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Prediction Models for Sliding Wear of AA3003/Al_2O_3 Composites

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ABSTRACT
In the present work, the AA3003/Al_2O_3 metal matrix composites were manufactured at 10% and 30% volume fractions of Al_2O_3. The composites were wear tested at different levels of normal load, sliding speed and sliding distances. The microstructure of worn surfaces pertaining to AA3003/ Al_2O_3 composite reveals the fracture of AA3033 alloy matrix as well as the detachment of Al_2O_3 particles from the matrix.
Keywords - Metal matrix composite, AA3003 alloy, aluminum oxide, wear, sliding distance, normal load, sliding speed.

I. INTRODUCTION

Particle reinforced metal matrix composites are more attractive due to their cost-effectiveness, isotropic properties, and their ability to be processed using similar technology used for monolithic materials. A large amount of work has been carried out in an attempt to characterize the mechanical behavior of particle reinforced metal matrix composites [1-4].

Most of the studies made in automotive and aerospace field shows that the material used for components should possess good toughness with better tribological properties. Adhesive wear behavior of AA 4147 and AA 4147/ boron carbide (B_4C) and silicon carbide (SiC) composite made-up through stir casting process has been studied and concluded that AA4147 exhibits severe wear regime whereas the B_4C and SiC reinforced composite reveals only mild wear regime at the same wear condition [5]. The automobile components undergo sliding as well as abrasive type of wear against the counter surface during operation. In order to understand this phenomenon, wear tests of the as-cast and aged-Al6061alloy/SiC composites were carried out at different loads [6]. In [7], the dry sliding wear characteristics of Al-Si-Mg-Fe alloy have been investigated. The influence of variables viz: contact time, sliding speed, and normal pressure on wear behavior were studied. The wear mechanisms include abrasive, adhesive, slip, melt-wear and oxidative phenomena. A two-dimensional anisotropic wear model is constructed to predict the anisotropic wear of composites based on the anisotropic strength and the contact behavior in [8]. In searching the literature for models and equations, over 300 equations were found for friction and wear [9]. Many of these equations were based on the assumption that a conventional material property (of the investigator's choice), usually Young modulus E or hardness H, would be important in the wear process.

Reports were enlightened that Taguchi's design of experiments (DOE) methodology was systematic and efficient way to analyze the effect of parameters on the response with the help of orthogonal arrays [10, 11].

In the present work, the composite was prepared by using stir casting method, which is one of the economic and commonly used methods. The present work is on the evaluation of wear characteristics and consequences of cast AA3003/alumina composites.

II. MATERIALS AND METHODS

The matrix material was AA3003 alloy. The reinforcement material was alumina (Al_2O_3) nanoparticles of average size 100nm. AA3003 alloy/ Al_2O_3 composites were fabricated by the stir casting process and low pressure casting technique with argon gas at 3.0 bar. The composite samples were given H14 solution treatment. The heat-treated samples were machined to get cylindrical specimens of 10 mm diameter and 30 mm length for the wear tests.

Table 1. Control parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, Vol.%	A	10	20	30
Load, N	B	10	20	30
Speed, m/s	C	1	2	3
Sliding distance, m	D	500	1000	1500

The levels chosen for the controllable process parameters are summarized in Table 1. Each of the process parameters was chosen at three levels. The orthogonal array, L9 was preferred to carry out wear tests (table 2). A pin on disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA3003 alloy/Al_2O_3 composites against hardened ground steel (En32) disc as shown in Fig.1.

Table 2. Orthogonal array (L9) and control parameters

Treat No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

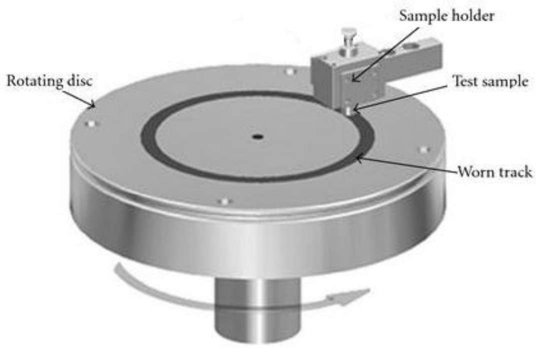

Fig. 1. Pin-on-disc wear test.

An investigation has been carried out to study the effects of sliding speed, contact time, normal pressure, and volume fraction of Al_2O_3 on the wear characteristics. The microhardness was measured in terms of Knoop hardness number before and after wear tests. Optical and Scanning electron microscopy analysis was also carried out to find consequence of wear test AA3003/Al_2O_3 composite specimens.

Stiffness and hardness are more or less the same things; it refers to the ability of a material to resist deformation. So, higher the young's modulus higher is the stiffness. The stiffness of the composites was calculated with formulae mentioned below.

The upper-bound equation is given by

$$\frac{E_c}{E_m} = \left(\frac{1-v_v{}^{2/3}}{1-v_v{}^{2/3}+v_v}\right) + \frac{1+(\delta-1)v_p{}^{2/3}}{1+(\delta-1)(v_p{}^{2/3}-v_p)} \qquad (1)$$

The lower-bound equation is given by

$$\frac{E_c}{E_m} = 1 + \frac{v_p - v_p}{\delta/(\delta-1)-(v_p+v_v)^{1/3}} \qquad (2)$$

where, $\delta = E_p / E_m$, v_v and v_p are the volume fractions of voids/porosity and nanoparticles in the composite respectively, and E_m and E_p are elastic moduli of the matrix and the particle respectively.

III. RESULTS AND DISCUSSION

The elastic stiffness and knoop hardness were increased with volume fraction of Al_2O_3 as shown in Fig.2 At first glance of technical information before wear test is that the ability to resist deformation would increase with increase of Al_2O_3 content in AA3003 matrix.

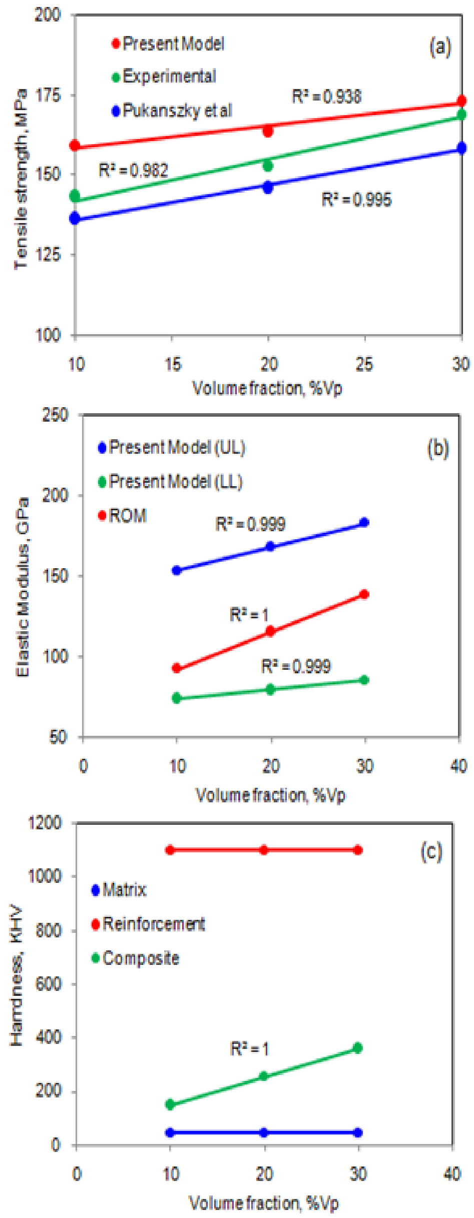

Fig. 2. Mechanical Properties of AA3003/ Al_2O_3 composites.

3.1 Effect of volume fraction, Normal Load, Sliding Speed, Sliding distance on Wear Rate

For the analysis of variance (ANOVA), all parameters qualify Fisher's test at 90% confidence level. In Table 3, the percent contribution indicates that the parameter A, volume fraction of Al_2O_3 contributes two-third (73.34%) of variation in the wear rate. The normal load (B) commits 10.15% of variation in the wear rate. The speed (C) confers 2.07% of variation in the wear rate. The sliding distance (D) affords 14.44% only of the total variation in wear rate.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	19.75	18.13	14.17	5.49	1	5.49	1.93E+14	73.34
B	16.12	18.04	17.89	0.76	1	0.76	2.67E+13	10.15
C	17.70	17.55	16.80	0.15	1	0.15	5.45E+12	2.07
D	16.66	91.52	52.05	1.08	1	1.08	3.81E+13	14.44
E				0.00	4	0.00	1.00E+00	0
T	70.23	145.24	100.91	7.49	8			100

Note: SS is the sum of square, v is the degrees of freedom, V is the variance, F is the Fisher's ratio, P is the percentage of contribution and T is the sum squares due to total variation.

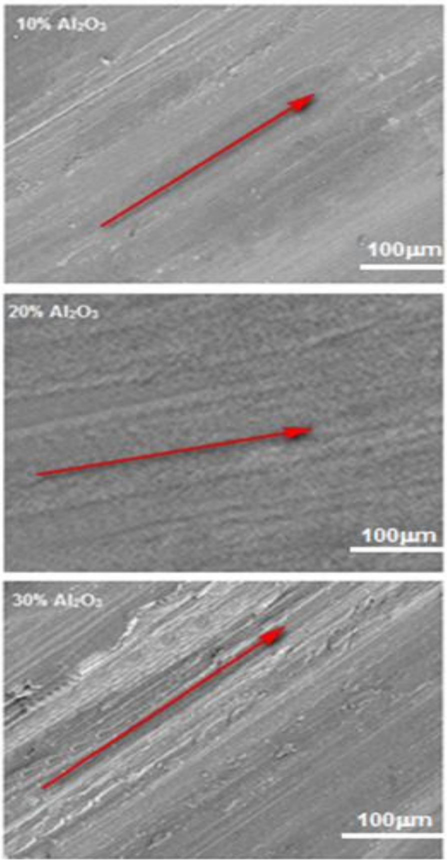

Fig.3. Scratches on worn surfaces.

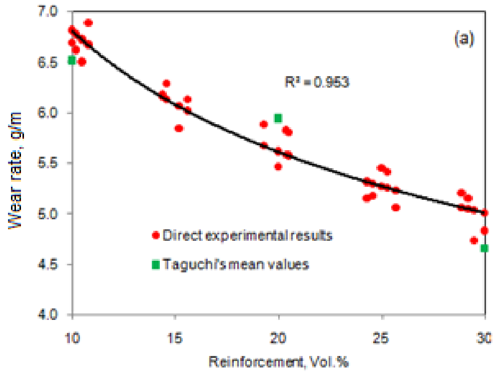

Fig.4. Influence of reinforcement on wear rate.

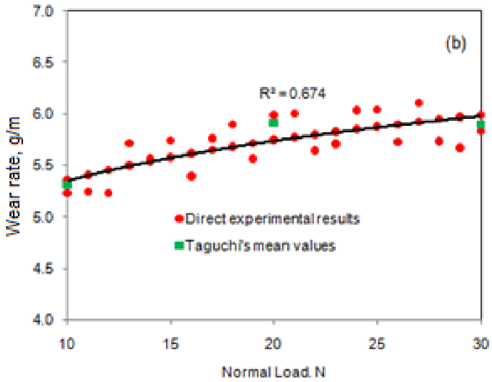

Fig.5. Influence normal load on wear rate.

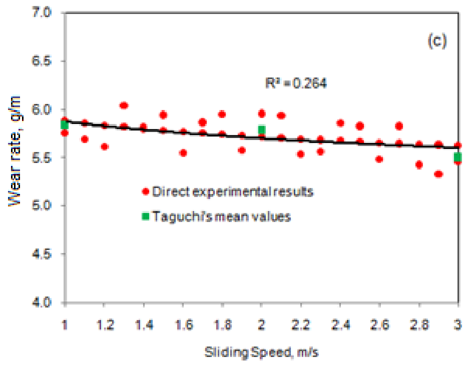

Fig.6. Influence of sliding speed on wear rate.

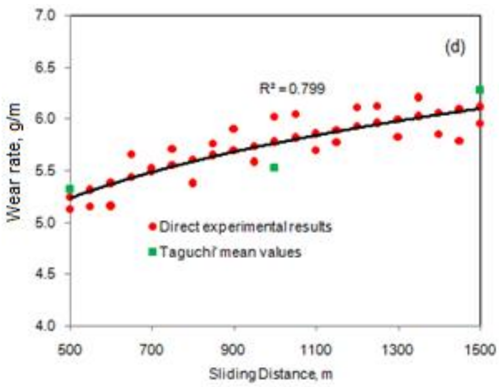

Fig.7. Influence of sliding distance on wear rate.

The tested specimens are shown in Fig.3. The scratches on the worn surfaces were increased with increase of volume fraction of Al_2O_3. It can be seen from Fig. 4 that the wear rate was decreased with increase in volume fraction of Al_2O_3 in AA3003 alloy matrix. This owes to increase of stiffness and hardness of composites with increase of Al_2O_3. Composites produced by low volume fraction of Al_2O_3, wear out faster than those produced by high volume fraction of Al_2O_3. The wear rate was increased with load as shown in Fig. 5. An increase in the load leads to increased wear and loss of the metal. The initial rubbing duration breaks the surface layers, which clean and smoothen the surfaces and increase the strength of the connections and contact between the surfaces. Subsequently, the increase in the load causes rise in friction. The wear rate was decreased with increase of sliding speed (Fig. 6). Because speed increases, momentum transfer in the normal direction increases presenting an upward force on the upper surface. This results in an increased separation between the two surfaces which will decrease the real area of contact. Contributing to the increased separation is the fact that at higher speeds, the metal loss is low. As seen in Fig.7, the wear rate was proportional to the sliding distance. The wear rate for the matrix alloy continues to increase with sliding distance, consequently loose of Al_2O_3 nanoparticles from the matrix. Hence the result is more wear rate with increase of sliding distance.

The mathematical relations between wear and volume fraction of reinforcement, normal load, speed and sliding distance are given by

$$W_{rp} = 12.98 \times v_f^{-0.28} \quad (6)$$

$$W_{rf} = 4.24 \times F^{0.101} \quad (7)$$

$$W_{rn} = 5.87 \times N^{-0.04} \quad (8)$$

$$W_{rd} = 2.205 \times d^{0.139} \quad (9)$$

where,
W_{rp} is the wear rate due to volume fraction of reinforcement (v_f), g/m
W_{rf} is the wear rate due to normal load (F), g/m
W_{rn} is the wear rate due to speed (N), g/m
W_{rd} is the wear rate sliding distance (d), g/m.

The R-squared values, which are attributable to volume fraction of reinforcement, normal load, sliding speed and sliding distance, are 0.953, 0.674, 0.264 and 0.799, respectively. This trend is similar to the percent contributions of process parameters obtained from Taguchi techniques. The mean values obtained by the Taguchi techniques are within the range of curve fitting as seen in Figs.4-7.

3.2 Consequence of Wear in AA3003/Al_2O_3 Composites

It is essential to know the consequence of wear in AA3003/Al_2O_3 composites. The worn specimens are not length enough for tensile testing to evaluate tensile strength and %elongation. Therefore, the worn specimens were tested for knoop hardness only. The hardness contours of the worn specimens are shown in Fig.8. It can be seen that the hardness values increase after wear test. The increase in hardness in the worn specimens may be attributed to the work hardening mainly due to influence of volume fraction of Al_2O_3, sliding distance and normal load applied on the test specimens.

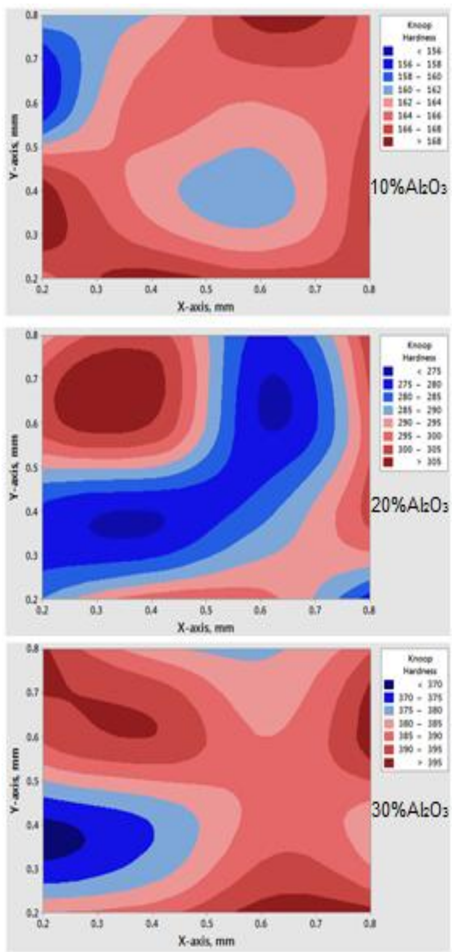

Fig.8. Hardness contours of AA3003/Al_2O_3 composites after wear test.

The microstructures of worn specimens are revealed in Fig.9. When the reinforcement is 10% (Fig.9a), the material loss is from matrix. In the composites having 20 or 30% of Al_2O_3, detachment of particles from the matrix was observed (Fig. 9b-c). In the composites having 10% of Al_2O_3, a large amount of matrix material debris was observed (Fig.10a). The debris of composites having 20 or 30% Al_2O_3 consists of detached particles too. The trend of hardness contours matches with microscopic worn surfaces.

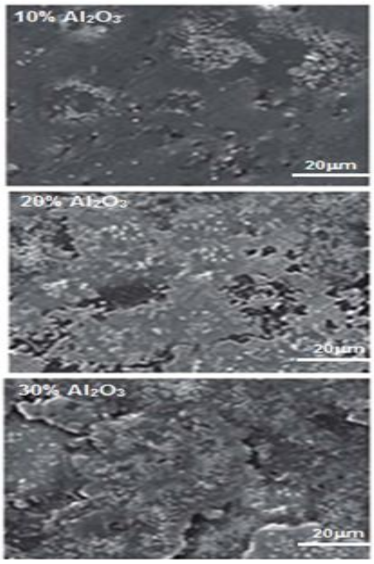

Fig.9. Images of worn surfaces of AA3003/Al_2O_3 composites: (a) 10% Al_2O_3 (b) 20% Al_2O_3 and (c) 30% Al_2O_3.

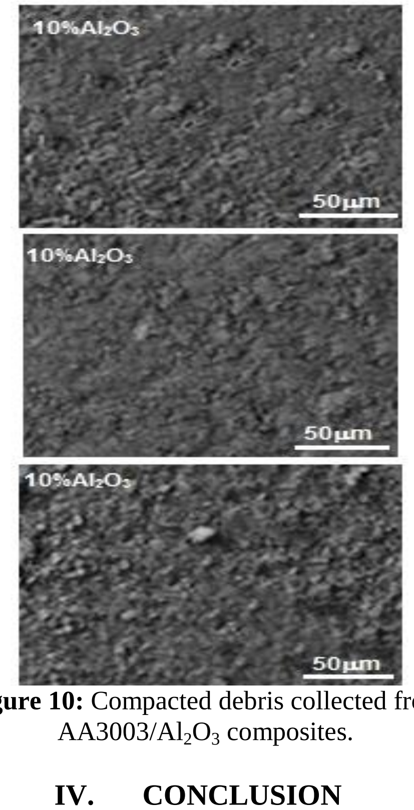

Figure 10: Compacted debris collected from AA3003/Al_2O_3 composites.

IV. CONCLUSION

The wear resistance increases with increase of volume fraction of Al_2O_3 in AA3003 alloy matrix. The material loss increases with increase in normal load and sliding distance. The influence of sliding speed on the wear rate is nearly insignificant.

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