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# The Effect of Ultrasonic Vibration on the Morphology of Intermetallic Compounds on the aluminum alloy A356

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## Abstract

Refinement of intermetallic compound in Al-Si alloy is considered as an important task that results from solidification process. In general there are two different methods to the refinement of microstructure by solidification. The first one is chemically stimulated approach and the second one physically induced approach. The chemical method depends primarily on addition of grain refiner, where as the physical one relies mainly on the use of external field, such as ultrasonic vibration, which as the subject of this research work. In this research the effects of ultrasonic vibration on the morphology of iron-containing intermetallic compounds of A356 alloy have been studied. The mechanism of shape-transformation of Fe-containing phases such as β-$Al_5FeSi$, δ –$Al_4FeSi_2$, α-$Al_{15}(Mn,Fe)_3Si_2$ is also been investigated. The obtained samples were characterized by scanning electron microscopy (SEM), and EDS X-ray analysis( EDS). The results showed that the intermetallic compounds particles are in blocky form was significantly modified in shape and refined in size.

Keywords: Intermetallic compound, ultrasonic vibration, refinement, SEM, EDS.

## 1.INTRODUCTION

Aluminum A356 alloy is one of the widely used casting aluminum alloys because of its good mechanical strength, ductility, hardness, fatigue strength, pressure tightness, fluidity, and machinability(1)In the particular case of hypoeutectic Al-Si alloy such as A356, besides a usually coarse and dendritic ، α -Al solid solution and Al–Si eutectic where Si usually assumes an acicular shape.Works of various researchers reported the presence of intermetallic phases like the eutectic $Al_2Cu$ “Chinese script” shaped α-$Al_{15}(Mn,Fe)_3Si_2$ and long and sharp needles of β-$Al_5FeSi$ and δ –$Al_4FeSi_2$, which precipitate in the interdendritic and intergranular regions, and are strongly detrimental to the alloy mechanical and fatigue properties Puga et al (2011) [2, 3].

At the temperature below 577 °C, the previously δ- phase transforms into the β- phase with peritectic reaction L + δ –$Al_4FeSi_2$→ β –$Al_5FeSi$ + Si, These phases ( β-$Al_5FeSi$ ) and (δ–$Al_4FeSi_2$ ) have a monoclinic and tetragonal crystal structure respectively, until the ternary eutectic reaction of α-Al, Si and β- phases occurs at about 576 °C L→ α- (Al) + Si + β –$Al_5FeSi$, which is located in the intervals (570–582) °C, are well below the treatment temperatures. In addition, silicon and other stable and metastable binary and ternary phases can precipitate during the decomposition of supersaturated solid solutions or upon cooling of ingots or castings[4]. In recent years, processes of refinement of intermetallic compounds of aluminum alloy under ultrasonic vibration, neutralization elements addition and melt superheating were widely studied. With the addition ofMn according to certain ratio ofMn/Fe, the coarse plate phase transforms is observed to be more effective Chinese script $Al_{15}(Fe,Mn)_3Si_2$ phase [2,5].

Ultrasonic vibration is a new technique used for grain refinement of aluminum alloys. The same process has now more attention. The solidification structure and mechanical property of alloys, are obtaining now and more attention. The application of ultrasonic energy into molten alloys can bring about some nonlinear effects, such as cavitation, acoustic stream, emulsification, and radiation pressure, which can be used to refine microstructure, reduce segregation and degassing. [ 6-10]

## 2. EXPIRMENTS

### 3.1 Materials

The material of this interest investigation was commercial aluminum – silicon based alloy, A356, with chemical composition ( ASTM){10} showed in table 1

Table 1: Chemical Composition of A356 (ASTM)

| Si | Fe | Cu | Mn | Mg | Zn | Ti | Other | Al |
|---|---|---|---|---|---|---|---|---|
| 6.5-7.5 | 0.6 | 0.25 | 0.35 | 0.20-0.45 | 0.35 | 0.25 | 0.15 | Balance |

This alloy was supplied from Aluminum Company of Egypt in got form with trade manner of A356-1, the delivered alloy A356, was analysis with the help of optical immersion process and the result is shown in table 2.

Table 2: Chemical Composition of A356

| Si | Fe | Cu | Mn | Mg | Zn | Ti | Other | Al |
|---|---|---|---|---|---|---|---|---|
| 7.36 | 0.15 | 0.0462 | 0.00129 | 0.329 | 0.00229 | 0.136 | 0.012 | Balance |

The aluminum – silicon phase diagram is shown that the equilibrium eutectic constitution is about 12.6 wt% silicon. The chosen aluminum alloys in this study fall into the hypoeutectic category. Their liquiduses temperatures are in the range of 610 – 660 °C. Their microstructure comprises both primary fcc aluminum solid solution containing 1.65 – 12.6 wt% silicon and eutectic containing silicon enriched aluminum and pure silicon.[11]

### 3.2 Melt of Aluminum alloys A356

The 1500grams of A356 alloy was melted in heat resistance furnace with the help of a steel crucible coated inside with a graphite and put inside a resistance furnace, and after

completely melting of the alloy, the temperature of the crucible kept for half an hour at a temperature of 740 °C± 10 °C, which is 100 °C higher than its liquidus temperature to allow the complete dissolution of silicon particles.
The thermocouple type K was used in measuring the temperature during melting process. The thermocouple is calibrated before and after each series.

### 3.3 Pouring and ultrasonic application

The pouring of melted alloy A356 was carried out into a preheating permanent mould made of cast iron. The mould is kept in the top of ultrasonic sonotrode at different temperature at 200 °C, the dimension of permanent mould was 40 mm inside diameter and 200 mm length. An ultrasonic generator unit with high power capacity was used, it consists of a 3.2 KW electric power supply, and frequency a 22.4 kHz acoustic generator, an water cooled converter, a booster, a probe, and an acoustic radiator made of titanium alloy Ti-6Al-4V. Fig.1 illustrates the setup of the experiment where ultrasonic vibration is applied directly to lower part of the mould through the sonotrode and the casting bar.

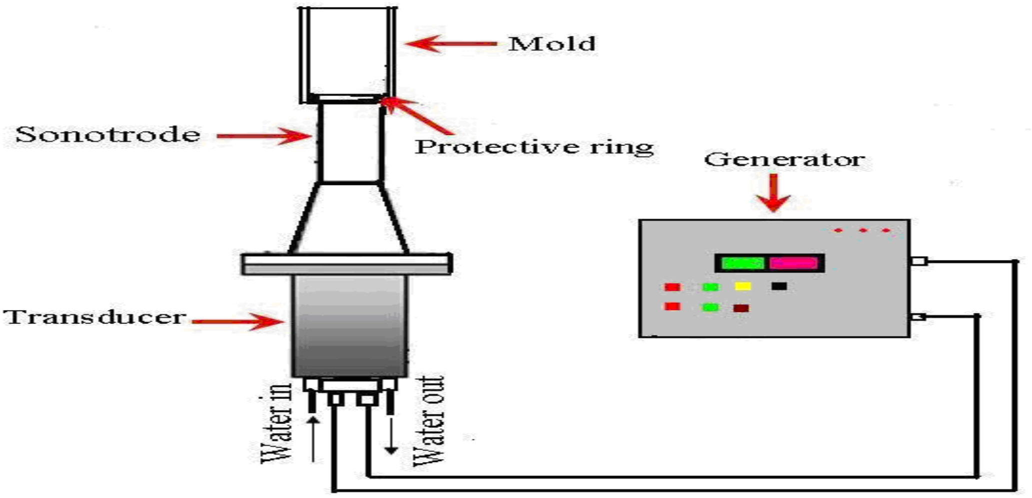


Fig.1 The setup experiment of ultrasonic treatment equipment.

### 3.4 Microstructure Analysis

Metallographic samples were cut from the same position for all experiments 15mm from the bottom of casting as shown in Fig.2 and prepare according to used procedures development for aluminum alloys. Investigated specimens were obtained under different condition without and with ultrasonic vibration at different powers and mould temperature of aluminum alloys A356. Samples for microstructure analysis were taken from each cast sample by sectioning the cylinders parallel to its longitudinal axis, three specimens for microstructure analysis were made from one section, the location of specimens is .15 mm from the bottom of cast as shown in Fig. 2. Samples were first cut and ground using standard metallographic procedures. They were grinding by using 240, 320, 400, and 600 *grit* papers. After grinding samples were polished using 1 µm, and 0.05 µm Alumina suspension in water. Final polishing was done using silica suspension. Between each step, samples were thoroughly cleaned.

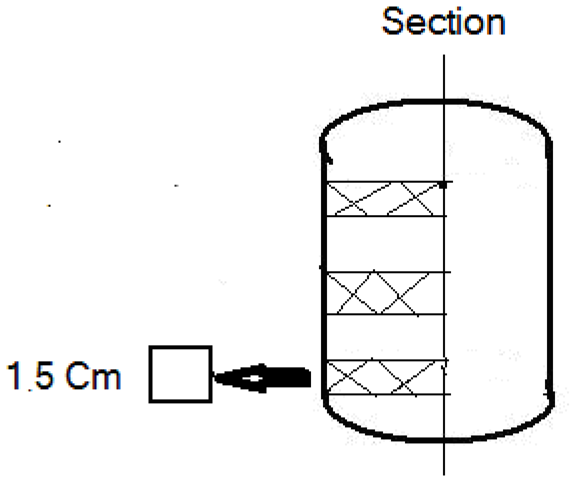


Fig. 2 location of specimens from bottom of cast cylinder of aluminum alloy A356.

## 3.5SCANNING ELECTRON MICROSCOPE (S.E.M.)

Scanning Electron Microscope (SEM) was used for the observation of the three-dimensional α-aluminum phase, eutectic Si morphology and analysis of composition of intermetallic phase of the specimens by deep-etched solution. Two deep etchants method, specimens were immersed in solution techniques were used in this research. First of 30% NaoH in distilled water at temperature of 70 °C for time from 3-20 minutes.[12] Second, specimens were immersed in a solution of 15cm$^3$HCL, 10cm$^3$HF and 90cm$^3$ $H_2O$ (distilled water) for time from 15-20 minutes, then the specimens were immersed in water from 1-2 minutes, then in alcohol from 3-5 minutes, finally the specimens were held in dryer at temperature 80 °C for time 60 minutes.[13]

## 4. RESULTS AND DISCUSION

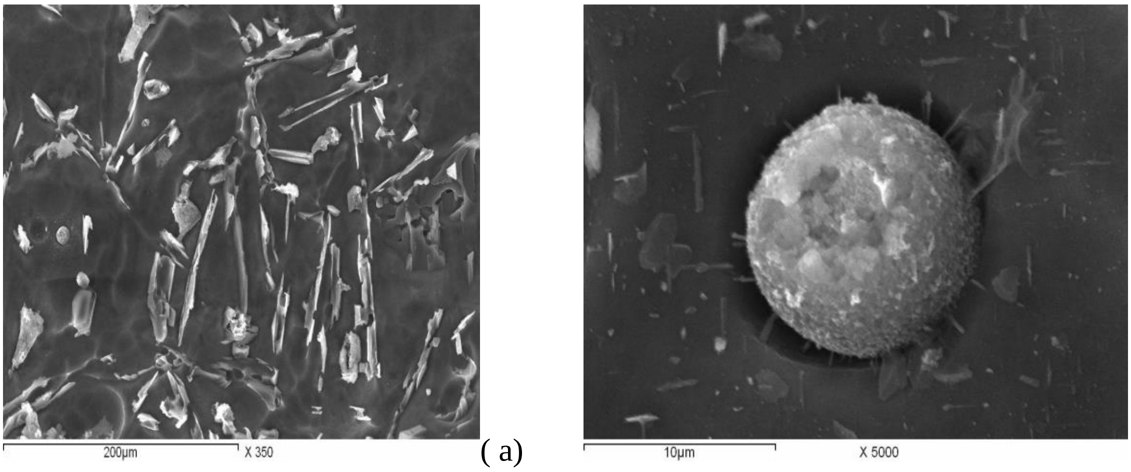
### 4.1 Microstructure of aluminium Alloys A356 Without Ultrasonic Vibration

The SEM at Fig. 3(a) shows the microstructure of the A356 alloy non treated by ultrasonic vibration at mould temperature 200 °C and ultrasonic power 3.2 Kw. It can be seen the small sphere particle of intermetallic phase inside the microstructure.

The intermetallic particles at a high magnification 350 in the alloy A356 produced without ultrasonic vibration are coarse acicular or plate-like, as shown in Fig. 3 (a,b). It can be clearly seen that the intermetallic particles inside the microstructure are in the form of rounded agglomerations.

An EDS analysis in the Fig.4(a) shows that the nature and chemical composition of the small sphere particle shape are observed in the aluminum alloy A356. The EDS X-ray analysis verified that particle shown in the eutectic areas were mainly intermetallic phases and inclusions rather than silicon or aluminum elements,. The compound of particle contain the elements Al, Si, Fe and Mg atoms, also other slightly amount of inclusion, element maps also show that the precipitates present (particles within the A356 alloy) are Na, Ni, Ca, S and Cl as shown in element map Fig.4(b).The chemical composition were detected in non treated aluminum alloys A356 suggest that they presence of intermetallic phases like the eutectic "Chinese script" shaped α-$Al_{15}(Mn,Fe)_3Si_2$ and long and sharp needles of β-$Al_5FeSi$, which precipitate in the interdendritic and intergranular regions, while Puga et al (2011) [2] were reported the same intermetallic phase in hypoeutectic $AlSi_9Cu_3$ alloy.

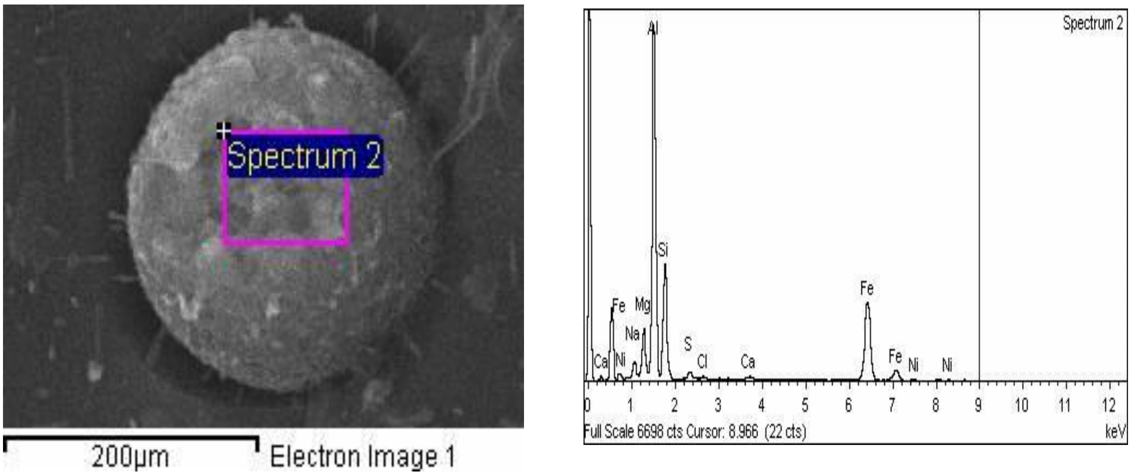
Besides its highly detrimental effect in the alloy mechanical properties, this morphology can promote shrink-age porosity since the platelets restrict feeding by causing physical restrictions to the movement of compensatory feeding liquid, as reported by Liu et al [14]



( a)

(b)

Fig. 3 SEM photomicrographs of the as-cast A356 (a) without ultrasonic vibration (b) High magnification of intermetallic compound from (a).



(a)

(a) (b)

(b) EDS Identifications

Fig. 4 SEM micrographs and EDS identifications of intermetallics in experimental alloy A356 (a) morphology of intermetallics without ultrasonic treatment; (b) composition

### 4.2 **Effects of ultrasonic vibration on intermetallic phases**

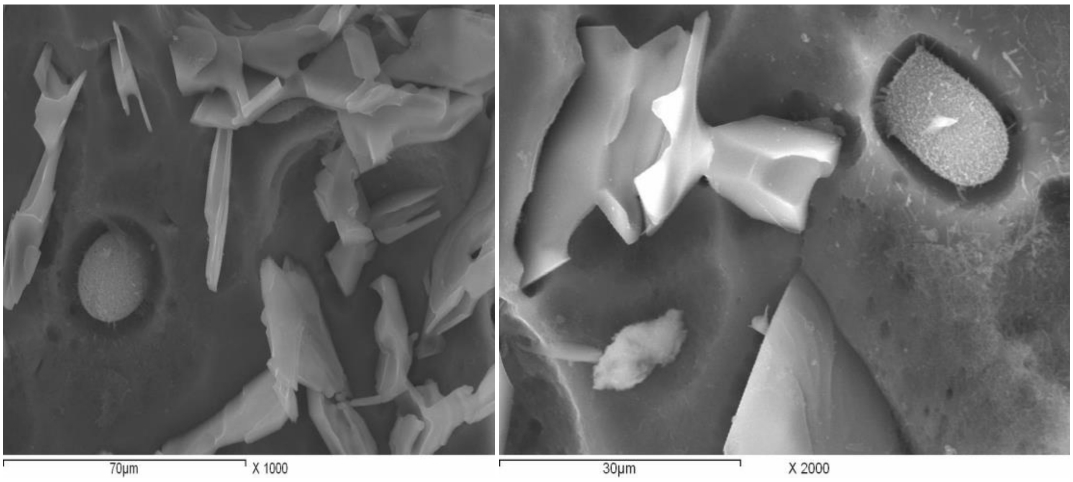
Upon application of ultrasonic vibration to the A356 alloy, Most of intermetallic compounds particles are in blocky form as shown in Fig.3(b), obvious changes can be found in the intermetallic compounds, the morphology of the intermetallics, including both the α-$Al_{15}(Mn,Fe)_3Si_2$, β-$Al_5FeSi$ and δ –$Al_4FeSi_2$ phases, was significantly modified in shape and refined in size Fig. 5 (a,b) and Fig.6(b,c). The size of the intermetallic compounds particle agglomerations is also decreased, and the distribution of the agglomerations is more uniform. Consequently, the agglomeration of α-$Al_{15}(Mn,Fe)_3Si_2$, β-$Al_5FeSi$ and δ –$Al_4FeSi_2$ particles is lightly alleviated with ultrasonic vibration as shown in Fig.5(a,b) and Fig. 6 (b,c). They major refinement of intermetallic compounds particles in hypoeutectic and hypereutectic aluminum alloy under ultrasonic vibration also were confirmed by Puga et al (2011) and Zhong et al (2010). [2,5]

The ultrasonic vibration refinement mechanism of intermetallic compounds on Si–Cu or Mg aluminium alloys is not well understood, and available references on this field are very scarce, requiring more research work on this particular field.

Zhong et al (2010)[15], the intermetallic compounds, such as Al-RE-Si-Cu-Ni compound, can also be refined by direct ultrasonic vibration and their cutting effect to the matrix of the alloy is minimized. As a result in the microstructure of slurry with direct ultrasonic vibration applied is improved, and the mechanical properties of the formed parts are enhanced.Zhong et al. (2010) [5], investigated the effects of ultrasonic vibration on iron-containing intermetallic compounds of two high silicon aluminum alloys. They found that ultrasonic vibration not only refined the needle like β-$Al_5FeSi$ and plate-like δ-$Al_4FeSi_2$ intermetallic phases, but it encouraged the formation of δ- phases more than β- phases as well. They associated the latter observation with the effects of ultrasonic vibration on more uniform distribution of iron atoms ahead of the solidification front and with the decrease in the formation temperature of the β - phase. They also argued that more uniform distribution of solute in the melt restrained the rapid growth of δ- phase in a single direction, causing the refinement of δ- phase. For instance, let us consider this phenomenon suggests that their modification was not due to the ultrasonic vibration itself, but it is a consequence of other factors promoted by the ultrasonic vibration. A possible explanation might be the decrease of the intergranular spacing due to the formation of a large number of globular α-Al grains, which might have restricted the growth of intermetallic phases, particularly the β –$Al_5FeSi$ compound as can be seen in Fig.4.24(c). For the same reason, and as the β –$Al_5FeSi$ phase forms directly from the liquid after the primary α-Al grains, the volume of reminiscent liquid at the formation temperature of β –$Al_5FeSi$ is also less, reducing the phase size.

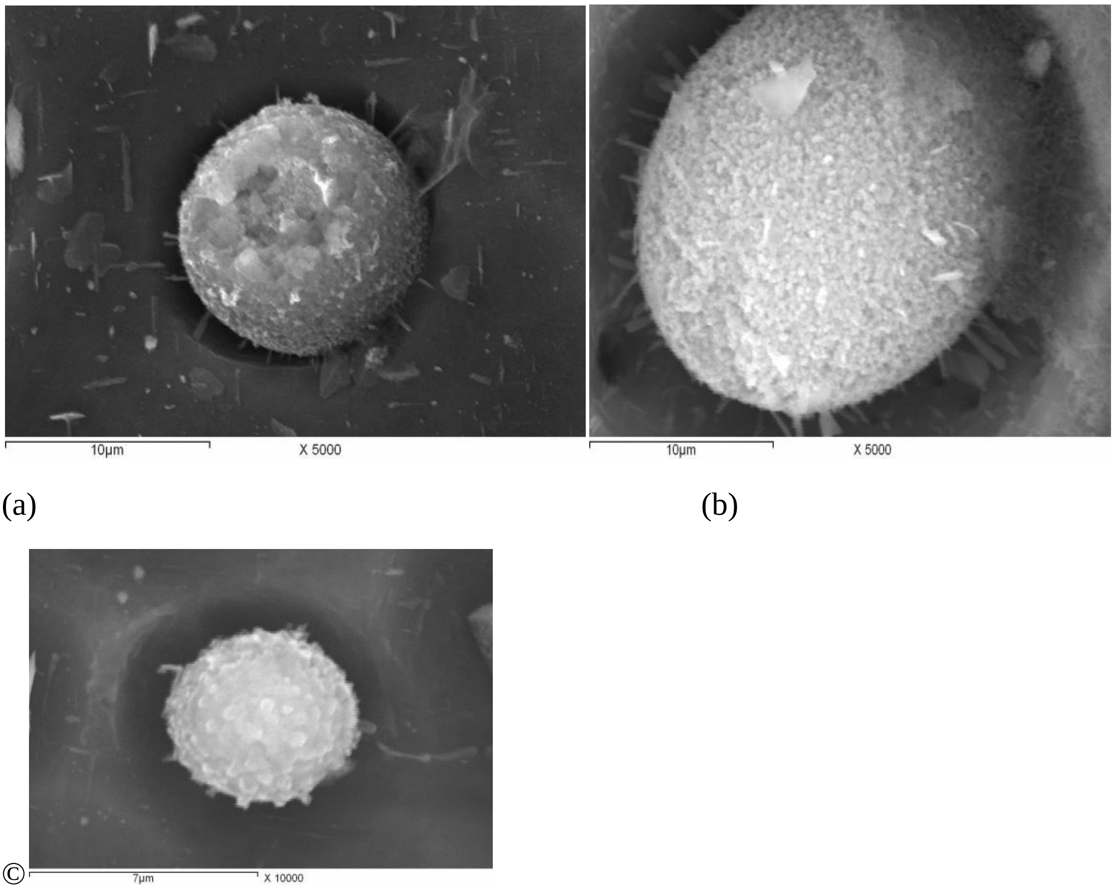
Another suggestion is that their mechanisms governing the changes in the shape and size of intermetallic phases is indeed the cavitation phenomenon which cleans the surfaces of the foreign particles in the melt and improves their wettability by the melt, thereby increasing the heterogeneous nucleation of the intermetallic phases. This seems to be a general mechanism effective in all the three intermetallic phases.

It also suggests that the effective mechanism for all the three intermetallic phases is the disintegration and distribution of the agglomerated nucleant particles existing in the melt under the effects of cavitation and streaming which increases the effective nucleation sites. Zhong et al (2010) [5], the evenly distributed fields of temperature and solute of the melt generated by the effect of acoustic cavitation and acoustic streaming, it is not only promoted by the formation of δ- phase, but also inhibited the rapid growth of δ-phase in a single direction bringing the refinement of particles.



(a)((b)

Fig. 5 SEM photomicrographs identification of intermetallic phases α-$Al_{15}(Mn,Fe)_3Si_2$, β-$Al_5FeSi$ and δ –$Al_4FeSi_2$ of the as-cast A356 with ultrasonic vibration at different magnification (a&b)



(a) (b)

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Fig. 6 SEM photomicrographs identification of intermetallic phases α-$Al_{15}(Mn,Fe)_3Si_2$, β-$Al_5FeSi$ and δ –$Al_4FeSi_2$ of the as-cast A356 (b) without ultrasonic vibration. (a& c) with ultrasonic vibration at different magnification.

### 4.5. Mechanisms for the effect of ultrasonic vibration on intermetallic compound

Several researchers have proposed mechanisms by which the intermetallic compound was significantly modified in shape and refined in size are produced via ultrasonic vibrations[2, 5-9, 14-16 ]. These mechanisms are related to ultrasonically induced dendrite fragmentation, heterogeneous nucleation.

Two mechanisms explaining the effect of ultrasonic vibration on grain refinement have been proposed by Eskin (1998)[16], cavitation-enhanced heterogeneous nucleation and dendrite fragmentation. Cavitation enhanced heterogeneous nucleation can be explained as follows: when a liquid metal is submitted to high intensity ultrasonic vibrations, the alternating pressure above the cavitation threshold brings about numerous tiny bubbles in the liquid metal, which start growing, pulsing on a continuous expansion/ compression regime and finally collapse. During expansion, bubbles absorb energy in the melt, undercooling the liquid at the bubble liquid interface, resulting in nucleation on the bubble surface. When bubbles collapse acoustic streaming develops in the melt, distributing the nuclei into the surrounding liquid producing a significant number of nuclei in the molten alloy, thus promoting heterogeneous nucleation. Dendrite fragmentation is explained using a different analysis: when cavitation develops, the shock waves generated by bubbles collapse lead to fragmentation of dendritic cells in the mushy zone, which are redistributed throughout the melt by acoustic streaming, increasing the number of solidification nuclei. The main difference between both mechanisms, is that dendrite fragmentation only occurs in melts already containing a minimum solid fraction volume, while cavitation enhanced heterogeneous nucleation can occur in melts with 100% liquid fraction volume. Although both mechanisms can occur, cavitation enhanced heterogeneous nucleation seems to be considered the most valid hypothesis, as claimed by Jian et al. (2005)[1], since globular and non-dendritic microstructures have not been obtained when the ultrasonic treatment occurred with the alloy in the mushy zone.

Zhong et al. (2010) [5], the effects of acoustic cavitation and acoustic streaming generated by ultrasonic vibration which is imposed near the liquidus temperature of the alloy, homogenizes the solute distribution field and the temperature field of the melt. The mixing effect of ultrasonic vibration on the solidification front lowers the concentration of Fe atoms, decreases the start freezing temperature of β- phase and promotes the formation of Fe-containing intermetallic compounds in the form of δ- phase. The uniform distribution of solute in the melt restrains the rapid growth of δ- phase in a single direction, causing the refinement of block δ- phase. In general, the main mechanism of the microstructure refinement of aluminum alloy A356 including α- aluminum, silicon phase and intermetallic compound was that the combination of cavitation enhanced heterogeneous nucleation and acoustic streaming generated by ultrasonic vibration.

## CONCLUSION

To summarize, this study was carried out to evaluate the influence of ultrasonic melt treatment in the morphology of intermetallic compound in aluminum alloy A356. The mechanism of shape-transformation of Fe-containing phases such as β, δ and α- also investigated. The experiment carried out at ultrasonic power 3.2 Kw and mould temperature 200C°, that gave the was following results:-

1- Ultrasonic treatment is an efficient physical technique to control the morphology and size of intermetallic phases, refinement and distribution of intermetallic phases and promotes modification;

2- The iron containing intermetallic phases changed their morphology from large needles or coarse “Chinese Script” shape into short and thin particles with different shapes, uniformly distributed throughout the matrix. As a results the intermetallics size is decreased.

3- The effects of acoustic cavitation and acoustic streaming generated by ultrasonic vibration which is imposed near the liquidus temperature of the alloy, homogenizes the solute distribution field and the temperature field of the melt. the combination mechanism of ultrasonic cavitation and acoustic streaming leads to the refinement of both intermetallic phases.

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