Tribological Behavior of Al6061-Beryl Metal Matrix Composite and Optimization of Parameters using Taguchi Method

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***Abstract*—Composites in today's world play an important role as they are being used as replacements for conventional materials. Aluminum is most widely used as base matrix in a composite because of its low density high strength property . To maintain similar density range along with improvement in material strength, Beryl (Beryllium aluminum cylcosilicate) is used as the reinforcement . The combination of aluminum and beryl enhances the material properties of aluminum without any drastic increase in the total mass density of the composite. Stir-casting technique has been employed to cast Al-Beryl MMC by varying beryl's percentage each time. Friction, wear, hardness and tensile tests has been carried out in this work. Taguchi method is performed on the results obtained from the experiments .Optimization of parameters using S/N ratio and ANOVA is carried out.**

Index Terms—Al-6061, Beryl, MMC, Taguchi, Tribology.

I. INTRODUCTION

Composites are combination of two or more than two materials most likely to have different properties. A composite has a base matrix and reinforcement(s) as its constituents. Majority of the composite is composed of the base material. Addition of reinforcement improves the performance of the material. Some of the benefits that composites have over conventional materials are High strength, Light weight, Corrosion resistance, High impact strength, Flexibility, Durability etc.

Among different types of composites available MMC's(Metal Matrix Composites) generate wide interests in the research field. MMC's are widely known for their stiffness, High strength, Fracture toughness. They can withstand corrosion at higher temperature. These composites are stable even at elevated temperatures. Aluminum, Titanium, magnesium are popular choices as the matrix base. In this project Aluminum 6061 has been considered as the base matrix.

Aluminum metal matrix composites are known for their low density and high specific mechanical properties. The strength and wear resistance is equal to that of cast iron. The castings of Aluminum metal matrix composites are seen competitive economic wise ,when compared to iron and steels. Liquid metallurgy according to research has been considered as the ideal method to manufacture Aluminium MMC's at laboratory level[1]. Wide range of aluminium alloys are available for composite manufacturing. The alloy used here is Al6061. Aluminium 6061 containing major alloying elements such as Silicon and Magnesium is a precipitation hardened Aluminium alloy. At research level it is the most commonly used alloy. It is generally extruded, exhibits good weldability and mechanical properties. The density of Al6061 is 2.70g/cm^3. It is commonly available in three grades : pre-tempered 6061-O, tempered grade 6061-T6 and 6061-T651.Depending on the heat treatment of the material and temper , the mechanical properties vary greatly. Al6061 is commonly used in construction of aircrafts, yacht, automotive parts, food and beverage cans, etc.

Reinforcements are added in order to increase the strength of the composite. The reinforcement chosen should be stiffer and stronger than the base matrix. Reinforcements in composites can be whiskers, fibers, fabric particles etc. Apart from providing additional strength to the base matrix, they also improve properties such as heat resistance, conductivity, rigidity , corrosion resistance etc.

Beryllium aluminium cyclosilicate also known as Beryl is used as reinforcement in this metal matrix composite. It’s a naturally occurring mineral that is generally found in the form of crystals(hexagon shaped). Beryl in its purest form is colorless, but more often is seen in colors such as green, yellow, red, white and blue due to the presence of impurities in the mineral. Beryl when added as reinforcement for Aluminium metal matrix composites show significant improvement in the tribological property when compared to individual base matrix i.e. aluminium. Wear rates and friction coefficients were lower than the parent matrix [2]. As per previous studies it was found out Aluminium and beryl composite had significant improvement in hardness and tensile strength when compared to base matrix[3].

In order to optimize the process and experiment parameters Taguchi methods have been used. They improve the quality of the fabricated products[4]. In this method large number of experiment combination results can be generated without actually conducting the experiments. With the help of Signal to noise ratio(S/N) and Analysis of variance(ANOVA) a robust design has been generated and the optimized results are presented in this paper.

II. EXPERIMENTAL DETAILS

A. MATERIAL SELECTION

In the composite fabricated Aluminium was taken as the base matrix and Beryl as the reinforcement. Among various grades of aluminium present, Al6061 alloy was considered in this experiment. Aluminium 6061 grade has high corrosion resistance, good strength ,hardness and is easier to fabricate when compared to pure aluminium. Al 6061 has density of about 2.7g/cm^3. Aluminium 6061 is widely used for the following applications : ship building, rail coaches, aircraft structures, truck frames etc. Composition of Al 6061 is given in Table 1.

Table 1- Al6061 chemical composition

Element	Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	Al
Wt(%)	0.15	0.7	1.2	0.8	0.4	0.2	0.15	0.3	91.1

Beryl(Beryllium Aluminium Cyclosilicate) is considered as the reinforcement for the Aluminium Metal Matrix Composite. Density of Beryl varies from 2.6-2.8g/cm^3. Beryl particles in the size range of 50-75µm were used. The chemical composition of Beryl($Be_3Al_2(SiO_3)_6$) is given in Table 2.

Table 2- Beryl chemical composition

Element	SiO_2	Al_2O_3	BeO	Fe_2O_3	CaO	MgO	Na_2O
Wt(%)	67.2	17.1	12.2	0.9	1.1	0.67	0.48

B. FABRICATION

Stir casting technique was used to cast Aluminium MMC. It's called as liquid metallurgy method. At laboratories this method is considered most economical and is widely used. Bottom pouring stir casting equipment was used to manufacture the composite. Solid Aluminium ingots were first heated in the furnace at 750°C.A graphite crucible was used inside the furnace where the composites were mixed. To the molten Aluminium pre-heated beryl particles were added. The stirrer was then assembled and at about 300rpm the molten composite of Al6061 and beryl were stirred . A vortex was formed that allowed uniform mixing of Beryl particles with the base matrix Aluminium. Three sets of casting were prepared by varying the percentage of Beryl each time from "0% to 8%".The molten mixture of Al 6061 and Beryl was collected in a mould and were allowed to solidify at room temperature.

C. SPECIMEN PREPARATION AND TESTING

The specimens obtained from the cast were machined for Tensile, Wear and Hardness tests. ASTM-E8 standard was followed in preparing the specimen for Tensile test. The specimens were assembled in an electronic Tensometer. Tensile loads were applied till fracture occurred. Three trials for each specimen and there average values have been considered in the final results. The dimensions of the tensile specimen is given in fig 1.

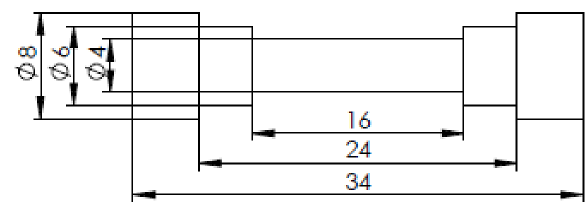

Fig 1. - Tensile test- specimen dimension

Fig 2. - Tensile specimen

The wear tests were performed on Pin-on-disc apparatus according to ASTM G99-95 standards. A diameter of 6mm and a length of 30mm were fabricated for the pin-on-disc wear tests. In this experiment the sliding distance was kept constant at 100mm and the load and speed(rpm) were varied for each trial. The wear tests were performed on every specimen for a duration of 10minutes. Resulting wear rates in the form of graphs has been put up in the results section. The specimen sample used for wear test is as shown in fig.2.

Fig 3. Wear test specimen

For a material to show good wear resistance the hardness value should be high. For hardness test, parallel surfaced specimen were prepared. Brinell hardness test was performed. Using Brinell hardness test equipment indentations were made at multiple points on one side of the specimen and diameter of those indentation were measured using a microscope . The formulas to calculate BHN (Brinell Hardness Number) is given below:

$$BHN = \frac{F}{\frac{\pi}{2}D.(D - \sqrt{D^2 - d^2}} \quad (1)$$

Where,

BHN = Brinell Hardness Number (Kgf/mm^2)
F = Load (Kgf)
D = Steel ball diameter (mm)
D = depression diameter (mm)

III. RESULTS AND DISCUSSION

A. *TENSILE TEST*

Tensile tests were performed in accordance with ASTM-E8 standards on all three specimens. The specimens were clamped between the jaws of the tensometer and continuous incremental loads were applied till failure occurred. The tensile results are listed out in Table 3. It was noticed that as the percentage of reinforcements added to aluminium alloy increased the composites showed increase in the strength. The tensile strength and to an extent certain amount of ductility were enhanced upon addition of Beryl particles. The bonding between the reinforcement and matrix at molecular level may be one of the reason for the increase in strength. Apart from this the composite becomes more densely packed with stronger reinforcements as the percentage of reinforcement increases, taking the place of Al6061 particles and hence may result in increased strength with increased amount of reinforcements.

Table 3- Tensile test

Material	Al6061	Al6061-Beryl 4%	Al6061-Beryl 8%
UTS(N/mm^2)	115	120.9	157.6

B. *HARDNESS TEST*

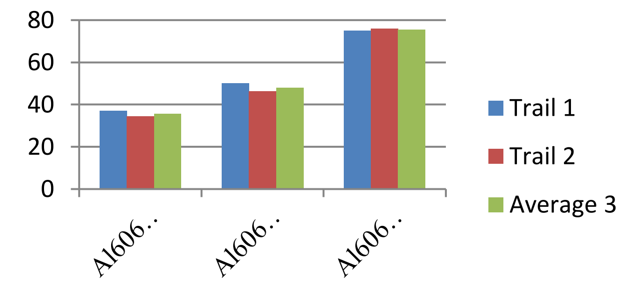

Fig-4 Chart showing hardness test results for different trials

Using equation (1) the BHN i.e. Brinell Hardness Number for the composite was calculated. The tests were performed for three different samples. The chart gives us a clear indication of increase in hardness property of the material with the increase in reinforcement percentage content. The Beryl particles are stronger than base matrix Al6061.Their incorporation with aluminium base matrix results in the composite turning out to be more harder and stronger. Hence, we can summarize by stating a noticeable increase in hardness for the composite is seen when compared to pure Al6061.

C. *WEAR TEST*

Pin-on-disc apparatus was used to perform the wear test. The specimen were prepared in line with ASTM G99-95 standards. The tests were performed on three specimens(Al6061, Al6061-Beryl4% and Al6061-Beryl8%). The sliding distance was taken as constant(100mm). The RPM and Loads were varied for different trials. The three different loads used were 0.5Kg, 1Kg and 1.5Kg. The speed(rpm) of disc rotation considered was 382,477,572 rpm. A total of 27 experiments with different combination of materials, loads and speeds were conducted. It can be noticed from the chart given in Fig-5 ,the material wear starts to reduce with the increase in reinforcement percentage. The material having 8% of Beryl showed good resistance to wear when compared to pure Al6061. This result can be linked to hardness, as the hardness property for a material increases the wear resistance also increases.

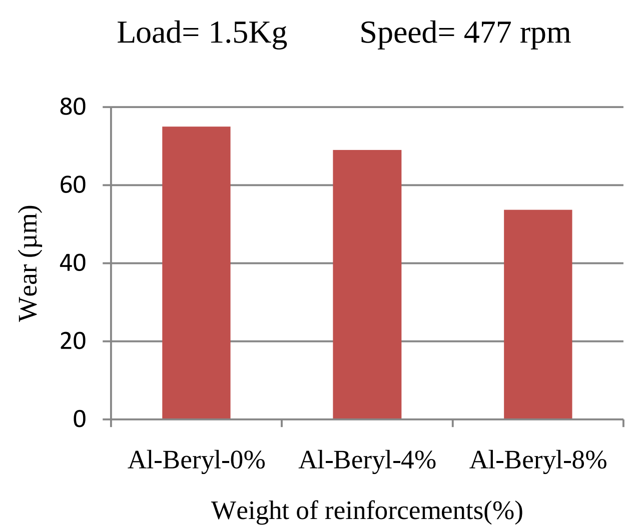

Fig-5 Wear vs. Weight(%) of reinforcements

It can be seen from Fig-6 that at a given constant speed of 572rpm there is an increase in wear with increase in load. The loads have been increased from '0.5 to 1kg'. The graph also shows that for the given speed and the load the highest wear is found for pure Al6061 with 0% reinforcement and the lowest for Al6061-Beryl8% combination. This gives us a clear picture that addition of reinforcement in this case 'Beryl' improves wear resistance of the material. The reinforcements act like load bearers initially and prevent deformation of plastic nature to an extent. The coefficient of friction(COF) also reduces with increase in wt(%) of the reinforcement. There seems to a formation of protective layer at the sliding surface when it comes to reinforced composite. These layers cope up with high stresses generated and eventually reduce the sliding wear of the material.

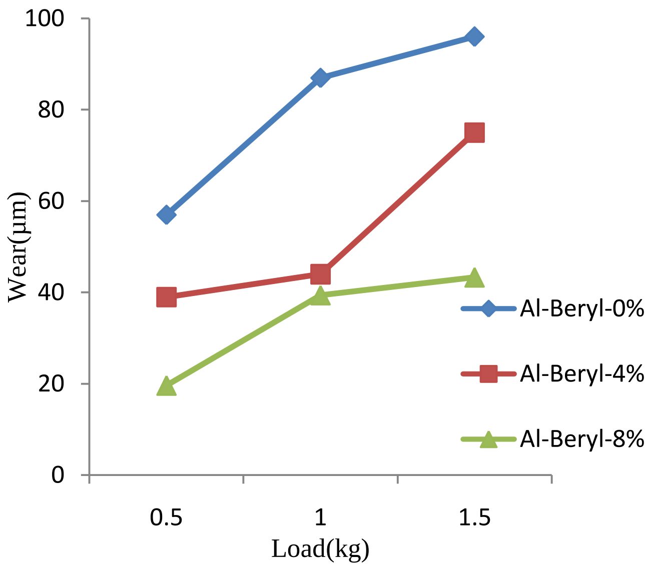

Fig-6 Wear at 0.5,1 and 1.5 kg load with constant speed 572rpm

D. TAGUCHI RESULT

The Taguchi orthogonal array design was of the size L9(3**2). Only two parameters, speed and load were varied throughout the experiments. The COF and wear results were computed using Minitab. The main effect plot for S/N ratio is given in Fig-7. The criteria to chose optimum result is to follow the rule of signal-to-noise: smaller is better.

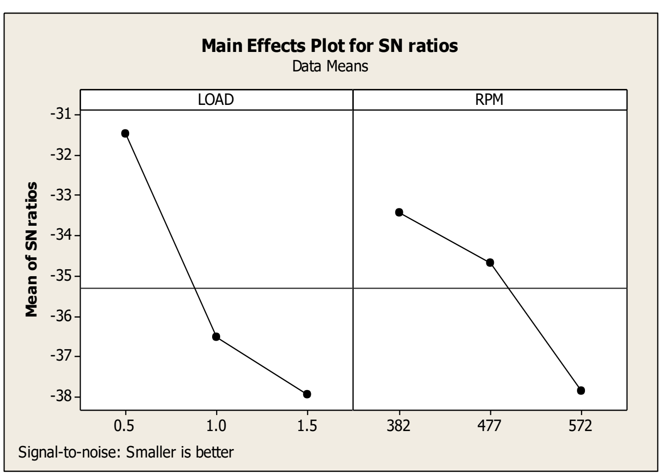

Fig-7 Main effects plot for S/N ratio

Table 4- Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	3790.17	3790.17	1895.08	40.0291	0.0003389
LOAD	1	2440.17	2440.17	2440.17	51.5427	0.0003691
RPM	1	1350.00	1350.00	1350.00	28.5155	0.0017613
Error	6	284.06	284.06	47.34	n/a	
Total	8	4074.22	n/a			

From the mean effect plot graph shown in Fig-7 we can say the material has high value of wear resistance at particular combination of 1.5kg load and 572rpm.

The ANOVA table for Al6061 is given in Table-4 . The P column in ANOVA table tells us if the computed values are significant or insignificant. If the values obtained are below 0.02 then the parameters are termed significant. The analysis of variance table even gives the contribution of parameters to the final result. The signal to noise ratio response table is given in Table-5.Based on the results from ANOVA table the ranks in the S/N ratio table can be validated. The parameter whose contribution is the highest and significant from the ANOVA table is given the higher rank and is termed as the most influential parameter.

Table 5- Response table for S/N ratio

Level	LOAD	RPM
1	-31.48	-33.41
2	-36.52	-34.67
3	-37.93	-37.85
Delta	6.46	4.44
Rank	1	2

IV. CONCLUSION

In the experiment conducted the following conclusions can be derived:

- The addition of Beryl to Al6061 resulted in enhancement of tensile and hardness property of the base matrix.
- The wear resistance showed improvement as the wt(%) was increased. The COF values also showed decrease in value with increase in reinforcement percentage
- While fabrication it was observed that as the percentage of reinforcements were increased the composite became more brittle in nature.
- Using Taguchi technique L9 orthogonal array was selected and experiments were designed.
- The S/N ratio was plotted for wear and COF. Using ANOVA technique influence of parameters were determined.

REFERENCES

[1] Aluminium Alloy-Based Metal Matrix Composites: A Potential Material for Wear Resistant Applications, Runa Dasgupta, ISRN Metallurgy(2012).

[2] Tribological Properties of Aluminium 2024 Alloy– Beryl Particulate MMC's, H.B. Bhaskar and Abdul sharief, Bonfring

International Journal of Industrial Engineering and Management Science, Vol. 2, No. 4, December 2012.

[3] Studies on Mechanical and Wear Properties of Al6061/Beryl Composites, Hosur Nanjireddy Reddappa, Journal of Minerals and Materials Characterization and Engineering, (2012)11, 704-708.

[4] Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation, Srinivas Athreya , Dr Y.D.Venkatesh-IRJES Vol 1, Nov 2012, pp. 13-19.