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Abrasive Wear of Nano-Al_2O_3 Particles and Cnts Strengthened 2024 Aluminum Alloy Composites Manufactured by Powder Metallurgy

سلوك البرى لمادة مركبة من سبيكة الالومنيوم 2024 مقواة بحبيبات النانو الومنيوم اوكسيد و النانو كاربون تيوب مصنعة بطريقة ميتالورجيا المساحيق.

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الملخص

المواد المركبة من الالومنيوم المقواة بحبيبات النانو الومنيوم اوكسيد او النانو كاربون تيوب تعتبر من المواد الواعدة فى الصناعة ومناسبة لعدد كبير من التطبيقات.فى هذا البحث يتم دراسة تحسين خواص الالومنيوم 2024 وذلك باضافة حبيبات النانو الومنيوم اوكسيد والنانو كاربون تيوب حيث يتم التصنيع عن طريق متالورجيا المساحيق، تم عمل ثلاث انواع من المادة المركبة: الاولى الومنيوم 2024 بالاضافة الى 2% النانو كاربون تيوب والثانية الومنيوم 2024 بالاضافة الى 2% النانو الومنيوم اوكسيد والمادة الثالثة الومنيوم 2024 بالاضافة الى 1% النانو كاربون تيوب +1 % النانو الومنيوم اوكسيد.تم دراسة تاثير حبيبات النانو الومنيوم اوكسيد والنانو كاربون تيوب على التركيب المجهرى للمواد والصلابة والبرى، اظهرت نتائج الفحص المجهرى توزيعاً متجانساً لحبيبات النانو الومنيوم اوكسيد والنانو كاربون تيوب فى الالومنيوم 2024. المادة الثالثة الومنيوم 2024 بالاضافة الى 1% النانو كاربون تيوب +1 % النانو الومنيوم اوكسيد اظهرت ارتفاعاً فى الصلادة بنسبة 47% و انخفاضاً فى نسبة تأكل المادة بنسبة 80% مقارنة بسبيكة الالومنيوم 2024 بدون اضافات. أظهرت النتائج ان تقوية سبيكة الالومنيوم 2024 بنوعين مختلفين من المادة الداعمة تعطى نتائج افضل من استخدام مادة داعمة واحدة .

Abstract

Metal matrix composites reinforced by carbon nanotubes as well as the effect of Nano Al_2O_3 (n- Al_2O_3) particles and carbon nanotubes (CNTs) are very promising materials, suitable for a large number of applications. These composites consist of a metal matrix filled with Nano-particles featuring physical and mechanical properties very different from those of the matrix. The Nano-particles can improve the base material in terms of electrical properties, damping properties and mechanical strength. In this work we investigated the effect of reinforcing Al-2024 with CNTs and n- Al_2O_3. The Al-2024 alloy was produced by powder metallurgy. The alloy strengthened by a dispersion of two weights % CNTs, 2wt% n- Al_2O_3, and 1weight % CNTs + 1wt% n- Al_2O_3 respectively. The effect of the CNTs, and Nano Al_2O_3 on the microstructure, hardness, and wear, were studied. The micro structural results showed a homogeneous dispersion of CNTs and n- Al_2O_3 into Al2024. We obtained that the composite 1weight % CNTs + 1wt% n- Al_2O_3 can increase, hardness as well as reduce the weight loss by 46%, and 80%, respectively. Our results enhance the wear behavior of the composites by using different types of reinforcements.

Keywords

Nano composite; SEM; CNT; Nano Al_2O_3; Wear; Hardness.

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1-Introduction

Aluminum matrix composites (AMCs) are under consideration for numerous applications in the car, aviation and military commercial enterprises in light of high quality/weight degree, high specific modulus, great wear resistance and additionally, they can have great electrical and thermal conductivity [1].Broad works have been done on AMCs to improve their mechanical and tribological properties due to the potential for high elastic modulus and administration life expanding in numerous applications [2]. Ceramics or intermetallic particles have been utilized as fortifying materials, for example, Al_2O_3 [3] the composites that contain more than one reinforcement has higher quality than those strengthened by stand out fortification.

2024 Aluminum alloy (A2024) as a heat treatable alloy has gotten a lot of consideration for past decades, because of their high specific quality and firmness [4]. The utilization of A2024, in this way, has been developing steadily in the business as a material of plane developments, autos, and pulling wheels [5].

In spite of the fact that the fundamental exploration push over the previous decade has centered on utilizing carbon nanotubes (CNTs) to strengthen polymer and earthenware networks [6,7], a couple of gatherings have researched metal matrix with the center enthusiasm being unadulterated aluminum [8]. Actually, the enthusiasm for CNTs-fortified aluminum composites has been becoming impressively. The imparted point of the different gatherings is to produce composites with upgraded mechanical properties. Such composites would make alluring novel materials with potential applications in the aviation, auto and games commercial enterprises where light weight joined with high firmness and quality is sought. Powder metallurgy procedures have been the favored method for most specialists [9,10].

CNTs fibers were often used for reinforcements of the aluminum matrix composites. n-Al $_2$ O_3 was selected because of its large production and low cost. CNTs were selected because it is an advanced reinforcement which possesses both anti-wear and lubrication effects *[11]*.

Through combination of n-Al_2O_3 and CNTs, the composites were expected to possess both excellent wear resistance, and good electrical conductivity. So, the wear performance of the composite, the hybrid effect of n-Al_2O_3 and CNTs on the tribology performance were investigated.

2. Experimental procedure

As received n-Al_2O_3 particles applied were 99.99% in purity, 50 nm in average size. CNTs 95% in purity, 30 nm in average diameter, and 30 µm in average length, produced by nanotech Egypt. Pure Aluminum powder with an average particle size of 70 µm purity 99.8%, Cu, Mg and Mn powder of 99.98% with average particle size of 100 µm produced by Alpha Chemika, were selected as the starting materials of matrix of the composites. Four compositions were prepared, Al-2024 (Al 93.6 wt%, Cu-4.3 wt%, Mg-1.5 wt%, Mn 0.6 wt%), Al-2024-2wt% CNTs, Al-2024-2wt% n- Al_2O_3, and1wt % CNT + 1wt% n- Al_2O_3,and Al-2024-2wt% n- Al_2O_3. The initial powders of the matrix alloy, the reinforcement and 2 wt% acetone as a binder were blended for 90 min. at 300 rpm in a stainless steel mixing jar with stainless steel bars with 10 mm diameter and 50 mm length, giving a rod- to-powder weight ratio of 3:1 The mixture was put in dryer for 60 min., at 100 °C to remove the acetone. The mixed powder was poured into a rectangular die of 28mm length and 7mm width and uni-axially pressed at pressure of 800 MPa .The prepared green compacts were sintered in vacuum furnace at a temperature of 550 °C for one hour with 10 °C/min. heating rate. Scanning electron microscopy (SEM) was carried out using

SEM-JEOL JSM5800-LV operated at 15 kV, in order to evaluate the morphological. Vickers hardness studies were carried out for the alloy and composites using Vickers hardness tester (Lecco Vickers hardness tester, Model: LV 700, USA) with 1 kg load. The indentation time for the hardness measurement was 15 seconds. An average of six readings was taken for each hardness value. Abrasive wear tests were carried out on alloy Al2024 and composites using a pin-on-disk technique under normal loads of 2, 4and 6 N, at constant sliding speed 1.5 m/s,. In these tests, each specimen is ground up to grade 1200 abrasive paper to ensure that the wear surface is in complete contact with the abrasive counter face. Rectangular specimens having contact area of 28× 7 mm are loaded against a disk, which rotated at 250 rpm. The disk carried an abrasive SiC paper of 400 Grit. The sliding distance was kept constant at 200 m for each sample. During sliding, the abrasive wear rate of the pins was defined as the weight loss suffered per unit sliding distance. An electronic balance having a resolution of 0.0001 g was used to measure the weight loss. The pins were cleaned in acetone and dried prior to each weight measurement. The relative humidity was measured but not controlled and was in the range of 60% during these tests. The volume loss due to the test was calculated from weight loss according to the following equation [12]:

$$\boldsymbol{Volume\ loss}\ (\boldsymbol{mm^3}) = \frac{\boldsymbol{Weight\ loss}\ (\boldsymbol{g}) \times \mathbf{1000}}{\boldsymbol{Density}\ \left(\frac{\boldsymbol{gm}}{\boldsymbol{mm^3}}\right)} \rightarrow (\mathbf{1})$$

And the wear coefficient was measured according to the formula [13]:

$$\text{Wear coefficient}(\text{mm}^3/\text{N Km}) = \frac{\boldsymbol{Volume\ loss}\ (\boldsymbol{mm^3})}{\boldsymbol{Applied\ load}\ (\boldsymbol{N}) \times \boldsymbol{Sliding\ distance}(\boldsymbol{Km})} \quad (\mathbf{2})$$

3-Results and Discussion

Figure (1) (A) shows the SEM of Al 2024 alloy which is a hypoeutectic alloy. This alloy is consisting of soft aluminum solid solution matrix (α) and hard $CuMgAl_2$ phase. Hence, microstructure is composed of (α) primary grains and a eutectic mixture of (α + $CuMgAl_2$). The figure shows an increase in the porosity of the alloy (in black areas).

Composites Fig. 1B, and Fig. 1D in comparison with Fig. 1C Here, the increase in the porosity is due to the natural hardening effect caused by the deformation and the presence of harder particles. In addition, bright areas of two different morphologies can be observed in alloys and composites ***[14]***. SEM analysis of the microstructure reveals dark areas consisting in almost of pure Al, where as bright areas contain Cu-rich phases. Al–Cu phase is observed in conglomerates of small particles of irregular shape well located crystals ***[14].*** These phases appear homogeneously distributed for both alloys and composites. The image of the alloy Al2024 without any reinforcement is quite similar to the composite in Fig**.**(1D) in comparable with the composites due to the good distribution of the reinforcement and wetting between the reinforcement and the matrix.

➢ Hardness

Figure (2) shows the effect of the different type of reinforcement on the hardness of the matrix Al-2024. Here, the composites have higher values of hardness than the alloy Al-2024. Where in, the composite Al-2024-(1% CNTs+1% n-Al_2O_3) gives higher value than the alloy by 37%. Also, Micro-hardness was significantly affected by the incorporation of CNTs and n-Al_2O_3 into Al 2024 composites. The increase in hardness is also due to the restriction of dislocation by the presence CNTs and n-Al_2O_3.

For CNTs/metal composites, it has been found that the formation of the limited amount of carbides at the interface can largely improve the composite strength [15] The CNTs and n- Al_2O_3, As for hybrid composite, the two Nano-reinforcements show a hybrid effect on the hardness of the hybrid composites,. The first type of reinforcement in composite (Al2024 -2% CNTs) the hardness was higher than the alloy 20% and the composite (Al2024 -2% n- Al_2O_3) was higher than the alloy by 30%. A comparison of the interface characteristic in the present CNTs/Cu composites with Al/CNTs and Mg/CNTs composites reported in the literature stresses the role of the formation of interfacial carbides responsible for the interfacial bonding and load transfer ability in the CNTs/metal composites ***[16].***

- **Wear**

Figure 3 (A - B) demonstrates the effect of the normal load on wear and friction coefficient, of the examined materials. In Fig.3 A. all composites were worn not as much as matrix. Composite Al-2024-1wt % CNTs + 1wt% n- Al_2O_3 was worn not as much as composite Al-2024-2wt% CNTs by 76 %, which was the most worn among all the composites. This implies that nAl_2O_3 was more productive in enhancing the wear resistance of the Al-2024 composite. On the other hand, as the quantity of Al_2O_3 particles build, the imperviousness to the entrance of rough particles increments and so the profundity of infiltration by the grating is decreased prompting better grating wear resistance ***[11].***With the normal load expanding, the wear of all materials expanded progressively, when the load was higher than 4 N. The wear contrast among the composites will be particular on the grounds that the wear of composite Al-2024-1wt % CNTs + 1wt% n- Al_2O_3 was expanded more gradually than the others, and turned into the most wear safe. This implies that the mix of 1% n-$A1_2O_3$ and 1%CNTs demonstrates a crossover impact on the wear execution of the Al-2024 network composites [17]. Fig.3 B shows the impact of n-Al_2O_3, and CNTs content on wear coefficient of compound and composites. The wear coefficient of Al-2024-1wt % CNTs + 1wt% n- Al_2O_3 composite is impressively higher than those of different composites when the load was 2 N yet, the wear coefficient of composites and alloy were practically consistent when the load was higher than 2 N. These demonstrated that hybrid impact of n-$A1_2O_3$ and CNTs on the wear execution of the Al-2024 matrix composites Al_2O_3.

4-Conclusions

Alloy Al-2024 and three composites Al-2024-2wt% CNTs, Al-2024-2wt% n-Al_2O_3, and Al-2024 (1wt % CNTs + 1wt% n-Al_2O_3) were fabricated by powder metallurgy. The CNTs and n-Al_2O_3 were uniformly dispersed in the matrix in the three composites. CNTs and n- Al_2O_3 possess hybrid effect on the hardness of the Al-2024 alloy matrix composites, and Al-2024 (1wt % CNTs + 1wt% n-Al_2O_3) composite has the highest micro hardness that is 37% higher than those of Al- 2024. The wear resistance of the composites was much higher than that of the alloy. Al- 2024 (1wt % CNTs + 1wt% n-Al_2O_3) shows excellent wear resistance when compared with the other two composites it lower than composite Al-2024-2wt% CNTs by 76 %, even by increasing load that could be attributed by the hybrid effect of CNTs and n-Al_2O_3.

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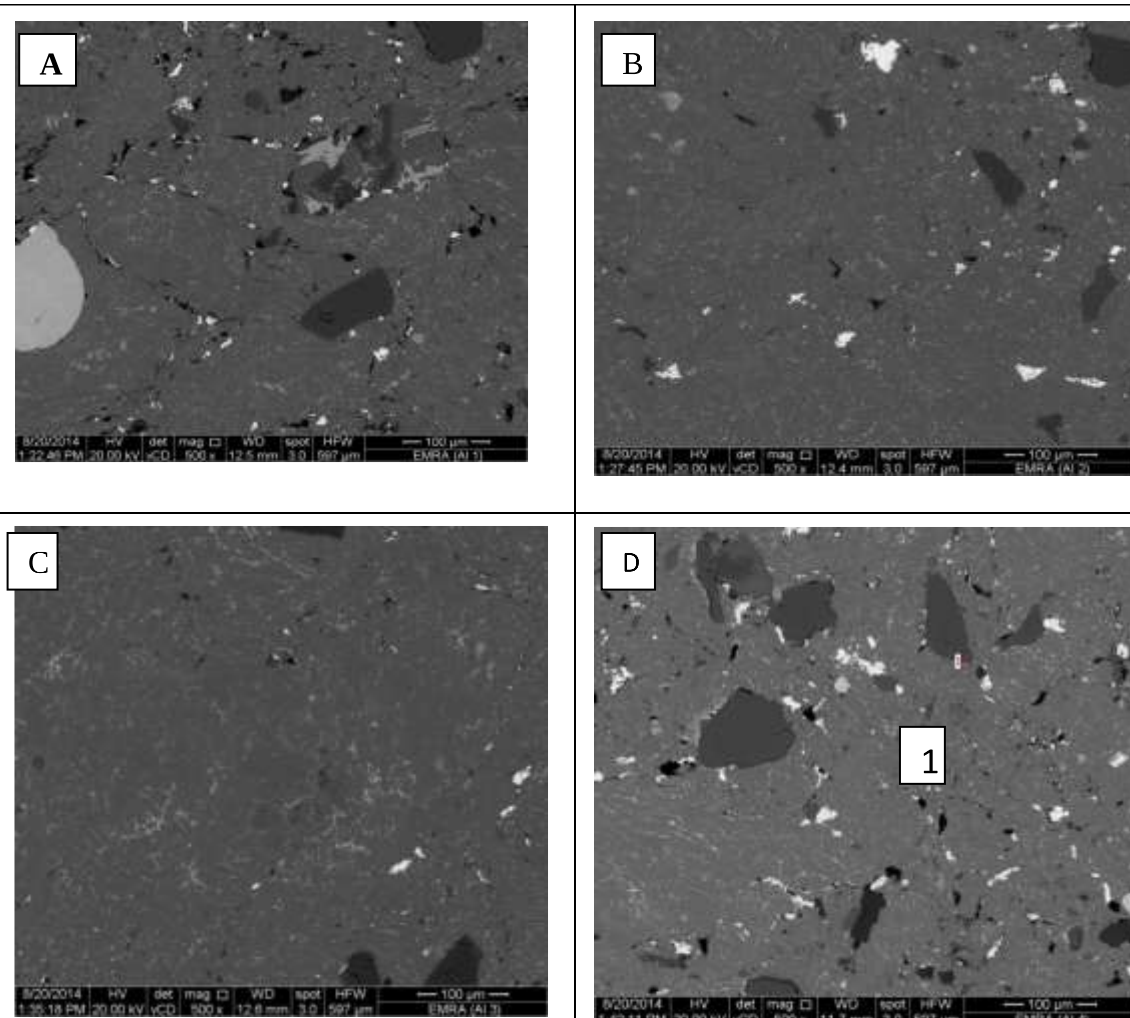

Figure 1 SEM micrographs of (A) Al2024, (B) composite Al2024-2% CNTs, (C) composite Al2024-2% n-Al_2O_3, and (D) composite Al2024 – (1% CNTs+% n-Al_2O_3)

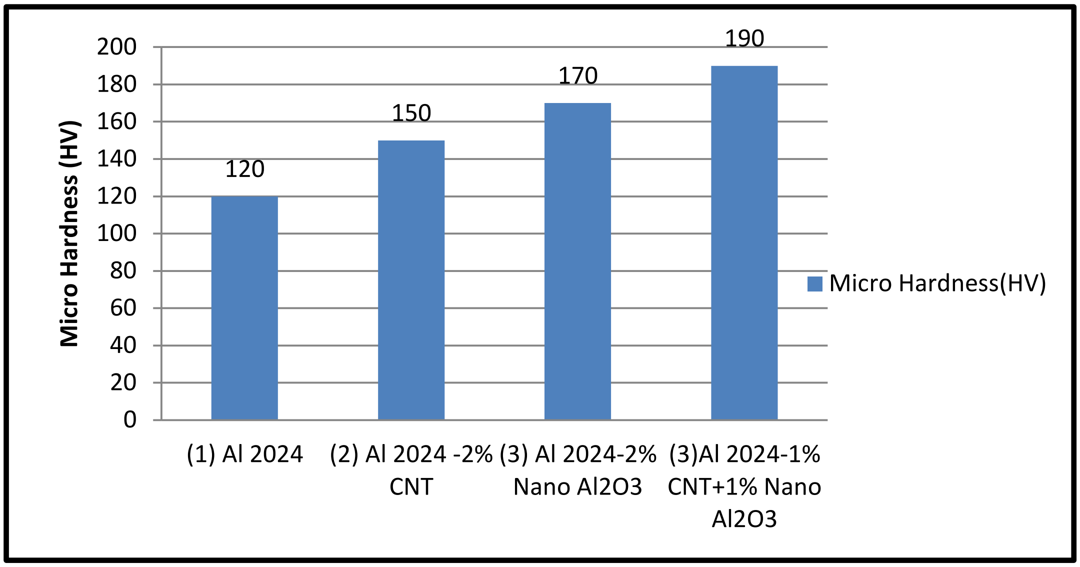

Figure 2 The effect of reinforcement on micro hardness of alloy 2024 and composites

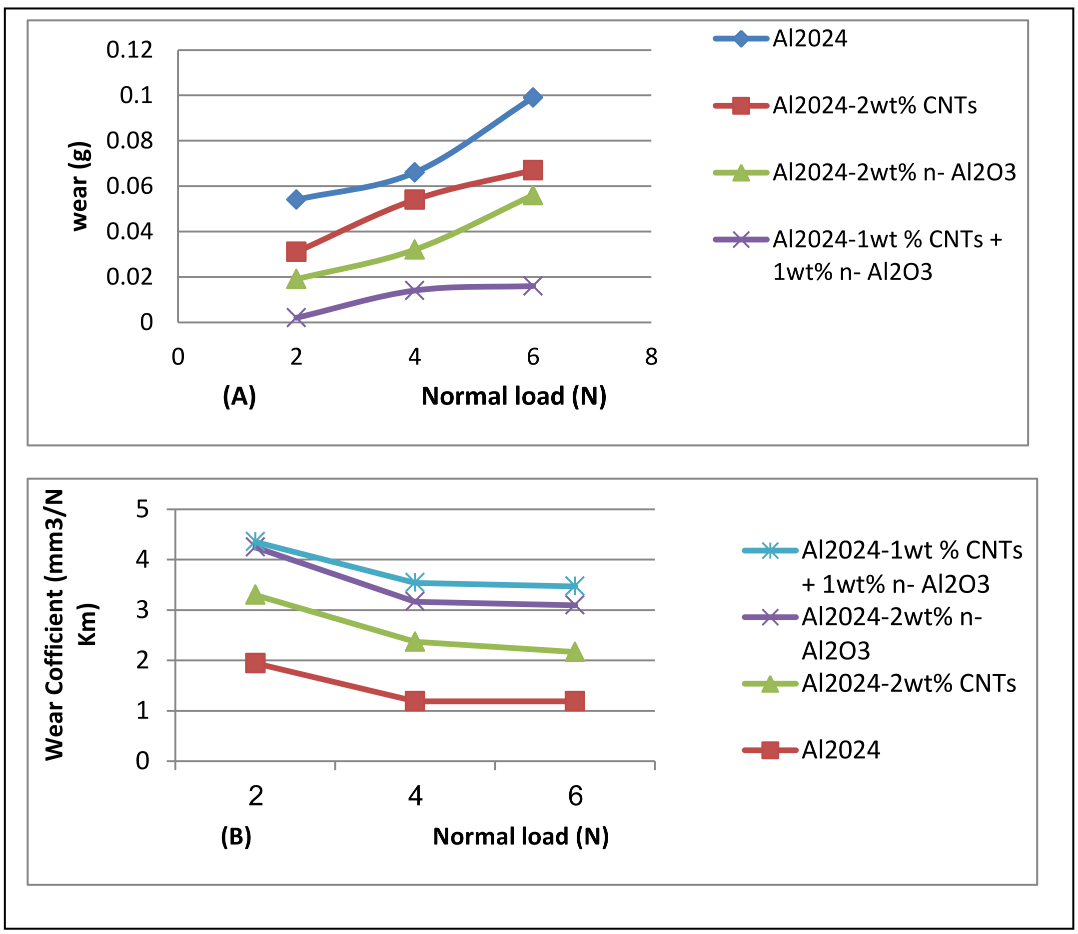

Figure 3 Relation between wear, wear coefficient and normal load;(A)wear and (b)Wear Coefficient.