High Temperature Mechanical Properties of Silicon Carbide Particulate Reinforced Cast Aluminum Alloy Composite

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Abstract

The effect of high temperature on mechanical properties of silicon carbide particulate reinforced cast aluminum alloy composite has been investigated. 15% volume fraction silicon carbide aluminum alloy (6063) composite was cast by stir casting technique. The samples were machined to tensile, impact and hardness test samples and were tested at room temperature and elevated temperatures of 100°C, 250°C and 400°C. The results showed that the ultimate tensile strength, yield strength and hardness of the composite are enhanced at the elevated temperature. However the impact energy was observed to decrease with increase in temperature.

Keywords

Silicon Carbide; Composite; Aluminum Alloy (6063); High Temperature; Volume Fraction.

Introduction

Silicon carbide particulate reinforced aluminum alloy composite (SiCp/Al) are low cost aluminum alloy composites made using irregular shaped particulates of silicon carbide in the range 3-200µm diameter. The particulates which are sometimes given a propriety coating can be mixed with the molten aluminum alloy and cast into ingot or extruded billet for further fabrication. There is a considerable interest in producing low cost aluminum alloy based composite with improved properties over the monolithic counterparts [1, 2].

Silicon carbide reinforced aluminum alloy has become one of the strongest candidates as structural materials for many high temperature and aerospace applications. The main objective of using silicon carbide reinforced aluminum alloy composite system is to increase service temperature and specific mechanical properties of structural components by replacing the existing super alloys. A good example of high temperature application of SiCp / Al is the use as an automobile engine component (connecting rod) [3], valves, camshafts, gear parts, suspension arms breaking system [2]. It also finds application as fan exit guide vanes (FEGV) of gas turbine [2].

Stir casting technique according to [4], is the most promising route for making particulate reinforced aluminum alloy composite because of its simplicity and adaptability to all shapes of castings. Hence its adoption in this research works. The work seeks to study the response of this composite to high temperature capabilities.

Materials and Method

Materials

A 15% volume fraction silicon carbide particulate aluminum alloy (6063) composite was used for this investigation. The equipment used includes a crucible furnace, stainless steel stirrer (powered by a motor), a thermocouple, heat treatment furnace, tensile, impact and hardness testing machines, tongues and an optical microscope.

Method

The composite was cast using an aluminum alloy (6063) with composition shown in table 1 and 15 % by weight of silicon carbide powder. 1 kg of the aluminum alloy was weighed and 150g of the silicon carbide was made available. A diesel fired crucible was used to melt the aluminum ingot. The alloy was heated to a temperature of 680°C (superheated). The heat input was then reduced by controlling the fuel and air supply to the furnace. The temperature was monitored to between 630°C and 650°C (liquid-solid phase) and then the already pre heated silicon carbide (preheated inside a heat treatment furnace to 1000°C) was quickly introduced into the melt and stirred vigorously. The melt was then reheated to 670°C and the mixtures also thoroughly stirred. The melt was then cast into rods of length 250mm and diameter 16mm inside already prepared metal moulds. The cast samples were then machined to tensile, impact and hardness test samples.

For room temperature tests, the samples were tested at room temperatures. But for the high temperature tests, the test samples were heated to 50°C above the test temperatures (100°C, 250°C, 400°C) to account for heat losses during transfer to the test machines from the reheating furnace. The samples were held at the test temperature for 30 minutes for homogeneity before transfer to the test machine. These were done for hardness, impact and tensile tests. For each test, three samples were used and the average values for each test was computed.

Results

The composition of studied aluminum alloy is presented in Table 1.

Table 1. Chemical composition of the aluminum alloy (6063)

Element	Composition	Element	Composition
Si	0.4430	Zn	0.0001
Fe	0.1638	Cr	0.0024
Cu	0.0041	Ti	0.0078
Mg	0.5832	Ca	0.0003
Mn	0.0132	Al	98.751

UTS as cast 162 N/mm^2;
Yield strength as cast 68 N/mm^2

The characteristics for 15% SiCp/Al composite at the test temperatures were graphically represented as follow: ultimate tensile strength (Figure 1), .yield strength (Figure 2), hardness (Figure 3), ductility (Figure 4) and impact energy (Figure 5).

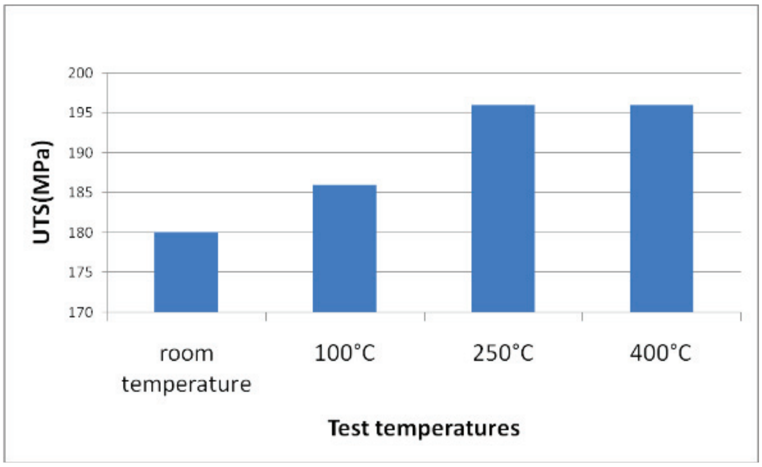

Figure 1. Ultimate Tensile Strength for 15% SiCp/Al Composite at the Test temperatures

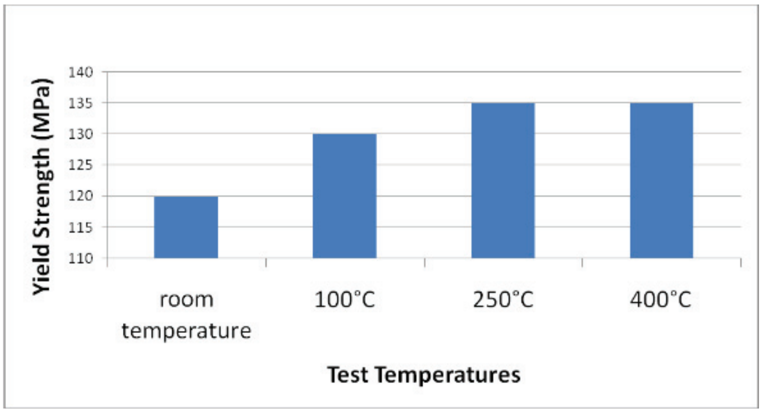

Figure 2. Yield Strength for 15% SiCp/Al Composite at the Test temperatures

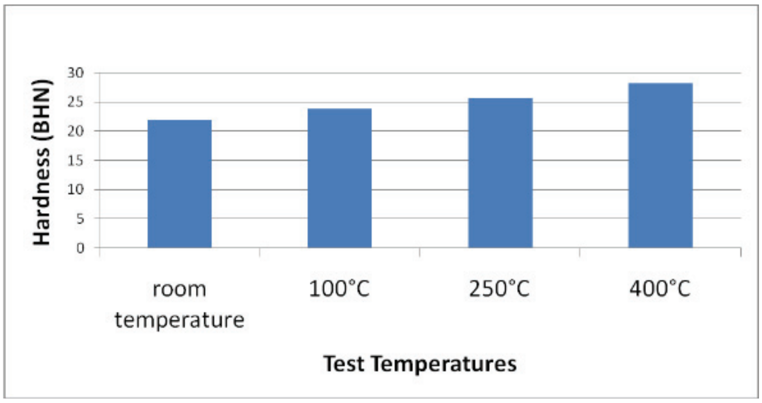

Figure 3. Hardness for 15% SiCp/Al Composite at the Test temperatures

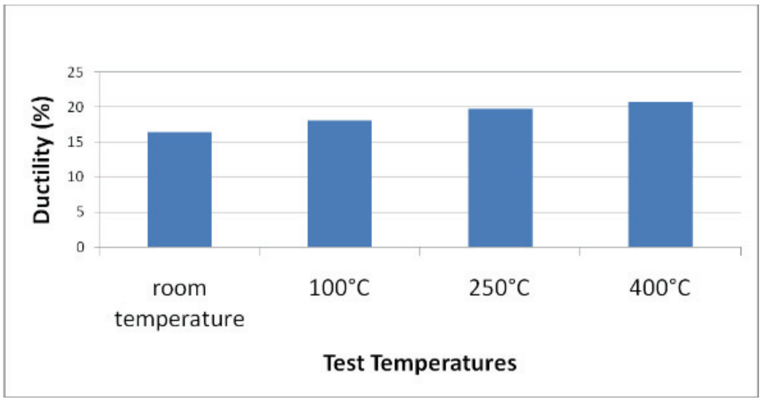

Figure 4. Ductility for 15% SiCp/Al Composite at the Test temperatures

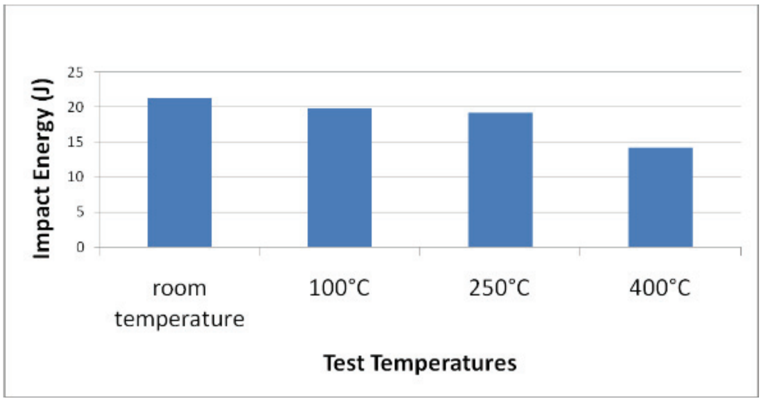

Figure 5. Impact Energy for 15% SiCp/Al Composite at the Test temperatures

From the micrographs in Figures 6-9 two distinct phases can be observed the dark phase revealing the silicon carbide phase and the grayish portion showing the aluminum alloy matrix.

Micrograph of sample at room temperature, Figure 6, shows a homogeneous distribution of phases due to the primary processing history.

Figure 6. As cast 15% Volume Fraction SiCp/ Al 6063 V Heated to 100°C. Etched in 190ml Distill Water, 6 ml HNO_3 acid and 4 ml HCl X100

At 100°C, Figure 7, the grain structures are fine. This must be due to recrystallization resulting from plastic deformation as a result of thermal expansion mismatch of the two phases.

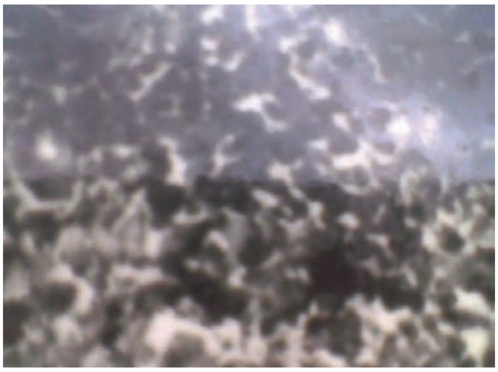

Figure 7. 15% Volume Fraction SiCp/ Al 6063 Heated to 100°C, Held for 30 minutes and Cooled in Air. Etched in 190 ml Distill Water, 6ml HNO_3 *acid and 4ml HCl X100*

Figure 8. 15% Volume Fraction SiCp/ Al 6063 Heated to 250°C, Held for 30 minutes and Cooled in Air. Etched in 190 ml Distill Water, 6ml HNO_3 *acid and 4 ml HCl X100*

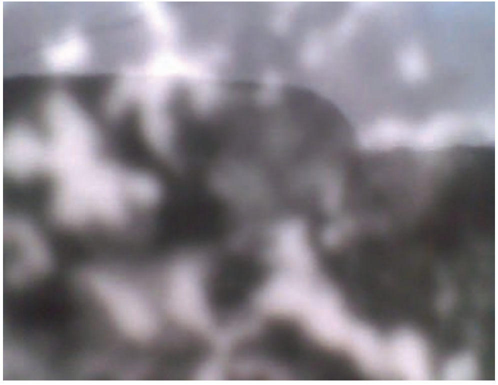

Figure 9. 15% Volume Fraction SiCp/ Al 6063 Heated to 400°C, Held for 30 minutes and Cooled in Air. Etched in 190 ml Distill Water, 6ml HNO_3 *acid and 4ml HCl X100*

As the temperature increases to 250°C and 400°C, Figure 8 and Figure 9, the grain sizes grow. This is more pronounced at 400°C, Figure 9. This growth must be due to the initial plastic deformation that occurred as a result of coefficient of mismatch of the two phases.

Discussion

It is observed that the tensile strength, yield strength, hardness and ductility of the Particulate Aluminum Matrix Composite (PAMC) show improvement with increase in temperature (Figures 1 to 4). Some factors are responsible for this behavior.

According to [5], by introducing insoluble particles such as Silicon Carbide into a metal matrix, the metal or alloy can be dispersion strengthened and thereby retaining its properties to temperature well above the normal softening temperature because dislocations are impeded from moving and softening by recrystallization and grain growth is prevented by the pinning effect of the particles [3], proved that the properties of the composite might be enhanced and that the enhancement might be due to the high value of dislocation density generated due to the difference in coefficient of thermal expansion (CTE) between the silicon.

Carbide particulates and the aluminum alloy matrix. The mismatch in the coefficient of thermal expansion between these two phases produced thermal stresses that can be sufficient to deform this matrix plastically. This leads to high dislocation density which invariably strengthens the composite material. This can be likened to the effect of cold working on metal or an alloy.

Also, according to [3], isothermal exposure at high temperature for a long time tends to induce a thicker reaction zone at the matrix - fiber / particulate interface, and since strength is also controlled by matrix fiber /particulate interfaces which consists of reaction bond strength, it means that the thicker the reaction zone (which depends on temperature and time) the better the strength of the composite material.

The enhancement in ductility of the material as shown in figure 4 can be seen from the fact that increases in temperature increases the ductility of most materials.

As observed in Figure 3, the hardness of this PAMC improves with increase in temperature. This can be seen from the fact that hardness and strength are linearly related.

Figure 5 shows the variation of impact strength with temperature. This shows that the composite material absorbs high impact energy at lower temperatures compare to when it is at high temperature.

This growth and the subsequent plastic deformation go simultaneously. The effect of this growth on mechanical properties of the composite has been counteracted by the effect of increase dislocation density and the increase in density of the material. Hence the enhancement of the mechanical properties at elevated temperatures.

Conclusions

It has been established that the silicon carbide PAMC shows good mechanical properties at elevated temperature. The yield strength, ultimate tensile strength, hardness and ductility show stability and slight improvement at higher temperature suggesting that this material has high temperature capabilities. The only property that decline with increase in temperature is the impact strength.

From the foregoing, silicon carbide PAMC apart from its high specific strength and high specific modulus is also suited for high temperature applications.

References

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