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# Wear and Friction Characteristics of Aluminium Matrix Composites Reinforced With Flyash/Cu/Gr Particles

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**Abstract :** The present paper has been focused on the use of fly ash, graphite and copper in a valuable way by reinforcing it into aluminium alloy Al6061 to produce a composite by stir casting technique. By using Taguchi's orthogonal array an attempt has been made to study for optimizing the percentage composition of aluminium alloy Al6061 reinforced with fly ash, graphite and copper. The mechanical property studied is wear resistance and friction characteristics. Taguchi's $L_4$ ($2^3$) orthogonal array is used to plan the experimentation and four compositions of aluminium matrix composites were produced and the samples prepared for testing. The experimental results showed significant changes in each composition and wear resistance was improved.
**Keywords :** Al6061, fly ash, graphite, copper, Taguchi, wear, friction.

## 1. Introduction

Composite material is a material involving no less than two physically or chemically distinct phases[1-3]. Composites are light in weight with high strength. The light weight materials are in need today to reduce the weight of the component manufactured Aluminium matrix composites (AMC) insinuate the class of light weight elite material frameworks[3-5]. The composite materials are reinforced with fibres. The reinforcement could be as constant/irregular fibres or particulates[6-9]. Properties of AMC can be exclusively fitted to the different present day applications by suitable mixes of matrix, reinforcement and processing route[10-14].These days the particulate reinforcedaluminiummatrix composite are picking up significance as a result of their ease with preferences like isotropic properties and the likelihood of auxiliary preparing encouraging themanufacture of optional segments[15-19]. Numerous observers exhibited that cast aluminum matrix particle strengthened composites have unrivaled elasticity, hardness and furthermore have great wear protection when compared with unreinforced alloys. Planning of random experimentation seems critical, Taguchi's orthogonal array gives the route for planning the experimentation and for optimisation.[17, 20, 21].

Surappa[2] presented an outline of Aluminium Matrix Composite (AMC) on aspects relating to processing, microstructure, properties, and applications. He also identified that liquid state handling of the AMC is the easiest and most commercially used technique for the preparation of AMC.

Anilkumar et.al,[3] investigated and determinedthatthe mechanical properties of fly ash reinforced aluminium alloy Al6061 compositeprocessed by stir casting route revealed that the tensile strength, compressive strength, and hardness of the aluminium alloy Al6061 composites decreased with the increase in the particle size of reinforced fly ash

Babu et.al,[5] investigated and found that, fly ash could be preheated in a muffle furnace at $80^0$C to $100^0$Cfor 3 hours to expel any moisture in fly ash.

Dunia[6] made an attempt to develop an aluminium/SiC/graphite/alumina based AMC. He observed that maximum hardness of the AMChas been obtained at 25 % weight fraction of SiC and at 4% weight fraction of graphite.

Arun et.al, [9] investigated and found that, Flyash/eglass/Al6061 alloy composites having 2 wt%, 4wt%, 6wt% and 8wt% of flyash and 2 wt% and 4wt % of e-glass fiber were fabricated by stir cast method. Significant improvement in tensile properties, compressive strength and hardness are noticeable as the wt% of the flyash increases. The tensile property of the composite material compared to the as cast Al6061 alloy, increased significantly by 60-70%.

Moorthyet.al, [13] investigated and found that, the hybrid metal matrix composites with fly ash and graphite reinforced Al6061 composites processed by stir casting route. The aluminium alloy was reinforced with 3 wt. %, 6 wt. %, 9 wt. % fly ash and fixed 3 wt. % of graphite. The design of experiments approach using Taguchi method was employed to analyze the wear behavior of hybrid composites. Signal-to-noise ratio and analysis of variance were used to investigate the influence of parameters on the wear rate.

From the literature review, it turns out to be evident that the planning of AMC has been examined by numerous specialists. In any case, there stays some trouble in creating AMC with unrivaled mechanical properties, which uncovers that still more investigates must be done to locate a solution.Therefore, thepreparation of AMC (aluminium alloy Al6061 reinforced with fly ash/copper/graphite) was carried out using stir casting technique in order to study the hardness and wear resistance.

## 2. Raw materials

The raw materials used in the experimental study are as follows,

- Aluminium alloy Al6061
- Fly ash
- Graphite powder
- Copper powder

### 2.1.Aluminium alloyAl6061:

This is the slightest costly and most adaptable of the heat-treatable aluminium alloy. It has a large portion of the great characteristics of aluminium. It offers a scope of good mechanical properties and great corrosion resistance. It can be created by the vast majority of the ordinarily utilized procedures. In the annealedcondition it has great workability. The Al6061 utilized for this examination was thetype of round and hollow pole of measurement 80mm, which is portrayed in figure 2.1.

### 2.2.Fly ash:

Fly ash is a fine substance got from the tidy gatherers in the thermal power plants that utilize coal as fuel. The fly ash can be penetrated by liquid metal to frame strong, alumina encased circles. Fly ash can also be blended with liquid metal and cast to lessen general weight and density, because of the low density of fly ash. The fly ash particles with anormal size of 50μm were utilized for this examination, which is delineated in figure 2.2.

**Figure 2.1Aluminium alloy Al6061 80mm rod**

**Figure 2.2 Fly ash of 50µm**

**2.3. Graphite powder :**

Graphite and graphite powders are broadly utilized as a part of modern applications for their outstanding dry lubricating properties. Thus, if a strong lubricant like graphite is contained in the aluminium alloy, it could be discharged naturally during the wear procedure and can possibly decrease wear, increment the counter seizure impacts and enhance warm strength. The graphite powder utilized for this research is of thenormal size of 20µm was utilized for this investigation, which is delineated in figure 2.3.

**2.4. Copper Powder :**

Copper powders have been utilized as a part of mechanical applications for a long time. The unadulterated copper powder is utilized as a part of the electrical and the gadgets enterprises in light of its astounding electrical and warm conductivities. The copper powder utilized for this examination is 99.5% unadulterated and of thenormal size of 20µm was utilized for this investigation, which is delineated in figure 2.4.

**Figure 2.3Graphite powder**

**Figure2.4Copper powder**

**3. Experimental work**

The experiment was planned based on Taguchi's $L_4$ ($2^3$) orthogonal array. The processing of the job was done by stir casting method.

**3.1. Experimental Conditions :**

The experimental control factors and the corresponding levels are specified in Table 3.1are as follows;

**Table 3.1 Experimental levels & factors**

| **Factor notation** | **Control factors** | **Factor levels** | |
|---|---|---|---|
| | | **Level 1** | **Level 2** |
| A | Fly ash | 10% | 15% |
| B | Copper | 3% | 4% |
| C | Graphite | 3% | 4% |

*For 1kg of Aluminiumalloy Al6061

### 3.2.Taguchi's standard $L_4$ ($2^3$) Array

The control factors assigned into the standard $L_4$ ($2^3$) orthogonal array is given in the table Table 3.2 as follows;

**Table 3.2 Plan of experiments**

| Expt. No | A | B | C |
|---|---|---|---|
| 1 | 10% | 3% | 3% |
| 2 | 10% | 4% | 4% |
| 3 | 15% | 3% | 4% |
| 4 | 15% | 4% | 3% |

### 3.3.Processing of Composites:

Fly ash/graphite powder/copper powder reinforced with Al6061, are processed by stir casting method. Liquid metallurgy route was used to producethe hybrid composite specimens. The matrix alloy Al6061 was first superheated above its melting temperature and then the temperature was lowered gradually until the alloy reached a semisolid state.The required quantities of fly ash, graphite powder, and copper powder were weighed accurately and stored in powder containers.Till the matrix reaches the molten state, the fly ash particles were pre heated to 750$^o$C and maintained at that temperature for about 30 minutes. The photograph of the pre heated fly ash particleswere depicted in figure 3.3.1.

**Figure 3.3.1 Pre heated Fly ash particles**

The blended mixture of preheated fly ash, graphite powder, and thecopper powder were introduced into the slurry and the temperatures of the composite were increased slightly. Small quantity of magnesium 0.3wt% was added to the molten metal to enhance wettability of reinforcements with molten aluminium. Stirring was for carried at 650rpm about 50 seconds until the interface between the particle and the matrix promoted wetting and the particles were uniformly dispersed. The melt was solidified in a cast iron permanent mould to obtain flat plate samples. Thus four different compositions were cast as mentioned above by stir casting method. The stir casting setup used for the study, control panel for controlling the stirrer speed and the temperature, pouring of molten metal into the die is depicted in figure 3.3.2, figure 3.3.3and figure 3.3.4 respectively. The wear test specimens are shown in figure 3.3.5.

**Figure 3.3.2Aluminium stir casting setup**


**Figure 3.3.3Control panel**

**Figure 3.3.4Pouring of molten metal**

**Figure 3.3.5Wear test specimens**

## 4. Results and Discussion

The castcomposite samples were machined to specified dimensions as per test standards and the mechanical test was done respectively as follows;

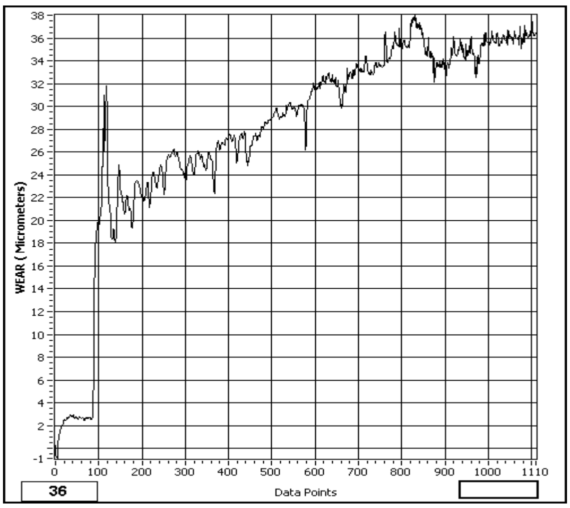
### 4.1 Wear and friction characteristics

The test was performed for 17 minutes with load of 9.82 N, Sliding velocity of 1 m/s, sliding distance of 1000mm. The disc rotates at 287 rpm. The wear rate of the four specimens was obtained. They are tabulated in table 4.4.

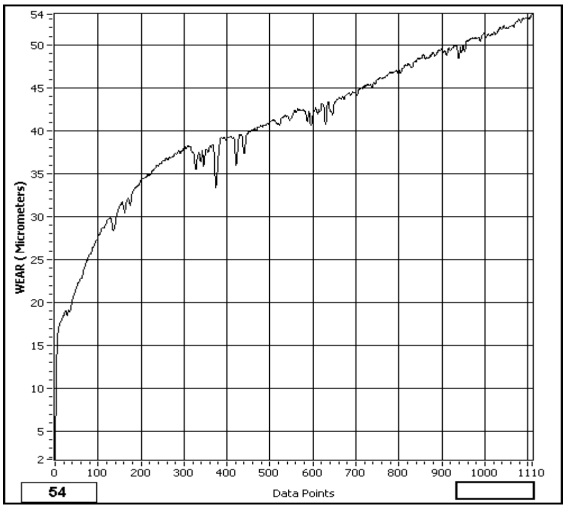
**Table 4.4 Wear rates of specimens**

| Specimen ID | Wear Rate $mm^3$/ min |
|---|---|
| C1 | 36.5 |
| C2 | 53.5 |
| C3 | 64.6 |
| C4 | 48.9 |

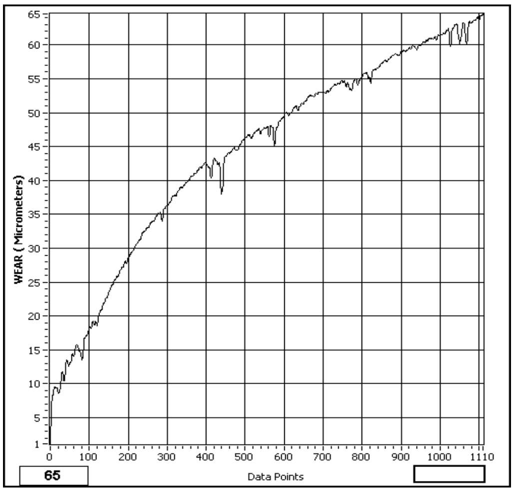
The wear test conducted on the pin on disc apparatus yielded the graphs. The graphs are plotted with data points in x- axis andwear in y- axis, shown in figure 4.1.1.

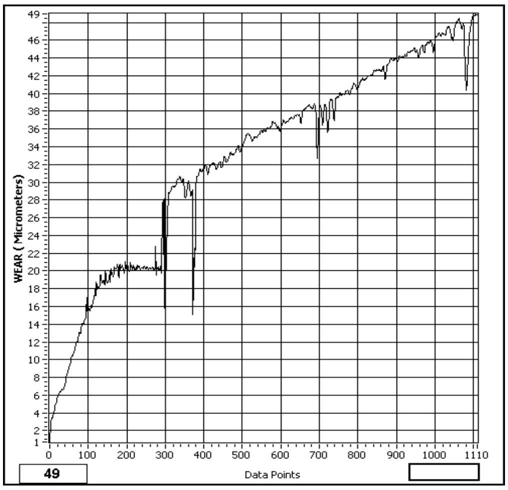



C1




C2

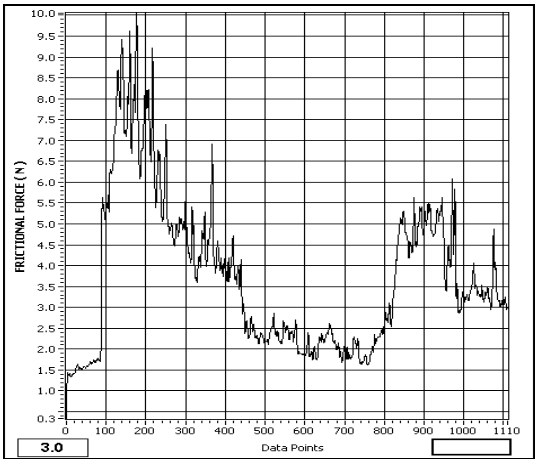


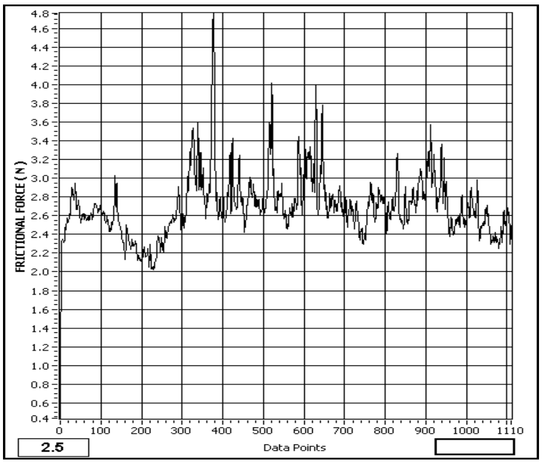




C3 C4

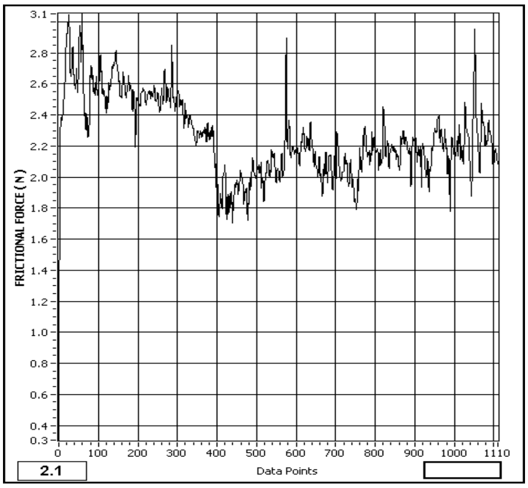
**Figure 4.1.1Wear graphs of Specimens C1, C2,C3&C4.**

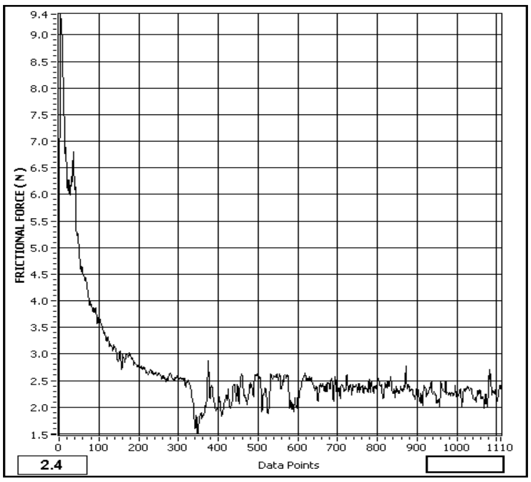
The friction was also observed while performing the wear test. The co-efficient of friction is found out. The friction graphs are plotted with data points in x- axis andfrictional force in y- axis, which is shown in figure 4.1.2.




C1 C2




C3 C4

**Figure 4.1.2Friction graphs of Specimens C1, C2, C3&C4**

The obtained wear and friction results have been plotted together for better understanding of how these both vary with relative to each other in figure 4.1.3,figure 4.1.4,figure 4.1.5 and figure 4.1.6 for specimens C1, C2, C3 and C4 respectively.

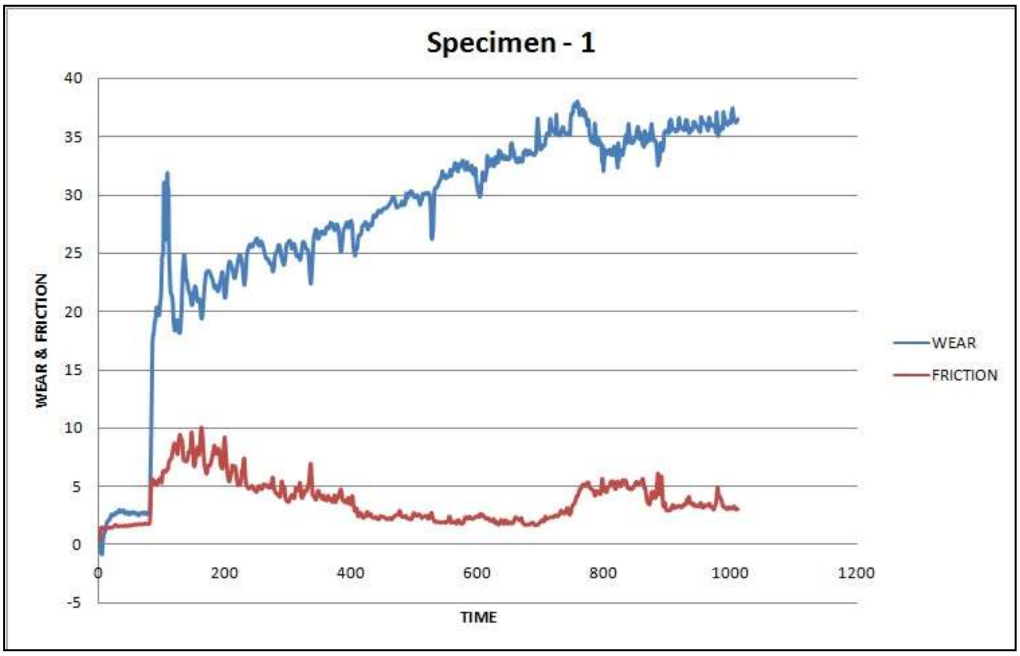



**Figure 4.1.3 Wear & Friction Vs Time graph for C1**

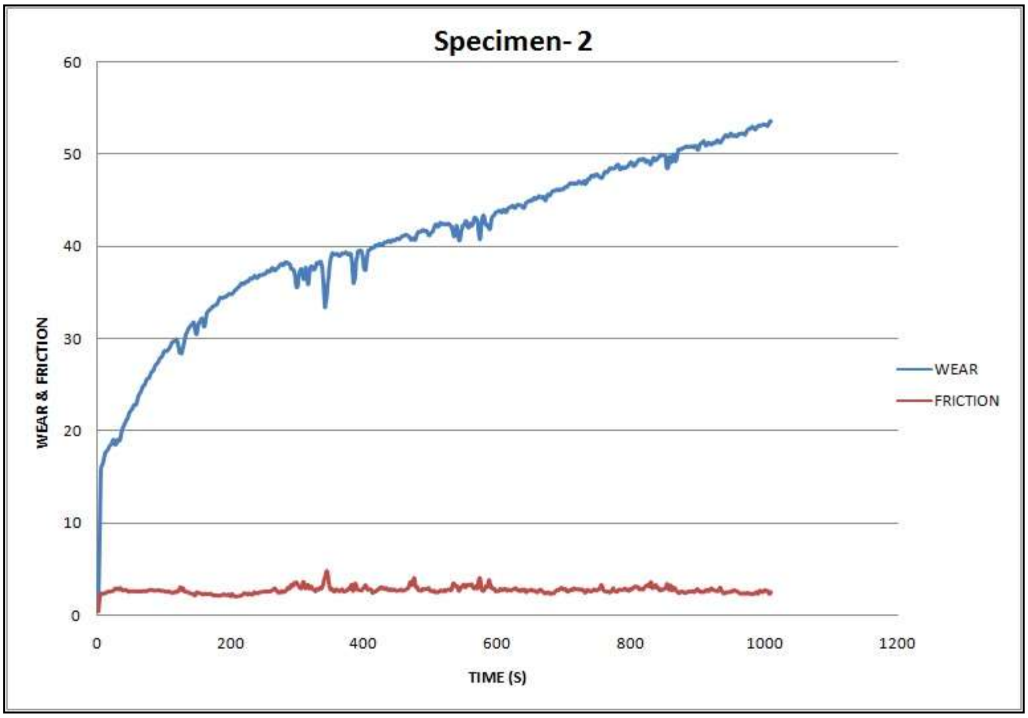



**Figure 4.1.4 Wear & Friction Vs Time graph for C2**

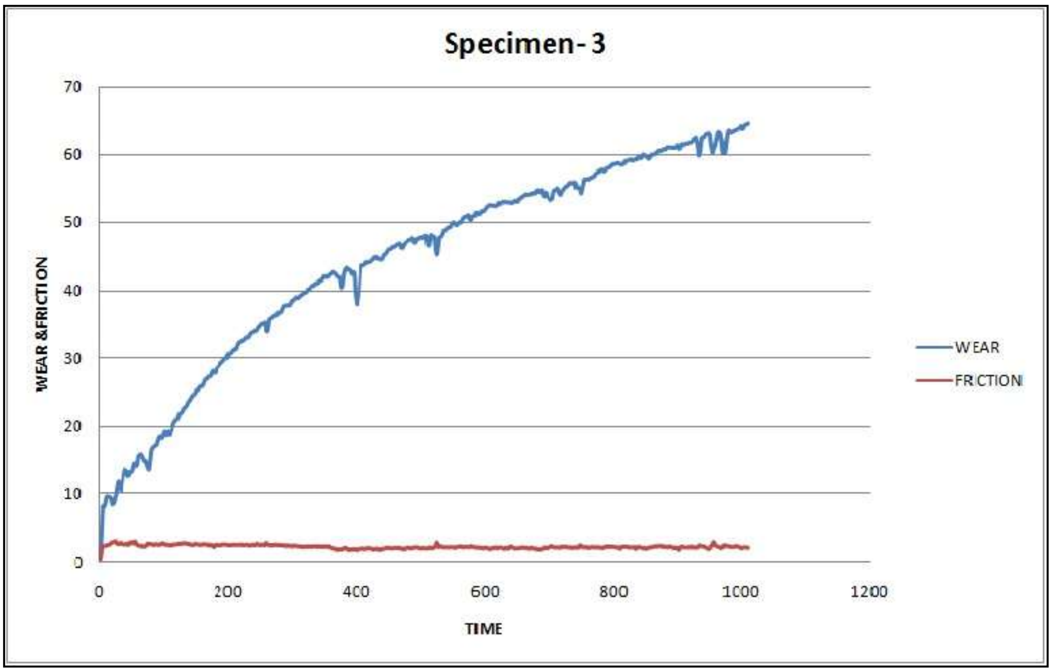



**Figure 4.1.5 Wear & Friction Vs Time graph for C3**

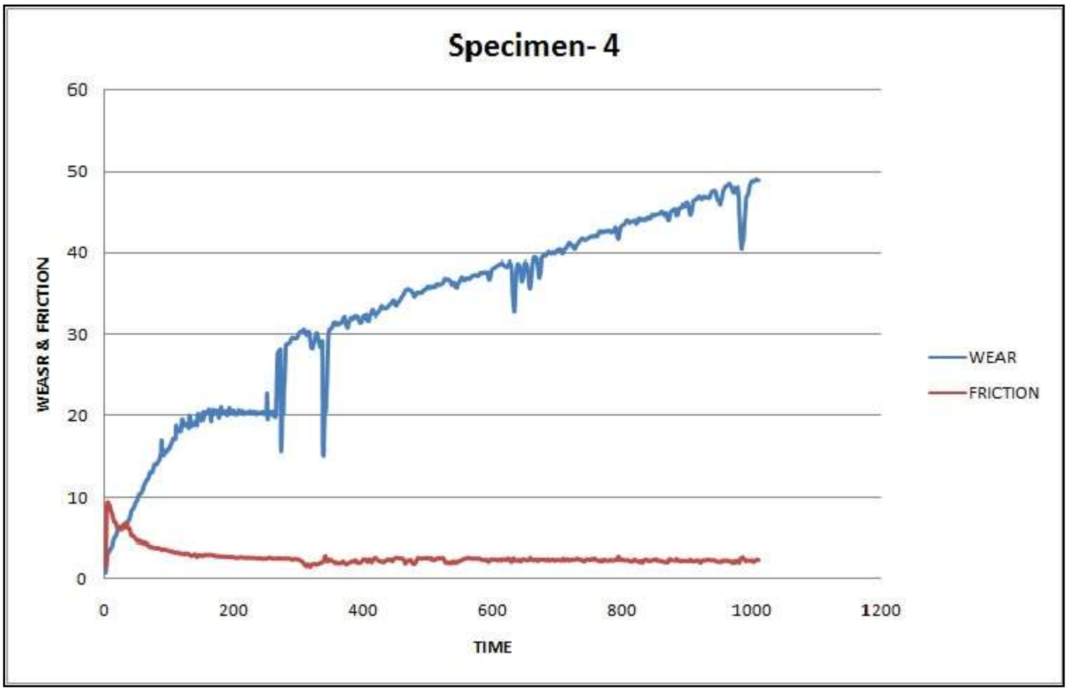



**Figure 4.1.6 Wear & Friction Vs Time graph for C4**

## 4.2 Optimization by Taguchi Technique

### 4.2.1 S/N ratio calculation

The quality attribute with the sort of "smaller-the-better" measured in this research work was wear of the castsamples. The S/N ratio for the yield response was computed by using following Equation (1) for each machining condition and their values are given in Table 4.2.1.

$$S/N(dB) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} Ra_i^2\right) \qquad (1)$$

Where*i* = 1, 2,*n* (here *n* = 3) and wear is the response value.

**Table 4.2.1 Experimental Conditions and S/N Ratio**

| Expt. No. | Control factors | | | Wear | S/N Ratio (dB) |
|---|---|---|---|---|---|
| | A | B | C | | |
| 1. | 10% | 3% | 3% | 8.584 | -18.6738 |
| 2. | 10% | 4% | 4% | 12.595 | -22.0040 |
| 3. | 15% | 3% | 4% | 15.193 | -23.6329 |
| 4. | 15% | 4% | 3% | 11.494 | -21.2094 |

### 4.2.2 Response Curve

Response curves are graphical representations of change in performance characteristics with the variation in machining parameter level. Figure 4.2.1 shows the response graph for three factors and two levels. The peak points are chosen as the optimum levels of machining parameters, with fly ash at level 1, copper at level 1, graphite at level 1.

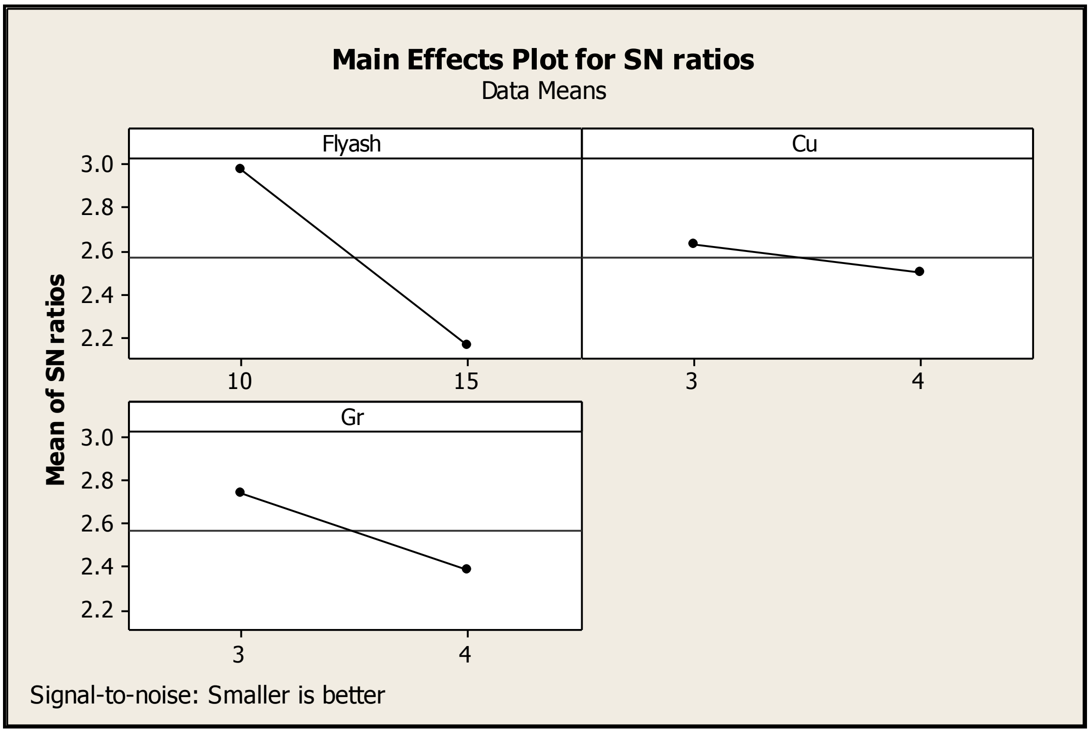



**Figure 4.2.1Response Curve**

### 4.2.3 Confirmation test:

From the responses, the optimum set of parameters was found and given in the table 4.2.2.

**Table 4.2.2 Optimal parameters for wear**

| Expt. No. | Control factors | | | Experimental value | Theoretical value | Error % |
|---|---|---|---|---|---|---|
| | A | B | C | | | |
| 1 | 10%* | 3%* | 3%* | 8.584 | 8.568 | 0.18% |

*For 1kg of Aluminium 6061

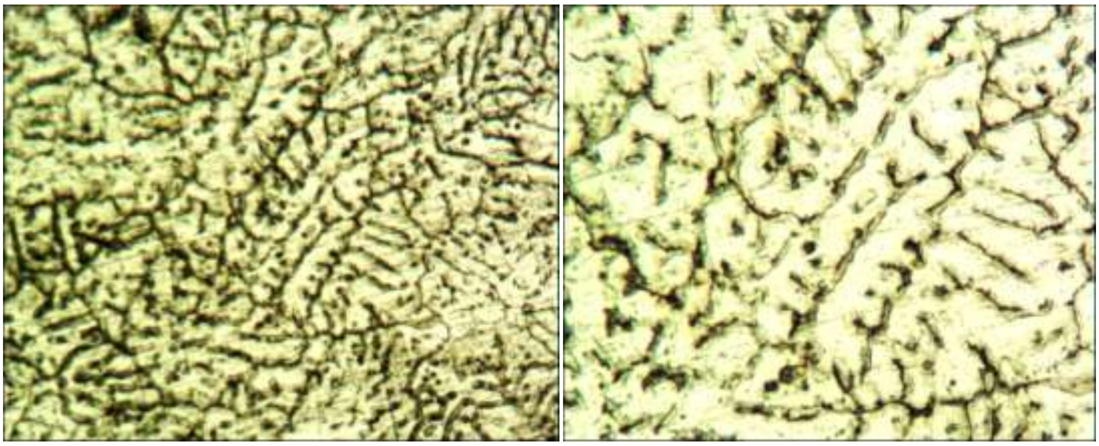
### 4.2.4 Mathematical model

By means of regression analysis with the aid of MINITAB 17 statistical software, the effect of control factors on mean tensile strength was modeled as follows.

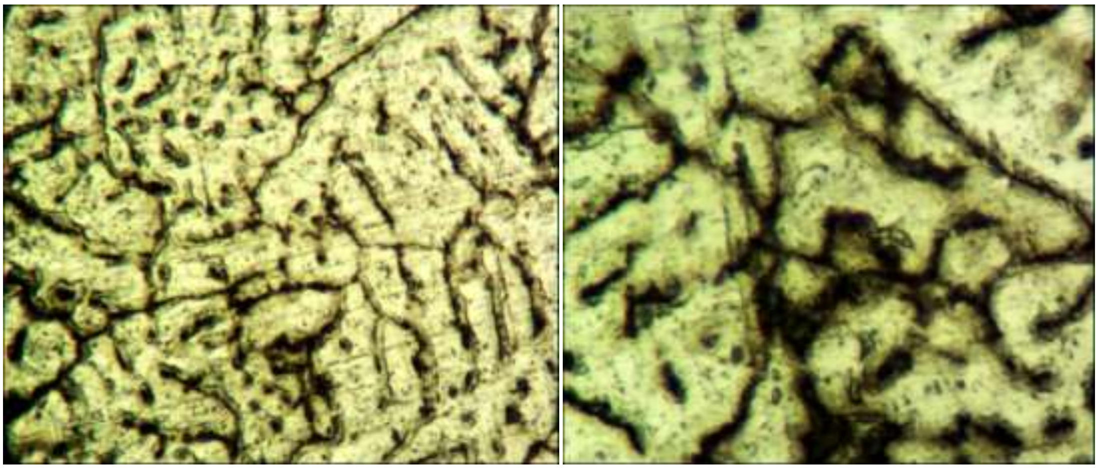
Wear = - 8.96 + 0.551*Flyash + 0.156*Cu + 3.85*Gr (2)

### 4.2.5 Microstructure ofthe Optimum Specimen

The microstructure of the optimum specimen of ID C1 is done and the microstructure picture is obtained at four different levels of 100x, 200x, 300x, 400x. The pictures are shown in figure 4.2.2.



**1) 100x** **2) 200x**



**3) 300x** **4) 400x**

**Figure 4.2.2 Microstructure of Specimen C1 at four different magnification levels**

## 5. Conclusion

From the study it is concluded that we can use fly ash for the production of composites and can turn industrial waste into industrial wealth. This can also solve the problem of storage and disposal of fly ash. Fly ash up to 15%, Copper up to 4% and Graphite up to 4% by weight can be successfully added to aluminium alloy Al6061 by stir casting route to produce better hybrid composites. The hardness of Al-fly ash/Cu/Gr composites has increased with increase in addition of fly ash and graphite. Both the frictional forces and the wear rates have decreased significantly with the incorporation of fly ash, graphite and copper.

The future scope of this project work is to conduct tests to find out the corrosion resistance and thermal conductivity of the composites. Because copper is a good conductor of heat and also it has a very good corrosion resistance. Since copper is added to this composite these tests shall be conducted and assumption is that it will prove better results.

**Nomenclature**

| | |
|---|---|
| Al | Aluminium |
| Cu | Copper |
| Gr | Graphite |
| AMC | Aluminium Matrix Composite |
| wt% | weight percentage |
| MPa | MegaPascal |

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