Effect of Steel slag on Wear Characterization of Aluminium Composite Using Taguchi Technique

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Abstract: A wear behavior of steel slag reinforced aluminium A356 composite was fabricated by stir casting technique. Here an attempt has been made by reinforcing steel slag particle of size (1-5micron) in the aluminium matrix alloy fabricated through stir casting process. Dry sliding wear behavior of the composite was studied by pin on disc method. The experiment was conducted through Taguchi technique. A L16 orthogonal array was developed using ANOVA and the regression analysis was determined to find the optimum parameter. The parameters such as applied load, sliding speed, percentage reinforcement, and the distance travelled are considered for wear test. By considering the' smaller the best' the dry sliding wear was analyzed. Based on analysis of variance (ANOVA) the single-to-noise ratio are used to investigate the wear rate parameters. By studying the SEM analysis the worn out parts are studied.

1. Introduction

Metal matrix composite has found many applications in the areas of automobiles, aircrafts, and marine. MMCs have been used commercially in reinforced piston and aluminium crank case which strengthen its cylinder surface and brake pads. It has high thermal and corrosion resistance and improves fatigue strength at higher temperatures. Aluminium is the most popular metal matrix composite that are attractive due to its low density high thermal and electrical conductivity good wear resistance and high damping capacity [1-3]. In general aluminium matrix are reinforced with SiC, Al2O3, mica, but very rare research have been in SiO2, BN, B4C.Since boron carbide and boron nitride are hardest material and is most widely used in armors, nuclear reactor etc. can be used as the reinforcing medium [4]. The aluminium composites are currently used in automobile industries for fabrication of brakes, pistons in engines[5-8]The steel slag is the by product that has been produced during the separation of molten metal from impurities in induction
furnace. A large amount of slag was dumped as a waste material which will affect the land debris. Since the properties of steel slag are similar to silica an attempt has been done by considering these as the reinforcing material. HuLin Li et al, in his research on PTFE copper composite was prepared by compression molding. The result analysed that sliding speed influence the wear rate of the composite[9]. M.Walczak et al., discussed the tribological test on AlSi9Mg with 20% of SiC and they concluded that the wear rate gets reduced [10]. Shaoyang Zhang and Fuping Wang in their research investigate the wear properties of aluminium with Sic particle and it was observed that friction coefficient decreases as the load and the speed increases[11]. Hemanth Kumar.T.R.et.al., investigated the aluminium 2618 reinforced with TiO$_2$. By using Taguchi technique a mathematical model was developed and their result delivers that when the sliding speed and the reinforcement percentage increases the wear rate reduces gradually[12].

2 Experimental Details

2.1. Materials selection
Aluminium AlSi6Mn alloy was used matrix and its chemical composition given in Table 1. Its average tensile strength is 135Mpa and average hardness was 107HV. The steel slag which was the byproduct obtained from melting of metals from induction furnace was used as the reinforcing material which has the following chemical composition given in Table 2. By varying the weight percentage of steel slag (3%, 6%, 9%, 12%) the composite was fabricated by stir casting technology. In order to achieve good mechanical properties and good interfacial bonding between the matrix and the reinforcing particle stir casting technique was adopted to fabricate the specimen. The wear specimen of size 30mm x 8mm x 8mm was machined as per ASTM G99 standard for testing.

| Si  | Fe  | Cu  | Mn  | Mg  | Ni  | Zn  | Ti  | Al  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 6.58| 0.16| 0.06| 0.06| 0.57| 0.01| 0.01| 0.14| balance |

| Fe  | Mg  | Mn  | Si  | Ca  | Cr  | Ti  | Al  |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 10  | 0.32| 15.66| 57.01| 2.45| 0.58| 0.63| 13.35 |

Figure 1. Experimental Setup of stir casting
2.2 Wear Study

The wear characteristic was analyzed by using dry sliding wear test as shown in fig. 2. By using pin on disc method the wear behavior of the composite was studied. The composite material was taken as the pin which was pressed against the rotating EN31 carbon steel disc. Different parameters like applied load (N), Sliding speed(S), weight percentage of slag (%), distance travelled (D) are identified as the influencing parameter for wear rate. Based on Taguchi technique L\textsubscript{16} orthogonal array was developed and the experiment were conducted accordingly. The objective of ‘Smaller the best’ was considered and the wear response was studied by signal to noise ratio. The process parameters are shown in Table.3. By using logarithmic transformation the S/N ratio were analyzed.

Figure 2. Pin on Disc wear setup

2.3 Design of Experiments (DOE)

Design of Experiments (DOE) is one of the most powerful and important statistical technique that was used to optimize the parameters. By considering four levels and four parameters an orthogonal array was developed. In the present study the wear parameters chosen are applied load (N), sliding speed (m/s), % reinforcement (%) and the distance travelled are considered. According to L\textsubscript{16} orthogonal array was developed and the experiments were conducted [14]. The wear rates are tabulated with respect to orthogonal array. The response to be studied is the wear rate with the objective of ‘smaller the best’. To determine the finest process design the experimental outcome uses signal to noise ratio to transform the output. The process parameters are shown in Table.3. By using logarithmic transformation the SN ratio were analyzed.

\[
S/N \text{ ratio } (\eta) = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} y_{ij}^2 \right)
\]

Table.3 Process parameter for wear test

|                  | Level 1 | Level 2 | Level 3 | Level 4 |
|------------------|---------|---------|---------|---------|
| Load (N)         | 20      | 40      | 60      | 80      |
| Sliding speed (m/s) | 0.5    | 1.0    | 2.5    | 2       |
| % reinforcement (%) | 3       | 6       | 9       | 12      |
| Distance (m)     | 500     | 1000    | 1500    | 2000    |

3. Result and Discussions

The experimental results were calculated and its response are calculated by signal to noise ratio using equation (1) and are listed in Table.4. The signal to noise ratio are predicted based on the experimental values, and the optimum parameters resulting in wear rate are shown in fig. 3. The fig.3 clearly shows that
the speed plays major influence. In table 4 the higher the value of S/N ratio lower the wear rate are identified at 60N load and at 2m/s of speed ,at 6% reinforcement the lower wear rate occurs.

Table 4. $L_{16}$ Orthogonal array of Taguchi method for wear rate

| Expt. No. | Load (N) | Speed (m/s) | Percentage Reinforcement (%) | Distance (m) | Wear rate ($mm^3/m$) | S/N Ratio (wear)db |
|-----------|----------|-------------|-------------------------------|-------------|---------------------|------------------|
| 1         | 20       | 0.5         | 3                             | 500         | 0.0011664           | 50.1437          |
| 2         | 20       | 1           | 6                             | 1000        | 0.0029403           | 51.3035          |
| 3         | 20       | 1.5         | 9                             | 1500        | 0.0016468           | 62.1849          |
| 4         | 20       | 2           | 12                            | 2000        | 0.0016468           | 58.6630          |
| 5         | 40       | 0.5         | 6                             | 1500        | 0.0014409           | 50.6322          |
| 6         | 40       | 1           | 3                             | 2000        | 0.0050483           | 55.6672          |
| 7         | 40       | 1.5         | 12                            | 500         | 0.0020121           | 55.6672          |
| 8         | 40       | 2           | 9                             | 1000        | 0.0024145           | 56.8273          |
| 9         | 60       | 0.5         | 9                             | 2000        | 0.006036            | 45.9371          |
| 10        | 60       | 1           | 12                            | 1500        | 0.0065120           | 53.9270          |
| 11        | 60       | 1.5         | 3                             | 1000        | 0.0032560           | 52.3435          |
| 12        | 60       | 2           | 6                             | 500         | 0.0016280           | 64.3850          |
| 13        | 80       | 0.5         | 12                            | 1000        | 0.0016280           | 43.7257          |
| 14        | 80       | 1           | 9                             | 500         | 0.0011664           | 49.7463          |
| 15        | 80       | 1.5         | 6                             | 2000        | 0.0029403           | 55.7669          |
| 16        | 80       | 2           | 3                             | 1500        | 0.0016468           | 55.7669          |
Table 5. Analysis of Variance for wear rate (mm$^3$/m)

| Source      | DF | SS          | MS          | F   | P   |
|-------------|----|-------------|-------------|-----|-----|
| REGRESSION  | 4  | 1.023e-07   | 2.559e-08   | 11.50 | 0.001 |
| RESIDUAL ERROR | 11 | 2.448e-08   | 2.225e-09   |      |     |
| TOTAL       | 15 | 1.2688e-07  |             |      |     |

The response values are tabulated in Table 5, and it shows that the speed plays major role in wear rate. The ANOVA table shown the speed has major influence on the wear of the composite.

3.1 Multiple linear regression models

A multi linear regression model is developed using statistical software MINITAB R16. It shows the relationship between independent/predictor variable and a response variable by fitting a linear equation to the observed data. The regression equation for wear rate is

\[
\text{Wear rate} = 0.00341 + 0.000028L - 0.00238S + 0.000117\% - 0.00000D
\]

R-Sqr (adj) = 73.7%

Table 6 Response table for wear rate

| Level | Load   | Speed   | % reinforcement | Distance |
|-------|--------|---------|-----------------|----------|
| 1     | 55.57  | 45.47   | 53.48           | 54.99    |
| 2     | 53.57  | 52.66   | 54.39           | 51.05    |
| 3     | 53.14  | 56.49   | 52.66           | 54.50    |
| 4     | 51.25  | 58.91   | 53.00           | 53.00    |
| Delta | 4.32   | 13.44   | 1.73            | 3.94     |
| Rank  | 2      | 1       | 4               | 3        |

3.2 Confirmation Experiment
Based on the Taguchi’s technique the optimum parameter was selected and the confirmation test was compared with the regression model. The experimental values are compared with the regression model which was developed by mathematical model.

Table 7. Result of confirmation experiment

| Level | Load (N) | Sliding speed (S) | Weight percentage of steel slag (%) | Distance (D) | Predicted wear rate | Experimental wear rate |
|-------|----------|------------------|-------------------------------------|-------------|---------------------|-----------------------|
| 13    | 80       | 0.5              | 12                                  | 1000        | 0.0016280           | 0.001841              |

4. Conclusion

The steel slag reinforced aluminium composite was fabricated and the dry sliding wear characteristic was analyzed and optimized by Taguchi Technique. From the study the following conclusions was obtained

- Optimum wear rate was obtained.
- The wear rate was dominated by sliding speed followed by applied load, distance travelled and the percentage reinforcement of the steel slag.
- ANONA test concluded that sliding speed increases the wear rate of the composite material decreased significantly.

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