논 문

A Study on the Structural Controlling of Al-Si Alloy by Using Electromagnetic Vibration

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전자기 진동을 이용한 Al-Si 합금의 조직 제어에 관한 연구

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Abstract

The structural control of Al-Si alloy, which was not studied among various electromagnetic processing of materials, was considered applying the alternating current and direct current magnetic flux density. The main aim of the present study is to investigate the effects of electromagnetic vibration on the macro and microstructure of Al-Si alloy in order to develop a new process of structural control in Al-Si alloy. When the electromagnetic vibration is conducted for changing the shape of primary aluminum, at low frequency(<60Hz), the shape of dendrite is changed speroidal shape. When the electromagnetic vibration is conducted for changing the shape of eutectic silicon, the fact that a morphological change of the eutectic silicon from coarse platelet flakes to fine fiber shape is observed and the improvement of the mechanical properties is achieved with EMV (Electro Magnetic Vibration) process at high frequency(>500Hz).

초 록 : 여러 전자기 재료 프로세싱 연구 중에서 연구 되어지지 않았던 Al-Si 합금의 조직제어를 직류 자기장과 교류 전류장을 사용하여 시도 하였다. 본 연구의 목적은 Al-Si 합금에서의 새로운 거시, 미시 조직제어를 하기 위해 사용된 전자기 진동의 영향을 조사하는 것이다. 전자기 진동이 초정 알루미늄의 형상 변화를 위해 낮은 진동수 (<60 Hz)로 주어질 경우, 수지상의 형상이 구상화 형상으로 변해갔다. 전자기 진동이 공정 실리콘 형상 변화를 위해 주어졌을 경우, 높은 진동수 (>500 Hz)에서 조대한 판상 조직이던 실리콘이 미세한 섬유상 조직으로 변화하고, 기계적 성질도 우수해졌다.

Key words: Aluminum alloy, Electromagnetic, Eutectic silicon, Vibration, Primary aluminum.

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1. Introduction

Al-Si alloys are of very common use in foundries because they offer good castability and resistance to cracking. Such properties depend on the alloy structures. Especially, such properties depend on the eutectic Si, which may have an acicular or lamellar form at hypoeutectic system, on the primary aluminum, and on the primary Si size at hypereutectic system [1,2]. For controlling these structures, a number of theories have been proposed, but no theory has attained universal acceptance or really explained the principles of the phenomenon. In these old theories, some element (Na, Sr, Sb, P, Ti, etc) are added in the Al-Si melt. The adding element is different for controlling the structure.

For example, the element of TiB used for refining of primary aluminum, the element of Na, Sr, Sb used for modification of eutectic silicon, and the element of P, AlP, AlCuP used for refining of primary silicon [3,4].

So, it is difficult to obtain both phenomenons, which is refining and modification. Because of each elements reacting to each other and preventing refining and modification. And this chemical method is difficult to adjust the amount of

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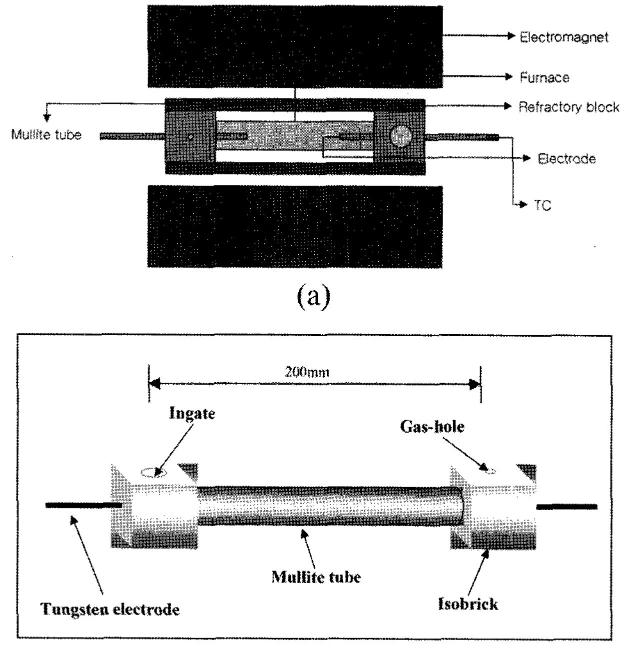
adding elements and difficult to recycle.

The vibration of the melt has been known to show effects that refine the solidification structure and reduce the internal gas, solidification shrinkage cavities and segregation of the solute [5]. This study considers the grain primary silicon morphology changing process and eutectic modification process with electromagnetic vibration. Because of the electromagnetic process has better merit than the existing other chemical method. The merits of this electromagnetic process are easy control, fast process, continuous process, non-pollutive process. And it has no chemical reaction process [7].

2. Experimental

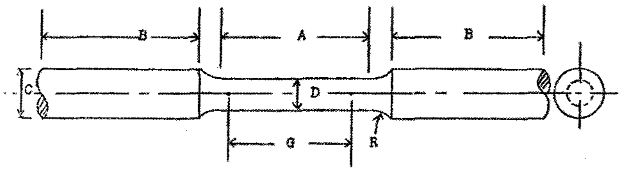
Experiments were carried out on commercial casting aluminum alloy, A356. First, a sample was made as shown in Fig. 1(b). Devices used in the experiment consisted of a D.C. magnetic field generator and an alternating current generator. The stationary D.C. magnetic field generator was fixed to 0.5T. The sample was put into a pre-heated electric furnace, which was located between cores of magnetic field generator as Fig. 1(a). The sample was first heated to 973 K, and then cooled naturally to 923 K at which time electric field was induced. Following this, the sample was cooled (about 1.5 K/sec) until it fully solidified with changing frequency and current density by 2.1×10^5, 4.2×10^5, 6.3×10^5, 8.4×10^5, $1.05\times10^6 A/m^2$ coming each 60, 300, 500, 700, 1000 Hz at 0.5 T.



(a)

(b)

Fig. 1. The schematic sketch of the experimental device (a) inside of the yoke (b) mullite tube configuration.



G : gage length 20.0±0.1mm
D : diameter 4.0±0.1mm
R : radius of fillet 4mm
A : length of reduced section 24mm

Fig. 2. The standard design of UTS and Elongation Test (ASTM E8M).

The center section of the specimen was observed using an optical microscope. Primary aluminum and eutectic Si were observed and to determine the detailed shape of the eutectic Si, the specimen was etched for 10 minutes in NaOH solution of 1 mole and observed its shape by SEM. Then, an image analyzer program (IPP: Image Pro Plus) was used for image analysis and to measure the mean size and the degree of sphericity of the primary Al and the mean size of eutectic Si. A tensile test was carried out to evaluate the mechanical properties of the specimen at room temperature after being set to ASTM E8M regulations (Fig. 2) and samples were measured UTS and elongation with cross head speed by 2.0 mm/min and observed fracture surface with SEM after tensile test. For estimating the mechanism of this phenomenon, an XRD experiment was performed and twin probability was calculated.

3. Results and Discussions

In this study, the EMV was applied to 2 different structure controlling processes. They are 1) the controlling of primary aluminum phase, and 2) the controlling of eutectic silicon phase.

3.1 The controlling of primary aluminum phase

Fig. 3 represent the microstructure of the EMV processed alloy. The intensity of magnetic field , induced current density and cooling rate are each 0.5T, $1.05\times10^6 A/m^2$, 1.5 K/s. Fig. 3 (a) is present the general microstructure of A356 as-cast. Fig. 3 (d) shows that entire dendrite arms are broken and become spheroidal type of primary aluminum particles. This means that this degree of force ($1.05\times10^6 A/m^2$, 0.5 T) can entirely change dendrite structure at 60 Hz. Fig. 4 represent the trend curves of mean diameter and degree of sphericity varies with frequency and intensity of EMV in 1.5 K/s cooling rate. Fig. 5 shows the frequency and amplitude map at the liquid Al. If the frequency increases, the amplitude of liquid Al decreases. This result indicates that if experiment is processed in low frequency region, liquid Al lying in mixed or turbulent drag

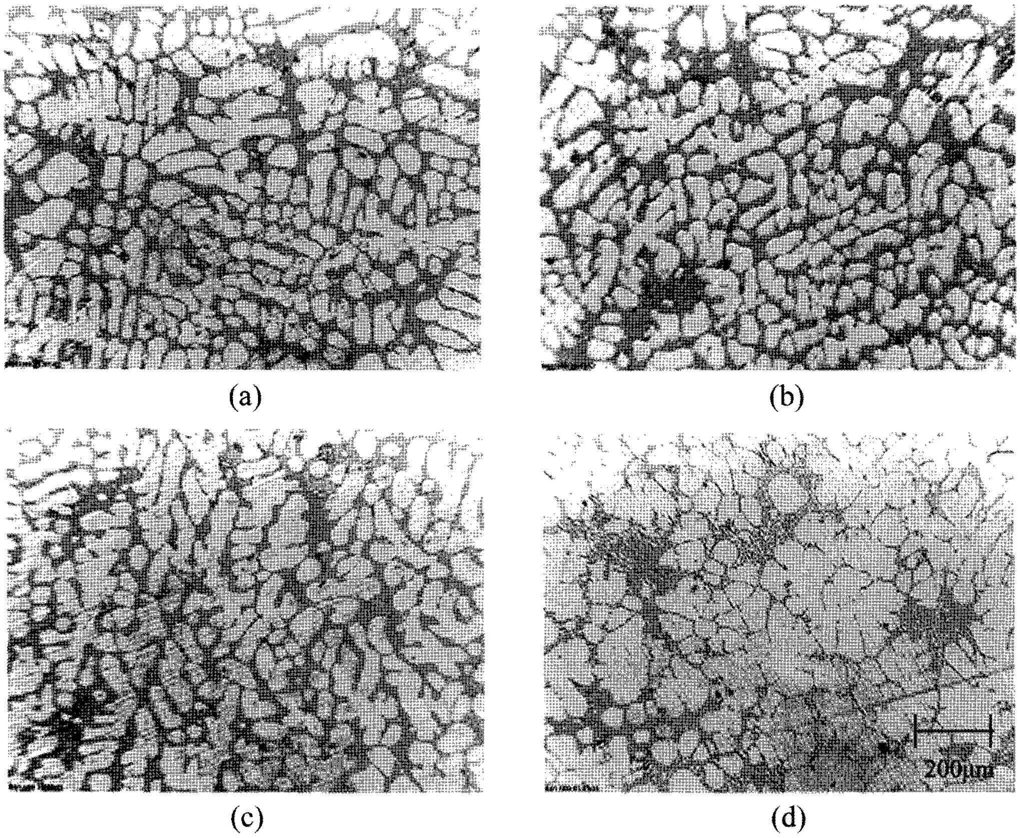


Fig. 3. Microstructures of the A356 alloy with EMV processed to various frequencies. (a)As-cast, (b) 1000 Hz, (c) 500 Hz, (d) 60 Hz (Cooling rate =1.5 K/s, 1.05×10^6 A/m^2, 0.5 T)

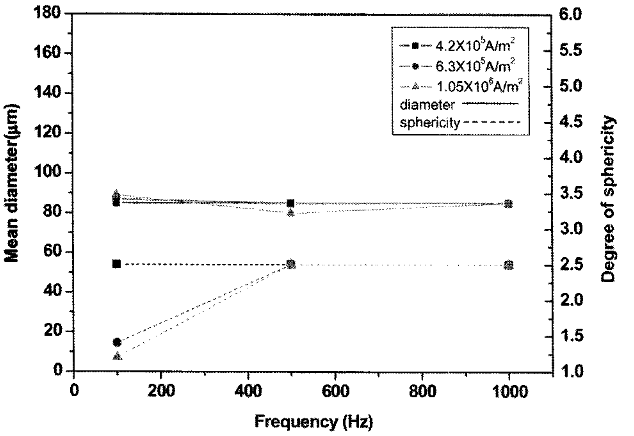


Fig. 4. The trends of mean diameter and degree of sphericity varies with frequency and intensity of EMV (cooling rate=1.5K/s)

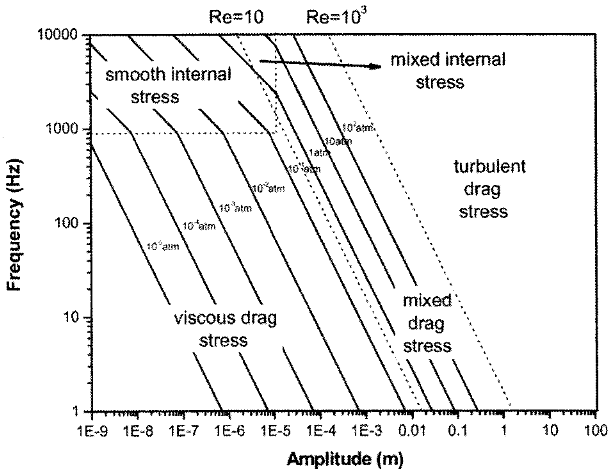
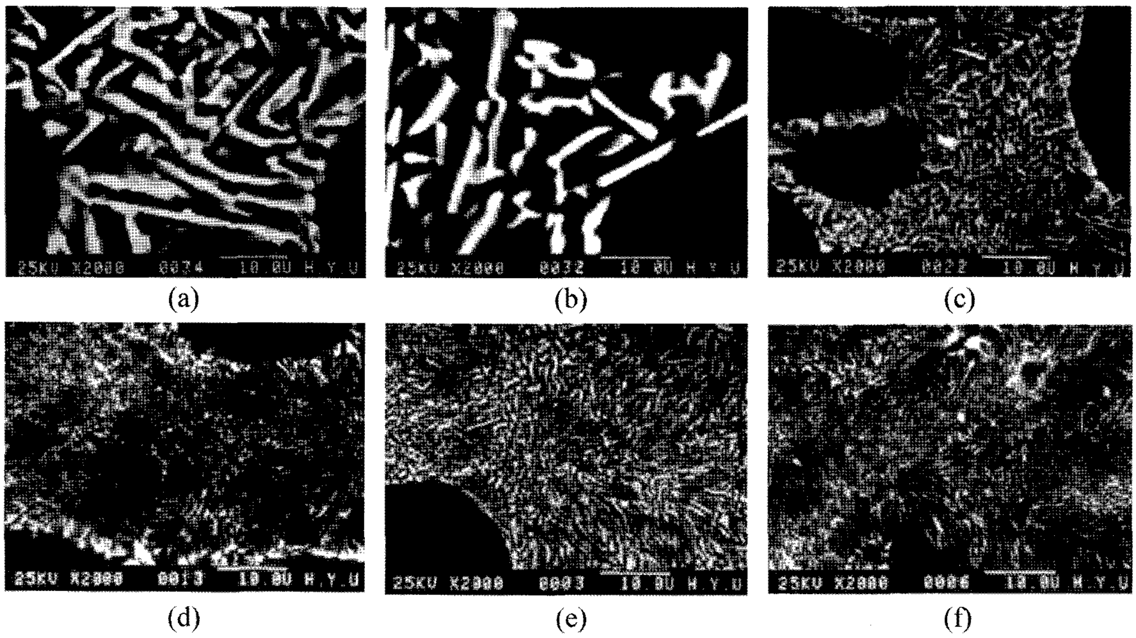


Fig. 5. f-a map showing bending stresses in roots of aluminum alloy.

condition. This means that Al dendrite will be bended or fragmented at low frequency region.

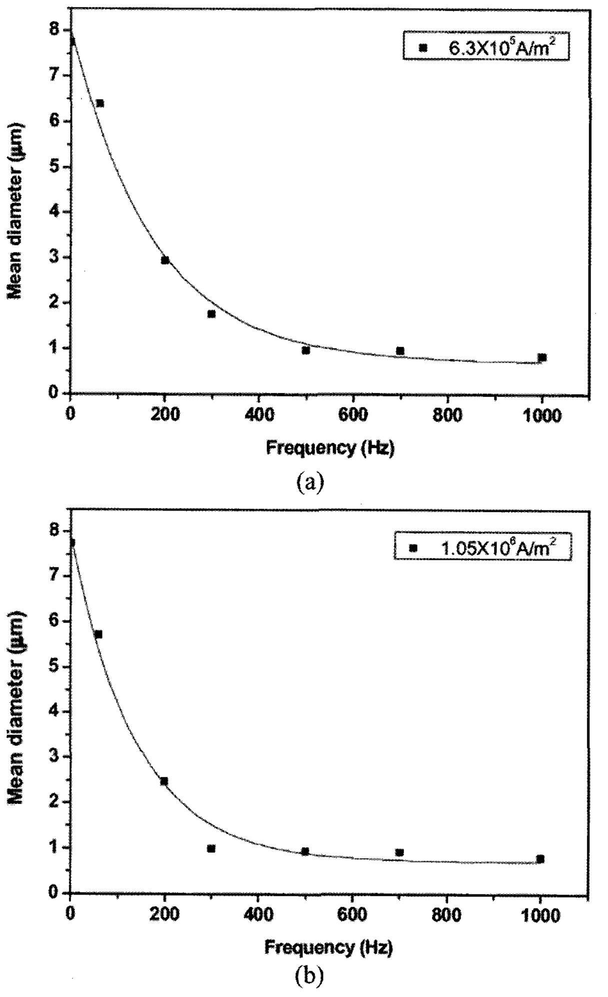
3.2 The controlling of eutectic silicon phase

Fig. 6(a) shows microstructures of an as-cast sample, which cooled without the imposition of an electromagnetic vibration. The eutectic Si phase has a traditional morphology growing in a faceted manner. Fig. 6(b), (c), (d), (e) and (f) shows microstructures of the sample induced at the same current density of 1.05×10^6 A/m^2 according to a different frequency (60, 200, 500, 700 and 1000 Hz). As shown in Fig. 6, there was little difference in the cases between the non-electromagnetic vibration processed sample and EMV processed at a frequency of 60 Hz. However, a fine and globular morphology



(a) (b) (c) (d) (e) (f)

Fig. 6. Microstructures of Al-Si-Mg alloy according to the frequency at 1.05×10^6 A/m^2 (a) as-cast, (b) 60 Hz, (c) 200 Hz, (d) 500 Hz, (e) 700 Hz, (f) 1000 Hz.



(a)

(b)

Fig. 7. Size of the eutectic Si with frequency and current density.

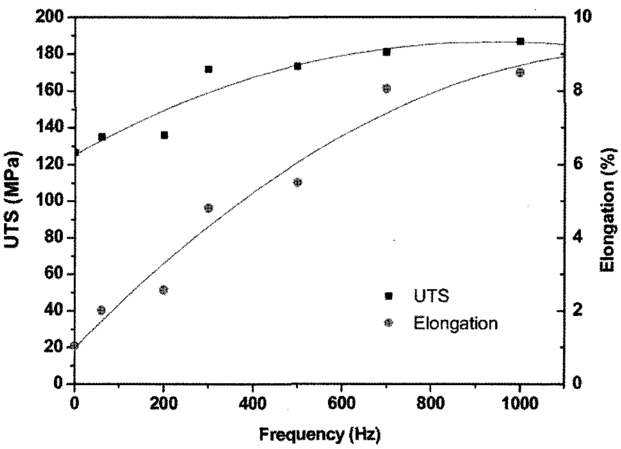


Fig. 8. Variation of the mechanical properties with frequency.

of the eutectic Si phase was observed in the case of a frequency of 1000 Hz. It has been noted that the vibration phenomenon due to a low frequency does not affect the modification of the eutectic Si phase. However, according to the increase of frequency, the morphology of the eutectic Si phase was transformed from flakes to a fibrous shape. Fig. 7 represent the mean diameter of eutectic Si varies with frequency and current density. The mean diameter of eutectic Si decrease with increasing frequency and also decrease with increasing current density from 6.3×10^5A/m^2 to 1.05×10^6A/m^2. Fig. 8 represent the mechanical property varies with frequency. The UTS value of the specimen is increased from 126.5 to 186.9 MPa with increasing frequency. This is the 47% increasing from its basic properties. Especially, the elongation of the specimen at 1000 Hz is 8.5%. This shows the rate of significant increase of elongation with 750% from 1% at as-cast to 8.5% at 1000 Hz. In this result, the size of eutectic Si effect significantly on mechanical properties of hypoeutectic Al-Si alloy.

It has been well documented that the transformation of unmodified flakes to modified fibrous structures arises from a very different type of growth of the Si phase and this difference appears to lie in the number of twins found in unmodified and modified Si. The electromagnetic vibration was supposed to prevent the Si atom from attaching to its crystallographic site and to cause a drastic increase in the twin probability of eutectic Si. In order to ascertain this assumption, it is necessary to evaluate accurately the twin probability in the eutectic Si. The conventional method for the accurate measurement of twin probability is the X-ray diffraction (XRD) method, which is more convenient to investigate using the bulk of eutectic Si. In order to obtain the precise peak from (220) to (400) reflection, the step scanning is used from 2θ=45° to 72° with a time interval of 15sec and angular interval of 0.02°. The 2θ of each of (220), (311) and (400) reflections, peak separation, α, $1/\alpha$ and the average twin spacing (λ) of the alloy were summarized in Table 1.

XRD Peak displacement caused by twinning in eutectic silicon is expressed as follows by defining α as the probability of finding a twin between any two (111) layers [6].

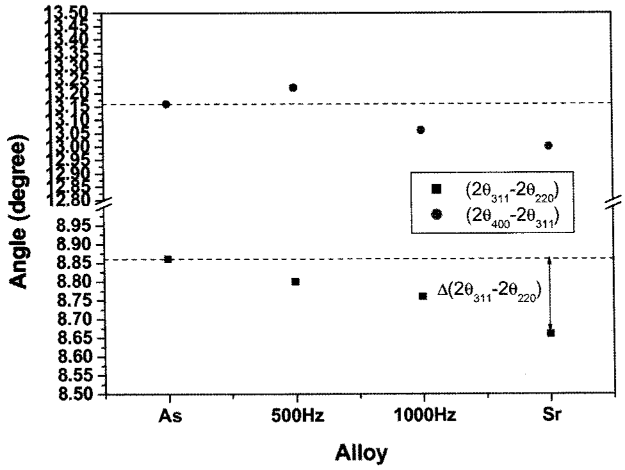


Fig. 9. Peak separations of (311)-(220) and (400)-(311) for normal, EMV modified and strontium modified alloys.

$$\Delta(2\theta)^{o} = \frac{90\sqrt{3}\alpha tan2\theta}{\pi^{2}h^{2}(u+b)}\sum_{b}(\pm)L_{0} \qquad (1)$$

where $L_0=h+k+l=3M\pm1$, b and u are designated as broadened and not broadened : the component $L_0=3M\pm1$ which are broadened by twinning, and the component $L_0=3M$ which are not broadened by twinning. From a measured peak displacement $\Delta(2\theta)^{o}$ (in Fig. 9), we obtain directly the twinning probability α, since all the other quantities in Eq. (1) are readily evaluated. Because of twinning, the reflections of (220), (400) shift toward a larger 2θ.

The peak separation $\Delta 2\theta_{311\text{-}220}$ of the electromagnetically vibrated alloy appeared to be -0.06 and -0.1° for 500 and 1000 Hz, respectively, while that of strontium modified alloy was as large as -0.2°. Since another separation, $\Delta 2\theta_{311\text{-}220}$ did not give any consistent results owing to high angle reflection, it was ignored in Table 1.

Measured twin probability of EMVed alloy at a frequency of 1000 Hz was approximately six times as high as that of the normal alloy and half of that of Sr modified alloy. Although the twin probability of the electromagnetically vibrated alloy was less than that of sodium or strontium, the electromagnetic vibration during solidification of the Si phase could be believed to increase twin density. Therefore, the mechanism for the increase in twin density due to the electromagnetic vibration may be preventing the Si atom from attaching to the growing interface. It can be supposed from this fact that the preferential growth along <112> in silicon (TPRE growth) was suppressed and twin density was increased by preventing the Si atom from attaching to the growing interface of the Si phase and by changing the solid/liquid interfacial energy of silicon due to the electromagnetic vibration during solidification.

4. Conclusions

From an experiment about the electromagnetic vibration for observing the effect of electromagnetic vibration on primary aluminum and eutectic Si in hypoeutectic Al-Si alloy, the following results were obtained.

1. At low frequency (<60 Hz), the shape of dendrite is changed to speroidal shape. The degree of sphericity decreases with increasing current density and decreasing frequency.

Table 1. Measured diffraction angle (2θ), peak separation, twinning probability(α) and average twin spacing of alloys.

	$2\theta_{220}$	$2\theta_{311}$	$2\theta_{400}$	Peak separation ($\Delta 2\theta_{311\text{-}220}$)	α	$1/\alpha$	Average twin spacing (nm)
Normal	47.34	56.2	69.36	0	-	-	-
500 Hz	47.44	56.24	69.46	-0.06	0.0093	107.5	67.4
1000 Hz	47.7	56.46	69.52	-0.1	0.015	66.7	41.8
Sr	47.84	56.50	69.50	-0.2	0.031	32.3	20.25

2. If the frequency increases, the amplitude of liquid Al decreases. This result indicates that if experiment is processed in low frequency region, liquid Al lying in mixed or turbulent drag condition. This means that Al dendrite will be bended or fragmented at low frequency region.

3. A morphological transformation of the eutectic Si phase from coarse platelet flakes to fine fibrous shapes was observed when an electromagnetic vibration (EMV) with a different frequency and current density was applied to the solidifying hypoeutectic Al-Si-Mg alloy.

4. The mechanical properties of the electromagnetically vibrated alloy were increased as increasing frequencies due to the fine size and modification of the eutectic Si phase. The tensile strength and elongation of EMVed alloy at a frequency of 1000 Hz were measured to 186.9 MPa and 8.5%, respectively.

5. Measured twin probability of EMVed alloy at a frequency of 1000 Hz was approximately six times as high as that of the normal alloy and half of that of Sr modified alloy.

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