MILITARY TECHNICAL COLLEGE
CAIRO - EGYPT

7th INTERNATIONAL CONF. ON
AEROSPACE SCIENCES &
AVIATION TECHNOLOGY

ABRASIVE WEAR OF Al-Mg and Al-Mg_2 Si-Si ALLOYS

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ABSTRACT :

The abrasive wear (weight loss) of Al-4.4% Mg and Al-4.30% Mg-5.4% Si (Al-Mg_2Si-Si) alloys is investigated. It is found that as applied stress and the grain size of the abrasive material increase, the weight loss increases as the sliding distance increases. As hardness increase, the weight loss decreases. Carrying out abrasive wear on one surface rather than different surfaces shows high weight loss. Al Mg_2Si-Si (Al-4.3% Mg-5.4%Si) alloy is heat-treatable and has hardness higher than Al-7% Si and Al-11.5% Si (eutectic) alloys. Mg_2Si has density equals to 1.88 gm/cm^3. Therefore Al-Mg_2Si alloys are recommended to be used in aircraft industry, missiles components and armor plates.

KEYWORDS :

Abrasive wear, Al-Mg and Al-Mg-Si alloys.

INTRODUCTION :

Wear is the slow, undesired change of dimension in service resulting from pressure exerted by some other body and motion relative to it. Wear tends to decrease the dimension of machine parts. It changes the degree of fit, exposing moving part to unbalanced stresses, the existence of which may increase the possibility of failure by fatigue or other causes. Abrasive wear occurs because the hard particles dig into the metal and tear off the projecting burr that results. As hard metals ought to resist the penetration of the abrasive better, and the tough material would resist the tearing off process [1].

Aluminum alloys have 4.5-5.5% Mg are used in marine, auto and aircraft application, transportation equipment, missile components, armor plate and high strength welded structure [2]. An equation to express the abrasive wear rate has been derived for the case where a hard particle interact with a flat soft body [3].

$$Q = q / S = \beta W / H$$

where : Q=total wear volume per unit sliding distance, q=wear rate (wear/time), S=sliding speed, β=the probability of producing wear fragment (abrasive wear constant), W=normal applied load, H=the hardness of soft metal.

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Magnesium is the major constituent in the aluminum - magnesium group of alloys which achieve high strength with good ductility through cold work. These alloys have excellent corrosion resistance and weld ability. The phase in equilibrium with aluminum is Mg_2 Al_3 (Mg_5 Al_8). The yield stress, ultimate tensile strength, and Vickers hardness increase as Mg% increase up to 15% Mg for the as annealed and cold worked condition. Al-Mg alloys are wrought alloys but unheat - treatable. It can be heat - treatable by forming Mg_2 Si, Mg Zn_2, ... [4]. This is equals to Al - Si alloys with Mg addition to form Al-Mg_2 Si-Si alloys.

Several researches have been carried out to investigate the abrasive wear of Al - Si alloys after addition Mg, Al_2O_3, SiC and graphite [5-13] to the alloy matrix, non for Al-Mg alloys only.

In this work, the abrasive wear of Al-4.4% Mg and Al-4.30% Mg-5.4% Si will be investigated.

EXPERIMENTAL WORK :

Aluminum 5% Mg alloy delivered by Egyptian Aircraft plant is remelted and poured into metallic mould this is the first alloy. The second alloy is formed, as Al-Mg alloy is remelted a certain amount of master Al-50% Si alloy is added to the molten metal. Waiting 10 minutes after silicon alloy addition, the molten Al-Mg-Si alloy is poured from 850 C° into a metallic mould. The amount of silicon alloy added is more than that the required amount to form Mg_2 Si in the alloy matrix, i.e there is excess free Si. The chemical analysis of the two alloys is shown in table (1) :

Table (1) : The chemical analysis of Al-Mg and Al-Mg-Si alloys

Alloy Designation	Chemical Composition %						
	Mg	Si	Mn	Fe	Cr	Cu	Zn
Al-Mg	4.40	0.15	0.43	0.36	0.13	0.06	0.04
Al-Mg-Si	4.30	5.40	0.49	0.41	0.15	0.06	0.04

The abrasive wear specimens are block 23 X 23 X 30 mm. The worn surface is 23 X 23 mm. The abrasive testing machine is the standard aggregates abrasive machine, shown in Fig. (A.1). The drum diameter is 610 mm and rotates at 30 r.p.m. This the peripheral speed = 0.96 m/sec.

The abrasive wear is carried out at 200, 350 and 500 revolutions. The weight loss is measured using electrical sensitive balance with accuracy 0.001 gm. It is used two jows for fixing the abrasive specimen. The first metallic jow weighs 1600 gms. The second is limon wood jow weighs 230 gms. The abrasive material is quartz sand and having two grain sizes 300 μm and 600 μm. The abrasive worn surfaces are investigated using scanning electron microscope.

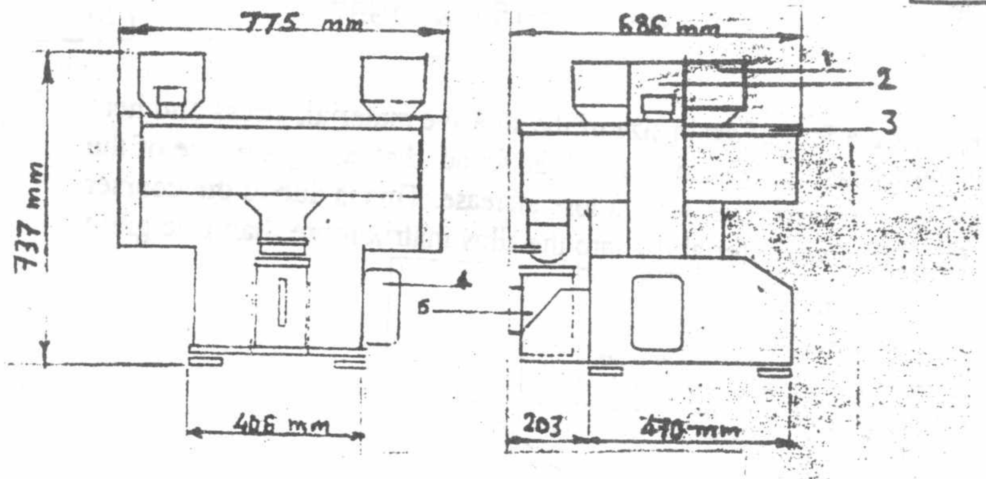

Fig.(A.1) The abrasive testing machine.
1- Sand hopper 2-Specimen mould assy 3- Specimen lapping wheel
4- Ratchet reset counter 5- Rajet sand container

RESULTS AND DISCUSSION :

Fig 1 shows the effect of sliding distance on the abrasive weight loss for Al-4.4% Mg and Al-4.30% Mg-4.5% Si in the as-cast condition. The abrasive material is quartz sand having grain size = 300 μm. It is noticed that as number of revolution (sliding distance) increases the weight loss increase. Al-Mg-Si alloy shows abrasive wear (weight loss) less than Al-Mg alloy. This can be explained by the Al-Mg-Si alloy has two hard phases Mg2Si and silicon. The required amount of Si to form Mg_2Si in Al-4.30%Mg is 3.72% Si. Therefore 2.89% excess free silicon is in the matrix. This mean that as hardness increases, (the measured hardness is HRB = 61.25), the abrasive wear (weight loss) decreases. This result coincides with results of many researches [14-18]. As the abrasive wear is carried out on the same surface rather than different surfaces (accumulative wear), the weight loss increases as sliding distance (number of revolution) increases. The accumulative weight loss is more than that weight loss for Al-Mg alloy as the abrasive wear is carried out on different surfaces.

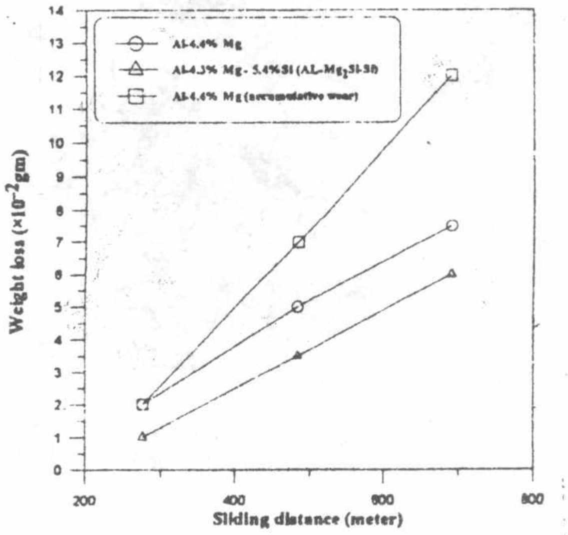

Fig.1 The abrasive wear of Al-4.4%Mg and Al-4.3%Mg-5.4%Si alloys, as cast (grain size of the abrasive material =300μ m)

Fig. 2 shows the effect of grain size of the abrasive material, stress and heat treatment on the abrasive weight loss. It is found that as grain size of the abrasive material increase, the weight loss increase. This is due to the coarser grain size of the abrasive material dig into the alloy matrix more than fine grain size.

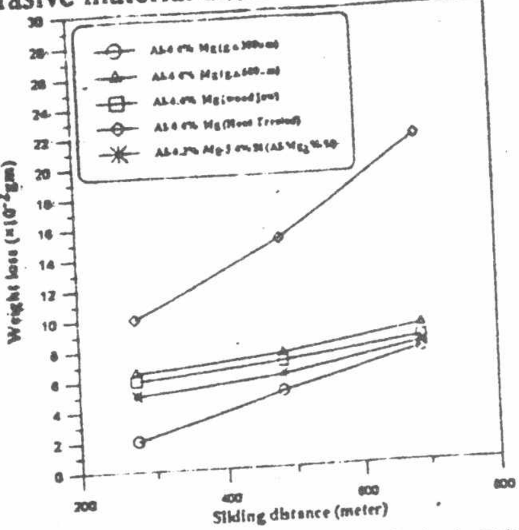

Fig. 2 Effect of stress, hardness and grain size of the abrasive material (600μ m) on the weight loss. (HRB of Al-4.4% Mg=54, solution-treadted =50.8 and Al-Mg_2Si-Si=61.25)

Fig. 3 shows the micro structure of the as-cast AI-4.4% Mg alloy. The dendritic structure is noticed clearly. Fig. 4 is for the same alloy after homogenizing at 540° C for 3 hours and water-quenched. There is a homogenized one phase. The measured hardness to this alloy is HRB = 50.6.

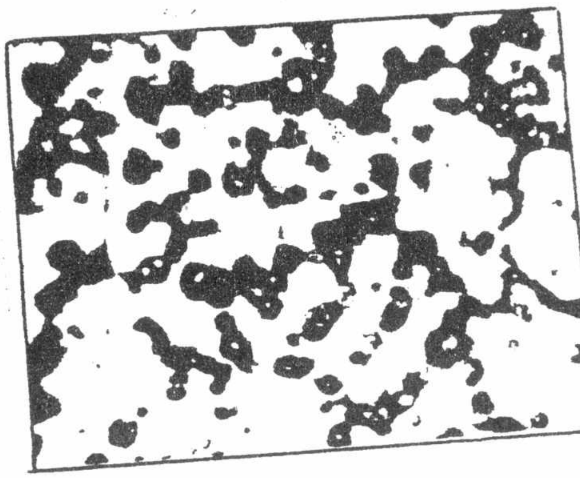

Fig. 3 The micro structure of Al-4.4% Mg alloys (as-cost), X100.

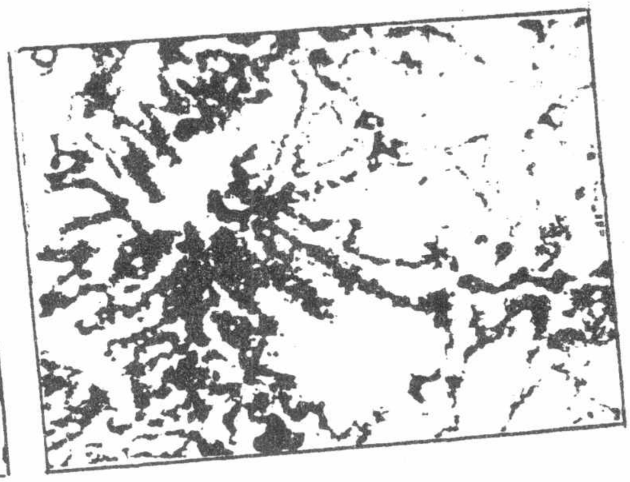

Fig. 4 The micro structure of Al-4.47% Mg (Solution treatment at 540°C for 3 hrs. and water quenched), X 100.

Fig. 5 shows the effect of silicon addition on the micro structure of Al-4.4% Mg alloy. The dendritic structure of Al-4.4% Mg alloy is not seen. There is a modified structure of α ductile aluminum phase + eutectic structure (α + Mg_2 Si).

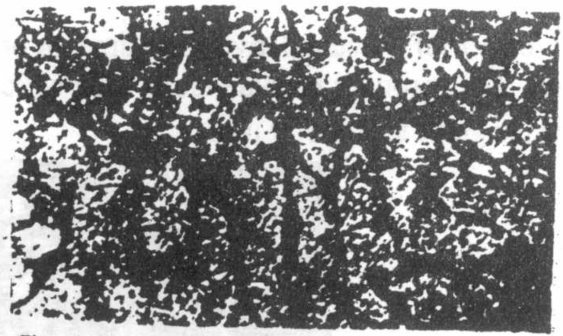

Fig. 5 The micro structure of Al-4.30% Mg-5.4%Si (as - cast), X 100.

Fig. 6 shows the X-rays diffraction of this alloy. It is found that there are Al, Mg_2 Si and free silicon phase.

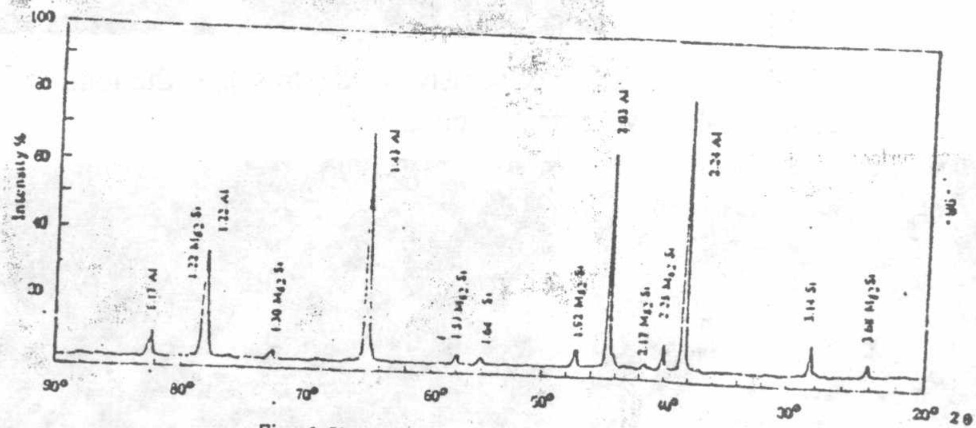

Fig. 6 X-rays diffraction of Al-4.30%Mg-5.4% Si shows free silicon phase.

Figures 7-15 show the scanning micrographes for selected abrasive worn surfaces. Fig. 7 and Fig. 8 show the effect of the grain size of the abrasive material for Al. 4.4% Mg. alloy. It is observed that as grain size increases the abrasive wear increase, wide grooves and more damage in the worn surface.

Fig. 7 The abrasive worn surface of Al-4.4% Mg (P=1.6Kg. sliding distance= 483 m., abrasive g.s. = 600 μ m), X 1000 (SEM).

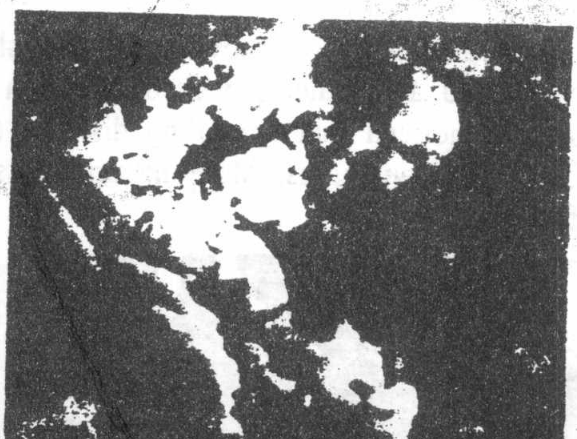

Fig. 8 The abrasive worn surface of Al-4.4% Mg (P=1.6Kg. sliding distance= 483 m., abrasive g.s. = 300 μ m), X 1000 (SEM).

Fig. 9 shows the effect of accumulative wear time on one surface rather than different surfaces. The grooves become more wide which indicate much material loss. The abrasive grain size is 300 μm.

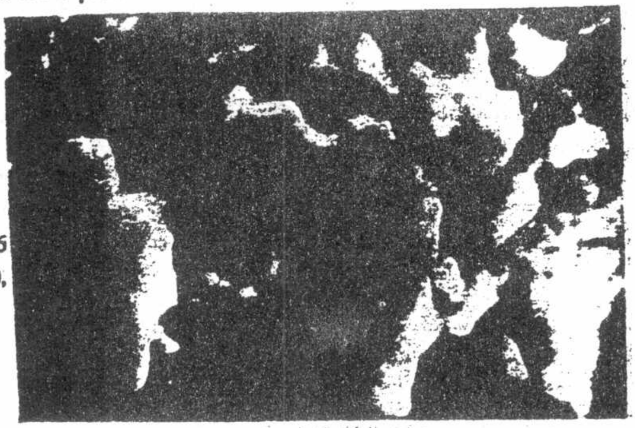

Fig.9 The abrasive worn surface of Al-4.4% Mg (P=1.6 Kg, sliding distance =276 + 483 + 690 m, g.s = 300 μm), X 1000 (SEM).

Fig. 10 and Fig. 11 show the effect of abrasive load (stress), as the load increases, more damage of the abrasive surface is observed.

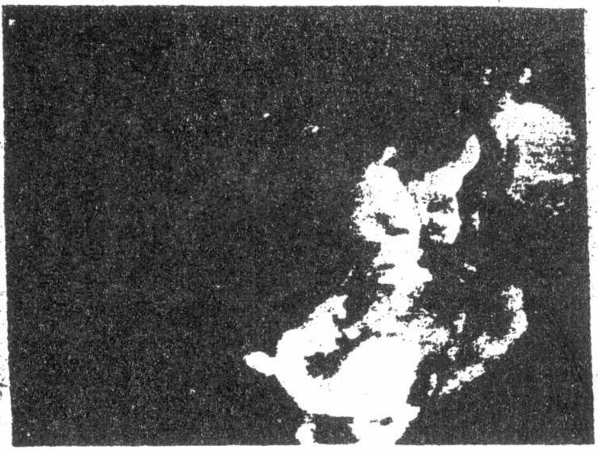

Fig. 10 The abrasive worn surface of Al-4.4% Mg (P=1.6 Kg, sliding distance =276 m, g.s = 600 μm), X 1000 (SEM).

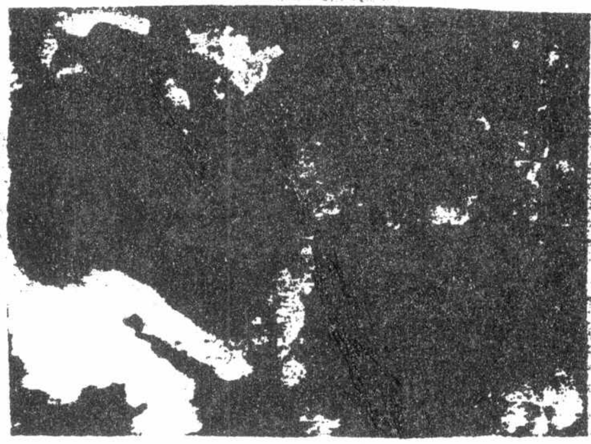

Fig. 11 The abrasive worn surface of Al-4.4% Mg (P=0.23 Kg, sliding distance =276 m, g.s = 600 μm), X 1000 (SEM).

Fig. 12 and Fig 13 show the effect of sliding distance for Al-4.4% Mg as homogenized and water-quenched (solution treatment) on the abrasive weight loss. It is noticed that as sliding distance (no of revolution) increases, the abrasive wear increases. More material loss due to large area of the worn surface is removed.

Fig. 12 The abrasive worn surface of Al-4.4% Mg (Solution treatment at 540°C for 3 hrs. and water quenched), P= 1.6 Kg, sliding distance = 690 m, g.s = 600 μm), X 1000 (SEM).

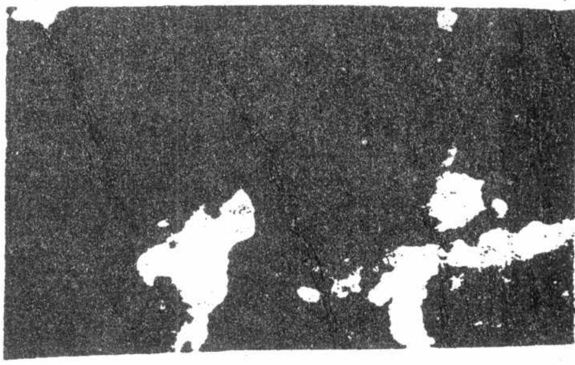

Fig. 13 The abrasive worn surface of Al-4.4% Mg (Solution treatment at 540°C for hrs. and water quenched), P=1.6 Kg, sliding distance = 483 m, g.s = 600 μm), X 1000 (SEM).

Fig. 14 and Fig 15 show the effect of abrasive material grain size on the abrasive wear of Al-4.3% Mg- 5.4% Si alloy. The weight loss increase as the abrasive material grain size increase. The micro graphs show free excess silicon (or silica grains embedded into) the alloy matrix.

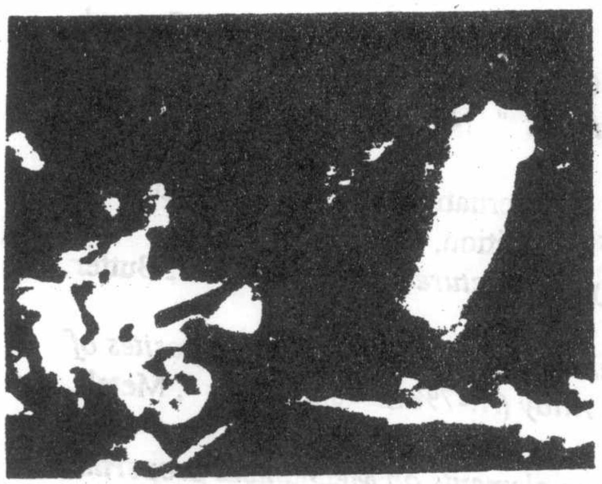

Fig. 14 The abrasive worn surface of Al-4.30% Mg - 5.4% Si, as cast (P=1.6 Kg, sliding distance = 690 m. g.s = 600 µm), X 1000 (EM).

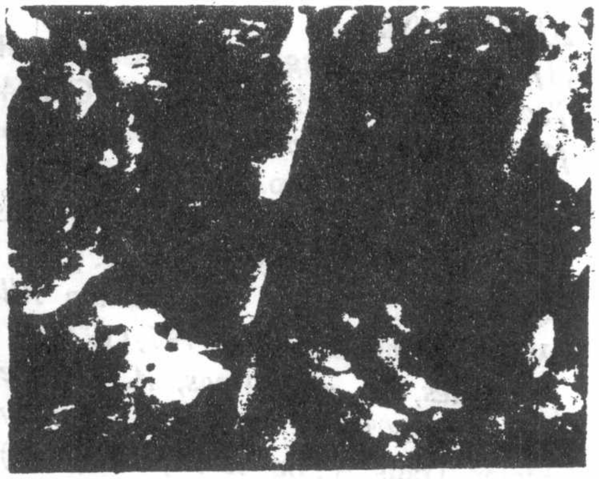

Fig. 15 The abrasive worn surface of Al-4.30% Mg - 5.4% Si, as cast (P=1.6 Kg, sliding distance = 690 m. g.s = 300 µm), X 1000 (EM).

Finally Mg_2 Si and Si phases are very hard and corrosion resistance. Al-4.30% Mg-5.4% Si alloy is heat-treatable alloy. The Al-Si alloys are unheat-treatable. Thus Al-4.30% Mg-5.4% Si (Al-Mg_2Si-Si) alloy is better than Al-Si alloys. The hardness of Al-Mg2Si-Si alloy is 98 HV for the as cast condition, while the hardness of Al– 7% Si alloy at the same condition equals to 47.4 HV [19]. The hardness of the eutectic Al-Si alloy (11.5% Si) equals to 60 HV [20]. Therefore Al-4.3% Mg-5.4% Si can be used in aircraft industry, missiles, armor plates much better than Al-Mg alloys only.

CONCLUSIONS:

The abrasive wear of Al-Mg_2Si - Si (Al-4.5% Mg-5.4% Si) alloy is better than Al-4.40% Mg alloy. As the hardness increase the abrasive wear (weight loss) decreases. Also as grain size of the abrasive material increases the weight loss of the worn alloy increases. It is found that as the applied load (stress) increases the weight loss increases. Carrying out the abrasive wear on one surface rather than different surfaces (for the same alloy at the same condition), the accumulative weight loss increases as sliding distance increases. Al-Mg_2Si-Si alloy shows better abrasive wear than Al-4.4% Mg alloy. Also Al-Mg_2Si-Si alloy ((Al-4.3% Mg-5.4% Si) has hardness higher than Al–7% Si and the eutectic Al-Si alloy (Al-11.5% Si). Mg_2Si has density equals to 1.88 gm/cm^3. Thus Al-Mg_2Si-Si alloy is light alloy with high hardness and good abrasive wear. Therefore it can be used in aircraft industry, missiles components and armor plates.

ACKNOWLEDGMENT :

The author would like to offer special thanks for authorities at Egyptian Aircraft Plant for supplying him with the Al- 5% Mg alloy.

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