THE PREDICTION OF SOME MECHANICAL PROPERTIES OF AL-7Si% ALLOY REINFORCED WITH PARTICULATE ALUMINA WITH THE AID OF IMPERICAL FORMULAE

Khedre O M* , Dandachi J M A and Algahtany S*****

* Khedre O M, Associate Professor in Production Engineering and Machine Design Department, Menoufia University, Shebin El-Kom, EGYPT.

** Dandachi J M A, Assistant Professor in Jeddah College of Technology, Mechanical Technology Department, Vehicles Section, PO Box 17608, Jeddah 21494, Kingdom of Saudi Arabia.

*** Algahtani S, Assistant Professor, Dean of Faculty-Colleges of Technology Affairs, General Organization for Technical Education and Vocational Training, Riyadh.

Abstract:

Nowadays, it is well known that Aluminum and its alloys, when reinforced with different particulate materials, can provide designers with a group of composites of some valuable mechanical properties such as elastic modulus, poisson's ratio, ultimate strength, ductility, internal friction, and wear characterization.

Such mechanical properties are important aspects in the design procedure for many moving and rotating parts in the mechanical field. Finding them through an experimental way is a hard and long way as the designer needs to prepare many composites alloys with different contents in order to find the best fit for his design.

Finding imperical formulae, which describe these mechanical properties, gives the chance to choose the contents of the composites materials very near to the desired contents and hence reducing the number of specimens needed in the experimental work.

In the present work, the authors suggesting some imperical formulae based on statistical approach for the experimental results on the composite material AL-7Wt% Si/Al_2O_3. As an example, the wear rate can be predicted on different loads and for many sliding distances as well. Also, a percentage error evaluation was done for the curve fitting between the experimental results and the theoretical values drawn from the imperical formulae.

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1. INTRODUCTION

Addition of hard ceramic particles such as SiC, ZrO_2 or Al_2O_3 to Al-matrix alloys can improve the elastic modulus and strength as well as wear resistance of the produced composites. It has reported[1] that an increase in the dry sliding wear resistances of 2014 Al-Al_2O_3 alloys with increasing weight percent and size of non-metallic particles, while, it was observed[2] that the addition of 5% Al_2O_3 particles to hypereutectic Al-Si alloys does not significantly contribute to the wear resistances.

Elastic modulus and internal fricition are very important physical-mechanical properties, where the former relate directly to interatonic potentials, and the latter refers to all mechanisms by which energy is dissipated internally. These properties have been investigated for particulate metal-matrix composites by several outhors [3-5].

Where the effect of distribution of added particles, such as SiC and Boron, on elastic modulus and internal friction has been studied. Also, high damping has been obsterved in aluminum alloys [6] and characterized by wide region of solid solutions (Al-Zn) or by almost full absence of solubility (Al-Sn), and it is possible to have second phase inclusions with small hardness (Zn,Sn, graphite) or great hardness (Al_2O_3). However, same authors [6] reported that, damping in the first case is connected with the plastic deformation of inclusions, while in the second one, damping is referred to the friction at the interphase boundaries and microdeformation of matrix in the field of inclusions.

The present work is aimed to investigate the effect of addition of alumina particles up to 12 wt% into an Al-7%Si alloy, on some mechanical properties e.g. elastic modulus, possion's ratio, ultimate strength, ductility, and wear characterization in addition to internal friction through applying comprehensive different techniques.

Furthermore, some imperical formulae based on statistical approach [7] were given to describe the experimentally determined values for some mechanical properties.

2. EXPERIMENTAL PROCEDURE

2-A Compsoite Preparation

Fig.(1) presents the flow cahrt of the experiment. All the experimental procedure described in this section are referred to this chart. Al-Si hypoeutectic alloys of a nominal composition, 7Wt% Si was first prepared by mixing the appropriate amount of 99.7% commerical purity Al with a 50% Al-Si master alloy. The composites containing alumina particles were prepared using the set-up described in details elsewhere [8]. A single particulate size 90 μm of Al_2O_3 was selected to yield up to 12 wt% of composite materials.

The pouring temperature of the melt and the die temperature were maintained at 710°C and 500°C, respectively. The viscous slurry was controlled in a preheated crucible and transferred to the preheated die for squeeze casting.

The compsoite specimens, 60 mm diameter and 100 mm long were squeeze casted under 80 MPa pressure and duration of 120 sec. which were shown to give the optimum properties.

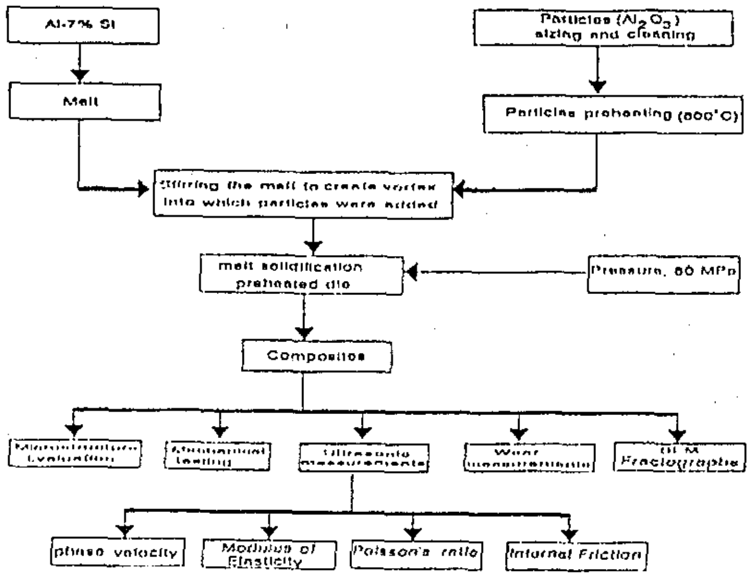

Fig. (1): Flow chart of the experiment.

2-B- Test Programme

2-B-1 Tensile Tests

Cylindrical specimens of 8 mm diameter and 40 mm gauge length (according to BS 1987 and ASTM E 8-89 b), were machined from the squeezed composites with their gauge length parallel to the longitudinal axis of the casting. Testmetric machine was used throughout the present work for room temperature tensile testing at a constant cross-head speed of 3 mm/min. A minimum of three specimens were tested for each case.

2-B-2 Ultrasonic Measurements

A sonar type pulse echo system used a magnetostrictive transducer was employed to excite, in-plane vibration, of rectangular strips and square plated of Al-Si composites reinforced with alumina. This sytem has been explained in details elsewhere [9,10]. Longitudinal elastic modulus (E), shear elastic modulus (G), and the bulk modulus (B), and the internal friction Q^{-1} are determined.

2-B-3 Wear

The wear study was performed on a testing machine of the pin-on-disc type, specially designed, built up and instrumented for experimentations. Squeeze casted cylindrical specimens of 25 mm diameter and 14 mm height were tested.

The sliding counterface disc was made of steel 1% C and 1.5% Cr (which corresponds to AISI-SAE grade 52100) with an initial surface roughness, Ra, of about 0.5 μm. The disc diameter was 170 mm and the disc width was 7 mm. The tests were performed at room temperature without lubrication. The length of the friction track was 540 mm. Before each test, the pin was polished with grit SiC paper and cleaned with dry methanol. The applied loads on the specimen were 1,2, 2.6, and 3 kg. The tests were made for different lengths of running times up to 60 min. Wear measurements were made after the initial run-in period when the pin surface was completely in contact with the disc surface.

The weight loss was converted into volumetric (linear) wear per kilometer of sliding distance to obtain wear rate. The friction tract was changed and a fresh one was provided each 6 km of the sliding distance. To avoid vibrations, all the parts were isolated by rubber sheets.

3. RESULTS AND DISCUSSION

3-1 *Strength, Ductility and Internal Friction*

The effect of alumina content on the mechanical properties (ultimate tensile strength and ductility) of the investigated composite materials is shown in Figs. 2-6.

Regarding the ductility behaviour (Fig.2), it seams that composites of alumina content in the range (4 - 8%) have an appropriate elongation. Higher alumina content results in a considerable reduction in ductility simply due to the high density of imperfections associated with the high level of Al_2O_3 particles content.

Figs. (3-5) show the dependence of elastic modulus, the poisson's ratio and internal friction Q^{-1} of the studied Al-7%Si/Al_2O_3 compsoites on the alumina %. The effect of Al_2O_3% on the UTS is shown in Fig. 6. The increase in tensile strength, modulus of elasticity, and poisson's ratio with Al_2O_3 is not obsolute, since strength stasts to decrease beyond 4-8% Al_2O_3. Metallographic examinations on the fractured surface of 12%Al_2O_3 composites have shown the high density of imperfections inclcuding voids, transgranuler microcracks and particle decohesion. These defects have their negative effect in reducting the strengths.

Moreover, the dynamic properties of composite materials are determined by the properties of its components, the morphology of the system and the nature of the interphase.

Studies on homogeneous materials show an inverse relation between damping and elastic modulus. However, composites could behave differently since modulus and damping may arise from separate factors. Volume fraction may control modulus while matrix-interfacial area may control damping. It has been suggested [3] that internal friction in composites originates from four separate sourses: reinforcement, matrix, interfaces and geometry. In the present, work we expect a high stiffness material such as Al_2O to possess a low internal friction. Also, the damping level in the Al-7% Si alloy before adding alumina into it is somewhat lower than those contained it in the matrix. This suggests that the Al-Si alloy is characterized with small contribution to the internal friction. Therefore, the observed increase in the internal friction as the alumina particle is added into the Al-Si alloy is attributed to be due to some interfacial frictional effects and micro defromation of the matrix in the field of inclusions [4] as resulted from the reduction interbonding forces which can decrease the elastic modulus and increase the damping.

The Curve Fitting Approach

In all the curve fittings, the softwere used is called "The Cricket Graph" on the Macintosh Computer [12].

In Fig. 2, the polinomyal fitting technique gives a polinomyal equation for four experimental points relating the percentage elongation (EL) with the percentage of Al_2O_3 (Al),

$$El = 12-1.435\ Al + 0.27875\ (Al)^2-0.01875\ (Al)^3 \qquad (1)$$

The RMS for this equation is 1 i.e. these fitting is perfect.

Fig. 3: presents three parameters:

E = longitudinal modulus

B = bulk modulus

C = shear Modulus

The polinomyal fitting technique gives a polynomyal equation of the second order (i.e. parabolic) for these three modulus and are as follow,

$$E = 8303 + 108.25\ (Al) - 14.063\ (Al)^3 \qquad (2)$$

The RMS for this equation is 0.993 and the average percentage error was found to be 0.00757.

The percentage error for each point was estimated using the following equation:

$$\%\ error = (E_{eq\ theq} - E_{exp})\ /\ E_{exp} \qquad (3)$$

and the average % error is $\sum_{n=1}^{p} \%\ error / P$

$$B = 4177.5 + 59.37\ (Al) - 7.9688\ (Al)^2 \qquad (4)$$

The RMS is 0.993 and the A.P. error is = -0.11 %

$$G = 3103 + 38.25\ (Al) - 4.6875\ (Al)^3 \qquad (5)$$

RMS = 0.996 and Al. error is 0.00095 %

The fitting technique gives also a parabolic for the poisson's ratio (γ) with respect to Al_2O_3%, (Fig. 4).

$$\gamma = 0.3356 + 0.0019 (Al) - 0.0003125 (Al)^2 \quad (6)$$

RMS = 0.981 and A.P. Error is 0.579 %

The fitting technique gives a straight line for the internal friction (IF) with respect to Al_2O_3% (Fig. 5).

$$IF = 0.00159 + 0.000255 (Al) \quad (7)$$

RMS = 0.994 and A.F. Error is 0.624 %

In Fig. (6), the fitting technique gives a parabolic for the ultimate tensile stress (U) with respect to Al_2O_3%.

$$U = 117.24 + 14.195 (Al) - 1.2812 (Al)^2 \quad (8)$$

RMS = 1 i.e. perfect fitting.

3-2 Wear in Al-7wt% Si/ Al_2O_3 Composites

The experimental data for wear behaviour of the investigated composite materials as affected by contact load as well as alumina content are shown in Figs. (7,8 & 9).

The curves have the two distinct features for the wear behaviour. The first is characterised by lower wear as a result of the existence of oxide layer on the surface of the composite that will decrease the frictional stresses due to its lubricating character. The second wear process is the metallic wear which is characterised by severe attack and the rapid exposure of the fresh matrix to the hard disk.

However, the extent of the two processes depends on the contact load and alumina level. Increasing the load results in a rapid transition from oxidation to metallic wear for a given alumina content of the matrix. On the other hand, alumina tends to decrease the wear level due to its strengthening effect on the matrix (dispersion hardening).

Figs (10,11 & 12) present reconstrustion of the three figures (6,7,8) using the straight line fitting technique. Each line has an equation relating the wear rate (W.R.) with the (S.D.) but for a specific load and Al_2O_3 %.

The general equation would be in the form of:

$$W.R. = a + b \ (S.D) \quad (9)$$

Figure 9 has three equatios for the three lines at load = 10 N but at three values of Al_2O_3 % (4,8 and 12). We can generalize equation (9) with respect to Al_2O_3% by relating the constants a and b with respect to Al_2O_3 %. So, we get:

$$a = c - d (Al) \quad \& \quad b = e - f (Al) \quad (10)$$

Thus, eq. (9) tgives the W.R. for any values of (S.D.) and Al_2O_3 % but at Load = 10 N.

If we repeat the procedure made on figure 9 to figures 10 and 11, we would have three equations for both a and b at N = 10, 26 and 30 N respectively.

To generalize eq. (9) with respect to any load we have to relate the constant (c and d) in equation (9) and (e and f) in equation 10 to the load as well.

So, we get,

for a
$$c = g + h\,(load)$$
$$d = j + k\,(load)$$

for b
$$e = m + n\,(load)$$
$$f = u + v\,(load)$$

So by relating c,d, e and f to load, eq. (9) gives the W.R. for any (S.D.) and Al_2O_3 % at any load as well.

An example to this claculations is presented in Table (1).

A simple G N Basic program was writting to calculate the wear rate at any sliding distances and at any load for any Al_2O_3 %.

The predicted W.R. was calculated by using this program and then the percentage error for each point was calcualted and it was found to be varied between 51.6 % and 90.8% .

And the average percentage error for all these point was found to be 3.52%.

CONCLUSIONS

Within the scope of the present test results, the following conclusions can be made:

1- The ultimate tensile strength at room temperature of the investigated composites was found to increase with Al_2O_3 -additions and attained its maximum at 4% Al_2O_3. Above this level, UTS began to decrease.

2- Within the examined range of alumina content, internal friction has shown strong dependence on Al_2O_3 -content in the composite, i.e. additions of alumina particles increase the internal friction remarkably.

3- The wear behaviour of Al-7% Si/ Al_2O_3 composites is a strong function of both the applied load and Al_2O_3 content. At low levels of the ceramic phase, the wear resistance of the composites is superior to that of the unreinforced alloy. However, increasing Al_2O_3 -content, particles at the contact surfaces are fractured and wear proceeds by a subsurface delamination process. In this regime, Al_2O_3 -particles also cause the abrasion of the Al-matrix. This transition to a high wear rate regime is induced by increasing the applied load above a critical value.

4- The proposed imperical formulae for predicting both the static mechanical properties (tensile strength, ductility), dynamic properties (internal friction, dynamic modulus), as well as wear have proved to be a very useful tool that enables the designer to choose the right contents of the composite materials.

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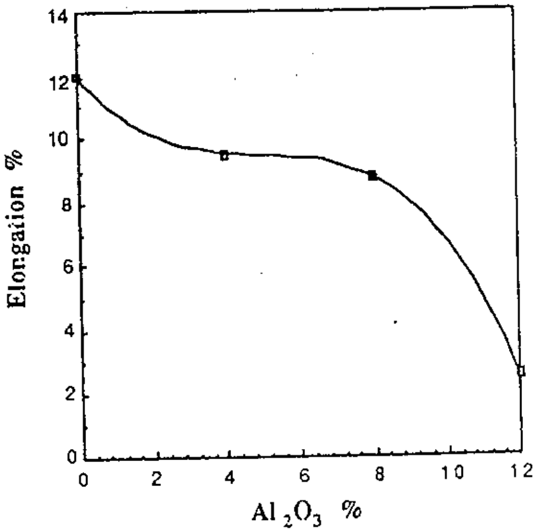

Fig.2: The predicted dependence of elongation % on AL_2O_3%.

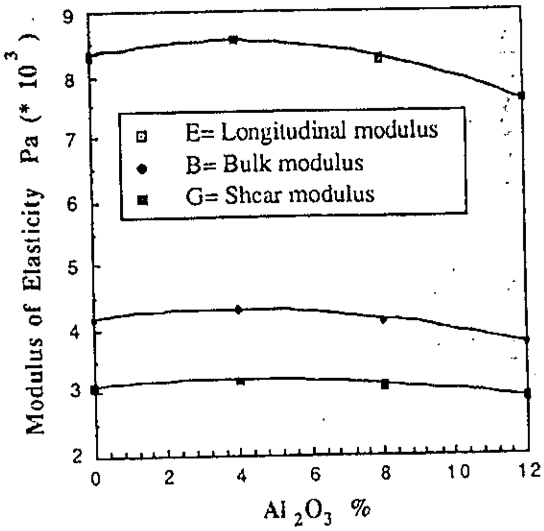

Fig.3: The predicted dependence of the modulus on AL_2O_3%.

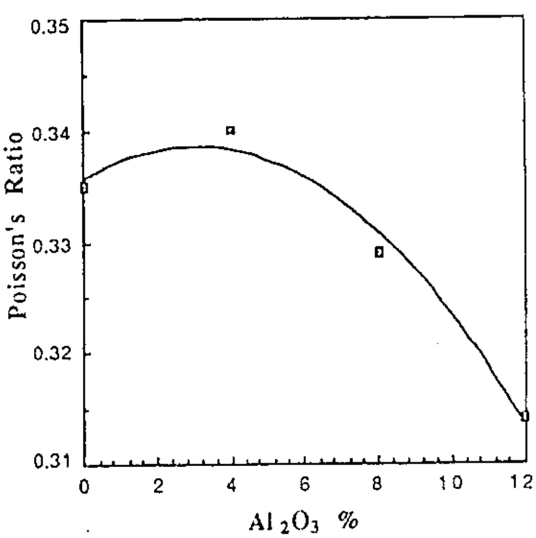

Fig.4: The predicted dependence of Poisson's ratio on AL_2O_3%.

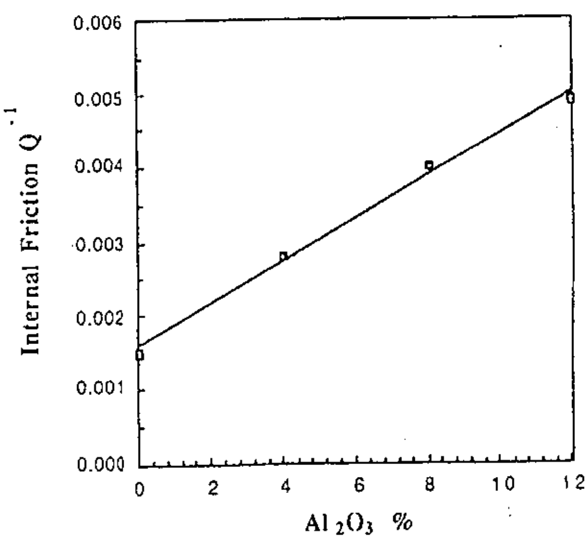

Fig.5: The predicted dependence of internal friction on AL_2O_3%

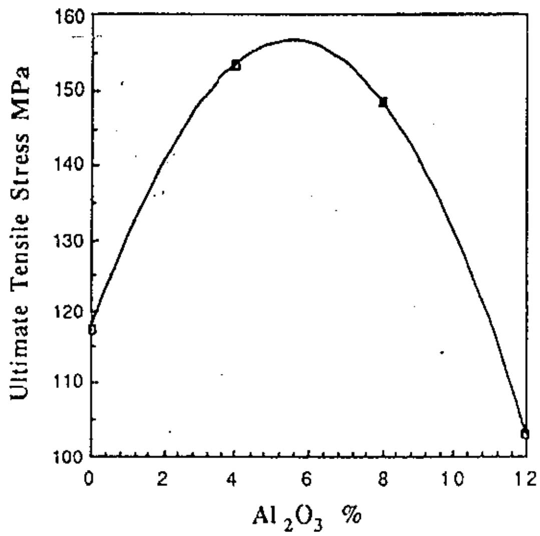

Fig.6: The predicted dependence of UTS on AL_2O_3%.

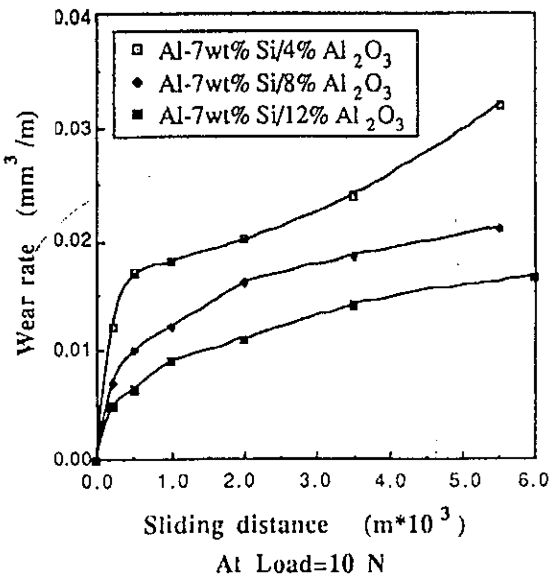

Fig.7: Variation of wear rate with sliding distance (Exp.).

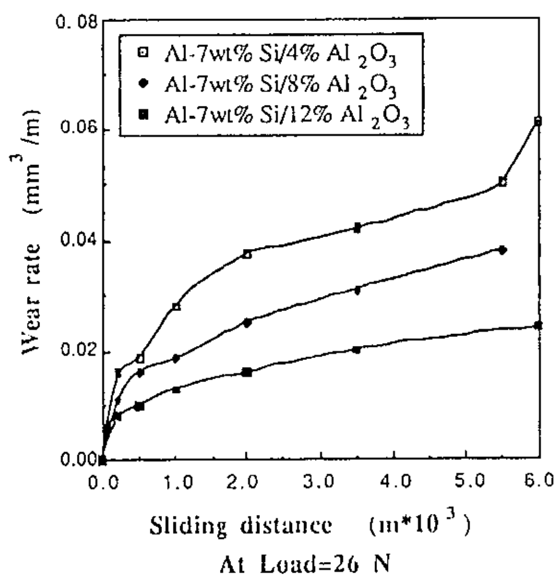

Fig.8: Variation of wear rate with sliding distance (Exp.).

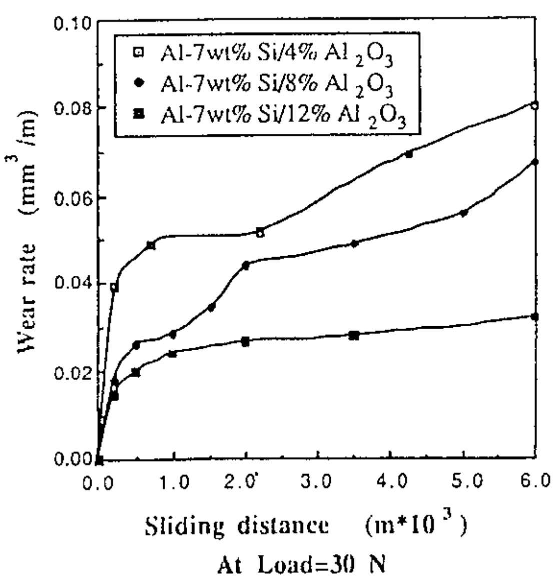

Fig.9: Variation of wear rate with sliding distance.

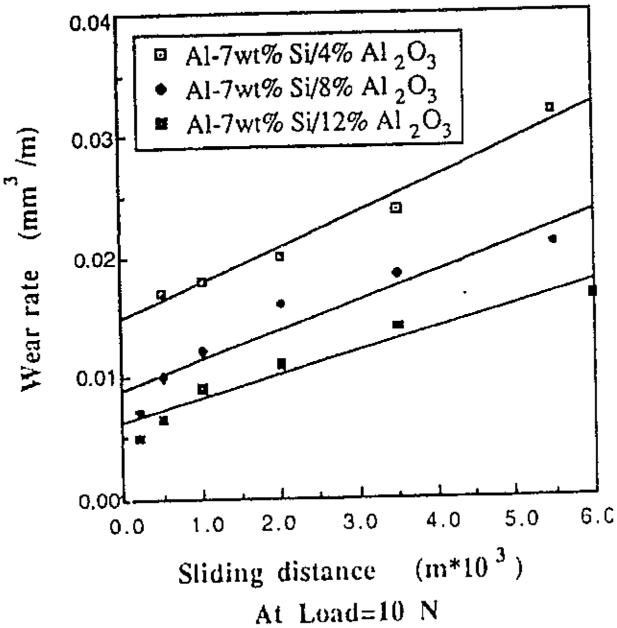

Fig.10: The predicted dependence of wear rate on sliding distance.

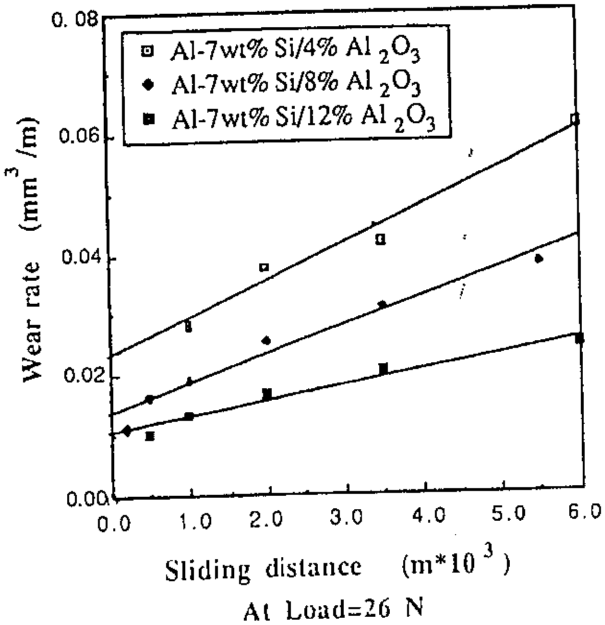

Fig.11: The predicted dependence of wear rate on sliding distance.

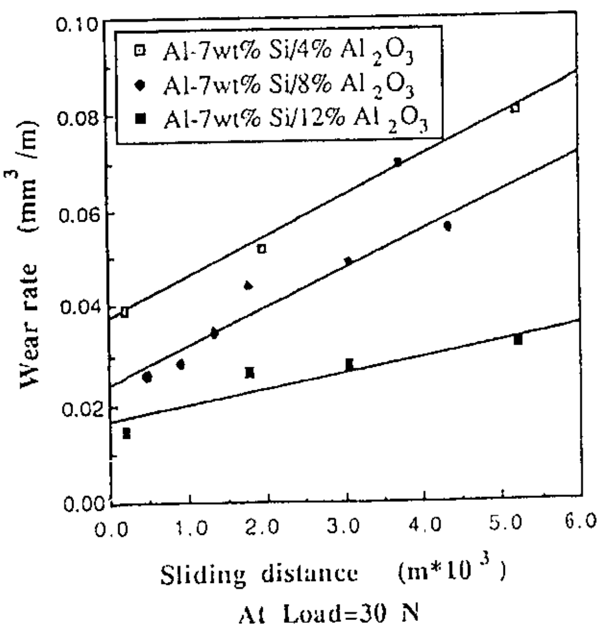

Fig.12: The predicted dependence of wear rate on sliding distance.

For 4 % Alumina AT LOAD = 10 N

YOU WANT TO FIND THE WEAR RATE AFTER SLIDING DISTANCE OF 1 KM

General Equation W.R. = a + b (S.D.)

a = c - d (AL)

c = g + h (Load)

c = 0.0054373 + 0.0011528 (Load) R^2 = 0.735

c = 0.0054373 + 0.0011528 (10)

c = 0.0169653

d = j + k (Load)

d = 0.00042345 + 0.000057745 (Load) R^2 = 0.734

d = 0.00042345 + 0.000057745 (10)

d = 0.0010009

a = c - d (AL)

a = 0.0169653 - 0.0010009 * (4) → $\boxed{a = 0.0129617}$

b = e - f (AL)

e = m + n (Load)

e = 0.00052214 + 0.00030004 (Load) R^2 = 1.000

e = 0.00052214 + 0.00030004 (10)

e = 0.00352254

f = u + v (Load)

f = -0.00003823 + 0.000018059 (Load) R^2 = 0.944

f = -0.00003823 + 0.000018059 (10)

f = 0.00014236

b = e - f (AL)

b=0.00352254-0.00014236*(4) → $\boxed{b = 0.0029531}$

General Equation W.R. = a + b (S.D.) → W.R. = 0.0129617 + 0.0029531 (1) → W.R. = 0.0159148

Table 1: Case study: How to find the wear rate for AL-7%Si/4%AL_2O_3.

" استنباط بعض الخصائص الميكانيكية لسبيكة الألومنيوم

٧% سيليكون المعززة بحبيبات الألومنيا بالاستعانة بمعادلات وضعية "

من المعروف أن تعزيز فلز الألومنيوم وسبائكه بالحبيبات يعطى المصمم مجموعة من المؤتلفات ذات خصائص ميكانيكية قيمة مثل معامل المرونة و نسبة بواسان ، اقصى اجهاد شد ، ممطولية ، القدرة الإخمادية ، وخصائص مقاومة البرى

و للخصائص الميكانيكية أهمية بالغة عند تصميم المنشآت الديناميكية والتى تتطلب متانة عالية مع الإنخفاض فى الوزن وتزايد القدرة على الإخماد .

وللحصول على قيم تلك الخصائص يلزم اجراء سلسلة من التجارب يبذل فيها جهدا كبيرا وهذه الدراسة تمثل محاولة للاستغناء عن التجارب العملية بمجموعة من المعادلات الوضعية يمكن تحديد جوانبها بدقة لإستنباط الخصائص الميكانيكية والترابيولوجية للمؤتلفات

وبمقارنة النتائج التى استنتجت من هذه المعادلات الوضعية بالنتائج التى حصلنا عليها بعد سلسلة من التجارب معمليا وجد أن هناك تطابق بينهما .