Effect of SiC particulates on fracture toughness of an Al-1.5% Mg matrix composite.

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Abstract:

The fracture toughness of the SiC-Al-1.5%Mg PMMCs has been studies. The MMCs were prepared by conventional method's the stir cast. The SiC preheated particle content was varied from 2, 4, 6 to 8 wt% and their average size was 53μm. we have noticed that the fracture toughness was decreased due to the increase in SiC wt%. Also the hardness has been investigated and show the hardness of the composite material was increased with the increases in the SiC wt%.

The X-ray diffraction test was also investigated to the matrix alloy, SiC particle and the reinforcement material in order to study the phases which are produced into the MMCs structure. Its show that there is good contact has been produced between them.

Keywords: Aluminum/SiC composites; fracture toughness; stir cast; MMCs

Introduction:

Metal-matrix composites (MMCs) are engineered combinations of two or more materials (one of which is a metal) in which tailored properties are achieved by systematic combinations of different constituents. Combinations of strength, stiffness, coefficient of expansion, and low density, because the metal-matrix composites are used in structural applications, and in applications requiring wear resistance, thermal management, and weight savings. By far the most common commercial MMCs are based on aluminum, magnesium, and titanium alloys reinforced with silicon carbide (SiC), alumina (Al_2O_3), carbon, or graphite. Both continuously and discontinuously reinforced MMCs are used in structural applications; but the Aluminum- reinforced composites are a range of advanced materials providing properties heithertofore not achieved by conventional materials, due to the excellent mechanical properties of Aluminum- reinforced composites and the relatively low production cost make them very attractive for a variety of applications. Also it has a high strength to weight ratio, and therefore are increasingly used in automotive and aerospace structures [1] [2].

Aluminum Particulate reinforced metal matrix composites (Al-PRMMCs) are classical examples of ductile/brittle two-phase materials, in which a ductile matrix is combined with rigid and brittle ceramic particles, generally with a goal of producing a lightweight material that is stiff and strong with attractive physical properties. The major drawbacks of these materials are associated with their relatively poor fracture properties [3]. The addition of second phase can result in loss of tensile ductility, lower fracture toughness. And an increase in density, specific properties of the composite are usually improved enough to provide considerable weight savings potential in load bearing and high temperature applications, In particular, they offer widespread potential due to their essentially isotropic properties and substantially improved strengths and stiffnesses compared to unreinforced alloys. [4][5][6] [7][8][9][10]. Particle size for the brittle ceramic particles is assumed to be another key factor for a given volume fraction and matrix property [11]. The decreasing of particle size, the bonding strength of the composites increases, while the fracture toughness of the composites decreases, [12]. Due to the low weatablity between the brittle ceramic particle and the matrix alloy, so that some of alloying elements are used one of them is the magnesium. The purposes of Mg additions are manyfold:

i. Enhance the wetting behavior with the SiC particles (particularly important for pressureless infiltration).[13]
……
ii. The formation of spinel (MgAl2O4) or MgO at the interface of oxidized SiC particles thus protecting the SiC particles from reaction with Al.
iii. Enhance the interfacial bonding.
iv. Strengthening of the Al matrix (by solid solution hardening)

$$2Al + 2Mg + 2SiO_2 \rightarrow MgAl2 + 2Mg_2Si \quad \ldots\ldots\ldots(1)$$

$$4Mg + SiO_2 \rightarrow 2MgO + Mg_2Si \quad \ldots\ldots\ldots(2)$$

Mg acts solely as solid solution hardening element; at contents below 4wt% it does not form any intermetallic phase with Al. Mg is prone to react with Al. Mg is prone to react with SiC and its surface oxide SiO_2 , Thus influencing the interfacial bonding strength and to enhance interfacial bonding between Al and SiC [14]. In regard to the reaction between SiC and aluminum, the following reaction between SiC and aluminum, the following reaction equation is usually considered,[15]

$$3SiC(s) + 4Al(l) \rightarrow Al_4C_3(s) + 3Si(s) \quad \ldots\ldots\ldots\ldots(3)$$

Experimental procedure:

The matrix alloy of the composites was pure aluminum. The matrix alloys were reinforced by SiC particles (2, 4, 6 and 8%) were added by mechanical stirring method. the melted aluminum was degassed with nitrogen. the preheated SiC particles at 300^{o}C were introduced into the molten metal and stirred continuously by using mechanical clay coated stirrer at 750^{o}C to about 5-10

minutes at an average stirring speed of 500 rpm. Before stirring magnesium was added in square pieces to increase the wettablity of SiC particle with taking into account the reaching to 1.5% in Mg. Preheated cylindrical permanent steel mould was used, the mould temperature was 50°C. The pouring temperature was controlled to be around 750°C. In all experiments 500 gm of aluminum alloy was melted in electrical furnace using alumina crucible.

Results:

In this test were used Charpy-Impact instrument for standard matrix specimen and reinforcement specimen the notch depth was 2mm according to (Bs-131)

The equation which is used in the calculation the impact toughness:

$$\delta = \frac{E}{A} = \frac{WL(cos\alpha_1 - cos\alpha_2)}{A} \quad \text{.....(4)}$$

Where:

δ = the impact strength ($\frac{KJ}{m^2}$).

E = impact energy (J) or (KJ).

W = the load (25.9Kg).

L = the length of pendulum arm (75cm).

α_1 = the Impact angle.

α_2 = the angle of the pendulum arm at upper position(141.5°).

A = the area cross section at the notch(0.8cm^2).

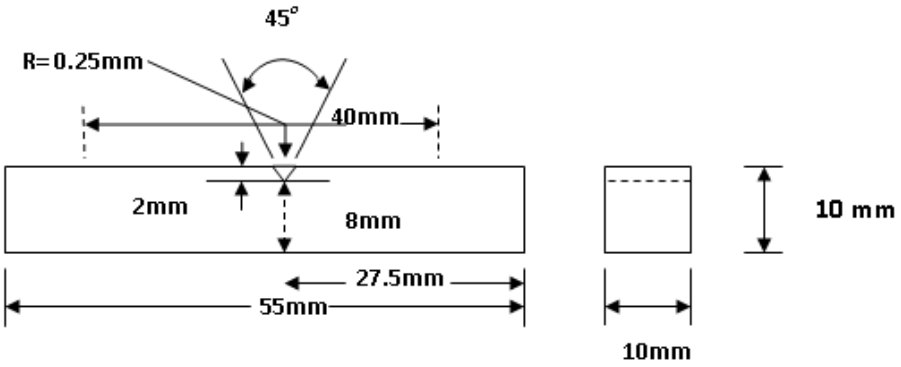


Fig.(1) Standard specimen for the Charpy impact test

Table (1) the result of Impact test for matrix and reinforcement material:

SiC %	E (J)	δ ($\frac{KJ}{m^2}$)
0	3.22	40.25
2	2.55	31.875
4	2.09	26.125
6	1.78	22.250
8	1.08	13.5

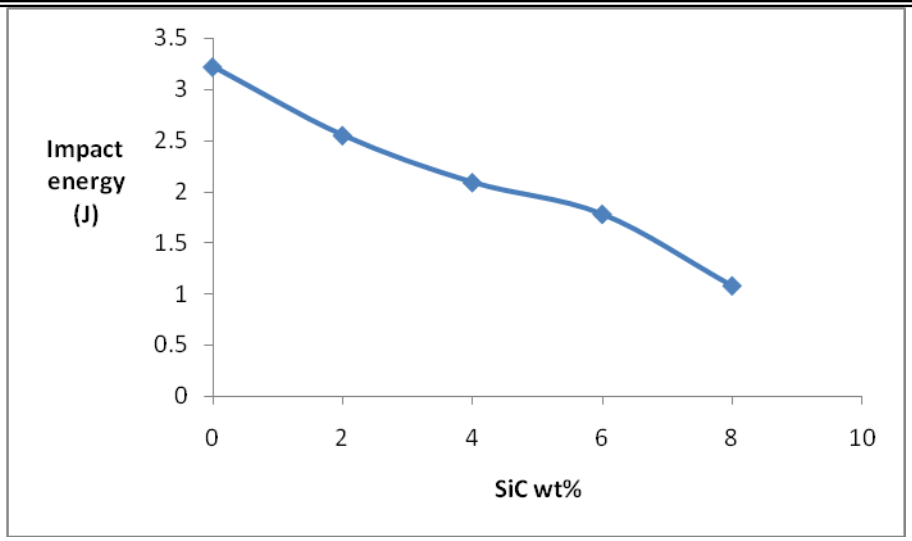


Fig.(2) variation in the impact energy with different wt% of SiC

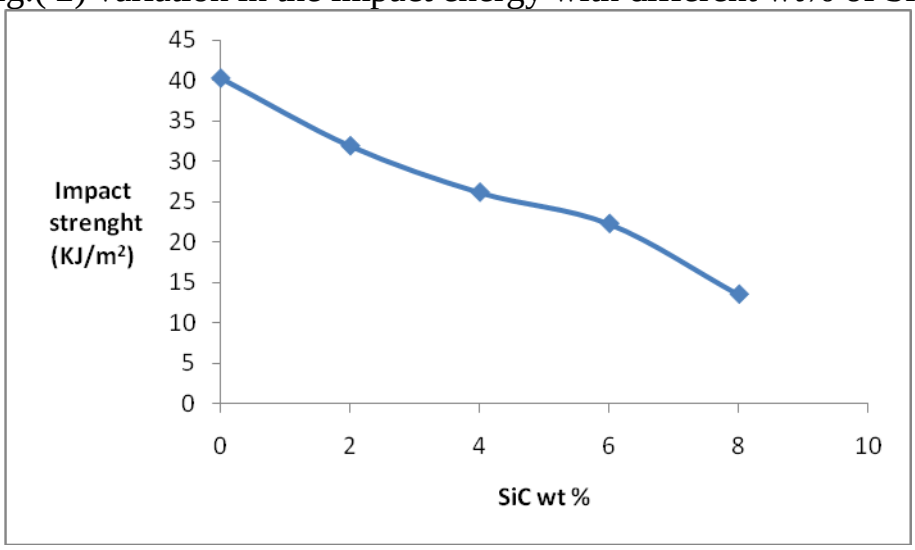


Fig.(3) variation in the impact strength with different wt% of SiC

It is one of the most simple and rapid means of determining the mechanical behavior of materials by measurement of hardness [16]. The hardness of each sample was measured by using Brinell hardness apparatus, hardness measure by used 10mm ball which is forced into the surface of material to be tasted under load of 500kgf exerted for 30 seconds with Thickness of the specimen more than ten times the depth of impression. Three measurements at the bottom, intermediate and top sections of the samples were taken and then averaged to obtain the mean value for every section.

$$BHN = \frac{2P}{\pi D\left[D-\sqrt{D^2-d^2}\right]} \qquad \text{.....(5)}$$

Where:

P = applied load in kg.

D = diameter of ball in mm.

d = diameter of indentation in mm.

Table (2) the result of hardness for matrix and reinforcement material

SiC %	HB
0	55
2	60.7
4	63.6
6	66.7
8	70.5

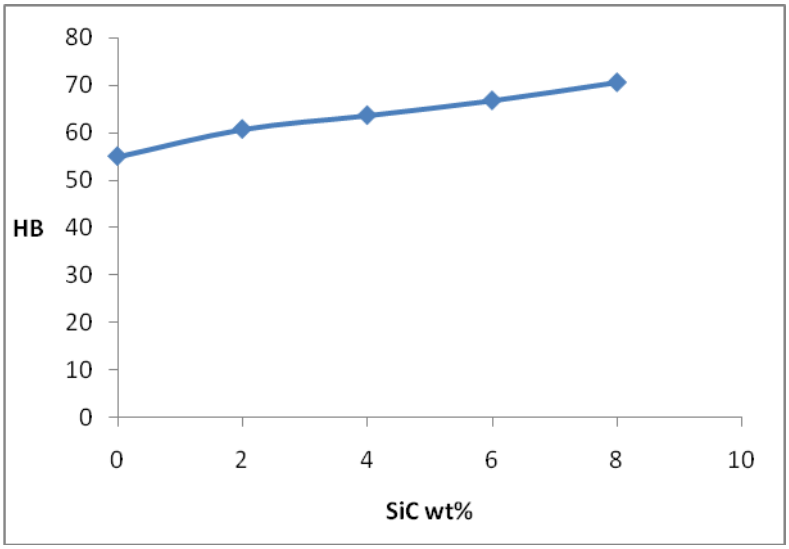


Fig.(4) variation in the hardness with different wt% of SiC

Identification of the phases in the raw material and stir-cast samples was done by using X-Rays diffraction unit with the following specifications. The target of the X-ray tube was copper with wavelength Cukα equal to 0.15405 nm as the following data for the X-ray unit used X-ray diffraction type; philips pw-1840; Power; (Voltage 40Kv), (Current 20 mA), average wavelength ; 1.5405 A^o. By using Bragg law, the d-values can be determined as follows:

$n\lambda=2d \sin \theta$ ..... (6)

Where:

n = order of reflection 1, 2, 3, - - -

λ = wave length of X- ray = 0.15405 nm

d = interplanr distance in A^o

θ = angle of incidence or reflection of X-ray beam.

From interplanar distance, the intensity of the X-ray present, and by the standard files, the phases can be defined.

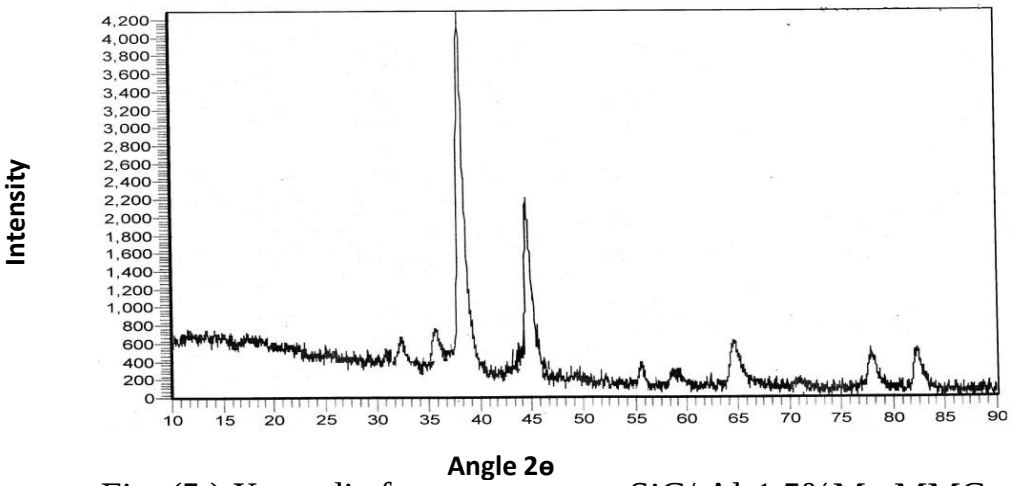


Fig. (5) X ray dirrfaction chart for SiC/ Al-1.5%Mg MMCs.

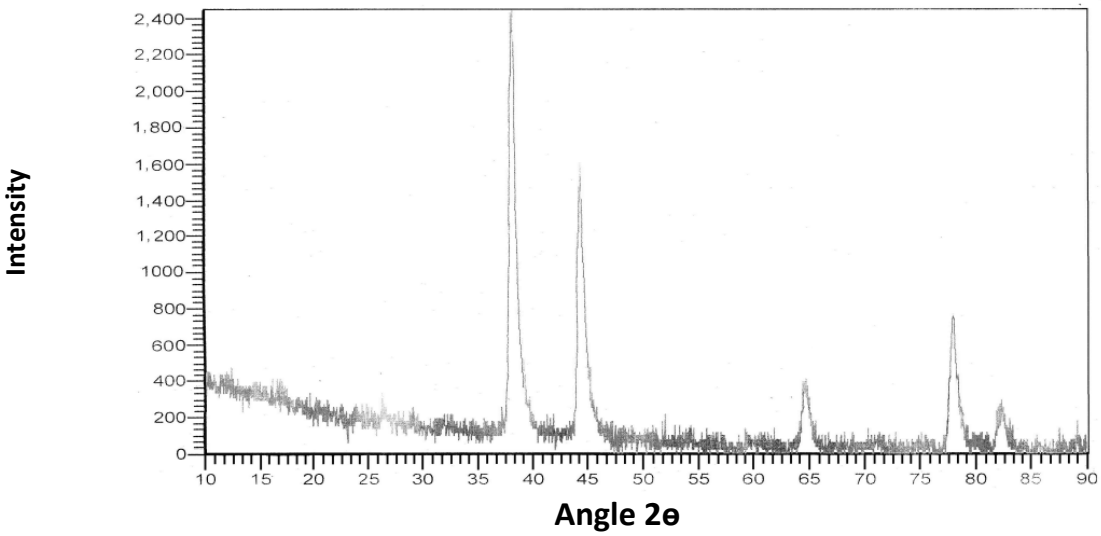


Fig. (6) X ray dirrfaction chart for Al 1.5% Mg alloy.

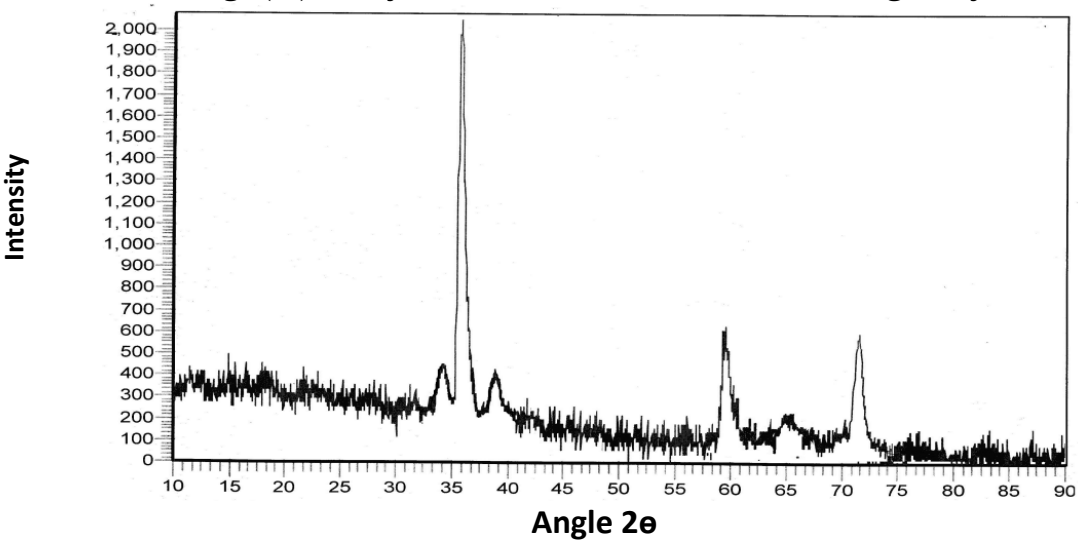


Fig. (7) X ray dirrfaction chart for SiC particles.

Discussion:

The improvements in stiffness and strength generally come at the expense of ductility and fracture resistance. It's difficult to offer an attractive combination of both strength and toughness. The addition of hard ceramic particles like SiC particles increases the hardness of the composite, which enhances the resistance of the matrix to the penetration and reduces subsequent removal of material by debris and other third-body particles found**.** In this work impact test were used to study the affect of SiC content on the fracture toughness, the change in the impact energy and impact strength of composites with increased content of the reinforcement particles were shown in the fig (2) and Fig (3), they represent the variation in the impact energy and impact strength respectively which evaluated by use charpy impact test, it show that the effect of SiC wt% is malfic on the fracture toughness of the MMCs material. The interaction between reinforcement particles and the crack were controls the local direction of crack growth in MMCs. This is because reinforcement particles modify the stress field surrounding the crack tip. The exact nature of this modification depends on whether the particles fracture, decohere, or remain intact during the impact. The main factors controlling the capability of MMCs are therefore; Reinforcement type (composition and shape) Reinforcement volume fraction and aging condition. nonhomogeneous, anisotropic characteristics, pose significant challenges for defect detection and materials property characterization. Throughout their, composites are susceptible to the formation of many possible defects, primarily due to their multiple-step production process, nonhomogeneous nature, and brittleness in the matrix and the SiC particles. These defects include delaminations, matrix cracking, SiC particle fracture, and impact damage.

In this work also we have used the hardness test to study the samples indentation resistance.. The change in the hardness of composites with increased content of the reinforcement particles shown in the fig (4) represents the variation in the hardness evaluation by Brinel hardness test. It's obvious that the hardness increases with increased content of The SiC reinforcement. This is due to the reason that the reinforcement material is much harder than that of the matrix material and it is also due to the good bonding between the matrix and reinforcement material

From The x-ray diffraction test we recognize the phases which are produced into the matrix alloy and the MMCs structure as shown in fig. (5), fig. (6) and fig. (7). its shows that there is a good bonding between the matrix and reinforcement material as a result to the interface reaction which has been produced between them.

Conclusion:

1. The ceramic particles increase the MMCs ability to resist deformation at low strain rate like what happened in the hardness test; but at high speed, high strain rate of deformation as in the impact test, the ceramic particles decrease the MMCs ability to resist the deformation.
2. The hardness of the MMCs highly dependent on the ceramic particle content, particle size and applied load. Consequently, these parameters affect hardness of MMCs.
3. Cracks initiated from defects or due to slip in the unreinforced alloy and at clustering of particles in MMCs.
4. The failure in the matrix is initiated by defects spatially the micro void nucleation at different initiation sites. Void initiation is more pronounced in the matrix near the interface. A number of micro cracks can grow from these micro voids to absorb available strain energy. Crack propagation occurs by linking these micro cracks locating the crack path preferentially in the matrix adjacent to the interface.
5. The alloying elements should not give rise to interfacial reactions with the SiC particles; the alloying elements should not form primary insoluble intermetallics neither at the interface nor within the matrix; the alloying elements should preferentially be soluble in the matrix and respond to controlled age hardening treatments, without reaction with the SiC particles; the alloying elements should provide sufficient fracture toughness to the matrix alloy to accommodate local stress intensities. To achieve good bonding between SiC and Al alloy must improve the wettablity between them and its happen by adding a third material Mg as alloying element, This will increase the toughness of the material. Mg addition during melting of the Al-alloy matrix improved the wettability resulting in certain bonding at the particulate-matrix interface. However, under higher stress levels the interfacial bond strength was not sufficient and cracks initiated at the debonded interface.
6. If the particle strength is apparently sufficient to minimize particle breakage in the crack path. High particle strength prevents particle breakage which leads to crack deflection around the reinforcement.
7. If the particle strength is not sufficient to minimize the crack with high stress, then another crack initiation mechanism happen, it was the fracture of SiCp especially seen in the specimens with coarse particulates so that the particle morphology and distribution within the matrix plays an important role in the mechanisms. The failure mechanism changes from interface debonding and crack of ceramic particle.

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ألخلاصة:

ان متانة الكسر للمادة المركبة SiC-Al-1.5%Mg PMMCs قد درست في هذا البحث. والذي حضرت فية المواد المركبة عن طريق الخلط الميكانيكي بواسط الخلاط للحبيبات السيراميكية في المنصهر المعدني. وكانت نسب الاضافة للحبيبات السيراميكية هي 2، 4، 6، و 8 wt% مع معدل للحجم الحبيبي 53µm ، وقد لوحظ ان متانة الكسر للمادة المركبة قد انخفضت نتيجة لزيادة النسبة المئوية لحبيبات SiC مقارنة مع المادة الاساس . وكذلك لوحظ ان الصلادة قد ارتفعت نتيجة زياد النسبة المئوية لحبيبات SiC.

قد تم اجراء فحص حيود الاشعة السينية للمادة الاساس واللحبيبات السيراميكية والمادة المركبة لمعرفة الاطوار الناتجة خلال عملية انتاج المادة المركبة . وقد لوحظ انة قد حصل تفاعل بيني مناسب لتوليد ربط بين المادة الحبيبية والمادة الاساس.

الكلمات المرشدة: المادة المركبة الالمنيوم/SiC ، متانة الكسر ، السباكة ، MMCs .