DRY SLIDING WEAR CHARACTERISTICS OF ALUMINUM 6061-T6, MAGNESIUM AZ31 AND ROCK DUST COMPOSITE

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Abstract. In recent years, the use of aluminum composite is gaining popularity in a wide range of applications like automobiles, aerospace and constructions (both interior & exterior) panels etc., due to its high strength, low density characteristics. Various reinforcing materials are used with aluminum 6061-T6 in order to have better mechanical properties. The addition of 0.3% of magnesium AZ31 will increase the ultimate tensile strength by 25%. The reinforcement of rock dust will decrease the density. Hence, in order to have an advantages of magnesium AZ31 and rock dust, in this work, these two constitutes are varied from 1% to 2% on the base material of Al6061-T6 in stir casting. To evaluate the wear characteristics, Pin on disc is used in these composites. The input parameters are speed, time & load. The output response is wear. To minimize the number of experiments, L9 orthogonal array is used. The test results showed that a composite of 97% of Al (6061-T6), 1% Mg (AZ31) & 2% of rock dust produced less wear. To find the best value of operating parameter for each sample, ANN-GA is used.

1. Introduction:

A composite is when at least two different materials are joined together to make a common and one of a kind material. Composites are made up of individual materials referred to as constituent materials. The composites are classified i) Polymer Matrix Composite (PMC) ii) ceramic Matrix Composite (CMC) and iii) Metal Matrix Composite (MMC). Aluminum composites have high strength to weight ratio and high corrosion resistance properties. These days these composites are broadly utilized as a part of many designing fields and specifically in settings in which weight decrease is a basic figure, for example, aviation applications. Even though unmodified aluminum is a standout amongst the most boundless components on earth, it is too soft and flexible. Therefore, it is frequently consolidated with a wide range of components, such as Cu, Si, Mg, Zn, Mn to form compounds. Al 6061-T6 has a place with the aluminum arrangement 6,000 with silicon and magnesium as important alloying segments. These compounds are formed by warmth treatment (in present case T6) and they demonstrate great formability, workability, weldability and shaving. The Rock dust powder as a strengthening phase can improve the wear resistance of aluminum alloy materials. In order to have the advantages of Aluminum, Magnesium and Rock dust, an Al MMC’s is prepared & dry sliding wear characteristics are analyzed in this work.
2. Literature survey

The table-1 shows the importance and the noteworthy research work carried on Al 6061-T6.

**Table 1. Important & note worthy contributions on Al 6061.**

| S1.No | Author                          | Year | Material                           | Remarks                                                                                                                                   |
|-------|---------------------------------|------|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| 1     | Wei Guo et al.                  | 2016 | Al 7A04 alloy & Mg AZ31            | The thickness of intermetallic compounds interlays consisted of Mg & Al. The experiments authors showed that by intermetallic layers, the tensile strength of the joint increased and its maximum value is 96 MPa. |
| 2     | Zilong Zhao, et al.             | 2016 | Al 5052 & MgAZ31                  | In this work, the authors made magnesium aluminum composite panels by asymmetric metal packaging and studied rolling temperature, holding time, and high temperature heat treatment. It is concluded that the new composite panels' elongation is 24% as compared to traditional magnesium aluminum composite panels' elongation. |
| 3     | Ratna Sunil, et al.             | 2016 | 1.Pure Mg, nano-hydroxyapatite (32 nm) 2. AZ31, Al2O3 3. AZ61, SiO2 4. AZ91, Al2O3 5. ZM21, SiC, B4C | The Process parameters, for example, apparatus rotational and travel speeds assumes a vital part in creating deformity free mix zone in contact mix welding of magnesium composites. |
| 4     | Gali et al.                     | 2016 | AISI 52100, Mg                     | The surface/near surface parts confined on an Al-Mg blend in the midst of a 10 pass hot moving timetable using work moves with a surface harshness (Ra) estimations of 0.1 μm and 1.1 μm was investigated. |
| 5     | Jufu Jiang, et al.              | 2016 | Al 7075 & β –SiC(80 nm)            | The stress–strain curve at 600 °C is same as that of 500 °C. The increase in SiC particles leads to increasing Peak stress & steady stress. |
| 6     | Taherzadeh Mousavian, et al.    | 2016 | A356, SiC                          | Hot-rolling aluminum structure composites strengthened with multimodal estimated SiC. The fracture enhanced SiC consolidation. |
| 7     | Kimura, et al.                  | 2015 | Pure Mg, Pure Al                   | The welded joint had the intermetallic compound layer (IMC) at the weld interface. The end result showed that the fracture passed off by means of thermal strain in radial and/or circumferential directions. |
8  Mojtaba, et al.  2015  Al 606, AZ31  Dispersion welding of Al to Mg compounds becomes accomplished without utilizing an interlayer. The ideal holding parameters included $T = 440 \, ^\circ C$, $P = 29 \, MPa$ and $t = 60$ min. The bond quality at a temperature of 440 °C was accomplished as 42 MPa.

9  Ansary Yar, et al.  2009  A356+Mgo (50nm)  A Composite of 1.5 Vol% MgO was fabricated at 850 °C and test results demonstrated that properties, for example, hardness, quality and strength are enhanced when contrasted with different examples. Moreover, sturdiness of composites, for the most part diminished by expanding the substance of MgO.

From the literature, it is shown that the use of aluminum composite has widely attracted by many researchers. The application of Magnesium & rock dust as reinforcement with Al 6061-T6 has gotten less attention to the researchers. Hence, in this work, the Al 6061-T6 is taken as base material and Mg AZ31 & rock dust are taken as reinforcement.

3. Methods & manufacturing:

The table 2-4 shows the compositions of Al 6061-T6, Mg AZ31 & Rock dust respectively.

| **Table 2.** AL 6061-T6 composition. |
|-----------------|---|---|---|---|---|---|---|---|
| Element         | Al | Si  | Zn  | Mg  | Mn  | Cr  | Fe  | Cu  | Ti  |
| Percent         | 98 | 0.4-0.8 | 0.25 | 0.8-1.2 | 0.15 | 0.04-0.35 | 0.7 | 0.15-0.4 | 0.15 |

| **Table 3.** Mg AZ31 composition. |
|-----------------|---|---|---|---|---|---|---|---|---|
| Element         | Al | Zn  | Mn  | Fe  | Si  | Ni  | Cu  | Be  | Mg  |
| Percent         | 3.08 | 0.76 | 0.15 | 0.005 | 0.01 | 0.002 | 0.001 | 0.0001 | 95.9929 |

| **Table 4.** Rock dust composition. |
|-----------------|---|---|---|---|---|---|---|---|---|
| Element         | SiO$_2$ | Al$_2$O$_3$ | CaO | Fe$_2$O$_3$ | MgO | Na$_2$O | TiO$_2$ | K$_2$O | Others |
| Percent         | 51 | 18.4 | 10.2 | 9.29 | 5.0 | 2.1 | 0.78 | 0.59 | Bal |
3.1. Manufacturing process

In this work, stir casting is used to fabricate the proposed composite consisting of Al 6061-T6, Mg AZ31 and Rock dust. The Stir Casting process is the best method to fabricate composites for a few volumes of production. Aluminum 6061-T6 compound was mix thrown with magnesium AZ31, rock dust as support in order to figure Al 6061-T6/Mg AZ31/Rock dust composites.

The hotness of the heater was absolutely measured and precisely controlled (±1°C) by thermocouples with the controller. The experimental setup have 1 HP motor to run the stirrer at various speeds. The Al 6061-T6 is heated up to 720°C and then solid material of Mg AZ31 is added. The stirrer is kept rotating at constant speed. Then the preheated rockdust power is added at a uniform rate to molten metal of Al & Mg. Throughout the experiment the batch is kept at 720 °C. Then molten metal is cast into required shape. There are three test specimens were prepared and are shown in Table 5.

Table 5. Composition of proposed composite.

| Test Specimen | Aluminum (%Wt) | Magnesium (%Wt) | Rock Dust (%Wt) |
|---------------|----------------|-----------------|-----------------|
| T1            | 97             | 2               | 1               |
| T2            | 97             | 1               | 2               |
| T3            | 96             | 2               | 2               |

4. Experimental work

A pin on disc tribometer comprises of a stationary pin under a connected load in contact with a rotating disc. The pin on disc test has demonstrated valuable in giving a basic wear and friction test for low friction coatings. The disc material is made of EN134 Carbon.
4.1. Selection of machining parameters

The wear tests are carried out all 3 specimens. To minimize the number of trial runs L9 Orthogonal array is used. The input parameters are Speed, Load and Time. The output response is wear. The table 6 shows the coded value along with experimentation.

| Sl.No. | INPUT Parameters | Wear for specimen (microns) |
|--------|------------------|----------------------------|
|        | Speed (rpm) | Time (Minute) | Load (N) | T1  | T2  | T3  |
| 1      | A  | A  | A  | 150 | 5   | 20  | 138 | 205 | 204 |
| 2      | A  | B  | B  | 150 | 10  | 40  | 107 | 230 | 222 |
| 3      | A  | C  | C  | 150 | 15  | 60  | 196 | 320 | 299 |
| 4      | B  | B  | C  | 300 | 10  | 60  | 189 | 300 | 294 |
| 5      | B  | C  | A  | 300 | 15  | 20  | 101 | 139 | 117 |
| 6      | B  | A  | B  | 300 | 5   | 40  | 158 | 94  | 94  |
| 7      | C  | C  | B  | 450 | 15  | 40  | 195 | 72  | 68  |
| 8      | C  | B  | A  | 450 | 10  | 20  | 212 | 84  | 72  |
| 9      | C  | A  | C  | 450 | 5   | 60  | 289 | 145 | 183 |

Figure 2. Pin on disc wear testing machine

Figure 3. Graph of wear result for the specimen T1 with Speed, Load & Time.
From the figure 3, shows the average value of wear, friction force and co-efficient of friction for the test specimen T1 with speed (150), Load (5) & Time (20).

4.2 Analysis of test specimen: T1

Table 7 shows the composite Al (6061-T6) 97%, Mg (AZ31) 2% & Rock dust 1%.

Table 7. ANOVA for specimen T1.

| Source    | Sum of Squares | DEGREES OF FREEDOM | Mean Square | F value | P-value | Prob> F |
|-----------|----------------|--------------------|-------------|---------|---------|---------|
| Model     | 26792.67       | 6                  | 4465.44     | 25.07   | 0.0388  | Significant |
| A-SPEED   | 15505.93       | 1                  | 15505.93    | 87.06   | 0.0113  |
| B-Load    | 137.52         | 1                  | 137.52      | 0.77    | 0.4722  |
| C-Time    | 58.34          | 1                  | 58.34       | 0.33    | 0.6249  |
| Residual  | 356.22         | 2                  | 178.11      |         |         |
| Cor Total | 16058.01       | 5                  |             |         |         |

Wear = 195.63492 + 0.77143×speed − 10.55238×load − 2.60000×time

Equation 1

Figure 4. Contribution of various parameters.

From the contributions, the model A-speed (97%), B-load (1%) & C-time (0%).
4.3. Analysis of test specimen: T2

Table 8 shows composite Al (6061-T6) 97%, Mg (AZ31) 1%, Rock dust 2%.

| Source    | Sum of Squares | DEGREES OF FREEDOM | Mean Square | F value | Prob> F | P-value  |
|-----------|----------------|--------------------|-------------|---------|---------|----------|
| Model     | 54542.33       | 3                  | 18180.78    | 6.66    | 0.0338  | Significant |
| A-SPEED   | 34352.67       | 1                  | 34352.67    | 12.58   | 0.0165  |
| B-Load    | 18928.17       | 1                  | 18928.17    | 6.93    | 0.0464  |
| C-Time    | 1261.50        | 1                  | 1261.50     | 0.46    | 0.5270  |
| Residual  | 13657.89       | 5                  | 2731.58     |         |         |          |
| Cor Total | 68200.22       | 8                  |             |         |         |          |

\[ W_a = 186.55556 - 0.50444 \times \text{speed} + 2.80833 \times a + 2.90000 \times i \]  

... Equation 2

\[ \text{Figure 5. Contribution of various parameters.} \]

From the contributions, the model A-speed (50%), B-load (28%) & C-time (2%).
4.4 Analysis of test specimen: T3

Table 9 shows composite 3 Al (6061-T6) 96%, Mg (AZ31) 2%, Rock dust 2%.

**Table 9. ANOVA for specimen T3.**

| Source    | Sum of Squares | DEGREES OF FREEDOM | Mean Square | F value | P-value | Prob>F |
|-----------|----------------|--------------------|-------------|---------|---------|--------|
| Model     | 51383.67       | 3                  | 17127.89    | 6.4895  | 0.0355  | Significant |
| A-SPEED   | 26934          | 1                  | 26934       | 10.2049 | 0.0241  |
| B-Load    | 24448.17       | 1                  | 24448.17    | 9.2631  | 0.0286  |
| C-Time    | 1.5            | 1                  | 1.5         | 0.0006  | 0.9819  |
| Residual  | 13196.56       | 5                  | 2639.311    |         |         |
| Cor Total | 64580.22       | 8                  |             |         |         |

\[ W_a = 177.88 - 0.4466 \times a + 3.191 \times a + 0.1 \times i \]  

..... Equation 3

![Figure 6. Contribution of various parameters.](image)

From the contributions, the model A-speed (42%), B-load (1%) & C-time (0%).
5. ANN-GA Approach: Using Software – Neural Power

![Diagram of ANN-GA Approach](image)

**Figure 7.** ANN-GA Approach.

Artificial Neural Networks (ANNs) widely applied to deterministic models to find the best value of operating range. In this, Back Propagation Neural Network (BPNN) is used to solve non-linear problems. However, while training BPNN it may converge into local extreme and convergence may be slow. To overcome these problems and improve reliability of network with genetic algorithm is used to achieve global convergence quickly. In this work, Neural power is used to obtain best parameter. The input to the neural power is wear values of each sample. The output is best parameter.

The table-12 shows the best operating parameter for each sample obtained from ANN-GA.

| Sl. No | Wear samples | Speed (rpm) | Time (minutes) | Load (Newton) | Wear (micron) |
|-------|--------------|-------------|----------------|---------------|---------------|
| 1     | Sample 1     | 234.84      | 14.99          | 22.43         | 99.16         |
| 2     | Sample 2     | 449.49      | 5.00           | 24.20         | 59.13         |
| 3     | Sample 3     | 434         | 14.99          | 20.002        | 63.14         |

On investigating the result values of three samples, sample 2 has low wear rate compared to others and corresponding parameters are Speed - 449.949 rpm, Time - 5.00 minutes, Load - 24.20 N, the wear value obtained is 59.13 microns.
6. Conclusion

In this work, the reinforcing materials, magnesium AZ31 and rock dust are used with aluminum 6061-T6 to find the wear characteristics. The mg and rock dust are varied from 1% to 3% and with Al 6061-T6 during stir casting process. The aluminum and magnesium are taken as solid metal and rock dust as taken as fines (30 µm) powdered form. The temperature of a crucible is maintained around 500 – 800 degrees and stirred continuously. The molten metal is converted into a solid work piece 120 mm lengths with 20 mm diameter.

The wear tests are carried on pin on disc under dry condition as per ASTM G 99-95 measures. To limit the quantity of experimentation ANOVA is utilized. The model developed form ANOVA is significant for the entire three test specimen. The test result shows that the sample-2 (Al (6061-T6) 97%, Mg (AZ31) 1%, Rock dust 2%) posses minimum wear (59.13) as compared to other two specimens. From the iteration plots, it is observed that average contributions of parameters are the speed (63%), load (23.33%), and time (0.67). To find the best value of operating parameters for each sample ANN-GA is used. For the further extension, the above test specimen can be machined using any one of the non-traditional machines.

7. Reference

[1] Wei Guo, Guoqiang You, Guangyu Yuan and Xiuli Zhang November 2016 Microstructure and mechanical properties of dissimilar inertia friction welding of 7A04 aluminum alloy to AZ31 magnesium alloy Journal of alloy compound Volume 695 pp 3267-3277.

[2] Zilong Zhao, Qiang Gao, Junfeng Hou, Ziwei Sun and Fei Chen September 2016 Determining the microstructure and properties of magnesium aluminum composite panels by hot rolling and annealing Journal of Magnesium and Alloys Volume 4 Issue 3 Pages 242–248.

[3] Ratna Sunil B, Pradeep Kumar Reddy G, Hemendra Patle and Ravikumar Dumpala March 2016 Magnesium based surface metal matrix composites by friction stir processing Journal of Magnesium and Alloys Volume 4 Issue 1 pp 52-61.

[4] Gali O A, Shafiei M, Hunter J A and Riahi A R November 2016 The influence of work roll roughness on the surface/near-surface microstructure evolution of hot rolled aluminum–magnesium alloys Journal of Materials Processing Technology Volume 237 pp 331-341.

[5] Valavan D, Balasundaram R and Rajkumar G November 2016 Experimental Design and Analysis of Carbon fiber Reinforced Composite Drive Shaft Asian Journal of Research in Social Sciences and Humanities Volume 6 Number 11 pp 167-178 DoI:10.5958/2249-7315.2016.01183.7.

[6] Jufu Jiang, Gang Chen and Ying Wang November 2016 Compression Mechanical Behaviour of 7075 Aluminium Matrix Composite Reinforced with Nano-sized SiC Particles in Semisolid State Journal of Materials Science & Technology Volume 32 Issue 11 pp 1197-1203.

[7] Kimura M, Fuji A and Shibata November 2015 S Joint properties of friction welded joint between pure magnesium and pure aluminium with post-weld heat treatment Materials & Design Volume 85 pp 169-179.

[8] Taherzadeh Mousavian R, Azari Khosroshahi R, Yazdani S, Brabazon D and Boostani A F January 2016 Fabrication of aluminum matrix composites reinforced with nanometer-sized SiC particles Materials & Design volume 89 pp 58-70.
[9] Mojtaba Jafarian, Alireza Khodabandeh and Sahebali Manafi January 2015 Evaluation of diffusion welding of 6061 aluminum and AZ31 magnesium alloys without using an interlayer Materials & Design Volume 65 pp 160-164.

[10] Ansary Yar A, Montazerian M, Abdizadeh H and Baharvandi H R September 2009 Microstructure and mechanical properties of aluminum alloy matrix composite reinforced with nano-particle MgO Journal of alloy and compounds volume 484 Issues 1-2 pp 400-404.