Wear Behavior of Aluminum-TiB$_2$ Metal Matrix Composites using Taguchi Method.

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Abstract. In the present day engineering design and growth activities many Engineers and Scientists are striving hard to develop novel and better engineering materials, which accomplishes high strength, light weight and energy efficient materials since the problems of environment and energy are major threshold areas. In this paper attempts are made to study the abrasive wear loss and coefficient of friction of the Al 6061 reinforced with varying weight percentage of TiB$_2$ composites by in situ process was investigated. The wear test was conducted using pin-on-disc wear testing apparatus (POD) as per the design of experiments (DOE). Taguchi Technique, Analysis of Variance (ANOVA) and Regression Analysis were adopted to optimize the wear loss. Further, Scanning Electron Microscopy images of worn out surface are carried to study the wear behaviour. Wear loss and Co-efficient of friction decreases with increase in the wt. % of TiB$_2$ particles and noticed form the ANOVA and regression analyses that reinforcement plays a crucial role in the development of Al 6061-TiB$_2$ composite system.

1. Introduction

An aluminium matrix composite plays very important role in the present day engineering applications. Because conventional materials have many limitations in achieving required strength, stiffness, toughness, corrosion and wear resistance. The development of new materials is growing day by day to replace the conventional materials in the field of automobile, marine engineering, aerospace etc., Hence, composite material are found to be an alternative materials. Fabrication of metal matrix composites has several problems like poor wettability between matrix and reinforcement, porosity and non homogeneous distribution of reinforcement.

Aluminium 6061 is the mostly used 6xxx series which offer good mechanical, corrosion and wear resistance. Among various reinforcements titanium diboride is an exceptional ceramic material due to its high strength, hardness, superior wear resistance and good thermal stability and more prominently it does not react with molten aluminium [1, 2]. The aluminium 6061 embedded with different ceramic particles can be synthesized using various manufacturing methods like stir casting, in situation stir casting process, powder metallurgy, squeeze casting etc.,[3]. In situ stir casting route has been found to be one of the most important technique in the synthesis of aluminium reinforced with TiB$_2$ due to the fact that this process is thermodynamically stable, uniform distribution of reinforcement in the...
matrix and economical. Composites materials are developed using an exothermic reaction route with addition K2TiF6 and KBF4 salts [3, 4]

Wear is a specific property of substance which is denoted by removal or loss of the material from surface due to relative motion between a surface and the contacting substance. Wear test can be performed in dry as well as in lubricating conditions.

In the present paper dry sliding wear test has been carried out on Al 6061 reinforced with 3 to 12 wt. % of TiB2 composites by using Pin-on-Disk wear test apparatus with normal loads of 10-50 N, sliding distance 500 m to 2500 m in the step of 500 m and sliding velocity 1 m/s to 5 m/s to know the influence of applied load, reinforcement, sliding speed and sliding distance on wear rate. The worn out surface morphology was studied using Scanning Electron Microscope.

2. Optimization technique

Optimization is a method for maximize or minimize a real function by choosing the input functions. In general, optimization is a process of finding the "best available" value among the variety of objective functions and domains. Design of Experiments (DOE), Taguchi Technique, Analysis of Variance (ANOVA) and Regression Analysis are adopted in this paper [6]

3. Experimental Procedure

Aluminium 6061 reinforced with TiB2 by varying 3 to 12 Wt % are used to develop composite materials to study the wear characteristics of the composites synthesized using In-situ technique. In this process, the reinforcement phase is formed in situation, by adding halide salts to form required combination of composites.

| Table 1. Chemical Composition of Al 6061 alloy |
|---------------------------------------------|
| Element | Weight % |
| Mg      | 1.08     |
| Fe      | 0.17     |
| Si      | 0.63     |
| Cu      | 0.32     |
| Mn      | 0.52     |
| V       | 0.01     |
| Ti      | 0.02     |
| Al      | Balance |

Al 6061 rods were weighed and placed in a coated graphite crucible and heated by means of an electrical furnace up to 850°C. The chemical composition of Al 6061 aluminium alloy is presented in Table 1. A coating was applied inside the crucible to avoid contamination. The temperature of the molten aluminium was maintained at 850°C. The measured quantities of inorganic salts like K2TiF6 and KBF4 were added into the molten aluminium and thoroughly stirred using a graphite stirrer at intervals of every 10 minutes. A total reaction holding time for about 45 min to 1 hr to form titanium diboride and then 1.5 Wt % of magnesium was added and stirring was continued so that the TiB2 and Mg particles are completely dispersed in to the molten alloy [15, 16, and 18]. After solidification process castings were machined as per ASTM standards.
The dry sliding wear test was carried out using pin-on-disc apparatus as shown in Fig.2. The wear test was conducted as per ASTM G-99 standards. The dimensions of test specimens are 10mm×10mm×50mm. Results obtained from the Pin-on-disc experiments are used to conduct statistical using MINITAB software. After conducting the tests, the worn out surfaces were observed by scanning electron microscope to examine the wear behaviour of the composite materials.

**Plan of Experiments**

The experimental plan is to formulate by considering parameters (factors) and levels based on the Taguchi technique. The levels of variables chosen for experiments are planned in Table 2.

| Table 2. Parameters and their levels |
|-------------------------------------|
| Level | Load(N) | SV (m/s) | Sliding Distance (m) | Wt% of TiB$_2$ |
|-------|---------|----------|---------------------|----------------|
| 1     | 10      | 0.5      | 300                 | 0              |
| 2     | 20      | 1        | 600                 | 3              |
| 3     | 30      | 1.5      | 900                 | 6              |
| 4     | 40      | 2        | 1200                | 9              |
| 5     | 50      | 2.5      | 1500                | 12             |

Dry sliding wear test was conducted by varying load, sliding velocity, sliding distance and wt. % of TiB$_2$ at five levels. According to the rule, the degree of freedom for an orthogonal array should be greater than or equal to sum of wear parameters. In this study L25 Orthogonal array was selected. The Signal to Noise (S/N) ratio, was used to condense numerous data points within a trial to establish different characteristics. In this process “Smaller the Better” characteristic was selected to study the dry sliding wear resistance. The S/N ratio of wear rate through “Smaller the Better” characteristic is given by the equation as follows

$$ S/N = -10 \log \left[ \frac{1}{n} \sum y^2 \right] $$

Where, $n = \text{number of observations}$ and $y = \text{observed data}$.

**4. Results and Discussion**

**Wear rate analysis**

The experiments were conducted by varying the Reinforcement percentage, applied Load, Sliding velocity and Sliding distance to determine wear loss and coefficient of friction. The objective of this study is to find out the important factors influence on wear process to achieve the minimum wear rate.

| Table 3. Results of L25 array for Al 6061/TiB$_2$ composites |
|------------------------------------------------------------|
| Sl.No | Wt % of R | Load (N) | SV (m/s) | SD (m) | Wear Loss (gm) |
|-------|-----------|----------|----------|--------|----------------|
| 1     | 0         | 10       | 0.5      | 300    | 0.0093         |
| 2     | 0         | 20       | 1        | 600    | 0.0111         |
The Influence of process parameters such as applied load, percentage reinforcement, sliding speed and sliding distance on wear has been analyzed. The ranking of process parameter by signal to noise ratios obtained for different parameter levels for wear are given in the table 4 and table 5.

**Table 4. Response table for means for wear**

| Level | Wt % Reinforcement | Load | SV | SD |
|-------|---------------------|------|----|----|
| 1     | 0.01244             | 0.00622 | 0.00762 | 0.00754 |
| 2     | 0.0087              | 0.00766 | 0.00794 | 0.00784 |
| 3     | 0.00748             | 0.00818 | 0.00818 | 0.00816 |
| 4     | 0.00668             | 0.00864 | 0.00832 | 0.0076 |

The Influence of process parameters such as applied load, percentage reinforcement, sliding speed and sliding distance on wear has been analyzed. The ranking of process parameter by signal to noise ratios obtained for different parameter levels for wear are given in the table 4 and table 5.
Fig 3. Main effects for plot for Al 6061-TiB₂ composites (a) Means Wear Rate (b) SN Ratio – Wear Rate

It is observed from the above table 4 and 5 the control factors are statistically significant in the SNR for wear rate. Percentage reinforcement is the dominant factor on the wear rate followed by load applied, sliding distance and sliding velocity.

The main effect plot for means, Signal to noise ratio for the wear effect plots between the process parameters are shown in Figure.3. The significance of each factor is found out from the inclination of the main effect plot. A parameter for which the line has the maximum inclination will have the most significance. It is clear from the main effect plot that percentage reinforcement is the most significant wear parameter while applied load, sliding distance and sliding speed also has considerable effect [10]

ANALYSIS OF VARIANCE (ANOVA)
To find out the significance of each process parameters and their relations on the system response, an efficient statistical tool ANOVA is used. In this study, analysis of variance is applied to assess the significance parameters and their interactions on the wear behaviour of Al 6061-TiB₂ composite materials. Table 6 shows the ANOVA results with their wear performance of the composite materials developed. Percentage of contribution (Pr. %) of Wt. % of Reinforcement (48.57%), load (16.09%), sliding speed (8.21%) and sliding distance (7.93 %) are the main controlling factors on the wear behaviour.[7]

5. Multiple linear regression equation

The multiple linear regression equation is developed using MINITAB software. This developed equation gives the relation between predicted and independent variables using linear equation to the measured data.

Wear rate = 0.00889 - 0.000602 Wt. % of Reinforcement + 0.000066 Load + 0.000090 Sliding Velocity + 0.000001 Sliding Distance.

6. Confirmation Experimentation

Finally, confirmation test was conducted for the composite materials to check the accuracy of the equation developed with predefined experimental parameters as shown in table 7 and table 8.

Figure 4 shows the microstructure of the worn out surfaces of the Al 6061-TiB₂ composite materials. Grooves were formed by the reinforcing particles of titanium diboride.

| Source                  | Df | Seq.SS | Adj.SS | Adj.MS | F    | P    | Pr.% |
|-------------------------|----|--------|--------|--------|------|------|------|
| Wt% Reinforcement       | 4  | 347.5  | 347.5  | 86.88  | 5.07 | 0.025| 48.57|
| Load                    | 4  | 115.17 | 115.17 | 28.79  | 1.68 | 0.247| 16.09|
| SV                      | 4  | 58.79  | 58.79  | 14.7   | 0.86 | 0.528| 8.21 |
| SD                      | 4  | 56.76  | 56.76  | 14.19  | 0.83 | 0.543| 7.93 |
| Error                   | 8  | 137.19 | 137.19 | 17.15  |      |      |      |
| Total                   | 24 | 715.4  |        |        |      |      | 100  |

Table 6. ANOVA Results

| Trails | % Reinforcement | Load | SV  | SD  |
|--------|-----------------|------|-----|-----|
| 1      | 9               | 5    | 0.25| 250 |
| 2      | 9               | 15   | 0.75| 500 |

Table 7. Confirmation Test values

| Trails | Experimental wear rate. | Regression wear rate. | % Error |
|--------|-------------------------|-----------------------|---------|
| 1      | 0.0041                  | 0.00407               | 0.60    |
| 2      | 0.00493                 | 0.00503               | 2.02    |

Table 8 Comparisons of Confirmation test results
7. Conclusions

- Wear performance of Al6061-TiB2 composites were conducted using Pin-On-Disc equipment as per the design of experiments using L25 orthogonal array.
- Wear loss decreases with increase in wt % of Reinforcement.
- Reinforcement is the highest influencing factor on wear loss followed by load, sliding distance and speed.
- Linear Regression equation was developed which is good agreement with confirmation wear test results SEM images shows uniform tracks in the direction of rotation of the disc which clearly indicates the uniform distribution of the particles in the matrix.

8. References

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