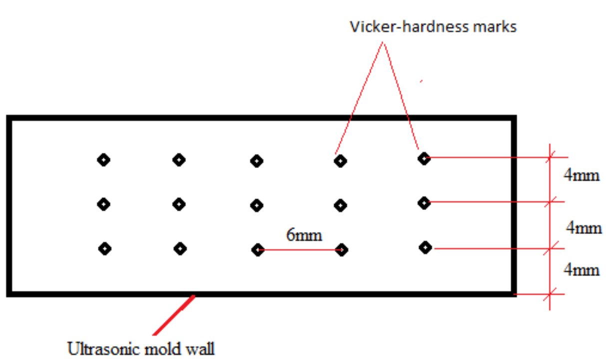


Figure 4 Vicker hardness measurement positions on the specimen

Tensile strength measurement

Casting samples are machined according to the standard tensile test ASTM–E8/E8M-08, presented in Figure 5.

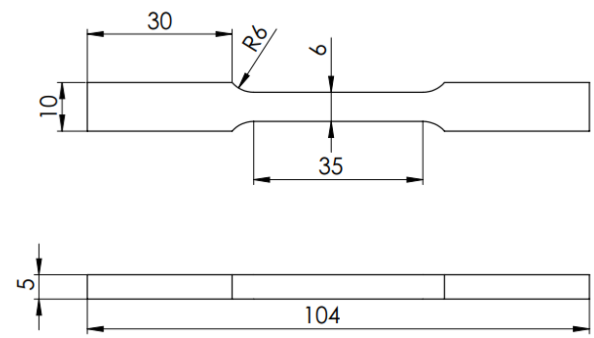


Figure 5 Area of monitoring and surveillance

Mold filling ability measurement

The fluidity of liquid metal is especially important in complex shape casting. To determine filling ability, a die is designed as step-shaped to cast parts with steps of different thicknesses. In this study, the steps are evaluated with a thickness of 3mm or less to consider the ability to cast products with a thickness of less than 3mm when there is an ultrasonic vibration effect. To determine the degree of filling ability in narrow sections in the mold (the wall thickness of the casting does not exceed 3 mm) some dimensions such as the length and width of the metal strip filled in the cavity are measured to calculate the filling ratio compared to the entire cavity size.

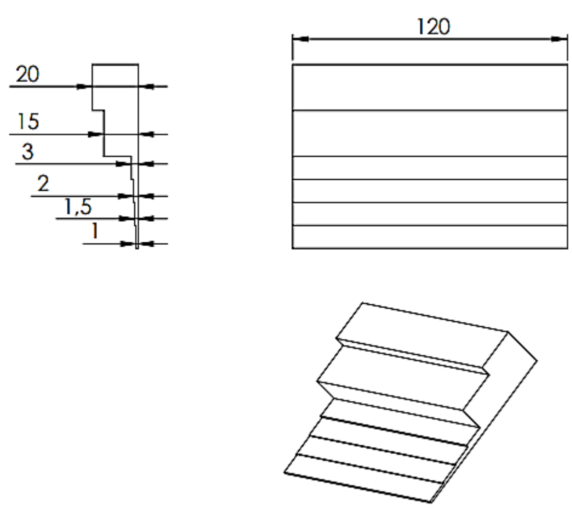


Figure 6. Casting's shape to assess the filling ability

Experiment procedure

ADC12 alloys were poured in a metal mold under the conditions with and without ultrasonic vibration. Before casting, the mold was preheated to at least 200ºC, this is suitable for actual casting conditions when the mold is in continuous use. Ultrasonic mold vibrations started from before pouring until the point at which the non-transmissible vibration effect was vibrating into the material due to solidification, which occurs when the ratio of the solid is 95%. The ADC12 aluminum alloy was melt in a resistance furnace at different temperatures of 660ºC and 700ºC, then poured into the cavity. The series of experiments were summarized in Table 2.

During the experiment, the mold wall temperature was measured with an infrared thermometer. Data are recorded by a computer and are subsequently processed. After the metal solidified and cooled, casting samples were measured for the degree of filling ability and then cut and machined as required to prepare for microstructure analysis, measure hardness, and tensile strength.

Table 2. Table Of Parameters For The Casting Experiment.

Order	Temperature (ºC)	Ultrasonic vibration time (s)	Repetition frequency
1	660	0	3
2	700	0	3
3	660	20	3
4	700	25	3

3.0 RESULTS AND DISCUSSION

Tensile strength and hardness

The comparison between the tensile strengths of ultrasonic casting and non-ultrasonic casting at two temperature levels of 660ºC and 700ºC was presented in Figure 7. The average tensile stress of the casting with ultrasonic vibrations is higher than that of the non-ultrasonic casting. When applying ultrasound, the tensile strength increased by 20% at 660ºC, and at 700ºC, the tensile strength increased by 9%. This is due to the small fine grain, few porosity defects.

The highest tensile strength of the ultrasonic cast is about 212 Mpa (sample cast at 660ºC) with relative elongation of 5.2%, while the non-ultrasonic cast only reaches the strength limit of 189 Mpa (sample cast at 700ºC) with 3.2% elongation. It can be seen that the tensile strength increases by about 11% and the elongation increases by about 2% when ultrasound is applied at lower temperatures. Observing the fracture of the tensile test sample, some samples have quite low tensile strength due to internal porosities. These samples were cast in the absence of ultrasound.

The hardness of the cast specimen is measured in terms of distance from the ultrasonic vibrating surface. The average hardness of the sample increases slightly (from 89HV to 93HV) under the ultrasonic effect. For the areas close to the mold wall, the hardness is higher than the center of the casting, at the same time the hardness increases gradually from bottom to top of the sample. This is because the cooling rate is higher in the areas near the mold wall and the bottom of the mold, the ultrasonic effect in these areas is not clear due to the fast cooling rate resulting in a relatively short ultrasonic duration. Particularly in the center of the casting, it shows clearly that a tendency to increase hardness when applying ultrasound. Result also reveals that at temperature of 660ºC, the casting achieves a higher hardness than that of the casting at 700ºC. Although the hardness distribution varies between regions in the casting, for an ultrasonic affected cast, the difference in hardness is negligible between regions.

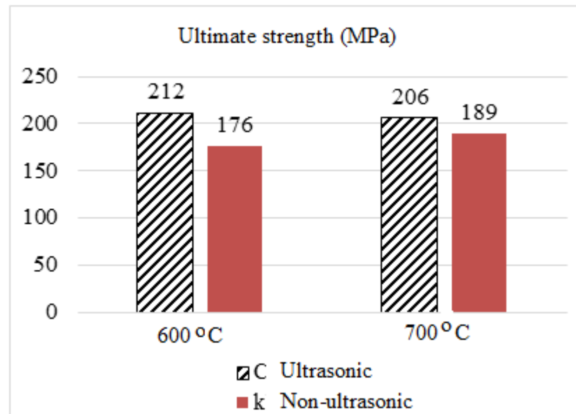


Figure 7. Comparison between tensile strengths of ultrasonic casting and non-ultrasonic casting at 2 temperature levels: 660ºC and 700ºC

Porosity and defects

In casting specimens that are non-ultrasonic vibrated, many porosities can be observed. The porosity defects and shrink pitting inside the mold have an ultrasonic effect which is significantly reduced in number and size compared to the non-ultrasonic casting. Defects in the casting sample have concentrated distribution with ultrasound, while for non-ultrasonic castings, defects are scattered throughout the casting cross-section (Figure 8).

At the pouring temperature of 660ºC, the short solidification time results in the gas cannot escape in time or not enough gathering time to form large bubbles to emerge, so throughout the casting one sees a lot of pitting of tiny gas. When an ultrasonic vibration is applied, these tiny air bubbles gather and escape from the metal. Although the sample was cast at 700ºC, although there is less dispersion of air pitting, some air bubbles are trapped in the final cold metal. From this result, ultrasound has a quite good degassing effect.

The grain structure of the non-ultrasonic casting specimen has a large size and dendrites type of continuous long or floral pattern. Meanwhile, on the cast specimen with ultrasound, the dispersed particles and dendrites are significantly reduced, in the far ultrasound still have flower-like structures. The casting shell area has a fine grain structure due to the rapid cooling rate when liquid metal contact with the mold wall. When poured at a temperature of 700ºC, near the mold wall, the particles are organized in the form of a columnar of grain, with relatively large size. Under the impact of ultrasound, the grain shape is rounder, and the size is significantly smaller and smoother than that of non-ultrasonic casting.

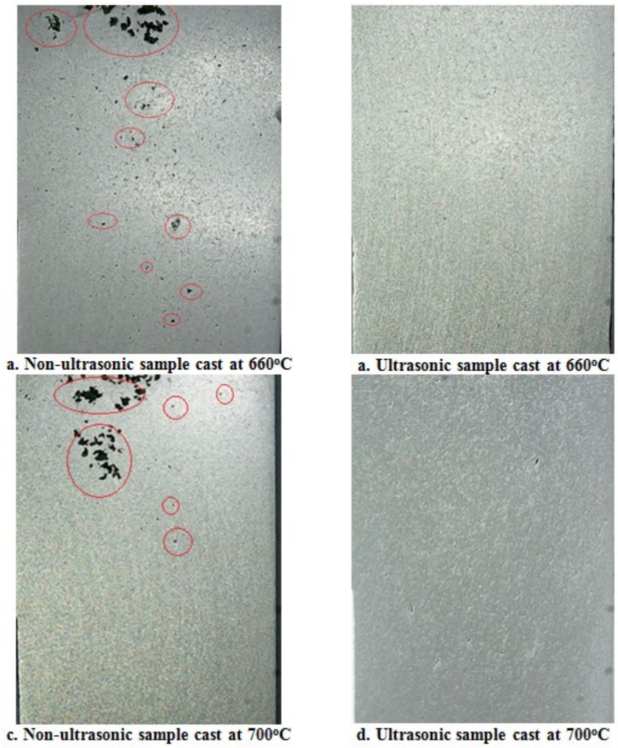


Figure 8 The porosity defects and shrink pitting inside the non-ultrasonic and ultrasonic casting samples

Grain size

Generally, the samples cast at 660°C have a smaller grain size than those cast at 700°C. In each casting condition, ultrasound reduces the size of α-Al particles. In the shell area, due to the very fast cooling rate, the grains are round and fine, the grain size in the shell area ranges from 150-250µm without ultrasound and less than 100µm with ultrasound. Specimen cast at 700°C has larger grain sizes than those cast at 660°C due to longer cooling times. When there is an ultrasonic vibrating, the cooling rate increases while fragmentation of the dendrites makes the area smooth (Figure 9; Figure 10). The morphology of the grain changes to a spherical shape at a lower pouring temperature.

Particle shape α-Al has a considerable change when impacted by ultrasonic vibrations. The metal area near the vibrating head is strongly influenced by changes in both shape and grain size. The farther the ultrasonic placement is the less affected the particle structure is, in these regions, the α-Al particle shape and size are similar to the non-ultrasonic cast. On the side of the mold opposite to the site of ultrasonic impact, the structure of the dendrite is observed. The center of the casting has a similar structure between the other specimens, which is the ultrasonic region of little influence due to the loss of vibration transmission when the amount of metal in the mold has solidified by more than 75%. The particle size in this region ranges from 300 µm to 400µm. However, it can be seen that the crystallization nuclei creation under the effect of ultrasound resulted in a decrease of grain size despite the dendrite structure still exists (Figure 11, and Figure 12).

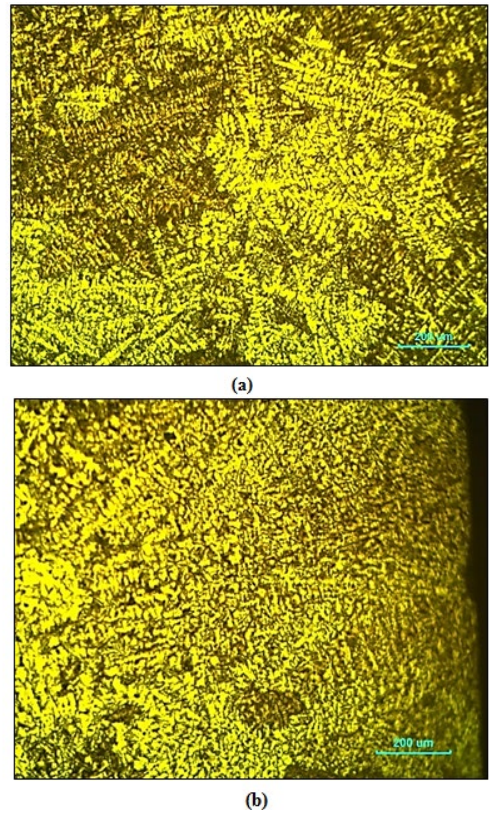


Figure 9 Microstructure at the shell area (0- 4 mm from the ultrasonic mold wall) at 700°C: a) with ultrasonic vibration and b) Without ultrasonic vibration (magnification of 100X)

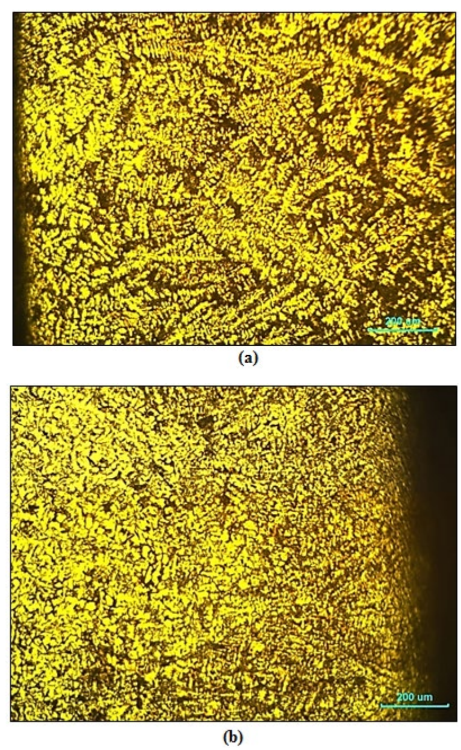
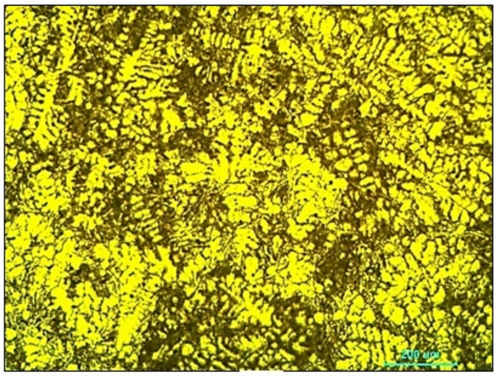
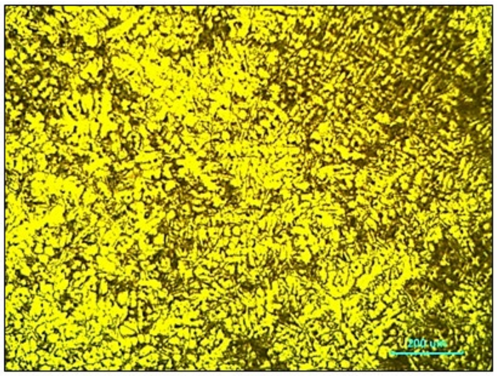


Figure 10 Microstructure at the shell area (0- 4 mm from the ultrasonic mold wall) at 660°C: a) with ultrasonic vibration and b) without ultrasonic vibration (magnification of 100X)

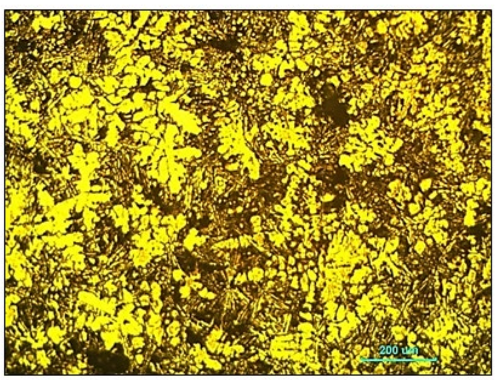


(a)

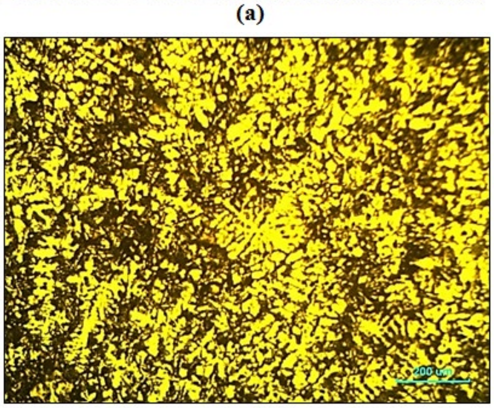


(b)

Figure 11 Particle structure at the central area at 700°C: a) with ultrasonic vibration and b) without ultrasonic vibration (magnification of 100X)



(a)

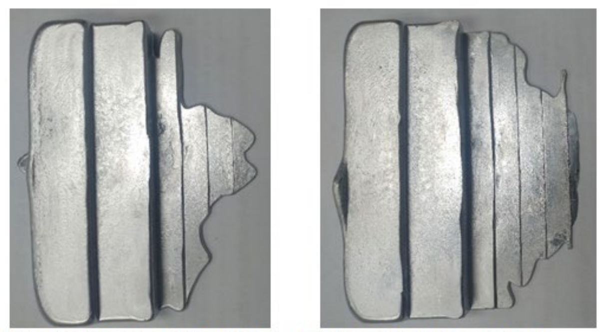


(b)

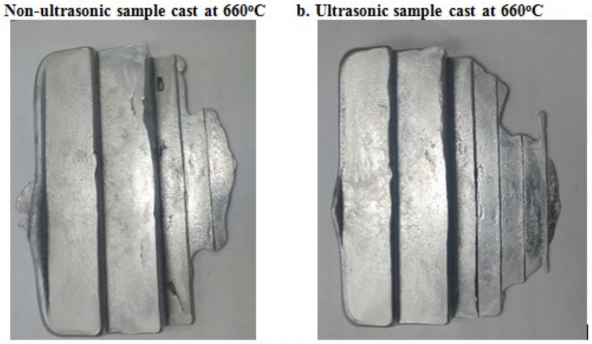
Figure 12 Microstructure at the central area at 660°C: a) with ultrasonic vibration and b) without ultrasonic vibration (magnification of 100X)

Mold filling ability

The lengths of fill were measured under different casting conditions. The casting pattern's geometry presented in Figure13 shows a significant increase in the metal flow length measured at both fill temperatures when ultrasonic is applied. Among the factors influencing the fluidity, reducing friction and increasing kinetic energy for the liquid metal flow is considered the main one, which can be seen in the metal strip shape when filling the mold cavity. Because the ultrasonic probe has a circular cross-section with a diameter of 70mm, the vibrating impact area with enough amplitude will be in this range. At that time, the metal stream preferentially fills the area with high-intensity vibration impact, thereby forming a semicircular shape with a metal filling in the middle and missing on both sides according to the area of the vibrating head. The grain size decreases slightly when ultrasound is applied. Smaller particle size means that during solidification, ultrasound reduces dendrite size or fragmentation resulting in the minimized formation of large dendrites (these large crystals interfere with the metal flow) that improves fluidity. Besides, ultrasound also helps to increase the wetting ability of the oxide particles mixed in liquid metals, and at the same time, to destroy the oxide films and disperse them to increase the fluidity.



a. Non-ultrasonic sample cast at 660°C b. Ultrasonic sample cast at 660°C



c. Non-ultrasonic sample cast at 700°C d. Ultrasonic sample cast at 700°C

Figure 13 Samples cast at 660°C and 700°C with and without ultrasonic vibration

For casting parts in a static metal mold, the minimum allowable cross-section is not less than 3mm to ensure that the metal completely fills in the mold cavity before solidifying. Under the action of ultrasonic vibrations, the minimum cross-section can reach 2 mm. The ultrasonic vibration-free castings have an incomplete 3mm cross-section, meanwhile, with ultrasonic vibrating castings, the 3mm cross-section is filled and achieves the required definition of the cavity shape, moreover, the cross-section 2mm is also filled from 95-100% of required width (Figure 14).

In general, the fluidity increases with increasing pouring temperature. However, some samples cast at high temperature have somewhat inferior fill rates than those cast at low temperature (negligible). The reason is that the oxide film forms a lot when the metal is liquid at high temperatures, thereby hindering the mobility of aluminum alloys. Thus, under the influence of ultrasound, the oxide film can be broken, or in other words, the fill level of the casting in the presence of ultrasound at two heat levels. almost the same degree.

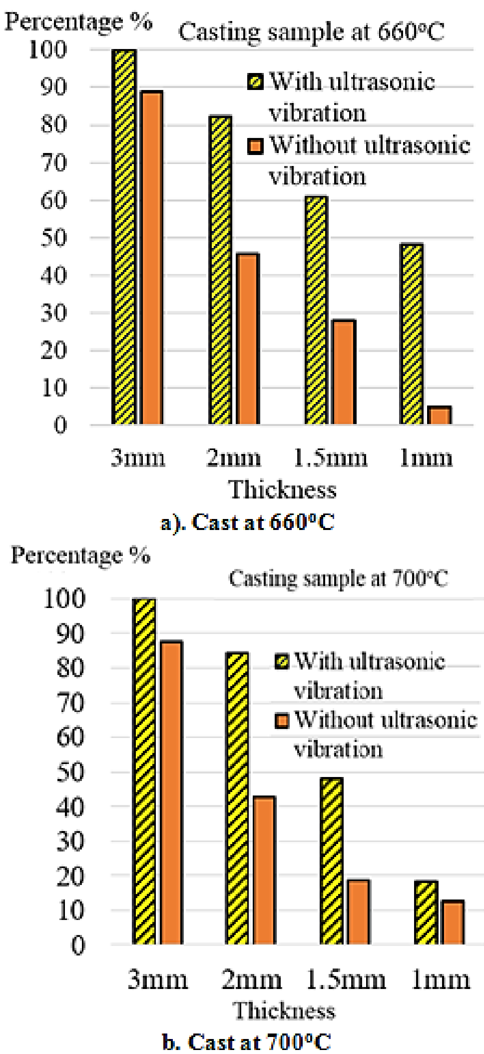


Figure 14 Filling percentage with respect to the cross-sectional area of the mold

4.0 CONCLUSION

The experimental results in this study clearly show that ultrasonic treatment makes the metal filling the mold cavity better with small cross-sections, promoting air escape from the metal and reducing defects in the casting. The castings without vibration have an incomplete 3mm cross-section, meanwhile, with ultrasonic vibrating castings, the 3mm cross-section is filled and achieves the required definition of the cavity shape, moreover, the cross-section 2mm is also filled from 95-100% of required width.

The ADC 12 aluminum alloy grain refining increases the hardness slightly and significantly improves the tensile strength. Comparing the mechanical test results between the casting conditions shows that, when ultrasound is applied the mechanical properties are better than casting without ultrasonic in both hardness and tensile strength. When applying ultrasonic vibration, the tensile strength increased by 20% at 660°C and 9% at 700°C, while the hardness changed insignificantly Also under the ultrasonic impact, the liquid metal dissipates heat into the mold faster resulting in a change in the growing conditions of the crystals, especially when ultrasound is applied at high temperatures, this effect becomes significant.

At higher temperatures, although the fluidity increases slightly, the oxidation of the metal surface takes place more strongly, and the microstructure after cooling becomes coarser, so 660°C is choosen temperature for further experiments.

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References

[1] Khalifa, W., Tsunekawa, Y., & Okumiya, M. 2008. Effect of ultrasonic melt treatment on microstructure of A356 aluminium cast alloys. *International Journal of Cast Metals Research*, 21(1-4): 129-134. DOI: https://doi.org/10.1179/136404608X361819

[2] Ferguson, J. B., Schultz, B. F., Cho, K., & Rohatgi, P. K. 2014. Correlation vs. causation: The effects of ultrasonic melt treatment on cast metal grain size. *Metals,* 4(4): 477-489. DOI: https://doi.org/10.3390/met4040477

[3] Eskin, G. I., & Eskin, D. G. 2014. Ultrasonic Treatment of Light Alloy Melts. DOI: https://doi.org/10.1201/b17270.

[4] Abramov, V. O., Abramov, O. V., Straumal, B. B., & Gust, W. 1997. Hypereutectic Al-Si based alloys with a thixotropic microstructure produced by ultrasonic treatment. *Materials & Design*, 18(4-6): 323-326. DOI: https://doi.org/10.1016/S0261-3069(97)00072-1

[5] Eskin, G. I. 1995. Cavitation mechanism of ultrasonic melt degassing. *Ultrasonics Sonochemistry,* 2(2): S137-S141. DOI: https://doi.org/10.1016/1350-4177(95)00020-7.

[6] Xu, H., Jian, X., Meek, T. T., & Han, Q. 2004. Degassing of molten aluminum A356 alloy using ultrasonic vibration. Materials letters, 58(29): 3669-3673. DOI: https://doi.org/10.1016/j.matlet.2004.02.055

[7] Jian, X., Meek, T. T., & Han, Q. 2006. Refinement of eutectic silicon phase of aluminum A356 alloy using high-intensity ultrasonic vibration. *Scripta Materialia,* 54(5): 893-896. DOI: https://doi.org/10.1016/j.scriptamat.2005.11.004

[8] Puga, H., Costa, S., Barbosa, J., Ribeiro, S., & Prokic, M. 2011. Influence of ultrasonic melt treatment on microstructure and mechanical properties of AlSi9Cu3 alloy. *Journal of Materials Processing Technology*, 211(11): 1729-1735. DOI: https://doi.org/10.1016/j.jmatprotec.2011.05.012

[9] Feng, H. K., Yu, S. R., Li, Y. L., & Gong, L. Y. (2008). Effect of ultrasonic treatment on microstructures of hypereutectic Al-Si alloy. Journal of materials processing technology, 208(1-3), 330-335. DOI: https://doi.org/10.1016/j.jmatprotec.2007.12.121

[10] Abu-Dheir, N., Khraisheh, M., Saito, K., & Male, A. 2005. Silicon morphology modification in the eutectic Al-Si alloy using mechanical mold vibration. *Materials Science and Engineering: A,* 393(1-2): 109-117. DOI: https://doi.org/10.1016/j.msea.2004.09.038

[11] Han, Y., Li, K., Wang, J., Shu, D., & Sun, B. 2005. Influence of high-intensity ultrasound on grain refining performance of Al-5Ti-1B master alloy on aluminium. *Materials Science and Engineering: A,* 405(1-2): 306-312. DOI: https://doi.org/10.1016/j.msea.2005.06.024

[12] Puga, H., Barbosa, J., Teixeira, J. C., & Prokic, M. 2014. A new approach to ultrasonic degassing to improve the mechanical properties of aluminum alloys. J*ournal of materials engineering and performance*, 23(10): 3736-3744. DOI: https://doi.org/10.1007/s11665-014-1133-2

[13] Meidani, A. N., & Hasan, M. 2004. A study of hydrogen bubble growth during ultrasonic degassing of Al-Cu alloy melts. *Journal of Materials Processing Technology*, 147(3), 311-320. DOI: https://doi.org/10.1016/j.jmatprotec.2003.11.012

[14] Xu, H., Han, Q., & Meek, T. T. 2008. Effects of ultrasonic vibration on degassing of aluminum alloys. *Materials Science and Engineering: A*, 473(1-2): 96-104. DOI: https://doi.org/10.1016/j.msea.2007.04.040

[15] Tsunekawa, Y., Suzuki, H., & Genma, Y. 2001. Application of ultrasonic vibration to in situ MMC process by electromagnetic melt stirring. *Materials & Design,* 22(6): 467-472. DOI: https://doi.org/10.1016/S0261-3069(00)00079-0

[16] Eskin, D. G. 2015. Ultrasonic melt processing: Achievements and challenges. In M*aterials Science Forum* 828: 112-118. Trans Tech Publications Ltd. DOI: https://doi.org/10.4028/www.scientific.net/MSF.828-829.112

[17] Eskin, D. G. 2017. Ultrasonic processing of molten and solidifying aluminium alloys: overview and outlook. *Materials Science and Technology,* 33(6): 636-645. DOI: https://doi.org/10.1080/02670836.2016.1162415

[18] Eskin, G. I. 2002. Effect of ultrasonic (cavitation) treatment of the melt on the microstructure evolution during solidification of aluminum alloy ingots. *International Journal of Materials Research,* 93(6): 502-507 DOI: https://doi.org/10.3139/146.020502

[19] Puga, H., Barbosa, J., Seabra, E., Ribeiro, S., & Prokic, M. 2009. The influence of processing parameters on the ultrasonic degassing of molten AlSi9Cu3 aluminium alloy. *Materials Letters*, 63(9-10): 806-808. DOI: https://doi.org/10.1016/j.matlet.2009.01.009

[20] Puga, H., Barbosa, J., Tuan, N. Q., & Silva, F. 2014. Effect of ultrasonic degassing on performance of Al-based components. *Transactions of Nonferrous Metals Society of China*, 24(11): 3459-3464. DOI: https://doi.org/10.1016/S1003-6326(14)63489-0