Journal of Minerals and Materials Characterization and Engineering, 2012, 11, 679-684
Published Online July 2012 (http://www.SciRP.org/journal/jmmce)

Dry Sliding Wear Behaviour of Aluminium/$Be_3Al_2(SiO_3)_6$ Composite Using Taguchi Method

H. B. Bhaskar[1*], Abdul Sharief[2]
[1]Department of Mechanical Engineering, Sri Siddhartha Institute of Technology, Tumkur, India
[2]Department of Mechanical Engineering, P. A. College of Engineering, Mangalore, India
Email: *bhaskarhbssit@gmail.com

Received February 13, 2012; revised March 31, 2012; accepted April 21, 2012

ABSTRACT

The present study deals with investigation relating to the influence of wear parameters like sliding speed, applied load and sliding distance on the dry sliding wear of aluminium metal matrix composites. The design of experiment approach was employed to acquire data in controlled way using Taguchi method. A pin-on-disc apparatus was used to conduct the dry sliding wear test. An orthogonal array, signal-to-noise ratio and analysis of variance were employed to investigate the wear behavior of aluminium and it's composite. The mathematical model was obtained to determine the wear rate of the aluminium and it's composite. The confirmation tests were conducted to verify the experimental results. The incorporation of $Be_3Al_2(SiO_3)_6$ as reinforcement material in aluminium matrix material improves the tribological characteristics.

Keywords: AMMC's; Wear; Orthogonal Array; ANOVA; Taguchi Method

1. Introduction

Metal matrix composites (MMCs) have proved their viability as good alternatives to conventional alloys in high strength and stiffness application in industries like automobile, aerospace and mineral processing. To enhance the mechanical and tribological properties, hard reinforcement phase such as hard ceramic particles or fibers or whiskers are uniformly distributed in the soft matrix phase [1,2]. As result of reinforcement phase, the modulus and strength of the composites were increased while the ductility decreases [3]. The composite materials have emerged as the important class of advanced materials giving engineers the opportunity to tailor the material properties according to their needs. Essentially these materials differ from the conventional engineering materials from the viewpoint of homogeneity [4]. Particulate metal matrix composites are most commonly manufactured either by melt incorporation and casting technique or by powder blending & consolidation [5]. Moreover, when a ceramic reinforcement is added to the aluminium matrix, the properties are further enhanced there by making it a prospective material for many light weight applications [6]. The high strength and modulus with low friction and improved wear resistance at low cost of production have leaded the way for commercial production of particulate composites [7]. The particulate reinforced composites can be prepared by injecting the reinforcing particles into liquid matrix through liquid metallurgy route and this casting method is preferred because of less expensive and amenable to mass production [8]. The presence of hard reinforcement phases has endowed these composites with good tribological characteristics. These properties along with good specific strength, modulus makes them good candidate materials for many engineering situations where sliding contact is expected. An extensive review work on dry sliding wear characteristics of aluminium alloy based composites was undertaken by A. P. Sannino *et al.*, [9]. Esteban Fernandez *et al.*, [10] used a statistical method and the factorial experimental design to investigate the effects of reinforcement, load and abrasive grain size of Ni based alloy coatings both with and without WC reinforcement. The summary of the result is grain size exerted the greatest effect on abrasive wear followed by reinforcement. The load applied has a much lower effect and the environment was found to have minor effect. Hemanth Kumar *et al.*, [11] used the DOE and ANOVA analysis to find the significant factor, which affects the dry sliding wear of Al2618 alloy and Al2618/TiO_2 composite. The sliding distance is the significant factor for the dry sliding wear and wear resistance of Al2618/TiO_2 composite composites was significantly higher than that of Al2618 alloy. Leisk *et al.*, [12]

*Corresponding author.

adopted statistical approach to optimize the heat treatment of alumina reinforced aluminium alloy composites. The heat treatment was carried out according to orthogonal array. The highest yield strength and UTS are obtained for the aging time (6 h) and aging temperature (160˚C) for both 10% and 20% alumina composites. In this present investigation an attempt is to find the influence of wear parameters on dry sliding wear and to establish correlation between sliding speed, load, sliding distance and combined effect of these parameters on dry sliding wear of the aluminium and its composite.

2. Taguchi Technique

The Taguchi technique is a powerful design of experiment tool for acquiring the data in a controlled way and to analyze the influence of process variable over some specific variable which is unknown function of these process variables and for the design of high quality systems [13,14]. This method was been successfully used by researchers in the study of wear behavior of aluminium metal matrix composites [15]. The aim of this technique is to make the products that are robust with respect to influencing parameters. Taguchi creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiment [16,17]. The experimental results are analyzed using analysis of means and variance to study the influence of parameters.

3. Experimental Details

3.1. Material

The matrix material selected was commercially available pure aluminium. The chemical composition of the matrix material is given in the **Table 1**. The reinforcement material used was "Beryl" which is naturally occurring and chemically having beryllium-alumina-silicate and its chemical formula was $Be_3Al_2(SiO_3)_6$. The chemical composition of the reinforcement material is given in the **Table 2**.

3.2. Preparation of the Composite

The pure aluminium and aluminium/6 wt% $Be_3Al_2(SiO_3)_6$ reinforcement composite were fabricated by liquid metallurgy method. This method is the most economical to fabricate composites materials. The matrix was first superheated above its melting temperature and preheated reinforcement particles were added into molten metal. The molten metal was stirred for duration of 8 minutes using a mechanical stirrer and speed of the stirrer was maintained at 300 rpm. The melt at 750˚C was poured into the preheated cast iron molds. The castings were tested to know the common casting defects using ultrasonic flaw detector.

3.3. Testing of Composites

A pin-on-disc test apparatus was used to investigate the dry sliding wear characteristics of the composite. The wear specimens were machined to the pin size of diameter 8 mm and height 30 mm and then polished metalographically. The initial weight of the specimen was measured in a single pan electronic weighing machine with a least count of 0.1 mg. During the test the pin was pressed against the rotating counter part EN32 steel disc with hardness 60HRC by applying the load. After running through a fixed sliding distance, the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The differences in the weight measured before and after the test gives the weight loss due to wear of the specimen. The each experiment was repeated thrice and mean response values were tabulated in **Table 4**. The specimens were tested as per the procedure reported in papers Uyyuru *et al.*, [18] and C. S. Ramesh *et al.*, [19]. The experiments were conducted as per the standard L_9 orthogonal array. The wear parameters selected for the experiment were sliding speed in m/s, load in N and sliding distance in m. The each parameter was assigned three levels which are shown in **Table 3**.

The standard L_9 orthogonal array consists of nine tests as shown in the **Table 4**. The first column is assigned by sliding speed, second column was assigned by load and third column was assigned by sliding distance. The response studied was wear in terms of grams with the objective of "smaller is the better" type of quality characteristic.

4. Results and Discussion

4.1. S/N Ratio Analysis

The influence of control parameters such as sliding speed (S), load (L) and sliding distance (D) on wear was been evaluated using S/N ratio response analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance [20]. The sliding wear quality characteristic selected was smaller is

Table 1. Composition of aluminium (wt%).

Al	Cu	Fe	Mg	Mn	Si	Ni	Zn
99.77	0.005	0.095	0.005	0.011	0.083	0.015	0.013

Table 2. Composition of reinforcement material (wt%).

SiO_2	Al_2O_3	BeO	Fe_2O_3	CaO	MnO	K_2O	MgO
68.01	16.74	12.01	1.91	0.86	0.05	0.003	0.001

Table 3. Process parameters with their values at three levels.

Factors	Units	Level 1	Level 2	Level 3
Sliding speed (S)	m/s	1.571	2.095	2.618
Load (L)	N	29.43	39.24	49.05
Sliding distance (D)	m	600	1200	1800

Table 4. Orthogonal array (L_9) of Taguchi for wear test.

L_9 Test	Sliding speed S (m/s)	Load L (N)	Sliding distance D (m)	*Wear of aluminium (gm)	*Wear of composite material (gm)
1	1.571	29.43	600	0.0086	0.0082
2	1.571	39.24	1200	0.0109	0.0088
3	1.571	49.05	1800	0.0166	0.0155
4	2.095	29.43	1200	0.0145	0.0110
5	2.095	39.24	1800	0.0181	0.0189
6	2.095	49.05	600	0.0142	0.0129
7	2.618	29.43	1800	0.0141	0.0135
8	2.618	39.24	600	0.0096	0.0092
9	2.618	49.05	1200	0.0176	0.0149

*Wear of the aluminium and its composites are in terms of weight loss.

the better type and same type of response was used for signal to noise ratio which is given below.

$$\eta = -10\log_{10}\left\{\frac{1}{10}\sum_{i=1}^{n} y_i^2\right\} \quad (1)$$

The S/N ratio response was analyzed using the above Equation (1) for all nine tests and presented in **Table 5**. **Figures 1** and **3** show the main effects plots of S/N ratios for aluminium and aluminium/6wt%$Be_3Al_2(SiO_3)_6$ composite material graphically and **Figures 2** and **4** show the main effects plots of means for wear of aluminium and aluminium/6wt%$Be_3Al_2(SiO_3)_6$ composite. From the figures it is evident that the average mean wear of aluminium is 0.0139 grams, where as for the composite material it is 0.0125 grams. This shows that wear resistance of composite material is more than that of aluminium matrix material.

Table 5. S/N ratios for aluminium and composite material.

L_9 Test	SN ratio for aluminium (db)	SN ratio for composite material (db)
1	41.3100	41.7237
2	39.2515	41.1103
3	35.5978	36.1934
4	36.7726	39.1721
5	34.8464	34.4708
6	36.9542	37.7882
7	37.0774	37.3933
8	40.3546	40.7242
9	35.0897	36.5363

4.2. Analysis of Variance

The analysis of variance (ANOVA) was used to analyze the influence of wear parameters like sliding speed, load and sliding distance. The ANOVA establishes the relative significances of factors in terms of their percentage contribution to the response. This analysis was carried out for a level of significance of 5% (*i.e.*, the level of confidence 95%). **Tables 6** and **7** show the results of ANOVA analysis of aluminium and aluminium/6 wt% $Be_3Al_2(SiO_3)_6$

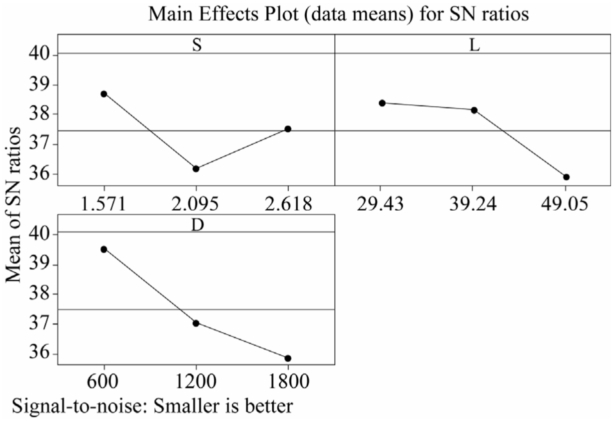

Figure 1. S/N ratio of aluminium.

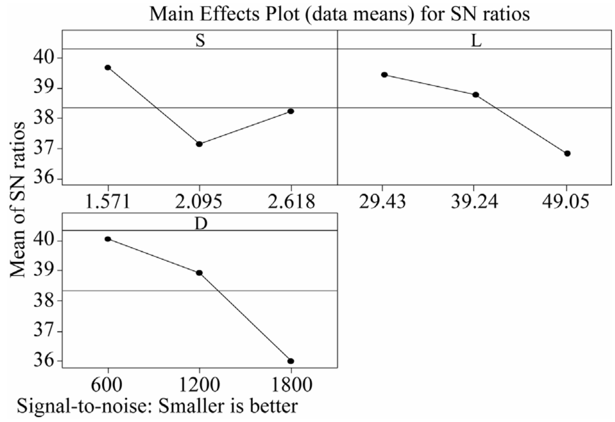

Figure 3. S/N ratio of composite material.

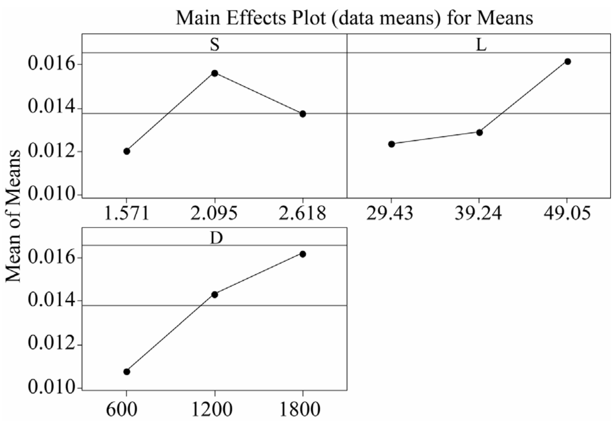

Figure 2. Analysis of means of aluminium.

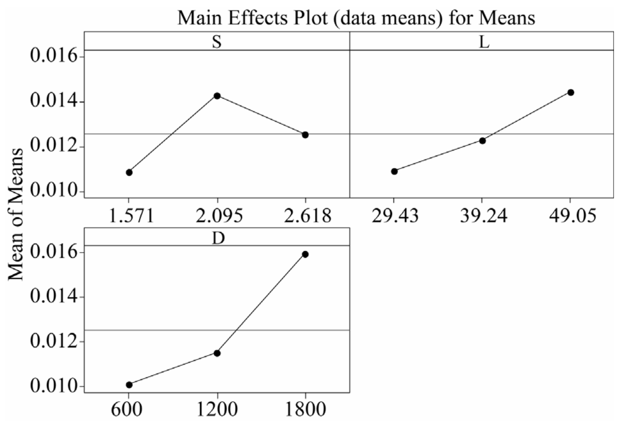

Figure 4. Analysis of means of composite material.

Table 6. Analysis of variance results for SN ratio for pure aluminium.

Source of variances	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
S	2	9.597	9.597	4.798	12.99	0.071	21.36
L	2	11.490	11.490	5.745	15.56	0.060	25.74
D	2	21.375	21.375	10.687	28.94	0.033	48.63
Error	8	1.111	1.111	0.369			4.28
Total	26	43.20					100

Table 7. Analysis of variance results for SN ratio for composite material.

Source of variances	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage contribution
S	2	9.691	9.691	4.845	3.63	0.216	16.87
L	2	10.869	10.869	5.435	4.08	0.197	19.25
D	2	26.307	26.307	13.153	9.86	0.092	50.42
Error	8	3.992	3.992	1.334			13.46
Total	26	49.534					100

composite.

We can observe from the ANOVA analysis (**Table 6**) that the sliding speed, load and sliding distance have the influence on wear of aluminium matrix material. The last column of the **Tables 6** and **7** indicate the percentage contribution of each factor on the total variation indicating their degree of influence on the result. One can observe from the ANOVA **Table 6** that the load (25.74%) and sliding distance (48.63%) have great influence on the wear of the aluminium matrix material. The **Table 7** shows ANOVA analysis of aluminium/6wt%$Be_3Al_2(SiO_3)_6$ composite material. From the results, it is found that load (19.25%) and sliding distance (50.42%) have great influence on the wear of the composite material.

The mechanism of material removal during wear process of the aluminium is by plastic deformation and gouging. The wear resistance of the composite material is improved due to the presence of hard reinforcement particles in the matrix material. The wear process in the composite material is by plastic deformation, gouging and reinforcement particles will crush to very minute particles and form a very thin sub surface layer designated as mechanically mixed layer (MML) which provides protection to the matrix material. The MML forms a layer between the work hardened pin and the counter face which withstands high stresses and is very effective in reducing the sliding wear. **Figures 5** and **6** show the micro structure of the aluminium and aluminium/6 wt% $Be_3Al_2(SiO_3)_6$ composite material.

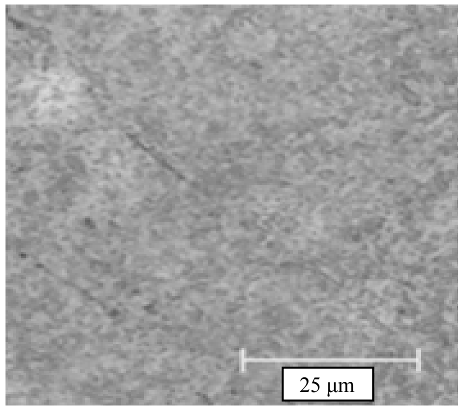

Figure 5. Micrograph of aluminum.

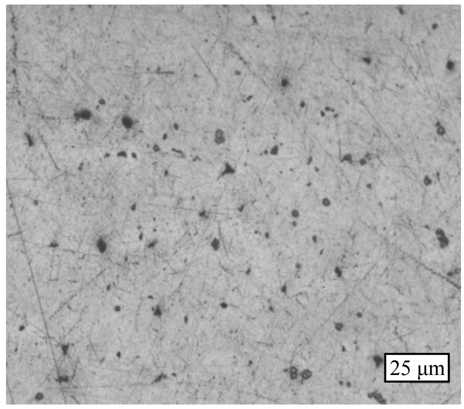

Figure 6. Micrograph of Al/6wt%$Be_3Al_2(SiO_3)_6$.

4.3. Multiple Linear Regression Model

A multiple linear regression analysis attempts to model the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data [21,22]. In order to establish the correlation between the wear parameters: sliding speed, load, sliding distance and the wear, the multiple linear regression model was used [23,24].

The regression equation for aluminium:

$$W_{aluminium} = -0.00258 + 0.00163\ S + 0.000192\ L + 0.000005\ D \quad (2)$$

The regression equation for composite material:

$$W_{composite\ material} = -0.00379 + 0.00163\ S + 0.000180\ L + 0.000005\ D \quad (3)$$

4.4. Confirmation Test

The confirmation test was performed for composite material by selecting the set of parameters as shown in **Table 8**. The **Table 9** shows the results obtained using regression Equation (3) and the experimental results. Both the results were compared and observed that the calculated error varies from 5.52% to 9.8%. Therefore the multiple regression equation derived above correlate the evaluation of the wear of the composite with the reasonable degree of approximation.

Table 8. Parameters used in the confirmation wear test.

Test	Sliding speed (m/s)	Load (N)	Sliding distance (m)
1	1.58	9.81	750
2	1.98	19.6	1150
3	2.30	39.2	1350

Table 9. Confirmation wear test and comparison with regression model.

Test	Expt.	Reg. model (Equation (3))	% of error
1	0.0046	0.0043	5.52
2	0.0094	0.0087	7.4
3	0.0153	0.0138	9.8

5. Conclusions

Based on the above analysis the following conclusions are drawn from this present study.

1) The DOE technique was successfully used to study the dry sliding wear of aluminium and aluminium/ 6wt% $Be_3Al_2(SiO_3)_6$ composite;

2) The analysis of variance shows that the sliding distance (48.63%) and load (25.74%) have significant influence on the wear of the aluminium matrix;

3) The analysis of variance shows that the sliding distance (50.42%) and load (19.25%) have significant influence on the wear of the composite material;

4) The wear resistance of composite is more than that of aluminium matrix. The average mean wear of aluminium is 0.0139 grams, where as for the composite material it is 0.0125 grams;

5) The conformation tests showed that error associated with wear of the composite material varies from 5.52% to 9.8%.

REFERENCES

[1] B. G. Park, A. G. Crosky and A. K. Hellier, "Material Characterisation and Mechanical Properties of Al_2O_3-Al Metal Matrix Composites," *Journal of Material Science*, Vol. 31, 1997, pp. 1775-1788.

[2] T. S. Srivastava, "Microstructure, Tensile Properties and Fracture Behaviour of Al_2O_3 Particulate-Reinforced Aluminium Alloy Metal Matrix Composites," *Journal of Material Science*, Vol. 31, No. 5, 1996, pp. 1375-1388. doi:10.1007/BF00353120

[3] N. R. P. Swamy, C. S. Ramesh and T. Chandrashekar, "Effect of Heat Treatment on Strength and Abrasive Wear Behaviour of Al6061-SiCp Composites," *Bulletin of Materials Science*, Vol. 33, No. 1, 2010, pp. 49-54. doi:10.1007/s12034-010-0007-y

[4] J. A. Hooker and P. J. Doorber, "Metal Matrix Composites for Aeroengines," *Material Science and Technology*, Vol. 6, No. 7-8, 2000, pp. 725-731.

[5] I. Sinclair and P. J. Gregson, "Structural Performance of Discontinuous Metal Matrix Composites," *Materials Science and Technology*, Vol. 3, No. 9, 1997, pp. 709-726. doi:10.1179/026708397790290254

[6] T. W. Clyne, "Metal Matrix Composites: Matrices and Processing," Elsevier, Amsterdam, 2001.

[7] V. K. Lindroos and M. J. Talvitie, "Recent Advances in Metal Matrix Composites," *Journal of Materials Processing Technology*, Vol. 53, 1995, pp. 273-278.

[8] M. Singla, D. D. Dwivedi, L. Singh and V. Chawla, "Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite," *Journal of Minerals & Materials Characterization & Engineering*, Vol. 8, No. 6, 2009, pp. 455-467.

[9] A. P. Sannino and H. J. Rack, "Dry Sliding Wear of Discontinuously Reinforced Aluminium Composites: Review and Discussion," *Wear*, Vol. 189, No. 1-2, 1995, pp. 1-19. doi:10.1016/0043-1648(95)06657-8

[10] J. E. Fernandez, M. R. del Fernandez, R. V. diaz and R. T. Navarro, "Abrasive Wear Analysis Using Factorial Experimental Design," *Wear*, Vol. 255, No. 1-6, 2003, pp. 38-43. doi:10.1016/S0043-1648(03)00103-0

[11] T. R. H. Kumar, R. P. Swamy and T. K. Chandrashekar, "Tribological Studies on Discontinuously Reinforced Metal Matrix Composite Using Design of Experiment," *Journal of Manufacturing Engineering*, Vol. 6, No. 2, 2011, pp. 106-110.

[12] G. Leisk and A. Saigal, "A Statistical Approach to the Heat Treatment Optimization of Al-Al_2O_3 Particulate Composite," *Journal of Materials Engineering and Performance*, Vol. 1, No. 1, 1992, pp. 45-48. doi:10.1007/BF02650031

[13] K. R. Roy, "A Primer on the Taguchi Method," Van Nostrand Reinhold, New York, 1990.

[14] P. J. Ross, "Taguchi Technique for Quality Engineering," McGraw-Hill, New York, 1993.

[15] Y. Sahin, "The Prediction of Wear Resistance Model for the Metal Matrix Composites," *Wear*, Vol. 258, No. 11-12, 2005, pp. 1717-1722.

[16] G. Taguchi and S. Konishi, "Taguchi Methods Orthogonal Arrays and Linear Graphs: Tools for Quality Engineering," American Supplier Institute, Dearborn, 1987.

[17] G. Taguchi, "Taguchi on Robust Technology Development: Bringing Quality Engineering Upstream," ASME Press, New York, 1993. doi:10.1115/1.800288

[18] R. K, Uyyuru, M. K. Surappa and S. Brusethang, "Effect of Reinforcement Volume Fraction and Size Distribution on the Tribological Behavior of Al-Composite/Brake Pad Tribo-Couple," *Wear*, Vol. 260, No. 11-12, 2006, pp. 1248-1255. doi:10.1016/j.wear.2005.08.011

[19] C. S. Ramesh, S. K. Sheshadri and K. J. L. Iyer, "A Survey of Aspects of Wear of Metals," *Indian Journal of Technology*, Vol. 29, No. 4, 1991, pp. 179-185.

[20] K. Palanikumar, "Application of Taguchi and Response Surface Methodologies for Surface Roughness in Machining Glass Fiber Reinforced Plastics by PCD Tooling," *The International Journal of Advanced Manufacturing Technology*, Vol. 36, No. 1-2, 2008, pp. 19-27.

[21] D. C. Montgomery and G. C. Runger, "Applied Statistics and Probability for Engineers," John Wiley & Sons, New York, 1999.

[22] D. C. Montgomery, "Design and Analysis of Experiments," Wiley India Pvt. Ltd., New Delhi, 2007.

[23] S. Basavarajappa and G. Chandramohan, "Wear Studies on Metal Matrix Composites: A Taguchi Approach," *Journal of Materials Science and Technology*, Vol. 21, No. 6, 2005, pp. 845-850.

[24] K. Hokkirigawa and K. Kato, "An Experimental and Theoretical Investigation of Ploughing, Cutting and Wedge Formation during Abrasive Wear," *Tribology International*, Vol. 21, No. 1, 1988, pp. 51-57. doi:10.1016/0301-679X(88)90128-4

