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EFFECT OF CARBON FIBERS ADDITION ON WEAR BEHAVIOR OF AS41 MAGNESIUM ALLOYS

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ABSTRACT

The objective of the present study is to evaluate AS41 alloy in adhesion wear and the effect of carbon addition on that behavior. In the present work, experimental study has been carried out to characterize and evaluate magnesium alloys AS41 and AS41+C. Different techniques have been used to investigate the microstructure, hardness and wear behavior of AS41 and AS41+C. The dominance of a wear regime is discussed in the light of SEM micrographs of worn surfaces. The wear experiments have been carried out under conditions of varying speed as well as varying load. The results of this study have highlighted the wear behavior of the AS41 and AS41+C alloys matrix composites. The results indicate that the AS41+C had the highest wear resistance followed by the AS41 alloy under both conditions, of constant speed and increasing load. Also, the same orders of decreasing wear resistance as that of decreasing hardness. Only the use of cheap materials both the alloy and the reinforcement in relation to cost effective production processes for manufacturing of magnesium based MMCs can introduce this class of low density materials for automotive and light industries.

تهدف هذه الدراسة الى تقييم سلوك البري لسبائك المغنيسيوم AS41+C , AS41. لتحقيق هذا الهدف تم عمل تجارب معملية لتوصيف وتقييم هذه السبائك. استخدمت تقنيات مختلفة لفحص البنية المجهرية، الصلادة، وسلوك البري. وتم مناقشة طبيعة البري للاسطح البالية في ضوء الماسح المجهري الالكتروني. وقد اجريت تجارب البري في ظروف سرعات مختلفة فضلا عن أحمال متغيرة. وأظهرت نتائج الدراسة سلوك البري للسبيكة AS41 والسبيكة المؤتلفة AS41+C. وتشير النتائج أن السبيكة المؤتلفة AS41+C لها مقاومة للبري أعلي ثم السبيكة AS41 تحت كل الظروف، من سرعة ثابتة وتحميل مختلف . أيضا نفس النتيجة عندما تنخفض الصلادة تنخفض مقاومة البري. باستخدام مواد اقتصادية لكل من السبيكة والتقويات فيما يتعلق بتكلفة عمليات الانتاج يمكن تصنيع مواد مؤتلفة الاساس فيها المغنيسيوم ذات الكثافة المنخفضة بالنسبة للصناعات الخفيفة والسيارات.

***Keyword**:* wear; adhesive; magnesium alloys; AS41; AS41+C.

1. INTRODUCTION

Today's interest in magnesium alloys for automotive applications is based on the combination of high strength properties and low density [1]. For this reason magnesium alloys are very attractive as structural materials in all applications where weight savings are of great concern. In automotive applications weight reduction will improve the performance of a vehicle by reducing the rolling resistance and energy of acceleration, thus reducing the fuel consumption and moreover a reduction of the greenhouse gas CO_2 can be achieved [2]. They are, however, poor to the mechanical properties, such as Young's modulus, tensile strength, hardness and heat resistance. In particular, when applying them to friction materials, the wear or seizure phenomena easily occur by magnesium leads to solid solution hardening and grain refinement contacting with the counter materials [3–5].

Therefore, the additives of hard particles and lubricants are effective to improve the mechanical and tribological properties of the conventional magnesium alloys [6–9].

Currently, the three main systems of magnesium alloys used commercially from die casting processes are magnesium-aluminum-zinc (AZ) such as AZ91, magnesium-aluminum-manganese (AM) such as AM60 and magnesium-aluminum-silicon (AS) such as AS41. The most important commercial magnesium wrought alloy is AZ31. Also magnesium composites are being developed in order to reach the same properties as those reached by aluminum metal-matrix composites. The addition of aluminum and zinc to alloy strength. Also the tribological properties of the sintered magnesium material were significantly improved which results in an increase in the by the additive reinforcement, and the friction coefficient was low and stable under the dry sliding condition [10].

Magnesium-matrix composites are being developed in order to reach the same properties as those reached by aluminum-matrix composites. Magnesium serves as an excellent matrix for metal-matrix composites as it has an excellent bonding affinity to the reinforcing materials. Magnesium composites can be manufactured using continuous casting, squeeze casting, diffusion bonding and powder metallurgy.

In practice, the two main criteria among which lies the choice of using either aluminum or magnesium as a matrix are the weight versus the corrosion resistance. The main principle of metal-matrix composites is the incorporation of a high performance second phase, such as carbon, metallic or ceramic addition, into a conventional engineering material, such as aluminum, magnesium or titanium, to produce a combination with features that are not obtained from any of the individual constituents by itself.

Magnesium alloys reinforced with discontinuous aluminum oxides or silicon carbides are being investigated to be used in commercial automobile pistons as their wear properties are superior to other typical magnesium alloys.

Magnesium matrix composite used for engine components and low expansion electronic materials [2]. Also grain size is a very important factor that influences the behavior and a lot of the properties of magnesium and its alloys.

Several wear mechanisms have been suggested to explain how material is removed from the surface during abrasion. These mechanisms include plowing, wedge formation, cutting, microfatigue and microcracking. Dobrzanski et.al. [11], have investigated the mechanical properties and wear resistance of magnesium casting alloys of AZ12-1, AZ91, AZ61 and AZ31 in the as cast as well as under different heat treatment conditions. Their research concluded that there exists a high coloration between the hardness and the wear behavior for magnesium alloys. Among the four different tested alloys, the highest hardness was for the AZ12-1 alloy while the lowest was for the AZ31 alloy. Accordingly, the highest adhesion wear resistance was for the AZ12-1 alloy and the lowest was for the AZ31 alloy. This shows the importance of the addition and the effect of increasing the aluminum content in the magnesium alloys causing a profound effect on mechanical properties, especially hardness and wear resistance.

The wear behavior of magnesium alloys has been evaluated as previous studies for wear behavior of AS41were developed. Thus, the aim of the present study is to characterize the wear behavior of carbon fibers reinforced metal - matrix composite AS41 magnesium alloys compared to the wear behavior of the common AS41 with carbon fibers magnesium alloy.

2. EXPERIMENTAL WORK

2.1. Chemical Composition Analysis

The chemical composition of the samples was detected using Inductive Coupled Plasma by Atomic Emission Spectroscopy (ICP-AES) for detection of very low alloying concentrations. The chemical composition is shown in the Table 1.

Table 1: The chemical composition of AS41

Elements (wt. %)									
Al	Si	Zn	Mn	Ni	Cu	Fe	Pb	Sn	Mg
4.37	0.93	0.09	0.35	<0.0005	<0.0002	0.0028	0.0027	0.0049	Balance

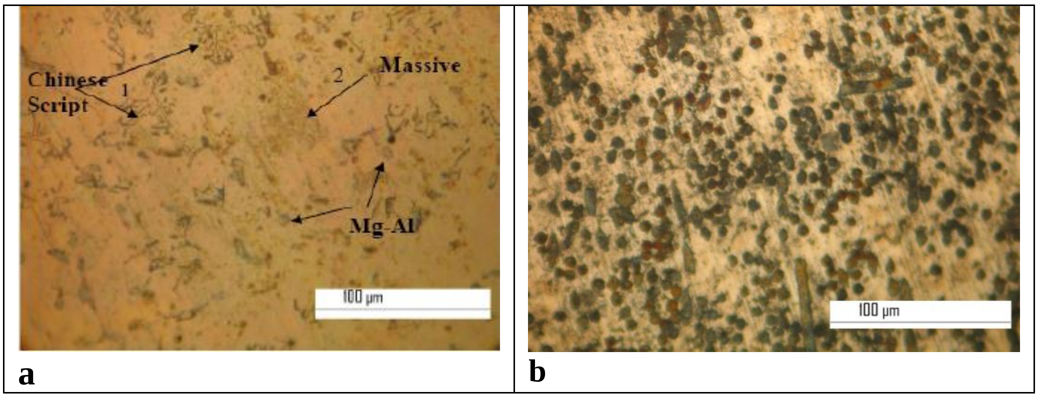

Fig.1. Macrostructure at 50X, (a) AS41, (b) (AS41+C).

The carbon fiber reinforced magnesium-matrix composite AS41 alloy differs only in composition from the AS41 alloy in the presence of about 25% of short carbon fibers. Less percentage (< 25%) of carbon fibers were studied but higher value will not be considered as addition to AS41 properties [12, 13]. The composite was produced by squeeze casting process in which the molten magnesium alloy was forced into the carbon short fiber performs.

2.2. Microstructure Investigation

2.2.1. Surface Preparation

Before microstructure investigation, samples were grinded and then polished to have a uniform surface which is clear of scratches and clean of any impurities. The grinding process is done on the grinding/polishing machine. The grinding papers used were 320, 500, 800, 1000 and finally 1200. Polishing is then done on the same machine by using a set of finer grinding papers. The lubricant used was a diamond paste. The samples have been itched by using etching solution (25 mL distilled water, 75 mL ethylene glycol and 1 mL HNO3). After etching, samples were washed by distilled water and then finally dried by hot air.

2.2.2. Optical and Scanning Electron Microscope

Optical microscopy Carl Zeiss x100 was used to investigate the itched samples under magnification of 20X and 50X. The pictures have been transferred to the computer through a digital camera. Also Scanning electron microscope (SEM) JEOL JSM 5410 was employed after wear test to investigate the difference in the samples surfaces after various wear test conditions. Magnifications 100X and 500X were selected.

2.2.3. Hardness Measurement

Hardness measurements were carried out on grinded and polished samples by using Vickers hardness tester. The load used on the samples was 30 g and dwell was 15 seconds. The indentations were separated from each other by about 3 mm. Three readings in each sample were recorded.

2.3. Wear Measurement

The following steps were considered for the adhesion wear test: Due to the nature of our samples being both in rectangular and cylindrical shapes, rectangular samples were machined to dimensions of 8 mm x 8 mm x 12 mm and cylindrical samples were machined to dimensions of 8 mm diameter and 12 The effect of different loads (20, 35, 55, 75 and 90 N) on the wear behavior were monitoring during tests. The speed of the rotating disc was also adjusted so the effect of different speeds (53, 106, 160, 215 and 265 rpm) on the wear behavior can be recorded. Each test was carried out for the same time interval of 30 minutes, which is enough for setting linear wear rate. After each test, the weight loss was recorded, so wear mm length with the 12 mm dimension for both samples being the depth that would decrease due to the adhesion action against stainless steel ring with surface hardness of 63 HRC. The weight of each sample was measured before and after each test. So wear rate was calculated in g/sec.

3. RESULTS AND DISCUSSION

3.1. Microstructure Analysis

The macrostructure of the three alloys as received are shown in Fig.1a and 1b. We can notice the presence of silicon in the form two types of Mg_2Si precipitates. The first type is the Chinese script like products shown in the above alloy substrate. The second type of Mg_2Si precipitation is formed from the massive silicon in the preform **[14].** Secondly, it can be notice the presence of aluminum the form of dark circular spots of $Mg_{17}Al_{12}$.

3.2. Hardness Measurement

Fig. 2 shows the hardness of the three studied samples. It was notice that the hardness gradually increases from the AS41+C alloy to AS41 alloy. There is a relatively small increase in hardness between the AS41+C sample and the AS41 sample. This increase can be justified by the increased carbon content of the AS41 alloy. While when comparing the hardness of the carbon reinforced AS41+C alloy with the other alloys, we find its hardness to be more than double the hardness of the AS41 alloy. This huge increase in hardness can be attributed to the presence of the reinforced short hard carbon fibers [15].

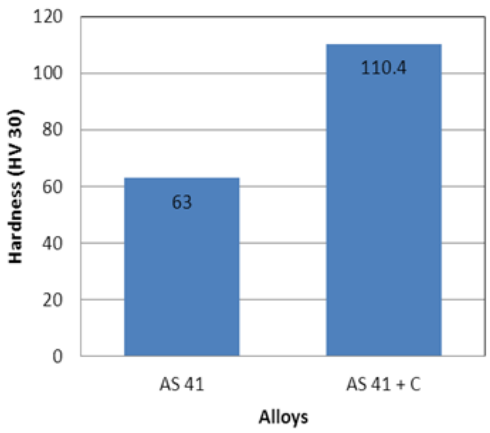

Fig.2. Hardness values for AS41 and AS41+C.

3.3. Wear Results

In Fig.3 the wear rates of the alloys under constant speed of 265 rpm and with varying loads. As expected, the wear rate increased with increasing the applied load due to increasing the shear stress over the increasing load from 20 to 95 N. While the wear rate of the other two alloys, can be notice an almost common behavior in their performance represented in a sudden increase in the wear rate above 60 N. This increase in the wear rate might indicate that a critical load is reached. For applications with similar speeds and with the possibility of subjection to similar loads these critical values should be avoided. However, the wear rate depends on the content of additives [16].

The wear test results showed that the wear rate exhibited increase for higher speed and loads. Therefore, the wear should be controlled by different mechanism. SEM photographs of the worn surfaces of AS41 and AS41+C at different load are shown in Figs. 4, 5, 7 and 8, respectively. SEM micrographs of Fig. 4 and 5 showing reported for AS41 +C due to its high hardness value, the AS41 alloy showed a war rate higher than AS41 + C.

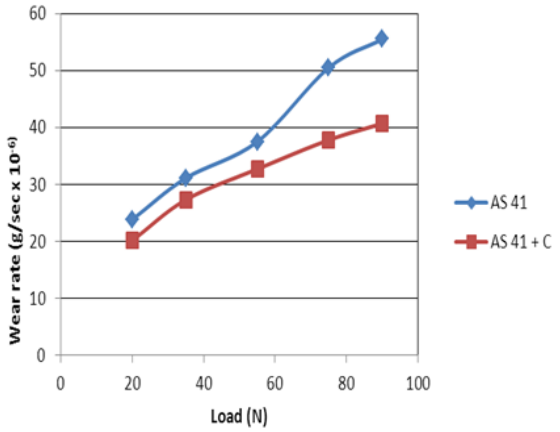

Fig.3. Wear rates of AS41and AS41+C at different loads

The wear rate of the AS41+C alloy was increasing gradually and almost linearly along the path of the general increasing effects of adhesion wears on as a result of increasing the applied load. This effect can be seen in the increased damage on the samples surface denoted by the increase of grooves and track-like lines on the surface. From these figures, we can notice the presence of large quantities of small chipped particles in the grooves formed during the wearing process. These small particles show that the worm surface with increasing the applied load from 20 N to 90 N. (Fig. 3). Maximum wear rate was also dominating wear mechanism is microcracking due to the high hardness of the AS41+C alloy as a result of carbon fibers reinforcement.

Also, with increasing load, the surface became smooth due to deformation and cracks can be observed at the edge of smooth area. As the load was increased up to 95 N, the plastic deformation was much more evident and series of fine cracks roughly perpendicular to the sliding direction were formed [16], which generally is associated with delamination (Figs.5 a, b and c respectively). From Fig. 5 a, b and c it can be seen increased damage on the samples surface denoted by the increase of grooves and track-like lines on the surface. From these figures, we can notice that the formation of a lot of wedges on the samples surface in the surface of contact between the samples surface and the ring surface. These formed wedges show that the dominating wear mechanism is wedge formation.

A	**B** **C**

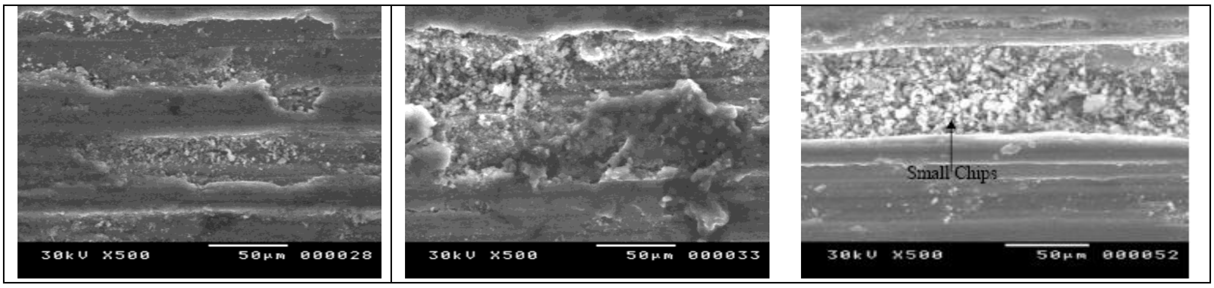

Fig.4. SEM of Worn Surface for AS41+C at, (A) 20 N, (B) 55 N, and (C) 90 N at 160 rpm.

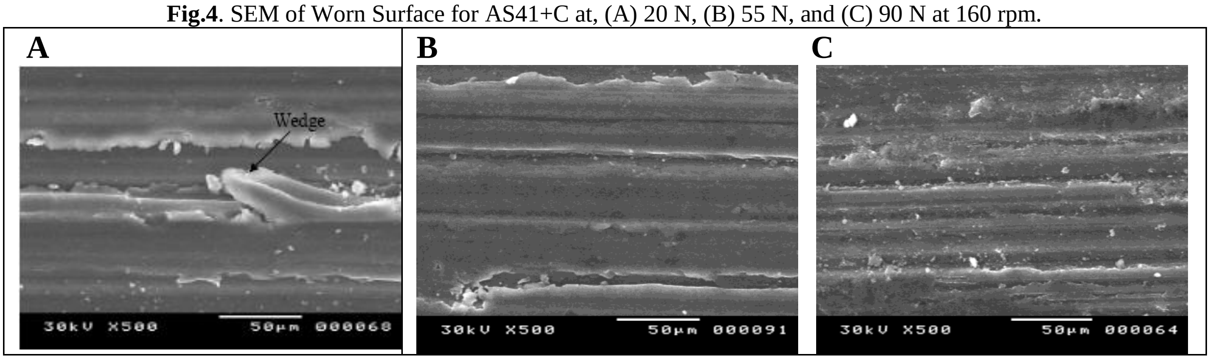

Fig.5. SEM of Worn Surface for AS41 at, (A) 20 N, (B) 55 N, and (C) 90 N at 265 rpm.

Wedge formation is a wear mechanism where the total amount of material removed from the groove is greater than the material moved to the sides. However, wedge formation adhesion wear is a mild form of adhesion wear justifying the small range of difference between the wear rates of AS41 and its carbon reinforced version. This shows that the AS41 alloy in itself has relatively. good wear resistance and yet the addition of carbon fibers can contribute to improving it [8], cutting parameter is the most severe adhesion wear mechanism related to ductile and low hardness materials In Fig. 6 the wear From Fig. 6 it can be notice that the rates of the alloys under constant load of 20 N and with different rotating speeds of 53, 106, 160, 215, and 265 rpm. wear rate of the AS41+C and AS41 alloys was increasing gradually and almost linearly along the path With the increasing speeds from 53 to 265 rpm. Furthermore, the wear rate of both alloys is very close to each others, and with almost identical behavior, that the only difference is the smaller wear rate of the carbon reinforced alloy than its carbon free edition This is primarily due to the fact that the hard dispersoid makes the matrix alloy plastically constrained and improves the high-temperature strength of the virgin alloy [16].

Additionally, the hard dispersions, present on the surface of the composite as protrusions, protect the matrix from the severe contact with the counter surfaces [17,18], and thus resulting in less wear, lower coefficient friction and temperature rise in composite as compared to that in the alloy [19 and 20]. Fig. 7 and 8 of the (AS41+C) alloy showed less damage and much fewer signs of adhesion wear. Microcracking only appeared at a speed of 265 rpm as shown in Fig.8.prior to that, the carbon reinforcement showed its contribution in raising the alloy hardness, and accordingly raising its wear resistance against the applied loads and speeds.

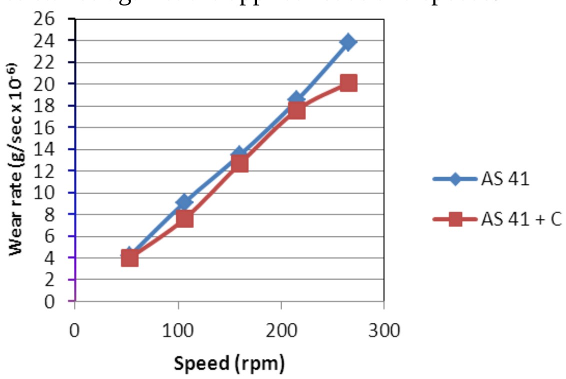

Fig.6. Wear rates at constant load 20 N and different speeds

It can be also notice that the formed grooves look shallower and much less severe than the grooves formed previously under constant speed and varying loads. From Fig. 7 and 8, it can be notice that the later have shown fewer signs of damage and a lower total number of formed grooves. Also Fig. 7 and 8 showed that the dominating wear mechanism is a mixture of plowing and wedge formation. Plowing is an adhesion wear mechanism where the material is not removed; however, it is only displaced to the sides of the groove.

This mechanism can be clearly seen in images. Figure 8 b and 8c, shows material is accumulating on the sides of the groove. Plowing occurs under light loads and results in very small material loss which justifies the smaller wear rate of

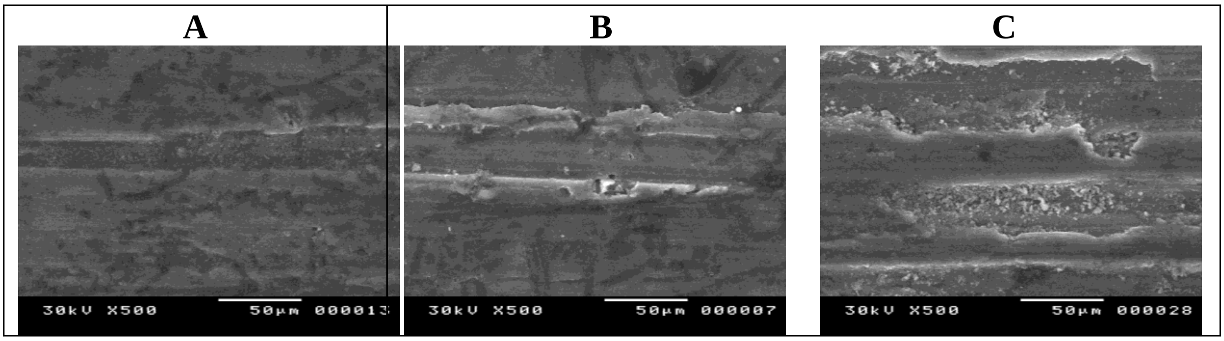

Fig.7. SEM of Worn Surface for AS41+C at, (A) 53 rpm, (B) 160 rpm, and (C) 265 rpm at 20N.

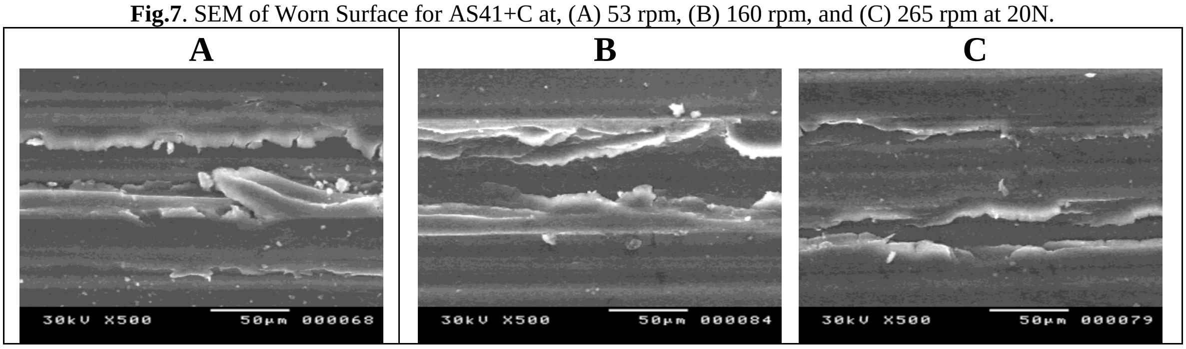

Fig.8. SEM of Worn Surface for AS41 at, (A) 53 rpm, (B) 160 rpm, and (C) 265 rpm at 20N.

the alloy in comparison to the wear rate resulting from the previous conditions of constant speed and increasing load . As mentioned earlier, in wedge formation, the total amount of material removed is greater than the amount of material moved to the sides. However, the large differences in the ductility of the three specimens might result in different adhesion wear modes among the various materials, and thus affect the amount of material removed from the pin surfaces. However, the large differences in the ductility of the three specimens might result in different adhesion wear modes among the various materials, and thus affect the amount of material removed from the pin surfaces.

The ploughing mode of adhesion wear is also thought to be, in part, responsible for the reduction in wear rates when sliding speed increased. As speed increases, frictional heating leads to a rise in the temperature of the pin surface. It has been found that more slip planes are activated in pure magnesium at 225 ^{o} C [21**],** resulting in a sudden increase in ductility. Thus it might be reasonable to conclude that under higher sliding speeds, increased plastic deformation of the matrix led to a transition from cutting to ploughing, and a corresponding decrease in wear loss from pin surfaces [22]**.**

Wedge formation can be seen in Fig 7 and 8 where we reach relatively high speed that was sufficient to cause enough damage and transfer the wear mechanism from plowing into wedge formation. The above studies in SEM observation of subsurface of alloy suggest the following: (i) the depth of highly deformed surface increases with the applied load, (ii) there is flow of alloy along the direction of sliding and (iii) the voids are usually formed at the interface of intermetallic phase and Mg dendrites and joining of voids lead to formation of wear debris [16]**.**

However, one can notice a clear difference between the formed grooves in this case and in the previous case. The grooves in Fig. 7c and 8c looked much deeper and more severe than the grooves we can notice in Fig. 7a and 8a. The difference in the grooves can be contributed to the fact that the combination of loads and speeds used in the final group of tests was higher and of more severe effect on the alloy.

4. CONCLUSION

The following conclusions can be drawn from the present studies:

1. The AS41+C had the highest wear resistance followed by the AS41 alloy under both conditions, of constant speed and increasing load. Also the same orders of decreasing wear resistance as that of decreasing hardness.

2. The wear rate of the AS41+C and AS41 alloy showed an increase with sliding speed when applying a constant load and varying the speed.

3. Wear mechanisms was in type of microcracking for the AS41+C alloy, while it was wedge formation for the AS41 alloy in the conditions of constant speed and varying load.

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