# Chapter 1
# Cerium Oxide and Silicon Carbide Reinforced Al6063 Metal Matrix Composites Comparative Evaluation for Mechanical Properties and Fractography Studies

**Abdul Nazeer and Mir Safiulla**

**Abstract** Aluminum matrix material is considered as advanced material because of its very good mechanical, tribological properties which have been used in automobile, aerospace industries at the larger end, and now aluminum matrix materials have been used in medical and electronics industries because of its good and high strength to weight ratio and low coefficient of thermal expansion. The present work is focused about the improvement in mechanical properties and fracture graphic studies of aluminum matrix reinforced with ceramic particulate silicon carbide and cerium oxide of laboratory grade size, respectively. Here, the reinforcement is varied in terms of weight percent ranging from 0 to 8% in the steps of 2%, and the composites were fabricated using a stir casting route. Prepared specimens were tested as per ASTM standard and performed tensile, compressive, impact and hardness test and fracture surfaces studies done under the scanning electron microscope (SEM) and X-ray diffraction (XRD). The results reveal that with increase in percentage of reinforcement, the mechanical properties of the composite system have increased, SEM images clearly reveal the modes of fracture, and XRD shows the presence of reinforcement.

**Keywords** Aluminum matrix composite · Stir casting · Mechanical testing · SEM · XRD

## 1.1 Introduction

The term "composites material" deals with mixing two different materials, where one is called as matrix and other as reinforcement. Composite materials are becoming increasingly popular because of its good mechanical, tribological properties and good resistance to wear, good fatigue life, prevention to corrosion and ability to the

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coefficient of thermal expansion. Composite material is broadly classified on the basis of matrix and reinforcement. On the matrix, it is classified as polymer matrix composite (PMC), Metal matrix composite (MMC), and ceramic matrix composite (CMC), on reinforcement is classified as continuous fibers, discontinuous fibers, Whiskers and particulates. The function of reinforcement is to carry the load, and the matrix is used to transfer and distribute the applied load. These composite materials have been used in many industries mainly in automotive and aerospace industries due lightweight, high load carrying capacity and good resistance to wear, and metal matrix composite is gaining more importance because of easy processing and cost effectiveness. Other advantage of composite metal matrix is that it can be fabricated as hybrid composite in order to increase the properties for specific requirement, where in a single matrix two different reinforcements are introduced such as Al6061 as matrix and SiC and $Al_2O_3$ as reinforcement [1]. In order to increase tensile strength, hardness and toughness, hybrid composites are prepared by reinforcing fly ash and SiC [2]. Researchers have done work on aluminum alloy with alumina and boron carbide and found that tensile strength, flexural test, impact test and Brinell hardness test values have marginally increased.

Lightweight aluminum alloy matrix composites (AMCs) become increasingly popular due to great mechanical and tribological properties as compared to conventional aluminum alloys. Cast particle-reinforced composites show good results in the automobile sector due to inherent simplicity in fabrication combined with an advantage of mass production [3]. Silicon carbide (SiC)-reinforced aluminum matrices have been widely accepted as potential candidates for weight-critical automobile and aerospace applications.

## 1.2 Experimental Details

### *1.2.1 Matrix and Reinforcement Material*

Aluminum 6063 is used as metal matrix, silicon carbide and cerium oxide as reinforcement in laboratory grade.

Silicon carbide of laboratory grade 10–20 μm size is chosen as reinforcement owing its high hardness, low coefficient of thermal expansion and highly wear resistant.

Cerium oxide of 5 μm size was considered as a reinforcement. It is an important commercial product and an intermediate in the purification of the element from the ores.

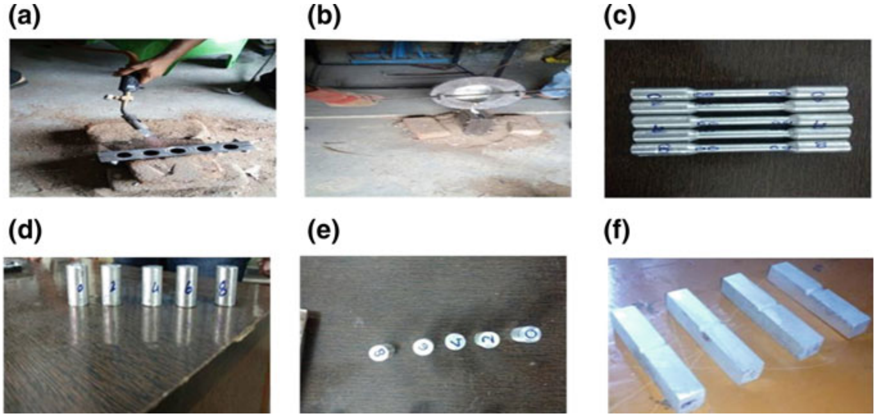

**Fig. 1.1** Preparation of composite system with various reinforcements and testing for mechanical properties. **a** Preheating of mold, **b** pouring of molten material into mold, **c** tensile test specimen, **d** compression test specimen, **e** hardness test specimen, **f** Charpy impact specimen

### *1.2.2 Preparation of Composites*

Aluminum 6063 alloy was melted utilizing a 6 kW electric heater. Hereliquid metallurgy route stir casting technique adopted where mechanical stirrer is turned to make a vortex, reinforcement SiC and $CeO_2$ powders is at first preheated and gradually mix in liquid metal with consistently stirred. The stirring time was 10 min. The molten composites maintained at a constant temperature of 740 °C. The reinforcement induced 0–8% in steps of 2%, and Fig. 1.1a, b shows the preparation of composite.

### *1.2.3 Scanning Electron Microscopy (SEM)*

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The analysis was conducted on Hitachi SU 3500 make at Centre for Incubation Innovation Research and Consultancy (CIIRC) Jyothy Institute of Technology, Bangalore (INDIA). The fractured surfaces of tensile test specimen were studied under SEM.

### *1.2.4 X-Ray Diffraction*

When the geometry of the incident X-rays impinging the sample satisfies the Bragg Equation, constructive interference occurs and a peak in intensity occurs. The powder

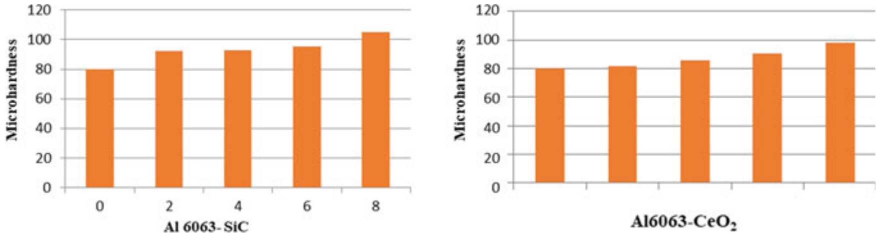


**Fig. 1.2** Variation of micro hardness with increased content of SiC and $CeO_2$ for cast matrix alloy and its composite systems

was collected from the samples of Al6063–SiC and $CeO_2$ composites for all weight percentage of (0, 2, 4, 6, 8), and diffraction patterns were recorded to confirm the presence of SiC and $CeO_2$ in the composite. The sample is in powder form so that it can be easily placed in sample holder of dimension 24.6 mm × 1.0 mm.

## 1.3 Result and Discussion

### *1.3.1 Micro Hardness Test*

Micro hardness tests were performed by applying load of 10 N for a period of 20 s. It can be observed from Fig. 1.2 that the hardness value of composite goes on increases with increase in reinforcement for all composites with different reinforcement which indicate that hardness of the base alloy can be increased with increase in reinforcement which clearly shows the effect of hard reinforcement. It also found that hardness value is more for reinforcement SiC as compared to $CeO_2$. Addition of 8 wt% of SiC increases hardness of matrix alloy 31.6%, while addition of $CeO_2$ is 22.25%.

### *1.3.2 Compression Strength*

The results reveal that as percentage of reinforcement increased, the compressive strength also increases. This is because SiC and $CeO_2$ are strong and hard particulate added to aluminum alloy. The strength of composite systems increases which requires high energy to compress. The variation compressive strength for composite systems is very much similar to other researchers (Fig. 1.3).

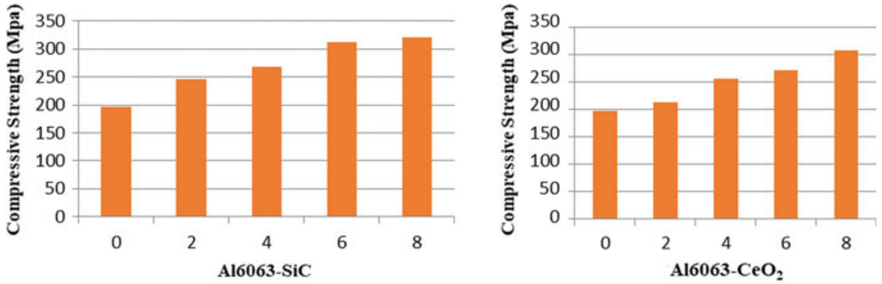


**Fig. 1.3** Variation of compressive strength with increased content of SiC and $CeO_2$ for cast matrix alloy and its composite systems [2, 4]

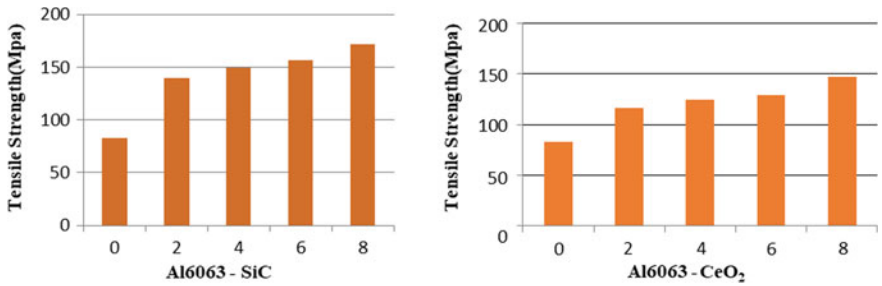


**Fig. 1.4** Variation of tensile strength with increased content of reinforcement for cast matrix alloy and its composite systems

### *1.3.3 Tensile Test*

Figure 1.4 summarizes the tensile strength of cast alloy and its composite systems and tries to identify which reinforcement will give the maximum ultimate tensile strength, and from Fig. 1.4 it clearly observed that the maximum tensile strength is for silicon carbide reinforcement, as silicon carbide is harder than cerium oxide. The maximum ultimate tensile strength at 8 wt% composites is found for Al6063–SiC in comparison with Al6063–$CeO_2$. It was found 51.9% of increase in tensile strength with reinforcing 8% of SiC and 43.6% increase in tensile strength with reinforcing 8% of $CeO_2$ as compared with base metal matrix alloy.

### *1.3.4 Charpy Impact Test*

It is observed from Fig. 1.5 that as the percentage of reinforcement is increased, the ductility of the material is decreased and brittleness is increased, so due to the impact, the energy absorbed by the composite is decreased with increase in percentage of reinforcement, and similar results are obtained by other researchers [4, 5].

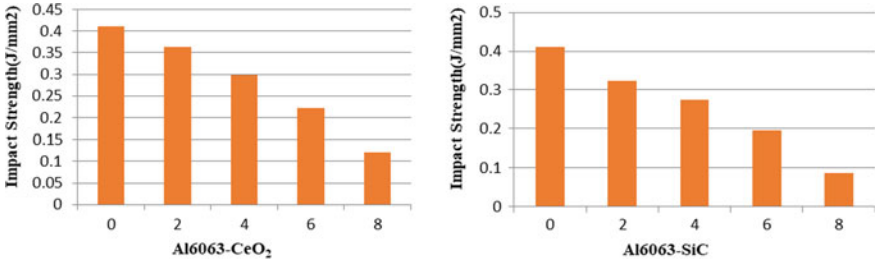


**Fig. 1.5** Variation of impact strength with increased content of SiC and $CeO_2$ for cast matrix alloy and its composite systems

## *1.3.5 Fractography Studies*

The study of fracture surfaces for different weight percentages of SiC and $CeO_2$ reinforcement under scanning electron microscope (SEM) technique is shown in Fig. 1.6 as the SEM photographs of the tensile test fractured surfaces of the cast Al6063 and its composite systems. It is evident that the base matrix alloy has got larger dimples when compared with different composite system studied for given content of reinforcement. Al6063 matrix alloy showing very large dimples indicates

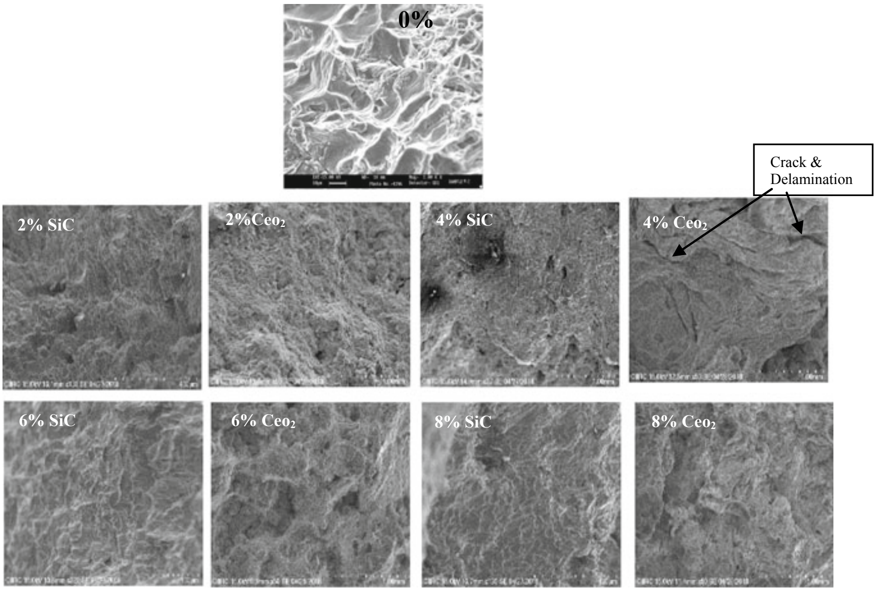


**Fig. 1.6** SEM of tensile fractured surface of Al6063 0–8 wt% composites system

ductile fracture as shown in Fig. 1.6 for 0% reinforcement, whereas in case of Al6063-8 wt% composite, particles of reinforcement and medium-sized dimples are visible as evident from Fig. 1.6, and these observations are similar to other researchers [2].

### *1.3.6 X-Ray Diffraction Analysis*

XRD graphs and results given below clearly indicate the presence of reinforcement in the matrix alloy with varying percentage, XRD result shows a variation in the amount of reinforcement embedded in matrix alloy, and this is because XRD samples in powder form in minute quantity from a particular region are taken.

In X-ray diffraction pattern (Fig. 1.7a–i), many peaks are obtained in the 2 span ranging from 5 to 90, but the common peaks at 2 of 38.44°, 44.7°, 65.32° and 77.2° belong to pure Al and the peaks at 2 of 28.5, 38.83°, 50.80°, 78.88° and 82.43° belong to $CeO_2$ and for SiC 35.1960, 38.370 and 38.31,83.0. With the help of Match software, graphs are compared with JCPDS card JCPDS file #04-0787 for SiC (Table 1.1).

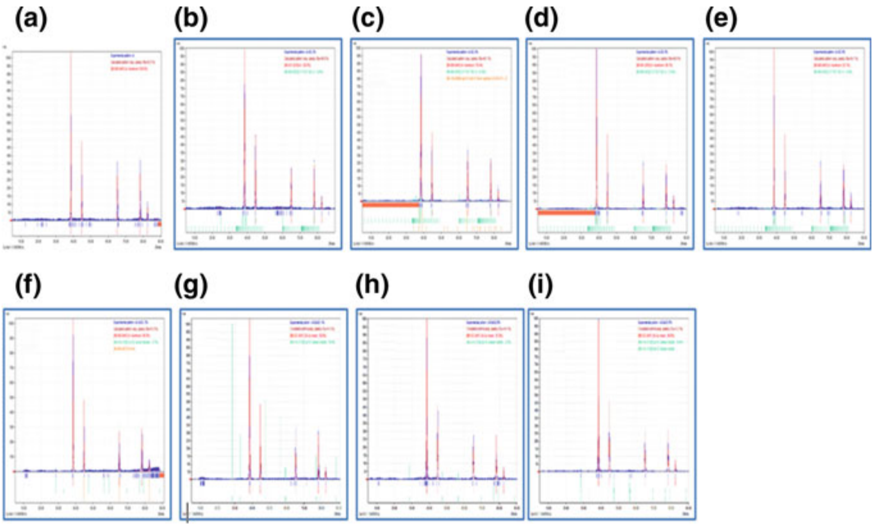


**Fig. 1.7** XRD pattern for Al6063 matrix alloy and its composites

**Table 1.1** Analysis of XRD data using Match software and identification of the presence of reinforcement with following percentage

| Figure 1.7 | a | b | c | d | e | f | g | h | i |
|---|---|---|---|---|---|---|---|---|---|
| Name | Al6063 | Al6063-2 wt% SiC | Al6063-4 wt% SiC | Al6063-6 wt% SiC | Al6063-8 wt% SiC | Al6063-2 wt% $CeO_2$ | Al6063-4 wt% $CeO_2$ | Al6063-6 wt% $CeO_2$ | Al6063-8 wt% $CeO_2$ |
| Amount (%) | 100% | 92% Al | 93.1% Al | 86.1% Al | 78.4% Al | 99.3% Al | 97.8% Al | 99.6% Al | 80.6% Al |
| | | 8% SiC | 6.9% SiC | 13.9% SiC | 21.6% SiC | 0.7% $CeO_2$ | 2.2% $CeO_2$ | 0.4% $CeO_2$ | 19.4% $CeO_2$ |

## 1.4 Conclusion

- Successful synthesis and characterization of Al 6063-silicon carbide and cerium oxide composites are obtained.
- Tensile strength of composites increased significantly with increased content of SiC and $CeO_{2.}$
- Energy absorbed during the impact test on composites decreased with increased content of SiC and $CeO_2$ in matrix alloy under identical test condition.
- Micro hardness of composites increased significantly with increased content of SiC and $CeO_{2.}$
- It has been noted that the compressive strength of composite increased with increased content of reinforcement and is higher than base aluminum alloy, and Al6063 SiC composites have higher compressive strength than $CeO_2$ for identical test condition.
- SEM studies clearly show the modes of fractured occurred.
- XRD analysis confirms the presence of SiC and $CeO_2$ in Al6063 composite with varying percentage.

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