Abrasive wear and frictional behavior of polyoxymethylen

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Article Information

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In the present study, abrasive wear and frictional behaviors of polyoxymethylene were investigated experimentally. To realize this, a test apparatus was designed and fabricated. Wear tests were carried out under dry conditions at room temperature. A central composite design was used to describe response and to estimate the parameters in the model. An empirical model had been developed to predict wear loss as a function of applied load and sliding distance. Friction coefficient decreases with increase in applied load. On the other hand, it is also found that friction coefficient increases with the increase in sliding velocity.

Many polymers and polymer based composites are widely used for sliding/rolling couples such as gears, cams, bearings, rollers, transmission belts and grinding mills against metals, polymers and other materials. However, when contact between sliding/rolling pairs is present, wear and friction problems occur [1, 2].

The researchers investigated wear and friction behaviors of materials because of the adverse effect observed in the performance and life of machinery components [3]. A considerable number of papers dealing with wear and frictional behaviors of polymer materials have been published [4-6].

Franklin [7] focused on the wear performances of several engineering polymer based materials under dry reciprocating sliding conditions to estimate the wear and reported the effect of sliding speed on the wear. Shipway and Ngao [8] studied the abrasive wear behavior of polymeric materials and they concluded that wear performances depend on the polymer type. Zhang et al. [9] applied an ANN model to predict the erosive wear of three polymers.

Unal et al. [10] studied abrasive wear behavior of aliphatic polyketone (APK), polyoxymethylene (POM), ultra-high molecular weight (UHMWPE) polyethylene, polyamide 66 (PA 66) and 30 % glass fiber reinforced polyphenylene sulphide (PPS + 30 % GFR) engineering polymers at room temperature using pin-on-disc test results. Liu et al. [11] studied the influence of the parameters sliding distance, contact pressure and sliding speed on the wear performance of UHMWPE, polyamide 6 (PA-6) and PA-6/UHMWPE using regression equations. Unal et al. [12] studied sliding friction and wear behavior of polytetrafluoroethylene and its composites under dry conditions at ambient conditions in a pin-on-disc arrangement.

Unal et al. [13] investigated tribological behavior of PA-6, POM and UHMWPE polymers, sliding friction and wear behavior of polytetrafluoroethylene and its composites under dry conditions at room temperatures using a pin-on-disc arrangement. Brentnall and Lancaster [14] reported that the friction coefficient of polymers rubbing against metals decreases with the increase in load. Sagbas et al. [15] studied the influence of the parameters applied load and sliding distance on the wear performance of POM using response surface methodology and neural networks. Several researchers [13,16-18] reported that friction coefficient of polymers and its composites rubbing against metal increases or decreases depending on the range of normal load, sliding speed and sliding pairs.

In this study, the abrasive wear and frictional behaviors of POM have been investigated. The wear test was performed under dry sliding conditions at room temperature using a test equipment. Wear and frictional behaviors of studied material have been identified using experimental test results.

Experimental procedure

Wear tests were carried out to analyze the influence of testing parameters on the wear loss of the test samples. For the experiments, POM material was used as sample material. Test samples with rectangular cross section were prepared in the dimensions of $25 \times 25 \times 10$ mm^3. Three replications of each factor level combinations were conducted resulting in a total of 39 tests. Wear tests were carried out on in-house designed test machine as seen in Figure 1. Tests with AISI 4140 steel as the counter face material were carried out under dry sliding condition. To apply different abrasive conditions during each test, on the rotating disc the surface of the samples were fixed in a holder. Before wear test, each sample was cleaned with alcohol and dried in air. The samples were loaded against the abrasive medium. Samples were weighed by analytical scales with ±0.01 g sensitiveness. After each test, samples were weighed again. The wear loss was computed from the mass loss of the sample. Central composite design (CCD) is an experimental design in response surface methodology (RSM) for building an empirical model for the response variable. This design consists of a factorial portion and axial portion, and a central point [19]. Applied load and sliding distance were considered as model variables and wear loss as response variable. RSM with CCD was adopted to obtain an empirical model of wear loss as a function of the applied load (N) and sliding distance (m). The range of each parameter was coded in five levels (−1.41, −1, 0, 1, +1.41). The levels of model variables are shown in Table 1.

Results and discussion

Experimental levels for process variables were selected according to CCD. This design has 9 different design points for all combinations of process variables. The arrangement and the experimental (actual) and predicted wear loss values based on the CCD rotatable design are shown in Table 2. Experimental results are used to determine the mathematical model. Regression analysis indicates that linear model adequately represents the wear loss. The regression equation can be expressed by Equation (1) in terms of coded factors

$$y = 0.28 + 0.064x_1 + 0.034x_2 \tag{1}$$

with y: wear loss, x_1: coded factor that represents the applied load, x_2: coded factor that represents sliding distance.

It is observed that applied load and sliding distance have positive influence on the wear loss. The wear loss of POM material increased with increasing applied load and sliding distance.

ANOVA was employed to find significance of the factor effects based on 95 % confidence level. The ANOVA table for the linear model for the wear loss is given in Table 3. Higher F-value indicates that the variation of the process parameter results in a big change of the wear loss. The value of Adjusted R^2 between experimental results and predictive values is obtained as 81 %. The R^2 value indicates that the abrasive wear parameters explain 81 % of variance in wear loss. This value showed that the empirical model fits well with experimental results. The comparisons of experimental results with the RSM predictions have been depicted in terms of percentage absolute average error. The average absolute error is found to be 7.86 %.

The relationship between wear loss, applied load and sliding distance is shown in Figure 2. It can be realized that the combination between high applied load and high sliding distance results in a considerable increase in wear loss. It is known that polymers are viscoelastic materials and that their deformation under load is viscoelastic. Therefore, the variation of friction coefficient with applied load follows the Equation (2):

$$\mu = KN^{(n-1)} \tag{2}$$

with μ: coefficient of friction, N: load, K: constant and n: constant with a value of 0.66 < n < 1 [16, 20].

According to this equation, the coefficient of friction decreases with load increase. Figure 3 shows the variation of friction coefficient with normal load for POM-AISI 4140

Table 1: Experimental factors and levels for CCD

Factors/Levels	-1.41	-1	0	1	+1.41
Applied load (N)	17.93	20	25	30	32.07
Sliding distance (m)	1374.91	1570	2041	2512	2707.09

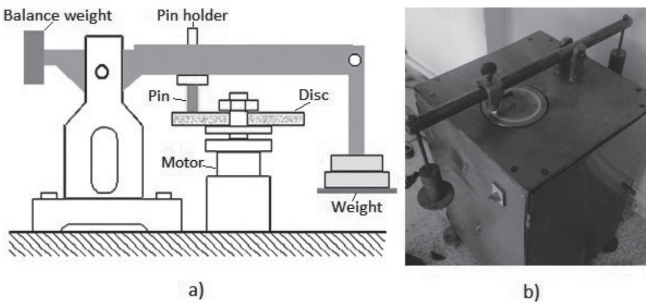

Figure 1: Test setup, a) schematic illustration of pin-on-disc test, b) wear test apparatus

Table 3: Response surface graphs surface graph for wear loss

Source	SS	DF	MS	F-value	p-value
Model	0.042	2	0.021	26.84	<0.0001 suggested
A	0.033	1	0.033	41.91	0.0001*
B	9.41E-003	1	9.41E-003	11.76	0.0064*

*significant factors at 5 % significance level
SS: sum of square, DF: degree of freedom, MS: mean square

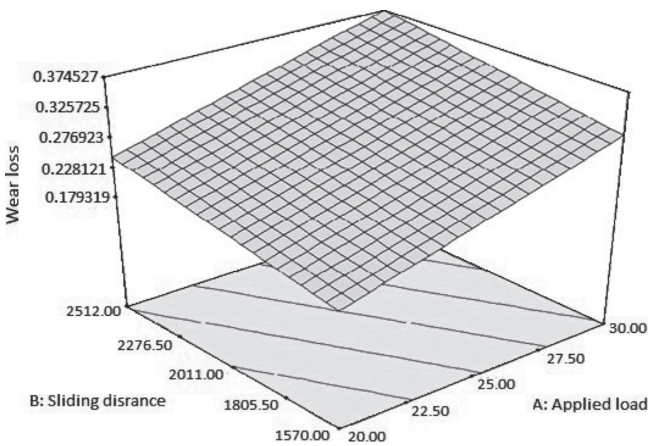

Figure 2: Response surface graphs surface graph for wear loss

Standard	Run	Applied load (N)	Sliding distance (m)	Actual wear loss (g)	Predicted wear loss (g)
13	1	20	1570	0.19	0.18
10	2	30	1570	0.33	0.31
5	3	20	2512	0.21	0.25
6	4	30	2512	0.34	0.37
12	5	17.93	2041	0.21	0.19
4	6	32.07	2041	0.38	0.37
1	7	25	1374.91	0.18	0.23
11	8	25	2707.09	0.35	0.32
7	9	25	2041	0.29	0.28
3	10	25	2041	0.28	0.28
2	11	25	2041	0.30	0.28
9	12	25	2041	0.27	0.28
8	13	25	2041	0.35	0.28

Table 2: Experimental (actual) and predicted wear loss (g) values for CCD

steel counter face at different sliding velocities. Coefficient of friction decreased with the increase in applied load as seen in Figure 3, and coefficient of friction increased with the increase in sliding velocities.

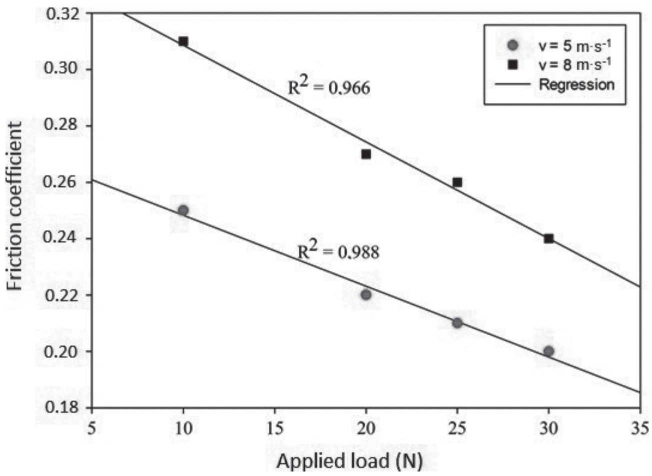

Figure 3: Friction coefficient as a function of applied load for POM at different sliding velocities

Conclusions

From the above experiments and analysis, following conclusions can be drawn:

- Regression analysis indicates that the first order regression model adequately represents wear loss in terms of process variables. Since the coefficients of the applied load and the sliding distance are positive, the wear loss increases with increasing the applied load and increasing the sliding distance.
- The correlation with experimental results and predicted values was good within the range of their investigation and the individual operating parameters.
- According to the statistical analysis, adjusted R^2 value is obtained for CCD as 0.81.
- Results show that the predicted values are close to the actual values. In the prediction of wear loss, average error for CCD was found to be 7.86 %.
- The coefficient of friction decreases with the increase in applied load for POM-AISI 4140 steel counter face.
- The coefficient of friction increases with the increase in sliding velocity for POM-AISI 4140 steel counter face.

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Abstract

Abrasivverscheiß und Reibverhalten von Polyoxymethylen. In der diesem Beitrag zugrundeliegenden Studie wurde der Abrasivverscheiß und das Reibverhalten von Polyoxymethylen experimentell untersucht. Um dies zu erreichen, wurde ein Versuchsaufbau designt und erstellt. Die Verschleißversuche wurden unter trockenen Bedingungen und bei Raumtemperatur durchgeführt. Es wurde außerdem ein empirisches Modell entwickelt, um den Verschleißverlust als Funktion der aufgebrachten Kraft und der Reibdistanz vorherzusagen. Dabei wurde ein zentrales Kompositdesign verwendet, um die Antwort zu beschreiben und die Parameter in dem entsprechenden Modell abzuschätzen. Der Reibkoeffizient nimmt mit zunehmender aufgebrachter Last ab. Auf der anderen Seite wurde auch ermittelt, dass der Reibkoeffizient mit steigender Reibgeschwindigkeit zunimmt.

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