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IMPROVEMENT OF TRIBOLOGICAL PROPERTIES OF A356-AL_2O_3 CAST COMPOSITES BY HEAT-TREATMENT

D. Saber

Materials Engineering Dept., Faculty of Engineering, Zagazig University, Zagazig, Egypt

ABSTRACT

Metal matrix composites have better mechanical and tribological properties compared to the matrix materials. This study presents effect of heat-treatment on hardness and tribological properties of A356 aluminum alloy reinforced with different weight fractions of Al_2O_3 particles. Metal matrix composites were fabricated by stir casting method. The sliding wear test was carried using Pin-on-Disc apparatus at a constant sliding speed of 1m/s and load of 30 N. Wear resistance of A356 alloy and its composites was improved after heat treatment with improving ratio between 14-17.3% as compared to as cast conditions. The heat treated test specimens also resulted in marked improvements in hardness as compared with these materials in the as-cast condition.

Keywords: Tribological properties; A356 alloy; Metal matrix composites; Heat-treatment; Hardness

1. INTRODUCTION

Aluminum-silicon alloys have been commonly used in aero-space, electronic packaging and automotive industries because of their lightweight, good thermal conductivity, low coefficient of thermal expansion and high specific strength. Aluminum alloys with ceramic particles as metal matrix composite materials are gaining considerable attention as lightweight metallic materials in high-performance application areas of aerospace and defense sectors. These composites exhibit excellent mechanical properties, resistance to creep at the higher temperature and good fatigue strength compared to base aluminum alloys [1-3].

The particles reinforced aluminum alloys matrix such as SiC, Al_2O_3 and B_4C are generally used to improve hardness. The increasing in volume fraction of hard ceramic particles is an essential reason in increasing the bulk hardness of aluminum alloys matrix[4].

Sliding wear of metal matrix composites is indispensable where there is relative motion. This motion may be intentional, as in an internal combustion engine piston or auto motive brake disc.

Several researchers testified sliding wear behavior of aluminum metal matrix composite. They also investigated the effects of normal load, sliding velocity, sliding distance, size and amount of reinforcement on the sliding wear characteristics [5-9].

Most of these studies have been reported that the wear resistance of aluminum metal matrix composite increases with increase in volume fraction and size of the hard ceramic particles. One of the prime factors of the improvement in wear resistance is an increase in hardness of the Al-alloy due to the addition of hard ceramic particles [10,11].

The hardness and sliding wear properties of the metal matrix composite depend on the matrix microstructure; therefore, the properties of metal matrix composite can be improved by heat treatment. Through heat treatment, the matrix of composite behaves almost similar to that of the base alloy and the dispersed remains unchanged. Attempts have been made to improve hardness and wear resistance of Al–Si alloy and Al–Si alloy reinforced with hard particle composites by altering the matrix microstructure through heat treatment [12]. The aim of this study is to investigate the enhancement of hardness and sliding wear resistance of Al_2O_3 particle reinforced A356 aluminum alloy composites by heat-treatment.

2. EXPERIMENTAL PROCEDURE

In this study, the composite materials were composed of A356 aluminum alloy and Al_2O_3 particles with average particles size (75µm). The chemical analysis of A356 used in this investigation is 7.1% Si, 0.3% Mg, 0,01% Mn, 0.02% Cu, 0.01% Ni. The composites with, 10, 15, and 20 wt% Al_2O_3 particles were fabricated. The composites have been produced by using stir casting method. The melt was at temperature about 750 oC, stirring speed was 700 r.p.m and stirring time was 5 minutes after the completion of particle feeding. 1% Mg was added to the melt to improve wettability .

The specimens of A356- Al_2O_3 composite were heat treated in a muffle furnace (VECSTAR Muffle Furnace). The specimens were heat treated in the following way: solution treatment at 540 ^{0}C for 8 h, water quenching at 60 ^{0}C and isothermal aging at 155 ^{0}C.[13]

The hardness of A 356 as well as the composites were measured after polishing to1 micro finish. The hardness was determined applying a Vickers indenter using load 10 kg. Tests were done at randomly selection of points on the surface by maintaining necessary spacing between indentations and distance from the edge of the specimen.

Dry sliding wear tests were carried out on a pin-on-disc wear testing machine. This test was performed under dry sliding conditions between the specimen and steel disc. The wear pin specimens were of a cylindrical shape having diameter of 9 mm and height of 15 mm. Before wear tests each specimen was ground upto grade 800 abrasive paper making sure that the wear surface was in complete contact with the surface of the disc. The sliding wear tests were performed at constant sliding speed of 1m/s under constant load of 30 N and the sliding distance was 1240 m. The wear track diameter was kept constant at 80 mm in all tests. The weight losses of the specimens were obtained by determining the weight of the specimens before and after wear tests. The sliding wear rate were calculated by converting the mass loss measurements to volume loss by using the respective densities [14].

3. RESULTS AND DISCUSSION

3.1 Microstructure

Figure (1) shows optical microstructure of the A356 alloy and the composite material with 20% Al_2O_3 particles. As shown in Fig.1.a, the microstructure of matrix alloy consists of primary α-Al dendrites and inter-dendritic regions of either eutectic Si-rich phase. The dark black regions may be indicate porosity. Figure.1.b, indicates the distribution of the particles, some of these particles are agglomerated.

SEM/EDS analysis on the A356 alloy-matrix reinforced with 20 wt.% Al_2O_3 additions are indicated in Fig.2. Fig. 2.a shows the interfacial region between the matrix and Al_2O_3 particles. The spectrum and mass fractions of the elements is shown in Fig. 2.b reflect the phases present in the microstructure. There is no evident debonding between Al_2O_3 particles and A356 matrix and consequently strong interface may be formed as a consequence of interaction between Al_2O_3 particles and molten A356 alloy during the fabrication process as indicated in Fig. 2.a. EDS analysis at the interfacial region between the matrix and alumina shown in Fig. 2.b may confirm the occurrence of the interaction between Al_2O_3 particles and molten A356 alloy during the fabrication process. The particulate/matrix interaction in the composites containing Al_2O_3 particulates and aluminum matrix containing Mg may be due to the formation of Al_2MgO_4 spinel or MgO at the interface. The formation of either MgO or $MgAl_2O_4$ spinel depends on the Mg content in the melt. If Mg content is lower than 7 wt.%, as in the present case, the formation of MgAl2O4 spinel is favored and present mainly at the particulates/matrix interface [13].

3.2 Effect of heat-treatment on hardness

Figure 3, presents the hardness results of the test specimens in as cast conditions and heat treated conditions. As shown, in Fig.3 the hardness improves with increasing Al2O3 particles. The addition of 10% Al2O3 improves the hardness by 47% compared to the hardness of the matrix alloy A356. The

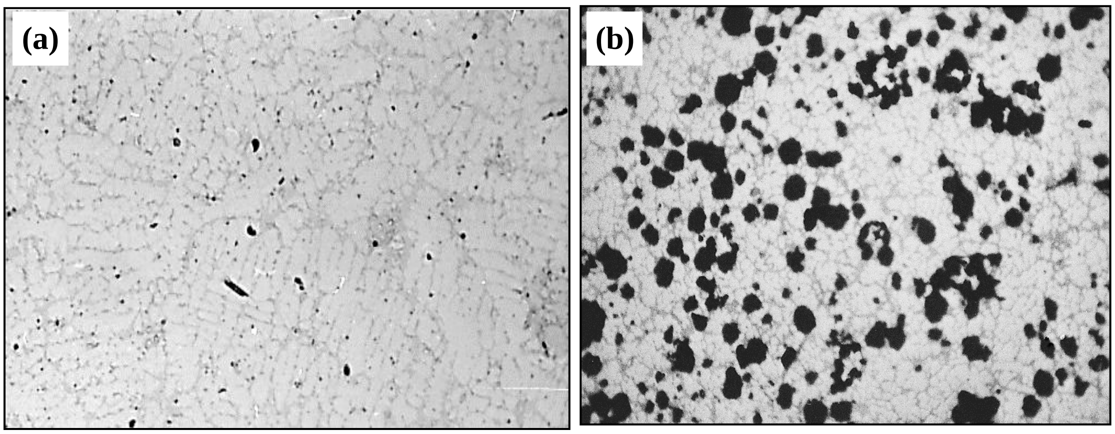
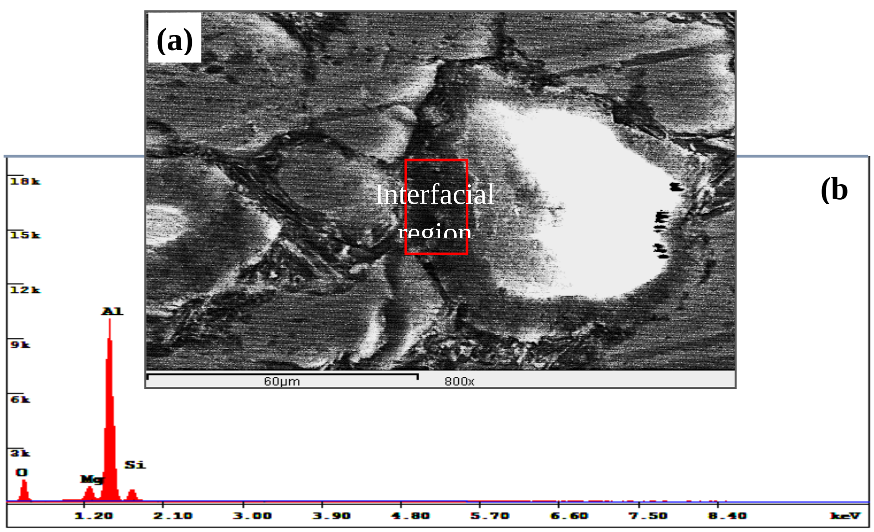


Fig.1: Optical micrographs of composites reinforced with: (a) A356 alloy, (b) A356 alloy+ 20% Al_2O_3 (100 X)



Element	Wt %	At %	K-Ratio	Z	A	F
O K	19.97	29.58	0.0643	1.0540	0.3051	1.0012
MgK	4.81	4.68	0.0390	1.0111	0.7810	1.0273
AlK	66.65	58.52	0.5368	0.9813	0.8191	1.0019
SiK	8.57	7.22	0.0360	1.0099	0.4165	1.0000
Total	100.00	100.00				

Fig.2: SEM/EDS analysis on the A356 alloy+ 20% Al_2O_3

maximum improvement in the hardness achieved in the composite with 20% Al_2O_3 particles by improving ratio 112%. A356 alloy as alloy is consider a soft material as compared to Al2O3 as a ceramic material. The hardness of Al2O3 particles and A356 alloy are 1800(VHN) and 68.24 (VHN), respectively [15]. In addition Fig.3 indicates remarkable enhancement in the hardness of heat treated specimens as compared to the specimens in as cast conditions. The hardness of A356 alloy in after heat treatment is found to be 77.1 compared to A356 alloy in as cast conditions with hardness 68.24 indicating 13% increase in hardness. The composite with 10 % Al2O3 particles has largest value of improvement indicating 14.9% increase in hardness. On the other hand the composite with 20 % Al2O3 particles after heat treatment shows minimum improvement only 3.6%. In the heat- treatment condition, the hardness of the composites materials were higher than that of the matrix. The reason for that is the increased matrix dislocation density, Fig (4) . The dislocation generation mechanism proposed by Arsenault to account for this high dislocation density is based on the large difference in coefficients of thermal expansion (CTE) of the matrix and reinforcement. When the composite is cooled from elevated temperature (during solidification or solution treatment), misfit strains occur due to differential thermal contraction at the matrix/reinforcement interface that are sufficient to generate dislocations [16].

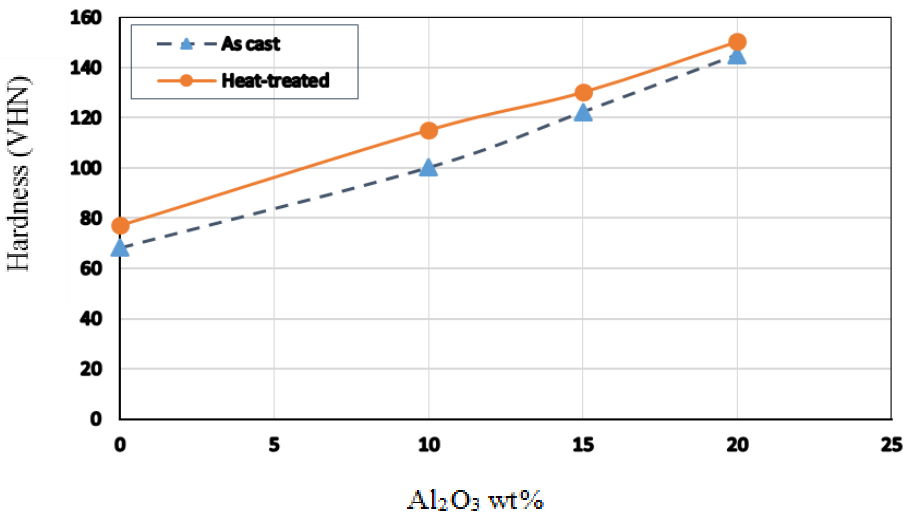


Fig.3: Effect of heat treatment on hardness of the test specimens

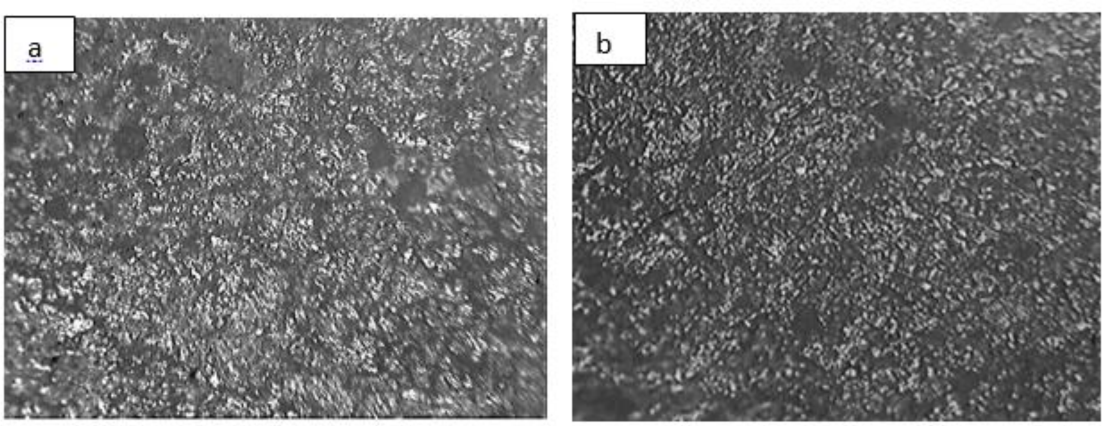


Fig.4: Optical micrographs of composites reinforced with A356 alloy+ 20%: (a) As cast, (b) Heat treated (100 X)

3.3 Effect of heat-treatment on Sliding wear

Figure 5, presents the wear rate of the test specimens and effect of heat treatment on the wear resistance of these specimens. As displayed, in Fig.4 the wear rate decreases by heat treatment. The wear resistance of A356 alloy is improved after heat treatment by 14.3% as compared to as cast conditions. The heat treated composites materials achieve more improvement by improving ratio between 16-17.3% compared with as cast composites materials. Several studies were carried out to investigate the effect of heat treatment on wear behavior of composites materials. Rao et al [17] investigated the effect of heat treatment on the sliding wear behaviour of aluminium matrix alloy reinforced by hard particle. Md Rezaul Karim [18] studied the wear behavior of as- cast and heat treated silicon carbide reinforced aluminum alloy composites Song et al [19] tested the abrasive wear resistance of aluminium-based composites when heat-treated to different ageing conditions. Shanmughasundaram [20] investigated the influence of the heat treatment, on the wear loss of the Al alloy 7075 reinforced by silicon carbide particles. H.R. Lashgari, et.al [21] studied effect of heat treatment of dry sliding wear behavior of A356–10%B4C. These investigation and other investigations are concluded that the wear resistance of heat treated specimens improved due to increase of hardness of these specimens. Through the wear process, cracks are generally nucleated at matrix and reinforcement interfaces. The matrix and composites after heat treatment displayed better hardness that caused less propensities for crack nucleation and exhibited improvement in wear resistance [4]. In case of heat-treated alloy, the effective stress applied on the composite surface through wear process is fewer due to higher strength and ductility of the Al matrix. This resulted in less cracking tendency of the composite surface as compared to the cast alloy [12]. The heat treatment did not drastically conversion the morphology but hardening of the matrix by precipitation hardening took place. The hardening of the matrix led to greater hardness causing the improvement in wear resistance [4]. The increase in hardness of the composite after heat treatment would have the advantage of avoiding the formation of aluminum debris and reducing its transfer to the surface of steel [21].

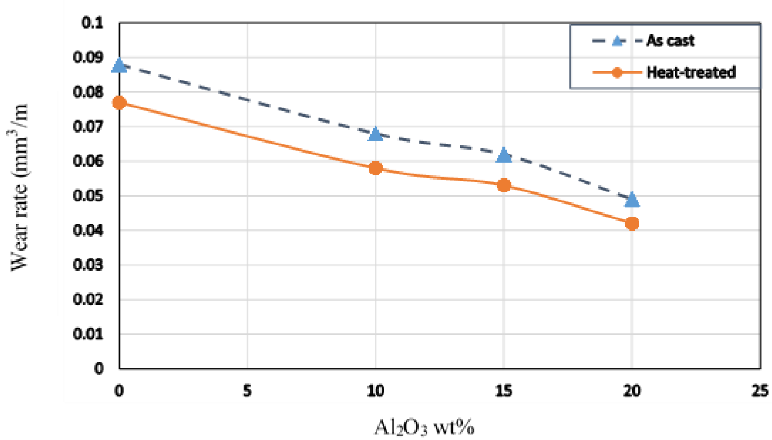


Fig.5: Effect of heat treatment on wear rate of the test specimens

4. CONCLUSION

EDS analysis at the interfacial region between the matrix and alumina may confirm the occurrence of good bonding between Al2O3 particles and molten A356 alloy.The hardness of A356 alloy after heat treatment is found to be 77.1 compared to A356 alloy in as cast conditions with hardness 68.24 indicating 13% increase in hardness. The improving ratio of hardness for the composites was between 3.6%-14.9%. The wear resistance also improved by heat treatment. The wear resistance of A356 alloy is improve after heat treatment by 14.3% as compared to as cast conditions. The heat treated composites materials achieve more improvement by improving ratio between 16-17.3% compared with as cast composites materials.

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