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Optimal Parameter Design by Taguchi Method for Mechanical Properties of Al6061 Hybrid Composite Reinforced With Fly Ash/Graphite/Copper

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Abstract: The present examination has been centered on the use of fly ash, graphite and copper in a valuable way by scattering it into aluminium alloy Al6061 to produce a composite by stir casting technique. An attempt has been made to study for optimizing the percentage composition of aluminium alloy Al6061 reinforced with fly ash, graphite and copper utilizing Taguchi's orthogonal array. The mechanical properties studied are the tensile strength, hardness and impact strength. Taguchi's $L_4(2^3)$ orthogonal array is used to plan the experimentation, in this way four compositions of aluminium matrix composite are produced and the samples are prepared for testing. The experimental results showed significant changes in each composition. Both the tensile strength and hardness tend to increase when compared to unreinforced Al6061. A mathematical model representing the tensile strength is developed using regression analysis with the help of MINITAB software.
Keywords : Al6061, fly ash, graphite, copper, Taguchi, regression equation, MINITAB.

1. Introduction

A composite material is a material comprising of at least two physically or chemically distinct phases[1-3]. The composite, by and large, has prevalent qualities than those of each of the individual parts. Aluminium matrix composites (AMC) allude to the class of light weight elite material frameworks [3-5]. The reinforcement in AMC could be as constant/irregular fibres or particulates [6-9]. Properties of AMC can be custom fitted to the requests of various modern applications by appropriate 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 [15-18]. Numerous observers demonstrated that cast aluminiummatrixparticle strengthened composites have superiortensilestrength, hardness and also possessgood wear resistance when compared with unreinforced alloys.

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 processing of the AMC is the simplest and most commercially used technique for the preparation of AMC.

Anilkumar et.al,[3] investigated and found thatthe 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 remove 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 survey, it becomes clear that the preparation of AMC has been investigated by many researchers. Still, there remains some difficulty in producing AMC with superiormechanical properties, which reveals that still more researches has to be carried out to find a reasonable 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 mechanical properties of the prepared AMC at thedifferentcomposition of the reinforcements.

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 2.3 Graphite powder

Figure2.4 Copper 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 Aluminium alloy 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 3.1 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 and control panel for controlling the stirrer speed and the temperature is depicted in figure 3.3.2 and figure 3.3.3 respectively.

Figure 3.3.2Aluminium stir casting setup **Figure 3.3.3Control panel**

4. Results and Discussion

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

- Tensile strength
- Hardness test
- Impact test

4.1. Mechanical properties:

4.1.1.The tensile strength:

Tensile strength test was carried out on the prepared composite samples using a computerized universal testing machine as per the ASTM E8/E8M-08 standard. Four samples were tested for each composition for the tensile strength. Theresults for tensile test are as follows;

Table 4.1.1Tensile Strength of the AMC

Expt. No.	Sample Id	Tensile strength
1	C1	155.673 MPa
2	C2	155.387 MPa
3	C3	195.469 MPa
4	C4	137.734 MPa

Figure 4.1.1Tensile test specimens

4.1.2. Rockwell Hardness Test:

Rockwell hardness test was employed on the cast samples following the test standard IS: 1586-2000. Four samples were tested for each composition and mean value was taken as the Rockwell hardness text result. The results for hardness test are as follows;

Table 4.1.2Rockwell hardness number ofthe AMC

Expt. No.	Sample Id	RHN
1	C1	26.00HR 30T
2	C2	46.00HR 15T
3	C3	44.60HR 15T
4	C4	55.00HR 15T

Figure 4.1.2 Hardness test specimens

4.1.3 Charpyimpact test:

Charpy impact test was carried out on the prepared composite samples using ananalog impact testing machine (FIE – IT 30) as per the ASTM E23 standard. Four samples were tested for each composition for as the impact strength. The results ofCharpy impact test are as follows;

Table 4.1.3 Impact Strength of composites

Expt. No.	Sample Id	Impact Strength
1	C1	0.075 MPa
2	C2	0.0625 MPa
3	C3	0.0625 MPa
4	C4	0.0625 MPa

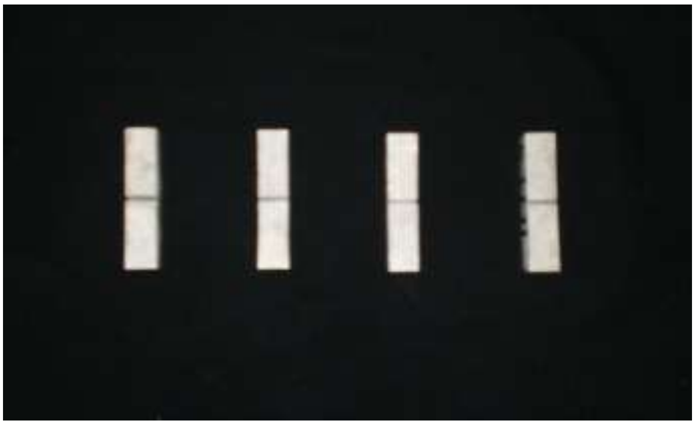

Figure 4.1.3Charpy Impact test specimens

4.1.4.Optimization by Taguchi Technique

4.1.4.1. S/N ratio calculation

The quality attribute with the sort of "larger-the-better" measured in this research work was tensile strength of the cast samples. The Signal to Noise (S/N) ratio for the yield response was computed by using following Equation (1) for each percentage composition and their values are given in Table 4.1.4.

S/N (dB) = -10 $\log_{10}$ (mean of sum squares of reciprocal of measured data) **(1)**

Table 4.1.4 Experimental Conditions and S/N Ratio

Expt. No.	Control factors			Tensile Strength (MPa)	S/N Ratio (dB)
	A	B	C		
1.	10%	3%	3%	155.673	43.8443
2.	10%	4%	4%	155.387	43.8283
3.	15%	3%	4%	195.469	45.8216
4.	15%	4%	3%	137.734	42.7808

4.1.4.2. Response curve:

Response curves are graphical representations of change in performance characteristics with the variation in the parameter level. Figure 4.1.4 shows the response graph for three factors and two levels. From the graphical representation, the peak points are chosen as the optimum levels of parameters.

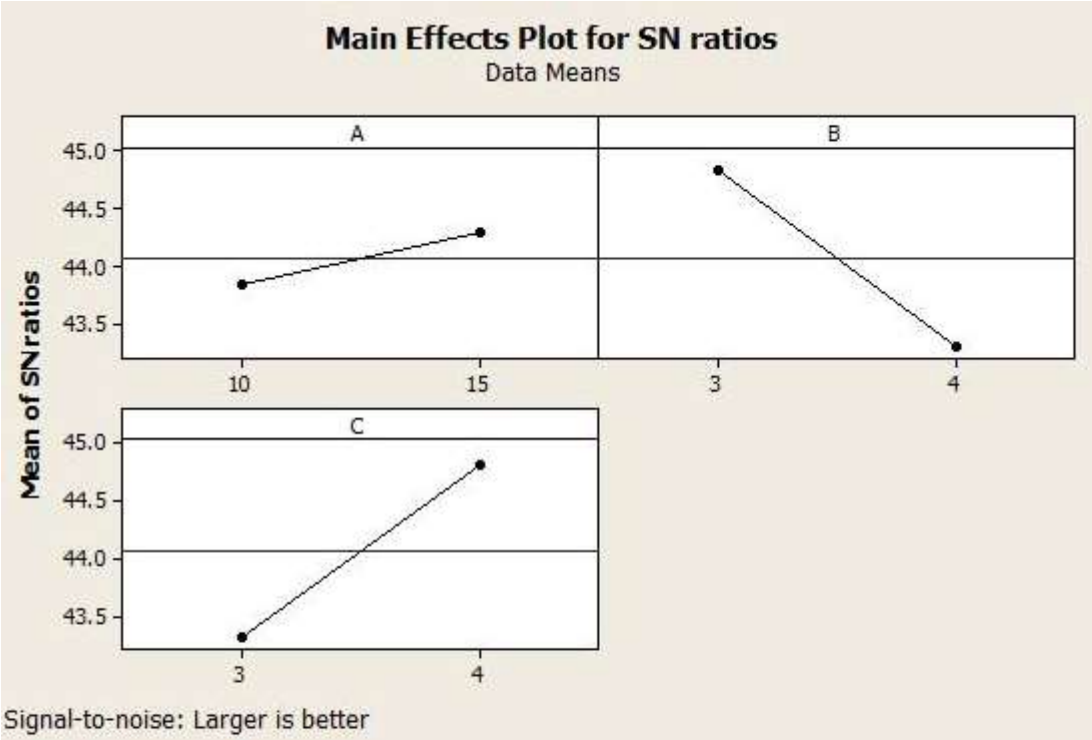

Figure4.1.4Response graph

4.1.5.Confirmation test :

From the responses, the optimum set of parameters was found and given in the table 4.1.5.

Table 4.1.5Optimal parameters for tensile strength

Expt. No.	Control factors			Experimental value	Theoretical value	Error %
	A	B	C			
3	15%	3%	4%	195.469 MPa	194.95 MPa	2.65 %

4.1.6.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.

$$\text{Tensile Strength} = 134 + 2.21\,A - 29.0\,B + 28.7\,C \quad \textbf{(2)}$$

For the above mathematical model, it was found that $r^2 = 0.97$, where ‘r’ is the correlation coefficient and the value range of ‘r^2’ should be between 0.8 and 1 (Montgomery, 2008). The value of ‘r^2’ indicates the nearness of the mathematical model representing the yield response.

4.1.7. Microstructure:

The Microstructure of optimum parameter composite sample (ie., C3) is given in the figure 4.1.7.

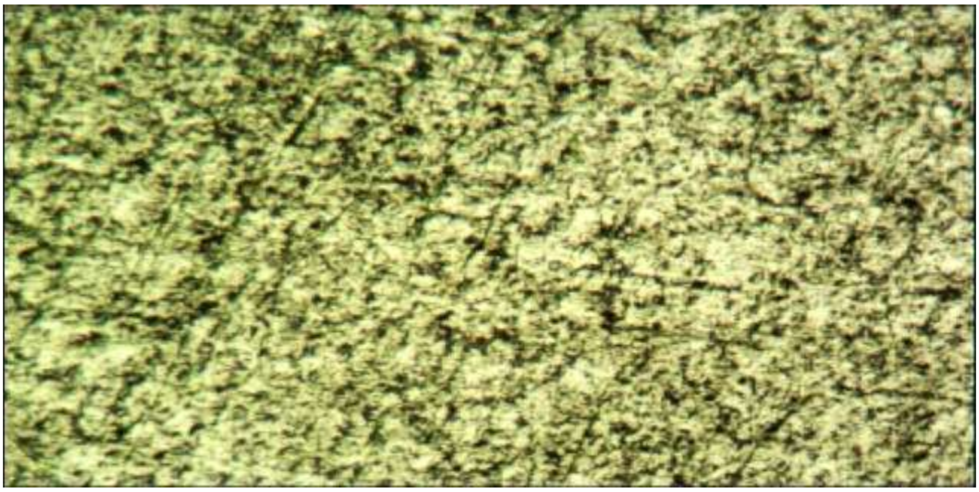

Figure 4.1.7 Microstructure of Al 6061 reinforced with 15% of fly ash, 3% of Cu, 4% of Gr

5. Conclusion

This research work is concluded with the following key points:

i. The stir casting method used to prepare the composites could produce auniform distribution of the reinforced fly ash particles, from the microstructure result it is evident.
ii. The hardness of the cast samples increased with the increase in the weight fraction of reinforced fly ash but the impact strength decreased with the increase in the weight fraction of reinforced fly ash.
iii. In case of tensile strength of the cast samples initially it increased with the increase in the weight fraction of reinforced fly ash and finally it decreased rapidly for the fourth sample, this might be due to the influence of theother reinforcements such as graphite powder and copper powder.
iv. Regression equation generated for the present model was used to predict the tensile strength of the hybrid composite with reasonable accuracy.
v. Experimental values and computed values showing an error associated with thetensile strength of composites is 2.65%. Thus, design of experiments by Taguchi method was successfully used to predict the tensile strength of composites.
vi. Thus from the fourexperiments, the third sample shows the best result with improved tensile strength.

Nomenclature

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

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