# The Effects of Electric Pulse Modification on the different Si Content of Al-Si Alloy*

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## ABSTRACT

Many methods have been used to control the silicon phase, such as adding modifiers and rapid solidification. In this paper, a novel electric pulse modification (EPM) technology was proposed and performed in different silicon content of Al-Si alloy, these researching materials can be divided in to 3 phases i.e. hypoeutectic at 7%Si, eutectic at12.6%Si and hypereutectic at 22%Si. The results indicate that Al-7%Si morphology changes from angular plates to fine fiber, the hardness increased by 10.31% from 56.31-62.12HV, Al-12.6%Si morphology changes from coarse and flakes with the sharp end of the Si phase which promote a crack initiation, when modified it changes to fine fiber shape, the primary silicon reduced from 50μm to a range of 5-20μm when compared with conventional casting process, the result of mechanical test showed that the hardness increases from 51.04HV-57.41HV which increases by 10% and Al-22%Si the Si phase changes from star shape, polygonal, it got more refined at 1000V to fine-scale eutectic Si structure, the minimum size of unrefined primary silicon was 30μm to a range of 23-90μm and the length of eutectic silicon was 20μm to a range of 18-30μm, when modified the minimum size of primary Si was 6μm to a range of 2-13μm and the minimum length of eutectic Si was 3μm ranges from 1-8μm at 1000V, hardness changes from 62.59-70.89HBW which increases by 24.76%.These changes in microstructure result in improving the mechanical properties of the alloy. Alloys at different pulse parameters were investigated, observing the microstructure, measuring the hardness and average size of the particles. The above works are bound to benefit for the applications of EPM on the Al-Si alloy system.



**Keywords :** Electric Pulse Modification (EPM); hypoeutectic; eutectic; hypereutectic; silicon phase

## 1 INTRODUCTION

ALUMINUM-SILICON alloys have great importance in industries due to its physical and metallurgical properties. These properties include high specific strength, high wear and seizure resistance, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity. This leads to their excessive use in many automobile and engineering sectors where wear, tear and seizure are the major problems in addition to the weight saving, the alloys are widely used as components for engines such as cylinder heads, pistons, connecting rods and drive shafts for automobile industries and impellers, agitators, turbine blade, valves, pump inlet, vortex finder in many marine and mining sectors [1]. Addition of Si increases the fluidity and decreases the solidification shrinkage, resulting in an increase in castability [2]. A further advantage is that Si can be added without increasing the density of the alloy and increases the strength and stiffness, but reduces the ductility.

Commercial Al-Si casting alloys have Si concentrations in the range of 5-23wt% [3]. Three different microstructures form depending on the Si concentration, i.e. the alloy can be hypoeutectic, eutectic or hypereutectic. The microstructure of the hypoeutectic alloys consists of $\alpha$-Al dendrites which solidify first followed by the Al-Si eutectic. Eutectic Si in Al–Si foundry alloys has often a very coarse and plate like morphology, leading to poor mechanical properties, particularly ductility [4]. Primary Si particles form first in hypereutectic alloys followed by the Al-Si eutectic. The Si particles have a plate-like morphology in unmodified aluminum alloys, which act as crack initiators and have a negative influence on ductility [5]. The alloy ductility can be improved by changing the morphology of the Si towards a more fibrous form.

Physical approaches to the refinement of primary Si, including ultrasound [6,7], electromagnetic stirring [8] and electromagnetic vibration [9] have been attempted with limited success. Treatments are localized within the melt and take of the order of ten minutes even within very small quantities of liquid. Therefore, a postulated, but representative model proposed by Wang [10] attempted to account for the operating mechanism of electric pulse modification (EPM) from only phenomenology and DLVO theory of colloids [11]. Using this technology the primary Si is improved in a certain degree through the electrical pulse modification on the melt [12-15].The study aims at analyzing the mechanism of EPM on hypoeutectic, eutectic and hypereutectic Al-Si alloy solidification structure and its inoculation changes. Also pulse voltage and frequency are they important factors to influence the modification effect [16].

Therefore, this paper is aim to analyze with increasing the Si contents from hypereutectic, eutectic, hypoeutectic how does the EPM affects the solidification structure and the corre-

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sponding properties, which is expected to establish the relationship between the Si addition and the EPM response.

### 1.1 Materials and methods

Al-Si alloy in 8kw silicon-carbide were molten with the high purity graphite as the crucible material. After the temperature at 750⁰C for 30min, and subsequent de-aeration with pure nitrogen, two columnar graphite electrodes with size of ϕ5 × 200mm will vertically inserted 50mm into the metal mold. The EP parameters were optimized as follows, 1000V peak voltage, 15Hz frequency and 30s treating time and taking a permutation of the parameter accordingly. Then the molten alloy was poured into a ϕ80 mm × 120 mm metal mould by manipulator at room temperature after 30s by EPM duration as in the (Fig. 1) below.

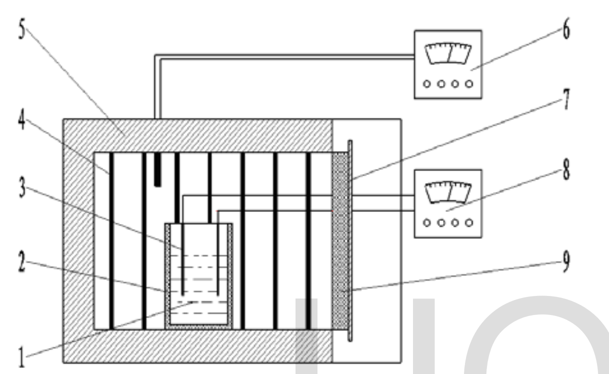



Fig. 1 EPM Process on Molten Alloys

1. Melt 2. Graphite crucible
2. Electrode 4. Element 5. Electric furnace 6. Temperature Controller 7. Metal board 8.EPM device 9.Asbestos

The specimen used for micro-analysis were the central section being cut at 15mm from the bottom of the ingots and grand mechanically on 200,400,600,800 and 2000Cw grid or sand papers, polished and etched with reagent HCL or 0.5%HNO3 solution at room temperature for 30s. Axiover200MAT metallurgical microscope was used to observe the samples microstructure. HV was used to measure the hardness.

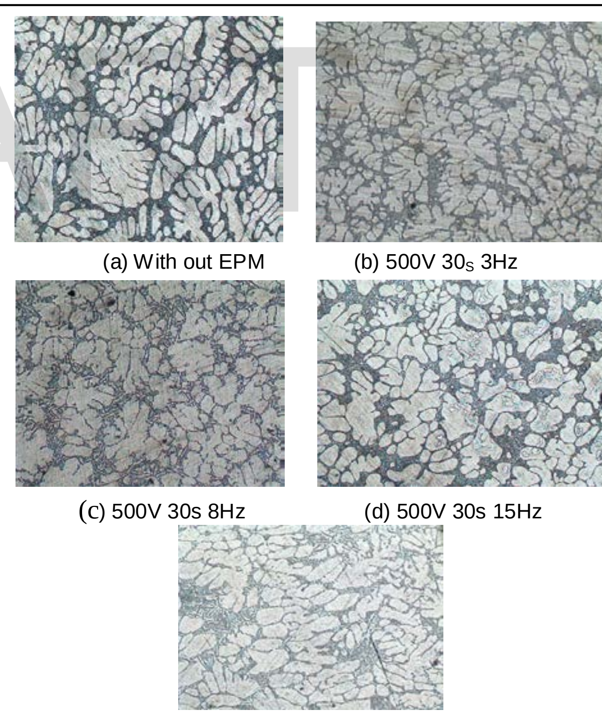
TABLE 1
Optimization Parameter in Al-7%Si, Al-12.6%Si and Al-22%Si Alloy Using EPM

| EPM Samples | Voltage(V) | Frequency(Hz) | Time(s) |
|---|---|---|---|
| A | 500 | 3, 8, 15, 22 | 30 |
| B | 700 | 3, 8, 15, 22 | 30 |
| C | 1000 | 3, 8, 15, 22 | 30 |

## 2. RESULT AND DISCUSSION

### 2.1 Microstructure

The microstructures of hypoeutectic Al-7%Si alloy treated by various EPM parameters are given in figure 1.1 (a)-(e), the typical microstructure of conventionally cast Al-7%Si for untreated in fig (a) and (b)-(e) are treated by EP. The untreated contain coarse primary Si where the size of primary Si is larger compare to that of treated. An unmodified Al–Si alloy has large, brittle flakes of silicon, which result in poor ductility to the casting; EPM was used in hypo-eutectic Al–Si alloys to refine the eutectic Si phase from angular platelets to fine fibers. This change in microstructure results in an additional development in the mechanical properties. The quality of the castings can be enhanced by grain refinement which decreases the size of primary α-Al grains in the castings, which else solidifies with a coarse, columnar grain structure. A fine equiaxed structure has many advantages like improved mechanical properties, better feeding during solidification, reduced and more evenly distributed shrinkage porosity, better dispersion of second phase particles, better surface finish and other desired properties.



(a) With out EPM (b) 500V 30s 3Hz
(c) 500V 30s 8Hz (d) 500V 30s 15Hz
(e) 500V 30s 22Hz

Fig. 2.1 Microstructure of Hypoeutectic Al-7%Si Alloy (100µm each)



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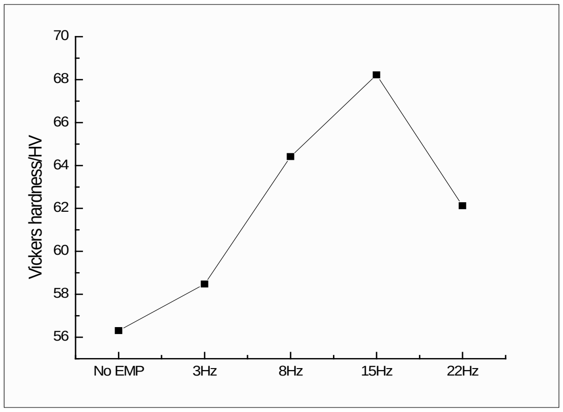
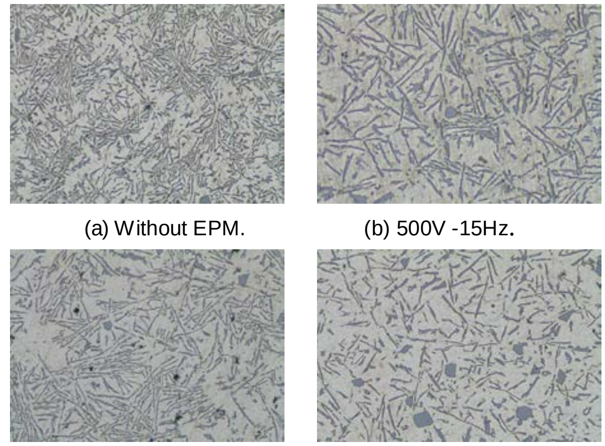



Fig.2.2 Vickers hardness at 500V in 7%Si Alloy



(a) Without EPM. (b) 500V -15Hz.

(c) 700V-15Hz (d) 1000V- 15Hz

Fig 2.3 Microstructure of Eutectic Al-12.6%Si Alloys (50 µm each)

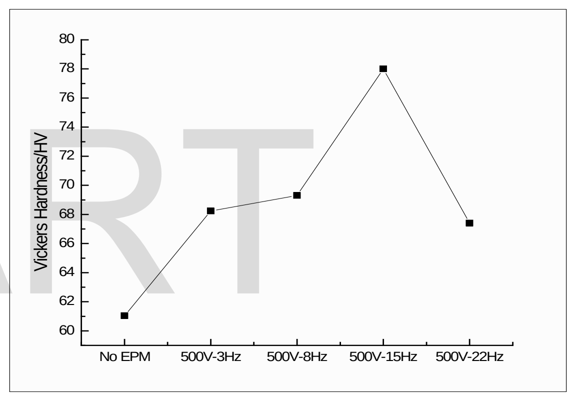



Fig 2.4 Vickers Hardness at 500V in 12.6%Si Alloy

The hardness test of the samples was carried out using Vickers hardness testing machine, figure 1.2 shows the Vickers hardness with varying frequency at 500V, the original samples hardness was 56.31HV, with increased in voltage the hardness increase to a peak value to 68.24HV at 500V-15Hz which increased by 21.19% then the hardness decreased when frequency was increased to 22Hz where the hardness was 62.12HV which also increased by 10.31% when compared with the original sample.

Typical resulting microstructures for Al-12.6wt%Si samples are shown in Fig.1.3 The sample has a microstructure characterized by an Al-rich dendritic matrix ($\alpha$-Al phase) and a eutectic mixture in the inter-dendritic region formed by silicon particles, which are coarse and distributed in a flake-like morphology which are compared with treated and untreated by Electric pulse modification (EPM) with different pulse parameter at 750 $^{o}$C.

The Fig 2.3 (a-d) above shows the microstructure of Al-12.6%Si alloy which comprises of treated and untreated sample, from (a) above the Primary silicon tends to assume different morphologies like massive crystals of geometric star like or dendrite shape and grow to some certain extent. After the dendrites impinge upon each other its mobility is restricted, inter-dendrite networks of eutectic silicon distributed in the matrix with the segregation state .In (b), (c) and (d) shows the refinement of eutectic silicon particles, the silicon has acicular and small amount of flake shape in (b) and the structure of (c) changes in size and size spacing, in (d) it has more fine grains.

In fig 1.4 above is a Vickers hardness, the untreated value was 61.04HV then changes to 68.24HV and to 78HV peak which shows that it increases to 27% then reduced to 67.41HV at 500V-22Hz it's also increased by 10%.

The microstructure analysis in fig.1.5 (a-d) above shows the size of primary silicon and the length of eutectic silicon, the distribution of eutectic silicon needle shapes are likely uniform over the entire samples but the size of primary silicon phase are coarse which reduce to some certain limit The microstructure of untreated sample in (a) with large size of primary silicon phase having a star shape, the minimum size of eutectic silicon was 30µm and the range size was 23-90µm while the minimum length of eutectic silicon was 20µm its ranges from 18-30µm. In fig (b) was treated which shows the effect of EPM at 500V, the minimum size of primary silicon was 25µm and size range was 12-30µm, the minimum length of eutectic was 10µm to a range of 3-28µm. At 700V both the size and length of primary silicon and eutectic silicon changes



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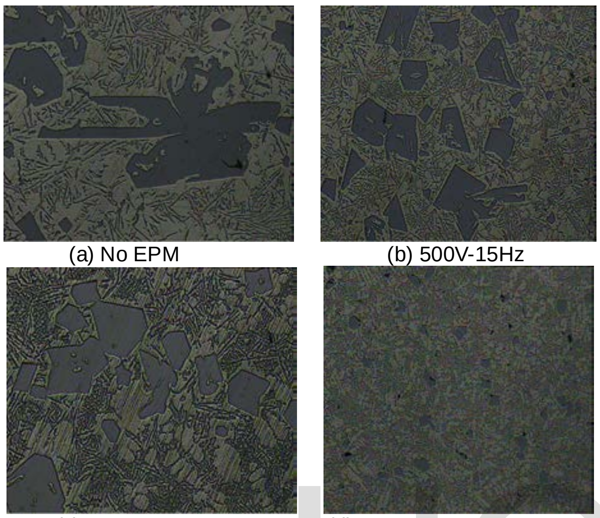
to a larger size having a polygonal shape as indicated in fig (c) its minimum size of primary silicon was 73μm and the range was 48-95μm, in eutectic silicon, the minimum length was 41μm with the range of 18-75μm. Analyzing the micrographs which had been found that the morphology of silicon changes from star-shape to polygonal , however , it got more refined at 1000V where the minimum size of primary silicon was 6μm at a range 2-13μm, for the minimum length of eutectic silicon was 3μm with range of 1-8μm.



(a) No EPM (b) 500V-15Hz

(c) 700V-15Hz (d) 1000V-15Hz

Fig 2.5 Microstructure of Hypereutectic Al-22%Si Alloys (50 μm each)

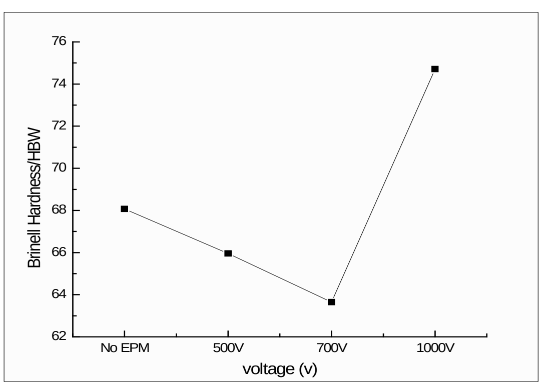



Fig 2.6 Brinell hardness test at 500V in Al-22%Si Alloy

The hardness test of the samples in fig 1.6 was conducted using Brinell hardness testing machine with the dwell time of 15s. Brinell hardness test using different voltage, the hardness decreased with increase in voltage up to 700V then increases when voltage increase to 1000V.The untreated samples average hardness was 68.07HBW and continuously decline to 63.64HBW which decreases by 6.96%, it increase to 74.71HBW at 1000V by 17.39% increase.

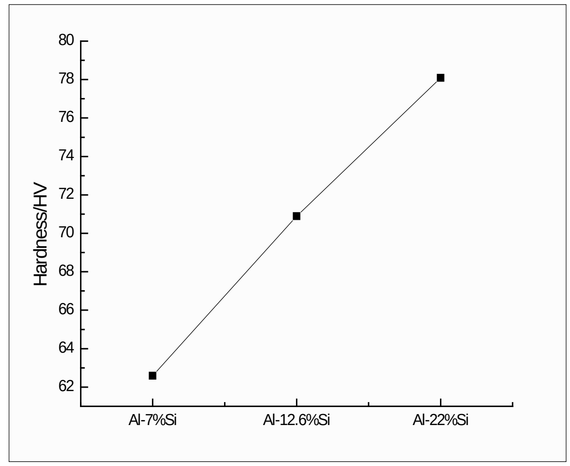



Fig.2.7 shows the increase in Si content with increase in hardness

The figure 4.12 above shows the variation of hardness at Al-7%Si. Al-12.6%Si and Al-22%Si, the hardness varied based on the silicon content, the hardness for Al-7%Si, Al-12.6%Si and Al-22%Si was 62.59HV, 70.89HV and 78.09BHN it indicate that with the increase in silicon there is corresponding increase in hardness of the material.

## Conclusion

The study was carried out to investigate the influence of Electric Pulse Modification on Hypoeutectic Al-7%Si, Eutectic Al-12.6%Si and Hypereutectic Al-22%Si alloys, its Microstructure analysis and hardness of the melt, the result shows that; Electric Pulse is an efficient and physical technique to control the morphology and size of primary silicon grains, refinement and distribution of intermetallic phases which promotes eutectic silicon modification. The morphology of eutectic silicon was modified from a different shapes such as needle shapes, star or dendrite shapes, tear-drop shapes in the samples without



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Electric Pulse to a coarse acicular plate like shapes and finally into a fibrous with change in parameters at 750°C. Electric Pulse, changes the melt structure the alloys which leads to increased of Si-Si cluster thus allowing the change in the number of primary silicon and the distribution of atom cluster of eutectic silicon also changed. Besides refinement, size and size spacing between eutectic silicon was decreased, and that effect increased with the increased in pulse processing Voltage, it indicate that there is homogenous distribution of the silicon throughout the cast, the hardness increases with the increase in silicon contents.

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