

## **TENSILE AND WEAR PROPERTIES OF EUTECTIC Al-Si-Mg-Ce ALLOY**

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### **ABSTRACT**

The effect of cerium addition on the microstructures and mechanical properties of the eutectic Al-Si-Mg alloys were investigated. Wear tests were conducted against a hardened carbon steel (Fe-2.3%Cr-0.9%C) using a pin-on-disc configuration with fixed sliding speed of  $1 \text{ ms}^{-1}$  and load of 30 N at room temperature ( $25^{\circ}\text{C}$ ). Both worn surfaces and collected debris were characterized by scanning electron microscope (SEM) equipped with energy dispersive X-ray spectrometer (EDX). The result shows that the addition of 1 - 3 wt% cerium resulted in the formation of rod-like intermetallic phases Al-Ce. The tensile strength of the as-cast alloy increases with the increase of Ce content, then fall down and reached a maximum value of 120 MPa when Ce content was 2 wt.%. The wear resistance of Al-12Si-4Mg alloy improved significantly with the addition of cerium up to 2 wt%. However, cerium addition of more than 2 wt% to the alloy leads to insignificant improvement in wear resistance of the as-cast alloys.

### **INTRODUCTION**

The major driving force in the development of Al-Si cast alloys are the superior wear resistance, low coefficient of thermal expansion (CTE), high corrosion resistance, high strength to weight ratio and excellent castability [1]. These make them potential candidate materials for a number of tribological applications in automobiles and other engineering sectors [2]. However, their low fracture toughness restricted the applications of these alloys. The production of cast Al alloys with improved quality (better structure and mechanical properties) involves the addition of alloying elements, heat treatment or plastic deformation (extrusion, rolling and forging). The addition of alloying elements is the easiest and efficient method to improve the mechanical properties of the alloys [3]. Among the alloying elements, rare earth has lots of positive effects on high strength aluminum cast alloys. They can refine grain sizes, modify eutectic microstructures and improve distribution of the inclusion phases. Rare earth elements have a strong chemical appetency with hydrogen and oxygen elements. The addition of rare earth elements can reduce the hydrogen and oxygen contents. Blowholes and pinholes which formed during the solidification process of the

aluminum liquid can also be eliminated. Thus a compactable casting can be achieved with these elements. Besides that the rare earth elements can also increase heat resistance properties and reduce linear expansion coefficient of aluminum alloys [4]. In this paper, the effects of cerium on the microstructures and mechanical properties of eutectic Al-Si-Mg alloy were investigated.

## EXPERIMENTAL METHOD

Al-Si-Mg alloys were prepared using high purity elements, aluminum (99.9 wt.% purity), silicon (99.95 wt.% purity) and magnesium (99.99 wt.% purity) with cerium contents varied from 1 to 3 wt.%. The chemical compositions of the alloys studied are listed in Table 1. The melting was carried out using a graphite crucible at 850 °C in electrical melting furnace under argon gas atmosphere. The melt was poured in a steel mould to produce a casting of 10 mm in diameter and 80 mm in length. The microstructures of the alloys were investigated by a metallurgical microscope (Zeiss-Axiotech 100HD). The tensile test was performed according to ASTM-E8 using Universal Instron 5567 with 2.5 ton capacity at speed of 1 mms<sup>-1</sup>. Dry sliding wear tests were carried out using a pin-on-disk configuration at a fixed speed of 1 ms<sup>-1</sup>. The pins of the test material were cylindrical rods (10 mm diameter and 15 mm length) with flat ends. The pin of the test material was held against a rotating hardened carbon steel EN-31(Fe-2.3%Cr-0.9%C) disc having a hardness of RC60.

Table 1: Chemical composition of the as-cast alloys

| Alloy           | Composition (wt%) |    |     |      |      |       |
|-----------------|-------------------|----|-----|------|------|-------|
|                 | Al                | Si | Mg  | Ce   | Cr   | Fe    |
| Al-12Si-4Mg     | Bal               | 10 | 3.0 | 0    | 0.12 | 0.044 |
| Al-12Si-4Mg-Ce  | Bal               | 14 | 3.1 | 0.68 | 0.21 | 0.04  |
| Al-12Si-4Mg-2Ce | Bal               | 14 | 3.6 | 0.93 | 0.22 | 0.039 |
| Al-12Si-4Mg-3Ce | Bal               | 13 | 3.4 | 1.8  | 0.44 | 0.038 |

## RESULTS AND DISCUSSIONS

### *Microstructure*

Optical microphotographs of as-cast alloy with cerium addition 1 – 3 wt.% are shown in Figure 1. It can be observed from the optical microphotograph that the as-cast alloys without cerium addition consists of eutectic mixture of  $\alpha$ -aluminium, Mg<sub>2</sub>Si intermetallic phase (chinese script) and silicon. The addition of cerium leads to the precipitation of Al-Ce intermetallic phases which exhibited a needle-like form structure [5]. By increasing cerium content up to 3 wt.%, the formations of the needle-like Al-Ce phase were increased and coarsened.

### *Tensile Properties*

Figure 2 shows the ultimate tensile strength test results of as-cast alloys of various Ce content where the ultimate tensile strength of as-cast alloy with cerium is higher than

that of without cerium. The ultimate tensile strength reached maximum value when the cerium content was 2 wt.%. The improvement in strength of as-cast alloy may be attributed to the presence of Al-Ce intermetallic phases. Mechanical properties of as-cast alloys mainly depend on the shape, size and size distribution of the  $\alpha$ -Al grains, eutectic silicon morphology and intermetallic phases in the interdendritic region [6]. The ultimate tensile strength of the alloy with 3 wt.% Ce is lower than that of the alloy with 2 wt.% Ce. Such a reduction may be associated to the amount of Al-Ce phase which increases the cracking tendency. Besides that, the decrease in tensile strength is also due to the needle-like shaped Al-Ce intermetallic phase that gives higher stress concentration and more easily to initiate microcrack [7].

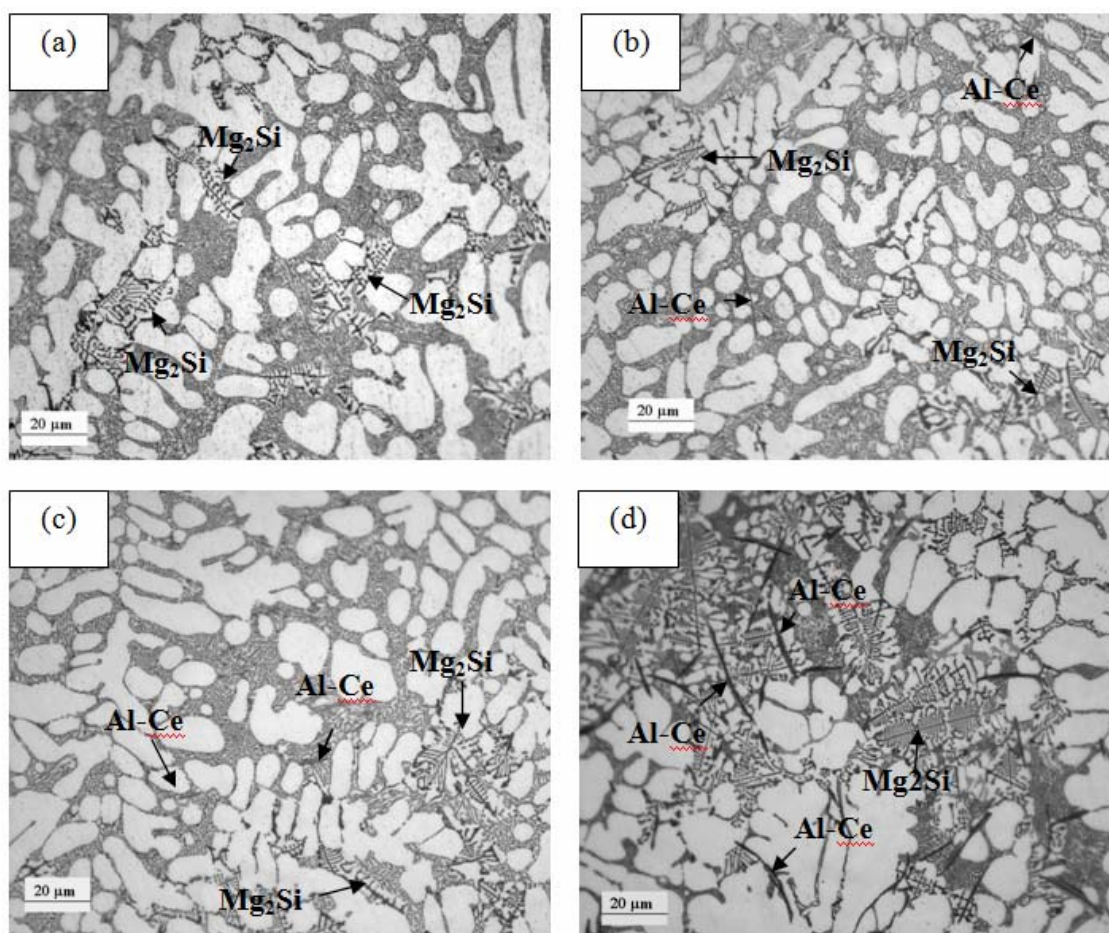


Figure 1. Microstructure of as-cast alloys with: (a) 0 wt.% Ce, (b) 1 wt.% Ce, (c) 2 wt.% Ce and (d) 3 wt.% Ce.

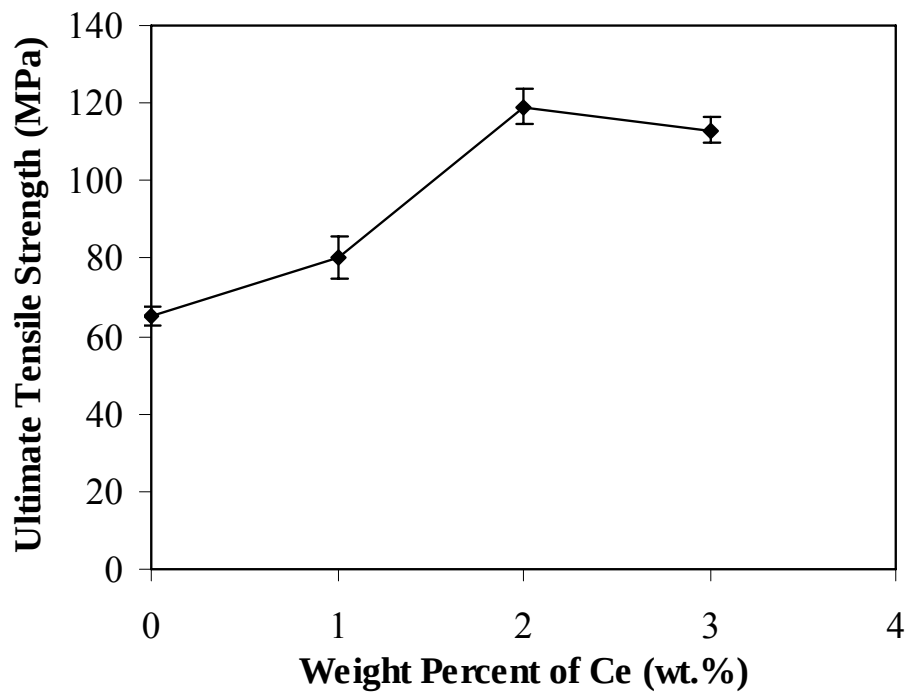


Figure 2: The ultimate strength of eutectic Al-Si-4Mg alloys as a function of Ce content.

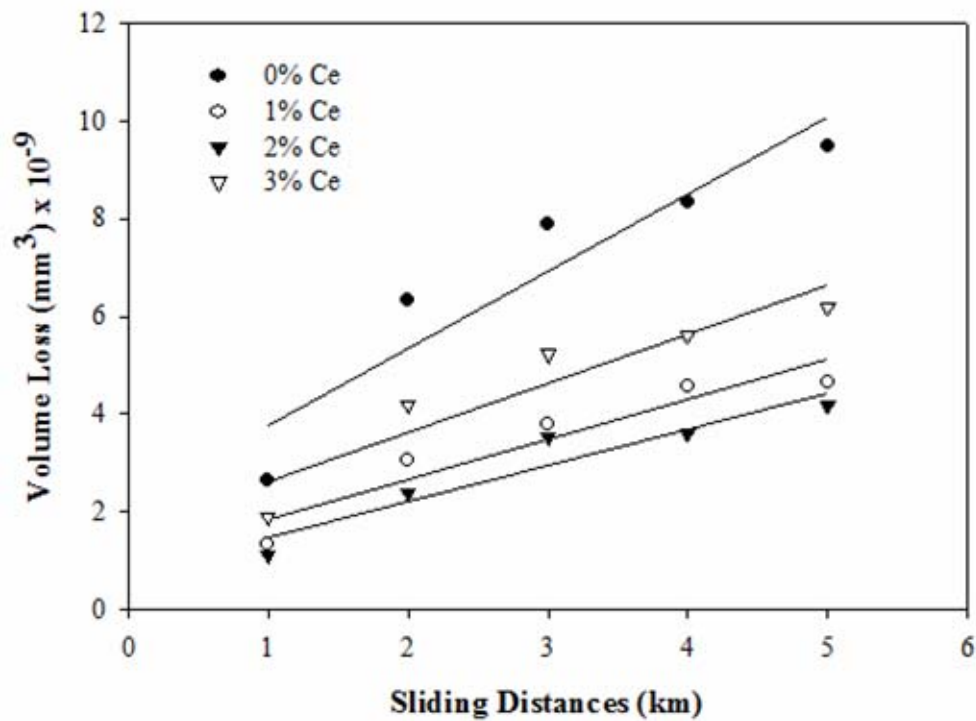


Figure 3: Volume loss as a function of sliding distances for each of the as-cast alloys.

*Wear debris and worn surface analysis*

Worn surfaces of alloys under investigation were studied with a scanning electron microscope (SEM) to analyze the wear mechanism of as-alloy containing Ce are shown in Figure 4. The worn surface of as-cast alloy shows wear scars, craters and oxides indicating oxidative wear. Wear debris collected from experiments carried out on each alloy was examined by SEM and analyzed by EDX. Figure 5 shows the SEM images of wear debris formed at 5 km sliding distance. As shown by EDX profile in Figure 6, the dominant element of eutectic Al-Si-Mg alloy containing 2 wt.% Ce wear debris has a composition consisting of Al, Si, Mg, Fe, Ce and O. Fe presence was suggested to derive from the transfer of the sliding steel disc whereas the element O was considered to arise due to the reactions with the environment. This indicates that the mode of wear is mild oxidative [9]. Changes in morphology of wear debris were found to be consistence with the severity of the worn surface.

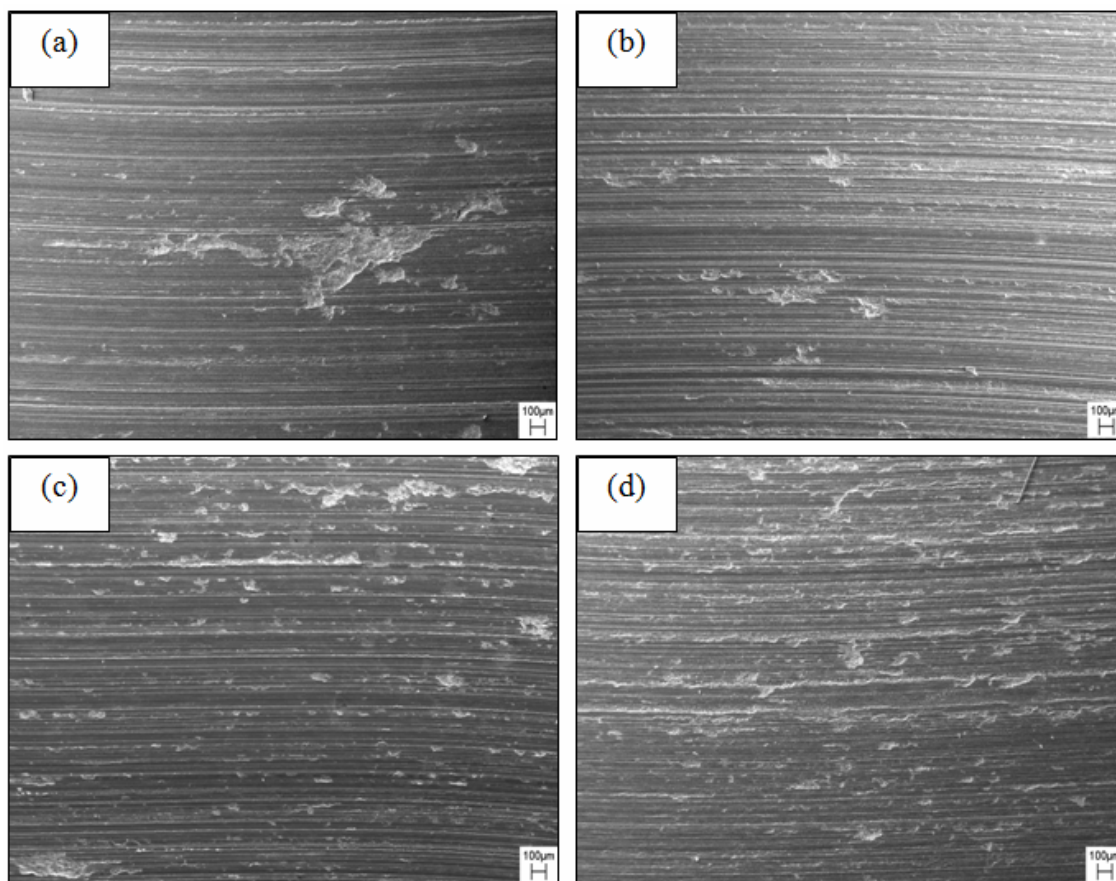


Figure 4: SEM morphologies of worn surfaces of as-cast alloys with (a) 0 wt.% Ce, (b) 1 wt.% Ce (c) 2 wt.% Ce and (d) 3 wt.% Ce.

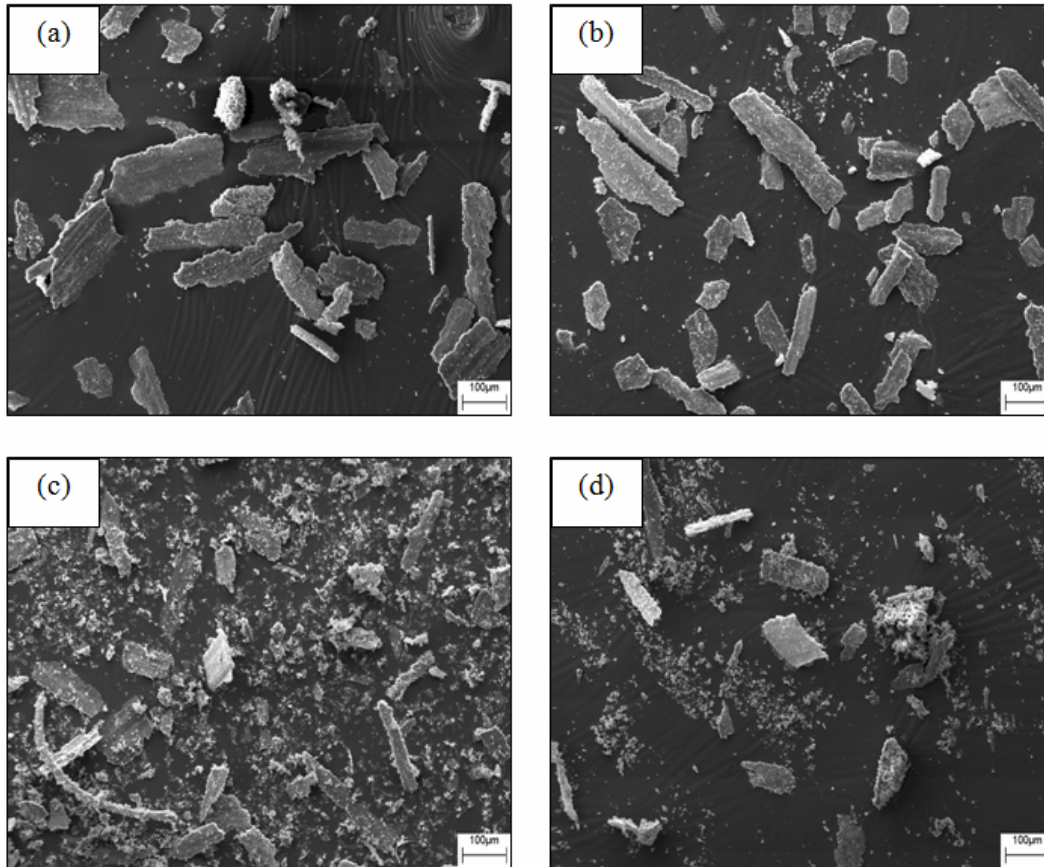


Figure 5: SEM micrographs of wear debris of (a) 0 wt.% Ce, (b) 1 wt.% Ce, (c) 2 wt.% Ce and (d) 3 wt.% Ce.

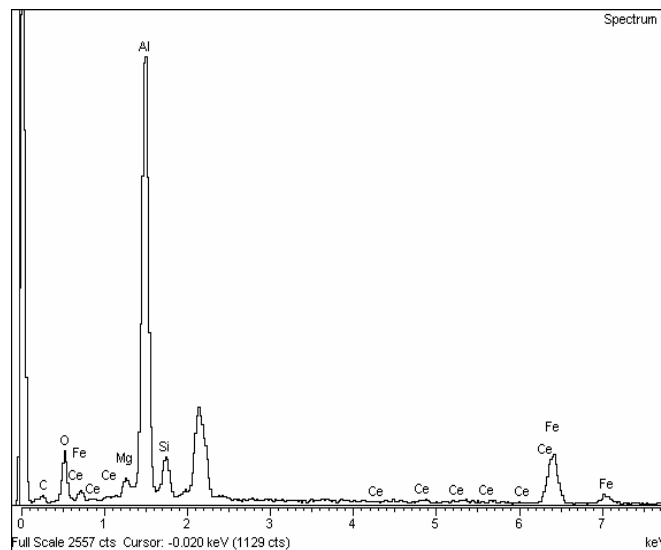


Figure 6: EDX analysis of wear debris of the as-cast alloy containing 2 wt.% Ce.

## CONCLUSIONS

It was revealed that cerium addition significantly influenced the morphology of the intermetallic phases of Al-Ce, resulting a formation of rod-like structures. The wear resistance and ultimate tensile strength of Al-12Si-4Mg alloy improves with the addition of cerium up to 2 wt%. However, cerium addition of more than 2 wt% to the alloy leads to lower wear resistance and ultimate tensile strength of the alloy. The severity of abrasive and delamination wear mechanisms observed on the worn surface was found to be consistent with the cerium content in the alloys. Formation of craters and localised plastic deformation were observed on the worn surface of alloys where fine particulates and sheet-like wear debris were produced.

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