Optimization of dry sliding wear parameters of Al4Mg system reinforced with high strength alloy particulate (HSAp)

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Abstract: The dry sliding wear behaviour of Al4Mg binary alloy and Al4Mg reinforced with Al20Cu20Mg composites was examined using pin on disc apparatus. The composites were synthesized by the reinforcement of different weight % (5, 10 and 15) of the high strength alloy particulate (HSAp) in the base binary alloy Al4Mg using stir casting technique followed by hot extrusion. In this way, composites were prepared with metal particulate reinforcement which are termed as metal-metal composites which is a novel idea instead of reinforcement of ceramic particulate. These extrudates of non-reinforced base alloy and composites were characterized to optimise dry sliding wear parameters, wear resistance and coefficient of friction under the load conditions of 0.5, 1 and 1.5 kgf at the sliding velocities is of 100, 120 and 140 metre per second and sliding times of 15, 30 and 45 seconds respectively. The wear parameters were optimised using Grey relational analysis (GRA) and ANOVA techniques and obtained the optimal combination of input parameters.

Keywords: High strength alloy particulate (HSAp), metal-metal composites, stir casting, hot extrusion, GRA, ANOVA.

1. Introduction

'Wear' is the property that acts on both ends positive and negative when considered in engineering applications. For anecdotal reasons the wear property intentionally induced or reduced depending on the application. Wear may be because of corrosion, adhesion, and abrasion. Each of these has their own advantages and disadvantages that lead to benefits and troubles depending on the type of application for a particular purpose. The benefits or problems may be influenced by the factors type of material, type of lubrication and amount of surface finish. Among Metal matrix composites (MMCs), Aluminium matrix composites (AMCs) hold more than 69% by weight for industrial functions as they holds excellent mechanical and thermal properties couples with better tribological properties [1-2]. Under dry lubrication conditions, the Aluminium based matrix composites are exhibiting poor wear resistance. These are confined to very limited applications due to this inadequacy [3]. It is examined that the strength of matrix alloy AA7075 was enhanced by 6%, on addition of hybrid particulate (SiC+ Al2O3) [4]. Among the hybrid reinforcement particulates RHA (Rice Husk Ash), Al2O3 and graphite in AA6063, the graphite influenced more on the wear rate. As graphite composition increases from 0% to 1.5% the rate of decreases drastically, as the graphite particulates are soft in nature [5]. The AMMCs with inclusion of hard metallic or ceramic particulates are greatly influenced by wear mechanisms like abrasive and adhesive [6-8]. In the global scenario, due to increasing competition for manufacturability with reduced weight to strength
ratio regarding engine parts of automobiles, the research in the AMMCs area is still running after new and innovative techniques for better performance [9]. The need is still in take away situation and the lacunae are to be bridged for the emerging applications and needs in all the related industries.

The wear properties of AMMCs are greatly influenced type of reinforcement particulates and volume and size of the particulate as well. Depending on the type of application and requirement of level of attainment of particular outcome from the material the type of reinforcement and its level of composition may be tailored. In the case of Al6061 matrix the hybrid composite is examined with inclusion of Silica and alumina particulates and the rate of wear was substantially decreased with gradual increase of volume of content of reinforcement particulate due to formation of high hard phases [10]. The friction coefficient is increasing with increase in the percentage of particulate in hybrid composite, whereas, the wear rate is decreasing. The higher values of permanent strain (plastic strain) due to TiO2 particulate which is adhesive in nature leads to higher values of frictional coefficient [11]. The distribution fashion as well as the volume and size of the reinforcement particulates are the determinants of stirring speed, impeller size, and holding temperature [12]. Depending on the type of matrix and its properties like viscosity and wettability and chemical composition and the type of reinforcement material the stirring speed and stirring time vary instant to instant. These parameters govern the vortex which results in required richness of mixing of matrix and reinforcements. We may also use the optimization techniques like ANOVA and Artificial neural networks for a better combination of stirring parameters to obtain the required output properties for the prepared composite. Using the ANOVA technique, it is concluded that at 550 rpm stirring speed and 12% weight percentage of SiC+Al2O3 particulate in AA7075 matrix will result in optimal or better strength properties [13]. Among industrial, automobile, aviation, and shipping, the wear property plays a vital role for the selection and design of materials [14]. The rate of wear for matrix or base alloy is uniform till 200N, later suddenly raised above the load 200N. But, for the composites the transition load point is higher than that of 200N as there is no sudden raise in rate of wear is observed [15]. Improved hardness is the main reason for enhancement of wear resistance with the inclusion of TiC particles, which was illustrated in the figure 5 for various percentage compositions of TiO2 [16]. The improvement of volume of wear of the material with load particularly for composite and this is because of the heat generated between the sliding surface and composites surface as heat softens materials which in turn causes easy aberration of material surface [17]. Speed increases volume loss also increases from the compositions. At higher speeds degenerated heat leads to soften the bond between the matrix and reinforcement which is the cause for higher laws of where volume at higher speeds sliding [18]. At the beginning of sliding the surface gruffness is having higher sharpness for both pin and disc which results in temperature rise which leads to adhesion welding open material with disc and hence increase in rate of wear. But as the sliding distance further increases the effluent debris which is formed due to the wear of pin which causes skidding of pin in the air track and hence decrease in the rate of wear.

2. Materials and Methods

In this investigation Al4Mg is matrix material, acknowledged for high compatibility for work hardening. When mixed with copper the alloy has most significance in aircraft industry, auto mobile industries and in many other load applications [19]. From the work done by M.Gopikrishna et al., the ternary alloy Al20Cu20Mg which is high dense and high strength material was chosen as the reinforcement [20]. Both binary and ternary alloys were casted and the particulate from Al20Cu20Mg was prepared from the conventional filing technique and obtained HSAp of average size of particle 200 micron. The composites were casted into billets of 60mm diameter using stir casting technique. The casted billets of composites were homogenized for 24 hours at a temperature of 1500C. The Billets were then extruded in to rods of 16mm diameter using a hot extrusion press of 200T capacity. The temperature of billet and the pressure pad both were maintained 4000C during extrusion process. The extrudates were tested for wear characteristics.

Dry sliding wear test was conducted using DUCOM TR-20 WEAR TESTING MACHINE pin-on-disc apparatus in ASTM: G99 standards. Standard wear specimens of diameter 4mm and 30mm length were cut from both base alloy and composites using wire EDM process. The cut specimens were shown in figure 1. The friction coefficient is the output parameter observed by considering the input parameters load, speed and sliding time along with the percentage of reinforcement.
3. Results and Discussions

3.1 Grey Relational Analysis (GRA):

The coefficient of friction is optimization through GRE relational analysis. The experiment is designed as per the orthogonality, the three factors are selected at three levels as shown in Table 1. Table 2 shows the analytical responses.

Table 1: Input levels of the process parameters

| Parameter   | Level1 | Level2 | Level3 |
|-------------|--------|--------|--------|
| Velocity (m/min) | 100 | 120  | 140 |
| Load (N)  | 4.92 | 9.81  | 14.72 |
| Time (min) | 15 | 30  | 45 |

Table 2: Analytical table of responses

| Exp | VEL | LOAD | TIME | Coefficient of Friction - COF |
|-----|-----|------|------|-----------------------------|
|     |     |      |      | Alloy | 5%P | 10%P | 15%P |
| 1   | 1   | 1    | 1    | 0.026 | 0.042 | 0.05 | 0.011 |
| 2   | 1   | 2    | 2    | 0.023 | 0.016 | 0.023 | 0.023 |
| 3   | 1   | 3    | 3    | 0.056 | 0.079 | 0.12 | 0.033 |
| 4   | 2   | 1    | 2    | 0.049 | 0.263 | 0.127 | 0.014 |
| 5   | 2   | 2    | 3    | 0.034 | 0.158 | 0.096 | 0.011 |
| 6   | 2   | 3    | 1    | 0.029 | 0.032 | 0.04 | 0.043 |
| 7   | 3   | 1    | 3    | 0.018 | 0.178 | 0.055 | 0.228 |
| 8   | 3   | 2    | 1    | 0.019 | 0.035 | 0.136 | 0.051 |
| 9   | 3   | 3    | 2    | 0.018 | 0.086 | 0.067 | 0.173 |

The grey rational coefficients (GRF) calculated form S/N ratio of each response parameter, grey rational grades (GRG) also calculated for each experiment and the ranks are assigned.
\[ \eta = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} y_{ij}^2 \right) \quad (1) \]

\[ \eta = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_{ij}^2} \right) \quad (2) \]

### 3.1.1 Grey Relational Analysis (GRA) for coefficient of friction:

In GRA, grey relations connected to the test information identified with quality attributes, the aftereffects of which used to acquire the grey relational grades consequently to rank every information arrangement. In the grey relations, the S/N ratio normalized as N-S/N ratio (0≤1) by utilizing the following equation to keep away from the impact of receiving diverse units and to decrease the variability.

\[
S/N \text{ ratio} = \frac{(\eta_i) - \min(\eta)}{\max(\eta) - \min(\eta)} \quad \ldots \quad (3)
\]

\[
f = \max (\eta_i) - (\eta_{ij}) \quad \ldots \quad (4)
\]

\[
\text{GRC} = \frac{\min(f Dc_j) + f \cdot \max(Dc_j)}{\max(Dc_j) + f \cdot \max(Dc_j)} \quad \ldots \quad (5)
\]

\[
\text{GRG} = \frac{1}{m} \sum_{k=1}^{m} \text{GRC}_{jk} \quad \ldots \quad (6)
\]

Where m= number of output parameters

In the Grey relations, the quality loss function ‘f ’calculated by using the N-S/N ratio, Computed the grey relational coefficient (GRC) form the quality loss function f, Where Dc = Distinguishing coefficient, which defined in the range 0≤Dc≤1. Table 3 shows the S/N ratios. In table 4 and table 5 GRC and GRG were calculated and tabulated respectively.

| Exp | Alloy | 5%P  | 10%P  | 15%P  |
|-----|-------|------|-------|-------|
| 1   | 4.293 | 5.680| 8.874 | 9.897 |
| 2   | 4.883 | 8.404| 9.897 | 10.458|
| 3   | 5.352 | 9.897| 10.458| 10.458|
| 4   | 5.193 | 6.745| 7.744 | 7.535 |
| 5   | 6.558 | 8.874| 10.458| 9.897 |
| 6   | 7.535 | 9.897| 11.057| 13.979|
| 7   | 5.352 | 6.745| 7.959 | 8.874 |
| 8   | 5.514 | 9.119| 9.897 | 10.458|
| 9   | 5.680 | 10.458| 10.458| 13.979|
Table 4: Grey relational Coefficient (GRC)

| Exp | Alloy | 5%P | 10%P | 15%P |
|-----|-------|-----|------|------|
| 1   | 1.000 | 1.000 | 0.595 | 0.577 |
| 2   | 0.733 | 0.467 | 0.435 | 0.524 |
| 3   | 0.605 | 0.362 | 0.379 | 0.524 |
| 4   | 0.643 | 0.692 | 1.000 | 1.000 |
| 5   | 0.417 | 0.428 | 0.379 | 0.577 |
| 6   | 0.333 | 0.362 | 0.333 | 0.333 |
| 7   | 0.605 | 0.692 | 0.885 | 0.706 |
| 8   | 0.570 | 0.410 | 0.435 | 0.524 |
| 9   | 0.539 | 0.333 | 0.379 | 0.333 |

Table 5: Grey relational grade (GRG)

| Exp | Alloy | 5%P | 10%P | 15%P |
|-----|-------|-----|------|------|
| 1   | 0.781 | 0.667 | 0.479 | 0.455 |
| 2   | 0.751 | 0.508 | 0.472 | 0.459 |
| 3   | 0.802 | 0.681 | 0.467 | 0.484 |
| 4   | 0.491 | 0.641 | 0.743 | 0.716 |
| 5   | 0.385 | 0.549 | 0.656 | 0.742 |
| 6   | 0.551 | 0.590 | 0.667 | 0.667 |
| 7   | 0.469 | 0.536 | 0.609 | 0.591 |
| 8   | 0.489 | 0.427 | 0.417 | 0.463 |
| 9   | 0.528 | 0.407 | 0.389 | 0.462 |

The obtained level means are tabulated in table 6. In grey relational analysis, higher value of level means better quality. So, optimal conditions using GRA for Alloy A1, B3, C1, for 5% A1, B3, C1 for 10% A2, B1, C3 for 15% A2, B1, C3 respectively.
Table 6: Level means of GRG

For Alloy:

| Parameter   | Level1 | Level2 | Level3 | Delta | Rank | Optimum level |
|-------------|--------|--------|--------|-------|------|---------------|
| Velocity (A)| 0.778  | 0.476  | 0.496  | 0.302 | 1    | L1            |
| Load (B)    | 0.58   | 0.542  | 0.627  | 0.085 | 2    | L3            |
| Time (C)    | 0.607  | 0.59   | 0.552  | 0.055 | 3    | L1            |

For 5%:

| Parameter   | Level1 | Level2 | Level3 | Delta | Rank | Optimum level |
|-------------|--------|--------|--------|-------|------|---------------|
| Vel (A)     | 0.619  | 0.593  | 0.457  | 0.162 | 1    | L1            |
| Load (B)    | 0.614  | 0.542  | 0.627  | 0.085 | 2    | L3            |
| Time (C)    | 0.561  | 0.519  | 0.589  | 0.07  | 5    | L1            |

For 10%:

| Parameter   | Level1 | Level2 | Level3 | Delta | Rank | Optimum level |
|-------------|--------|--------|--------|-------|------|---------------|
| Vel (A)     | 0.473  | 0.689  | 0.472  | 0.217 | 1    | L2            |
| Load (B)    | 0.611  | 0.515  | 0.508  | 0.103 | 2    | L1            |
| Time (C)    | 0.521  | 0.535  | 0.578  | 0.057 | 3    | L3            |

For 15%:

| Parameter   | Level1 | Level2 | Level3 | Delta | Rank | Optimum level |
|-------------|--------|--------|--------|-------|------|---------------|
| Vel (A)     | 0.466  | 0.708  | 0.505  | 0.242 | 1    | L2            |
| Load (B)    | 0.588  | 0.554  | 0.538  | 0.05  | 3    | L1            |
| Time (C)    | 0.528  | 0.546  | 0.606  | 0.078 | 2    | L3            |

3.2 ANOVA

3.2.1 Check for adequacy of model:

The normality of the data is shown in figure 2. The contribution of the three process parameters velocity, load and time on the responses, i.e., coefficient of friction has been calculated with the aid of ANOVA.

![Residual Plots for 10% COF](image-url)

Fig.2 Normality plot for input data analysis.
Table 7: ANOVA table for GRG Values

| Source       | DF | SS   | MS    | F value | P Value | Contribution |
|--------------|----|------|-------|---------|---------|--------------|
| **Alloy:**   |    |      |       |         |         |              |
| Velocity     | 2  | 0.17151 | 0.08575 | 109.27000 | 0.00900 | 3.72835      |
| Load         | 2  | 0.01098 | 0.00549 | 0.008549  | 0.12500 | 0.23874      |
| Time         | 2  | 0.00472 | 0.00236 | 0.00236   | 0.24900 | 0.10270      |
| Error        | 2  | 0.00157 | 0.00079 | 0.00079   | 0.03413 | 0.03413      |
| **Total**    | 8  | 0.18879 | 0.09439 |          |         |              |

| Source       | DF | SS   | MS    | F value | P Value | Contribution |
|--------------|----|------|-------|---------|---------|--------------|
| Velocity     | 2  | 0.04542 | 0.02271 | 14.14000 | 0.06900 | 58.48483      |
| Load         | 2  | 0.02163 | 0.01082 | 0.01082   | 0.12900 | 27.85188      |
| Time         | 2  | 0.00740 | 0.00370 | 0.00370   | 0.30300 | 9.52773       |
| Error        | 2  | 0.00321 | 0.00161 | 0.00161   | 0.03413 | 4.13555       |
| **Total**    | 8  | 0.07767 | 0.03883 |          |         |              |

5%

| Source       | DF | SS   | MS    | F value | P Value | Contribution |
|--------------|----|------|-------|---------|---------|--------------|
| Velocity     | 2  | 0.093807 | 0.046904 | 11.32   | 0.08100 | 73.76350512   |
| Load         | 2  | 0.019837 | 0.009918 | 2.397   | 0.29500 | 15.5975278    |
| Time         | 2  | 0.005242 | 0.002621 | 0.626   | 0.61300 | 4.121911712   |
| Error        | 2  | 0.008829 | 0.004144 | 0.626   | 0.61300 | 6.517055373   |
| **Total**    | 8  | 0.127175 | 0.063587 |         |         |              |

10%

| Source       | DF | SS   | MS    | F value | P Value | Contribution |
|--------------|----|------|-------|---------|---------|--------------|
| Velocity     | 2  | 0.101168 | 0.050584 | 14.422  | 0.00700 | 87.48605574   |
| Load         | 2  | 0.003853 | 0.001926 | 5.49    | 0.15400 | 3.331056132   |
| Time         | 2  | 0.00997  | 0.004959 | 14.21   | 0.06600 | 8.575826495   |
| Error        | 2  | 0.000702 | 0.000351 | 0.626   | 0.61300 | 6.07061631    |
| **Total**    | 8  | 0.115692 | 0.05782  |         |         |              |

15%
The ANOVA results are tabulated in Table 7. The p-value is less than 5%. The confidence level for the prepared model has 95%. Also, the p-value is less than 0.05 compared to the F-value. It confirms that the developed models are adequate, and the predicted values are in good agreement with the measured data which can be depicted in figure 3.

4. Conclusions

- Optimal conditions using GRA for Alloy A1,B3,C1, for 5% A1,B3,C1 for 10% A2,B1,C3 for 15% A2,B1,C3 respectively.
- The contribution of each input parameters i.e. Velocity (V), Load (L) and Time (T), on Coefficient of friction (COF) has been calculated by using Analysis of Variance (ANOVA) and GRA method.
- For alloy, it is found that velocity (V) has the highest contribution 3.7 % followed by Time (T) and Load (L) having contribution of 0.23% and 0.10 % respectively.
- For 5% composite, it is found that velocity (V) has the highest contribution 58 % followed by Time (T) and Load (L) having contribution of 27% and 9.5 % respectively.
- For 10% it is found that velocity (V) has the highest contribution 73% followed by Time (T) and Load (L) having contribution of 15% and 3.3 % respectively.
- For 15% it is found that velocity (V) has the highest contribution 87.48 % followed by Time (T) and Load (L) having contribution of 8.5% and 3.3 % respectively.
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