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Effect of Magnesium Addition on Fracture Toughness in Aluminium Silicon Carbide Metal Matrix Composite

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Abstract

Metal matrix composites are composites in which one component will be a metal and other metal or non metal. Among them Aluminium Silicon Carbide composites has wide application in various fields like automobile, aerospace and marine engineering etc. Earlier studies revealed that as the percentage of Silicon Carbide in Aluminium Silicon Carbide composites increases the properties like tensile strength, hardness and wear resistance etc gets also increases up to a limit but it decreases the fracture toughness. Since metal matrix composites have wider applications which require higher fracture toughness, which is the ability to resist failure due to crack propagation. In this work, Aluminium Silicon Carbide composites with different Magnesium contents were successfully fabricated by stir casting technique and the effect of Magnesium content on the fracture toughness of the metal matrix composite were investigated.

Key words: *metal matrix composites, SiC, Al-Mg alloy, Fracture Toughness, Stress Intensity Factor.*

1. Introduction

Metal matrix composites are metals reinforced with other metal, ceramic or organic compounds. They are made by dispersing the reinforcements in the metal matrix. Reinforcements are usually done to improve the mechanical properties of the base metal. Aluminium Silicon Carbide composites have emerged as a class of materials suitable for structural, aerospace, automotive, electronic, and wear applications owing to their advantages over the conventional monoliths. These advantages include high specific strength, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity. These properties are obtained through addition of alloy elements, cold working and heat treatment.

Among the variety of manufacturing processes available for metal matrix composites, stir casting is generally accepted as a particularly promising route. Its advantage lies in its simplicity, and applicability to large quantity production. In general, the solidification synthesis of metal matrix composites involves producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention, including (a) The difficulty of achieving a uniform distribution of the reinforcement material, (b) Wettability between the two main substances, (c) Porosity in the cast metal matrix composites [5]. In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, the wettability or bonding between these substances should be optimised and the porosity levels need to be minimised.

Wettability can be defined as the ability of a liquid to spread on a solid surface. It also describes the extent of intimate contact between a liquid and a solid. Successful incorporation of solid ceramic particles into casting requires that the melt should wet the solid ceramic phase. The basic means used to improve wetting are, (a) increasing the surface energies of the solid, (b) decreasing the surface tension of the liquid matrix alloy, and (c) decreasing the solid-liquid interfacial energy at the particles-matrix interface [3].

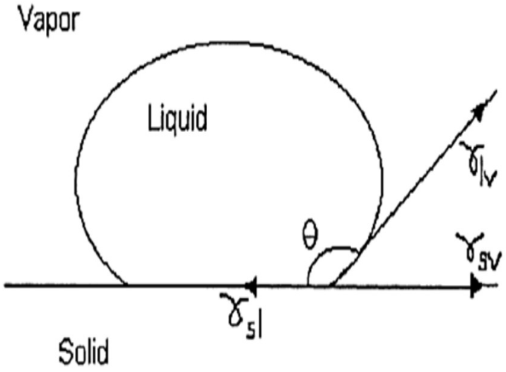

Fig 1: Schematic diagram showing the contact angle that describes wettability

The magnitude of the contact angles (θ) as shown in Fig: 1 describes the wettability, i.e. (a) $\theta = 0^{O}$, perfect wettability, (b) $\theta = 180^{O}$, no wetting, and (c) $0^{O} < \theta < 180^{O}$, partial wetting [5], where 'γ_{sv}' is the interfacial energies of solid and vapour, 'γ_{sl}' is the interfacial energies of solid and liquid and 'γ_{lv}' is the interfacial energies of liquid and vapour.

The addition of certain alloying elements, such as Magnesium, Calcium, Titanium and Zirconium can increase the wettability between the matrix and reinforcement by producing a transient layer between the particles and the liquid matrix. This transient layer has a low wetting angle, decreases the surface tension of the liquid, and surrounds the particles with a structure that is similar to both the particle and the matrix alloy [3]. Thus composites produced by adding alloying elements shows excellent bonding between the matrix and the reinforcement which increases the mechanical properties including fracture toughness. Alloying elements are selected based on their effects and suitability. However, the effect of Magnesium additions on fracture toughness in Aluminium Silicon Carbide Metal matrix composites has not yet been studied experimentally. This research aims at the effect of the Magnesium addition on the fracture toughness in Aluminium Silicon Carbide Metal matrix composites and to find the best percentage of magnesium which yields the higher fracture toughness.

2. Experimental procedure

2.1 Raw materials

Aluminium LM6 alloy with 20 vol.% of Silicon carbide powder (20μm size) with varying percentage of magnesium powder (purity of 99.7%) 0 wt.%, 0.6 wt.%,0.8 wt.%, 1 wt.%, 1.2 wt.%

2.2 Experimental Methodology

Aluminium Silicon Carbide metal matrix composite is prepared by stir casting process. First the scraps of aluminium have to be preheated for 3 to 4 hours at 450°C and silicon carbide also with 900°C. At first heater temperature is set to 500°c and then it is gradually increased up to 900°C. High temperature of the muffle helps to melt aluminium quickly, reduced oxidation level, enhance the wettability of the reinforcement particles in the matrix metal. Required quantity of aluminium alloy is taken and cleaned to remove slag and kept in the crucible of stir casting machine and when the temperature of the liquid Aluminium reaches 750°C, Magnesium powder has to be added in the melt. Magnesium is taken in quantity as to make different proportion or percentages. Then the heat treated Silicon Carbide particles is allowed to fall into the molten metal continuously through a funnel. Temperature of the heater is set to 630°C which is below the melting temperature of the matrix. An electrical resistance furnace assembled with graphite impeller used as stirrer was used for stirring purpose. A uniform semisolid stage of the molten matrix was achieved by stirring it at 500 rpm. Pouring of preheated reinforcement at the semisolid stage of the matrix enhance the wettability of reinforcement, reduces the particle settling at the bottom of the crucible. After stirring for 5 minutes at semisolid stage slurry was reheated and hold at a temperature 900°C to make slurry in liquid state. Stirrer rpm was then gradually lowered to the zero. The molten composite slurry is then poured in to the metallic mould which is preheated at temperature 500°C this makes sure that the slurry is in molten condition throughout the pouring. While pouring the slurry in the mould the flow of the slurry is kept uniform to avoid trapping of gas. Then it is quenched with the help of air to reduce the settling time of the particles in the matrix and to avoid oxidation.

After the required casting pieces are made, it has to be shaped according to the dimensions of ASTM E399 standard as shown in fig 2, which is commonly used for testing of fracture toughness. Two holes are to be drilled and a v grove is to be made in the test pieces which act as an initial crack.

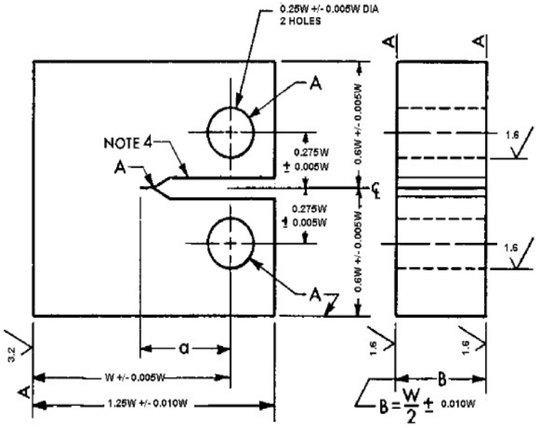

Fig 2: Compact tensile Specimen - Standard Proportions and Tolerances

2.3 Experimental testing

After the standard test piece is being made it is to be tested for finding fracture toughness. As fracture toughness cannot be found directly as a value, stress intensity factor is used for predicting the fracture toughness for that the maximum load that the test pieces will resist the crack propagation without failure has to be found out. As per the definition for fracture toughness it is the ability of a material which is having a crack to resist the propagation of the crack. In the test piece prepared groove prepared will act as initial crack and the load is applied till what load it can withstand without failure. Universal Testing Machine is used for testing. The fixtures for clamping the required test piece are fixed to the test piece with nut and bolt and then these fixtures are clamped on to the jaws of the machine. After setting the test piece properly, the load is given. By gradual loading the load at which test piece fails to resist crack is found out and recorded. The value is noted for all iterations.

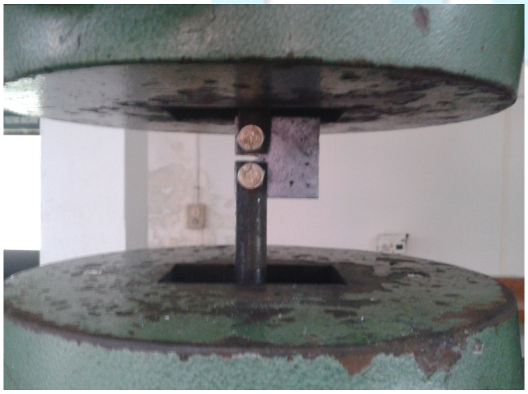

Fig 3: Test piece fixed in Universal Testing Machine

3. Results and Discussion

The results for experimental method have to be calculated using the formulae for finding the stress intensity factor.

This maximum load and dimension of standard piece are used to find out the stress intensity factor

Stress intensity factor, K uniquely determines the magnitude of stress in the crack tip region and strain energy available for crack extension. The fracture occurs when K reaches a critical value. In other words, if we measure the value of critical K in a laboratory specimen we can use it to predict when fracture will occur in a component, the critical value of K at fracture is a material property. On the other hand applied value of K is dependent on the applied load, the geometry and crack size. When applied K is equal to or greater than critical k, fracture occurs.

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Stress intensity factor is calculated in SI or inch-pound units of Pa√m (psi√in.) as follows

$$K_{IC} = \frac{P}{\sqrt{B X \sqrt{w}}} * f\left(\frac{a}{w}\right) \qquad (1)$$

Where,

$$f\left(\frac{a}{w}\right) = \frac{\left(2+\frac{a}{w}\right)\left[0.886+4.64\frac{a}{w}-13.32\left(\frac{a}{w}\right)^2+14.72\left(\frac{a}{w}\right)^3-5.6\left(\frac{a}{w}\right)^4\right]}{\left(1-\frac{a}{w}\right)^{3/2}} \qquad (2)$$

P = force as determined in Newton
B = specimen thickness as determined in metre
w = specimen width (depth) in metre
a = crack size in metre

Table 1: Result obtained from experiments

Sl No	Percentage of Mg (wt. %)	Stress intensity factor (MPa√m)
1	0	18.40
2	0.6	22.66
3	0.8	23.69
4	1	24.45
5	1.2	23.97

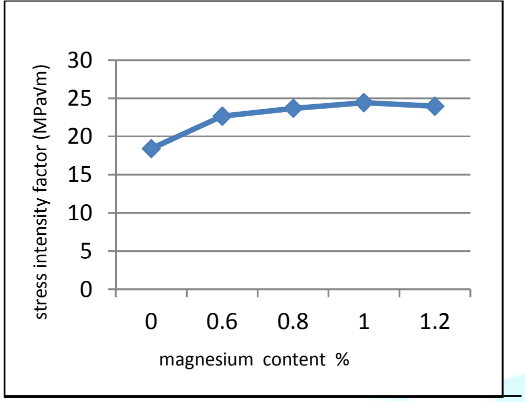

Fig 4: stress intensity factor vs. magnesium content

4. Conclusion

The objective of the study was to find the effect of magnesium addition in aluminium silicon carbide metal matrix composite and to find the optimum value of magnesium which yields the higher fracture toughness. Aluminium silicon carbide with different percentage of magnesium was prepared by stir casting and castings were shaped according to the ASTM E399 standard which is commonly used for testing of fracture toughness. As fracture toughness cannot be found directly as a value, stress intensity factor is used for predicting the fracture toughness. All the test pieces were tested in UTM and by using the maximum load which required for breaking the test piece, the stress intensity factor was found out. It was found that the fracture toughness of test pieces increases as magnesium content increases up to 1 wt. %. Further addition shows reduction in fracture toughness and the reason for the reduction is a scope for further research

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