Effect of load, sliding distance and sliding velocity on the wear properties of aluminum alloy AA5052

K. B. Arjun, R. Harikeshava, C. R. Sreenath, G. Srihari, R. Vaira Vignesh and R. Padmanaban
Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India
E-mail: dr_padmanaban@cb.amrita.edu

Abstract. Aluminum alloys are widely used in engineering applications. In motion established contact applications, wear is an inevitable phenomenon. In this study, the wear mechanism of AA5052 was explored using pin-on-disc tribometer. The wear test parameters namely load (kg), sliding distance (m), and velocity (m/s) were varied according to central composite design. The wear tracks of the worn specimens were observed using high-resolution scanning electron microscope and the elemental composition was analysed using energy dispersive X-ray spectroscopy. A hybrid model integrating the linear function and radial basis function was developed to explore the effect of load, sliding distance, and sliding velocity on the wear rate of the AA5052 alloy. The results indicate that increase in axial load and sliding distance decreases the wear rate of the AA5052 alloy.

1. Introduction
Aluminum alloys have been the first-choice for light weighting applications due to their high strength to density ratio. The non-heat treatable AA5052 possess corrosion resistance that enables its utility in engineering applications. Studies to further improve the properties of aluminum alloy have been conducted. Zhang et al., [1] explored the aluminum alloy’s delamination behaviour, which had secondary phases in the matrix. An increase in sliding distance (SD) and axial load (AL) increased wear rate of the aluminum alloy. Hanlon et al., [2] found that the wear rate of aluminum alloys is more influenced by alloying or second phase strengthening and the coefficient of friction is less influenced by grain refinement. The wear rate of aluminum alloy increased with increase in AL. Anita Mohan et al., [3] found that the cumulative volume loss for AA5052-TiB$_2$ in-situ composites was high in specimens slid for more distance. Narendar Kumar et al.,[4] found that the wear rate of aluminum alloy composite decreased as a volume percentage of ZrB$_2$ particles increased, while the coefficient of friction increased as a volume percentage of ZrB$_2$ particles increased. Profilometry results indicated that the specimens subjected to high temperature and AL in the wear test had higher surface roughness. Daniel et al., [5] estimated that the most influencing wear test parameters on the friction coefficient of SiC reinforced aluminum alloy composites were AL and SD. The study recommended 15% weight percentage of 10 µm SiC as an optimum level of reinforcement for better wear resistance and friction coefficient in aluminum alloys. Gautham et al.,[6] projected that increase in AL increased the wear rate and decreased the friction coefficient in AA5052(ZrB$_2$+Al$_3$Zr) in-situ composite. Rana et al., [7] found that the highest influential wear test parameter on the wear rate of AA5083+10%SiC composites was AL followed by SD and sliding speed.
Cao et al., [8] found that the carbon fibers in the aluminum matrix suppressed the propagation of micro-cracks. The suppression had prevented the peeling of material during the wear process and improved the wear resistance. Khodabakshi et al., [9] improved the wear resistance of AA5052 alloy by dispersing TiO$_2$ on the surface by friction stir processing. The wear resistance of AA5052 with 6% TiO$_2$ had 125% greater wear resistance than the wear resistance in the annealed condition. Kumar et al., [10-12] studied the wear performance of ZrB$_2$ reinforced AA5052 alloy. With increase in testing temperature, an increasing trend was observed in the wear rate and the friction coefficient of the AA5052- ZrB$_2$ composite [10]. The wear rate of AA5052- ZrB$_2$ composite decreased with increase in ZrB$_2$ composition, whereas the friction coefficient increased with increase in ZrB$_2$ composition [11]. The test results indicated that AA5052- ZrB$_2$-Al$_3$Zr composite had the least wear rate [12].

In this study, the wear mechanism of AA5052 was explored by pin-on-disc wear test. The wear test parameters namely AL (kg), SD (m), and sliding velocity (SV in m/s) were varied as per central composite design. The surface morphology of the worn specimens was observed using high-resolution scanning electron microscope. The elemental composition was analysed using energy dispersive X-ray spectroscopy. A hybrid model integrating the linear function and radial basis function was developed to explore the effect of AL, SD, and SV on the wear rate of the AA5052 alloy.

2. Materials and Methods

2.1. Materials
The study utilized wrought AA5052 plates of thickness 5 mm. The composition of aluminum alloy AA5052 is given in table 1.

| Element | Al  | Mg  | Cr  | Cu  | Fe  | Mn  | S   | Zn  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|
| Composition (%) | 96.3 | 2.3 | 0.25 | 0.08 | 0.4 | 0.1 | 0.18 | 0.12 |

2.2. Microhardness
The plate was cut into specimens of dimension 10mm×10 mm. The specimens were polished as per the guidelines of the standard ASTM E3-11. The microhardness of the specimen was measured using Mitutoyo make Vickers's microhardness tester. The diamond indentor was plunged into the specimen under an axial load of 50 N for a period of 15 seconds.

2.3. Wear test
The wear tests were done on a pin-on-disc tribometer. Specimens of dimension 10mm × 10 mm were cut from the plate and were mounted in steel tube using the cold setting compound. Standard ASTM E3-11 was followed for polishing the specimens and then degreased with acetone. The specimen was the pin, which was slid against the counter disc made of EN31 steel.

2.4. Design of Experiments
The wear test parameters (AL, SD, and SV) were varied at five levels as per central composite design. The chosen levels of wear parameters are shown in table 2.

| Sl. | Coded level | SV (m/s) | SD (m) | AL (kg) |
|-----|-------------|----------|--------|--------|
| 1   | -2          | 0.5      | 300    | 1      |
| 2   | -1          | 1        | 600    | 2      |
| 3   | 0           | 1.5      | 900    | 3      |
| 4   | 1           | 2        | 1200   | 4      |
| 5   | 2           | 2.5      | 1500   | 5      |
The SV was varied from 0.5 m/s to 2.5 m/s with a step of 0.5 m/s. The SD was varied from 300 m to 1500 m with a step of 300 m and the AL was varied from 1 kg to 5 kg with a step of 1 kg.

2.5. Linear – Radial Basis Function model

In this study, the wear rate of the AA5052 alloy was predicted using a hybrid model with a linear function and a radial basis function. A typical linear function – RBF mathematical model is given by equation (1).

\[
Y = LF + RBF
\]

Where \(Y\) is the response variable, LF is the linear function and RBF is the radial basis function. The details regarding the development of hybrid linear – radial basis function models are discussed elsewhere[13].

3. Results and Discussion

3.1. Microhardness

The microhardness of the alloy was found out using the Vickers hardness test. Ten indentations were performed on the specimen. The average microhardness was calculated to be 64.47 HV.

3.2. Wear test

The results of the adhesive wear test are given in table 3. The wear rate of the AA5052 alloy varied in the range between \(3.77544 \times 10^{-8}\) g/Nm and \(3.01563 \times 10^{-7}\) g/Nm for different combinations of the wear test parameters. A minimum wear rate of \(1.69895 \times 10^{-8}\) g/Nm was obtained for the specimen slid for 600 m at a SV of 2 m/s under an AL of 2 kg.

| Sl. | Specimen | SV (m/s) | SD (m) | AL (kg) | Wear Rate (g/Nm) |
|-----|----------|----------|--------|---------|------------------|
| 01  | BM01     | 1        | 600    | 2       | 1.27421\times 10^{-7} |
| 02  | BM02     | 2        | 1200   | 2       | 1.01937\times 10^{-7} |
| 03  | BM03     | 2        | 600    | 4       | 3.01563\times 10^{-7} |
| 04  | BM04     | 1        | 1200   | 4       | 2.12368\times 10^{-7} |
| 05  | BM05     | 1.5      | 900    | 3       | 1.51017\times 10^{-7} |
| 06  | BM06     | 1.5      | 900    | 3       | 3.77544\times 10^{-8} |
| 07  | BM07     | 2        | 600    | 2       | 1.69895\times 10^{-8} |
| 08  | BM08     | 1        | 1200   | 2       | 3.27047\times 10^{-7} |
| 09  | BM09     | 1        | 600    | 4       | 5.09684\times 10^{-8} |
| 10  | BM10     | 2        | 1200   | 4       | 4.45973\times 10^{-8} |
| 11  | BM11     | 1.5      | 900    | 3       | 7.55087\times 10^{-8} |
| 12  | BM12     | 1.5      | 900    | 3       | 7.55087\times 10^{-8} |
| 13  | BM13     | 0.5      | 900    | 3       | 8.30596\times 10^{-8} |
| 14  | BM14     | 2.5      | 900    | 3       | 5.66316\times 10^{-8} |
| 15  | BM15     | 1.5      | 300    | 3       | 3.39789\times 10^{-7} |
| 16  | BM16     | 1.5      | 1500   | 3       | 9.96715\times 10^{-8} |
| 17  | BM17     | 1.5      | 900    | 1       | 2.83158\times 10^{-7} |
| 18  | BM18     | 1.5      | 900    | 5       | 5.66316\times 10^{-8} |
| 19  | BM19     | 1.5      | 900    | 3       | 9.43859\times 10^{-8} |
| 20  | BM20     | 1.5      | 900    | 3       | 7.92842\times 10^{-8} |

The highest wear rate was obtained for specimen number BM 15 was worn at an SV of 1.5 m/s for an SD of 300 m and an AL of 3 kg. It is observed that the wear phenomenon had more fluctuations in the earlier stages and decreased as time progress, as shown in figure 1 (a).
The lowest wear rate was obtained for specimen number BM05 which was worn at an SV of 1.5 m/s for an SD of 900 m and an AL of 3 kg. Minimum fluctuations were observed during the initial stages of the wear test in specimen BM05. However, more fluctuations were observed in the later stages of wear, as shown in figure 1 (b). Those fluctuations in wear phenomenon are due to the uneven surface of the specimen, which is attributed to the effects of wear testing.

3.3. Surface Morphology and Elemental composition of the worn surface
Specimen BM15 showed the highest wear rate and Specimen BM05 showed the least wear rate among the tested specimens. The fragmented loose particles falling out from the worn out surface lead to high wear in the specimen BM15 [14]. Discontinuous shallow grooves were observed in the specimen BM05 and continuous deep grooves were observed in the specimen BM15 specimen, as observed in figure 2 (a) and figure 2 (b) respectively.

Figure 3 (a) shows the chosen area for elemental analysis. It is inferred from figure 3 (b) that Al and O are the dominant elements present in the worn surface of the specimen BM15. Hence, the wear particles are made of Aluminum oxide.
3.4. Linear – Radial Basis Function model
A statistical model was developed for predicting the wear rate of the base material using AL, SV, and SD as response variables and it is given in equation (2)

\[
\text{Wear Rate of Base Material} = -3.4335 \times 10^{-7} - 8.5534 \times 10^{-7} \times SD - 7.3311 \times 10^{-8} \times AL + 3.877 \times 10^{-7} \times SV + \text{Radial Basis Function}
\] (2)

The RBF was developed using a multiquadric kernel with 5 centers a global width of 0.67879. The regularization parameter, lambda, is 0.0001. The ANOVA and the statistical parameters for the developed model are given in table 4.

Figure 4. Experimental vs. Predicted wear rate of specimens

The plot of experimental versus predicted wear rate of the base material is shown in figure 4. A linear trend was observed between the experimental and predicted values. The closeness of RMSE to 0, \(R^2\) to 1, and linearity of experimental versus predicted value indicate the high potency of the developed model [15, 16]. Hence, the model was used to analyze the effect of wear test parameters on the wear rate of the base material.
### Table 4. ANOVA and statistical parameters

| Source    | SS       | DF | MS       |
|-----------|----------|----|----------|
| Regression| 1.859 × 10^{-13} | 7.992 | 2.326 × 10^{-14} |
| Error     | 2.586 × 10^{-15} | 7.008 | 3.691 × 10^{-16} |
| Total     | 1.888 × 10^{-13} | 15  | 0        |
| RMSE      | 1.921 × 10^{-8}  |   |          |
| R²        | 0.971     |    |          |

#### 3.4.1. Effect of SD and AL on the wear rate.

The effect of SD and AL on the wear rate of the base material is shown in figure 5. For an AL of 1 kg, the wear rate decreases from the maximum value to a minimum value as the SD increases from 300 m to 1500 m. For the AL of 2.5 kg, minimum wear rate was observed up to an SD of 1000 m, beyond which the wear rate increases.

![Figure 5](image_url)

**Figure 5.** Effect of AL and SD on the wear rate of AA5052 alloy

For the AL of 4 kg, the wear rate decreases from the maximum value to minimum value, with increases in SD. As the AL increases from 1 kg to 5 kg, the wear rate had trough parabolic trend for an SD of 400 m. The wear rate remains almost similar at all AL for an SD of 900 m. However, for an SD of 1500 m, the wear rate decreases with increase in AL from 1 kg to 5 kg. The maximum wear rate is predicted at ALs of 1 kg and 4 kg with an SD of 300 m.

#### 3.4.2. Effect of SD and SV on the wear rate.

The effect of SD and SV on the wear rate of the AA5052 is shown in figure 6. For the SV of 0.5 m/s, the wear rate decreases from the maximum value to a low value as the SD increases from 300 m to 1500 m. For the SV of 1.5 m/s, the wear rate decreases from the high value to a low value as the SD increases from 300 m to 1500 m. For the SV of 2.5 m/s, the wear rate decreases from the maximum value to a minimum value as the SD increases from 300 m to 1500 m. The wear rate remains almost similar at all AL for an SD of 300 m at all the sliding velocities. As the SV increases from 0.5 m/s to 2.5 m/s, the wear rate was high for an SD of 400 m. However, for an SD greater than 600 m, the wear rate decreases with increase in SV from 0.5 m/s to 2.5 m/s.
3.4.3. Effect of SV and AL on the wear rate

The effect of SV and AL on the wear rate of the base material is shown in figure 7. For the SV of 0.5 m/s, the wear rate decreases from the maximum value to a low value as the AL increases from 1 kg to 5 kg. For the SV of 1.5 m/s, the wear rate decreases from the high value to a low value as the AL increases from 1 kg to 5 kg. For the SV between 2.0 m/s and 2.5 m/s, the wear rate decreases from the maximum value to a minimum value as the AL increases from 1 kg to 2.5 kg. Further increase in AL, increases the wear rate.
4. Conclusion
The study explored the wear phenomenon of the AA5052 alloy experimentally. A linear – radial basis function was developed to predict the wear rate of the AA5052 alloy and to study the effect of wear test parameters on the wear rate of the alloy. The study concluded the following. A minimum wear rate was obtained for the specimen slid for 600 m at an SV of 2 m/s under an AL of 2 kg. A maximum wear rate was obtained for the specimen slid at an SV of 1.5 m/s for an SD of 300 m and an AL of 3 kg. The results indicate that increase in axial load and SD decreases the wear rate of the AA5052 alloy.

5. References

[1] Zhang J and Alpas A T 1993 Delamination wear in ductile materials containing second phase particles Materials Science and Engineering: A 160 25-35

[2] Hanlon T, Chokshi A, Manoharan M and Suresh S 2005 Effects of grain refinement and strength on friction and damage evolution under repeated sliding contact in nanostructured metals International Journal of Fatigue 27 1159-63

[3] Mohan A, Gautam G, Kumar N, Mohan S and Gautam R 2016 Synthesis and tribological properties of AA5052-base insitu composites Composite Interfaces 23 503-18

[4] Kumar N, Gautam G, R.K.Gautam, Mohan A and Mohan S 2016 High Temperature Sliding Wear Characteristics of AA5052/TiB2 insitu Composite. In: National Tribology Conference 2016, (Varanasi: IIT Varanasi)

[5] Daniel A A, Murugesan S and Sukkasamy S 2017 Dry Sliding Wear Behaviour of Aluminium 5059/SiC/MoS2 Hybrid Metal Matrix Composites Materials Research 20 1697-706

[6] Gautam G, Kumar N, Mohan A, Gautam R and Mohan S 2016 High-Temperature Tensile and Tribological Behavior of Hybrid (ZrB2+ Al3Zr)/AA5052 In Situ Composite Metallurgical and Materials Transactions A 47 4709-20

[7] Rana R S, Purohit R, Kumar Sharma A and Rana S 2014 Optimization of Wear Performance of Aa 5083/10 Wt.% SiCp Composites Using Taguchi Method Procedia Materials Science 6 503-11

[8] Cao X, Shi Q, Liu D, Feng Z, Liu Q and Chen G 2018 Fabrication of in situ carbon fiber/aluminum composites via friction stir processing: Evaluation of microstructural, mechanical and tribological behaviors Compos Part B: Eng 139 97-105

[9] Khodabakhshi F, Simchi A and Kokabi A H 2017 Surface modifications of an aluminium-magnesium alloy through reactive stir friction processing with titanium oxide nanoparticles for enhanced sliding wear resistance Surf. Coat. Technol. 309 114-23

[10] Kumar N, Gautam G, Gautam R K, Mohan A and Mohan S 2017 High-Temperature Tribology of AA5052/ZrB2 PAMCs J. Tribol. 139

[11] Kumar N, Gautam R K and Mohan S 2015 Wear and friction behavior of in-situ AA5052/ZrB2composites under dry sliding conditions Tribol. Ind. 37 244-56

[12] Mohan A, Gautam G, Kumar N, Mohan S and Gautam R K C 2016 Synthesis and tribological properties of AA5052-base insitu composites Composite Interfaces 23 503-18

[13] Ramalingam V V and Ramasamy P 2017 Modelling Corrosion Behavior of Friction Stir Processed Aluminium Alloy 5083 Using Polynomial: Radial Basis Function Transactions of the Indian Institute of Metals 70 2575-89

[14] Vaira Vignesh R and Padmanaban R 2018 Influence of friction stir processing parameters on the wear resistance of aluminium alloy AA5083 Materials Today: Proceedings 5 7437-46

[15] Jayakarthick C, Povendhan A P, Vignesh R V and Padmanaban R 2018 Analysing the influence of FSP process parameters on IGC susceptibility of AA5083 using Sugeno – Fuzzy model IOP Conference Series: Materials Science and Engineering 310 012045

[16] Vignesh R V and Padmanaban R 2017 Modelling tensile strength of friction stir welded aluminium alloy 1100 using fuzzy logic. In: 2017 11th International Conference on Intelligent Systems and Control (ISCO), pp 449-56