International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 02, February-2019

# DRY SLIDING WEAR BEHAVIOUR OF HYBRID NICKEL POWDER AND SILICON CARBIDE REINFORCED ALUMINIUM ALLOY COMPOSITES

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***ABSTRACT: The aim of this paper is to study dry sliding behaviour of Al6061-T6 hybrid metal matrix composite reinforced with nickel powder and silicon carbide. The composite sample are prepared by stir casting method with different percentage of Nickel powder (0,0.5,1,1.5 %wt. percentage) and fixed percentage of silicon carbide(2% wt).Wear test was performed on pin –on- disc tribometer. SEM analysis was done to confirm Uniform distribution of reinforcing particles. Taguchi's L16 orthogonal array (4 x 4) was used for design of experiments to evaluate dry sliding wear performance namely, wear rate. Percentage of filler content (0, 0.5, 1 and1.5 % wt) applied load (10, 20, 30 and 40 N), sliding distance (500, 750, 1000 and 1250 m), sliding velocity (1, 1.5, 2 and 2.5 m/s) are considered as four control factors for wear test. Analysis of variance and main effect plot was done to determine the statistical significance of control factors. A significance level of 5% is considered for the present study. It is observed that among the factors filler content and applied load have prime effect on the wear rate. Increase in percentage of nickel powder decrease the wear rate while increase in applied load increases wear rate. Whereas sliding velocity and sliding distance have insignificant effect on wear rate.***

***Key words: Stir casting; Nickel powder; hybrid aluminium composite; Al6061-T6***

## I. INTRODUCTION

The composite materials are tailored to fulfil the application-specific properties (like enhanced mechanical and tribological) for automobile and aerospace etc [1]. Composites are materials made of two or more distinct phases (matrix phase and reinforcing phase) and having characteristics that are different from those constituents. It consists of a matrix and reinforcement phases, matrix phase is the material that kept the reinforcement phase together in position and help in transferring the load [2].
The hybrid composites have better properties than composite materials containing only a single kind of reinforcement. Different varieties of reinforcements in the form of fibres, whiskers or particulate and matrix materials combinations are used in order to enhance the wear performance and mechanical properties to fulfil the specific application. [3]
Al is one of the most excellent choices available for matrix, because of its better mechanical property, with high corrosion resistance, high toughness and also low density [4-6]. Al is also not expensive compared to other light elements. Thus, the use of aluminum based MMCs increased in the area where, advanced structural applications, good wear resistance at elevated temperature, and enhanced mechanical properties are significant [7-10].
Wear rate is consider as key element of tribological behaviour of composites. The wear rate depends on weight percentage of filler content, applied load, sliding distance and sliding velocity. Stir casting method is most accepted commercial method for producing aluminium alloy composites because it needs easy handling, low setup cost, quickly to access and it is suitable for mass production without damaging the reinforcement particles.
After reviewing literature it has been noticed that researchers chosen various ceramic fillers for fabricating aluminium alloy composite to enhance mechanical and wear properties. Scrutiny of literature shows that less work has been carried out on metal powder as filler. It was found that there is little work reported on hybrid reinforcement [11-18].
The aim of present investigation is to study dry sliding wear behaviour of Al6061-T6/SiC/Nickel Powder hybrid composite. Taguchi's $L_{16}$ orthogonal array (4 x 4) is used for design of experiments. ANOVA is done to analyze the individual effect of parameters such as filler content, load, sliding distance and sliding velocity on wear rate. SEM analysis was done to confirm uniform distribution of reinforcing particles.

## II. PREPARATION OF AL7075/SIC/NICKEL POWDER HYBRID COMPOSITES

To fabricate the Al 6061-T6 alloy base composites, SiC and nickel powder are used as filler materials. The chemical composition of Al6061-T6 is shown in Table 1. Four different composite samples were fabricated by varying the filler content with fixed 2% wt of silicon carbide and nickel from 0-1.5% wt in increment of 0.5%.The set up for experiment consist of main furnace, muffle furnace, mechanical stirrer, graphite crucible, mould etc. For preparing the sample first the required quantity of aluminium rods and filler content (nickel powder and silicon carbide) were preheated at temperature $350^0$ C for 3-4 hour into muffle furnace. After that the melting of the aluminium alloy Al6061-T6 is carried out in the graphite crucible inside the furnace 820°C. Then manual mixing of Al6061-T6 with reinforcing particle was done by a steel stick for approximately 15 minutes. Then molten mixture was casted in the mould. After casting process, specimens were prepared for wear test.

TABLE 1: CHEMICAL COMPOSITION OF AL6061-T6 [19]

| **Elements** | **Weight %** | **Elements** | **Weight %** |
|---|---|---|---|
| Aluminium, Al | 95.8-98.6 | Manganese, Mn | Max 0.15 |
| Chromium, Cr | 0.04-0.35 | Silicon, Si | 0.4 - 0.8 |
| Copper, Cu | 0.15-0.4 | Titanium, Ti | Max 0.15 |
| Iron, Fe | Max 0.7 | Zinc, Zn | Max 0.25 |
| Magnesium, Mg | 0.8-1.2 | | |

## III. EXPERIMENTAL SETUP FOR WEAR TESTING

Wear testing is performed on the pin on disc tribometer. The test was performed according to ASTM G 90 standard with hardened steel disc (EN-31) of hardness 60-70HRC. The pin was held against the counter face of a rotating steel disc with wear track diameter 100 mm. Dead weight loading system was used to load the pin against the disc

To conduct the wear test the surface of both the specimens and the steel plate is polished using emery paper (2000grit size) and clean with aceton to remove dust or grease from the surface prior to each test. The dimension of wear specimen for the experiment is of 25 x 8 x 8 $mm^3$ in cuboids shape. The study on first 4 specimens which have same compositions is carried out by varying speed, load and sliding distance. The worn surfaces of the samples were examined using SEM.

Firstly, weight of the specimen is taken before wear. After weighing the specimen is mounted on the machine and after that the machine is run by changing the parameters like sliding speed, sliding distance and load. Specific wear rate is calculated by following formula as shown in equation 1.

$$W_S = \frac{\Delta m}{\rho \times v_s \times t \times f_n} \quad \dots.(1)$$

Where, Ws= specific wear rate in $mm^3 Nm^{-1}$,
Δm=mass loss composite during test (g),
ρ=density of composite($g\ cc^{-1}$),
$v_s$=sliding velocity ($m\ s^{-1}$),
t=test duration (s),
$f_n$= the normal load (N).

## IV. WEAR TEST ANALYSIS

Taugchi method was used for design of experiments in wear test analysis. Percentage of filler content (0, 0.5, 1, 1.5 weight % of nickel powder), applied load(10, 20, 30, 40 N), sliding distance(500, 750, 1000, 1250 m), sliding velocity(1, 1.5, 2, 2.5 m/s) are considered as four control factors for wear test as shown in table 2. Wear rate is consider as response variable which are computed by equation (1). Wear tests experiments were performed on pin on disk machine for each specimen and set values. Design of experiments consist of $L_{16}$ (4x4) orthogonal array in order to find the best results with minimum number of experiments as shown in Table 3.

TABLE 2: VARIOUS CONTROL FACTORS FOR WEAR TEST

| **Control Factors** | **Level** | | | |
|---|---|---|---|---|
| | I | II | III | IV |
| **Applied Load (N)** | 10 | 20 | 30 | 40 |
| **Velocity (m/s)** | 1 | 1.5 | 2 | 2.5 |
| **Composition (%)** | 0 | 0.5 | 1 | 1.5 |
| **Distance (meter)** | 500 | 750 | 1000 | 1250 |

TABLE 3: TAGUCHI ORTHOGONAL ARRAY DESIGN ($L_{16}$)
FOR WEAR TEST

| Test runs | Ni percentage (%) | Applied load (N) | Sliding distance (m) | Sliding velocity (m/s) |
|---|---|---|---|---|
| 1 | 0 | 10 | 500 | 1 |
| 2 | 0 | 20 | 750 | 1.5 |
| 3 | 0 | 30 | 1000 | 2 |
| 4 | 0 | 40 | 1250 | 2.5 |
| 5 | 0.5 | 10 | 750 | 2 |
| 6 | 0.5 | 20 | 500 | 2.5 |
| 7 | 0.5 | 30 | 1250 | 1 |
| 8 | 0.5 | 40 | 1000 | 1.5 |
| 9 | 1 | 10 | 1000 | 2.5 |
| 10 | 1 | 20 | 1250 | 2 |
| 11 | 1 | 30 | 500 | 1.5 |
| 12 | 1 | 40 | 750 | 1 |
| 13 | 1.5 | 10 | 1250 | 1.5 |
| 14 | 1.5 | 20 | 1000 | 1 |
| 15 | 1.5 | 30 | 750 | 2.5 |
| 16 | 1.5 | 40 | 500 | 2 |

## V. **RESULTS AND DISCUSSION**

The wear rates of silicon carbide and nickel powder reinforced Al6061-T6 hybrid metal matrix composites under various test conditions are determined experimentally. S/N ratio is the most commonly known approaches in Taguchi analysis. In present work the influence of control parameters, percentage addition fillers, applied load, sliding distance and sliding velocity on wear rate was evaluated using S/N ration response by software MINTAB 16.

### *A. main effect plots for the S/N ratio :*

Table 4 shows the results of $L_{16}$ orthogonal array. The second, third, forth, and fifth column of table shows the percentage addition of filler content in Al6061-T6,applied load ,sliding distance, sliding velocity respectively. Column 6 depicts the value of specific wear rate respectively for each run. In this study, "smaller the better" characteristics of wear was chosen to analyze.

Table 4 also shows the value of S/N ratio for each test. The effect plots are generated by software MINITAB 16. Figure 1 shows the main effect plots for the S/N ratio for composite samples. The plot indicates that increase in percentage of nickel powder wear rate decrease significantly. The wear resistance might be improving due to increase in hard particle reinforcement. It is also observed that the applied load influence the wear rate more significantly as compare to the other factor.

TABLE 4: RESULT OF $L_{16}$ ORTHOGONAL ARRAY

| Test Run | Nickel percentage (%) | Applied Load (N) | Sliding distance (m) | Sliding velocity (m/s) | Specific Wear rate ($10^{-3}$ mm3/Nm) | S/N Ratio (db) |
|---|---|---|---|---|---|---|
| 1 | 0 | 10 | 500 | 1 | 9.5625 | -19.6114 |
| 2 | 0 | 20 | 750 | 1.5 | 9.6042 | -19.6492 |
| 3 | 0 | 30 | 1000 | 2 | 12.0365 | -21.6100 |
| 4 | 0 | 40 | 1250 | 2.5 | 12.3258 | -21.8163 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 0.5 | 10 | 750 | 2 | 6.7250 | -16.5538 |
| 6 | 0.5 | 20 | 500 | 2.5 | 7.5360 | -17.5428 |
| 7 | 0.5 | 30 | 1250 | 1 | 5.9651 | -15.5124 |
| 8 | 0.5 | 40 | 1000 | 1.5 | 6.1921 | -15.8368 |
| 9 | 1 | 10 | 1000 | 2.5 | 7.2571 | -17.2153 |
| 10 | 1 | 20 | 1250 | 2 | 7.1537 | -17.0906 |
| 11 | 1 | 30 | 500 | 1.5 | 6.2528 | -15.9215 |
| 12 | 1 | 40 | 750 | 1 | 5.9750 | -15.5268 |
| 13 | 1.5 | 10 | 1250 | 1.5 | 5.3696 | -14.5988 |
| 14 | 1.5 | 20 | 1000 | 1 | 5.1825 | -14.2908 |
| 15 | 1.5 | 30 | 750 | 2.5 | 6.7640 | -16.6041 |
| 16 | 1.5 | 40 | 500 | 2 | 5.0325 | -14.0357 |

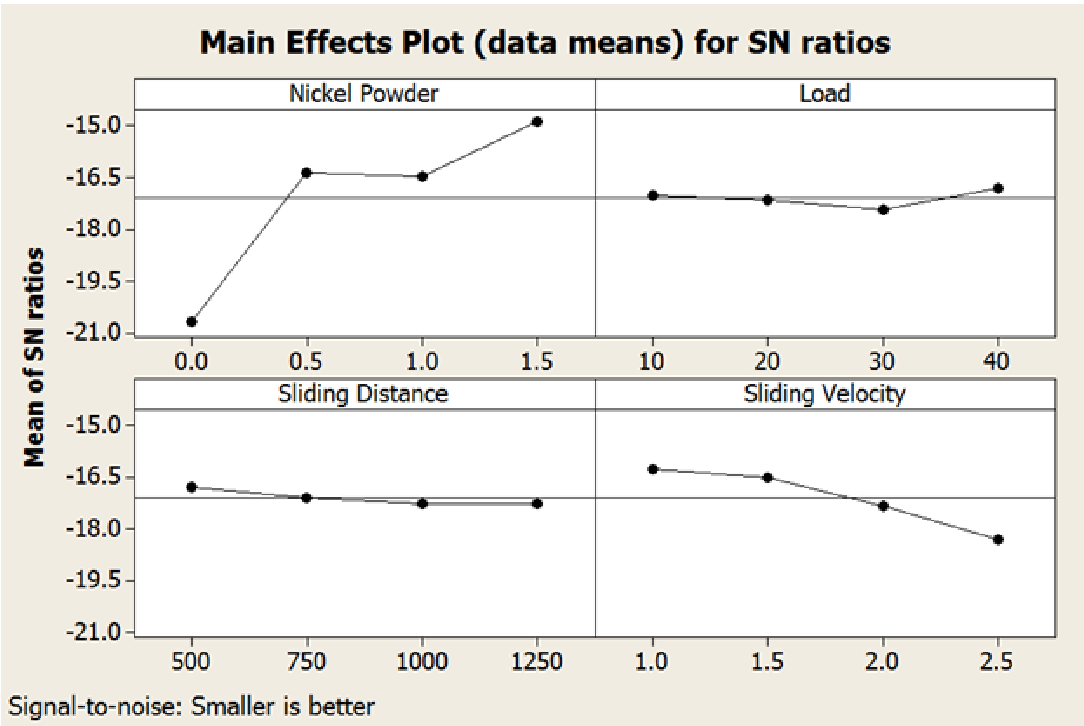



Figure 1: Input parameters v/s s/n ratios (wear rate )

*B. ANALYSIS OF VARIANCE (ANOVA)*

Analysis of variance was done to determine the statistical significance of control factors such as filler content, applied load, sliding distance, sliding velocity on wear rate. The ANOVA establishes the relative significances of factors in term of their percentage contribution to the response. A significance level of 5% in consider for the present study. The p- value in the last column of ANOVA Table 5 shows the significance of individual factors and their interaction for each composite sample. Lower the p- value higher the significance level of factors. The significance of control variables are shown by rank. From among the factors chemical composition and applied load are having prime effect on the wear rate.

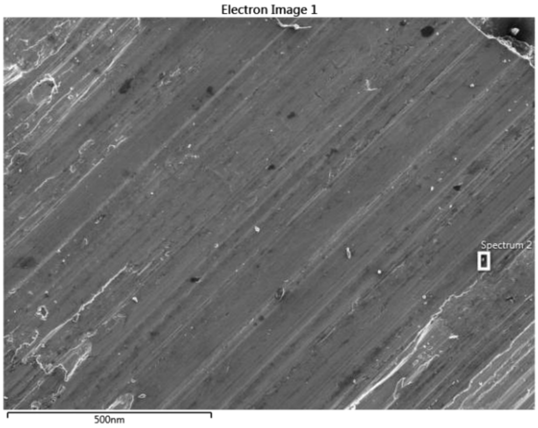
TABLE 5: RESULT OF ANOVA

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | Rank |
|---|---|---|---|---|---|---|---|
| **Applied Load** | 3 | 66.3555 | 66.3555 | 22.1185 | 48.39 | 0.005 | 1 |
| **Distance** | 3 | 0.6079 | 0.6079 | 0.2026 | 0.44 | 0.739 | 4 |
| **Velocity** | 3 | 1.0765 | 1.0765 | 0.3588 | 0.79 | 0.576 | 3 |
| **Composition** | 3 | 8.3357 | 8.3357 | 3.7796 | 8.08 | 0.046 | 2 |
| **Error** | 3 | 1.3713 | 1.3713 | 0.4571 | | | |
| **Total** | 15 | 77.7469 | | | | | |

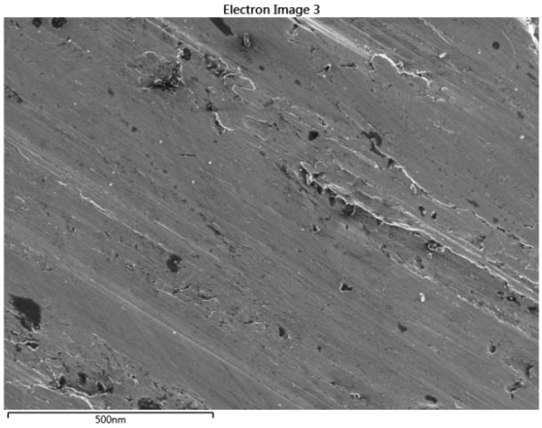
*C. SEM TEST RESULTS*

Worn surfaces of the fabricated hybrid composites were investigated by scanning electron microscope. Micrographs are taken at a scale of 5 mm. Figure shows SEM images of composites. These images of the hybrid composite show that how wear occurred on top surface of it. Uniform distribution of reinforcement particles was observed in Al6061-T6. Also strong interfacial bonding between reinforcement phase and aluminium matrix was observed.

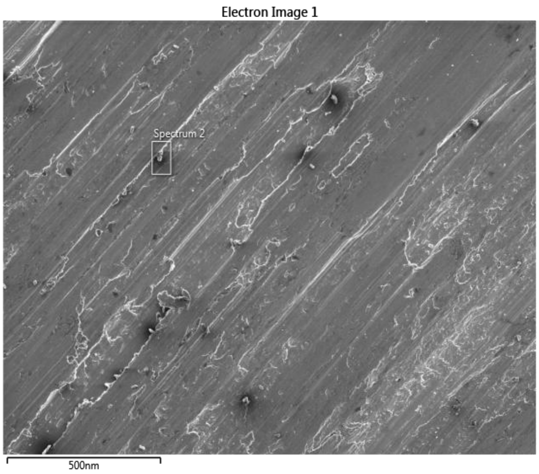
The cluster of reinforcements is shown by black spots visible in the micrograph images which causes porosity in the composites. The porosity is increased with increase in weight percentage of reinforcements. Stir casting method of fabrication causes higher porosity in the composite. Weak interfacial bonding between the particles of composite is caused by porosity present in it, which cause higher wear rate and increase the number of grooves on the top surfaces [20].



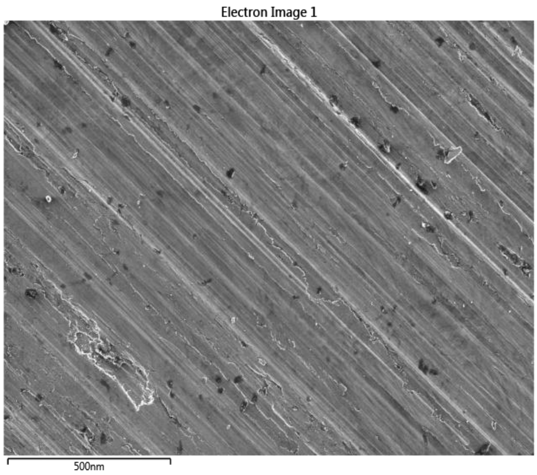

(A)




(B)




(C)




(D)

Figure 2: SEM images of (a) Al 6061-T6+0% Ni +2% SiC (b) Al 6061-T6+0.5%Nni+2%SiC

(c) Al-6061-T6+1% Ni+2% SiC (d) Al 6061-T6 +1.5% Ni+2% SiC

The wear surfaces have combined pattern of shallow grooves of varying size, small granules, wear debris. The delimitation between layers of composite along the sliding direction cause formation of such grooves and wear debris. The wear debris is in form of particles and small platelets. The size of debris increase with increase in load also ploughing marks are observed at higher load at perpendicular direction of sliding. The wear rate is increased from mild to serve with increase load, sliding velocity and sliding distance. Worn particles are attached to the surface of hybrid composite along the sliding direction. These worn particles also act as abrasive material itself and increase wear rate. Worn surface is observed because of adhesive and abrasive wear mechanism.

## VI. CONCLUSIONS

Study of dry sliding behaviour of Al6061-T6 hybrid metal matrix composite reinforced with different weight percentage of nickel powder and fixed weight percentage of silicon carbide is done on pin-on-disk tribometer. Taguchi method was used to plan and conduct wear test. The experimental study of wear rate has led to the following specific conclusions:

- Stir casting method was successfully used to fabricate Al6061-T6 hybrid composite filled with different weight percentage of nickel powder (0, 0.5, 1, 1.5%) and silicon carbide (2%).
- The small addition of filler content significantly improves the wear resistance. The optimization of different wear parameters was done by Taguchi method. And it is found that the composition and applied load are the most significant parameters followed by sliding velocity and sliding distance.
- From SEM images it can be seen that with increment in filler material, wear is decreased hence an increase is seen in wear resistance.
- From obtained SEM images it can be said that the reinforcement of silicon carbide and nickel powder is nearly uniform.

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