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Effect of Mold Vibration on Microstructure and Mechanical Properties of Al-Si Eutectic Alloy

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Abstract. Aluminum-silicon foundry alloys at eutectic region have small range of freezing, good castability and good properties. Such alloys are used in many engineering applications like automobile, aeronautical and aerospace industries. In present work, aluminum-silicon eutectic samples with silicon of 12-13wt.% were prepared using stir casting method. The microstructure, hardness, porosity, dendrite grain size, tensile strength, and elongation were studied to see the effect of mechanical mold vibration on this eutectic alloy. An amplitude of 0.5 mm and frequency of 5,10,15,20 and 25 Hz were used for casting the samples with mechanical mold vibration. The results showed that the values of the amplitude and frequencies have significant effect on the studied properties. A decrease in dendrite grain size by used mechanical mold vibration , at frequencies(5,10,15,20 and 25)Hz the decreased by 15%, 26%, 32%, 42%, and 53%. The hardness was increased by used mechanical mold vibration, at frequencies(5,10,15,20 and 25)Hz the hardness increased by 7%, 16%, 25%, 33%, and 40%. Also, a decrease in porosity by used mechanical mold vibration , at frequencies(5,10,15,20 and 25)Hz the porosity decreased by 35%, 46%, 58%, 69%, and 77%. The increase in tensile strength by used mechanical mold vibration, at frequencies(5,10,15,20 and 25)Hz the increased by 12%, 18%, 25%, 29%, and 36%; and increase in elongation percentage by used mechanical mold vibration, at frequencies(5,10,15,20 and 25)Hz the increased by 14%, 29%, 38%, 52% and 71% respectively.

1. Introduction

Silicon is considered as the main alloying element to aluminum alloys. It rises the fluidity for melt, decreases the melting temperature and reduces the shrinkage related with solidification of the alloy [1]. The eutectic of binary aluminum-silicon is simple system with (12-13wt %) of Si being at 577 ^{o}C. The eutectic region of alloys has the maximum fluidity and low shrinkage and tiny freezing rang. It is suitable for thin section of castings. Aluminum-silicon eutectic alloys are used for pistons and cylinders of engines for automobile and aeronautical industries [2]. Grain refinement is necessary for casting process as it decreases the defects and increases properties of the casting. Grain refining of Al alloys can achieve by mold vibration via electromagnetic, ultrasonic waves and mechanical vibrator. A better morphology, surface finish and reduced amount of shrinkage of casting can be obtained by using Mechanical mold vibration till solidification [3, 4]. Many published papers are focusing on refinement of grain size of many aluminum alloys by using mechanical mold vibration. Kocatepe, and Burdett [5] examined the effect of mechanical mold vibration at low frequency on [Ale- 12.3 % Si] alloy.

Bast, et . al [6] studied the influence of a vibration process for solidification of pure aluminum and the eutectic of Al -12 %Si and exhibited clear differences in the solidification and structure of casting. Chirita et. al [7] examined the influence of vibration on the mechanical properties of hypereutectic Al –Si alloy at fix amplitude and different frequencies. Rahul

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Kumar et.al [8] studied influence of mold vibration on microstructure and mechanical properties of casting during solidifications of aluminum silicon eutectic. The results showed clear refinement of grains and increasing of hardness for castings with mechanical mold vibration during solidification. Haydarr Al-Ethari et.al [9] studied the effect of mold vibration on fatigue life of Al -17%Si alloy.

The results showed reduced grains size, increased hardness, tensile properties, and fatigue life of casts prepared with mold vibration. In the present paper, the effect of mechanical mold vibration on microstructure and mechanical properties of Al -Si eutectic alloy will investigated. Salih Al-Ezzi et.al [10] studied the effect of ultrasonic vibration (USV) on grain size and interrupted porosity in Gas Tungsten Arc (GTA) spot-welded copper. Results illustrated a significant reduction of grain size. Notably, USV provided interaction between reformations (fragmentation) and provided nucleation points (detaching particles from the fusion line) for grains in the nugget zone and the elimination of porosity in the nugget zone. Qihao Chen et.al [11] examined the grain fragmentation in ultrasonic assisted TIG weld of pure aluminum. The results showed, The microstructure was transformed from plane crystal, columnar crystal, and uniform equiaxed crystal into plane crystal after application of ultrasonic assisted TIG weld. Jinwu Kang et.al [12] studied the comparison of ultrasonic effects in different metal melts. The effect of ultrasonic treatment of the melts is mainly ultrasonic streaming and cavitation. The ultrasonic streaming in water, aluminum and steel melts was compared. The results show that the effective streaming and cavitation area in steel melt is smaller than that in aluminum melt, and far smaller than that in water.

2. Experimental Procedures

2.1 Materials Used in the Present Study

Bulk of silicon with high purity of 99.8% and wires of aluminum with a purity of 99.69% are used to prepare the samples. Chemical composition analysis for aluminum wire is carried out using metal analysis by SPECTRO model (SPECTROMAX). Table (1) shows the chemical composition of the used aluminum wire.

Table 1. Chemical Composition of the Used Aluminum Wire

Al wt .%	**Mg wt .%**	**Fe wt .%**	**Si wt .%**	**Zn wt .%**	**Ti wt .%**	**Cr wt .%**	**Cu wt .%**	**Other Elements wt .%**
99.7	0.1201	0.113	0.022	0.02	0.004	0.003	0.001	0.0169

2.2 Samples Preparation

Six types of Al -Si samples were prepared by stir casting. The samples are coded in Table (2).

Table 2. Codes and Conditions of Prepared Samples

Code Sample	**Frequency (Hz)**	**Amplitude (mm)**
S0	_	_
S1	5	0.5
S2	10	0.5
S3	15	0.5
S4	20	0.5
S5	25	0.5

Al wire were cut into small pieces and melted in ceramic crucible at 750°C in an electric furnace type (ORH5-F102200). Silicon bulk weighted and enveloped in Al- foil and submerged slowly inside the melt. Then the molten is poured inside preheated die steel at 350°C , the die having a cylindrical cavity with dimensions (20ϕ×150) mm and attached with system to provides mechanical vibration, the vibration starting before pouring and continuings until a complete solidification. Figure 1 shows the vibration device. It provides this vibration by a rotating shaft with an eccentricity. A frequency of (5, 10, 15, 20, 25)Hz and an amplitude of 0.5 mm were used for casting the samples [13]. These frequencies were achieved via the electric motor. Figure 2 shows the cast sample in the present study.

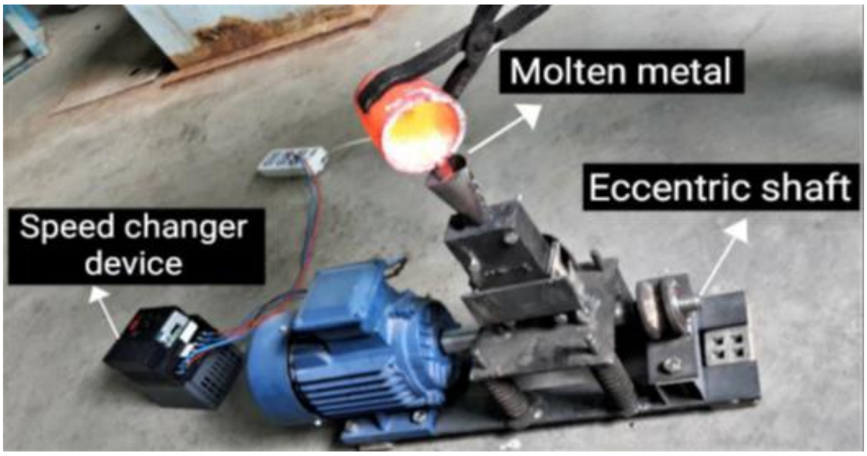

Figure 1. Vibration Machine for Mold Casting

Figure 2. The Cast Sample in The Present Study

3. Samples Test

A chemical Composition test was carried out by spectrometer for samples to ensure of aluminum,silicon percentages in the prepared samples. Optical microscope analyses was done for the samples after cut by lathing machine with dimensions(20 × 10) mm and using papers materials (180- 220- 400 - 600 -800 - 1000 -1200 -1500 -2000 grits size) for Grinding, and polishing by using diamond with 0.2 µm. Keller’s reagent (95 mL H_2O, 2.5 ml HNO_3, 1.5 mL HCl, 1.0 mL HF)[14], used to etch the samples. Optical microscope type (12280 X EQ-MM 300TU SB) of 100X magnification integrated with CCD camera was used for this test. The X-ray diffractions (XRD) test was done for the prepared sample to find out the elements and phase identification of specimen. The measurements conditions are Cu target at 40 kV and 30 mA, scanning speed 2 deg/min, for scanning rang of 10^{o}-80^{o} . All the X-ray diffraction tests were carried out at room temperature . The device type (xrd-6000 Shimadzu). Dendrite Grain size have significant effect on the mechanical properties of the aluminum-silicon alloys. samples with (20×10) mm in dimensions were cut from samples that prepared for dendrite grain size measurement. The samples were prepared to test by grinding , polishing , and etching operations. An optical microscope with magnification of 100X was used to capture the microstructure of each samples . The determining of dendrite grain size was carried out via TESCAN 2D-visualization with analysis software16. Porosity test was carried out for samples cut at top, center and bottom parts for the cast samples. Porosity was determined according to the ASTM (B 328 – 96), the following equation was used [15].

$$\text{Porosity (apparent)} = \frac{W_{w-}W_d}{W_{sat-}W_s}\ \text{x}\ 100 \quad \text{………..………………..(1)}$$

Where: W_d : drying weight, W_w : wetting weight (the sample is weighted after submerging for 24 hrs. in distilled water), W_{sat} : saturating weight (the sample is weighted after submerging for 5 hours in pure water at 80ºC), W_s : suspending weight (the sample is weighting in distilled water). The Hardness test was done according to AST M (El0-5 a)[16],with a ball indenter diameter of 2.5 mm and load of 31.25 g for 10 sec. Samples of (20 × 10)mm in dimensions were used in this test . Suitable grindings and polishing were done before testing. The test were conducted on a digital micro Brinell hardness testing machine type [UH -250, digital macro Brinell hardness tester , German]. The measurement of hardness for sections at the top, center, and bottom parts for each sample, then the hardness has been indicated as the average of three measurements for each specimen. Tensile test specimens were prepared according to AST M (B 557 m-1 5) [17]. Computer control universal testing machine model (W DW) was used with tensile speed rate of (2 mm /min) at room temperature .

4. Results and Discussion

A chemical composition for prepared samples is demonstrate in Table (3). The results indicate, the percentages of aluminum (86 - 88) wt%, silicon percentages (12-13) wt% and other element as impurities.

Table 3. Chemical Composition of The Prepared Alloy Samples

Sample Code	Al wt.%	Si wt.%	Fe wt.%	Mg wt.%	Zn wt.%	Ti wt.%	Cu wt.%	Cr wt.%	Other Elements wt.%
S0	86.493	12.807	0.368	0.149	0.051	0.001	0.001	0.001	0.126
S1	87.315	12.211	0.298	0.134	0.024	0.001	0.001	0.003	0.011
S2	86.889	12.622	0.251	0.073	0.033	0.003	0.002	0.002	0.123
S3	86.618	12.985	0.198	0.090	0.025	0.002	0.0089	0.004	0.066
S4	87.087	12.634	0.001	0.021	0.013	0.001	0.001	0.001	0.240
S5	86.756	12.914	0.003	0.068	0.029	0.001	0.002	0.002	0.22

The optical microstructure images are shown in Figure 3. The sample (S0) has the largest dendrite grain size, while the samples (S5) has the smallest grain size, and other samples have size between of them. A non-dendritic structure was observed at (S1,S2,S3,S4, and S5) as the dendrite grains are broken by using mechanical vibration till solidification and dispersed in the melts dispersed broken dendrite grains act as nuclei in the melt and produced finer grains and microstructure .

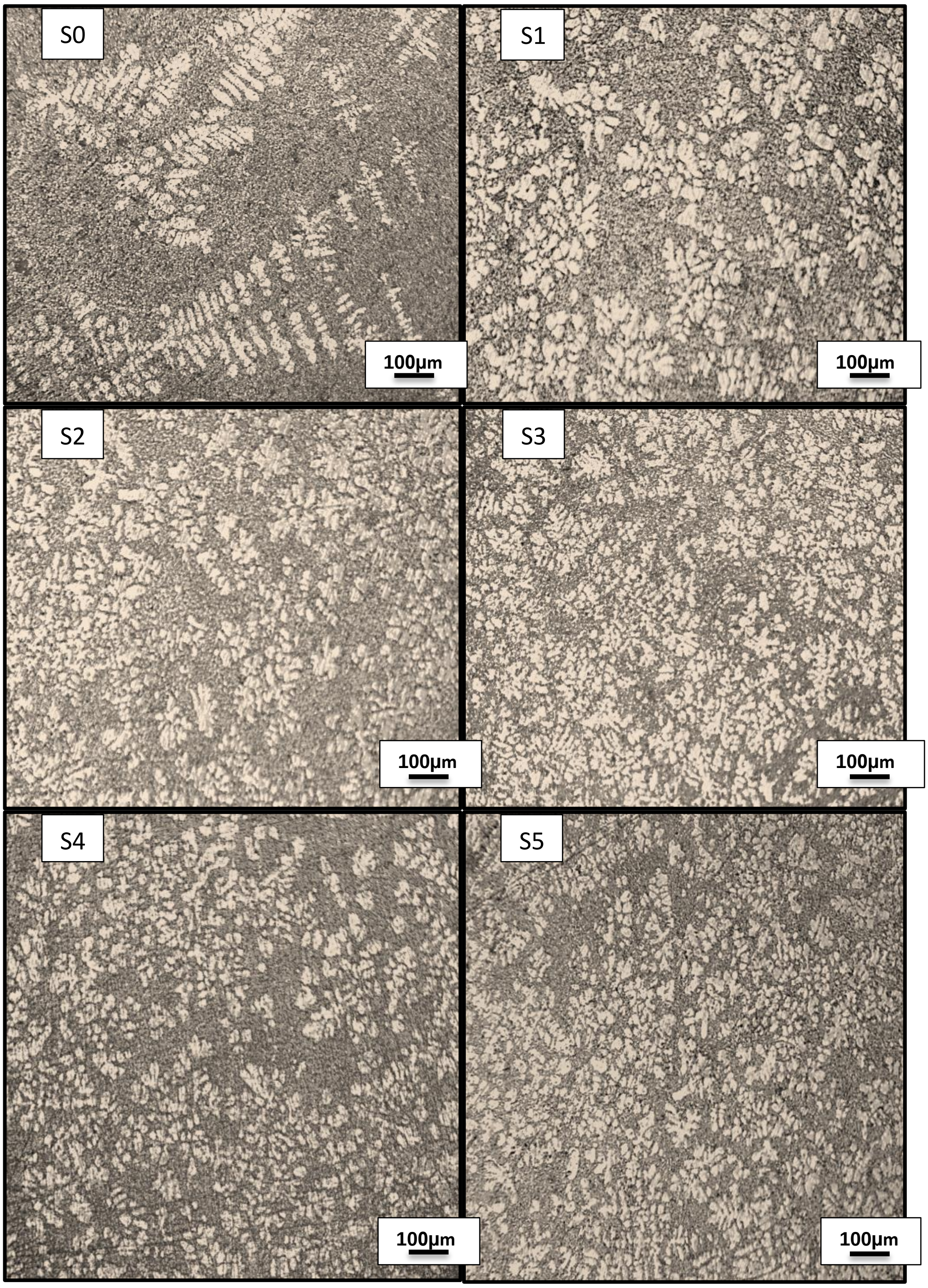

Figure 3. Optical Microscope of Samples S0,S1, S2 ,S3, S4 and S5

The Figures 4 and 5 represent the charts of the X -ray diffraction of S0 and S5 samples. The XRD results of the aluminum silicon eutectic sample should the presence of aluminum and silicon elements.

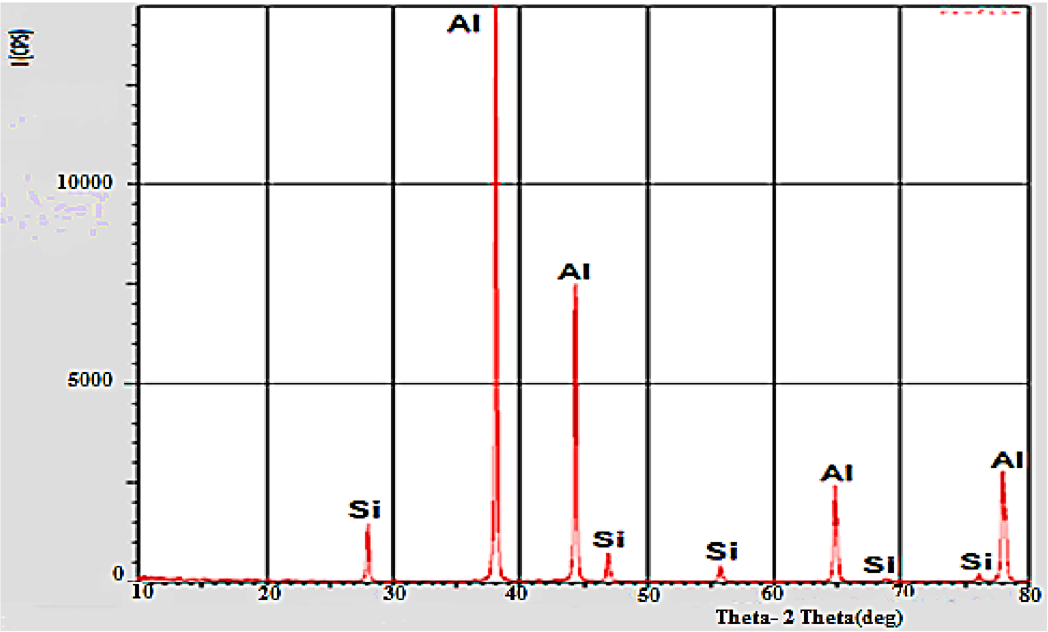

Figure 4. XRD Pattern of S0 Sample

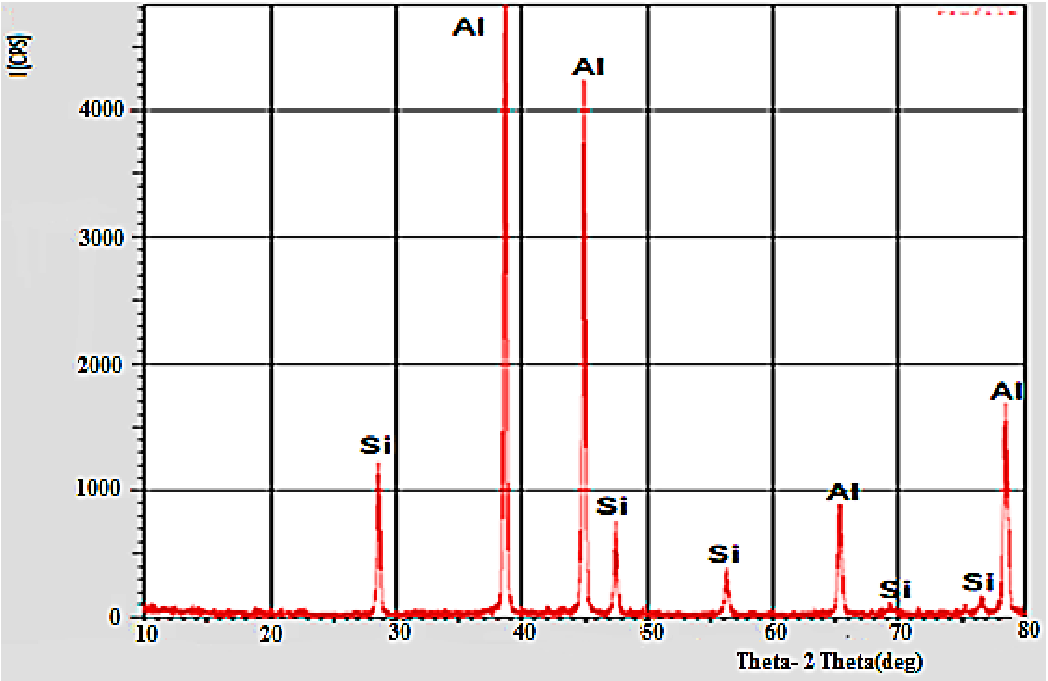

Figure 5. XRD Pattern of S5 Sample

The results of dendrite grain size test of the prepared alloy samples are shown in Figure 6. It is clear that the use of mechanical mold vibration lead to grains refinement of dendrite. The results indicated that these averaged size of dendrites that solidified without vibration was (35.4) µm, while for that solidified by applying mechanical vibrations (5,10,15,20 and 25)Hz , were (30.2, 26.3, 23.9, 20.5 and 16.6) µm respectively.

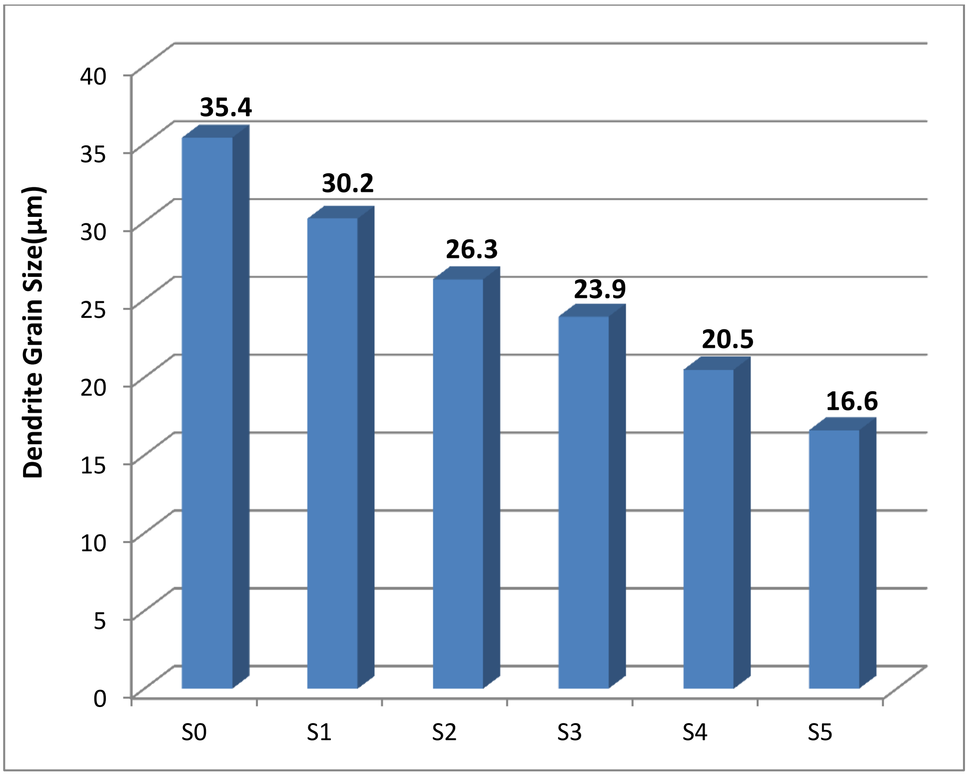

Figure 6. Average Dendrites Grain Size of the Cast Samples

Table (4) shows the results of the average hardness of samples. The results show that, the mold vibrations lead to improve the hardness of the alloy samples. This is due to the modification of microstructure. The coarsest dendrite grain size was found in the cast without mold vibration. Structure of the casting is governed by the cooling rate. As the rate of cooling is increase , the microstructure will decrease, therefore the hardness will be higher. The largest values of hardness were noted in the sample prepared with the mold vibration of the higher frequency (25Hz). These results are in agreement with reference [13].

Porosity results indicate that the test sample solidified without the effect of vibration have more porosities than that solidified with the effect of mold vibration. It is well known that the presence of the porosity in the structure of the casting is due to dissolved hydrogen in liquid and insufficient mass feeding of liquid into spaces between dendrite grains. Mechanical vibration causes broken dendrite grains and improve mass feeding of liquid phase, resulting in decreasing the volume and amount of porosity of microstructure of vibrated sample[18]. The sample that prepared with frequency (25Hz) has minimum porosity. This is due to the combined effect of cooling rate and frequency of vibration.

Table 4. Results of Average Hardness and Porosity Tests

Code Sample	Frequency (S^{-1})	Average Hardness (Kg/mm^2)	Porosity %
S0	_	55	3.26
S1	5	59	2.12
S2	10	64	1.76
S3	15	69	1.38
S4	20	73	1.01
S5	25	77	0.74

The tensile properties of the prepared samples are listed in Table 5. It is clear that the ultimate tensile strength and ductility of sample (S5) solidified under mechanical vibration with (25 Hz) frequency is more than that of other samples. The mold vibration induces a higher rate of cooling because of the alternated movement of the liquid . Furthermore, this movement also provide displacement of the heterogeneous solidification sites providing a higher solidification rate thereby it promotion of nucleation and thus reducing the grain size , reducing hydrogen absorption, and reduction the inner casting defects such as shrinkage cavity, inclusions, as well as porosity due to improved metal feeding , and producing more homogenous alloy structure. These results and behaviors were in agreement with reference [19]. Figure 7 shows the stress-strain curves of the aluminum silicon eutectic alloy samples.

Table 5. Results of Tensile Test

Sample Code	Ultimate Tensile Strength (MPa)	Elongation (%)
S0	174	2.1
S1	195	2.4
S2	206	2.7
S3	217	2.9
S4	225	3.3
S5	237	3.6

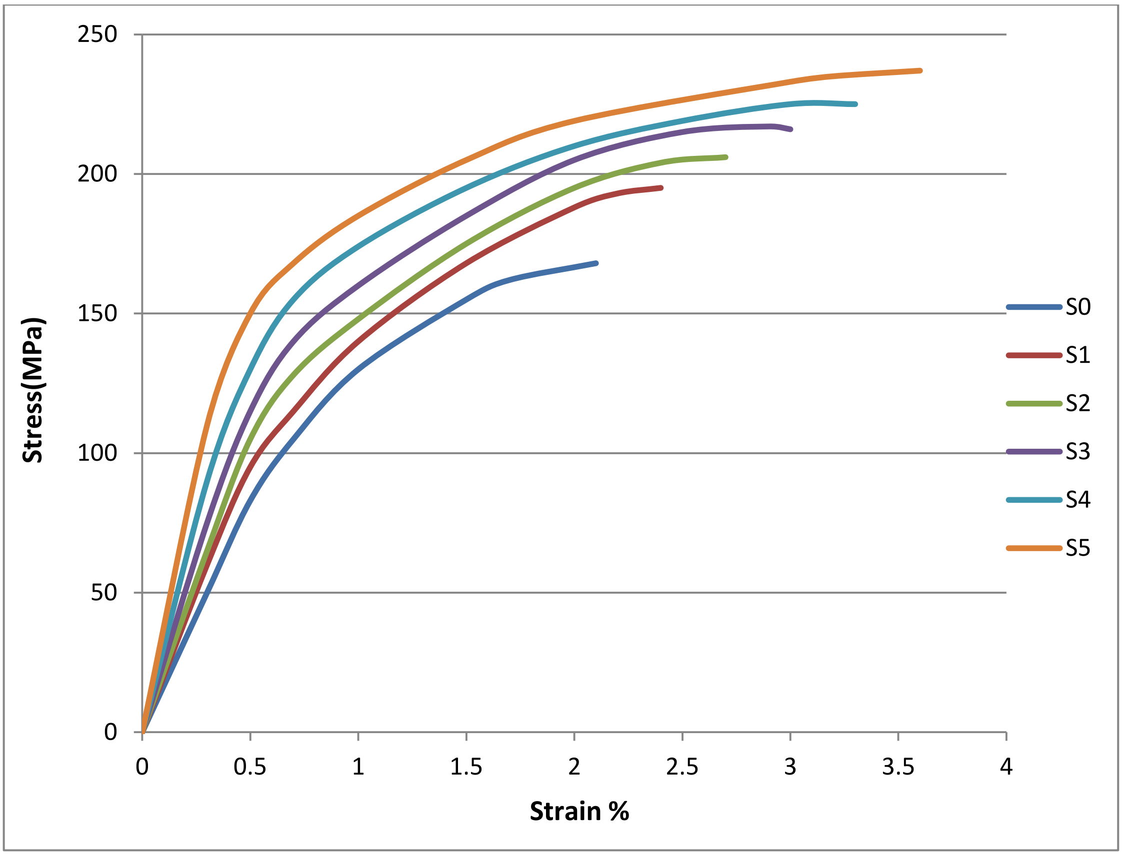

Figure 7. Stress-Strain Curve of the Aluminum Silicon Eutectic Alloy Samples

5. Conclusions

In this paper, influence of mechanical mold vibration on microstructure and mechanical properties of Al-Si eutectic was examined. The results obtained dictate the following conclusions: -

1-The dendrite grain size of the cast samples were reduced by using mechanical mold vibration. At frequency (5,10,15,20,and 25) Hz , they were reduced by 15%, 26%, 32%, 42% and 53% respectively.

2-The hardness of the cast samples were increased. The hardness of the samples prepared with frequencies(5,10,15,20 and 25)Hz were, increased by 7% , 16% , 25%, 33%, and 40% receptively.

3-The porosity of the cast samples was reduced. By mechanical mold vibration of frequencies (5,10,15,20 and 25)Hz , they were reduced by 35%, 46%, 58%, 69% and 77% receptively.

4-At frequencies (5,10,15,20 and 25)Hz ,ultimate tensile strength (UTS) is increased by 12%, 18%, 25%, 29% and 36%, elastic modulus (E) is increased by 3%, 9%, 13%, 17% and 22%, and the elongation is increased by 14%, 29%, 38%, 52% and 71% respectively.

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