Fatigue Behavior of Al – 4wt%Cu / SiCP and Al - 4wt%Cu/ Al2O3P Composites

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Abstract

Aluminum – copper (Al – 4wt%Cu) alloy metal matrix composites MMCs reinforced with 0.5 ,1.0 ,1.5 % wt of both SiC and Al2O3 particles were fabricated by stir-casting .The effects of SiC and Al2O3 particles content on the fatigue behavior of the Al – 4wt%Cu unreinforced base alloy and the resulted composites were investigated. The results show that fatigue strengths of base alloy increased with increasing weight fractions of ceramic particles and the fatigue strength of MMCs reinforced with SiC particles is higher than that of reinforced with Al2O3 particles .

Keywords: Metal matrix composites, Ceramic Particles (SiC and Al2O3) , Aluminum alloys , Fatigue .

سلوك الكلل للمواد المتراكبة (Al + 4wt%Cu) مدعمة بحبيبات SiC و Al2O3 ذات اساس من سبيكة

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الخلاصة

يهدف البحث الحالى الى دراسة سلوك الكلل لسبيكة (Al + 4wt%Cu) المقواة بدقائق كاربيد السليكون SiC و دقائق الالومينا Al2O3 و بنسب وزنية مختلفة (0.5 , 1.0 , 1.5)% . استخدمت طريقة السباكة بالمزج stir casting–، لتصنيع المواد المتراكبة . بعد ذلك اجريت فحص الكلل على العينات القياسية لكل من سبيكة الاساس و المواد المتراكبة . اظهرت نتائج فحص الكلل ان المادة المتراكبة تمتلك قيم مقاومة الكلال اعلى مقارنة بالسبيكة الاساس و تزداد هذه القيم مع زيادة نسب دقائق السيراميكية المضافة . اما تأثير نوعية المادة السيراميكية على تلك الخاصية فقد لوحظ زيادة ملحوظة في قيم مقاومة الكلل للمادة المتراكبة المقواة بدقائق كاربيد السليكون مقارنة مع المادة المتراكبة المقواة بدقائق الالومينا .

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Introduction

Metal Matrix Composite MMC represents a new generation of engineering materials in which a strong ceramic reinforcement is incorporated into a metal matrix to improve its properties including specific strength, specific stiffness, wear resistance, excellent corrosion resistance and high elastic modulus. MMCs combine metallic properties of matrix alloys (ductility and toughness) with ceramic properties of reinforcements (high strength and high modulus), leading to greater strength in shear and compression. [1]

Depending on the shape and type of the reinforcement , composite materials can be classified in to:

1- Fiber reinforcement composite materials
2- Grain reinforcement composite materials
3- Dispersion reinforcement composite materials[2] [3]

MMCs can be produced by various fabrication processes including melting process and powder metallurgy .Compared with powder metallurgy melting process which involves the addition of ceramic particles into molten material, has some important advantages, e.g., better matrix-particle bonding, easier control of matrix structure, simplicity and low cost of processing. However, the melting process has two major problems which are firstly,poor wettability between ceramic particles and liquid metal matrix, and secondly, the particles tend to float depending on their density relative to the liquid metal and so that the dispersion of the ceramic particles are not uniform . The application of SiC and Al_2O_3 reinforced aluminum alloy matrix composites in the automotive(pistons, cylinder heads….etc) and aircraft industries is gradually increasing . [4]

Many machine parts and structures are subjected to dynamic and fluctuating stresses . Under these circumstances it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load. This kind of failure is called Fatigue**.** Furthermore, it is catastrophic and insidious, occurring very suddenly and without warning. [5] [6]

Aluminum metal matrix composites reinforced with ceramic particles has been synthesized by many researchers .Smagorinski [7] investigated mechanical properties of aluminum based composite material reinforced with ceramic particles. Powder metallurgy and plasma processes manufactured were uses to produce composites . Results show that mechanical properties such as elastic modulus and thermal expansion factor of composites produced with powder metallurgy is better than that of produced with plasma process. while, composites produced by plasma its properties will be better after heat treatment processes.Sarmad [8] started with studying fatigue strength and hardness of Al - 4.5wt% Cu-1.5wt%Mg alloy reinforced by addition (ZrO_2 – Al_2O_3) particles with different weight fractions and particle size .The results show that fatigue strength and hardness increase with increasing weight fraction of added ceramic particles, also it is noticed that fatigue strength and hardness of composites reinforced with Al_2O_3 particles is higher than of that reinforced with ZrO_2 particles. Later, Salm and Ahmed [9] studied the effect of addition of Al_2O_3 particles on mechanical properties of Al – 4wt %Cu alloy . Their results show that mechanical properties MMCs , such as , hardness, tensile strength , increase with increasing weight fraction of ceramic particles while ductility decreases due to brittleness of ceramic materials .

The aim of the present work is to study of the fatigue behavior of the Al – 4wt%Cu alloy reinforced with both SiC and Al_2O_3 particles.

Experimental work
1. Materials:

In this study Al – 4wt %Cu alloy was used as the matrix material due to its wide applications, while SiC particles and Al_2O_3 particles with particle sizes 11 microns were used as a reinforcement. For manufacturing of MMCs 0.5 ,1 and 1.5% wt of both particles were used. [10] [11].
Spectro Spark Analyzer machine (CE, Gmb and KG Co., Germany, 2008) was used for the chemical analysis of the (Al - 4wt%Cu) alloy in Erbil Technical Institute ETI and the result is shown in Table 1 .

Table (1) The chemical composition of(Al - 4%wtCu) unreinforced base alloy, composition in wt %

Cu	Fe	Si	Mg	Zn	Cr	Ni	Pb	Sn	Sb	Al
4.022	0.182	0.211	1.02	0.016	0.012	0.015	0.013	0.004	0.011	Balance

2. Composite Synthesis and Testing Procedure:

Initially, 750gms weight of Al– 4wt%Cu alloy was charged into the crucible in the form small cut pieces, and heated to about 700 °C in electrical resistance furnace. After the entire alloy in the crucible was melted, the SiC particles, which were heated at 120 °C for 10 min. and air-cooled to room temperature about 25 °C were added to the molten alloy and mixed . After the completion of particle feeding, the crucible was returned in to the furnace and reheated to a bout 700 °C and mixed again, this process (re-melting and mixing) repeated two times with the aim of good particle distribution in the molten alloy. Finally the mixture was poured to pre-heated to about 120 °C cylindrical mold shape with dimensions 20 mm diameter and 160 mm height. Fabricated billets were air-cooled to room temperature. Same procedure was repeated with Al_2O_3 particles.
The resulted composites and unreinforced base alloy billets were machined out to fatigue samples on CNC cycle lathe machine, Proton 530, Germany, 2006 in ETI. The surface of samples was grinded on 1000 grit abrasive papers .Fatigue samples Fig. (1) were tested on fatigue tester machine MT3012, Germany, in ETI showed in Fig.(2). The tester is driven by an induction squirrel cage motor 3000 r.p.m. The motor is connected on one side to a counter mechanism which reads 7 figure number and on the other side attached to the shaft with conical fixture for fixing fatigue samples. The loading device consists of spherical ball bearing and micro switch with automatically switch off the motor when the fracture occurs. [12]
By turning the loading wheel clockwise the loading on the test sample is increased .A spring balance measures the loading (F).The value of (F) found as below . [13] [14]

$$б_b = FL / d^3 \qquad \text{……………(1)}$$

$$\mathbf{б_b} = 0.4\ \mathbf{б_{Utm}} \qquad \text{……………(2)}$$

Where, $б_b$ is bending stress MPa , F is applied load subjected at the free end of the samples and $\mathbf{б_{Utm}}$ is the ultimate tensile stress for aluminum alloy = 469MP

To understand and comparing the behaviors of the resulted composites and unreinforced base alloy, prepared samples tested with alternating stresses, σ_b (50, 150, 350) MPa .

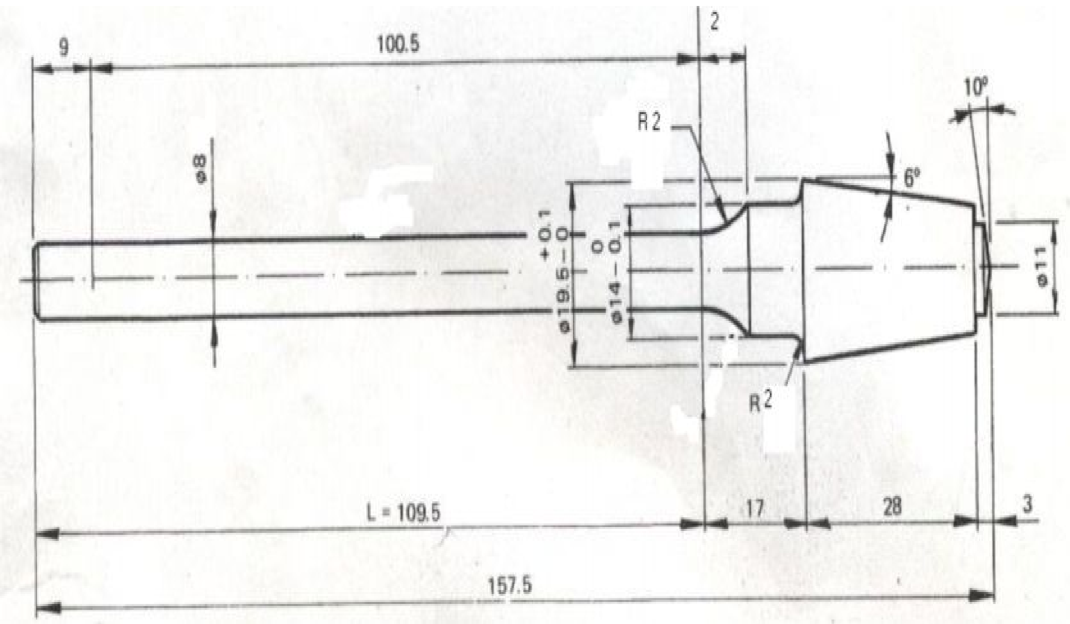

Fig. (1) Fatigue samples

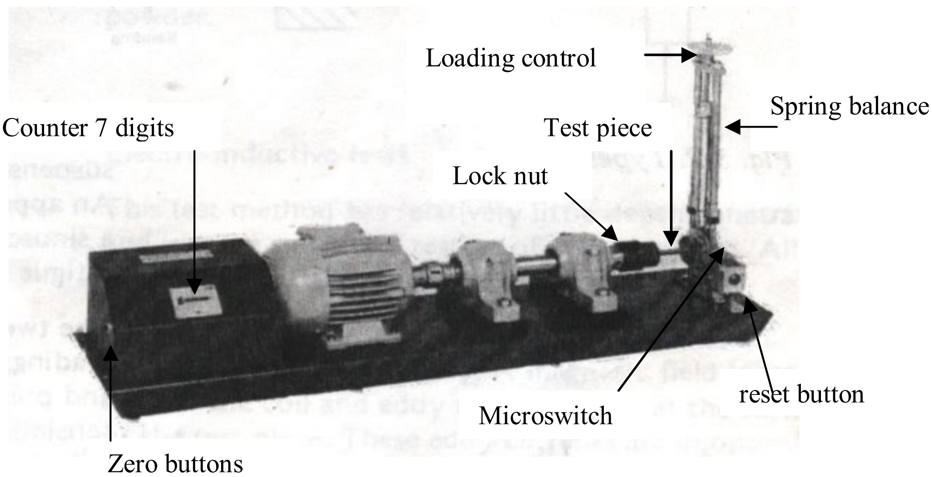

Fig. (2) fatigue tester machine M3012

Results and Discussion

The unreinforced base alloy and produced MMCs contain some dislocations that introduced during solidification and as a consequence of stresses that result from thermal cooling. The density of this dislocation which might arise as a result of the difference in thermal expansion between the metal matrix and ceramic particles is higher in composites compared with base alloy metal. The addition of ceramic particles induces higher dislocation density and these particles act as barriers to the movement of dislocations within the matrix aggravating their mobility.[15]

These barriers renders a MMCs to have more number of failure cycles compared with base alloy as shown in Fig. (3) and Fig.(4) .These two figures indicate increasing failure cyclic numbers with decreasing stress amplitude for MMCs and also it is appeared that the unreinforced base alloy and resulted composites do not have a fatigue limit .Decreasing stress amplitude is as a result of elastic – plastic fracture mechanism. In this mechanism high stress causes the deformation and growth of cracks. But, at low stress amplitude value, numbers of cyclic stress to failure is high which cause elastic deformation . [16]

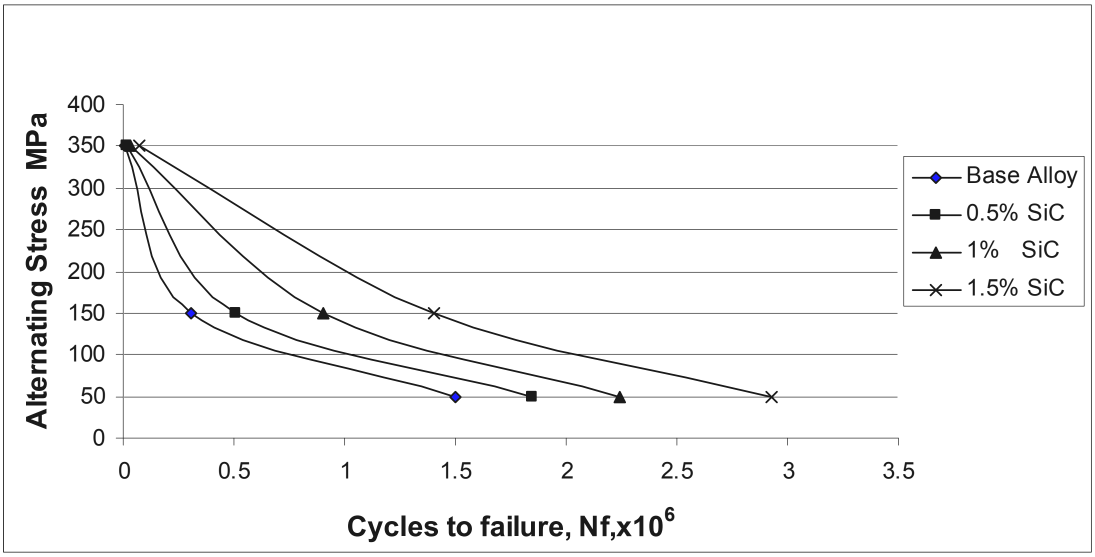

Fig. (3) Alternating stress versus cycles to failure

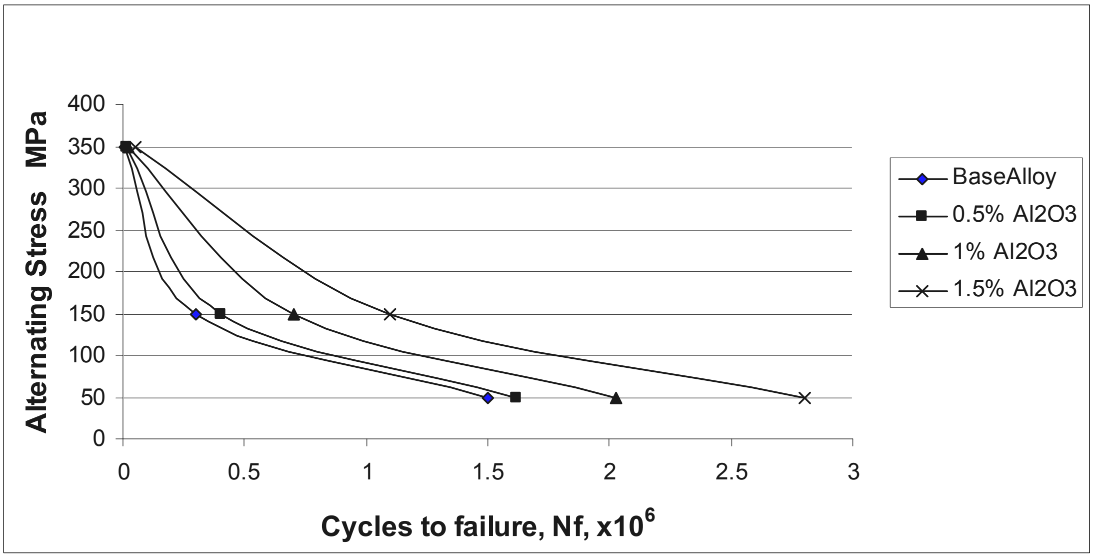

Fig. (4) Alternating stress versus cycles to failure

Fig.(5), Fig.(6) and Fig.(7) indicate increasing cycles to failure of both composites with increasing weight fractions of ceramic particles due to addition and distribution of ceramic particles in the base alloy .These particles block the movement of dislocations and produce a pronounced strengthening effect. The block average increase with increasing weight fractions of particles.

The cycles to failure of MMCs reinforced with SiC is a little bit greater than that of reinforced with Al_2O_3 particles this attributed to high mechanical properties of SiC particles compared with Al_2O_3 particles in which ultimate tensile strength of SiC and Al_2O_3 is is 6.5 GPa and 1.5 GPa respectively , while Vickers hardness for SiC and Al_2O_3 is 2500 kg/mm^2 and 1100kg/mm^2 respectively . [17] [18]

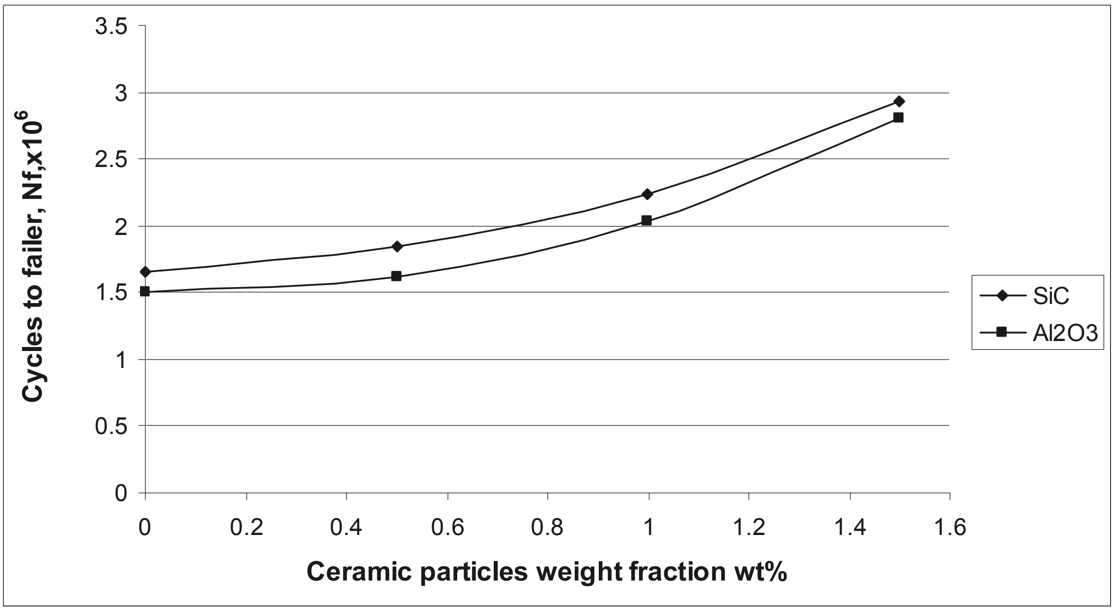

Fig.(5) cycles to failure versus ceramic particles weight fraction with applied stress 50 MPa

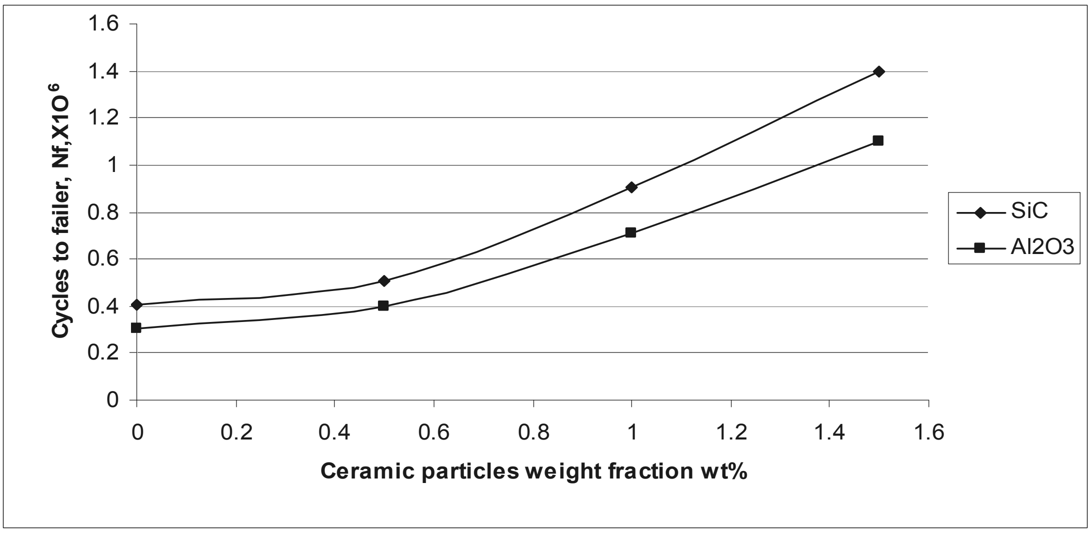

Fig.(6) cycles to failure versus ceramic particles weight fraction with applied stress 150 MPa

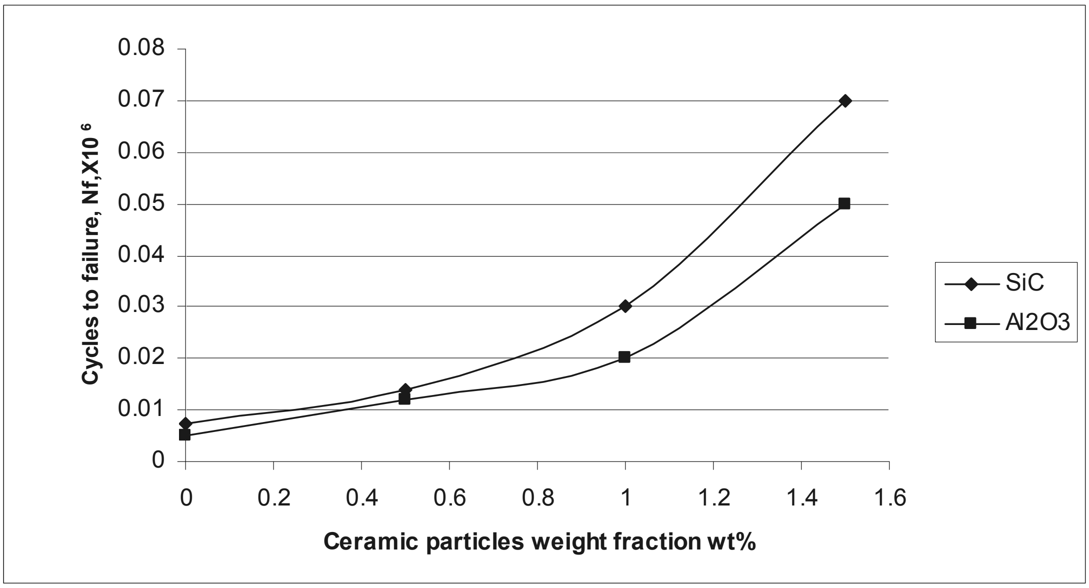

Fig.(7) cycles to failure versus ceramic particles weight fraction with applied stress 350 MPa

Conclusions

The main conclusions withdrawn from the current study are:

1. Adding and distribution of ceramic particles to aluminum base alloy caused increasing fatigue strength of the base alloy .
2. The fatigue strength of MMCs increased with increasing weight fractions of ceramic particles .
3. The fatigue strength of MMCs reinforced with SiC particles is higher than that of reinforced with Al_2O_3 particles .

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