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EFFECTS OF MOULD VIBRATION ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A HYPEREUTECTIC AL-SI ALLOY

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ABSTRACT
The effect of mechanical vibration during the solidification of hypereutectic Al-Si (Al-20% wt Si) alloy on the microstructure and mechanical properties was investigated. The specimen with a specification of 25 mm in diameter and 65 mm long were solidified in the frequency range of 0 to 6.3 Hz so as to examine the effect of the vibration on the grain structure, tensile strength, hardness value and impact energy. In comparison with the grains formed in the as-cast state without vibration, the morphology of the grains changes from predominantly dendritic to a more globular structure as the intensity of vibration increases. The test result shows that there is an improvement in the mechanical properties of the samples within the frequency threshold of 1.5 and 4.2 Hz.
Keywords: *Mould, vibration, aluminum-silicon.*

INTRODUCTION

In the automotive manufacturing process, the of foundry cast aluminum permits close to precise-shape parts to be fabricated for structural applications because of their high strength-to-weight ratio in heat-treated conditions. In particular, aluminum-silicon alloys have widespread applications in the field of transport especially for engine blocks due to their good castability, their corrosion resistance and their excellent recycling behaviour (Merlin and Garagnani, 2009). Globally Hypereutectic Al-Si alloys have their bulk application in the automobile and aerospace industries they possess unique properties, such as outstanding wear resistance, high strength-to-weight ratio, low coefficient of thermal expansion, better corrosion resistance, excellent fluidity, and good castability (Hedge and Prabhu, 2008).

In any case the majority of the mentioned attractive properties of hypereutectic Al-Si alloys rely upon the properties of their cast microstructures, namely secondary dendrite cell size or arm spacing, and the size, morphology (or shape), and distribution of eutectic and primary Si particles. Refinement and control of the eutectic and primary silicon particles is a powerful method of improving the properties of the hypereutectic Al-Si alloys. For instance, hypereutectic Al-Si alloys with a uniform distribution of fine primary silicon particles have higher strength and better wear resistance (Gupta and Ling, 1999).

Several different techniques have been proposed for the refinement of eutectic and primary silicon particles in hypereutectic Al-Si alloys (Chong and Zhong-xia, 2007; Zhang *et al.*, 2012). They include: (i) chemical treatments by addition of elements such as Na, P, Sr, La, etc. (ii) application of an electric current during solidification (iii) electromagnetic stirring and vibration (iv) ultrasonic treatment and (v) application of the mechanical vibration to the solidifying alloy.

It is archived that the use of mechanical vibration as a dynamic solidification process affect the microstructure and consequently on mechanical properties of the casting. (Abu-Dheir *et al*., 2004).

The fundamental downside of cast Al–Si alloys is perhaps that, under the conventional solidification conditions the Si phase is usually in form of plates which exhibits a coarse microstructure that prompt to poor mechanical properties. For better mechanical properties of the alloy, the Si plates needs to be broken down during solidification. The grain refinement agent such as titanium, boron, carbon and mother alloys including these elements are widely used in aluminium casting to refine and homogenize the microstructure and macrostructure. In addition to the high cost of these mother alloys, these grain refining agents induce some problems not only in production but also in recycling (Omura *et al*., 2012). This research was performed to determine the effects of mechanical vibration on cast microstructure of hypereutectic Al 20% Si alloy during solidification.

MATERIALS AND METHODS

To evaluate the effect of an applied mechanical vibration during solidification on the microstructure and mechanical properties of Al20% Si alloy, an experimental method was developed to produce castings with and without the application of vibration. Detail of the experimental setup and procedure used for this study is given here.

Casting Process Selection and Mould Design

In deciding which casting process to use for this work, consistency from casting to casting is of primary importance. For this purpose a permanent mould process was selected (Desphande, 2006). Additionally, this type of process was simple to implement using the foundry equipment available at the Department of Metallurgical and Material Engineering, A. B. U. Zaria.

The decision made was to cast cylindrical rods as is common in Literature (Anyalebechi and Tomaswick, 2009). The designed casting shape was 65 mm long, and 25 mm in diameter. Figure1 shows the general shape of the metal (mild steel) mould. The design includes holes (1) for two dowel pins (3) in order to locate the two halves (2 and 4) of the mould to each other having a good thermal conductivity (Deshpande, 2006).

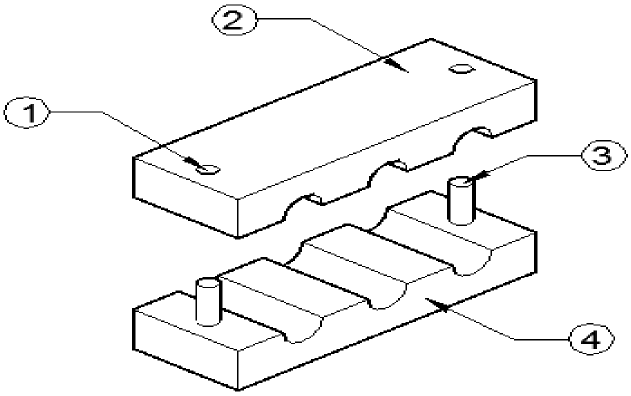

Figure 1: The general shape of the metal mould

Experimental Setup

The charge material (Al-20% wt Si) was melted in a graphite crucible using a natural gas furnace and pouring was performed manually. For each casting, 1.5 kg of charge material was used. The inside of the mould was coated with parting dust prior to each to ensure easy removal of the finished castings. The casting process, from removing the crucible from the furnace to completing the pouring of the material into the mould, lasted approximately 30 seconds and the finished casting was allowed to air cool. During the casting procedure, the speed regulator was connected to the electric motor attached to the vibrating table. An already melted charged Aluminium Silicon alloy was poured manually into the metal mould clamped on top of the vibrating machine and the melting temperature prior to pouring was recorded as 710^{o}C using a k-type thermocouple thermometer.

As soon as the mould cavity was completely filled, the mechanical vibration (vertical) was introduced to the set-up (Figure 2) at frequency of 1.5 Hz until the cast was completely solidified. The above procedure was repeated by increasing the frequency of the vibrator from 1.5, 2.3, 4.2, 5.9 to 6.3 Hz. In each of the procedure a sample was selected for mechanical test and microstructural examination.

Figure 2: (a) Mould vibrating machine

(b) A metal mould with the solidified alloy after vibration

Chemical Composition

A hypereutectic Al20% Si alloy was provided courtesy of NOCACO Nigerian Limited, Kaduna. The actual chemical composition of the sample was further determined after casting using the EDXRF machine (Model: Minpal 4 No. DY 1055) available at the National Geosciences Research Laboratory, Kaduna.

Tensile test

The tensile test was performed the samples using Monsanto Tensometer Type W, serial No. 9875 available in the Department of Mechanical Engineering, Ahmadu Bello University, Zaria. The sample was cut to the standard dimension as shown in Figure 3. Further the sample was gripped in between the chucks of hydraulic controlled loading system of the Tensometer. The load was then gradually applied until the sample finally fractured. The fracture load for each sample was noted as well as the initial diameter and the final gauge length. The initial diameter and initial gauge length for each sample was noted before uniaxial load. A total of 18 test specimen was used to obtain result for this test (3 samples for each vibration condition). From the generated data the ultimate tensile strength and percentage elongation of each sample was calculated.

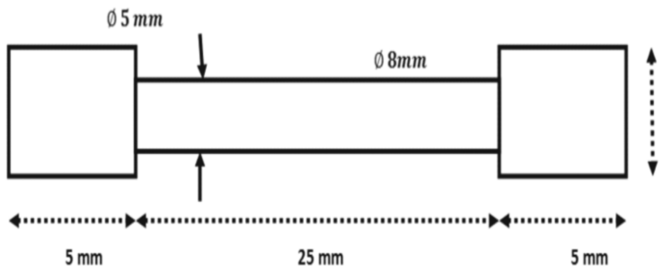

Figure 3: The standard sample for tensile test

Impact Test

The impact test was performed on 18 samples to determine the impact strengths by the "V-notch method using the Honsfield Balance Impact Testing Machine. Prior to mounting on the machine, the test sample was notched to a depth of 2 mm with v-shaped hand file. The notched test sample was then mounted on the impact-testing machine, which was then operated to apply a (constant) impact force on the test sample. The impact strength (the amount of impact energy the specimen absorbed before yielding) was then read off the calibrated scale on the impact testing machine.

Hardness Test

The hardness was determined according to the American Society of Testing and Materials (ASTM E18-79) standard. The test was carried out on the various test samples using the indentec Universal Hardness testing machine (Rockwell type), Model 8187.5 LKB at the department of mechanical engineering, Ahmadu Bello University, Zaria. The samples were first cut to the required dimensions of 20 mm diameter and 15 mm thickness. They were then placed on the anvil of the hardness testing machine with a diamond ball indenter of 2.5 mm under minor and major loads of 10 Kg and 187.5 Kg respectively. The minor load was applied to establish a zero datum position and then subjected to the major load. The loading process was repeated on three different positions on the circular surface of the sample and the average was recorded from the digital display of the machine.

Microstructural Examination

For each vibration condition after solidification, a sample was taken from the central horizontal plane of the casting for microstructure analysis. Samples were first cut and ground using standard metallographic procedures (Desphande, 2006). They were then polished using grit paper of grade 120, 400 and 800 with the application of lubricant intermittently to prevent overheating of the surface. Final polishing was done using a polishing machine to remove scratches left during grinding thereby obtaining a mirror liked polished surface. An etchant consist of a mixture of 5 vol. % HF, 20 vol % HCl, 20 vol % HNO_3, 55 vol % H_2O was used to reveal the grain structure of the sample. The micrographs of all the samples were obtained using the Photographic Visual Metallurgical Microscope (Model No. NJF-120A) at the Department of Metallurgical and Materials Engineering, A B U, Zaria.

RESULTS AND DISCUSSION

The X-ray florescence (XRF) test was used to determine the actual chemical composition of the Aluminium Silicon cast alloy. Table 4.1 shows the result of XRF test which was carried out at National Geosciences Research Laboratory (NGRL), Kaduna.

Table 1: Chemical composition of the Al-Si alloy using XRF

Element	Al	Si	Na	Ca	V	Cr	Mn	Fe	Ni	Cu	Sb	Eu
% Weight	73.06	19.6	1.76	0.18	0.044	0.03	0.11	1.58	1.42	1.63	0.01	0.19

The result in Table 1 vividly shows that the sample is hyper eutectic aluminium silicon (Al-19.6% Si) cast alloy. This is due to the silicon composition being above the eutectic composition (Al12.5% Si) (Sighworth, 2014).

Figures 4 to 7 show the variation of ultimate tensile strength, percentage elongation, energy and hardness of the cast samples with increase in frequency of vibration.

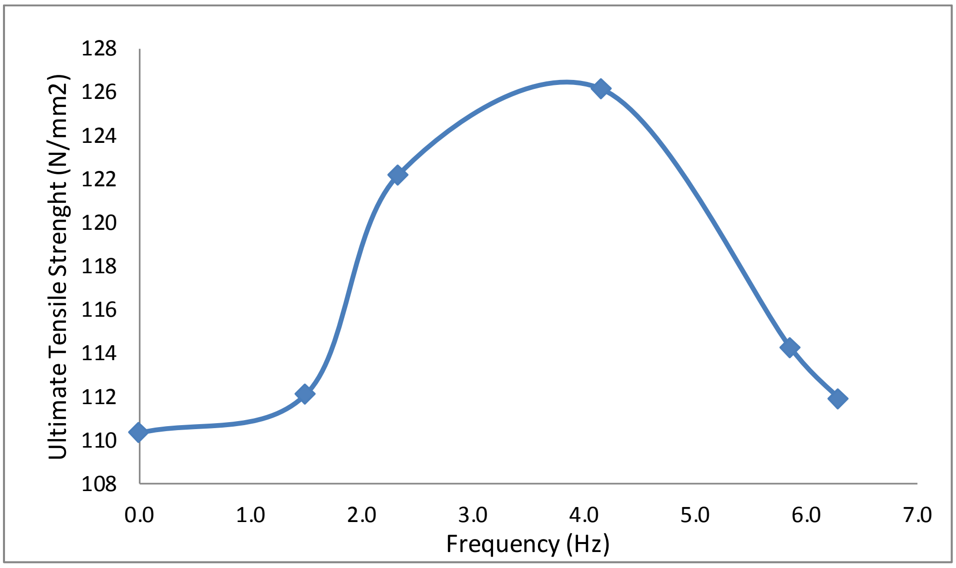

Figure 4: Variation of frequency of vibration with the ultimate tensile strength of the samples

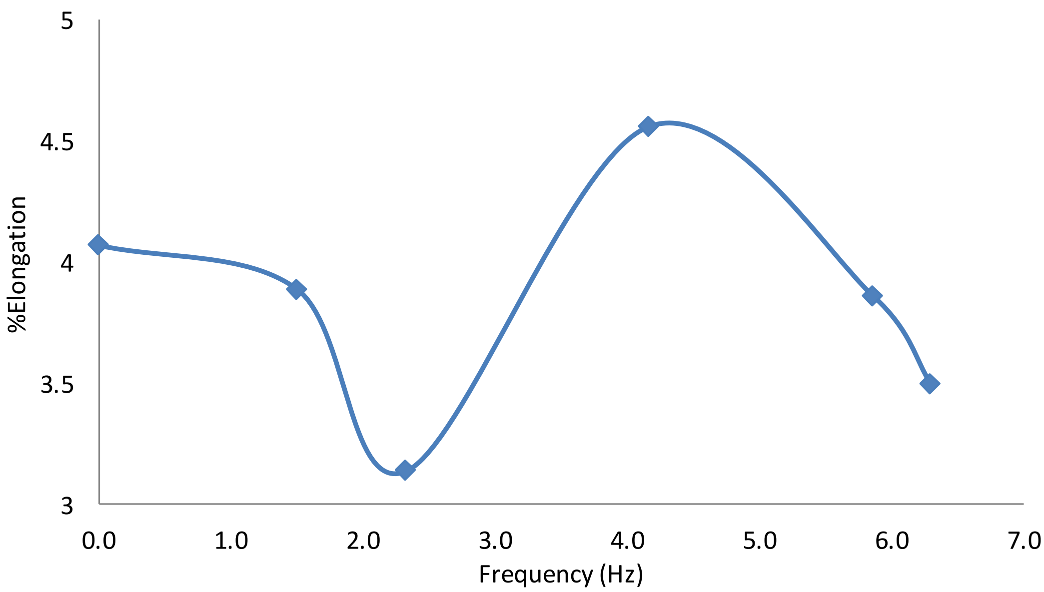

Figure 5: Variation of frequency of vibration with the percentage elongation of the samples

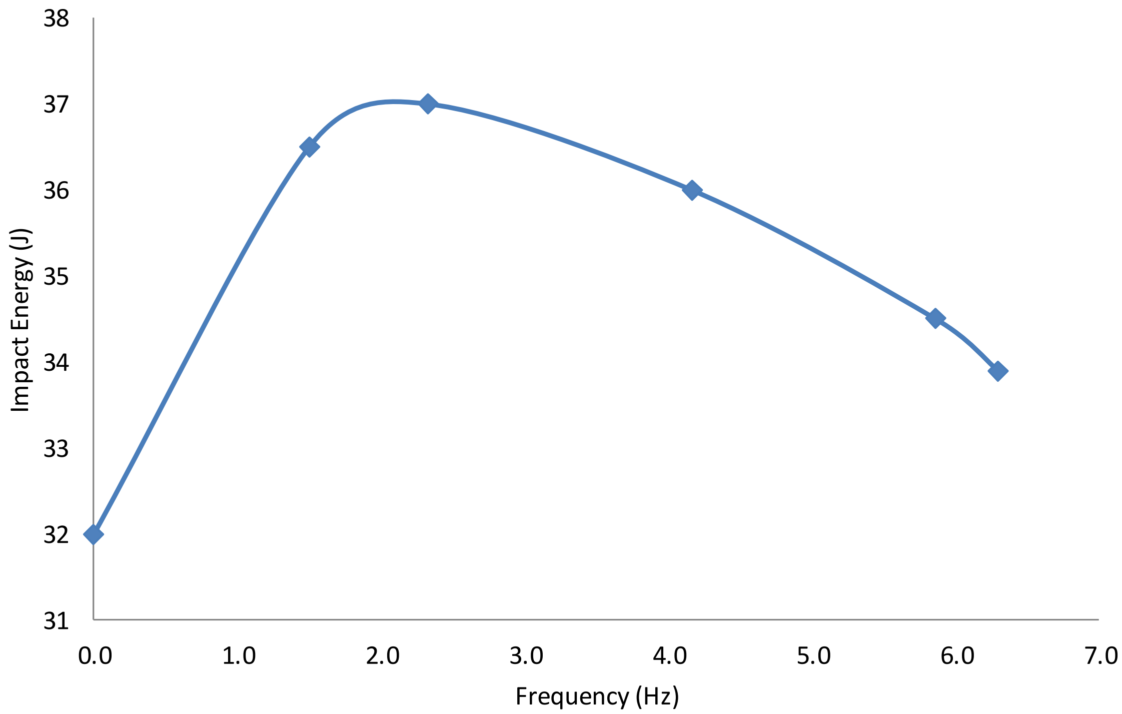

Figure 6: Variation of frequency of vibration with the impact energy of the samples

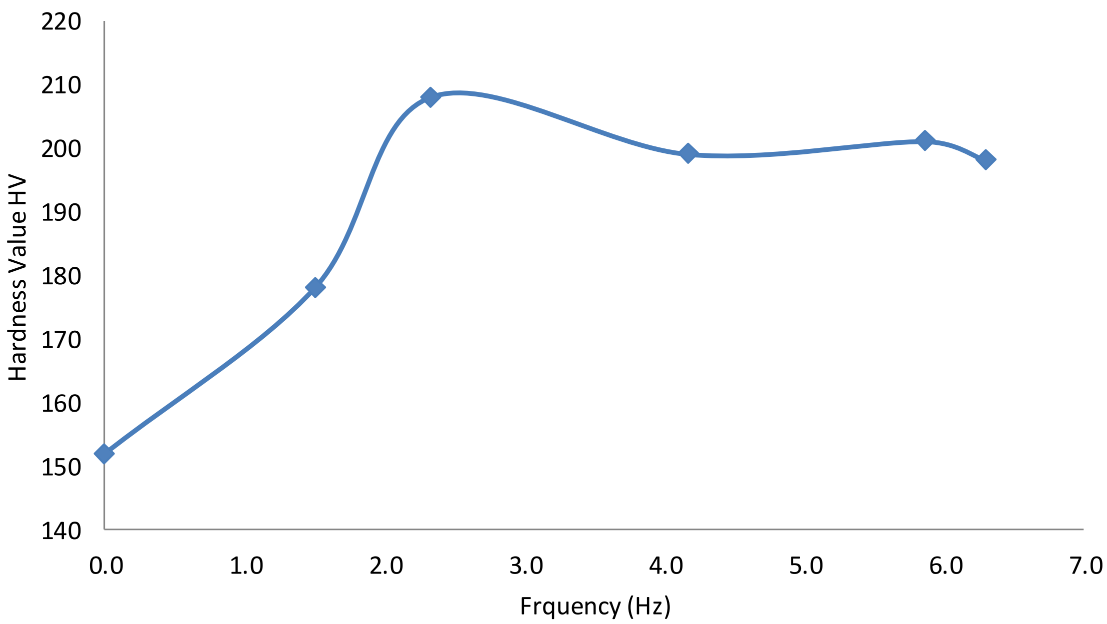

Figure 7: Variation of frequency of vibration with the hardness of the samples

Tensile Strength

Figure 4 reveals that the ultimate tensile strength (UTS) for the samples increases with increase in the frequency of vibration until maximum value is attained (between 3.8 Hz and 4.3 Hz). The value of the UTS then decreases with further increase in the frequency of vibration. The reason for this trend is due to the fact that, intense stirring changes dendrite to globular formation. This is in agreement with the study of Mollard *et al.* (1987) who demonstrated that sonic or ultrasonic vibrations of mechanical origin are effective in increasing fluidity by as much as a factor of three. Moreover, vibrations promote partial desorption of gases that could have resulted into casting flaws which would have drastically affected the UTS of the samples as reported by Higgins, (1991). It is observed that initially the UTS increase with the frequency vibration till maximum UTS is reached.

It thereafter dropped in value with further increase in the frequency of mould vibration. This is because shearing effects of the mould vibration breaks dendritic particles and deforms into a spheroidal (globular) shape. Both the intensity and frequency of mould vibration have some effects on the fineness of the globules formed; the higher the frequency the finer the globules formed. This is why the UTS is observed to increase with the frequency of mould vibration as posited by (Belyakov *et al*., 2000).

Percentage Elongation

Figure 5 depicts the effects of frequency of vibration of the mould during pouring till completion of solidification on the percentage elongation of the samples; it could be observed that the frequency of vibration of the mould during melt pouring affects the percentage elongation of the samples. Samples with no vibration have the least percentage elongation for the two sets of sample (4.125% elongation). The percentage elongation reaches the maximum at around 4.2 Hz and then begins to decrease with further increase in the frequency. It is also observable that the increase in vibration does not have significant influence on the ductility of the samples; this is probably due to the high percentage composition of silicon in the alloy which makes it more brittle (see Table 4.1) (Nikanorova *et al*., 2005).

Impact Energy Strength

Figure 6 shows the effects of the frequency of vibration on the impact (energy absorbed) strength of the samples. It was observed from the figure that the absorbed energy of the sample increases with the frequency of vibration; the absorbed energy reaches the maximum at around 2.3 Hz and then begins to decrease. The higher the intensity of mould vibration during solidification of molten metal the higher will be the toughness of the subsequent sample produced. The continuous precipitations inhibit the dislocation movement, while the discontinuous precipitations create boundary surfaces where dislocations can be developed and annihilated. In all the cases the intermetallic phases disperse in the vicinity of the grain boundaries and affect creep by impeding sliding and dislocation movements at the grain boundaries as stated elsewhere (Aramide and Ibitoye, 2012).

Hardness Value

Figure 7 presents the effect of frequency of vibration of the mould during pouring on the Brinells Hardness number of the samples. It is conspicuously revealed that the hardness of samples increases with the frequency of vibration, reaches the maximum around 2.3 Hz and then begins to fall to the minimum. The mechanical properties of the sample increases with increase in the frequency of vibration to the maximum (between 2.3 Hz to 4.2 Hz); subsequent increase in frequency of vibration results in the reduction of the UTS, percentage elongation, Hardness value and absorbed energy.

Microstructural Analysis Result of the Samples

Figure 8 to 13 show the grain structure of the samples obtained from the Photographic Visual Metallurgical Microscope under the magnification of 200. The cast microstructure of the castings produced with and without application of mechanical vibration during solidification consisted of primary silicon particles and eutectic aluminium dendrite cells.

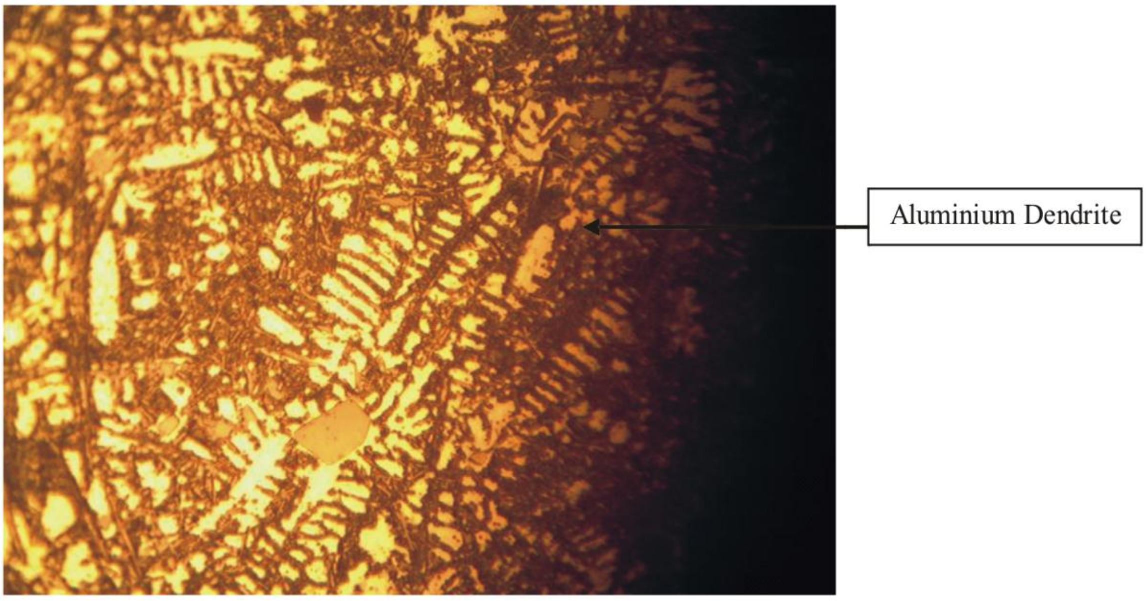

Figure 8: Optical micrographs of Al-20 wt % Si alloys cast without vibration showing silicon needles/dendrites. Mag. × 200

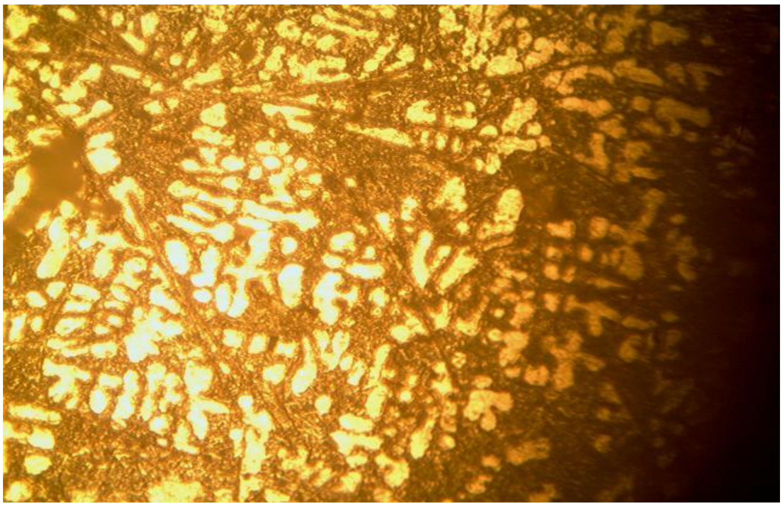

Figure 9: Optical micrographs of Al-20 wt % Si alloys cast vibrated at 1.5 Hz showing Silicon needles/Dendrites. Mag. × 200

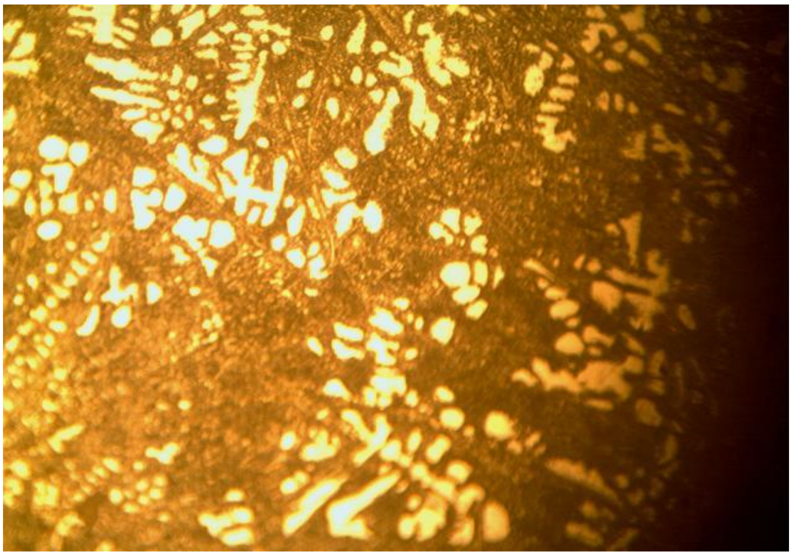

Figure 10: Optical micrographs of Al-20 wt % Si alloys cast vibrated at 2.3 Hz showing silicon needles/dendrites. Mag. × 200

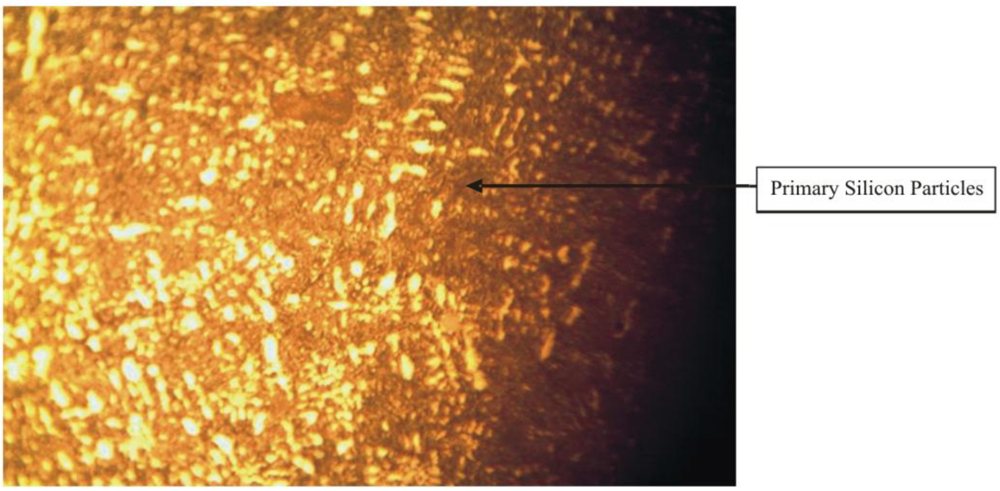

Figure 11: Optical micrographs of Al-20 wt % Si alloys cast vibrated at 4.2 Hz showing silicon needles/dendrites. Mag. × 200

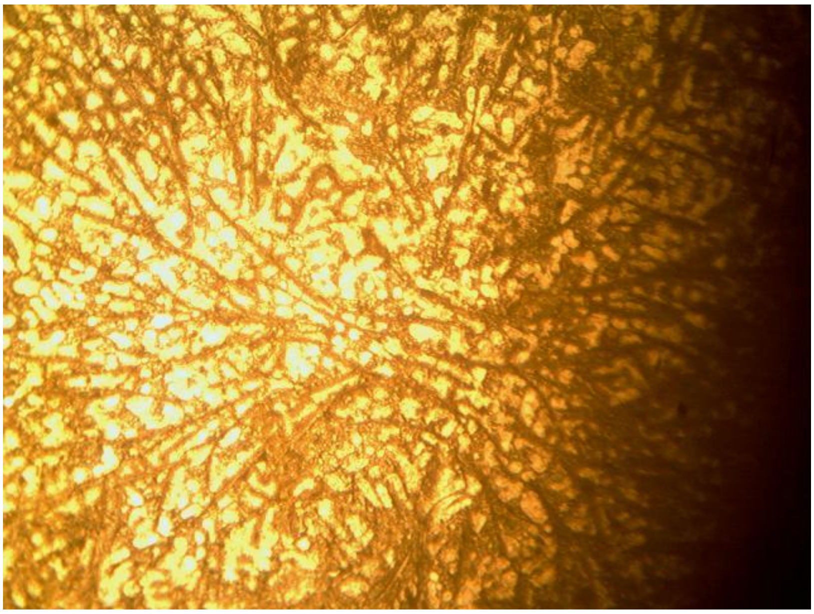

Figure 12: Optical micrographs of Al-20 wt % Si alloys cast vibrated at 5.9 Hz showing silicon needles/dendrites. Mag. × 200

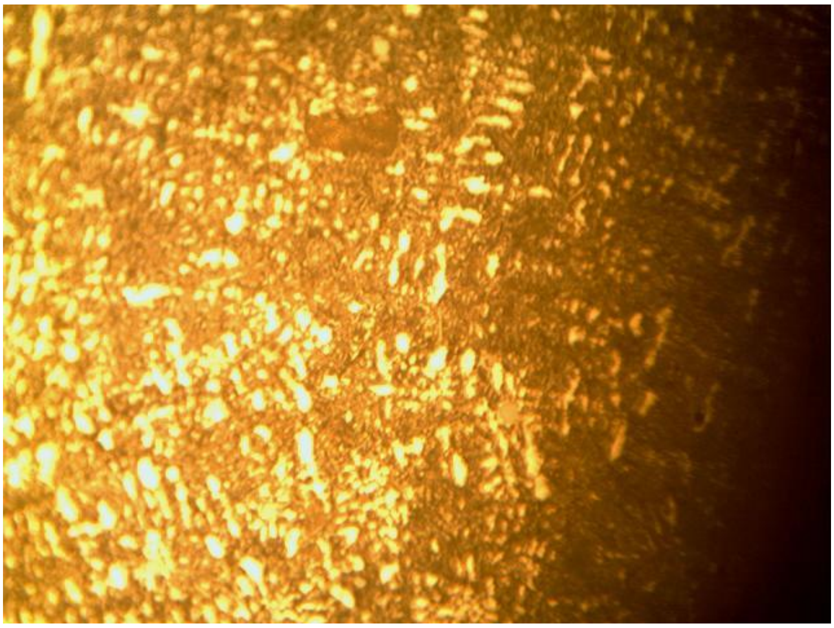

Figure 13: Optical micrographs of Al-20 wt % Si alloys cast vibrated at 6.3 H showing silicon needles/dendrites. Mag. × 200

Careful examination of Figure 8 to 13 reveal that the morphology of grains changes from a predominantly dendritic to a more globular structure, and grains become finer as the intensity of vibration increases. This is due to the growing dendrites being subjected to constant impact from the surrounding liquid due to the movement generated by the vibrations as observed by Desphande (2006). Also careful examination of the micrographs reveals that there is a reduction in aluminium dendrite size which was promoted by a process known as dendrite remelting. Vibration causes fluctuations in temperature as a result of the movement of the liquid metal. It is envisioned that the growing dendrite in a relatively cool region of the solidifying cast is carried away to a relatively hotter region of the casting. There, the dendrites begin to remelt at the necks of its arm as established by Appendinor *et al.* (2003).

CONCLUSIONS

The effects of frequency of vibration on the mechanical properties and microstructure of Al-based alloy was evaluated using the constructed mould vibrating machine. The aluminium alloy used for this work was Al-20% wt Si alloy; this was chosen so as to address the specific problems associated with the casting of hypereutectic Al-Si alloys.

The following conclusions can be drawn from the studies conducted on the effect of mechanical vibration on the mechanical properties and microstructure of the solidifying Hypereutectic Aluminium Silicon cast:

The result of chemical composition of the cast sample shows the presence of 73.06% wt Al and 19.60% wt Si. This classifies the sample as a Hypereutectic Aluminium Silicon Alloy (% wt of Si greater than 12.5, less than 20).

It was observed that the effect of mechanical vibration on the mechanical properties (Tensile, Impact and Hardness strengths) of the solidified cast increases with increases in frequency of vibration to the maximum (between 1.5 Hz to 4.2 Hz); subsequent increase in frequency of vibration results in the decrease of ultimate tensile strength, percentage elongation, hardness and absorbed energy.

Careful examination of the micrographs reveals that the morphology of the samples' grains changes from a predominantly dendritic to a more globular structure and the grains became finer as the intensity of vibration increases.

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