Fabrication and Fatigue Behavior Study of Metal Matrix Composite AA6063 /MgO

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Abstract. A metal matrix composite AA6063, Al-based reinforced with 10% of MgO particulate seized 20µ was fabrication by vortex method. The materials of investigations analysis by Energy Dispersive X-ray (EDXA) to be insure the exiting of MgO reinforcement. Optical microscope examinations illustrated that microstructure of the investigated composite shows good distribution with MgO. The fatigue test was carried out for both AA6063 alloy as a matrix and the composite material AA6063/MgO a compression between them have been done. The S-N curve for both matrix alloy and composite was carried out. The fracture fatigue surface was investigated by Scanning Electron Microscope (SEM). The study has shown improvement in the fatigue properties for the composite material (AA6063/MgO) more than the matrix.

1. INTRODUCTION

One of the most attractive categories of material is Metal Matrix Composite (MMC). Among all of the composites, there is a special attention to aluminum matrix composites, because of their unique characteristics and their potential for advance application, in commercial sectors, transport and aerospace industries. These composites can be produced in a wide variety of procedures; ranging from powder metallurgy methods to different kinds of casting processes [1-2]. It has been shown that, the properties and characteristics of composites are a function of the interface between matrix and reinforcement phases [3]. Reinforcements that were used for aluminum matrix composites include a extensive range of materials; continous fibers, short fibers or ceramics particles [4-5].

As structural components in aerospace applications, the composites are subjected to many cyclic stresses in their service lives, which can cause fatigue degradation of the materials. In this aspect, the fatigue behavior is crucial in the design, life prediction and reliability analysis of the components fabricated from these materials [6-8]. So, an increasing interest in the fatigue behavior of metal matrix composites because of their exceptionally high specific modulus, specific strength, fatigue strength, wear resistance, reasonable cost, etc. While MMCs have a superior fatigue resistance to the corresponding unreinforced counterpart in the high cycle fatigue, their resistance to the low cycle fatigue (LCF) is less satisfactory. A lot of research work has been carried out on the LCF life prediction of MMCs, e.g. [9–14].

2. EXPERIMENTAL WORK

2.1. Raw Materials

The matrix alloy was wrought aluminium (AlMgSi) AA6063. The chemical composition of this alloy is shown in Table (1) which carried out using spectrometer device Magnesia (MgO) particles were used as reinforcement with average size of 15 µm.

2.2. Composites Preparation

The composites were prepared using stir casting route. The alloy was heated to the molten state in electrical resistance furnace to 680°C, followed by mechanical stirring of the melt using a low carbon steel impeller. The stirring speed was 750 revolutions per minute. The stirring time ranged from 20 to 30 min according to the amount of reinforcement added to the melt. During the stirring process, preheated MgO particles were introduced into the melt inside the vortex. When the mixing was completed, the matrix/particles slurry was cast into a permanent steel mould.

2.3 XRD and EDX analysis

X-ray diffraction analysis using has been carried out for both Al matrix alloy 6063 and Al 6063/MgO composite to ensure the existence of reinforcement into the matrix. Energy Dispersive X-ray (EDXA) also carried out for the investigated materials.

2.3. Heat Treatment and Hardness Tests

Investigated materials (unreinforced matrix alloy and the composites) were solution treated at T6 condition (530 ± 1°C) for three hours and then quenched in cold water. After cooling specimens were artificially aged at 175 ± 1°C to for 6-8 hours in reducer atmosphere to prevent oxidation of investigated materials samples. The hardness of the produced composites, after the heat treatment, was measured using the Vicker's hardness test method. The tests were carried out using a load of 10 kg. A minimum of ten readings were taken for each condition and the average value was determined.

2.4. Metallographic Analysis

The microstructure examination was carried out using "Nikon" optical metallurgical microscope equipped with a 5 Megabyte pixels Olympus digital camera. The particles size and porosity measurements were conducted by image analyzing technique using "Thixomet" commercial image analyzer software. Scanning electron microscope (SEM) has been used to investigate the fracture surface of the sample for the matrix and composite materials after carrying out the fatigue test.

2.5 Tensile test

The tensile test was carried out according to ASTM E8 M standard. Universal testing machine (hydraulic operated) with a maximum load of 100 ton (manufactured by Shimadzu) was used for the test; the machine is computer controlled and has the ability to automatically detect the 0.2% proof stress (offset yield strength). A loading rate of 10 mm/min was used for all the tensile tests. The engineering stress-strain curve was monitored during the test. The result of the test as an average of at lest three reading and sample dimension as the fatigue test sample fig. 1

2.5 Fatigue test

Low cycle fatigue tests have been performed, on Al matrix and Al composite /MgO samples, using a rotating bending machine with maximum capacity 200N.m and maximum speed 50000 r.p.m. (manufactured by Roell Amsler, Germany). Testing was started at a very low load level (blow the yield strength) and then stopped if the specimen was not broken (the run-out condition). The load level was then increased and the testing continued. This procedure was carried out for each specimen in turn until it fractured. Fatigue samples had the following dimensions: full length 130 mm, external diameter 10 mm, gage length 18 mm, gage diameter 6 mm. The central test section of the samples has been mechanically polished to reduce as far as possible the surface roughness. The result of the test carried out for at lest ten samples for each reading.

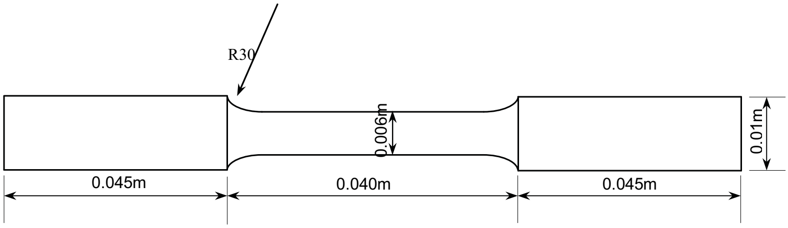


Fig. 1. the fatigue sample

4. RESULTS AND DISCUSSION

4.1 chemical composite analysis

The chemical composite of the Al matrix alloy 6063

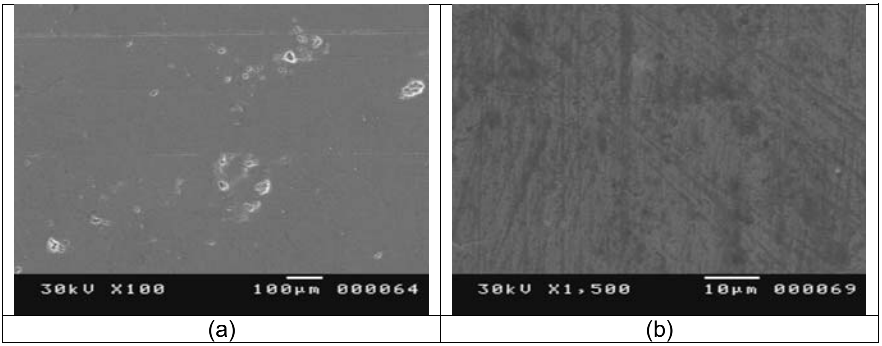
Alloy	Chemical Composition wt. %			
	Mg	Si	Fe	Cu
AA6063	0.46	0.15	0.38	0.01

Table 1. The chemical composition of AA6063.

4.2. Microstructure of Composites

Fig. 2 shows micrographs of the microstructure for the AA6063/10 vol.-% MgO composites. It is clear from the micrographs that the distribution of the MgO particles inside the AA6063 matrix is fairly regular. The composites exhibit higher porosity content when compared to the matrix monolithic alloy. The monolithic AA6063 alloy and the composites containing 10 vol.-% MgO exhibited porosity content values of 4, and 7 vol.-%, respectively. The high porosity content of the composites is due to mechanical stirring which is required to disperse the ceramic particles into the melt. Increasing the stirring time increases the amount of air invoked in the molten alloy during the agitation process [12].

Microstructure examinations showed that, the average grain size of monolithic AA6063 ally was about 145 µm, while, the grain sizes of the composites containing 10 vol. % MgO particles are about 100 µm . The grain refining of the matrix alloy due to the addition of ceramic particles is reported in many previous investigations [12, 13]. Actually, the ceramic particles can be considered as nucleation sites which can produce equiaxed fine matrix grains.



(a) (b)

Fig. 2. A and b SEM The microstructure of the prepared composites: A6063/10 vol.-% MgO and the matrix Al alloy 6063

4.3 XRD and EDX analysis

The figs.3.a and b illustrated the XRD analysis for both composite 6063/Mgo and Al 6063 matrix clear from the curves of composite the existing of Mgo which approved the good wetability between the reinforcement and the matrix .

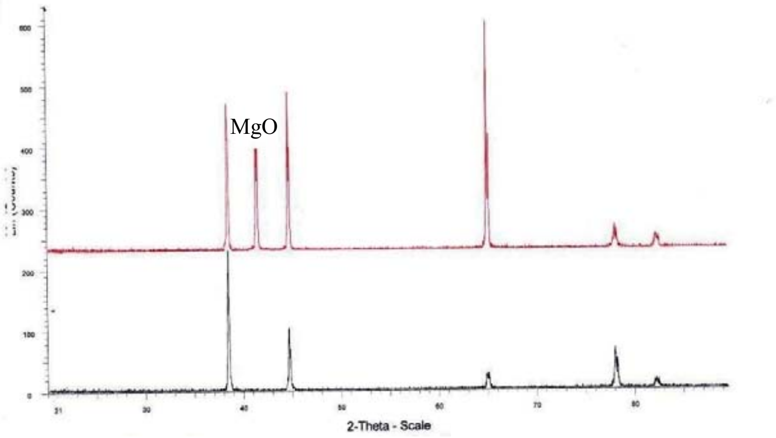


Fig.3 XRD for Al composite 6063/MgO (a) and XRD For Al matrix 6063

4.4. Hardness Results

As expected, increasing the MgO content in the composites increases the hardness of the alloy. The unreinforced AA6063 alloy and the composite containing 10 vol.-% MgO exhibited hardness values of 44, and 52 VHN, respectively.

4.5. Tensile test

Property	Yield stress MPa	Ultimate tensile stress MPa
value	132.85	172.97

Table 2 shows the tensile test for the Al alloy 6063 as a matrix

4.6. SEM analysis and fatigue strength

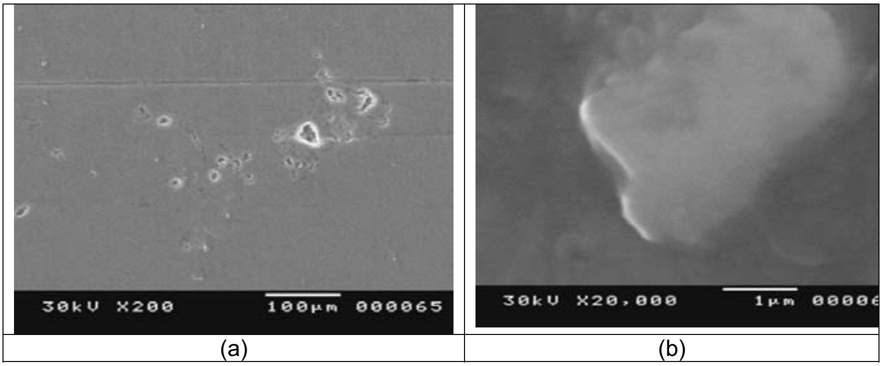
Low cycle fatigue tests have been performed, on Al matrix and Al composite /MgO at different stress with different cycle as shown in the table 3 and table 4 for all samples its ran out for the low cycle fatigue, the fracture occur only at stress 170MPa with 1350 cycle while table 4. shows that the fracture occurs for the Al alloy 6063 at stress 150Mpa with 2300 cycle and at 160Mpa with 700 cycles notce that the 150Mpa its more than the yield strength of the Al matrix that approved that the investgated material can be work successfully at this conditions even near the ultimate tensile strength Also for the composite material l(Al 6063/MgO). The improvement of the fatigue propriety for composite its due to the reinforcement by MgO which is little bit fine particles that are making a good wetability with the matrix which increases the bonding between the matrix and reinforcement particle. Fig.3 (a and b) illustrated the the reinforcement as embed in the matrix with a good interface between the matrix and the ceramic particles (MgO). The microstructural parameters of the composites, such as the volume fraction and size of reinforcing particles, bonding force between the matrix and particles, cyclic strain hardening exponent, cyclic strength coefficient, etc. are expected to exert a significant influence on the fatigue damage of the composites [9-14] .

Fig.4 shows the fracture surface of both Al 6063 alloy and Al 6063/MgO composite after carrying out fatigue test. Fig. 4a for the Al alloy it is clear that the morphology of the fracture is brittle while its ductile for the composite Fig. 4e. Crack propagation for the Al alloy fig. 4b around the grain boundary initiated from porosity and its too long than the crack which is far from the cavity for the surface of composite (fig. 4f) Fatigue cracking results from cyclic stresses that are below the static yield strength of a material.

Also the cavities is too deep than the Al matrix alloy. Fig. 4g illustrated that the composite alloy make like a vortex morphology while the matrix shows a horizontal surface that is due to the behavior of both of them during fatigue test. Fig. 4d and Fig.4h illustrated how the surface of the composite alloy is compacted with each other wile the surface of the Al alloy it looks like as separated surface.

Dislocations play a major role in the fatigue crack initiation phase (Fig. 4b and e). In the first stage, dislocations accumulate near surface stress concentrations and form structures called persistent slip bands (PSB) after a large number of loading cycles. PSBs are areas that rise above (extrusion) or fall below (intrusion) the surface of the component due to movement of material along slip planes. This leaves tiny steps in the surface that serve as stress risers where tiny cracks can initiate. These tiny crack (called microcracks) nucleate along planes of high shear stress which is often 45^{o} to the loading direction.

In the second stage of fatigue, some of the tiny microcracks join together and begin to propagate through the material in a direction that is perpendicular to the maximum tensile stress (Fig.4d and h). Eventually, the growth of one or a few crack of the larger cracks will loading, the growth of the dominate crack or cracks will continue until the remaining un-cracked section of the component can no longer support the load. At this point, the fracture toughness is exceeded and the remaining cross-section of the material experiences rapid fracture. This rapid overload fracture is the third stage of fatigue failure. Dominate over the rest of the cracks. With continued cyclic



(a) (b)

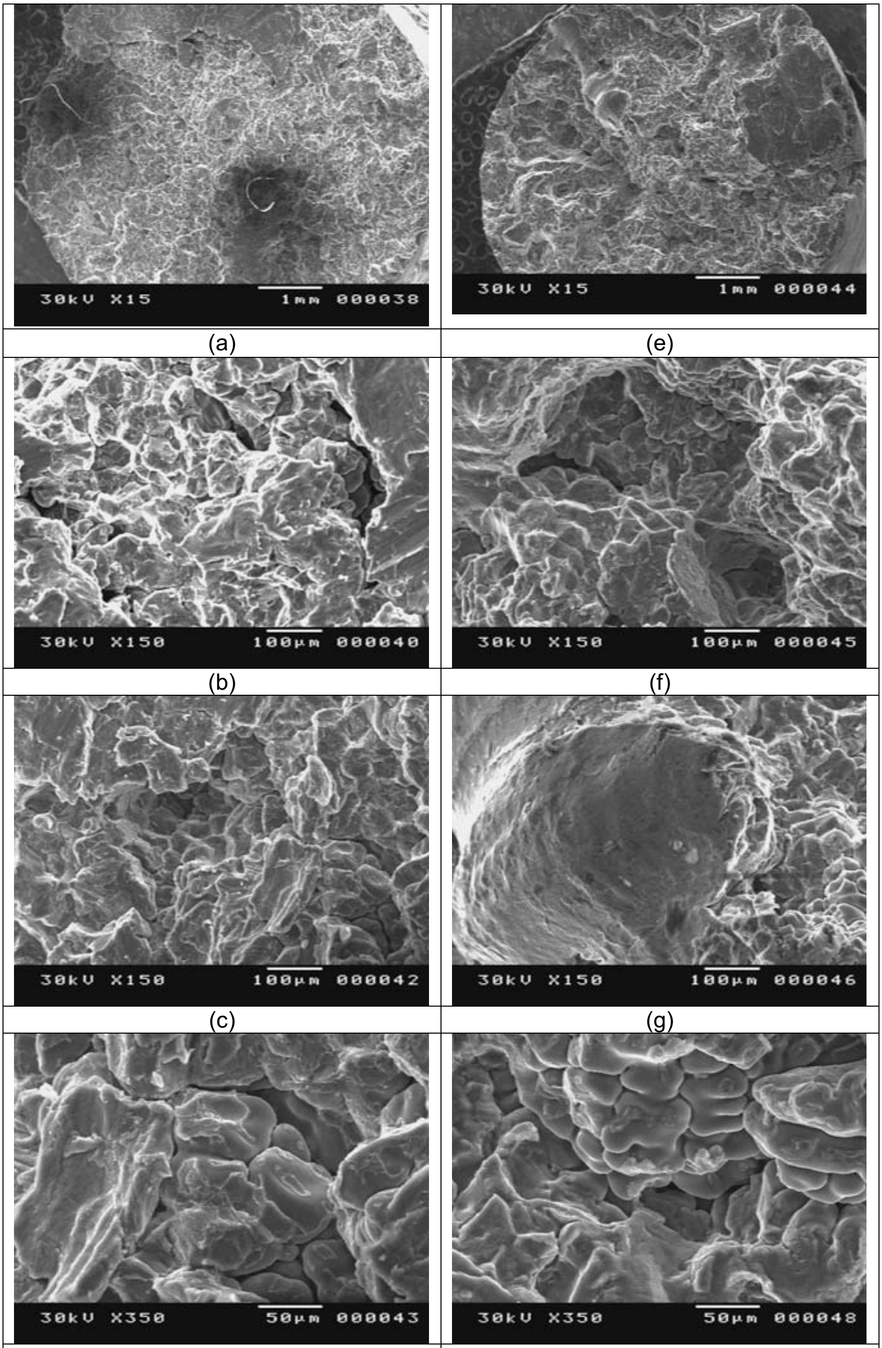
Fig. 3 a and b SEM for composite material and matrix before fracture occur

σ MPa	W(kg)	N*10 (cycle)	D(diameter)mm	fracture
110	0.250	1650	6.1	
120	0.273	1500	6.1	
125	0.298	1700	6.1	
135	0.307	1900	6.1	
150	0.366	6000	6.25	
160	0.390	6000	6.25	
170	0.410	1350	6.25	Occur

Table 3. Fatigue test results for composite Al 6063/Mgo

σ MPa	W (kg)	N*10 (cycle)	D(diameter)mm	fracture
110	0.295	1650	6.1	
120	0.315	1500	6.1	
125	0.310	1700	6.1	
135	0.340	1900	6.1	
150	0.380	2100	6.3	Occur
160	0.400	700	6.3	Occur

Table 4. Fatigue test results for Al 6063



(a) (e)

(b) (f)

(c) (g)

(d) Al alloy 6063 (h) Al 6063 /MgO composite

Fig. 4. SEM photos for both Al alloy 6063 and Al 6063/MgO composite

5.CONCLUSIONS

1- Aluminum matrix composite (Al 6063/Mgo) with 10% MgO was fabricated using stirring casting method.
2- XRD and EDX analysis carried out illustrated matrix Al alloy reinforcement with MgO forming composite.
3- Hardness of the composite Al 6063/Mgo higher than the matrix alloy(Al 6063)
4- Low cycle fatigue show that Al 6063/Mgo composite more resist to fatigue than the Al matrix alloy. Which mean that reinforcement of the matrix increases the fatigue strength.

6. REFERANCES

[1] Tong XC, Fang HS. Al–TiC Composites in situ – Processed by Ingot metallurgy and rapid solidification technology: Part I. microstructural evolution. Metal. Trans. A 1998; 29: 875–91.

[2] Karantzalis AE, Wyatt S, Kennedy AR. The mechanical properties of Al–TiC metal matrix composites fabricated by a flux – casting technique. Mater. Sci. Eng. A 1997; 237:200–6.

[3] Kennedy AR, Weston DP, Jones MI. Reaction in Al–TiC metal matrix composites. Mater. Sci. Eng. A 2001; 316:32–8.

[4] Geiger L, Jackson M. Low-expansion MMCs boost avionics. Adv. Mater. Process 1989; 7:23–8.

[5] Allison JE, Cole GS. Metal-matrix composites in the automotive industry. JOM 1993;45:19–24.

[6] Shackelford JF, Alexander W. CRC materials science and engineering handbook. 3rd ed. Boca Raton, FL: CRC Press; 2001.

[7] Ma ZY, Tjong SC. In situ ceramic particle-reinforced aluminum– matrix composites fabricated by reaction pressing in the TiO2(Ti)– A–B–B2O3 systems. Metall Mater Trans A 1997;28:1931–42.

[8] Tjong SC, Ma ZY. Microstructural and mechanical characteristics of in situ metal–matrix composites. Mater Sci Eng R 2000; 29:49–113.

[9] Ding HZ, Hartmann O, Biermann H, Mughrabi H. Modeling low cycle fatigue life of particulate-reinforced metal–matrix composites. Mater. Sci. Eng. A 2002; (A333):295–305.

[10] Fleming WJ, Temis JM. Numerical simulation of cyclic plasticity and damage of an aluminum metal matrix composite with particulate SiC inclusions. Int. J. Fatigue 2002; (24):1079–88.

[11] Koh SK, Oh SJ, Li C, Ellyin F. Low-cycle fatigue life of SiC particulate-reinforced Al–Si cast alloy composites with tensile mean strain effects. Int. J. Fatigue 1999; (21):1019–32.

[12] Levin M, Karlsson B. Crack initiation and growth during low-cycle fatigue of discontinuously reinforced metal–matrix composites. Int. J. Fatigue 1993; 15(5):377–87.

[13] Pedersen TO, Tvergaard V. On low cycle fatigue in metal matrix composites. Int. J. Damage Mech. 2000;(9):154–73.