Analysis of Abrasive Wear Characteristics of Brass 60/40 Using MATLAB

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Abstract.Abrasive wear behavior of Brass 60/40 was investigated using pin on disc wear testing machine. The abrasive wear test of brass was conducted by taking two variables viz. orientation and normal load. The normal load varies from 5N to 35N with different orientation angles (0°, 30°, 45°, 60°, and 90°), the speed of rotating abrasive disc kept constant at 1500 rpm. The experimental data was obtained from 5N to 20N only, by using pin on disc wear testing machine, however the data beyond 20N were validated with help of MATLAB. For proper validation of result for wear (mass loss), the exploratory data analysis (EDA) and regression analysis (RA) are used. These two analyses were conducted on MATLAB by using curve fitting tool and surface fitting tool. After the completion of experimental work, the results showed reduction in wear (mass loss) under constant loading condition with increase in orientation angle while increased in wear (mass loss) under constant orientation angle with increase in normal load.

Keywords: Abrasive wear, MATLAB, EDA.

1. Introduction
Brass is used in wide range products due to its excellent electrical and thermal conductivity, good strength, good formability and resistance to corrosion. Pipe and pipe fittings are commonly manufactured from the same due to its excellent corrosive resistance property. [1]. Wear leads to loss of material and increase in clearance in moving parts. In general, wear properties play a major role in deciding the life of movable parts which are in contact with each other, and so, it must be considered in the design and development of engineering components. Improvement in wear resistance under heavy loading conditions can help in application of copper alloy (brass) for bearing material used in several industries like in automobile and power plant industries. [2]
This paper is mainly focused on several factors, which directly affects the working condition of bearing brass. The main objective of this paper to use pin-on-disc setup, which can check wear rate or loss of mass of the selected specimen at different normal loading condition (5N-20N) and orientation angle (0°, 30°, 45°, 60°, 90°) [2-4].

2. Experimental Material and procedure: -
Brass 60/40 was obtained in the form casted ingots; the dimensions of the specimens are 1cm x 1cm with a length of 4.5 cm. To wear the surface of the specimen stone abrasive disc was used. After preparation of the specimen, wear test analysis was carried with pin-on-disc apparatus by considering several normal loading conditions in steps of 5 N, 10 N, 15 N & 20 N under different orientation angle. Mass of the tested specimens was measured using weighing machine with an accuracy of 0.001g. After a travel time of 5 min. against the grinding disc, the sample was taken out carefully and debris’s were removed from the valleys of the specimen to measure the exact wear (mass loss). This was continued for five times with same specimen and at same position. After that next specimen was taken for next test condition i.e. 30° angle and 5N applied load and so on. The tests were conducted for five different orientations namely 0°, 30°, 45°, 60°, 90°. Thus a total of 25 readings are taken for one particular load. This was continued for load of 10N, 15N and 20N respectively. The cumulative effect of mass loss was taken for calculating the wear mass. [5-13].

3. Results and Discussion

3.1 Wear mass loss and wear morphology
For complete analysis of wear morphology, the experimental and theoretical results were compared.

3.2 Experimental Results
After, analyzing the mass loss (gm) for different loading condition (5N, 10N, 15N and 20N) following results are come out from the experimental data-
- While exceeding the load beyond 5N amount of wear loss also increases.
- While considering different orientation angle from 0° to 90°, the amount of mass loss decreases.
- After analyzing the whole process, it seems that at 5N loading condition and at 90° orientation angle the possibility of mass loss is very less (experimental result – approximate 0.303mg).

3.3 Theoretical results – using MATLAB
Obtained experimental results were verified using exploratory data analysis (EDA) and regression analysis (RA). For EDA, curve fitting tool implemented with the help of MATLAB. Following steps mainly used to validate the result by comparing with the experimental data and exceeding the value of load beyond 20N [19].
- Exploratory data analysis using curve fitting tool with the help of MATLAB.
- Mathematical equation formulation (Regression analysis) using curve fitting tool and calculate the theoretical value for each loading condition.
- Plot a curve for complete data using surface fitting tool.
- Testing of adequate of the model developed (Statistical significance model).
- Validate the result by exceeding the value of load beyond 20 N.
3.3.1 Curve Fitting and surface fitting tool (MATLAB)
This function provides an application and functions for fitting curves and surfaces to data. Exploratory data analysis, pre-process and post process data, compare candidates’ models and remove outliers were perform on MATLAB. To achieve the desire result following theories are mainly used in curve fitting tool-

- Exploratory Data Analysis (EDA)
- Regression Analysis (RA) (Mathematical equation formulation)

Firstly, EDA method has been performed for detail analysis. For this first, Frame regression table that, which model (Linear or Non-Linear Model), is best suited for experimental results by comparing the value of R-square and Adjusted R-Square and then by using that model plot a best fitted curve for required model.

3.3.1.1. EDA for 5N load. From Table 1 it is observed that wear mass decreases from 0.916 gm to 0.303 gm as applied orientation angle on the specimen increases from 0° to 90° when loading condition is 5N.

| Angle (degree) | Mass Loss (mg) | Equation on name | SSE | R-Square | DFE | Adj R-Square | RMSE | Coefficient | Type of fit |
|---------------|----------------|------------------|-----|----------|-----|-------------|------|-------------|-------------|
| 0             | 0.916          |                  |     |          |     |             |      |             |             |
| 30            | 0.908          |                  |     |          |     |             |      |             |             |
| 45            | 0.75           |                  |     |          |     |             |      |             |             |
| 60            | 0.589          |                  |     |          |     |             |      |             |             |
| 90            | 0.303          | 1.5361*10^-4     | 0.9994 | 1 | 0.9977 | 0.0124 | 4 | Polynomial |

3.3.1.2. EDA for 10N load. From Table 2 it is observed that wear mass decreases from 1.027 gm to 0.405 gm as applied orientation angle on the specimen increases from 0° to 90° when loading condition is 10N. But the only difference is that its value is more than the previous result.

| Angle (degree) | Mass Loss (mg) | Equation name(Poly3/Poly4) | SSE | R-Square | DFE | Adj R-Square | RMSE | Coefficient | Type of fit |
|---------------|----------------|----------------------------|-----|----------|-----|-------------|------|-------------|-------------|
| 0             | 1.027          | Poly3                      |     |          |     |             |      |             |             |
| 30            | 0.908          | Poly4                      |     |          |     |             |      |             |             |
| 45            | 0.75           | Poly3                      |     |          |     |             |      |             |             |
| 60            | 0.589          | Poly4                      |     |          |     |             |      |             |             |
| 90            | 0.405          | Poly3                      |     |          |     |             |      |             |             |
3.3.1.3 EDA for 15 N Loads. From Table 3, it is observed that wear mass decreases from 1.098 gm to 0.512 gm as applied orientation angle on the specimen increases from 0° to 90° when loading condition is 15N. Again the value of wear loss is more than 5N and 10N load.

| Angle (degree) | Mass Loss (mg) | SSE         | R-Square   | DFE  | Adj R² | RMSE       | Coefficient   | Type of fit |
|----------------|---------------|-------------|------------|------|--------|------------|---------------|--------------|
| 0              | 1.098         |             |            |      |        |            |               |              |
| 30             | 0.999         | 3.2171*10⁻³⁰| 0.9929/1   | 1/0  | 0.9717/NaN | 0.0445/NaN  | 04/05         | Polynomial   |
| 60             | 0.641         |             |            |      |        |            |               |              |
| 90             | 0.405         |             |            |      |        |            |               |              |

3.3.1.4 EDA for 20 N Loads. From Table 4, it is observed that wear mass decreases from 1.262 gm to 0.638 gm as applied orientation angle on the specimen increases from 0° to 90° when loading condition is 15N. Again the value of wear loss is more than 5N and 10N load.

| Angle (degree) | Mass Loss (mg) | SSE         | R-Square   | DFE  | Adj R² | RMSE       | Coefficient   | Type of fit |
|----------------|---------------|-------------|------------|------|--------|------------|---------------|--------------|
| 0              | 1.068         |             |            |      |        |            |               |              |
| 30             | 0.968         | 6.7300*10⁻²³ | 0.9875/1   | 1/0  | 0.9502/NaN | 0.0566/NaN  | 04/05         | Polynomial   |
| 45             | 0.703         |             |            |      |        |            |               |              |
| 60             | 0.512         |             |            |      |        |            |               |              |
| 90             |               |             |            |      |        |            |               |              |
After successful completion of EDA method, the RA (regression analysis) method implemented. It is mainly established the relationship between two variables. After detail analysis, Non linear third degree polynomial equation whose value of R-Square and adjusted R-Square is quite good as compare to forth degree polynomial equation-

\[ W = 1.016 - 0.07447 \times L + 0.02484 \times A + 0.01064 \times L^2 - 0.0004322 \times L \times A - 0.0008015 \times A^2 \\
- 0.0003211 \times L^3 + 1.583 \times 10^{-5} \times L^2 \times A - 1.344 \times 10^{-7} \times L \times A^2 + \\
5.319 \times 10^{-6} \times A^3 \] \text{Eq. (1)}

Here \( W \) = wear loss in gm, \( A \) = orientation angle in degree, \( L \) = Applied load in N

After formulation of mathematical equation, detail comparison between experimental and theoretical results. Best comparison between experimental and theoretical result is visible in curve 5, curve 6, curve7 and curve 8.

3.3.1.5- RA for 5N load.

| Angle (degree) | Mass Loss (mg) | SSE  | R-Square | DFE | Adj R-Square | RMSE  | Coefficient | Type of fit |
|---------------|---------------|------|----------|-----|--------------|-------|-------------|-------------|
| 0             | 1.262         |      |          |     |              |       |             |             |
| 30            | 1.247         |      |          |     |              |       |             |             |
| 45            | 1.031         | 1.2942*10^{-6} | 0.9968/1 | 1/0 | 0.9872/NaN  | 0.0299/NaN | 04/05       | Polynomial  |
| 60            | 0.865         |      |          |     |              |       |             |             |
| 90            | 0.638         |      |          |     |              |       |             |             |
Curve 1: Variation of wear rate with different orientation angle of the work piece for 5N applied load

3.3.1.6- RA for 10N load.

Curve 2: Variation of wear rate with different orientation angle of the work piece for 10N applied load

3.3.1.7- RA for 15N load.
Curve 3: Variation of wear rate with different orientation angle of the work piece for 15N applied load

3.3.1.8- RA for 20N load.

Curve 4: Variation of wear rate with different orientation angle of the work piece for 20N applied load

3.4 Validate the result by exceeding the value of load beyond 20N-
For better result, exceed the value of load beyond 20N whether the required equation give the best result for this or not. Table (8, 9, 10) and curve (8, 9, 10) simply signifies that at initial stage it increases very rapidly up to 30° than decreases up to 90° angle and then increases at a very higher rate at an angle of 180°.

3.4.1- Under 25N loading condition.

| Angle (degree) | Mass Loss (mg) |
|---------------|----------------|
| 0             | 0.7871         |
| 30            | 0.9242         |
| 60            | 0.4742         |
| 90            | 0.2988         |
| 120           | 1.2598         |
| 150           | 4.2186         |
| 180           | 10.0372        |

Table 5. Theoretical values for 25N load

Curve 5. Variation of wear with respect to orientation angle
3.4.2- Under 30N loading condition

| Angle (degree) | Mass Loss (mg) |
|----------------|----------------|
| 0              | -0.3118        |
| 30             | -0.1095        |
| 60             | -0.4956        |
| 90             | -0.6082        |
| 120            | 0.4143         |
| 150            | 3.4335         |
| 180            | 9.3112         |

Table 6: Theoretical Values for 30N load

Curve 6: Variation of wear with respect to orientation angle.

3.4.3- Under 35N loading condition

| Angle (degree) | Mass Loss (mg) |
|----------------|----------------|
| 0              | -2.3236        |
| 30             | -2.0324        |
| 60             | -2.3308        |
| 90             | -2.3569        |
| 120            | 0.12491        |
| 150            | 1.8541         |
| 180            | 7.8146         |

Table 7: Theoretical Values for 35N load

Curve 7: Variation of wear with respect to orientation angle.
4. Conclusions
The abrasive wear of Brass 60/40 processed by pin-on-disc apparatus have been studied with varying loads (5N to 35N) and different orientation angles (0°, 30°, 45°, 60°, 90°), and the conclusions are summarized as follows:

- Non-Linear third order polynomial equation gives the best fit for the data which has been taken experimentally.
- The R-Square value of the empirical model and Adjusted R- Square value are very close to each other, which give the significant amount of variability to the wear loss. Predicted value of Rsquare is 0.9933 and adjusted R-square is 0.9872.
- A value closer to 1 indicates a better fit. Here the value of R-square is 0.9872 which indicates the good fit.
- Percentage deviation between measured wear loss and predicted wear loss is 7.27% which is 0.2711% in magnitude, which is less than the similar results reported in previous paper [6].
- As the fit is good, the equation (1) can be used for wide range of applied loads, hence it can be used to predict the wear of brass 60/40 beyond 20 N.
- When applied load increases, then mass loss (wear) first slowly increases up to 30° then increases very rapidly at higher rate by varying orientation angle from 0° to 90°.
- After exceeding the loading condition beyond 20N, wear (mass loss) increases at a very fast rate.
- For future references some modifications are required in the model so that after exceeding the loading condition beyond 35N load, it will give the better result.
- In case of brass the chances of wear is less under varying loading condition than other material because of its physical properties.
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