WEAR PERFORMANCE AND MAGNETIC PROPERTY OF ALUMINUM REINFORCED WITH FE_2O_3 AND AL_2O_3 HYBRID NANOCOMPOSITE USING POWDER METALLURGY P/M METHOD

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ABSTRACT

The current study deals with fabricating a hybrid nanocomposite. Pure aluminum as the base matrix and Fe_2O_3 and Al_2O_3. A reinforcements Fe_2O_3 weight percentage (wt%) is varied (1.5, 2.5 and 5 % wt%) and Al_2O_3 is held constant (2 wt%). The new designed nanocomposite was produced using Powder Metallurgy (P/M) method. The experimental results revealed that the microstructure images of nanocomposites showed uniformly distributed of Fe_2O_3 and Al_2O_3 in aluminum matrix. Dry tribological behavior (wear rate and coefficient of friction) was studied and for varying hybrid reinforcement content. The results observed that the wear resistance of hybrid nanocomposites improved with the increasing of Fe_2O_3 + Al_2O_3 reinforced material but the better wear resistance was recorded with the (1.5% Fe_2O_3 + 2% Al_2O_3) wt% than the base metal and other nanocomposites. It is evident that the maximum reduction of wear rate and COF were 4.87×10^{-8} g/m and 0.59 respectively for the (1.5% Fe_2O_3 + 2% Al_2O_3) nanocomposite. The hysteresis curve of nanocomposites showed that the magnetic properties which indicated that the better response of magnetic properties was found with the nanocomposite of (1.5% Fe_2O_3 + 2% Al_2O_3) content.

Keywords: hybrid nanocomposites, powder metallurgy, wear, magnetic properties.

أداء البلى والخصائص المغناطيسية لمعدن الألمنيوم المقوى بمُركب النانو Fe_2O_3 و Al_2O_3 باستخدام طريقة تعدين المساحيق.

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الخلاصة

تتناول هذه الدراسة تصنيع مادة متراكبة هجينة تتكون من الالمنيوم و اكسيد الحديد و الالومينيا. يكون الألومنيوم كمعدن اساس للمادة المتراكبة بالاضافة الى المواد النانوية Fe_2O_3 و Al_2O_3. يتم التعزيز بنسب متفاوتة من المواد النانوية و تتكون من (1.5 , 2.5 و 5 %) من Fe_2O_3 بالنسبة الوزنية، اما Al_2O_3 فتبقى نسبته ثابتة مع النسب الثلاث المختلفة و تكون بنسبة 2%. تم تصنيع هذا المركب الجديد بطريقة تعدين المساحيق (Powder Metallurgy). أوضحت النتائج أن الصور المجهرية للمركبات أظهرت توزيع متجانس لـ Fe_2O_3 و Al_2O_3 في مصفوفة الألومنيوم. تمت دراسة السلوك لخصائص السطوح في بيئة جافة (معدل البلى و فقدان الوزن و معامل الاحتكاك). تضمنت النتائج التجريبية حساب مقدار مقاومة البلى في المركبات النانوية الهجينة التي زادت مع زيادة المواد النانوية المعززة Fe_2O_3 + Al_2O_3 ولكن تم الحصول على افضل مقاومة بلى مع نسبة الوزن (1.5% Fe_2O_3 + 2 % Al_2O_3). لوحظ أن الحد الأقصى لتخفيض معدل البلى و فقدان الوزن و معامل الاحتكاك كان 4.87×10^{-8} جم / م ، 0.0023 جم و 0.59 على التوالي للمركب النانوي (1.5% Fe_2O_3 + 2 % Al_2O_3). أظهر مخطط التشبع المغناطيسي للمركبات إلى أن الاستجابة الأفضل للخصائص المغناطيسية كان مع المركب النانوي (1.5% Fe_2O_3 + 2 % Al_2O_3).

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INTRODUCTION

Aluminum matrix composites (AMCs) is one of the most important advance-engineering materials in industry, because of their high specific strength, lightweight, good wear resistance. AMCs have gained wide applications in automotive, aerospace, electronic equipment. At present AMCs reinforced with nanoparticles like Al_2O_3, SiC, TiB_2, Fe_2O_3. So, exhibit improved electromagnetic and mechanical properties and obtained rapid development in recent years. Powder metallurgy is an important processing technique for MMNCs, through which grain refinement of the composites and relatively uniform distribution of the nanoparticles in base metal can be obtained (A. Fathy 2015 and Ferreira 2018). Wear is the progressive loss of material due to relative motion between a surface and the contacting substance or substances. The wear damage may be in the form of micro-cracks or localized plastic deformation (A. Khleif 2017). Many studies were concentrated on improvement of Aluminum alloy properties, studied the mechanical, tribological and magnetic properties of Aluminum reinforced by different wt% of nanoparticles using powder technique. (A. Khleif 2017) observed that the addition of (CeO_2) nano powder with a different wt% to Al-alloy leads to the microstructure refinement and a few change in the density of nanocomposite materials, but all the wear rate were decrease for all the addition levels of composites compared to the base metal. While (E. Bayraktar 2010 and Ferreira 2018) studied the effect of Fe_2O_3 and Fe_3O_4 nanoparticles on mechanical and magnetic properties of Aluminum, they observed when increasing wt% of reinforcement the mechanical properties improve. In addition to the results were observed good improvement in magnetic properties with increase wt% of Fe_3O_4 nanoparticles. The major aim of this study is to evaluated wear behavior and magnetic property of aluminum based hybrid nanocomposites. Nano iron oxide (Fe_2O_3) and aluminum oxide Al_2O_3 particles were used as reinforcements and it was fabricated by P/M technique.

EXPERIMENTAL WORK

Samples preparation

In the present work will be fabricated a MMNCs hybrid based on powder aluminum reinforced by nanomaterials (Al_2O_3, and Fe_2O_3), with different wt% (1.5, 2.5, 5) % of Fe_2O_3 and (2 %) of Al_2O_3, for the three case. These percentages are added according to the results of previous work (E. Bayraktar 2010 and Ferreira 2018). The base material powder aluminum with grain size 60 µm and consisting of (99.6 % Al, 0.2 % Fe, 0.2 % Si). And the nano material Al_2O_3,type (α) with grain size 14-20 nm and purity 99.5 %. And the nano material Fe_2O_3 (α) with grain size 30 nm and purity 99 %.

(1) The aluminum powders were mixed with the nanoparticles to prepare composites with (1.5, 2.5 and 5) wt.% of Fe_2O_3 and 2 wt.% of Al_2O_3,for each percent reinforcement. (2) These powders are added to alcohol to be mixed well in two steps: First, mixing by magnetic field for 5 min. Second, mixing by (ultrasonic –cleaner) for 20 min. (3) In order to increase the homogeneity between the particles of the material. These mixed powders were dried at 70 °C for 15 min. (4) The powders have been added 5 % of (alcohol type PVA) as a lubricant to reduce friction during press, then leaves dry at room temperature. (5) The powder mixtures were compressed at room temperature under uniaxial press at 250 MPa (E. Bayraktar 2010). The samples were sintered at 600 °C under argon gas (E. Bayraktar 2010). In two steps, first step at 300°C for (1 h) and second step at 600°C for (2 h). The total weight per case (added percentage) was 25 g. The table below shows the percentage and weight details:

Three types of specimens were prepared for microstructure, wear and magnetic tests according to the types of tests required. The dimensions of microstructure test specimens were (diameter 10 mm & height 7 mm). The dimensions of wear test specimens were (diameter 10 mm & height 14 mm). Magnetic test specimens were powder.

Microstructure examination

During microstructure analysis, proper preparation of the specimen surface requires of small sample of the composite selected prepared and manufactured. Then polishing in addition to coating samples with gold and palladium spray (for 135 seconds), for reveal accurate content and get the best accuracy. The specimen must be free from scratches and other imperfection. After preparing the microstructure specimens, they were tested by Field Emission Scanning Electron Microscope (FESEM), using test device type (Cam Scan Mv 2300).

Pin on disc wear test

The adhesive wear tests were performed using (pin-on-disc) wear testing apparatus. Base metal and composites specimens were tested to obtain required tribological properties, under 10 N load with linear speed 52.5 cm/s based on speed 100 r.p.m for 15 min at room temperature according to ASTM G99 standard using steel alloy disc of high hardness type (52100). The end of cylindrical specimens was fixed in chuck jaws to prevent the rotation of specimens during the test. Each specimen is weighted before and after the test in order to determine: wear rate, volume loss and coefficient of friction employing a digital balance with accuracy of ± 0.0001 g.

Magnetic test

The magnetic test measures the magnetic properties of powders and the composites by using a vibrating sample magnetometer (VSM) device model (Meghnatis Daghigh Kavir Co., Iran) at a constant frequency. The examined was measured the magnetization against the magnetic field at room temperature. As the magnetic field is various over a limited range, the magnetization of the powders is measured by the sense coils with a lock in amplifier.

RESULTS AND DISCUSSION

Microstructure results

Figure (1) shows the FESEM images under 200 nm or under 800000X magnification respectively. These images show the microstructure of pure aluminum and nanocomposites containing (1.5 Fe_2O_3 + 2 Al_2O_3,, 2.5 Fe_2O_3+ 2 Al_2O_3, and 5 Fe_2O_3 + 2 Al_2O_3,) wt.% revealing the presence of Fe_2O_3 and Al_2O_3,and homogenous dispersion in the Al matrix. The images contain Fe_2O_3, Al_2O_3,concentrated at the grain boundaries of aluminum particles because the grain boundaries energy is high, attracting foreigner particles to it. the gray light which represents the Al matrix. Microstructure of nanocomposites reveals uniform distribution of the hybrid nanomaterials and less porosity along the grain boundaries. The nano ceramic Al_2O_3, is shown as white, while the nano Fe_2O_3 is dark.

Wear results

Fig. (2) show the results of wear rate and weight loss conducted on pure aluminum and composites containing (1.5 Fe_2O_3 + 2 Al_2O_3,, 2.5 Fe_2O_3 + 2 Al_2O_3, and 5 Fe_2O_3+ 2 Al_2O_3,) wt% with speed of 100 r.p.m and a constant load of 10 N. It is seen from the above figure that wear rate of nanocomposites decreases after addition the hybrid nanomaterials compared to matrix (pure aluminum), but the minimum reduction of wear rate and weight loss occurred in composite containing 1.5% Fe_2O_3 + 2% Al_2O_3,. On the other hand, the effect would be less significant in the other composites but still better than the as – cast sample. The coefficient of friction decreases (measured by the computer associated with the test) device as given in Fig. (3). For zero nanomaterials the coefficient of friction is 0.777 and it gradually decreases to 0.59 for (1.5 Fe_2O_3+ 2 Al_2O_3,) wt% and then slightly increase.

Fe_2O_3 and Al_2O_3 have good wear resistance and as it uniformly distributed with the Al. matrix, it helps to improve the wear resistance of the composites. Wettability is also one of important factors for evaluation the wear resistance. Poor wettability can lead to weak interfaces between matrix and reinforced materials and if the bounding between the reinforcement particles and matrix is good, then wear resistance increases considerably. But if bounding is not good enough, wear resistance increases up to certain amount and then decreases (**V.** Ravindranath 2017). These improvement in the wear properties might be explained by following:

1- A significant improvement in hardness can be attributed primarily to the presence of harder Fe_2O_3 + Al_2O_3 nanomaterials. (B.K.Prasad 2007)

2- The enhancement in mechanical properties leads to the incorporation of hard nanoreinforcements improves the wear resistance. (Hosseini N. 2010)

From the tribological results, it can be concluded that the (1.5% Fe2O3 + 2% Al_2O_3,) nanocomposite has the best combination of wear rate, weight loss and coefficient of friction. (Gaurav 2015) tested Al-SiC +, TiB_2 hybrid nanocomposites containing various compositions of hybrid nanocomposites using stir casting route. They concluded that the tribological properties decrease up to certain amount and then slightly increased for hybrid nanocomposite Al-SiC -., TiB_2

The variation of coefficient of friction COF against the reinforcement content is given in figure (3). From this figure it is evident that the hybrid nanoreinforced materials Fe_2O_3 + Al_2O_3 decrease the wear rate, weight loss and COF of composites compared to unreinforced aluminum. Also wear resistance increases (decrease in wear rate, weight loss and COF) with increase in weight percentage of Fe_2O_3 + Al_2O_3 up to (1.5% Fe_2O_3 + 2% Al_2O_3) and then slightly increase but still the tribological properties of composite are higher than the as – cast. The enhancement in wear resistance of the composites can be attributed to the improvement in the hardness of the composites. Aruri 2013 observed that the tribological properties of composites containing hybrid nanoreinforements SiC + Gr and SiC + Al_2O_3. (Gurusamy, 2016) tested hybrid nanocomposite containing SiC + B4C and they revealed that the wear rate, weight loss and COF decrease for composites compared to the as-cast. The higher tribological properties (wear resistance) were found in composite of (1.5%) of nanoreiforcements compared to other combinations.

Magnetic results

The absolute magnetic permeability (μabs) is main magnetic property of a material, which is concerning to magnetic susceptibility (χm). The magnetic susceptibility is a measurement of the amount of magnetization of a metal in reaction to an exterior magnetic field, as follows: (Rajinder P. 2015)

$$\mu abs = (1 + \chi m)\ \mu o \quad (1)$$

$$\chi m = \frac{M}{H} \quad (2)$$

where:

(μo) is vacuum permeability, equal to $4\pi \times 10^{-7}$ henry/m.

(M) is The Magnetization, ampere per meter.

(H) is Magnetic field, ampere per meter.

According to equations (1 & 2), the value of Xm (magnetic susceptibility) can be obtained by apply the above equation. It is clear that the value of Xm is maximum for the composite containing (1.5 Fe_2O_3 + 2 Al_2O_3) wt%. Table (2) shows the value of Xm and absolute magnetic permeability µabs with magnetic field between (12000 to - 12000 A/m) for four types of composites. Maximum magnetization (M) is occurred at the composite containing

(1.5 % Fe_2O_3 + 2% Al_2O_3) which is equal to 0.11666 A/m. The improvement in (M) value equal to 26 % compared to the magnetization for pure aluminum. Ferreira (2016) studied the effect of Fe_3O_4 on the magnetization for three types of composites AF-10 (10% Fe_3O_4), AF-20 (20% Fe_3O_4) and AF-30 (30% Fe_3O_4). They concluded that the best magnetization is obtained for AF-30. Also Fathy (2015) examined the effect of (Fe) on the magnetization for three types composites samples (5%, 10% and 15%) of (Fe) content using aluminum powder as a matrix. They recorded that the magnetization value is equal to 0.3816 × 10^{-3} A/m for 5% Fe and increase to 0.6597 × 10^{-3} A/m for 10% Fe and reduces to 0.0702 × 10^{-3} A/m for 15% Fe samples. Maximum µabs was found in (1.5% Fe_2O_3 + 2% Al_2O_3,) composite which is equal to 1.257 × 10^{-6} H/m and reduced to 1.256 × 10^{-6} H/m for (5% Fe_2O_3 + 2% Al_2O_3,) composite , while this value was recorded as 1.254 × 10^{-6} H/m for zero nano . The magnetization (M) is an intrinsic property depend on the distribution of the nanoparticles and grain size. The experimental results also show that the value of (M) for (1.5% Fe_2O_3 + 2% Al_2O_3,) composite is better than that of zero nano and other composites. This may be attributed to relatively fine grain size of (1.5% Fe_2O_3 + 2% Al_2O_3,) composite (Kaw A. 2006). The enhancement in µabs may be due to the following reasons:

1- The improvement of the permeability (µabs) of the nanocomposites was due to of the enhanced of dielectric loss properties.

2- The improvement of microstructure and mechanical properties resulted in improving the µabs induced by containing the hybrid nanomaterial. (Y. Hirano 2016)

COMCLUSIONS:

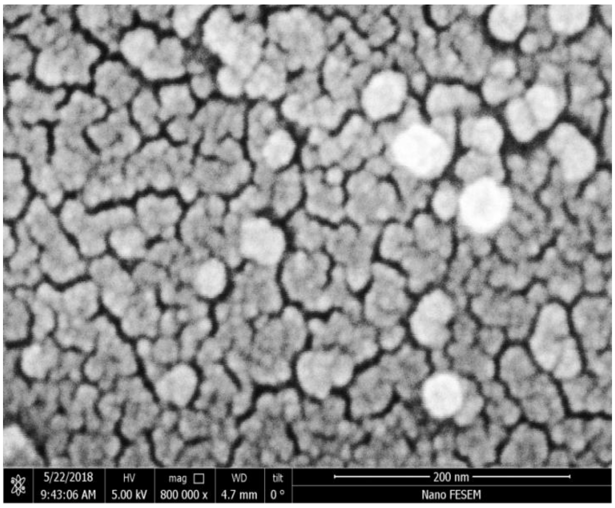
1- Fe_2O_3 + Al_2O_3, particles reinforced pure aluminum composites are successfully fabricated by powder metallurgy method.

2- The experimental results showed that (Fe_2O_3 + Al_2O_3,) Al composites can potentially be a useful material for automotive and aeronautic applications, which can be fabricated without difficulty using powder technology route.

3- It can be observed from microstructure observed that the hybrid nanomaterials (Fe_2O_3 + Al_2O_3,) could be uniformly distributed in pure aluminum and showing less porosity. This factor leads to significant enhancement in tribological and magnetic properties.

4- The wear test was carried out by sliding the manufactured nanocomposite cylindrical pins against the steel disc with speed of 100 r.p.m and a constant load of 10 N. Through the results observed that the addition nano Fe_2O_3 and Al_2O_3,reduced the wear rate, weight loss and (COF) while the maximum wear reduction was observed when addition of (1.5% Fe_2O_3 + 2% Al_2O_3,) wt% compared to the base metal and others composites. For the (1.5% Fe_2O_3 + 2% Al_2O_3,) composite, the tribological properties were 0.00000677 g/m (wear rate), 0.0023 g (weight loss) and coefficient of friction COF 0.59 represent the lowest values.

5- Magnetic properties of composites can be improved with small grain size especially in the nanoscale. The increase in weight percentage of particles Fe_2O_3 and Al_2O_3,increased the magnetic properties of the composite studied. However, the best magnetic properties were found in composite containing (1.5 Fe_2O_3 + 2 Al_2O_3,) wt%. The hysteresis curves for the three composites with pure aluminum gave the measured magnetization value was equal to 0.0927 A/m for pure aluminum, 0.11666 A/m for 1.5 Fe_2O_3 + 2 Al_2O_3,, 0.10733 A/m for 2.5 Fe_2O_3+ 2 Al_2O_3, and 0.10544 A/m for 5 Fe_2O_3 + 2 Al_2O_3,.



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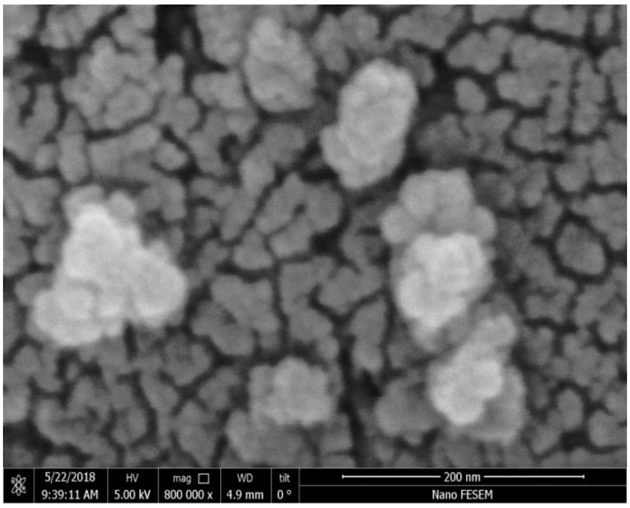
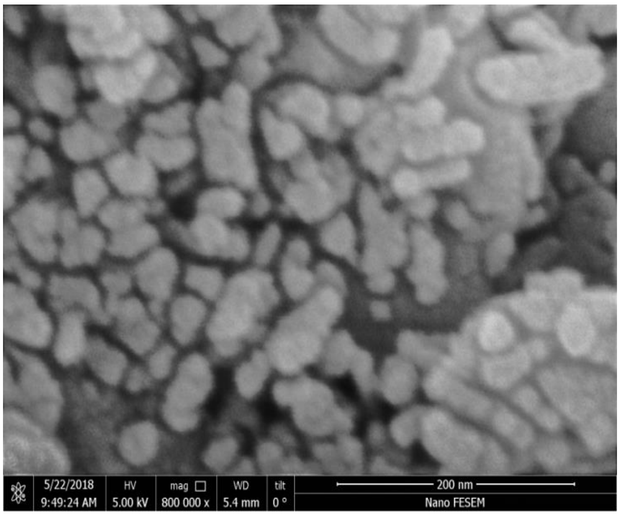
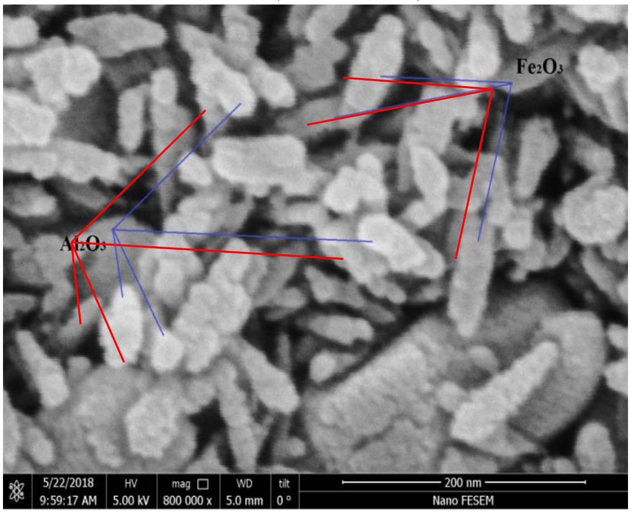


1.5% Fe2O3, 2% Al_2O_3, wt%



2.5% Fe_2O_3, 2% Al_2O_3, wt%



5%, Fe_2O_3 2% Al_2O_3, wt%

Fig. (1) the FESEM images under 200 nm

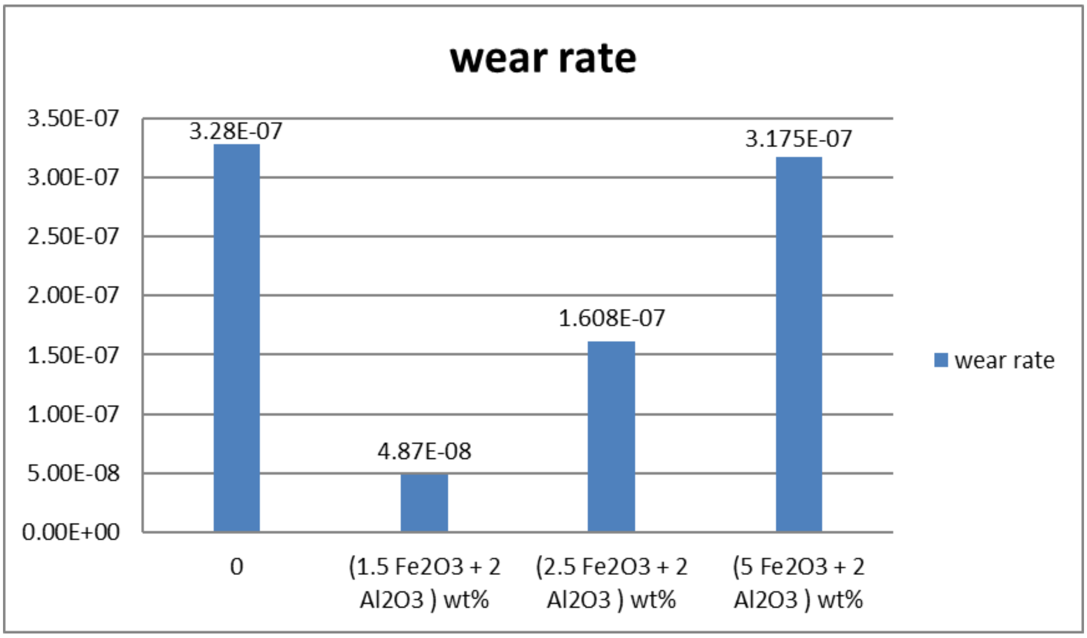


Fig. (2) the results of wear rate

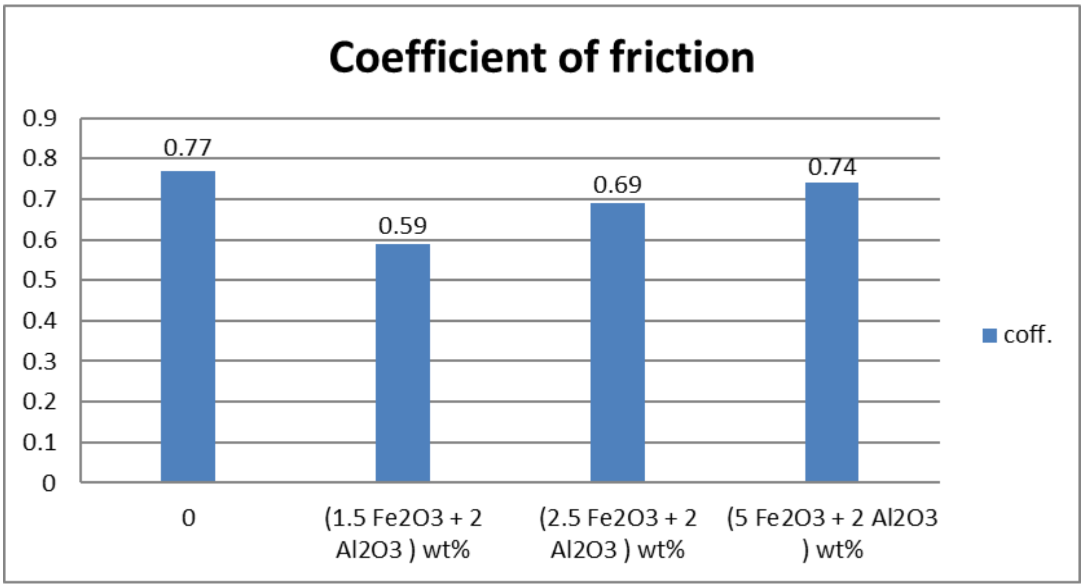


Fig. (3) the coefficient of friction versus the hybrid nanomaterials content

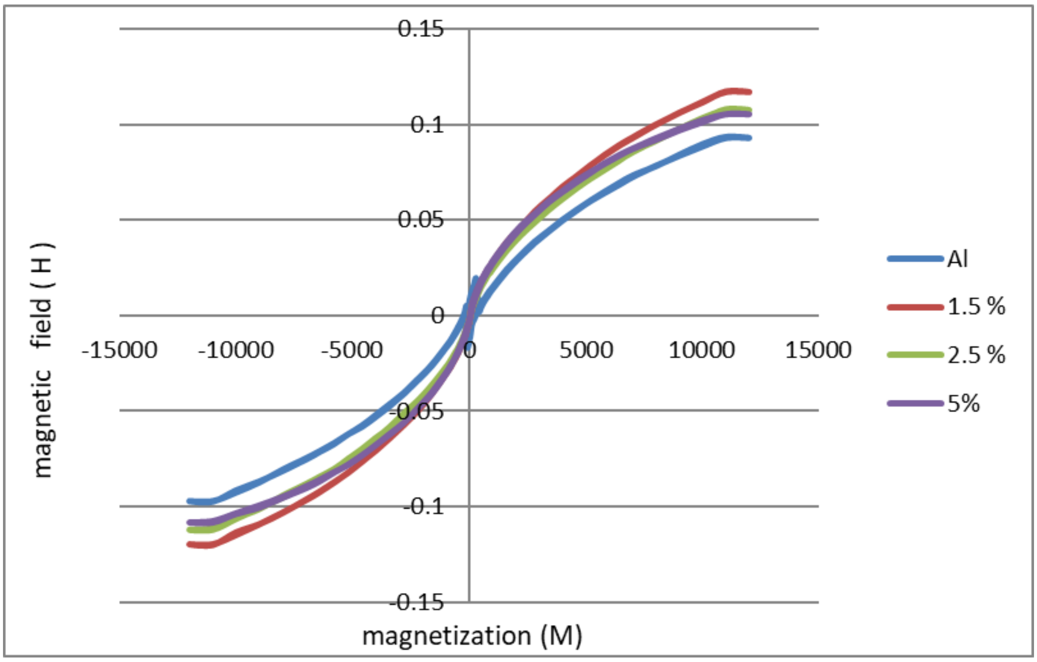


Fig. (4) the variation of magnetic field (H) against magnetization (M)

Table (1) shows the mixture rule

Al (g)	Fe_2O_3 (g)	Al_2O_3, (g)	Total(g)	Fe_2O_3wt.%	Al_2O_3,wt.%
25	0	0	25	0	0
24.125	0.375	0.5	25	1.5	2
23.875	0.625	0.5	25	2.5	2
23.25	1.25	0.5	25	5	2

Table (2) magnetic properties of nanocomposites

Magnetization (M) A/m	Xm	µabs (H/m)	Nanomaterial value
0.0927 to - 0.0927	7.7×10^{-6}	1.254×10^{-6}	(zero nano)
0.11666 to - 0.11666	9.73×10^{-6}	1.257×10^{-6}	(1.5 Fe_2O_3 + 2 Al_2O_3,) wt%
0.10733 to - 0.10733	8.95×10^{-6}	1.256×10^{-6}	(2.5 Fe_2O_3 + 2 Al_2O_3,) wt%
0.10544 to - 0.10544	8.79×10^{-6}	1.256×10^{-6}	(5 Fe_2O_3 + 2 Al_2O_3,) wt%

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