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Silicon Carbide Particle Reinforced Aluminum Matrix Composite Prepared by Stir-Casting.

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Abstract

The developed aluminum matrix composite (AMCs) is considered to be a promising material for low and high temperature applications. Particles reinforced AMCs materials have high specific strength and modulus of elasticity, together with excellent heat resistance.

Silicon carbide particles reinforced aluminum matrix composite (AMCs) for hardness, impact strength, and material toughness improvement were prepared. Stir-casting processing was optimized. The hardness, impact strength, and material toughness were evaluated. Under stir-casting, the silicon carbide particles were uniformly distributed in the aluminum and well bonded with aluminum matrix. The hardness and material toughness were increased 1.84 and 2.16 times respectively at particles weight fraction (10%) that of the of the unreinforced aluminum based on the high hardness and deformation resistance of the silicon carbide particles.

Main Words: Stir-casting, silicon carbide, particle reinforcement, composite, aluminum.

الخلاصة

تعتبر المواد المركبة المتقدمة ذات الأساس المكون من معدن الألمنيوم (AMCs) من المواد المهمة في التطبيقات ذات درجات الحرارة المرتفعة والمنخفضة. تمتاز هذه المواد (AMCs) بامتلاكها مقاومة نوعية ومعامل مرونة نوعي عالي مقترنة بمقاومة جيدة لدرجات الحرارة المرتفعة.

تم تحضير مادة مركبة ذات أساس ألمنيوم مدعم بدقائق كاربيد السليكون بهدف تحسين الصلادة ومتانة المادة المركبة. اعتمدت طريقة السباكة بالخلط في اسلوب التحضير، حيث توزعت دقائق كاربيد السليكون بانتظام في مادة الأساس (الألمنيوم). إذ ارتبطت الدقائق بشكل جيد مع مادة الأساس. ازدادت الصلادة ومتانة المادة بمقدار(1.84 ، 2.16) مرة على التوالي وبنسبة تقوية وزنية (10%) بالمقارنة مع معدن الألمنيوم غير المقوى. وهذا يعود إلى الصلادة العالية ومقاومة التشوه الجيدة التي تمتاز بها دقائق كاربيد السليكون.

الكلمات الرئيسية: السباكة بالخلط ، كاربيد السليكون، التقوية بالدقائق، المادة المركبة، كاربيد السيليكون.

1. Introduction

Aluminum and its alloys possess excellent properties such as low density, good plasticity and ductility, and good corrosion resistance. They find extensive applications in aeronautics, astronautics, and automobile and high speed train fields. However, low hardness and poor impact resistance results in their limited application in heavy duty environments. So it is important to develop used processing and technology for improvement of mechanical properties (Surappa, 2003).

It has been proved that particle reinforced aluminum matrix composites can improve considerably the strength and hardness of aluminum and its alloys. However, at the same time, the plasticity and ductility can substantially reduced. This will severely affect the safety and reliability of components fabricated from Al matrix composites (AMCs) (Yano et. al.,1992).

In aluminum matrix composites system (AMCs), one of the constituent is aluminum/ aluminum alloy, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminum/ aluminum alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al_2O_3. Properties of AMCs can be tailored by varying the nature of constituents and their volume fraction (Rohatgi et. al., 1986).

Aluminum matrix composites system (AMCs) offer superior combination of properties in such manner that today no existing monolithic material can rival. Over the years, AMCs have been tried and used in numerous structural, non-structural and functional applications in different engineering sectors. Driving force for the utilization of AMCs in these sectors include performance, economic and environmental benefits. The key benefits of AMCs in transportation sectors are lower fuel consumption, less noise and lower airborne emissions (Marchi et. al., 2003).

AMCs can be classified into four types depending on the type of reinforcement (Filmier et. al., 2008):

- ❖ Particle reinforced AMCs (PRAMCs)
- ❖ Whiskers or short fiber reinforced AMCs (SFAMCs)
- ❖ Continuous fiber reinforced AMCs (CFAMCs)
- ❖ Mono filament-reinforced AMCs (MFAMCs)

New and high performance particle reinforced AMCs (PRAMCs) are expected to satisfy many requirements for a wide range of performance-driven, and price sensitive, applications in aerospace, automobiles, bicycles, golf clubs, and in other structural applications. A PRAMCs consists of a uniform distribution of strengthening ceramic particles embedded within aluminum matrix. In general, these materials exhibit higher strength and stiffness, in addition to isotropic behavior at a lower density, when compared to the un-reinforced aluminum matrix. PRAMCs benefits from the ceramic's ability to withstand high velocity impacts, and the high toughness of the metal matrix, which helps in preventing total shattering. This contribution leads to an excellent balance between cost and mechanical properties, which are appealing for much application; the main drawback of these materials is their low ductility, which is caused by the nucleation, growth, and coalescence of voids created by the ceramic reinforcement (Al- Dheylan and Hafeez, 2006).

The main contribution to the strengthening of PRAMCs is particle addition, which affects most of the mechanical properties of PRAMCs. Several particle parameters, which are critical in determining the mechanical properties of PRAMCs, include the volume fraction (v_f), size, shape, and distribution of reinforced particles within the metal matrix. The most influential among these parameters is (v_f) (Sohn et. al., 2003).

This work aims to prepare and studying mechanical properties (Vickers micro hardness, impact strength, and material toughness) of aluminum matrix composite material reinforced by (5, 7, and 10 wt. %) silicon carbide particles using stir casting method.

2. Theoretical View

Fracture mechanics can be defined as material breaks into two parts due to the effects of external forces. Griffith was the first person who fixed the basic principles of fracture mechanics by energy balance theory. Griffith studies the process, which occurred to the crack by reverse thermodynamics process. He supposed existence of static equilibrium condition for crack through the effects of energies given by equations 1 and 2 (Boresl and Schmidt, 2002):

$$U = (-W_L + U_o) + U_S \qquad (1)$$

Where W_L: External performed work on system.

U_o: Saved energy in system.

U_S: Required energy to create new surface (free surface energy).

U: External impact energy.

Therefore, fracture mechanics is calculated from impact energy (U) if engineering sample dimensions and crack depth (a) are measured. When crack growth occurred,

malleability will increase for material according to the value of saved energy, therefore if malleability changes and crack depth (a) are known, absorbed energy is calculated by the following equation

$$U = \frac{1}{2} P^2 C \qquad (2)$$

Where P: applied load in Newton
  C: malleability.
If sample width is B in meter then:

$$G_c = \frac{1}{B} \frac{dU}{da} \qquad (3)$$

$$G_c = \frac{1}{B} \frac{dU}{dC} \frac{dC}{da} \qquad (4)$$

Where: G_C is material toughness when crack occurred.
This term (G_C) is one of the material properties, and it is regarded as absorbed energy by crack unit area, also it represents released critical strain energy, which is given by the following equation:

$$G_c = \frac{P^2}{2B} \frac{dC}{da} \qquad (5)$$

From equations, two and five, absorbed energy is calculated by impact test:

$$U = G_C B \frac{C}{dC/da} \qquad (6)$$

Practically, U is calculated for different crack depths.

$$G_c = \frac{U}{BDC} \frac{dC}{d(a/D)} \qquad (7)$$

Where D: Sample thickness in meter.
So, engineering configuration function Φ is given by malleability C:

$$\Phi = \frac{C}{dC / d(a/D)} \qquad (8)$$

So equation 8 can be solved to calculate material toughness G_C:

$$U = G_C BD\Phi \qquad (9)$$

$$\boldsymbol{\Phi = 0.135\ (a/D)^{-0.77}} \qquad \textbf{(10)}$$

The relationship between absorbed energy (U) and engineering configuration function (Φ) is linear, and the slop of this line is material toughness **G_C** (Boresl and Schmidt, 2002):

3. Experimental Work

3.1. Preparation of Composite Samples

Stir- casting was used here in preparing composite samples (Fig.1). This method could distribute silicon carbide particles homogenously in the aluminum microstructure by forming vortex in molten metallic. It could pull silicon carbide particles through molten metallic and distributed them homogenously. Stir- casting improve mechanical and physical properties of the aluminum matrix.

Matrix material (aluminum, assay 99.9%, supplied from universal company of electrical industries) cut into small pieces to obtain the required weight according to reinforcement silicon carbide particles weight fraction (5, 7, and 10 wt. %)[silicon carbide powder- (50- 100μm)- supplied from BDH Chemicals Ltd. Poole England].

Pre-weighted samples were putted in alumina pots, and then inserted in Carbolite tube furnace setting at 700 °C to ensure melting of the sample.

To ensure the homogeneity of the added silicon carbide particles through molten aluminum, electrical mixer was inserted into alumina pot, which is kept in the Carbolite tube furnace at 700°C . Molten aluminum was stirred at (900 r.p.m.) to get suitable vortex. Later silicon carbide particles were added to molten metal. This process was followed to modify reinforcement particles distribution through the molten aluminum.

Due to the vortex effect, silicon carbide particles were pulled inside the molten metal and uniformly distributed. Molten aluminum was stirred for (1- 5 min.) until the molten aluminum becomes slurry. Later molten aluminum was poured into suitable stainless steel mould, which is preheated at 250°C to prevent sudden cooling for molten aluminum.

This process was repeated several times according to reinforcement particles ratio. It was noted obviously increasing in slurry viscosity especially at 10wt. % silicon carbide particles. This phenomenon requires long stirring time to overcome the difficulties in casting process.

3.2.Samples Preparation
3.2.1.Impact Test Samples

Impact test samples were prepared according to ISO-179. Aluminum samples without and with reinforcement silicon carbide particles at (5, 7, and 10 wt. %) using (Charpy Impact Test).

3.2.2.Hardness Test Samples

All samples were subjected to Vickers micro hardness test using Micro hardness Tester HV 1000, where the average indentation diameter d (mm) were recorded. Micro hardness was calculated according to the following eq.(Itsukaichi et. al., 1992):

$$HV=1.854 \, L/ d^2 {}_{av.} \qquad (11)$$

Where L: Applied load (kg / mm).
Vickers micro hardness test was repeated several times to evaluate micro hardness average value.

4.Results and Discussion

Fig. 2 shows the effect of silicon carbide particles on aluminum hardness, the result show that, hardness increasing with increase reinforcement weight fractions. It reaches maximum micro hardness value (243) at 10 wt. silicon carbide particles. This is due to the high hardness values of silicon carbide particles in comparison with aluminum hardness and to the good bonding between the reinforcement particles and matrix phases.

Fig. 3 shows the microstructure of the stir-casting samples. It can be seen that the silicon carbide particles (5 wt. %) are distributed uniformly and well bonded with the aluminum matrix. From Fig.4 it can be seen that as the SiC particles content increases up to (10 wt. %), the microstructure became dense and darker. But the distribution of reinforcement particles still uniform and in good bonding with aluminum matrix.

The presence of silicon carbide particles in the microstructures could impede the movement of dislocations since these particles are stronger than the matrix in which they are embedded. The degree of strengthening produced also depends on the size of particles, their distance apart and the tenacity of the bond between particles and matrix. Since that the particles are stronger than the matrix, the dislocation cannot pass through them, but if the stress is high enough, the dislocation can by-pass them leaving a dislocation loop around each particle. This will make the passage of a

second dislocation much more difficult, particularly since dislocations have greater difficulty in passing between particles which are near to each other (Higgins ,2006)

Fig. 5 illustrates the effect of added silicon carbide particles in different weight fractions (5, 7, and 10 wt. %) to aluminum metal on impact energy (joule). It can be concluded that impact energy was increased with increasing SiC particles weight fractions up to (10 wt. %). Reinforcement particles act as strong obstacle against cracks propagation and this will tend to change crack shape and direction. Then this crack will transform into secondary cracks. Change in crack shape and direction leads to increase crack surface area and consumed fracture energy. All these factors tend to increase composite strength especially in case of good bonding between reinforced particles and matrix (Hanan et. al., 2005).

Further, Fig. 5 showed impact energy (U) variation with engineering configuration function (BDΦ) at variable crack depth (a) under selected reinforcement weight fraction of (5, 7, 10) %. It's clear that impact energy was decreased with increasing of crack depths. This is due to decreasing cross section area of sample under shock test. Results indicated that impact strength was increased by a ratio of (2.16%) in case of reinforced by silicon carbide weight fraction (10 wt. %).

Table 3 showed material toughness of prepared samples. The toughness G_C of composite (like that of any other material) is a measure of the energy absorbed per unit crack area. Material toughness (G_C) was calculated for each sample from the tendency of linear relationship between fracture energy (U) and engineering configuration coefficient BDΦ (Fig. 5). Results showed that maximum toughness was found in case of reinforced aluminum by 10 wt. % silicon carbide particles (489.7 kJ/m^2).

5.Conclusions

Silicon carbide particle reinforced aluminum matrix composite (AMCs) were prepared by stir-casting with different particle weight fraction (5 ,7, and 10%).the following conclusions can be drawn:

❖ The hardness, impact strength, and material toughness of (AMCs) are much better than the aluminum metal.

❖ In case of increased silicon carbide content, the hardness, and material toughness are enhanced, they are 1.84 and 2.1 times higher than that of the un reinforced aluminum at silicon carbide weight fraction (10%).

❖ The mechanical properties improvements are mainly due to the highly hardness silicon carbide particles.

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Table 1: Material toughness values for Aluminum samples with and without reinforcement silicon carbide particle at (5, 7, and 10wt. %).

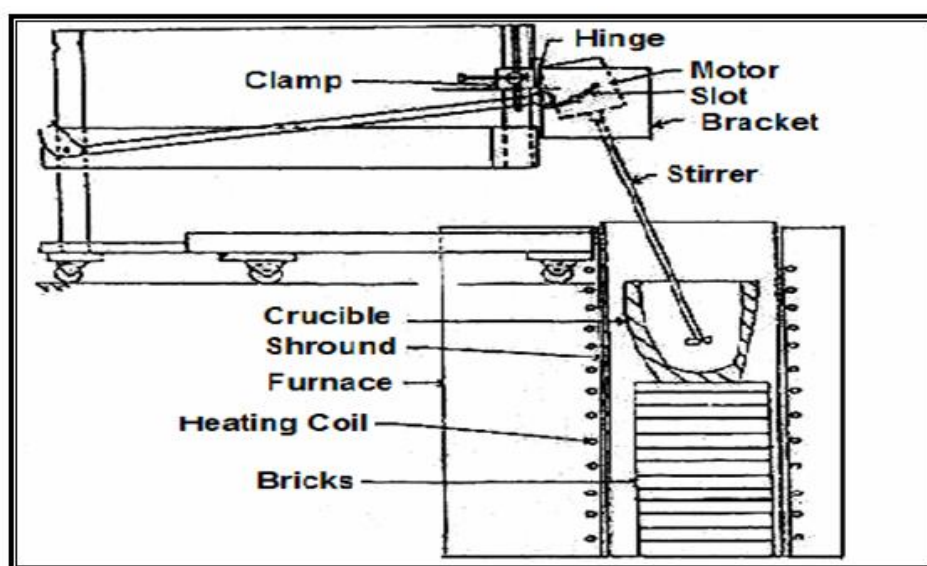| Material	Toughness (kJ /m^2)
Al	225.8
Al+5%SiC	356.4
Al+7% SiC	431.9
Al+10% SiC	489.7

Fig. 1:Stirring casting technique (Lioyd et. al.,1989).
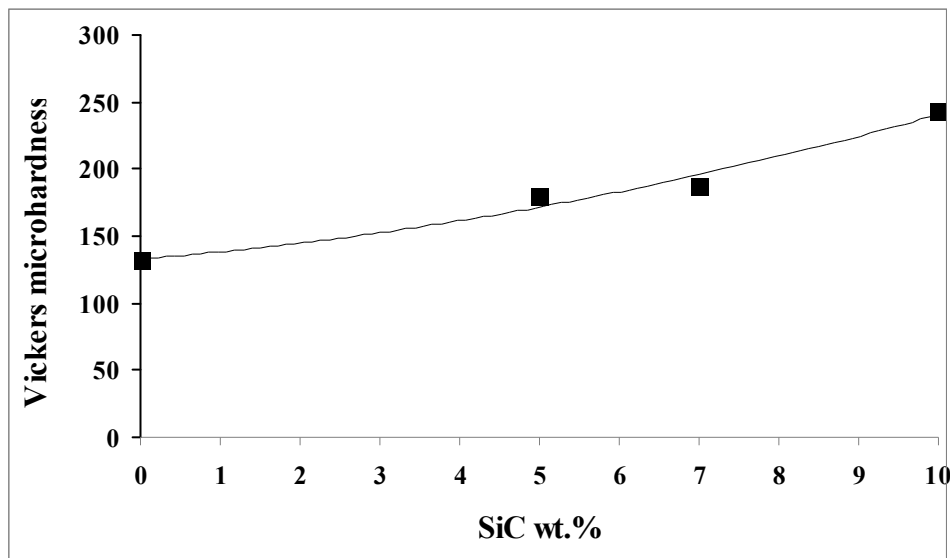

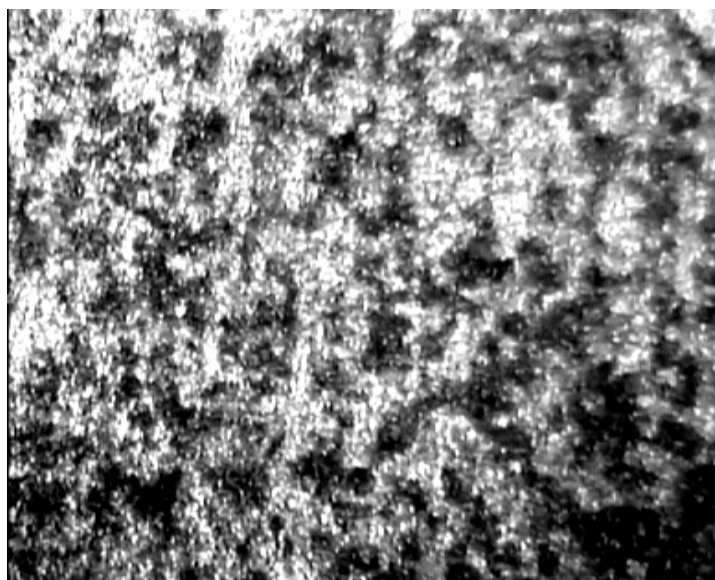**Fig. 2:Relationship between Vickers micro hardness and (SiC wt.%)**

Fig. 3:Light optical microscope image of AMCs reinforced by 5 wt.% SiC(Magnification 400X)

**Fig. 3:Light optical microscope image of AMCs reinforced by 10 wt.%
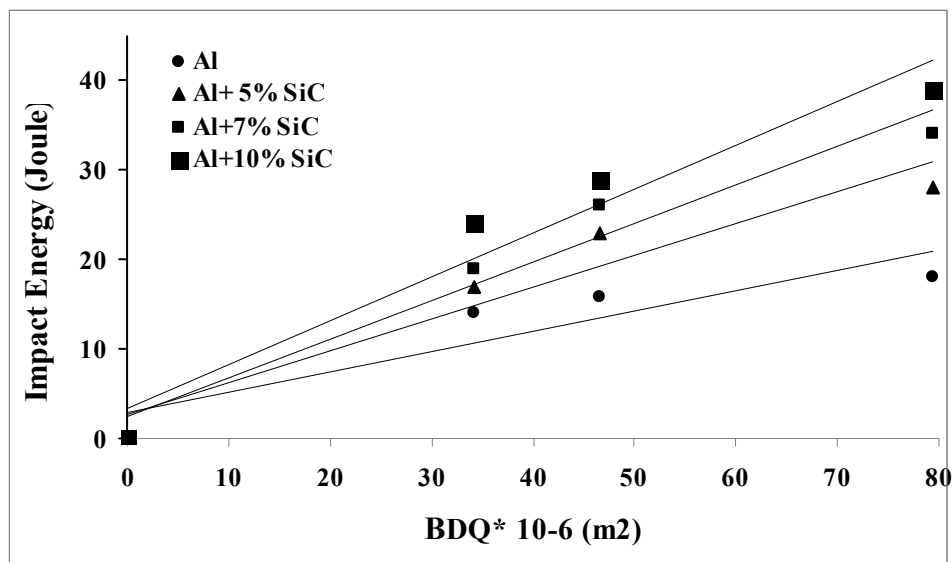SiC(Magnification 400X)**

Fig. 5: Relationship between impact energy and BDΦ