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Effect of Fly and Dust Ash Additions on Hardness and Wear Resistance of Composite Metal Matrix (Al-Si-Mg)

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Abstract

The current paper deals with the preparation of bars with a length of about 13 cm and 2.5 cm diameter from MMC materials. These composites consists of cast (Al-Si-Mg) as a matrix that reinforced with fly ash (0.454 μm) or fly dust (0.620 μm) in relative weights (2, 4, 6, and 8%) respectively. Both of composite materials samples were manufactured by casting method (Vortex method). Vortex method has been used successfully to obtain a homogeneous distribution of reinforcement particles. Samples were classified into two categories according to the type of reinforcement particles. The results showed that the wear rate of the samples depends heavily on the working conditions. Which increases with increased load and download time.The results also showed superiority aluminum alloy reinforced fly ash compared with the aluminum alloy reinforced with dust flying. Furthermore, a significant increase in the hardness and wear resistance for all samples prepared with increasing added particles for the purpose of reinforcement.

Keywords: Aluminum metal matrixes composite, Fly ash, fly Dust, Hardness and Wear

تأثير اضافة دقائق من الرماد المتطاير والغبار المتطاير على صلادة ومقاومة البلى لمادة متراكبة ذات اساس معدني (AL-Si-Mg)

الخلاصة

يتناول البحث الحالي تحضير قضبان بطول حوالي 13 سم و قطر 2.5سم. من مواد متراكبة من مسبوكة (المنيوم – سليكون - مغنيسيوم) كماده اساس والتي تم تقويتها بواسطة الرماد المتطاير بحجم حبيبي مقداره (0.454 ميكرون) أو الغبار المتطايرة ذات حجم حبيبي (0.620 ميكرومتر) وبا الأوزان النسبية (2 ، 4 ، 6 ، و 8 ٪) على التوالي. صنعت كل من عينات المادة المتراكبة بواسطة طريقة الصب (أسلوب دوامة). وقد استخدمت هذه الطريقة بنجاح للحصول على توزيع متجانس لدقائق التقويه. فقد تم تصنيف العينات المحضره الى فئتين وفقا لنوع دقائق التقويه المضافه. وأظهرت النتائج أن معدل البلى للعينات يعتمد اعتمادا كبيرا على ظروف العمل. حيث يزداد مع زيادة التحميل ووقت التحميل . كما أظهرت النتائج تفوق سبائك الألومنيوم المقواة بالرماد المتطاير بالمقارنة مع سبائك الألومنيوم المقواة بالغبار المتطاير. وعلاوة على ذلك ، تم تسجيل زيادة ملحوظة في الصلاده ومقاومة البلى لكافة العينات المحضرة مع زيادة الحبيبات المضافه لغرض التسليح

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1. Introduction

Aluminum alloys used in various industries, especially in aircraft industry, are subject to low resistance due to use. That leads to a change in its mechanical properties, especially when they are exposed to working circumstances of overload and high temperatures [1]. That thing has motivated many researchers to focus their efforts on the possibility of using aluminum alloys in the producing of aluminum matrix composite materials reinforced by fiber and ceramic particles. This has acquired a great importance for the low cost and good properties, such materials enjoy high resistance and good wear strength in comparison with non composite materials [2].

Researcher Milliere et al. studied the properties and the methods of production of composite materials with matrix of (Al-7%Si) reinforced with silicon carbide by using of squeeze casting method, it was noted that this method led to obtain a homogeneous material. Furthermore, resulting in improved the wear resistance, hardness, and tensile and compression strength for the matrix [3]. Addition of fly ash particles as reinforcement in metal matrix (Al-12%Si) composite and synthesis by squeeze casting technology in comparison with gravity casting are advantageous for obtaining higher structural homogeneity with minimum possible porosity levels, good interfacial bonding and quite a uniform distribution of reinforcement. Moreover, it was concluded that increasing the proportion of particles of fly ash increases the corrosion resistance of material prepared [4].

The effect of fly ash addition on the mechanical properties and microstructural behavior of aluminum casting alloy A535 were investigated in the as-cast and solution heat treated condition. It was found that the Charpy impact energy decreased with increasing fly ash content, the decrease in the mechanical properties of the composites is attributed to the decrease in the solid solution strengthening magnesium as well as an increase in porosity and particle clustering with increasing of fly ash content to (15%) [5].The microstructure of cast Al-4%Si-3%Mg reinforced with fly ash particles at various particle contents has been studied. The composites were fabricated by stir casting process. The results showed that particle contents affected to the presence of porosities and hardness of the composites. It was observed that the increasing of fly ash content up to 10 wt% increases the porosity in the composites, with the matrix alloy reinforced with 15 wt% of fly ash particles having the highest porosity and lowest hardness [6].

The mechanical properties and wear behaviors of metal matrix composite materials are functions of manufacturing processes (hot isostatic pressing, powder metallurgy technique, and stir cast method). Some factor such as the type of matrix, volume fraction of reinforcement particle size and their distribution as well as surface state (roughness) and heat treatment basically influence their mechanical behaviors particularly wear behaviors in service conditions.

Constitution, processing microstructures and properties of MMCS is available from other sources [7-15].

The present research had dealt studied the effect of particles addition from fly ash and fly dust that nano-particle size to matrix alloy (Al-Si-Mg) were prepared by stir casting method. This study investigated the effect of these particles on hardness and wear resistance of the composite material.

2. Experimental Procedure

Matrix alloy (Al-7%Si-1.5%Mg) was prepared from an ingot alloy (Al-12%Si). Chemical composition analysis is shown in Table (1). Melting practices were done in an electrical resistance furnace by using a graphite crucible at 750˚C. Pure Al (99.99%) was added to the matrix alloy to tuning the Si percentage to 7w%, some of Mg chips in mount of 1.5% after it was coated with aluminum foils are add to inside the metal molten. The molten mixture was then poured into a preheated (250C˚) cylindrical cast iron mould. Chemical composition analyses were repeated again for the prepared material ingots as shown in Table (2).

The synthesis of the composite was carried out by stir casting. The ingots of (Al-7%Si-105%Mg) alloy were taken in a graphite crucible and melted in an electric furnace. The temperature was slowly raised to 800^{o}C. In this process, the matrix alloy was first superheated above its melting temperature to create a vortex in the melt using a stainless steel mechanical stirrer coated with aluminates (to prevent the migration of ferrous ions from the stirrer material the aluminum alloy melt). The depth of impeller is approximately one third of the height of the molten from the bottom of the crucible. Al this stage the preheated (500^{o}C for 3 hours) fly ash or fly dust particles were slowly added into the melt, and the stirring was continued for about five minutes at an average stirring speed

of 500 rpm. The molten metal was poured into preheated (250^{o}C) cast iron mould of 2.5 cm in diameter and 15cm high.

composite materials samples were sorted into two groups, the first group is composite material that reinforced by Fly ash particles with particle size (0.454 µm) the particle size analysis was done as shown in figure(1) with chosen weight percentage (2,4,6,8%), chemical analysis was done for fly ash shown in Table (3).

The second group is composite materials samples that reinforced by fly dust particles with particle size (0.620 µm) the particle size analysis was done as shown in Figure (2) with chosen weight percentages (2,4.6,8%), chemical analysis was done for fly dust shown in Table (4).

Microhardness measurements

Vickers microhardness of the unreinforced alloy and composites was measured using digital microhardness tester at a load of lkg for 5sec, five measures were taken for each sample, then calculating the average values

Wear testing of samples

A pin –on-disc apparatus was used to investigate the dry sliding wear characteristics of the aluminum alloy and composites. Wear sample 10mm in diameter and 20mm high were cut from as-cast sample machined and then polished metalograpically. Carbon steel disc had been used with the hardness of (HRc=45) and the average disc speed was (510 r.p.m). Wear tests were conducted with loads (5, 10, 15 and 20 N) and sliding time that are used to measure the wear rate are (20, 30, 40, 50 and 60min). All tests were conducted at room temperature. The initial weight of the specimens was measured using a single pan electronic weighing machine with an

accuracy of 0.0001 gm. During the test the pin was pressed against the counterpart rotating against a steel disc. All the specimens followed a single – trunk. After running through a fixed sliding distance, the specimens were

removed, cleaned with acetone, dried, and weighed to determine the weight loss due to wear. The differences in weight

measured before and after tests give the wear of the composite specimen. The wear rates for samples are calculated from the following relation [16]:-

Wear rate (Wr) $=Vr/S_D$

Where

Vr= volume of removed material (mm^3) $= \Delta w/\rho$

S_D=sliding distance of material removal (mm) $= \pi Dnt$

Δw=lost weight after the test

P = density of the material

There fore

$Wr = \Delta w/\rho\pi Dnt$ (mm^3/mm)

D=distance from the centre of specimen to the center of disc (mm)

n = average disc speed (510 r.p.m)

T=time of test in minute

The wear rates of the composite were studied as a function of the weight fraction of reinforcement, applied load, and time of test.

Microscopy studies

The fabricated composites were subject to metallographic examination in order to establish their structural characteristics. The specimens of 20mm diameter and

1.5mm thickness were cut from the as-cast specimens for microstructural examinations. The specimens were carefully polished for metallographic examination. The microstructures of the samples were investigated by means of optical microscopy. Keller's reagent with composition of HF = 1.0 cc, HCl = 1.5 cc, HNO_3 = 2.5 cc and H_2O = 95 cc was used as etching reagent.

3. Results & Discussion

3.1 X-Ray Diffraction Results

X-ray diffraction at room temperature for the prepared models shown in figures (3-a, b, c), it was observed precipitating of the solid phases Al and Si in both matrix alloy and composite material in addition to the presence of intermediate phases of (AlFeSi) that would show an evidence of the reaction of cast elements presents in the matrix alloy with aluminum.

3.2 Hardness results

Hardness test is good indication of the materials strength, so that it is considered firstly in this work. Generally, hardness values were increased as the percentage of particle added was increased as shown in Figure (4). The increasing of hardness values belong to the hard of reinforcement particle which were particles size are less than (1μm). These particles with the very small sizes are going to dispersed in matrix alloy that in turn hinder the dislocation movement. This is due to the presence of hard particles inside the matrix alloy at different percentages, different particle size and also at the different distance between particles.

The existence of ash and dust particles in the matrix works as an obstacle and hinder the movement of dislocation. This obstruction will be increased as the percentage of added particle was increased. Therefore the penetration of dislocation through these scattered particles requires an increasing in the applied stress that is very enough to bending dislocation line and that leads to an increasing of hardness values [11, 17].

It is noted from Figure (4) that the hardness value of the composite material reinforced by fly ash is higher than the composite materials reinforced with fly dust particles that may be related to the components of fly ash particles contain hard particle represented in the high rates of alumina and silica. While the dust particles contain low rates of silica with high rates from LiO, CaO particles as shown in Table (4) which have relatively low hardness value.

3.3 Wear test results

Figure (5) shows the effect of particle reinforced on wear rate at constant load (10 N) and at time 20 min; it was observed that the wear rate of the matrix alloy decreases with increasing percentage of particle addition. It can also be observed from figure (5) that, the wear resistance of fly ash – composite is higher than that fly dust – composites. The reason behind such superiority is the composition of fly ash that contains high percentage of alumina and silica as shown in Table (3) compared with fly dust that improved the hardness and increase wear resistance.

The relationship between wear rate and applied load at a constant time (20 Min.) for matrix alloy and composite materials are shown in Figure (6-(a, b)), wear rate increases with increasing of applied load. The wear behavior of the alloy can be divided into three parts: mild wear, which occurs among the load value 5-10 N. The debris wear is tiny particle with forming of protected oxide film which reduces the contact area between a sample and the disk, which leading to reduction of wear rate. While the transition wear occurs in area between (10-15N). And sever wear which occurs among the load values (15-20N) when the wear debris particles are big and metal. Then, the formed oxide layer is breaking and leading to a contact with protrusions of the two surfaces and then breaking those protrusions and separate from the surfaces [18]. The load value has a direct effect on the plastic deformation that which occurs at the peaks protrusions and the areas near the surface. The intensity of dislocations increases and their movement are activated. Therefore, plastic deformation increases with increasing of applied load. Then, the dislocations are assembled forming small gaps approach each other to form tiny cracks, the process of removing the thin layers from the metal to form wear debris [18]. It is noted from these figures that the wear transition area become clearer after adding these particles within the rang of applied load (10-15). On the other hand, transition load influences by the rate of ash and dust particles which increase on 4% in which these figures shows high transition from oxidation wear to metallic wear. It was also observed from the two figures that wear rates decreased for the entire applied load with the increase the weight rates of the added particles either it was fly ash or fly dust. That is related to hard added particles which increase the values of hardness for the samples. Thus, wear rates are decreased [7].

A figure (7-(a, b)) shows the influence of loading time in wear rates at constant load (10N) for both groups. It was found that the wear rates of basic alloys and reinforced composite materials increases with the increase of loading time until 40 minutes. Then, wear rate is stable with the increase of loading time. Also, it is noted that the wear rates decreases with the increase of weight ratio for the added particles with the increase of wear time because of the nature of abrasive resistance of the fly ash particles as well as fly dust. Especially, both powders have tiny particle size (0.454 μm), (0.620 μm) respectively. Thus, the estimation of particle which will launch from material surface will decrease with time. Accordingly, the particles content which retention in matrix material will lead to the increase of resistance and consequently increase of wear strength.

4.3 Microstructure observations

From Figure (9), it was found that the microstructure of matrix alloy contains primary aluminum phase around by network eutectic from (Al-Si) with Si crystals presented along Al grains, the microstructure test and x-ray diffraction not observed the presence of any Intermetallic phases.

Figure (10(a, b)) showed the microstructure of composite material reinforced with fly ash and fly dust at percentage (6%), from these figures clearly shows the distribution of disperse particle in homogeneous way inside the matrix alloy, with no void and discontinuities observed. There was good interfacial bonding between the fly ash or fly dust particles and matrix material. Also it is observed from these figures the occurrence of granular softening form primary aluminum phase, with silicon slices still in the form of needle particles and a limited decrease in distances between the silicon particles.

4 .Conclusions

1- Both of fly ash and fly dust particles are dispersed in the matrix alloy, and in turn increase the hardness.
2- Metal matrix composite reinforced by fly ash showed better hardness than the metal matrix composite that reinforced with fly dust.
3- Addition of fly ash and fly dust particles on the other hand causes a decreasing in wear rate of metal matrix according to the change in the applied load.
4- Wear rate decreases with the increasing percentage of particles addition, wear rate of metal matrix composite reinforced with fly ash decreases higher than metal matrix composite reinforced with fly dust.

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Table 1: Chemical composition of the matrix alloy ingot.

Al	Si	Pb	Mg	Zn	Mn	Cu	Fe	Element
Rem.	11.44	0.02	0.27	0.25	0.22	0.88	0.6	%

Table 2: Chemical composition of the matrix alloy used in this study.

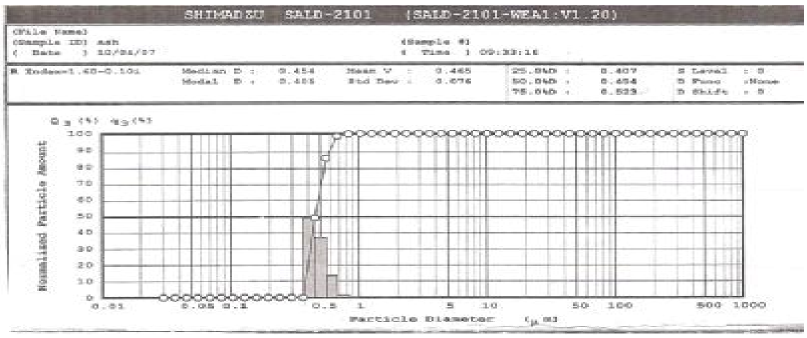
Al	Si	Pb	Mg	Zn	Mn	Cu	Fe	Element
Rem.	7.4	0.019	1.4	0.25	0.15	0.8	0.8	%

Table3: The chemical composition of Fly Ash.

LOI	Na_2O	P_2O_3	Mn_2O_3	K_2O	MgO	CaO	Tio_2	Fe_2O_3	Al_2O_3	SiO_2	Element
1.84	0.74	0.34	0.31	3.59	0.05	0.84	1.4	4.99	27.7	58.2	%

Table4: the chemical composition of fly Dust

LOI	SO_3	LiO	MgO	CaO	Al_2O_3	Fe_2O_3	SiO_2	Element
0.11	9.48	29.30	4.80	38.08	3.02	2.91	12.30	%



Figurer 1: Analysis particle size of fly ash.

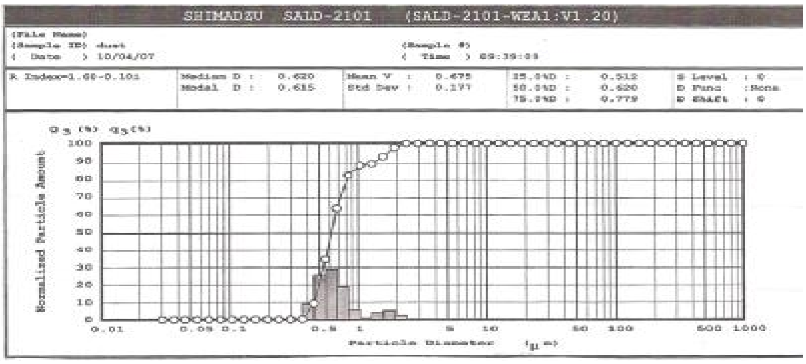


Figure2: Analysis particle size of dust ash.

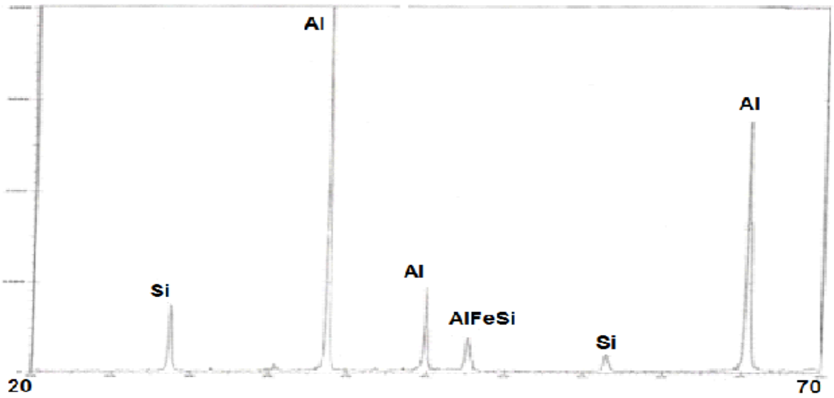


Figure 3a: XRD patterns of Matrix alloy.

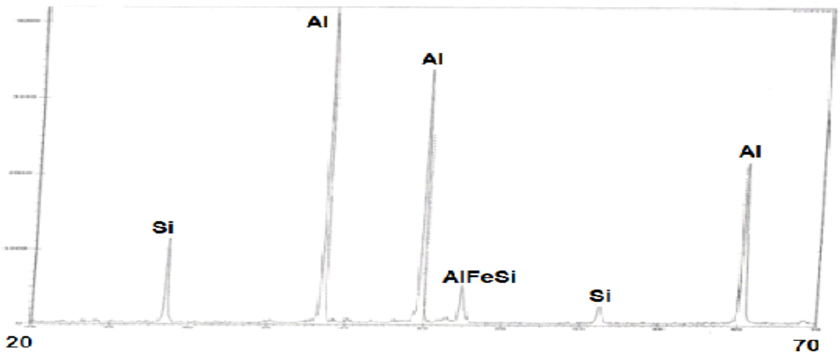


Figure 3b: XRD patterns of Metal matrix composite reinforced by 8% fly ash.

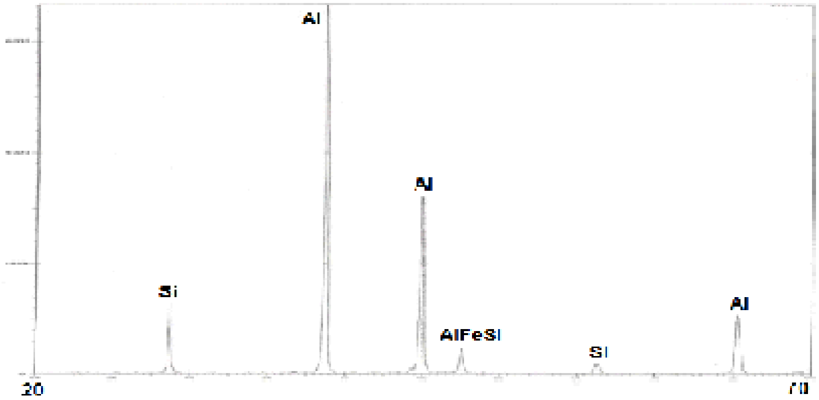


Figure 3c: XRD patters of Metal matrix composite reinforced by 8% fly dust.

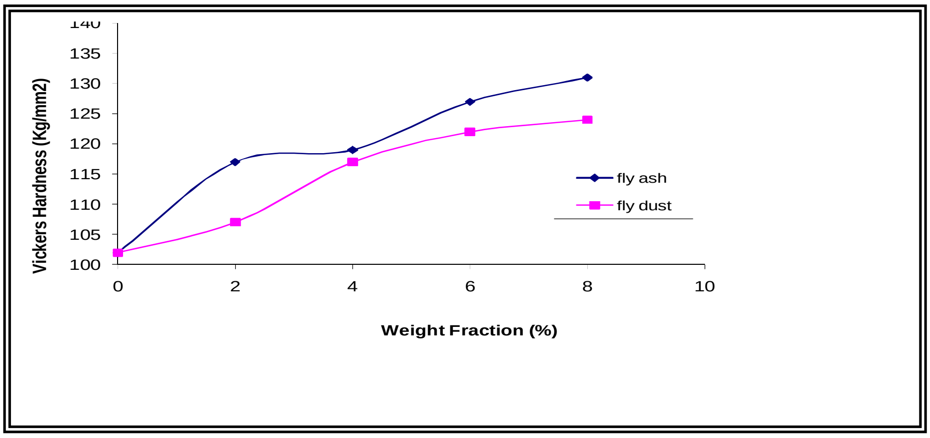


Figure (4): Effect of particle addition on matrix alloy on hardness values.

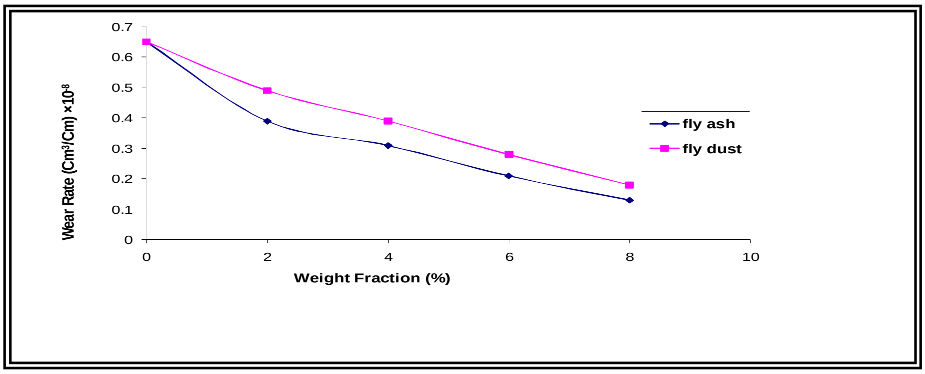


Figure (5): Relationship between wear rate and added Particles.

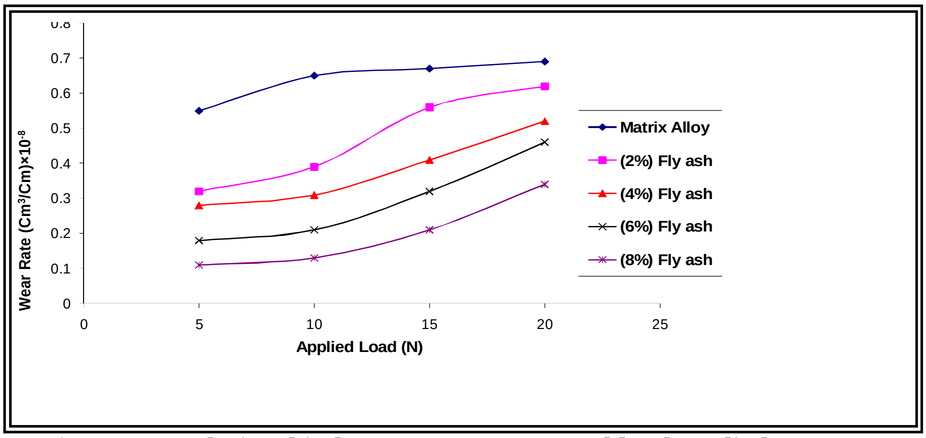


Figure 6a: Relationship between wear rate and load applied to metal matrix composite reinforced by fly ash.

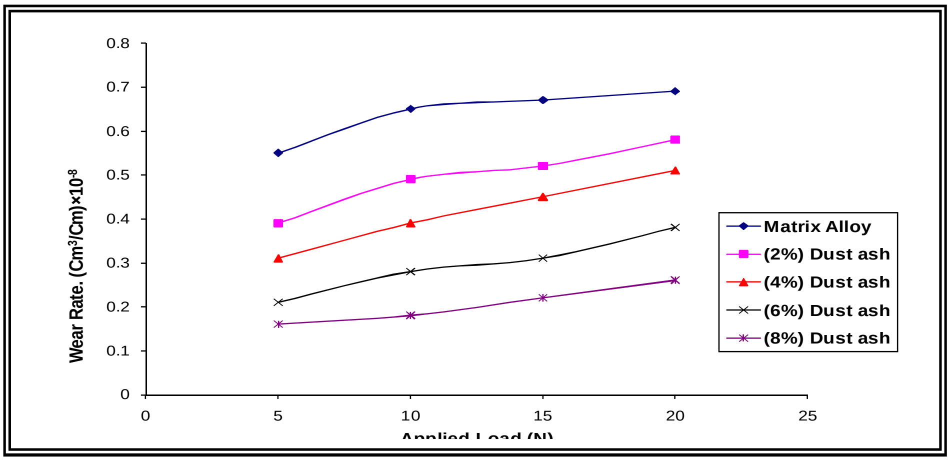


Figure 6b: Relationship between wear rate and load applied to metal matrix composite reinforced by fly dust.

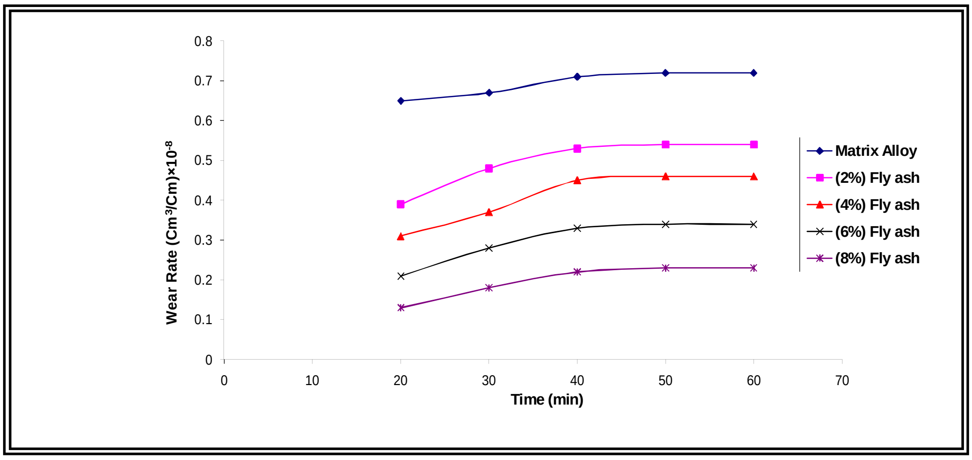


Figure 7a: Relationship between wear rate and loading time for matrix composite reinforced by fly ash.

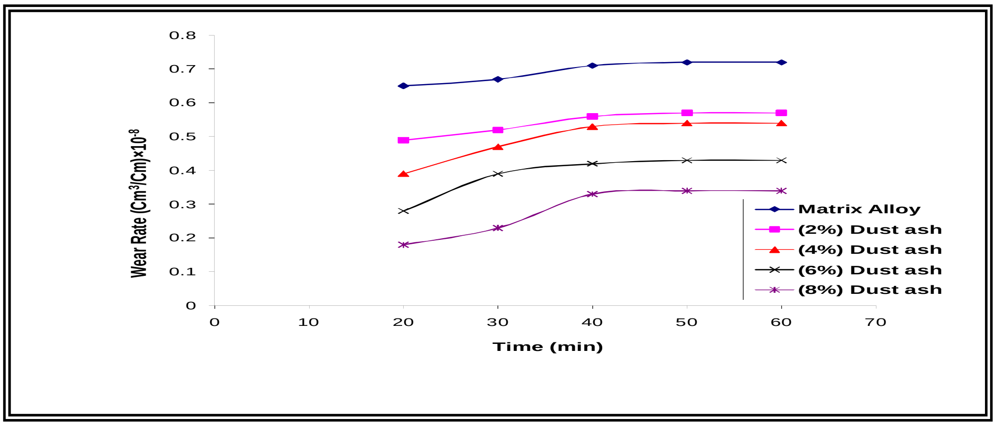


Figure7b: Relationship between wear rate and loading time for matrix composite reinforced by dust ash.

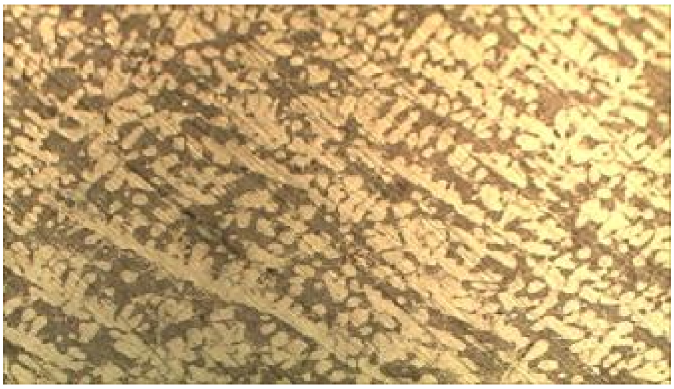


Figure 9: Microstructure of matrix alloy (200X).

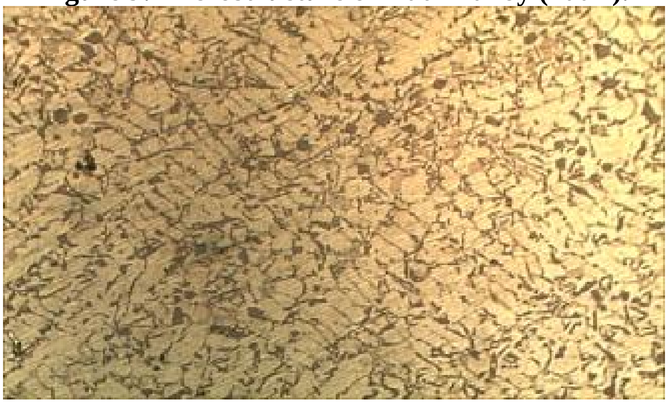


Figure 10 (a): Microstructure of metal matrix composite reinforced by fly ash (200X).

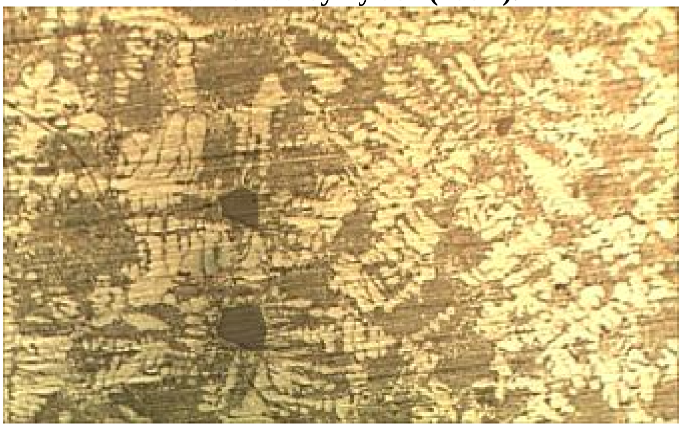


Figure 10(b): Microstructure of metal matrix composite reinforced by dust ash (200X).