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Received on: 25/02/2016
Accepted on: 29/12/2016

Effect of B_4C/Fly Ash Addition on Wear and Mechanical Properties of Al-Cu-Mg Alloy

Abstract- *This research studied the effect of adding fly ash and boron carbide (B_4C) particulates reinforcement on the mechanical properties and wear resistance of Al- 4.5% Cu- 1.18% Mg matrix alloy. Stir casting method has been used to fabricate the alloy and hybrid composite samples containing 2wt% of B4C and 5, 10, 15،20 wt % fly ash. The x-ray inspection revealed the dispersion of intermetallic compounds (Al2Cu,MgO and SiO2) Also, the mechanical properties have been evaluated, the results showed an increase in the tensile and yield properties with the increase of weight percentage of fly ash content up to 15 wt%, but the elongation decreased, while the hardness increased. Wear rate examination has been concluded by using pin on disc apparatus under different loads of (5, 10, 15) N, sliding velocities (1.413, 2.827, 4.241) mm/sec, and different times of (5, 10, 15) min. The results showed decrease in wear rate at 20% fly ash composite sample when compared with other composites samples and base alloy.*

Keywords- *Aluminum alloy matrix composite, Fly ash,B4C, Mechanical properties, Stir casting*

How to cite this article: I.A, Alkadir and L.S. Salim, "Effect of B_4C\Fly Ash Addition on Wear and Mechanical Properties of Al-Cu-Mg Alloy," *Engineering and Technology Journal*, Vol. 35, Part A. No. 4, pp. 301-310, 2017.

1. Introduction

Aluminum matrix composites (AMCs) are widely used in industrial applications, because they have best mechanical properties than the metals or alloys, high strength, good stiffness, lower density, improved corrosion resistance, greater high temperature properties, controlled thermal expansion coefficient, wear resistance and improved damping capabilities [1]. There are different reinforcement materials may be added, like continuous, discontinuous fibers, whiskers, or particulates. Recently, the particulate reinforced Aluminum composites commonly used are TiC, SiC, B_4C, Al_2O_3, SiO_2, TiN, TiO_2, fly ash, etc. The fly ash wastes which produced by electric power plants are used as a particulate reinforcement, since the fly ash has good properties, low cost, with low density spherical shape, and best physical and mechanical properties of composite material which are used to manufacture different engineering applications, aerospace, military and civil [2]. Basavarajappa and Chandrmohan [3] investigated the effect of adding different weight percentages from SiC and graphite fabricated by stir casting process. The wear conducted test at different loads 10-40N, and different velocities 1.53 m/s, 3m/s,4.6m/s and 6.1m/s. The results showed that the wear rate decreases with increasing the reinforcement particles of SiCp and graphite. Varaja [4] studied the effect of adding SiC and B_4C with 5 wt%, 10 wt% and 15wt%, respectively for two alloys Al 7075 and Al 6061. The results revealed that the hardness increased and reached to maximum value at 15-wt%, the wear resistance also improved. Nevertheless, the author also stated that the Al 7075 reinforced by SiC and B_4C depicted better, showed better properties than Al 6061 alloy. Lokesh [5] investigated the effect of fly ash and silicon carbide addition on the properties of Al-5%Cu alloy to maximum value at 15 wt%, the wear resistance also improved. However, the author also stated that the Al 7075 reinforced by SiC and B_4C depicted better, showed better properties than Al 6061 alloy. Lokesh [5] investigated the effect of fly ash and silicon carbide addition on the properties of Al-5%Cu alloy. The fly ash has particle size 49-60 µm and SiC 65 µm, the fly ash has adding was about 4wt% but SiC 6wt%, they manifested that the hardness and tensile strength increased Nagaral et al [6], studied the effect of constant addition%) when compared to base alloy Al 6061. They found that the Vickers hardness decreased with increasing the addition of graphite content in the composite, but the effect of graphite was less on tensile strength [6]. The aim of present research is to study the effect of adding a particulate reinforcement of 2 wt% boron carbide B_4C and different weight percentage (5, 10, 15) and 20) wt% fly ash on the mechanical

https://doi.org/10.30684/etj.35.4A.1
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properties and wear behavior for Al- 4.5% Cu-1.18% Mg matrix alloy.

2. Experimental Procedure

The chemical composition of Al-Cu-Mg alloy is represented in Table 1. Fly ash was added with different percentages 5%, 10 %, 15% and 20%, the chemical analysis of fly ash is shown in Table 2 with constant addition of 2% B_4C. Figures 1 and 2 represents the particles distribution of fly ash and B_4C, respectively. The reinforcement particles were heated both at 300°C for 2 hours before adding with aluminum foils into molten alloy. An electrical furnace and a steel mold were used to prepare the casting by stirring process. A Steel rod was linked by an electrical mixer and then inserted into the molten in a crucible, which is kept in the electrical furnace at 700°C. The molten aluminum alloy was stirred at medium speed in order to avoid excessive gas content that resulted from over agitating of melts, which led to unacceptable porosity content in the casting product. 200gm from Al-Cu-Mg alloy were melted in a graphite crucible at more than 100 ºC above liquids temperature at 700ºC. The slag was removed by degassing procedure by using calcium florid and argon gas. The calcium florid was added to the chemical composition of Al-Cu-Mg alloy is represented in Table 1.

Fly ash was added with different percentages 5%, 10 %, 15% and 20%, the chemical analysis of fly ash is shown in Table 2 with constant addition of 2% B_4C. Figures 1 and 2 represents the particles distribution of fly ash and B_4C, respectively. The reinforcement particles were heated both at 300° C for 2 hours before adding with aluminum foils into molten alloy. An electrical furnace and a steel mold were used to prepare the casting by stirring process.

Table1: Chemical composition of as cast Al-4.5% Cu-1.18% Mg base alloy

Group No.	Element	Wt%
GA	Cu	100
	Mg	100
	Mn	80
	Fe	4.58
	Cr	1.18
	Ni	0.924
	Ti	0.299
	Zn	0.042
	Pb	0.063
	Li	0.04
	Si	0.1
	Al	0.145

Table 2: Chemical composition of fly ash

Group No.	Element	Wt%
GA	Organic	87
	SiO_2	5.2
	Fe_2O_3	0.1439
	CuO	0.007
	Na_2O_5	0.0112
	K_2O_5	0.0016
	Oxide	Rem

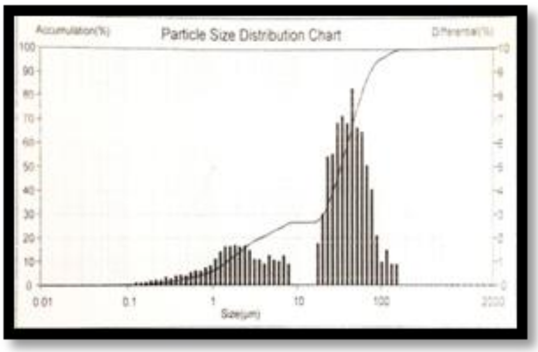

Figure 1: Fly ash particle size distribution chart

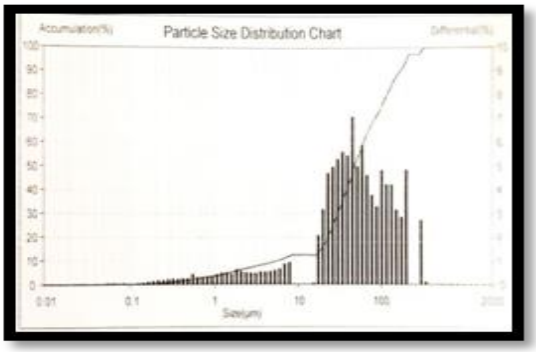

Figure 2: B_4C particle size distribution chart

A Steel rod was linked by an electrical mixer and then inserted into the molten in a crucible, which is kept in the electrical furnace at 700°C. The molten aluminum alloy was stirred at medium speed in order to avoid excessive gas content that resulted from over agitating of melts, which led to unacceptable porosity content in the casting product. 200gm from Al-Cu-Mg alloy were melted in a graphite crucible at more than 100 ºC above liquids temperature at 700ºC. The slag was removed by degassing procedure by using calcium florid and argon gas. The calcium florid was added to molten metal in crucible about 20 minute before adding the reinforcement materials, and the slag, which was formed on the surface of molten metal, was then removed. Every amount of these quantities was wrapped with a thin foil and then added slowly to molten alloy. After each addition of wrapped foil, the molten was quickly stirred by using coated and preheated steel plunger, stirred for 2-3 minutes at speed 300 rpm. Moreover, this process was followed to modify the reinforcement particles distribution through the molten aluminum and prevent the slag from existing inside the molten due to the vortex effect that enables complete dissolution and homogenization, and then the melt was poured into preheated mold. The mold was heated in the furnace at 220ºC for 1 hr. This method could distribute each of fly ash and B_4C powders homogenously in the aluminum alloy matrix by forming vortex in molten metallic. Then the melt was poured into preheated mold, 5-10 minutes after casting, the cast was removed out of the mold. The casting was produced after the addition of fly ash and B_4C .The specimens for microstructure inspection, michrohardness, and wear removed out of the mold. The casting was produced after the addition of fly ash and B_4C .The specimens for microstructure inspection, michrohardness, and wear test were prepared by using wet grinding by a grinder machine (model: MOPAO 160E) and using emery paper grades (220, 320, 500, 1000), respectively under the running tap water, and a polished by a polishing machine model UNIPOL 820) with 5µm and then with 0.5µm alumina slurry. Then, the specimens for optical microscopic examination only were only etched with Killer's solution (1ml HF+1.5ml HCL+ 2.5ml HNO_3 +95ml distilled water).

3. X-Ray Diffraction Inspection

The intermetallic phases which can appear in our hybrid composites after adding the reinforcement elements are examined in the laboratories of (State Company for Inspection and Engineering Rehabilitation-Ministry Industry and Minerals) by using Desktop x-ray diffractometer analyzer of model (Miniflex II) with copper tube of scan rate of 5 (deg/min). Figures 3 to 7 represent the results of x-ray inspection.

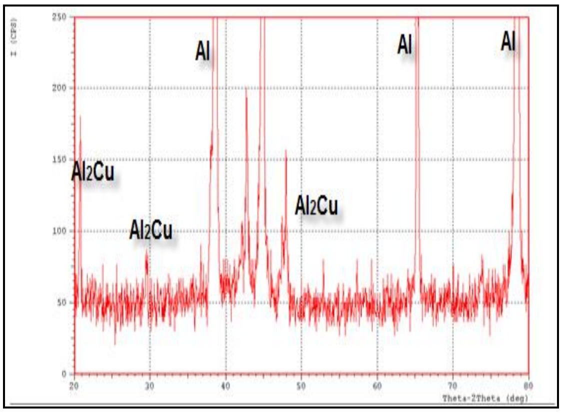

Figure 3: X-Ray diffraction of as cast Al-4.5% Cu-1.18Mg base alloy

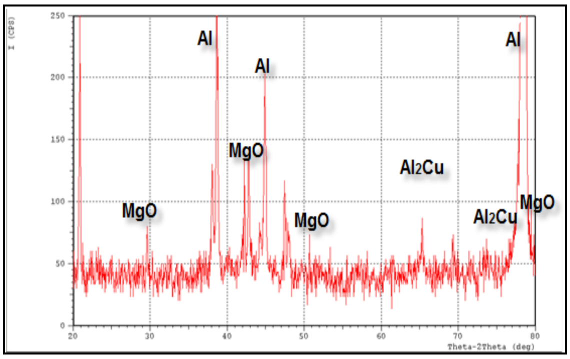

Figure 4: X-Ray diffraction analysis of hybrid composite Al alloy+ 2 wt% B_4C+ 5 wt% fly ash

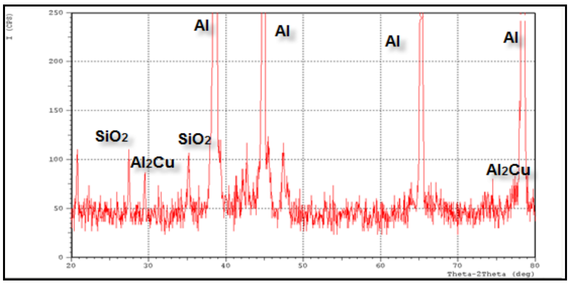

Figure 5: X-Ray diffraction analysis of hybrid composite Al alloy+ 2 wt% B_4C+ 10 wt% fly ash

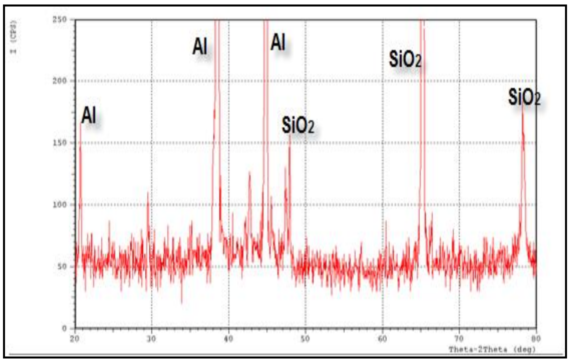

Figure 6: X-Ray diffraction analysis of hybrid composite Al alloy+ 2 wt% B_4C+ 15 wt% fly ash

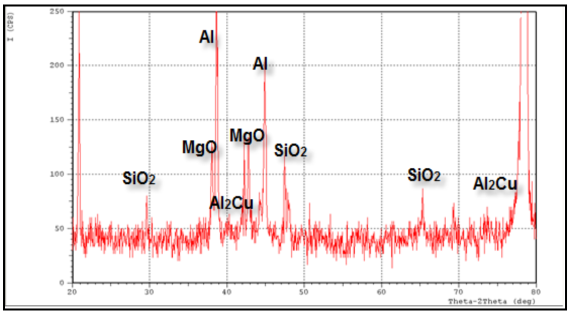

Figure 7: X-Ray diffraction analysis of hybrid composite Al alloy+ 2 wt% B_4C+ 20 wt% fly ash

4. Mechanical Properties Testing

The tensile properties of hybrid composite specimens and there unreinforced alloy were obtained by conducting tensile tests on universal testing machine. The standard tensile specimen test according was prepared to the ASTM standard E8M–00b [7]. While the hardness of samples was measured with Vickers hardness testing machine.

4. Wear Examination

Dry sliding wear tests were conducted using a pin-on-disc apparatus in laboratory conditions at different parameters of normal loads, sliding speeds and times as shown in Table 3 with different associated sliding distances at different. Levels. During sliding, the load was applied on the specimen through a cantilever mechanism, and the specimens brought in intimate contact with the rotating disc at different track radius of 60 mm, 120 mm and180 mm. The wear rate was calculated by weighing the specimens before and after the test. The weight loss of the specimen is calculated by finding the difference between initial and final weight. The measured values of weight loss for all specimens tested were converted into wear rate using specified measured sliding distance according to the experiment level. Wear test experiments were carried out in the department of production engineering and metallurgy. A carbon steel disc was used as a counter face with hardness 35 RC.

The linear speed was calculated as follows:

$$V = \frac{\pi D s N}{1000 \times 60} \quad (1)$$

Where

V: Linear sliding speed (m/sec)

Ds: Sliding circle diameter (mm).

N: Disc rotational speed (510) RPM

The formula used to convert the weight loss in to wear rate is:

Wear rate (weight loss) = $\Delta w/s$ (2)

Where

Δw: Weight loss of the sample (gm)

W1: Sample weight before the wear test (gm).

W2: Sample weight after the wear test (gm).

Total sliding distance (S) in cm was calculated as:

$$S = V x t \quad (3)$$

Where:

t: running time (15 min) at each test

Table 3: Wear rate input parameters and their levels

Level	Load (N)	Speed (mm/s)	Time (min)
1	5	1.413	5
2	10	2.827	10
3	15	4.241	15

6. Taguchi Method

A large number of experiments have to be carried out when the number of the process parameters increases. To solve this problem, Taguchi method uses a special design of orthogonal arrays that helps to study the entire parameter space with only a small number of experiments. Taguchi's techniques consist of an experimental plan to obtain information about the behavior of a process. Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing the variation using an appropriately chosen signal-to-noise ratio (S/N) [8]. In this research, the equation (4) of smaller is better was used to clarify the effect of parameters on wear behavior:

S/N: The ratio of the mean signal (S) to the noise (N) standard deviation.

y: Represents the average output variable of interest measured at specified experiment level.

n: Represents the number of observations.

The signal-to-noise ratio or the S/N number needs to be calculated for each wear rate experiment conducted. While, array of nine experiment runs was used to design the experiments as shown in table (4), Results of the wear rate variation with varied levels of the reinforcement percentage at different parameters are shown in tables (4to 7).

Table 4: Results of Taguchi experiments for wear rate of as cast Al- 4.5% Cu- 1.18% Mg base alloy

Exp. No	Specimen	Load N	Sliding velocity m/sec	Time min	Wear rate gm/cm
1	Alloy	5	1.413	5	4.01x10^-7
2	Alloy	5	2.827	10	0.88x10^-7
3	Alloy	5	4.241	15	0.52x10^-7
4	Alloy	10	1.413	10	5.54x10^-7
5	Alloy	10	2.827	15	1.76x10^-7
6	Alloy	10	4.241	5	3.85x10^-7
7	Alloy	15	1.413	15	8.02x10^-7
8	Alloy	15	2.827	5	11.43x10^-7

9	Alloy	15	4.241	10	9.83x10^-7

Table 5: Results of Taguchi experiments for wear rate of base alloy reinforced with 2-wt% B_4C and 5 wt% fly ash

Exp. No	Specimen	Load N	Sliding velocity m/sec	Time min	Wear rate gm/cm
1	5%fly ash	5	1.413	5	3.53.1x10^-7
2	. 5%fly ash	5	2.827	10	0.70x10^-7
3	. 5%fly ash	5	4.241	15	0.4 7x10^-7
4	. 5%fly ash	10	1.413	10	5.07x10^-7
5	5%fly ash	10	2.827	15	1.57x10^-7
6	5%fly ash	10	4.241	5	3.45x10^-7
7	5%fly ash	15	1.413	15	7.54x10^-7
8	5%fly ash	15	2.827	5	10.84 x10^-7
9	. 5%fly ash	15	4.241	10	4.67x10^-7

Table 6: Results of Taguchi experiments for wear rate of base alloy reinforced with 2-wt% B_4C and 10 wt% fly ash

Exp. No	Specimen	Load N	Sliding velocity m/sec	Time min	Wear rate gm/cm
1	10%flyash	5	1.413	5	2.83x10^-7
2	10%flyash	5	2.827	10	0.58x10^-7
3	10%flyash	5	4.241	15	0.41x10^-7
4	10%flyash	10	1.413	10	4.71 x10^-7
5	10%flyash	10	2.827	15	1.37 x10^-7
6	10%flyash	10	4.241	5	3.22 x10^-7
7	10%flyash	15	1.413	15	7.31 x10^-7
8	10%flyash	15	2.827	5	10.37 x10^-7
9	10%flyash	15	4.241	10	4.48 x10^-7

Table 7: Results of Taguchi experiments for wear rate of base alloy reinforced with 2-wt% B_4C and1 5 wt% fly ash

Exp. No	Specimen	Load N	Sliding velocity m/sec	Time min	Wear rate gm/cm
1	15%flyash	5	1.413	5	2.35x10^-7
2	15%flyash	5	2.827	10	0.41x10^-7
3	15%flyash	5	4.241	15	0.31x10^-7
4	15%flyash	10	1.413	10	4.36 x10^-7
5	15%flyash	10	2.827	15	1.29 x10^-7
6	15%flyash	10	4.241	5	2.75 x10^-7
7	15%flyash	15	1.413	15	6.99 x10^-7
8	15%flyash	15	2.827	5	9.55 x10^-7
9	15%flyash	15	4.241	10	4.20 x10^-7

Table 8: Results of Taguchi experiments for wear rate of base alloy reinforced with 2 wt% B_4C and 20 wt% fly ash

Exp. No	Specimen	Load N	Sliding velocity m/sec	Time min	Wear rate gm/cm
1	20%fly ash	5	1.413	5	2.12. x10^-7
2	20%fly ash	5	2.827	10	0.35x10^-7
3	. 20%fly ash	5	4.241	15	0.18x10^-7
4	20%fly ash	10	1.413	10	3.77x10^-7
5	20%fly ash	10	2.827	15	1.13x10^-7
6	20%fly ash	10	4.241	5	2,67x10^-7
7	20%fly ash	15	1.413	15	6,6x10^-7
8	20%fly ash	15	2.827	5	9.31 x10^-7

9	20%fly ash	15	4.241	10	4.00x10^-7

7. Results and Discussion

Figure 8a shows the microstructure before particulate reinforcement's addition of as cast aluminum alloy, the structure has a dendrite shape and consists of α-Al solid solution and solid solution and eutectic. Figure 8b-e represents the changing occurred in microstructure during addition of 2-wt% B_4C reinforcement particle with separates additions of 5%, 10 %, 15% and 20% of fly ash, respectively. These additions caused refining in α- phase at large percentage of fly ash with a change in the shape of grains into elongate form *as the* ceramic reinforcements have high thermal coefficient of expansion which tend to grains elongation with the direction of temperature. Furthermore, the reason for smaller grains at increasing the fly ash attributed to the nucleation process result from reinforcements positions. By x-ray inspection, it has been observed different intermetallic phases exist in microstructure such as SiO_2, Al_2Cu and MgO reinforcement to Al-4.5%Cu alloy matrix also the presence of different intermetallic compounds , these causing an increase in ultimate tensile strength and yielding of hybrid composite specimens until they reached to the maximum value at 15 wt% fly ash. The increasing in ultimate tensile strength and yield strength of the composites is due to reasoned to the strong interfaced that transfers and distributes the load from the matrix to the reinforcements. Further, the heating of reinforcement particles prior to the mixing process results in strength improvement [9,10]. Also, the dispersion of B_4C & fly ash particles of higher strength at the grain boundaries of soft and ductile strength at the grain boundaries of soft and ductile alloy matrix results In strength enhancement. Moreover, increasing in UTS and YS resulted in a reduction in composite grain size at large content of fly ash and generation of high dislocation of a high dislocation density in the matrix. At 20% wt fly ash addition the ultimate tensile strength and yield strength.

8. Wear examination

Figures 8 to 10 showed that the effect of normal applied load (5, 10, 15) N, sliding velocity (1.423, 2.827, 4.241) m/sec and sliding time (5, 10, 15) min on wear rate.

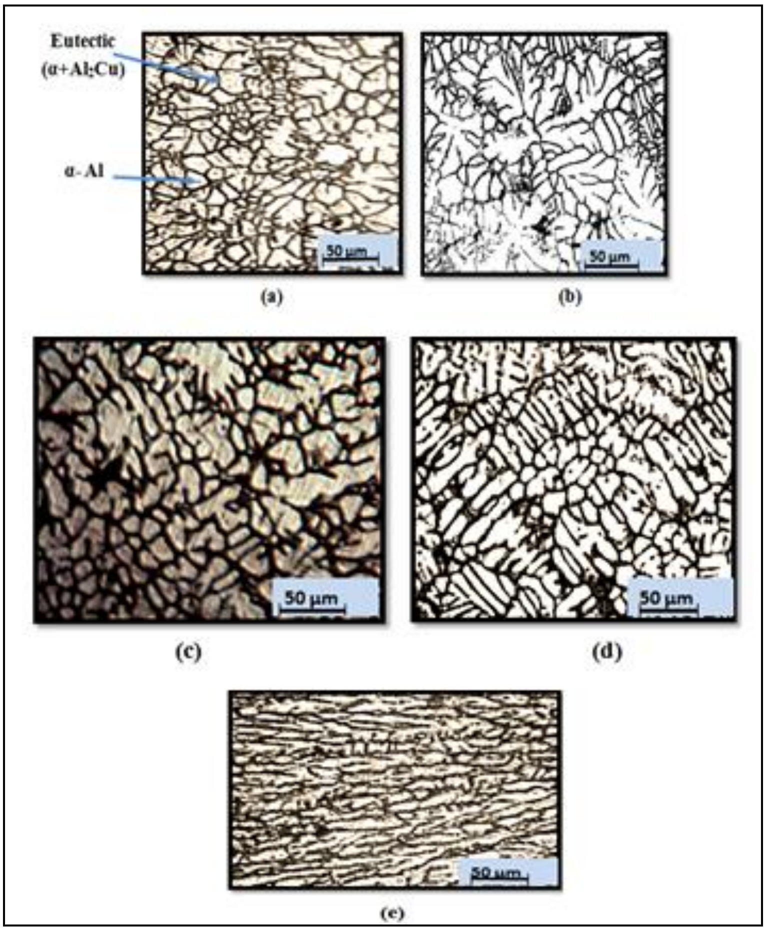

Figure.8: Optical microstructure of a- Al-Cu- Mg base alloy, b- hybrid composite of 5 wt% fly ash, c- hybrid composite of 10 wt% fly ash, d- hybrid composite of 15 wt% fly ash, e- hybrid composite of 20 wt% fly ash. Mag.Mg

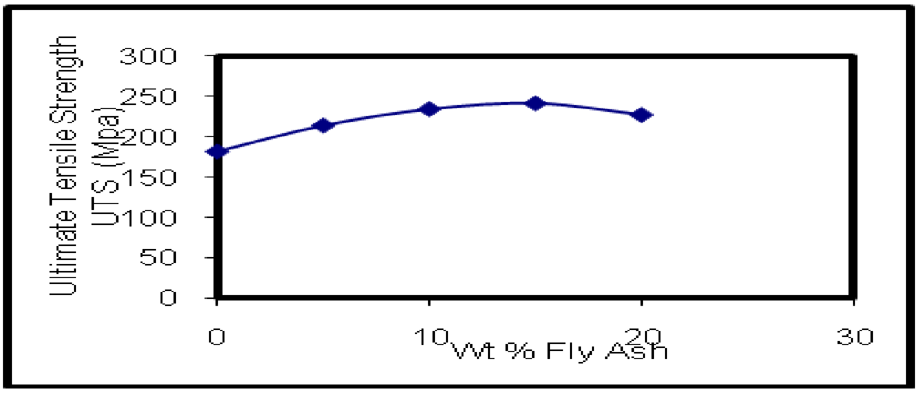

Figure 9: Effect of weight percentage of fly ash with 2 wt% B_4C particulate on ultimate tensile strength of Al- Cu- Mg alloy

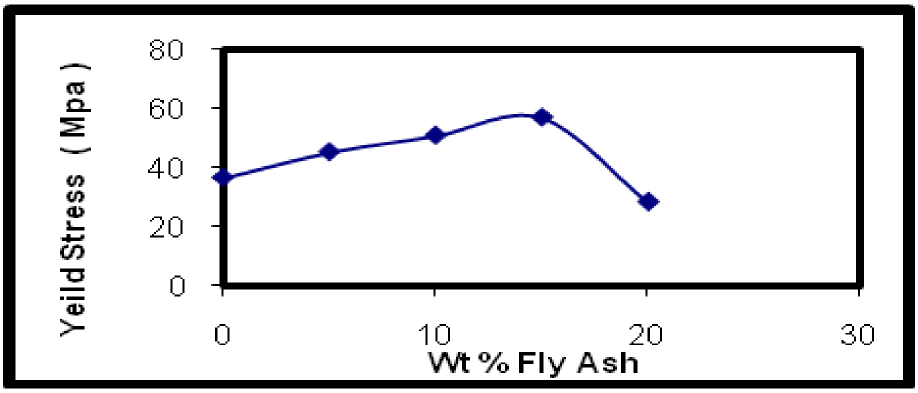

Figure. 10: Effect of weight percentage of fly ash with 2 wt% B_4C particulate on yields strength of Al- Cu- Mg alloy

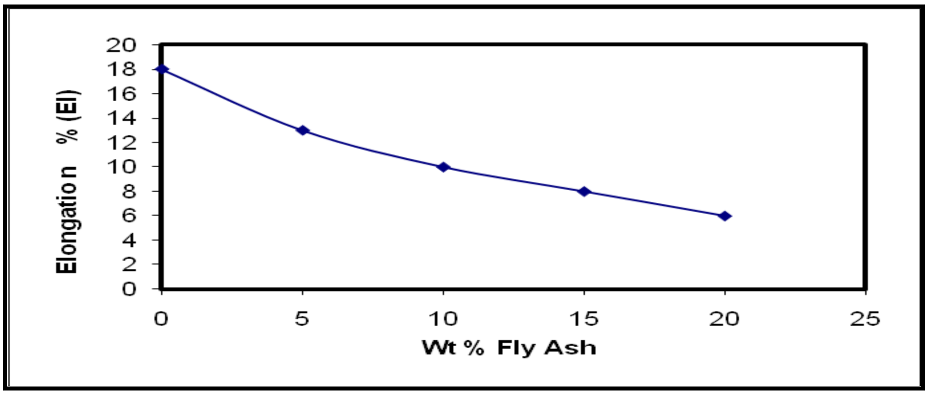

Figure 11: Effect of weight percentage of fly ash with 2 wt% B_4C particulate on elongation of Al- Cu- Mg alloy

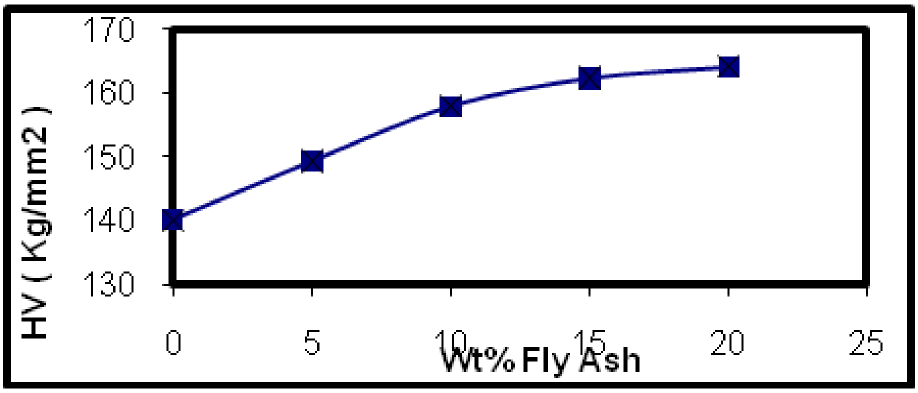

Figure12: Effect of weight percentage of fly ash with 2 wt% B_4C particulate on the hardness of Al-Cu-Mg alloy

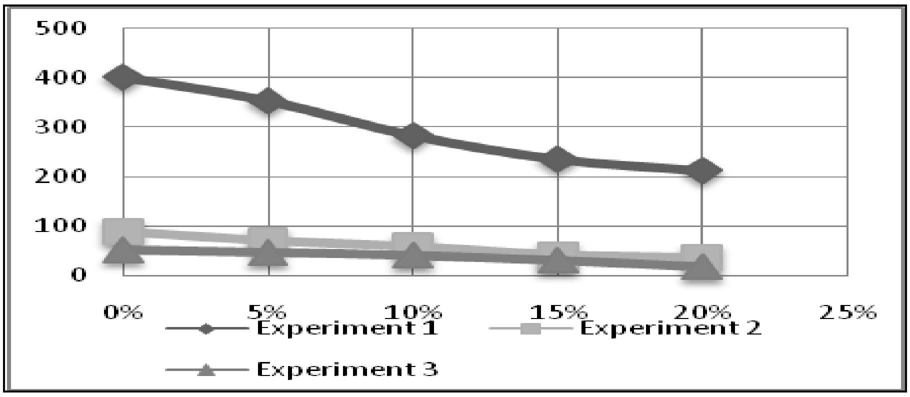

Figure13: Variation of wear rate with weight percentage of fly ash

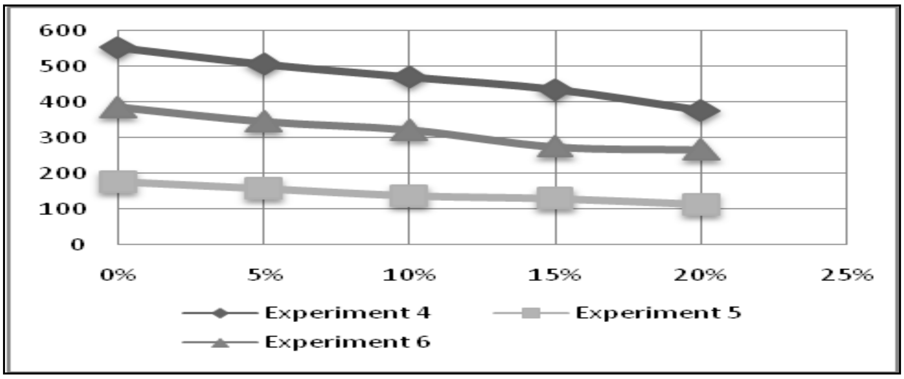

Figure 14: Variation of wear rate with weight percentage of fly ash

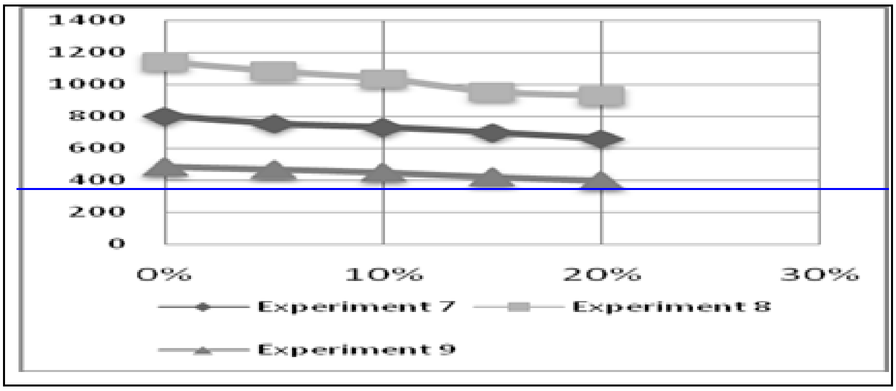

Figure15: Variation of wear rate with weight percentage of fly ash

The wear rate varies with the value of normal load. The weight loss. Increases generally with increasing applied normal load, this cause of increase in the wear rate at increasing of applied load due to increasing plastic deformation at tip of the specimen surface asperities. This can be explained by increase in the dislocation density and little increase in the hardness and brittleness of the base alloy. The wear resistance increased with increasing the fly ash content because the hardness increased due to the precipitates of the intermetallic compounds Al_2Cu, MgO and SiO_2 After completing the analysis of signal to noise ratio data, it's obvious that the applied load is the most dominating factor controlling the wear behavior, its effects on the wear rate of unreinforced alloy and hybrid composites is significantly showed in Table 10.

Table 10: Optimum design of parameters as a function of different conditions

Specimen	Highest S/N ratio	Experiment No.
Al-Cu-Mg alloy	145.67	3
Al-Cu-Mg alloy+5%fly ash	146.55	3
Al-Cu-Mg alloy+10%fly ash	147.74	3
Al-Cu-Mg	50.17.1	3

alloy+15%fly ash		
Al-Cu-Mg alloy+20%fly ash	154.89	3

It was noted that the wear resistance of the hybrid composite with a content of 20 % fly ash represents higher wear resistance than the base alloy and the other composite materials. Sliding velocity is one of the mechanical extrinsic factors that have an effect on wear behavior; it depends on both time and sliding distance. In a more illustrative, when the sliding velocity increased, more sliding distance will be covered by the sample in minor period, so the wear will be achieved faster. At a low sliding velocity, the wear mechanism described as fatigue-related surface cracking. Wear debris are small, and the wearing surface covered with oxide layer. In more obvious, the wear process proceeded with the removal of material by fracture of the reinforcement and the matrix due to high friction, which result in high wear rate. While at an intermediate speed, the wear rate was reduced. The predominant wear process was the formation of micro-grooves; these grooves were observed to form in fractured regions of the reinforcement and the matrix. It was suggested that the adhesive and abrasive wear the predominant mechanisms at low and intermediate sliding speeded. At higher sliding speed, a transition in the wear process occurred, which was associated with a breakdown down, of the tribolayer and wear binging controlled by sub-surface cracking-assisted adhesion transfer and by abrasion. In such case, the wear rate increase due to increase of instant temperature rises with increasing of sliding speed, when his happened, softening phenomenon will occur on.

8. Conclusions

1- Stir casting achieved homogenous distribution of particles in Al- matrix; they introduce some degree of refining and elongation in primary α-Al grains structure with increasing of fly ash amounts.

2- Ultimate tensile strength and yield strength increased gradually with increasing the weight percentage of fly ash up to 15% by weight, beyond this amount the strength of composite decreased gradually. While, total elongation and impact strength values decreases with the increase in weight percentage of fly ash amount.

3- Hardness value of Al-4.5% Cu-1.18% Mg base alloy is improved with the increase of fly ash reinforcement percentage as the peak hardness value was achieved at 20 wt% of fly ash.

4- Wear rates behavior of the hybrid composite specimens have been studied at different used parameters of applied load, sliding speed and time, the results show that wear rate is decreasing with the increase of fly ash percentage gradually

5- Taguchi method calculations have been used to design the wear experiments with clarifying the effect of each parameter on wear rate; the results showed that applied load is the main parameter affects the wear behavior by 48% of total effect.

Acknowledgement

I would to thank the head of production engineering and metallurgy department for financial support and help.

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