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# Optimization of wear parameters for aluminium 4% fly-ash composites

Subramaniam Magibalan[a]*, Palanisamy Senthilkumar[b], Chinnamuthu Senthilkumar[c] & Muthusamy Prabu[d]

[a,b,d]Department of Mechanical Engineering, K.S.R. College of Engineering, Tiruchengode 637215, India

[c]Department of Mechanical Engineering, University College of Engineering, Panruti 607106, India

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Dry sliding wear behaviour of aluminium matrix composites (AMCs) prepared by stir casting with 4% as fly ash reinforcement has been studied in the work. Dry sliding wear tests have been conducted using a pin-on-disc wear-testing machine to study the effect of changeable process parameters such as load, time, and sliding velocity, which have been used as design variables on the output parameters wear rate (WR) and coefficient of friction (COF). Sensitivity analysis has been carried out to find out the most significant parameter that can be controlled to minimize the WR. Further, the wear parameters have been optimized using the technique for order of preference by similarity to ideal solution (TOPSIS) approach to reduce the WR. Therefore, this study offers useful insights to composite manufacturers, especially for automotive industries.

**Keywords:** Aluminium Alloy 8011, Sensitivity analysis (SA), Response Surface Methodology (RSM), Wear rate (WR), TOPSIS

## 1 Introduction

Metal matrix composites (MMCs) have appear because of necessary group of material used in aerospace, transport and industry[1].The combined property of aluminium alloys with reinforcements increased the lifespan of the composite material, tensile with elevated temperature conditions[2]. Many methods have been used for development and processing of aluminium particulate metal matrix composites to optimize the wear and mechanical properties is commonly done by various methods such as spray deposition[3,4], mechanical alloying[5,6], stir casting[7,8] and direct metal laser sintering[9,10]. These properties mainly depend on many factors such as composition of the aluminium alloy, fabrication method, type of ceramic reinforcements, distribution over the matrix alloy and wettability between matrix alloy and reinforcement[11-18].

Dhar *et al.*[19] have studied the electrical discharge machining (EDM) of Al–4Cu–6Si alloy with 10 wt. % $SiC_P$ composites and developed a second order, non-linear mathematical model for establishing the relationship among machining parameter and responses.

Kumar *et al.*[20] studied the $AlB_2$ particles reinforced in Al 8011 alloy by in-situ technique to synthesize Al8011/6 vol. % of $AlB_2$ composite. During synthesis, in-situ reaction takes place between molten alloy and inorganic salt $KBF_4$ at 850°C and it led to the formation of $AlB_2$.

Dey *et al.*[21] have developed the mathematical model of AA6061/cenosphere. The process parameters and the mathematical model calculate all the responses such as cutting speed, kerf width and surface roughness. The Box Behnken is employed to analyze the effects of significant parameters on the performance characteristics.

Karaoglu *et al.*[22] analyses the weld bead process parameters with different penetration to vary the input parameters as well as the welding process. The developed a mathematical equation of response surface methodology (RSM) for powder mixed electric discharge machining (PMEDM) as reported by Kansal *et al.*[23].

Gadakh[24] has investigated the TOPSIS technique for best possible parameter selection of wire electrical discharge(WED) machine process. Genetic algorithm (GA), artificial neural network (ANN) and grey relational analysis (GRA). Among these methods, TOPSIS techniques are very simply implemented and also quite useful for the decision makers. TOPSIS technique almost matches with any derived from the earlier period of researchers to provide evidence.

Nayak & Mahapatra[25] have used the TOPSIS technique on the multi-response optimization in wire electrical discharge machining(WEDM) and work piece material $D_2$ tool steel. The process parameters with responses material removal rate (MRR) and surface roughness (SR). The range of best possible

*Corresponding author (E-mail: magibalan42@gmail.com)

process parameters in the wire electrical discharge machining (WEDM) method by considering the experimental values are represented higher value MRR and lower value Ra.

Yuvaraj & Pradeep Kumar[26] have studied the multiple-criteria decision-making (MCDM) using the TOPSIS method in the abrasive water jet machine and work piece material AA5083-H32 aluminium alloy. The selected parameters are feed rate, current, pulse on-time, and the gap voltage. The experimental results show the level and parameter by using TOPSIS method to optimize several output responses in optimal conditions were reported by Manivannan & Kumar[27].

Lakshminarayanan *et al.*[28] have conducted the experiments with three factors and three level and central composite design (CCD) with full factorial SA to predict the tensile strength of friction stir welded alloy AA7039 aluminium.

Senthilkumar and Kannan[29] have conducted the sensitivity analysis of arc welding material of super duplex stainless steel. This technique used insignificant coefficient values removed to create reduced models in machining parameters. Based on the results they concluded the sensitivity analysis to use to identify the important parameter and properties of the deposited layer.

Munda & Bhattacharyya[30] have created a RSM models for higher-order processes are analyzed using three methods namely TOPSIS, base component analysis, and GRA. TOPSIS provides the top results as reported by Gauri*et al.*[31].

In the present work, an attempt is pin-on-disc equipment is accustomed to investigate the dry sliding wear behaviour of the composite (AA8011-4 wt.-% fly ash) using multi criteria decision-making methods TOPSIS. In the group of this background, the present paper was conducted.

## 2 Experimental Method

### 2.1 Selection of Materials and Testing

AA8011 base material of Chemical composition shows that Fe 0.65%, Si 0.70%, Zn 0.10%, Cu 0.10%, Ti 0.08, Cr 0.05%, Mg 0.05%, Al98.07% and the reinforcement exact chemical composition of fly ash $SiO_2$ 65.93%, $Al_2O_3$ 23.69%, CaO 3.93 %, $Fe_2O_3$ 2.83%, $K_2O$ 2.77%, $Na_2O$ 0.86%. The separation of Al MMCsuse in this study is carried out by stir casting technique. Al in the form of sheet and the reinforcement materials in the form of particulates are used for trials [32-35].

### 2.2 Dry Sliding Wear Test

Figure 1 shows the ASTM Standard-G99with Pin on Disc machine (Model: DUCOM TR20) was used to conduct the wear test at an atmospheric temperature. Circular specimen 10 mm diameter and 50 mm height were machined from the castings. In this present work, WR and coefficient of friction were identified as the output and the WR was calculated by Eq. (1).

$$\text{Wear rate (g/min)} = \frac{(metalremovedfrompart)}{(Timeofmac\ hining)} \quad \ldots(1)$$

### 2.3 Development of Mathematical Model for Wear Rate

CCD method used on RSM full factorial design with Orthogonal Array 20 support to three level and three factor experimental was selected and the input parameter are load, time, sliding velocity are given in Table 1. The calculated WR and COF for all the 20 experiments are given in Table 2. In Eq. (2) formulate the RSM modelling related with response $Y_a$ Response surface modelling is accustomed establish the applied mathematics relationship between the response ($Y_a$) and therefore the numerous machining parameters was calculated by Eq. (2) [32-35].


Fig. 1 — Pin-on-disc setup.

Table 1 — Process parameters and their levels.

| PARAMETERS | LEVEL | | |
|---|---|---|---|
| | -1 | 0 | 1 |
| Normal Load (N) | 5 | 10 | 15 |
| Time (min) | 5 | 10 | 15 |
| Sliding velocity (m/s) | 1.5 | 3 | 4.5 |

$$Y_a = b_a + \sum_{m=1}^{k} b_k x_k + \sum_{k=1}^{k} b_{kk} x^2{}_k + \sum_{l>1}^{k} b_{kl} x_k x_l ...(2)$$

where,

$Y_a$ is the response and the $x_k$ (1, 2… etc) are coded level of k numerical variables.

$b_a$ is the endless term on constant value

$b_k$is linear term

$b_{kk}$is quadratic terms

$b_{kl}$is interaction terms.

## 3 Results and Discussion

### 3.1 TOPSIS using Wear Characteristics on AA8011-4% Fly-Ash Composite

Step 1: The normalize matrix for AA8011-4% Fly ash is given in Table 3and it follows the Eq. (3) as given below.

$R_{ab} = x_{ab}/ (\Sigma x^2{}_{ab})$ …(3)

for a = 1… m, b= 1… n

Step 2: The sum of allocated weights for given WR and COF should be equal to one (where WR =0.50 andCOF=0.50).

Step 3: In order to optimize decision matrix, the weighted normalized decision matrix Eq. (4) is constructed, and the weights for each criterion, $w_b$ for b = 1…n.

$Y_{ab} = W_b R_{ab}$ …(4)

To obtain the element, normalized decision matrix for each column is multiplied by its respective weight. Table 4 shows the weighted normalized matrix.

Step 4: Determine the positive ideal and negative ideal solution the following Eqs (5) & (6) are used.

For positive solution,

$A^+ = \{Y_a{}^+, \ldots, Y_n{}^+\}$ … (5)

where,

$Y_a{}^+ = \{ \max (Y_{ab}) \text{ if } b\in J ,\ \min (Y_{ab}) \text{ if } b\in J' \}$

For negative solution,

$A^- = \{Y_b{}^-, \ldots, Y_n{}^- \}$ …(6)

where

$Y_b{}^- = \{\min (Y_{ab}) \text{ if } b\in J, \max (Y_{ab}) \text{ if } b\in J'\}$

$Y^+ = 0.1465 Y^+ = 0.1514$

$Y^- = 0.0856 Y^- = 0.0674$

Step 5: The solution to the determination of the separation measure from the ideal alternative solution Eq. (7) is presented in Table 5.

$S_i{}^+ = [\Sigma(Y_a{}^+ - Y_{ab})^2]^{½}$ …(7)

Similarly, the solution for the determination of the separation measure from the negative solution is Eq. (8) is presented in Table 5.

$S_i{}^- = [\Sigma(Y_a{}^- - Y_{ab})^2]^{½}$ …(8)

Table 2 — Wear characteristics of AA 8011- 4% fly- ash composite.

| S.No. | Load (N) | Time (min) | Sliding velocity (m/s) | Wear rate (g/min) × $10^{-3}$ | COF (μ) |
|---|---|---|---|---|---|
| 1 | 5 | 5 | 1.5 | 0.342 | 0.559 |
| 2 | 15 | 5 | 1.5 | 0.434 | 0.372 |
| 3 | 5 | 15 | 1.5 | 0.372 | 0.497 |
| 4 | 15 | 15 | 1.5 | 0.484 | 0.542 |
| 5 | 5 | 5 | 4.5 | 0.428 | 0.369 |
| 6 | 15 | 5 | 4.5 | 0.534 | 0.334 |
| 7 | 5 | 15 | 4.5 | 0.454 | 0.266 |
| 8 | 15 | 15 | 4.5 | 0.585 | 0.452 |
| 9 | 5 | 10 | 3 | 0.422 | 0.523 |
| 10 | 15 | 10 | 3 | 0.535 | 0.523 |
| 11 | 10 | 5 | 3 | 0.398 | 0.344 |
| 12 | 10 | 15 | 3 | 0.434 | 0.375 |
| 13 | 10 | 10 | 1.5 | 0.380 | 0.383 |
| 14 | 10 | 10 | 4.5 | 0.466 | 0.249 |
| 15 | 10 | 10 | 3 | 0.430 | 0.382 |
| 16 | 10 | 10 | 3 | 0.435 | 0.38 |
| 17 | 10 | 10 | 3 | 0.434 | 0.384 |
| 18 | 10 | 10 | 3 | 0.430 | 0.386 |
| 19 | 10 | 10 | 3 | 0.432 | 0.384 |
| 20 | 10 | 10 | 3 | 0.432 | 0.382 |

Table 3 — Normalized matrix.

| Ex. No | Wear rate (g/min) × $10^{-3}$ | COF (μ) |
|---|---|---|
| 1 | 0.1713 | 0.3027 |
| 2 | 0.2173 | 0.2015 |
| 3 | 0.1863 | 0.2692 |
| 4 | 0.2424 | 0.2935 |
| 5 | 0.2143 | 0.1998 |
| 6 | 0.2674 | 0.1809 |
| 7 | 0.2273 | 0.1441 |
| 8 | 0.2929 | 0.2448 |
| 9 | 0.2113 | 0.2832 |
| 10 | 0.2679 | 0.2832 |
| 11 | 0.1993 | 0.1863 |
| 12 | 0.2173 | 0.2031 |
| 13 | 0.1903 | 0.2074 |
| 14 | 0.2334 | 0.1349 |
| 15 | 0.2153 | 0.2069 |
| 16 | 0.2178 | 0.2058 |
| 17 | 0.2173 | 0.2080 |
| 18 | 0.2153 | 0.2091 |
| 19 | 0.2163 | 0.2080 |
| 20 | 0.2163 | 0.2069 |

Step 6: With regard to the relative closeness coefficient calculation the Eq. (9) of a particular alternative, the results are presented in Table 6.

Table 4 — Weighted normalized matrix.

| Ex. No | Wear rate (g/min) × $10^{-3}$ | COF(μ) |
|---|---|---|
| Weights | 0.50 | 0.50 |
| 1 | 0.0856 | 0.1514 |
| 2 | 0.1087 | 0.1007 |
| 3 | 0.0931 | 0.1346 |
| 4 | 0.1212 | 0.1468 |
| 5 | 0.1072 | 0.0999 |
| 6 | 0.1337 | 0.0904 |
| 7 | 0.1137 | 0.0720 |
| 8 | 0.1465 | 0.1224 |
| 9 | 0.1057 | 0.1416 |
| 10 | 0.1340 | 0.1416 |
| 11 | 0.0997 | 0.0932 |
| 12 | 0.1087 | 0.1015 |
| 13 | 0.0951 | 0.1037 |
| 14 | 0.1167 | 0.0674 |
| 15 | 0.1077 | 0.1034 |
| 16 | 0.1089 | 0.1029 |
| 17 | 0.1087 | 0.1040 |
| 18 | 0.1077 | 0.1045 |
| 19 | 0.1082 | 0.1040 |
| 20 | 0.1082 | 0.1034 |

Table 5 — Separation measures of ideal and negative ideal solution matrix.

| Ex. No | S+ | S- |
|---|---|---|
| 1 | 0.1037 | 0.0000 |
| 2 | 0.0504 | 0.0557 |
| 3 | 0.0858 | 0.0184 |
| 4 | 0.0833 | 0.0359 |
| 5 | 0.0510 | 0.0558 |
| 6 | 0.0264 | 0.0776 |
| 7 | 0.0332 | 0.0842 |
| 8 | 0.0550 | 0.0674 |
| 9 | 0.0847 | 0.0223 |
| 10 | 0.0753 | 0.0493 |
| 11 | 0.0535 | 0.0599 |
| 12 | 0.0510 | 0.0549 |
| 13 | 0.0629 | 0.0486 |
| 14 | 0.0298 | 0.0895 |
| 15 | 0.0530 | 0.0528 |
| 16 | 0.0517 | 0.0538 |
| 17 | 0.0526 | 0.0527 |
| 18 | 0.0537 | 0.0518 |
| 19 | 0.0530 | 0.0525 |
| 20 | 0.0526 | 0.0530 |

$$P_i = S_i^- / (S_i^+ + S_i^-) \quad \ldots(9)$$

$0<P_i<1$: Select the option with $P_i$ closest to 1

From Table 6, the relative closeness coefficient value of each experimental run is known. By using TOPSIS, the experiment number 14 (Load: 10 N, Time: 10 min, Sliding Velocity: 4.5 m/s) shows the maximum closeness coefficient and explains that the ideal value is the nearest value for the corresponding experiment. The variation in closeness value of each experimental run can be observed from Figure 2.

Figure 3 highlights the percentage contribution of individual parameter and it is evident from the

Table 6 — Relative closeness coefficient.

| S. No | Relative Closeness | Rank |
|---|---|---|
| 1 | 0.0004 | 20 |
| 2 | 0.5247 | 6 |
| 3 | 0.1768 | 19 |
| 4 | 0.3011 | 17 |
| 5 | 0.5223 | 7 |
| 6 | 0.7466 | 2 |
| 7 | 0.7175 | 3 |
| 8 | 0.5508 | 4 |
| 9 | 0.2085 | 18 |
| 10 | 0.3959 | 16 |
| 11 | 0.5285 | 5 |
| 12 | 0.5187 | 8 |
| 13 | 0.4360 | 15 |
| 14 | 0.7501 | 1 |
| 15 | 0.4991 | 12 |
| 16 | 0.5100 | 9 |
| 17 | 0.5005 | 11 |
| 18 | 0.4909 | 14 |
| 19 | 0.4977 | 13 |
| 20 | 0.5018 | 10 |

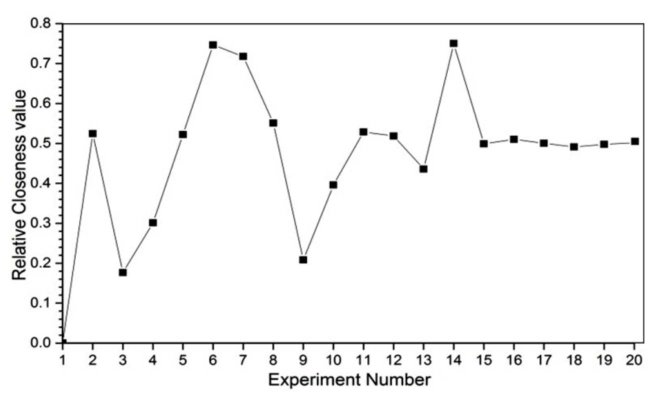


Fig. 2 — Experimental numbers versus Relative closeness coefficient.

observation that sliding velocity 67% and load 32% are the major domination parameter and time is 1% is the least significant parameter (Table 7).

**3.2 Optimization of Wear Characteristics using AA8011-4% Fly ash composite**

Table 2 givesthe experimental results for the characteristics of dry sliding wear for AA8011-4% Fly ash composite and the maximum value for WR (g/min) × $10^{-3}$is 0.466 and minimum value for COFis0.249 μ with the load of (10 N), Time (10 min) and sliding velocity (4.5 m/s). TOPSIS technique used in optimizing, WR and COF value is very near to the experimental value and is selected from Table 8.

The WR (g/min) × $10^{-3}$is 0.476 gm/min and the predicted parameters are load 10.8 N, Time 11 min and sliding velocity 4.8 m/s. A new experiment is designed and conducted with the optimum values of the wear parameters by predicting the response from the optimum condition.

In Table 9 shows the evaluation of predicted machining operation with actual machining operation is made to get results and a good agreement has been obtained between these operations. The residues are studied from the validation test a result of WR is found to be within the permissible limit.

**3.2 Sensitivity Analysis**

Sensitivity analysis the non-significant terms are eliminate response Eq. (10) for WRare given below.

$$WR\ (g/min)\ x10^{-3} = 0.31731 - 0.03017\ A + 0.01441\ B + 0.04885\ C + 0.001867\ A^2 - 0.000633\ B^2 - 0.003919\ C^2 + 0.000225\ AB + 0.000550\ AC \quad \ldots (10)$$

Sensitivity analysis the non-significant terms are eliminate response Eq. (11) forCOF are given below

$$COF\ (\mu) = 0.97512 - 0.14661\ A + 0.00639\ B + 0.10816\ C + 0.005475\ A^2 - 0.001065\ B^2 - 0.031172\ C^2 + 0.002265\ AB + 0.004883\ AC - 0.001550\ BC \quad \ldots (11)$$

Eqs 10 & 11 differentiating with high opinion to three parameters of Load (A), Time (B), and Sliding velocity (C) are given below.

$$\frac{dWR}{dA} = -0.03017 + 0.001867 * 2A + 0.000225\ B + 0.000550\ C \quad \ldots (12)$$

$$\frac{dCOF}{dA} = -0.14661 + 0.005475 * 2A + 0.002265\ B + 0.004883\ C \quad \ldots (13)$$

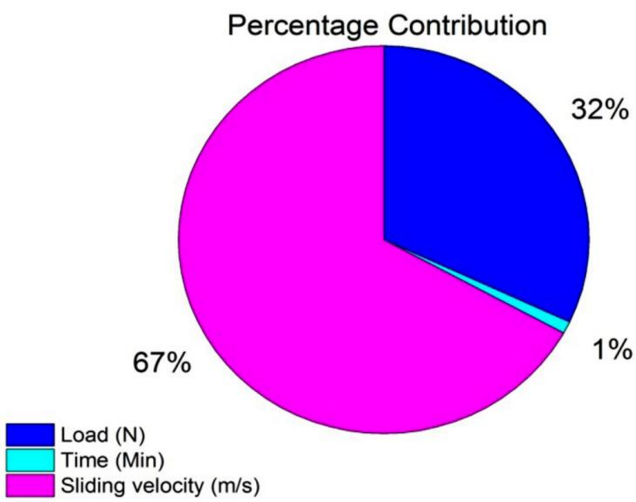


Fig. 3 — Percentage contributions of individual parameters.

Table 7— ANOVA using AA8011-4% fly -ash composite.

| S. No. | Parameters | DOF | Sum of squares | Mean square | F value | Percentage contribution (%) |
|---|---|---|---|---|---|---|
| 1 | Load (N) | 2 | 0.178292 | 0.08915 | 9.30 | 32 |
| 2 | Time (Min) | 2 | 0.003182 | 0.00159 | 0.17 | 1 |
| 3 | Sliding velocity (m/s) | 2 | 0.370036 | 0.18502 | 19.31 | 67 |

Table 8 — Optimal values of Wear rate using AA8011-4% fly- ash composite.

| Ex. No. | Load (N) | Time (min) | Sliding Velocity (m/s) | Wear rate (g/min) × $10^{-3}$ | COF (μ) |
|---|---|---|---|---|---|
| 14 | 10 | 10 | 4.5 | 0.466 | 0.249 |

Table 9 — Validation test results for Wear rate using AA8011-4% fly -ash composite.

| Ex. No. | Load (N) | Time (min) | Sliding Velocity (m/s) | Wear rate (g/min) × $10^{-3}$ | | |
|---|---|---|---|---|---|---|
| | | | | Predicted | Actual | %Error |
| 1 | 10.8 | 11 | 4.8 | 0.476 | 0.468 | 2.53 |

$$\frac{dWR}{dB} = 0.01441 - 0.000633 *2 B + 0.000225 \quad \ldots (14)$$

$$\frac{dCOF}{dB} = 0.00639 - 0.001065 *2 B + 0.002265 A - 0.001550 C \quad \ldots (15)$$

$$\frac{dWR}{dC} = 0.04885 - 0.003919 *2 C + 0.000550 A \quad \ldots (16)$$

$$\frac{dCOF}{dC} = 0.10816 - 0.031172 *2 C + 0.004883 A - 0.001550 B \quad \ldots (17)$$

Eqs (12-17) two responses (WR and COF) for sensitivities equation of load, time, sliding velocity is mentioned in Tables 10 & 11.

Figure 4 shows the load at 5-15 N of sensitivity analysis for WR and COF. At 5 N the WR and COF is negative value after increases the load 10 N and 15 N the sensitivity analysis for WR and COF on negative value.

Figure 5shows the time at 5-15 min of sensitivity analysis for WR and COF. At 5 min the WR and COF is positive value after increases the time 10 min and 15 min the sensitivity analysis for WR and COF on positive value.

Figure 6 shows the sliding velocity at 1.5-4.5 m/s of sensitivity analysis for WR and COF. At 1.5 m/s and 3 m/s sliding velocity of the WR and COF is positive value after increases the sliding velocity at 4.5 m/s the sensitivity analysis for WR and COF on positive value.

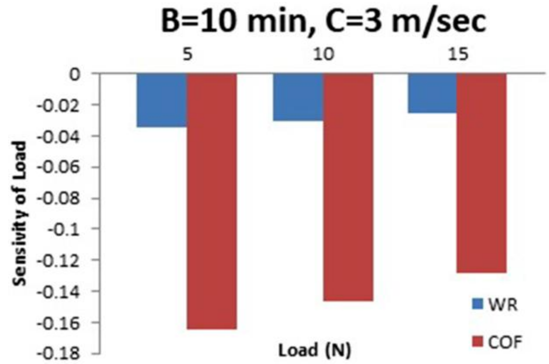


Fig. 4 — Sensitivity analysis results of load.

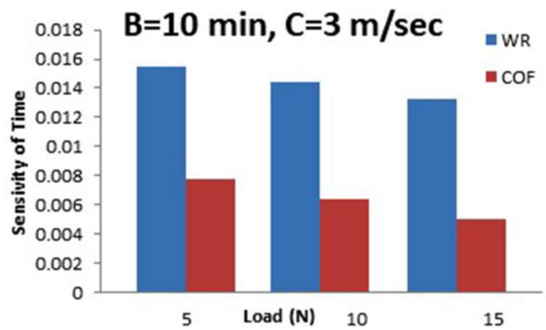


Fig. 5 — Sensitivity analysis results of time.

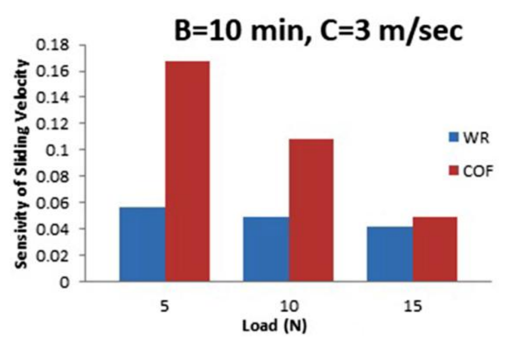


Fig. 6 — Sensitivity analysis results of sliding velocity.

Table 10 — Wear rate for sensitivities of process parameters.

| Load (N) | B=10 min,C=3 m/sec | | |
|---|---|---|---|
| | $\frac{dWR}{dA}$ | $\frac{dWR}{dB}$ | $\frac{dWR}{dC}$ |
| 5 | -0.0347 | 0.0155 | 0.0562 |
| 10 | -0.0302 | 0.0144 | 0.0489 |
| 15 | -0.0257 | 0.0133 | 0.0415 |

Table 11 — COF for sensitivities of process parameters.

| Load (N) | B=10 min, C=3 m/sec | | |
|---|---|---|---|
| | $\frac{dCOF}{dA}$ | $\frac{dCOF}{dB}$ | $\frac{dCOF}{dC}$ |
| 5 | -0.1647 | 0.0078 | 0.1672 |
| 10 | -0.1466 | 0.0064 | 0.1082 |
| 15 | -0.1285 | 0.005 | 0.0491 |

## 4 Conclusions

(i) Optimization of AA 8011 with 4 wt.-% of fly ash composite has been carried out using TOPSIS for all experiments. The optimized values obtained through TOPSIS have close agreement with the experimental values.

(ii) The relative closeness coefficient value 0.7501 of each experimental run is known by using TOPSIS, the experiment number 14 (Load: 10 N, Time: 10 min, Sliding Velocity: 4.5 m/s) shows the maximum closeness coefficient and explains that the ideal value is the nearest value for the corresponding experiment.

(iii) TOPSIS technique used in optimizing the dry sliding wear for AA8011- 4 % Fly ash composite and the maximum value for WR (g/min) × 10-3 is 0.466 and minimum value for COF is 0.249 μ with the load of (10 N), Time (10 min) and sliding velocity (4.5 m/s).

(iv) The WR (g/min) × 10-3 value is 0.476 gm/min and the predicted parameters are load 10.8 N, Time 11 min and sliding velocity 4.8 m/s. The predicted machining operation with actual machining operation is made to get results and a good agreement has been obtained between these operations. The residues are studied from the validation test results of WR are found to be within the permissible limit.

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