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# Effect of Cerium Addition on the Structure and Physico-Mechanical Properties of Aluminium-12wt%Silicon Alloy

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***ABSTRACT:*** *This research investigated the effect of cerium addition on the structure, physical and mechanical properties of Al-12wt%Si alloy. Cerium was added in concentrations of 0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.25 and 1.50wt% respectively. The samples were developed using permanent die casting method and machined to the required dimensions for the structural analysis, mechanical and physical properties tests. The structural analysis was conducted using an optical metallurgical microscope (Model: L2003A) and scanning electron microscopy (Model: Zeiss EVO LS10). Mechanical properties such as ultimate tensile strength, percentage elongation and hardness of the developed alloy were investigated using a 100KN JPL tensile strength tester (Model: 130812) and Brinell hardness testing machine (Model: 900-355) respectively. The electrical resistivity and conductivity were also determined using four-point probe electrical resistivity measurement machine (Model: Quad-Pro-301-6) which showed maximum increase and decrease at 0.5wt% cerium. The mechanical property test results confirmed that the mechanical properties of Al-12wt%Si alloy were improved with cerium addition, with optimal ultimate tensile strength (UTS) of 196.5MPa and percentage elongation of 30.9% at cerium content of 0.6wt%. Also, impact strength of 1.8J and hardness of 53.8BHW were achieved at cerium content of 0.9wt%. The improved mechanical properties were attributed to the structural modification of the silicon platelets.*

***KEYWORDS-*** *Al-Si alloy, cerium, mechanical properties, physical properties, structure*

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## I. INTRODUCTION

The unique combination of properties provided by aluminium and its alloys makes the alloy system one of the most adaptable, economical, and attractive metallic materials for a broad range of applications ranging from domestic and industrial to the most demanding engineering ones. Both the automotive and aerospace industries benefit greatly from the high strength-to-weight ratio of aluminium alloys [1]. Silicon is one of the least expensive alloying additions to aluminium and improves castability by imparting high liquid fluidity and low shrinkage on Al-Si alloys [2]. Also, silicon increases strength to weight ratio, enhances corrosion resistance, decreases the coefficient of thermal expansion, and imparts wear resistance to aluminium [3]. Eutectic alloy composition of Al-12%Si is widely used for casting because of its high fluidity and castability [4]. Eutectic and near-eutectic Al–Si casting alloys attract more attention due to their excellent castability and lower cost of raw materials compared to A356 alloys [4]. Although silicon is an important alloying element, it solidifies as coarse and brittle platelets and so impairs the mechanical properties in cast structures [5]. The sharp ends of this plate-like silicon act as stress raisers that initiate and propagate cracks, thereby reducing the mechanical strength of the alloy [6]. Through the process of modification, this brittle, coarse and plate-like eutectic silicon structure can be transformed to fine fibrous eutectic structure with much enhanced mechanical properties [7]. It was reported that several elements such as Mn [2], Mo [8], Co [4], Sb [7] are generally used to modify the Al-Si alloy. Additionally, modification of Al-Si alloy with trace addition of several rare earth elements was also reported to result in varying degrees of refinement [3][9][10][11][12][13][14][15][16]. In all a limited number of investigations on the effect of rare earth metals addition has been carried out on the structure and physico-mechanical properties enhancement of eutectic Al-12%Si alloy. This study investigates the effects of cerium addition on the structure and physico-mechanical properties of eutectic Al-12% Si alloy.

## II. MATERIALS AND METHOD

High purity aluminium and silicon were used as the base materials for this research. Cerium was used as refiner/alloying element. Permanent die casting technique was utilized for producing the alloy samples used for this research. For the control sample (Al–12wt%Si), high purity aluminium was charged into the preheated bailout crucible furnace and heated until melting was achieved and then superheated to the temperature of 750$^{o}$C. Subsequently, pure silicon was introduced into the melt and stirred vigorously to achieve homogeneity. The mixture was left for 5 mins to achieve a complete dissolution of the silicon metal. The molten metal was properly stirred again, deslagged and poured into pre-heated permanent metal mould. On solidification, the casting was removed from the permanent metal mould. The remaining alloys were developed by repeating the same procedure and then addition of cerium in concentrations of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.25 and 1.5wt%, casting and storing for machining. The cast samples were machined to required dimension and stored for the mechanical and physical property tests such as ultimate tensile strength, percentage elongation, impact strength, hardness, electrical resistivity and conductivity. The tensile strength, impact strength and hardness of the developed alloy were determined using an automated 100KN JPL tensile strength tester (Model: 130812), pendulum impact testing machine (Model: U1820) and Brinell hardness testing machine (Model: 900-355). A four-point probe electrical resistivity testing machine, Signatone, Model Quad-Pro-301-6 was utilised for the measurement of the electrical resistivity and conductivity of the developed alloy. The mounted specimens for microstructural examination was ground using P220C, P320C, P600C, and P800C grades of silicon carbide grinding paper sequenced from coarse to fine. The ground specimens were polished on a polishing machine using diamond paste and polishing cloth. The polished specimens were etched in Keller's reagent to reveal the specimens' surface for microstructural examination. The etched and dried specimens were finally subjected to microstructural examination using an optical metallurgical microscope (Model: L2003A) and scanning electron microscopy (SEM) (Model: EVO LS 10) at magnifications of x200 and x600 respectively.

## III. RESULT AND DISCUSSIONS

The results of the effect of cerium addition on the structure, mechanical and physical properties of Al-12wt%Si alloy were presented in Table 1 and Figure 1&2 respectively.

**Table 1: Mechanical and Physical properties of Al-12wt%Si alloys**

| Alloy Sample | UTS | %E | Hardness | Impact Strength | Electrical resistivity | Electrical conductivity |
|---|---|---|---|---|---|---|
| | MPa | % | BHW | Joule | $10^{-6}\Omega m$ | $10^{3}S/m$ |
| Al-12wt%Si (Control) | 151 | 24 | 47 | 1.5 | 121.8 | 8.21 |
| Al-12wt%Si-0.1wt%Ce | 177.8 | 30.6 | 48.8 | 1.5 | 201.9 | 5 |
| Al-12wt%Si-0.2wt%Ce | 137 | 21.8 | 53 | 1.5 | 40.1 | 25 |
| Al-12wt%Si-0.3wt%Ce | 135.2 | 24.4 | 50.2 | 1.7 | 62.9 | 15.9 |
| Al-12wt%Si-0.4wt%Ce | 135.3 | 23.6 | 53.8 | 1.6 | 85.7 | 11.7 |
| Al-12wt%Si-0.5wt%Ce | 131.8 | 25.1 | 48.2 | 1.5 | 86.3 | 11.6 |
| Al-12wt%Si-0.6wt%Ce | 196.5 | 30.9 | 51.9 | 1.5 | 230.5 | 4.3 |
| Al-12wt%Si-0.7wt%Ce | 166.4 | 28.1 | 49.1 | 1.7 | 39.2 | 25.5 |
| Al-12wt%Si-0.8wt%Ce | 158.8 | 26.3 | 51.4 | 1.6 | 121.2 | 8.3 |
| Al-12wt%Si-0.9wt%Ce | 139 | 24.4 | 48.5 | 1.8 | 196.1 | 5.1 |
| Al-12wt%Si-1.0wt%Ce | 137.2 | 23.6 | 50.8 | 1.6 | 114.3 | 8.7 |
| Al-12wt%Si-1.25wt%Ce | 135.3 | 23.1 | 49 | 1.5 | 63.9 | 15.7 |
| Al-12wt%Si-1.50wt%Ce | 135 | 23 | 53 | 1.5 | 39.1 | 25.6 |

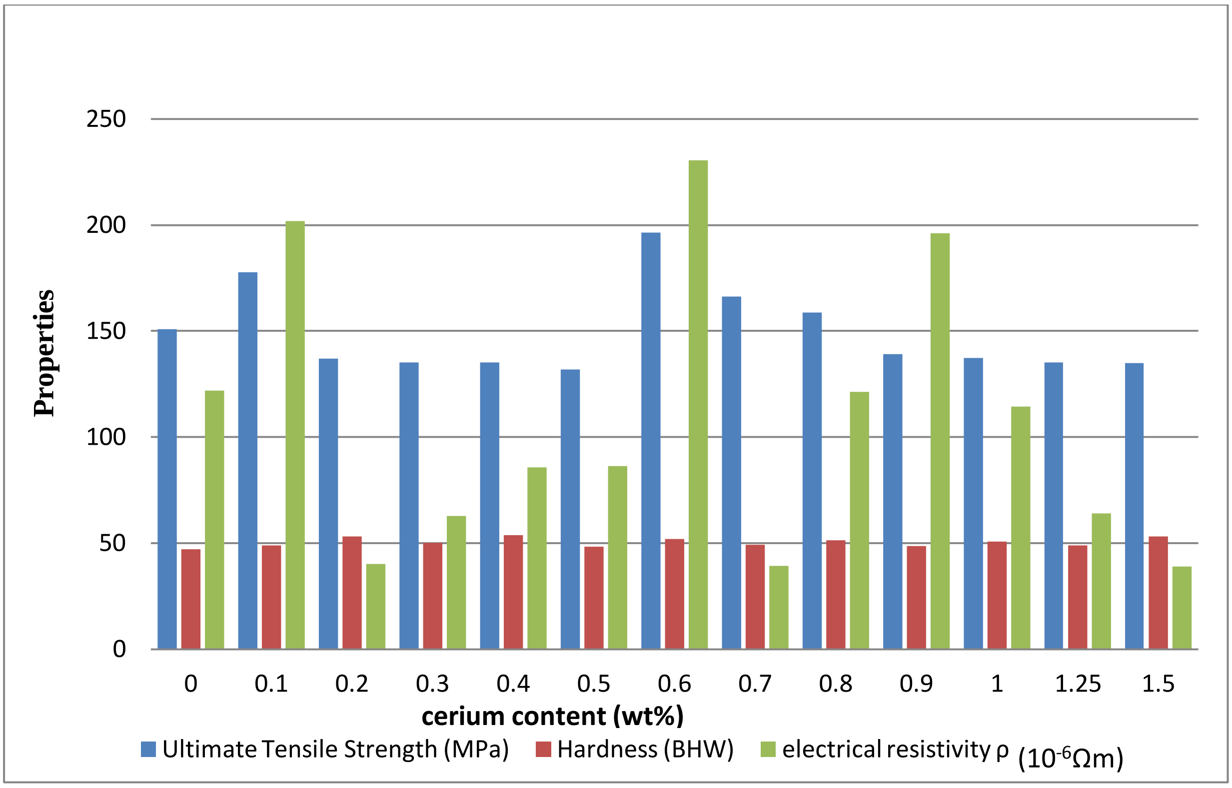


**Figure 1: Effect of cerium content on the properties of Al-12wt%Si alloy**

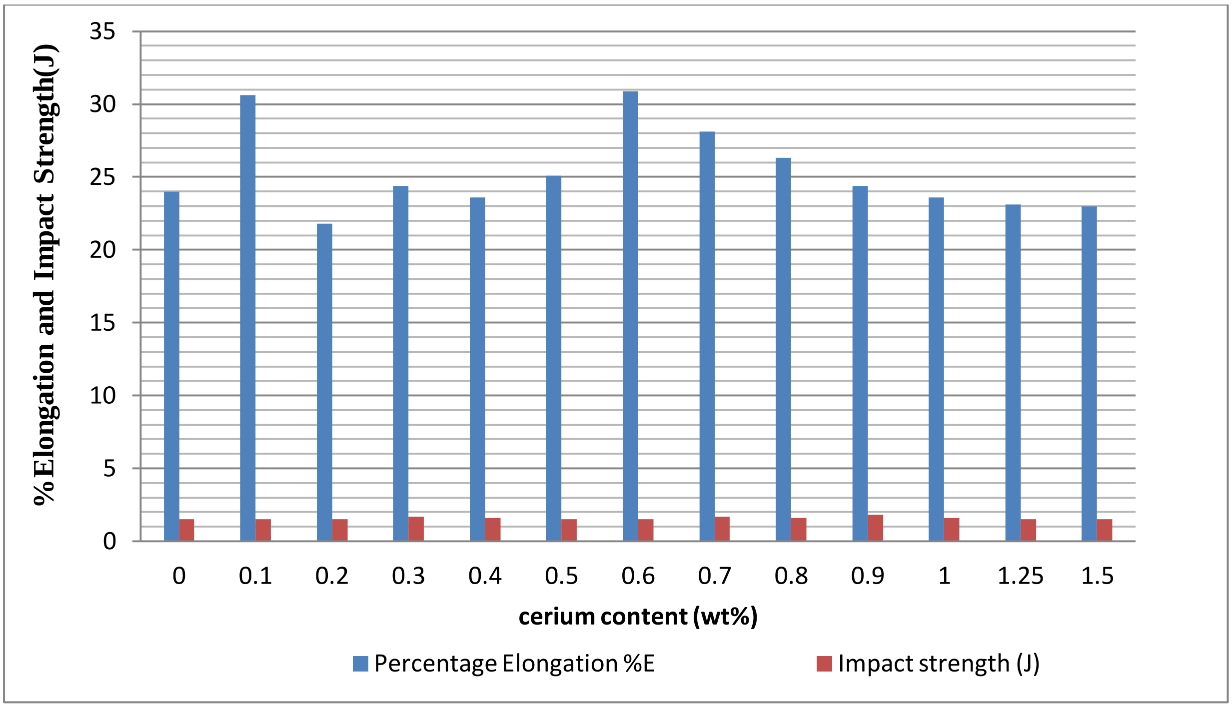


**Figure 2: Effect of cerium content on the percentage elongation (%E) and impact strength of Al-12wt%Si alloy**

The effect of cerium content on ultimate tensile strength, hardness and electrical resistivity of Al-12wt%Si alloy were presented on Table 1 and Figure 1. Figure 1 showed that cerium addition to Al-12wt%Si alloy increased the ultimate tensile strength, hardness and electrical resistivity of the alloy by 30.1%, 14.5% and 89.2% respectively. Figure 1&2 also showed that the ultimate tensile strength, percentage elongation and electrical resistivity of the alloy increased with increase in cerium content with maximum values of 196.5MPa, 30.9%E and 230.5 x$10^{-6}\Omega$m obtained at 0.6wt% cerium content respectively. The impact strength and hardness of the alloy also increased with increase in cerium content with maximum values of 1.8J and 53.8BHW respectively at 0.4wt% and 0.9wt% cerium content. The improvement in the mechanical properties was attributed to the microstructural changes as shown in Figure 5-9.

**Physical properties of the studied alloy**

Figure 3 shows the electrical resistivity and conductivity of Al-12wt%Si alloy doped with different concentration of cerium. Analysis of Figure 3 showed that addition of 0.6wt% cerium maximally increased the electrical resistivity (ρ), hence decreased the electrical conductivity (σ) of the alloy. The increase in the electrical resistivity and corresponding decrease in the electrical conductivity will be as a result of refining effect of cerium on the dendritic primary silicon formed in the alloy structure as shown in Figure 5-9.

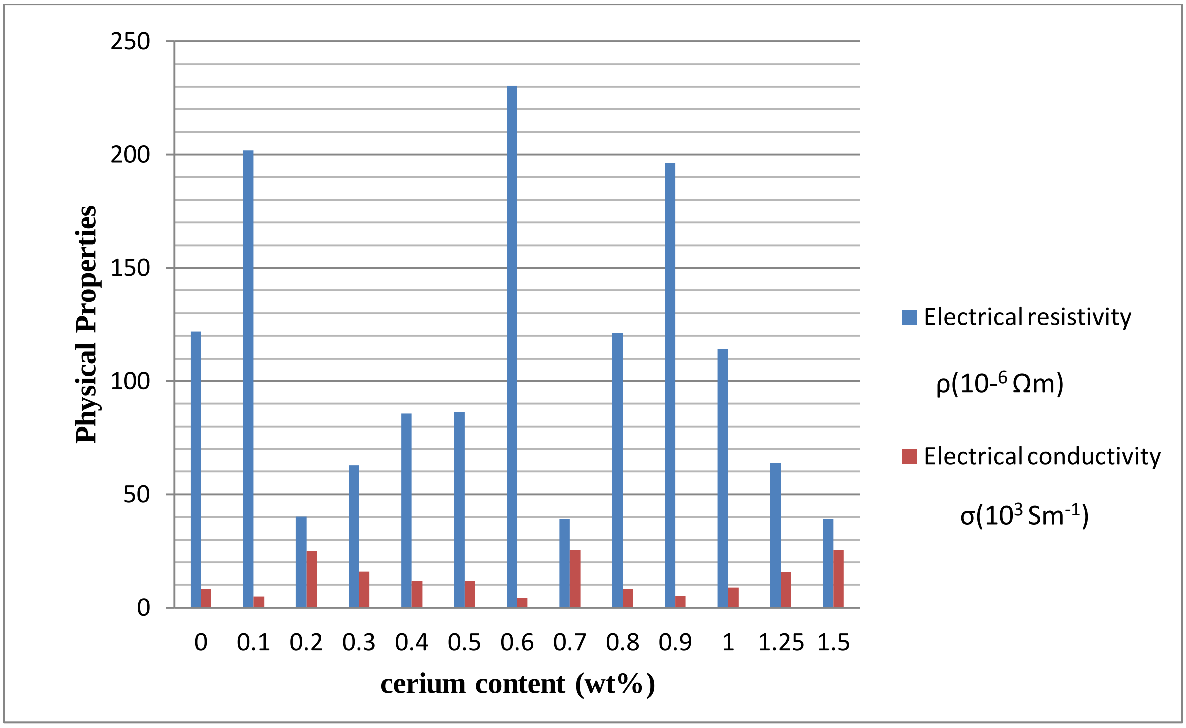


**Figure 3: Effect of cerium content on the electrical resistivity (ρ) and electrical conductivity (σ) of Al-12wt%Si alloy**

**Optical and scanning electron microscopy of the studied alloy**

The optical and scanning electron microscopy analyses of Al-12wt%Si alloy with different concentration of cerium were presented in Figures 5-9. The micrograph of the control sample presented in Figure 4 revealed the presence of coarse α-aluminium dendrite phase and plate-like coarse eutectic silicon β-phase. The micrographs of Al-12wt%Si alloy doped with different concentrations of cerium as presented in Figures 5-9 showed that the coarse α-aluminium dendrite phase has been modified to fine equiaxed α-aluminium dendrite phase. Also, it was observed that the plate-like eutectic silicon phase has been refined to finer particles. The morphological changes brought about by the modification and refining effect of cerium addition resulted in improvement of the mechanical properties of Al-12wt%Si alloy as evidenced in Table 1and Figure 1&2.

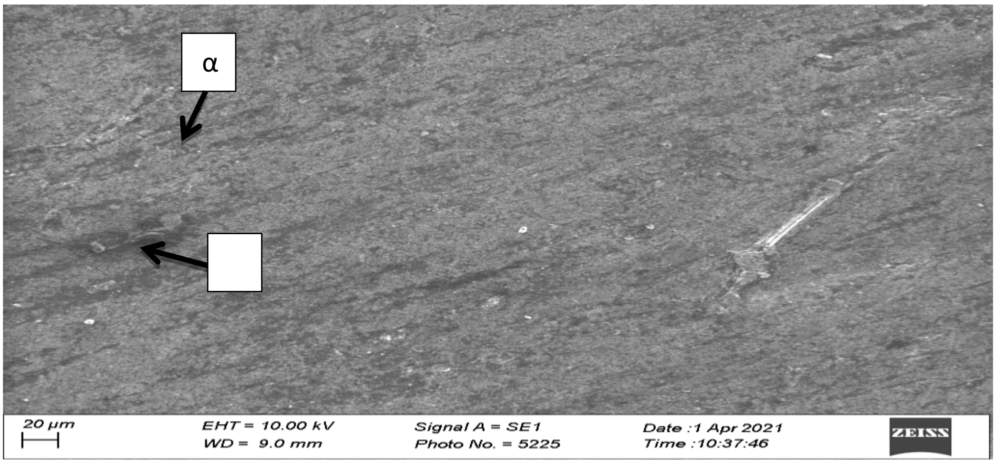


**Figure 4: Scanning electron micrograph (SEM) of Al-12wt%Si alloy (Control)**

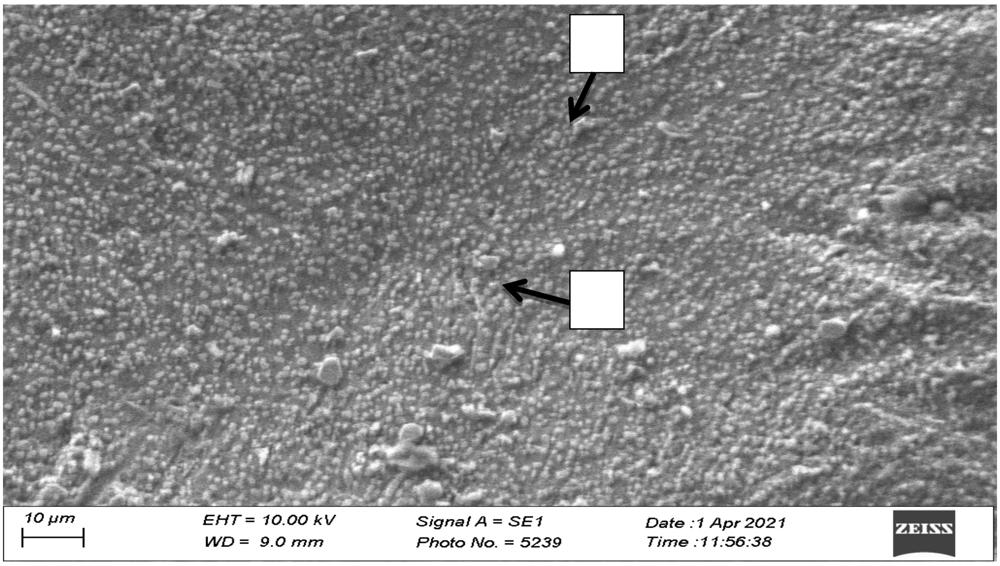


**Figure 5: Scanning electron micrograph (SEM) of Al-12wt%Si-0.6wt%Ce alloy**

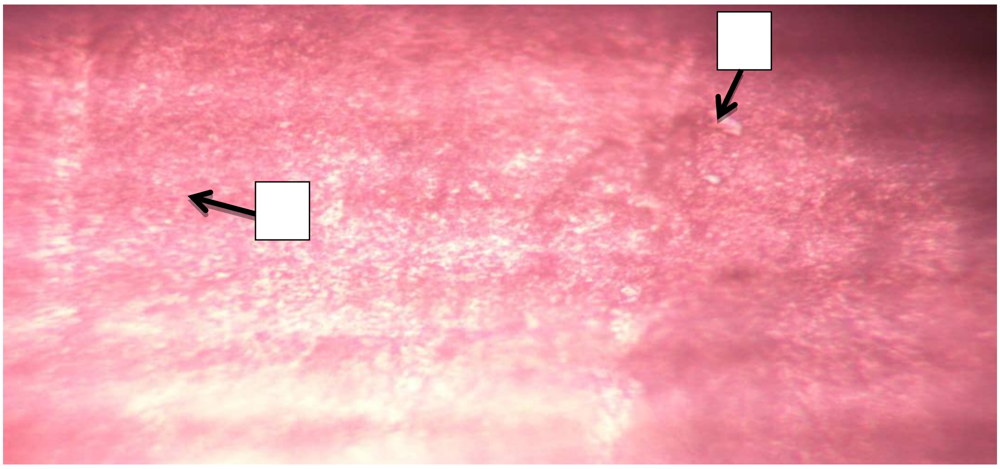

**Figure 6: Optical metallurgical micrograph of Al-12wt%Si-0.4wt%Ce alloy**

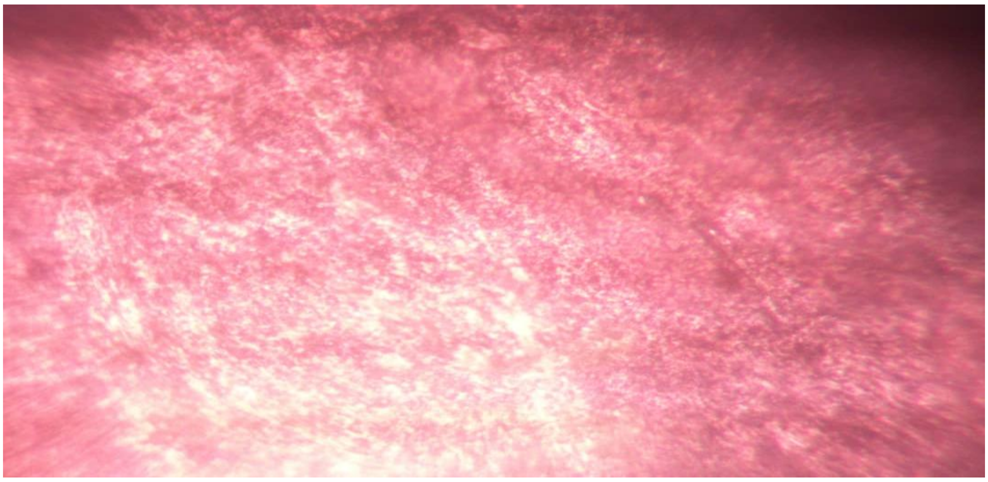

**Figure 7: Optical metallurgical micrograph of Al-12wt%Si-0.5wt%Ce alloy**

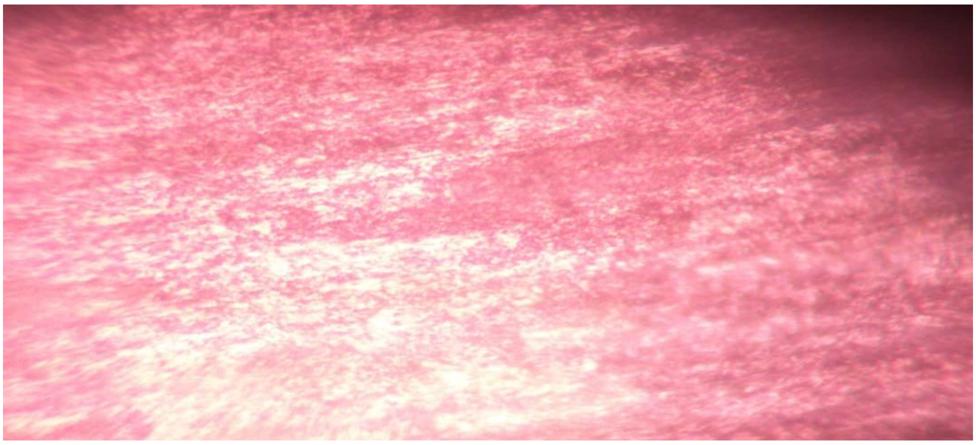

**Figure 8: Optical metallurgical micrograph of Al-12wt%Si-0.6wt%Ce alloy**

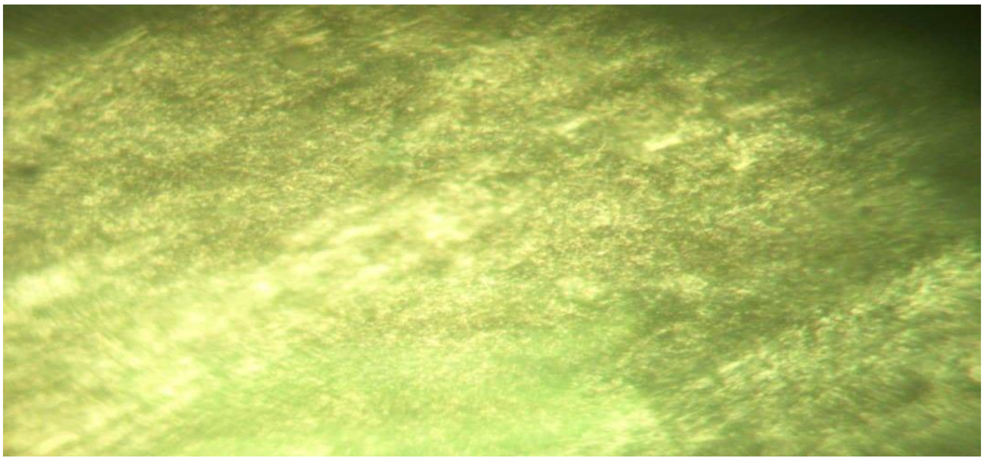

**Figure 9: Optical metallurgical micrograph of Al-12wt%Si-0.9wt%Ce alloy**

## IV. CONCLUSION

The following conclusions were drawn from the results of the study:

a) Cerium addition to Al-12wt%Si alloy improved the ultimate tensile strength (UTS) and percentage elongation (%E) ranging from 158.8.2MPa-196.5MPa and 24.4%-30.9%E respectively as compared to the control specimen with UTS of 151MPa and 24%E respectively.

b) Cerium addition to Al-12wt%Si alloy improved the hardness ranging from 48.2BHW-53.8BHW as compared to the control specimen with hardness value of 47BHW

c) Addition of 0.6wt%Ce significantly improved the ultimate tensile strength (UTS) and percentage elongation (%E) of Al-12wt%Si alloy. The significant improvement was attributed to the modification and refinement of the plate-like eutectic silicon phase and coarse α-phase in the alloy structure.

d) Addition of 0.6wt%Ce to Al-12wt%Si alloy maximally increased the electrical resistivity and decreased the electrical conductivity of the alloy.

e) Al-12wt%Si alloy with 0.6wt% cerium addition should be utilised in lightweight component parts manufacture where improved tensile properties are required.

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