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Research Paper

GRAIN REFINEMENT OF AA-356 BY ADDING AI-5TI-1B GRAIN REFINER AND INDUCING ULTRASONIC VIBRATIONS DURING SOLIDIFICATION

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Grain refinement plays vital role for improving the quality of AA-356 aluminium alloy castings. The aim of present investigation is to evaluate the grain refinement of AA-356 alloy by inducing ultrasonic vibrations through the die into the melt during solidification, which was treated at various frequencies and amplitudes by adding master alloy (Al-5Ti-1B) at different fractions. Experimental results shows that the columnar dendritic structure was changed into globular grain structure with reduced in grain size. These grains were obtained when melt was treated ultrasonically which leads to formation of equi-axed grains, degassing, increase in fluidity, refinement in phases, improvement in homogeneity, segregation control, uniform distribution of secondary phases and inclusions. It may imply that from the experiment the cavitations induces heterogeneous nucleation plays important role than dendrite fragmentation of globular grains. Due to cavitation phenomenon degassing of hydrogen from the melt during solidification takes place, due to this the formation small equi-axeed grain structure produced throughout the casting.

Keywords: AA-356, Master alloy, Ultrasonic vibrations, Nucleation, Cavitations

INTRODUCTION

Grain refinement of Al and its alloys is a common industrial practice, which otherwise solidifies with coarse columnar grain structure. Many workers have extensively carried out investigations on this topic over the past years (Birch Mej and Cowel Ajj, 1988; Mc Cartney, 1989; Kashyap and Chandrashekar, 2001; Qiu *et al.*, 2007; and Han *et al.*, 2012), not only to develop efficient grain refiners but also to achieve an understanding about the mechanisms of grain refinement and to

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improve the Aluminum properties (Gear, 2000; and Han *et al.*, 2007). Quality of the casting can be improved by grain refinement of aluminum by adding grain refiners (Gear, 2000), which reduces the size of primary ~-Al dendrites in the casting (Jines and Engh, 1985), which otherwise solidifies with coarse columnar grain structure.

Microstructure is one of the major factors that define the mechanical properties of aluminum alloy. The aluminum AA-356 alloy is widely used casting aluminum alloys due to light in weight, high fluidity, ease of casting, low density, machinability and to achieve optimum mechanical properties. They comprise aluminum with silicon additions (6.5-7%) hypoeutectic. To optimize the properties of AA-356 to control the grain size by adding grain refiners in to the AA-356 by inducing Magnetic field or ultrasonic vibrations (Charles Vives, 1998) during solidification. The ultrasonic vibration waves produce more heterogeneous nucleation in the melt. This is due to cavitations phenomena occur within the melt. This leads to degassing, reduce in hot cracking, reduce in porosities and formation of equi-axed grains in small size (Qiu *et al.*, 2007). Many techniques have been developed for physical refinement such as using electro-magnetic (Charles Vives, 1998), magneto hydrodynamics (Lui and Mao Zhao, 2006), electro-magnetic stirring (Chaowalik *et al.*, 2009), ultrasonic vibrations (Abramov *et al.*, 1998; Zoqui *et al.*, 2002; Han *et al.*, 2005; Jain *et al.*, 2005; Jain *et al.*, 2006; Wannasin *et al.*, 2006; Songli Zang *et al.*, 2009; Chaowalik *et al.*, 2009; and Ghadami *et al.*, 2013), Gas bubble pouring (Wannasin *et al.*, 2006). The most important grain refiner is Al-5Ti-1B master alloy (Han *et al.*, 2005) for aluminum alloy, which holding Ti/B ratios and increasing the number of effective nucleating sites for AA-356.

Many researchers studied that the vibrations are propagates in to the melt produces cavitations with large intensity pressure, tensile and compressive forces also the temperature fluctuations in the melt (Abramov *et al.*, 1998; Jain *et al.*, 2005; Jain *et al.*, 2006; Wannasin *et al.*, 2006; and Ghadami *et al.*, 201315-19). These pressure, temperature and force fluctuations induces heterogeneous nucleation and segregation control in the melt with reduced in grain size and formation of globular equi-axed non dendrite structure.

Jain and Laborde stated that a globular/non dendrite structure was obtained and grains were refined in the melt subjected to a continues acoustic vibrations. The dominant mechanism for grain refinement is due to cavitations induced heterogeneous nucleation (Laborde and Hita, 2000; and Jain *et al.*, 2006).

A fine grain size creates a more uniform distribution of secondary intermetallic interphases in addition to pores which form from the evolution of dissolved in the melt (Zang *et al.*, 2012). The resultant increase in casting integrity is companied by improvements in both mechanical properties and pressure tightness (Eskin, 1998; Alamanenko *et al.*, 2010; Eskin *et al.*, 2010; Eskin *et al.*, 2011; and Zang *et al.*, 2012).

In this method the ultrasonic vibrations are induced around the die isothermally for different frequencies, amplitudes with certain interval of time for different fractions of master alloy (Al-5Ti-1B) and the effect of

Table 1: Chemical Composition of AA-356

Element	Si	Mg	Mn	Fe	Ni	Zn	Sn	Ti	Pb	Al
Wt%	6.5-7	0.3	0.02	0.1	0.05	0.01	0.01	0.02	0.02	Bal

microstructure and properties have been investigated.

EXPERIMENTATION

In the experiment the commercial aluminum AA-356 is used as base material. The composition is as shown in Table 1.

The experimental setup consists of a permanent steel mold die with Teflon coating. A cavity is made around the die to supply water for cooling purpose and the cavity can be closed at the top as shown in Figures 1 and 2.

A copper coil having 3Ω resistance was wound around the die. A sine wave of frequency 20 KHZ to 30 KHZ was generated by functional signal generator and fed in to the coil as shown in Figure 3. Ultra-sonic vibrations create in the

Figure 1: Die (All Dimensions in mm)

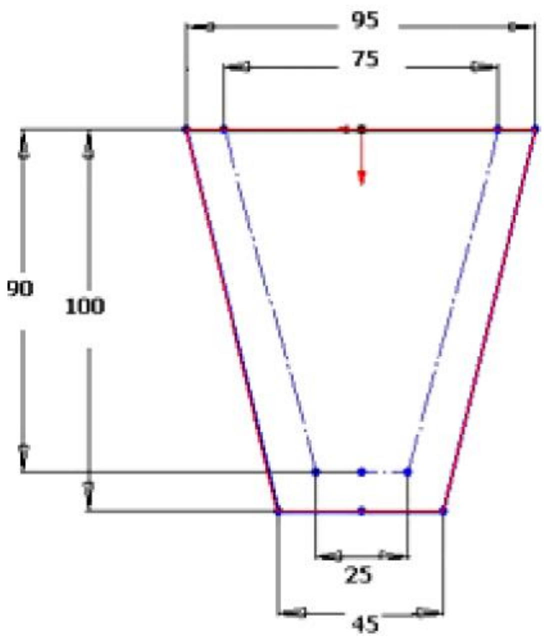
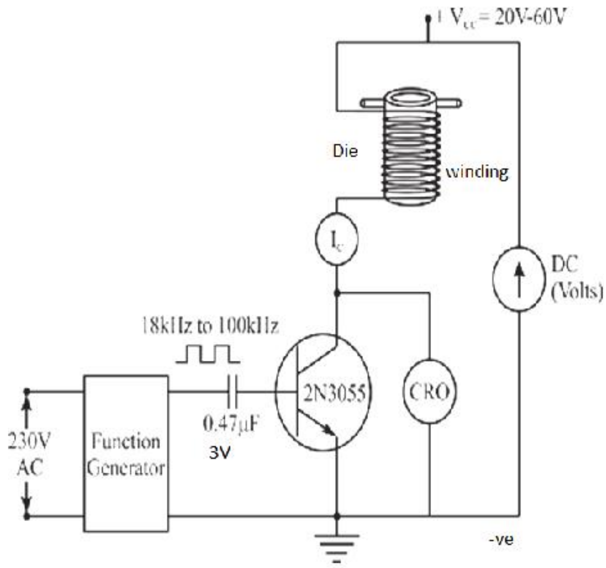


Figure 2: Die with Copper Winding

Figure 3: Circuit Diagram of Ultrasonic Vibration Set Up



form sine waves around the die which were propagate into the melt.

The aluminum AA-356 alloy was melted separately using graphite crucible melting furnace, the melt is maintained to liquids temperature 614 °C and the temperature increased to 780 °C for 2 hrs to melt completely. The primary Fcc structure of aluminum dendrites starts to form at 614 °C and the binary at 574 °C. Tertiary eutectic and complete intermetallics form at the later stages.

The master alloy (Al-5Ti-1B) is prepared separately and it is cut in to required Wt% fraction and add into the AA-356 melt. The master alloy is added to the AA-356 melt and allow to melt for one more hour, the mixer is thoroughly mixed using mechanical stirrer for different fractions 0.4 Wt% (Al-5Ti-1B), 0.6 Wt% (Al-5Ti-1B), 0.8 Wt% (Al-5Ti-1B).

The castings were prepared by taking the molten metal using ladle and poured into permanent steel mold die and it is solidified without inducing ultrasonic vibrations. Further for next experiments the molten metal is poured in to the die and ultrasonic vibrations were induced during solidification with 20 Khz. 24 khz, 28 Khz at 40 µm, 60 µm, 80 µm amplitude for 40s, 80s, 120s respectively for different compositions 0.4 Wt% (Al-5Ti-1B), 0.6 Wt% (Al-5Ti-1B), 0.8 Wt% (Al-5Ti-1B), etc.

Ultra-sonic vibrations create in the form sine waves around the die which are propagate into the melt. Which is already poured into the die and absorb these propagated waves and produces cavitations phenomenon in the melt, due to this the degassing, grain refinement and reduced in grain size takes place in the melt during solidification.

The specimens are prepared using castings for microstructure examination, the specimens are etched with use of HCL, HNO_3, Cu and water solution. These etched specimens are examined under microscope, compare them with and without ultrasonically treated specimens and analyzed.

RESULTS AND DISCUSSION

Ultrasonic vibration treatment was known to induce refining effect in AA-356 alloys (Eskin, 1998; Alamanenko *et al.*, 2010; and Eskin *et al.*, 2010). The basic principle is introduction of acoustic waves with frequency 20 KHz to 30 KHz in to the liquid metal and high amplitude oscillations result in the cavitations of the melt and also promote intense mixing through agitation (Eskin *et al.*, 2011). The reported nucleation through local under cooling and wetting of substrates to fragmentation forming grains.

The effect of ultrasonic vibrations on grain refinement is to decrease the grain size and control of columnar structure and formation of equi axed grains though out, these leads improve material homogeneity, segregation control and uniform distribution of secondary phases.

The casting sample made without addition of grain refiner and ultrasonic vibration treatment exhibit a dendrite columnar grain structure of AA-356 Alloy as shown in Figures 4a and 4b. The grains were coarse in size and looks like columnar tree structure.

When the melt is treated with ultrasonic vibrations by adding grain refiner 0.4 wt% of (Al-5Ti-1B) at frequency 20 KHz and amplitudes 40 µm at 30 s of time. The dendrite columnar grain structure was broken up in to small equi-axed fine and uniform globular grain structure as shown in Figures 5a and 5b. Which shows that the finer grain structure compare to Figures 4a and 4b. From above figure it shows that the reduction in grain size, columnar dendrite structure to equi-axed uniform globular grain structure, improvement

Figure 4a: Microstructure Without Grain Refiner and Without Vibration (100 X)

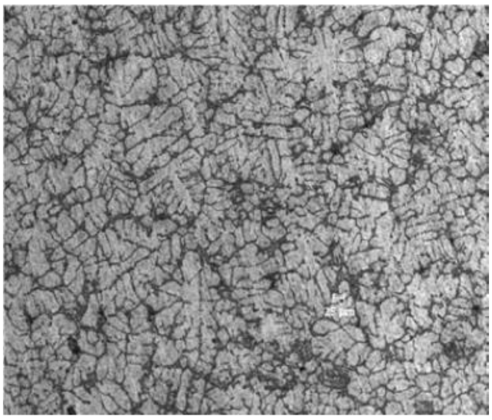


Figure 4b: Microstructure Without Grain Refiner and Without Vibration (500 X)

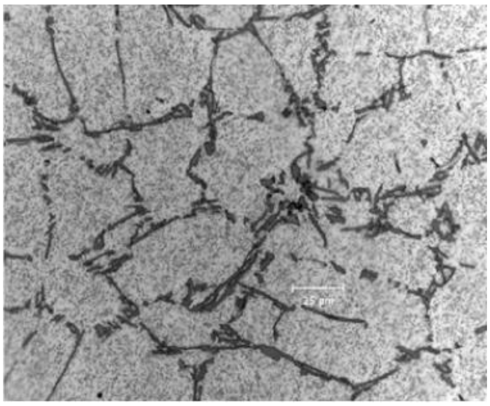


Figure 5a: Microstructure of AA-356 with 0.4 wt% of (Al-5Ti-1B) with 20 KHz Vibration (100 X)

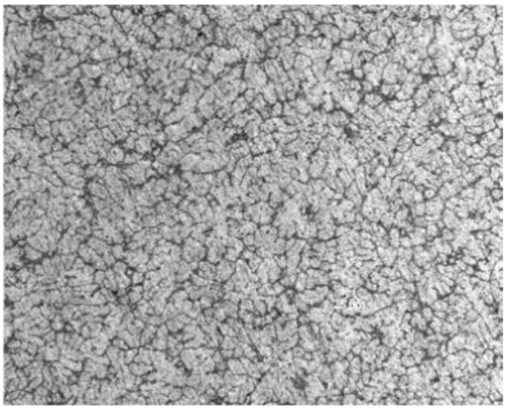
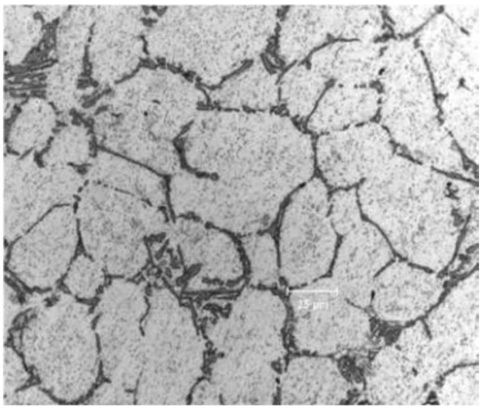


Figure 5b: Microstructure of AA-356 with 0.4 wt% of (Al-5Ti-1B) with 20 KHz Vibration (100 X)



of material homogeneity and uniform distribution of secondary phases.

Figures 6a and 6b Shows the resultant microstructure of AA-356 with 0.6 wt% of (Al-5Ti-1B) of inoculant, when it is treated to 24 KHz frequency with amplitudes 60 µm for time 80 s, which is more equi-axed than the Figures 5a and 5b, the melt is treated isothermally which is little effect than the Figures 5a and 5b, where that dendrite structure further break up and forming globular structure. In this the heterogeneous nucleation is more dominate

Figure 6a: Microstructure of AA-356 with 0.6 wt% of (Al-5Ti-1B) with 24 KHz Vibration (100 X)

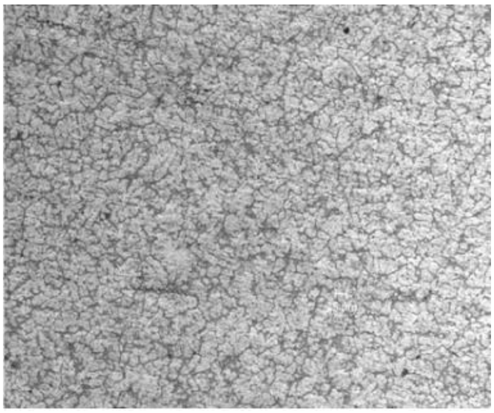
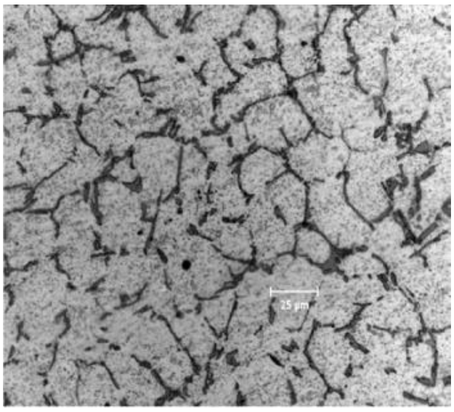


Figure 6b: Microstructure of AA-356 with 0.6 wt% of (Al-5Ti-1B) with 24 KHz Vibration (500 X)



to form equi-axed globular structure which leads to form small grains approximately 80 µm-100 µm in size.

The Figures 7a and 7b, and Figure 8, suggests that the globular structure is formed at solid fraction of 0.6% (Al-5Ti-1B) and 0.8 wt% of (Al-5Ti-B) 20 KHZ ultrasonic vibrations and 40 microns, 80 s, respectively. In this microstructure the grain refinement is better at 0.6 solid fraction compares to 0.8% grain refinement solid fraction. The fragmentation is too fast, so some % age of dendrites

Figure 7a: Microstructure of AA-356 with 0.6 wt% of (Al-5Ti-1B) with 28 KHz Vibration (100 X)

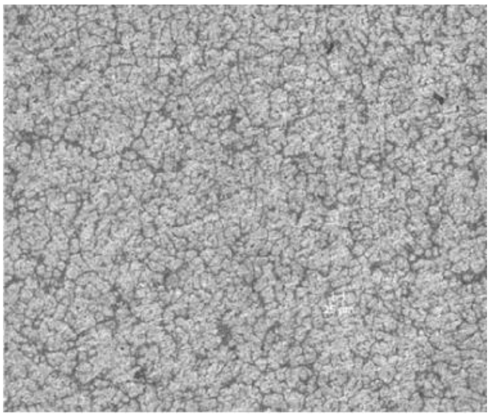


Figure 7b: Microstructure of AA-356 with 0.6 wt% of (Al-5Ti-1B) with 28 KHz Vibration (100 X)

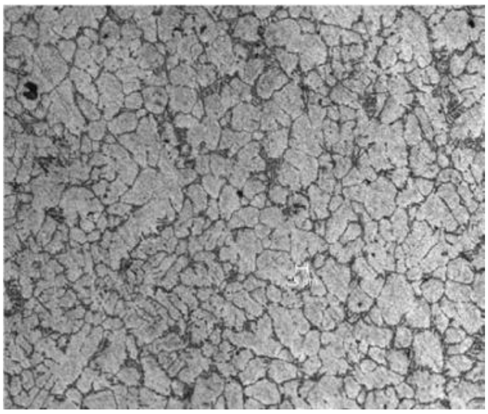
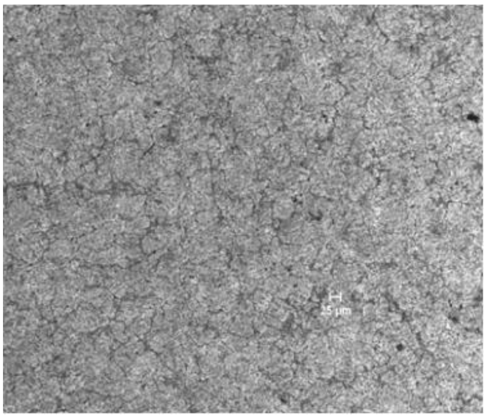


Figure 8: Microstructure of AA-356 with 0.8 wt% of (Al-5Ti-1B) with 28 KHz Vibration (100 X)



fragmentation is occurred in our experiment since the grain size is reduced with ultrasonic vibrations. In comparison of Figures 7a and 7b with Figures 4a and 4b the porosities are reduced to maximum extent and grain refinement has been improved which leads to improve in fluidity for complex mold designs.

CONCLUSION

The experimental result shows that the grain refinement of AA-356 is more effective when it is treated ultrasonically when it is compare with the pure aluminum AA-356 without ultrasonic treatment.

Results it shows that 0.6 wt% (Al-5Ti-1B) grain refiner is more effective when it is treated 24 KHz frequency with amplitudes 60 µm for 80 sec. This is due to cavitations assisted fragmentation is the main contribution to grain refinement to produce small grain size.

High intensity ultrasonic vibrations eliminate coarse grains and forms globular equi-axed grains small grains approximately 80 µm, which shows that the grains are refined is related to nucleation (hetrogeneuos) and survival of small nuclei or embryos of grains formation.

The microstructure shows that the porosities are reduced to larger extent under ultrasonic treatment which leads to better flow properties for fluidity of complex mold designs.

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