International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 06, June-2016

Optimization of Process Parameters of Stir Casting to Maximise the Hardness of Aluminium Reinforced Carbon Fibres Composites by Taguchi's Approach

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***Abstract*— Metal matrix composites are used in a wide range of high performance applications. In this paper, Aluminium 6063 alloy with 5 weight % of intermediate carbon fibres are produced by Liquid Phase process by varying its stirring speed, stirring time and melting temperature with aid of optimization technique called Taguchi's approach. And using the Orthogonal array L9 the experiments were conducted by varying its process parameters of Stirring speed (300 rpm, 400 rpm and 500 rpm), Stirring time (3 min, 5 min and 7 min) and Melting Temperature (720^{0}c, 740^{0}c and 760^{0}c). The scope of the work is to find out the influence of process parameters on its hardness property using the Signal to Noise ratio value and the microstructure of the produced composite is observed through the optical microscope and hardness value is obtained by Rockwell Hardness Testing machine. The effort revealed that the Stirring speed at 500rpm and Stirring time of 5 min and melting temperature of 740^{o}c have high influence on obtaining maximum hardness in the produced samples.**

Keywords*— Aluminium 6063 alloy, intermediate carbon fibre, stir casting , Rockwell Hardness, Taguchi

I. INTRODUCTION

Carbon materials reinforced aluminium composites, including carbon fibres, graphite, diamond, carbon foams, carbon nanotubes, and graphene reinforced aluminium composites, are attracting significant interest because of their light weight, superior mechanical properties, thermal conductivity and low coefficient of thermal expansion [1]. Carbon fibre reinforced aluminium matrix composites are widely used in structural applications such as aerospace, automotive and transportation industries, as well as functional applications such as heat sink and electronic packaging. [2]

Composite material is a material composed of two or more distinct phases (matrix phase and reinforcing phase) and having bulk properties significantly different from those of any of the constituents. The reinforcements can be in the form of continuous fibres, discontinuous fibres, particulates or whiskers. Carbon fibres reinforced aluminium matrix composites are widely used in structural applications such as aerospace, automotive and transportation industries, as well as functional applications such as heat sink and electronic packaging. However, manufacturing problems have limited the industrial applications of this material. [9] The main problems encountered in the development of metal matrix composite for engineering application was the high cost of producing components of even minimally complex shapes. In recent years many processing techniques have been developed to process metal matrix composite. These techniques are stir casting, liquid metal infiltration, squeeze casting, spray decomposition and powder metallurgy. Among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting is generally accepted and particularly promising route, currently practiced commercially. Its advantages lie in its simplicity and applicably to large quantity production. [12]

The Taguchi method, which is effective to deal with responses, was influenced by multi-variables. This method drastically reduces the number of experiments that are required to model the response function compared with the full factorial design of experiments. The major advantage of this technique is to find out the possible interaction between
the parameters.

The main objective of this paper is to study the effect of influence of process parameters in short carbon fibre reinforced with Aluminium matrix which is processed by Stir casting technique. And produced composites undergoes Optical microscope analysis and mechanical testing for hardness property.

Viktor Malau et al. From this study, the increasing parameter of SiC Content factors to 15%wt and melting temperature to 740^{0}c are able to increase the composite hardness made by stir casting process. Increasing rotation speed factor should not be too high from 100rpm, in this case it would decrease composite hardness. And the optimized value of process parameters is obtained by using Taguchi approach of L_{16} Orthogonal arrays. [7] Pengfei Yan et al. In this paper, 5% short carbon fibre reinforced with Aluminium matrix composites were prepared by stir casting method using different stirring speed and stirring time. The microstructure of the composites was observed by the optical microscope and scanning electron microscopy (SEM), the tensile test was carried out. At the conclusion of the paper the result demonstrated that stirring time and stirring speed influence the microstructure and mechanical properties of the composites. The higher stirring time and speed make the distribution of the fibres is uniform and improved the mechanical properties. But beyond certain parameter, the fibre cluster and breakage and the mechanical properties falls.[4] Sozhamannan et al. In the present study, Conventional stir casting process has been employed for producing discontinuous particle reinforced metal matrix composites aluminium metal matrix composites were fabricated by different processing temperatures with different holding time to understand the influence of process parameters on the distribution of particle in the matrix and the resultant mechanical properties. The distribution is examined by microstructure analysis, hardness distribution and density distribution. [8] Ajay Singh Verma et al. Authors elaborates the optimization technique of Taguchi approach for processing Al 6063 and Fly ash The control factor that may contribute to reduce variation can be quickly identified by looking at the amount of variation present as response. Taguchi has created a transformation of the repetition data to another value which is response measure of the variation present. The transformation is signal-to-noise ratio (S/N). [9] J. Hashim et al. gives the details about the Processing variables such as holding temperature, stirring speed, size of the impeller, and the position of the impeller in the melt are among the important factors to be considered in the production of cast metal matrix composites as these have an impact on mechanical properties. These are determined by the reinforcement content, its distribution, the level of the intimate contact of the wetting with the matrix materials, and also the porosity content. Therefore, by controlling the processing conditions as well as the relative amount of the reinforcement material, it is possible to obtain a composite with a broad range of mechanical properties. [10] Michael Bodunrin et al.Paper deals with the Aluminium hybrid composites are a new generation of metal matrix composites that have the potentials of satisfying the recent demands of advanced engineering applications. These demands are met due to improved mechanical properties, amenability to conventional processing technique and possibility of reducing production cost of aluminium hybrid composites. The performance of these materials is mostly dependent on selecting the right combination of reinforcing materials since some of the processing parameters are associated with the reinforcing particulates. A few combinations of reinforcing particulates have been conceptualized in the design of aluminium hybrid composites. This paper attempts tore view the different combination of reinforcing materials used in the processing of hybrid aluminium matrix composites and how it affects the mechanical, corrosion and wear performance of the materials. [12]

II. EXPERIMENT

A. *RAWMATERIAL SELECTION*

The raw material selected for this investigation is Aluminium 6063 alloy and Carbon fibre (IM-7) at chopped condition for preparation of Metal Matrix Composites.

i) *Chemical Composition Of Al 6063 Alloy*

The chemical composition of the material is given below Table 1,

TABLE 1: CHEMICAL COMPOSITION OF AL 6063 ALLOY

Chemical Element	% Present
Manganese (Mn)	0.0 - 0.10
Iron (Fe)	0.0 - 0.35
Magnesium (Mg)	0.45 - 0.90
Silicon (Si)	0.20 - 0.60
Zinc (Zn)	0.0 - 0.10
Titanium (Ti)	0.0 - 0.10
Chromium (Cr)	0.0 - 0.10
Copper (Cu)	0.0 - 0.10
Other (Each)	0.0 - 0.05
Others (Total)	0.0 - 0.15
Aluminium (Al)	Balance

ii) *Aluminium 6063 Alloy*

In this present investigation, Al 6063 alloy of 2.5 Kg is used. The figure of alloy is given below.

FIGURE 1: ALUMINIUM 6063 ALLOY

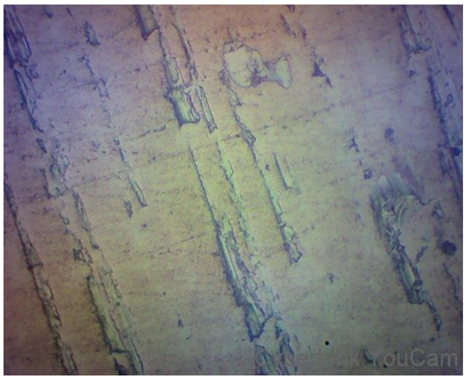

Figure 2: Microstructure Of Raw Material Al 6063

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 06, June-2016

iii) Chopped Fibre

Here the IM 7 continuous fibre (5wt%) is chopped into the short fibres of length 4 - 6 mm is used as reinforcement of the material. The short fibre image is given below,

FIGURE 3: CHOPPED FIBRE

TABLE 2: PROPERTIES OF IM-7 CARBON FIBRE

No. of Filam ents	Tensile Strength (MPa)	Tensile Modulus (GPa)	Strain (%)	Weight/ Length (g/m)	Density (g/cm^3)
6000	5516	276	1.9	0.223	1.78
12000	5654	276	1.9	0.446	1.78

B. PREPARATION OF COMPOSITES

Aluminium alloy (Al6063) is melted in furnace at 850ºc for three- four hours. Chopped carbon fibre is preheated in the preheating furnace for 30 minutes to make the surfaces oxidised. The furnace temperature is maintained above the liquidus temperature of Aluminium alloy to melt it completely. During the process, the molten metal was well agitated by automatic stirrer to create vortex. The depth of the immersed impeller was approximately 2/3 of the height of the molten metal from the bottom of the crucible. Finally the chopped carbon fibre is poured slowly in molten metal. And produce the different composite sample by varying its stirring speed (300 rpm, 400 rpm and500 rpm) Stirring time (3 min,5min and 7 min) and Melting temperature (720ºc, 740ºc and 760ºc) using the Taguchi's Experimental design and the slurry of the composites is poured into preheated steel die as per the experimental values. Then the collected specimen should undergo the optical microscope test and hardness test.

TABLE 3: PROCESS PARAMETERS VARIATION

Level	Stirring Speed (rpm)	Stirring Time (min)	Melting Temperature (ºc)
1	300	3	720
2	400	5	740
3	500	7	760

C. DESIGN OF EXPERIMENTS

In the design of experiment Taguchi method used because it is a problem – solving tool which can improve the performance of the product, process design and system. This method combines the experimental and analytical concepts to

determine the most influential parameter on the result response for the significant improvement in the overall performance. Design of experiment is a technique of defining

and investigating all possible conditions involving multiple factors, parameters and variables in an experiment. It establishes the method for drawing inference from observation, when these observations are not exact, but subject to variations and also used to collect data.

The experiments were conducted as per the standard orthogonal array. The election of the orthogonal array was based on the condition that the degrees of freedom for the orthogonal array should be greater than or equal to sum of those hardness parameters. The parameters chosen for the experiments were (1) Melting temperature (2) stirring speed (3) Stirring time and the factors and their level are indicated in the Table. The experiment consists of 9 tests (each row in the L9 orthogonal array) and the columns were assigned with parameters. In this approach, the response of the S/N ratio the larger is better is used for obtaining the influence of maximum hardness in the produced composites.

TABLE 4: DESIGN MATRIX FOR L_9 ORTHOGONAL ARRAY

Experiments	Experimental Factors and Parameters variation		
	X_1	X_2	X_3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

In the taguchi method the response variation were studied using signal-to-noise ratio and minimization the variations due to uncontrollable parameter. The larger the better S/N ratio used for these responses

$$S/N\ (dB) = -10\log\left(\frac{1}{r}\sum_{i=1}^{r}\left(\frac{1}{y_i}\right)^2\right)$$

Here db means decibel, y = observation, r = total number of observation and y_i= i[th] response .

TABLE 5: EXPERIMENTAL CONDITION

Experiments	Stirring Speed (rpm)	Stirring Time (min)	Melting Temperature (°c)
1	300	3	720
2	300	5	740
3	300	7	760
4	400	3	740
5	400	5	760
6	400	7	720
7	500	3	760
8	500	5	720
9	500	7	740

III. RESULT AND DISCUSSIONS

A. PREPARED SAMPLES

The samples fabricated through Taguchi Experimental Design and the samples views are given below,

Fig.1 : PRODUCED SAMPLES VIEW 1

Fig.2: PRODUCED SAMPLES VIEW 2

B. HARDNESS TEST

The produced composites Specimens undergoes Hardness Test in Rockwell Hardness machine. The values of the composites are given below in the Table 6.1.

Table 6.1: prepared samples with Hardness value

Experiments	**Stirring Speed (rpm)**	**Stirring Time (min)**	**Melting Temperature (°c)**	**Hardness Value (HRB)**
1	300	3	720	51
2	300	5	740	57
3	300	7	760	54
4	400	3	740	58
5	400	5	760	56
6	400	7	720	53
7	500	3	760	63
8	500	5	720	65
9	500	7	740	61

C. MICROSTRUCTURE OF SAMPLE

The microstructure were examined under 100x and 1000x magnification and these images were taken in the middle portion of the specimens.

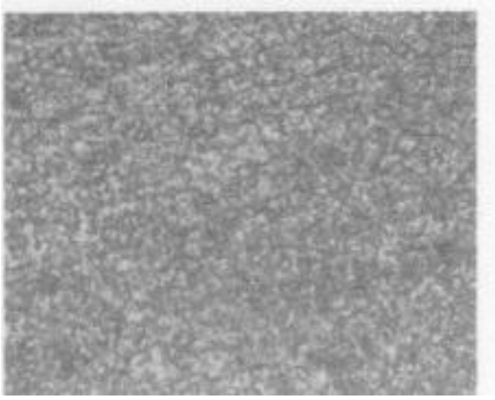

Fig.3: MICROSTRUCTURE UNDER 100X

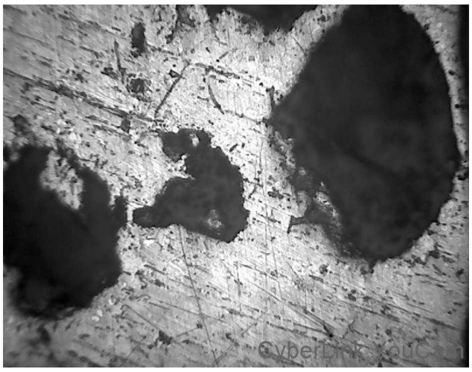

Fig.4: MICROSTRUCTURE UNDER 1000X_VIEW 1

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 06, June-2016

Fig.5: MICROSTRUCTURE UNDER 1000X_VIEW 2

In the above analysis, the microstructure revealed the distribution of fibres in the produced composites.

D. TAGUCHI EXPERIMENTAL RESULTS

Experiment condition and result of Hardness test for each experiment is based on L_9 orthogonal array. Response data of experiment results were calculated by MINITAB 16 and Microsoft Excel 2003 software. The result of experiment data calculations is given below in the Table 6.

TABLE 6: EXPERIMENTAL DATA AND RESULTS

Exp. no.	Stirring Speed (rpm)	Stirring Time (min)	Melting Temperature (°c)	Hardness Value (HRB)	S/N ratios (dB)
1	300	3	720	51	34.1514
2	300	5	740	57	35.1174
3	300	7	760	54	34.6478
4	400	3	740	58	35.2685
5	400	5	760	56	34.9637
6	400	7	720	53	34.4855
7	500	3	760	63	35.9868
8	500	5	720	65	36.2582
9	500	7	740	61	35.7065

TABLE 7: RESPONSE TABLE OF S/N RATIOS FOR HARDNESS- LARGER IS BETTER

Level	Stirring speed	Stirring Time	Melting Temperature
1	34.64	35.14	34.97
2	34.91	35.45	35.36
3	35.98	34.95	35.20
Delta	1.34	0.50	0.40
Rank	1	2	3

TABLE 8: RESPONSE TABLE FOR MEANS FOR HARDNESS

Level	Stirring speed	Stirring Time	Melting Temperature
1	54.00	57.33	56.33
2	55.67	59.33	58.67
3	63.00	56.00	57.67
Delta	9.00	3.33	2.33
Rank	1	2	3

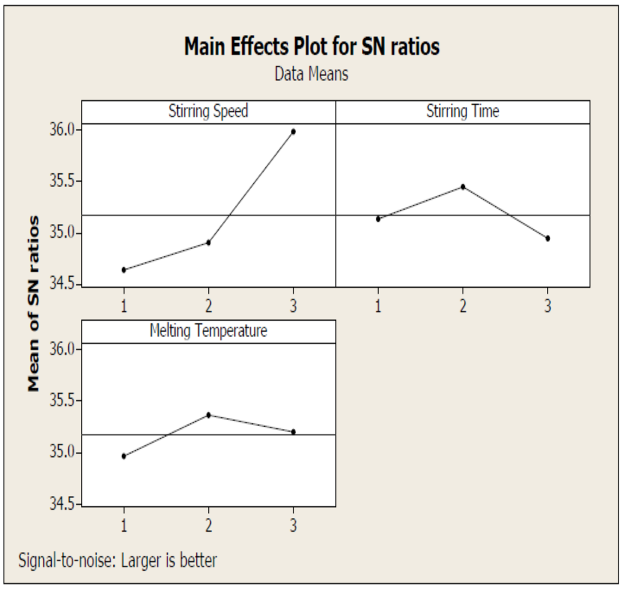

Fig. 6: MAIN EFFECTS PLOT FOR SN RATIOS VERSES PARAMETERS

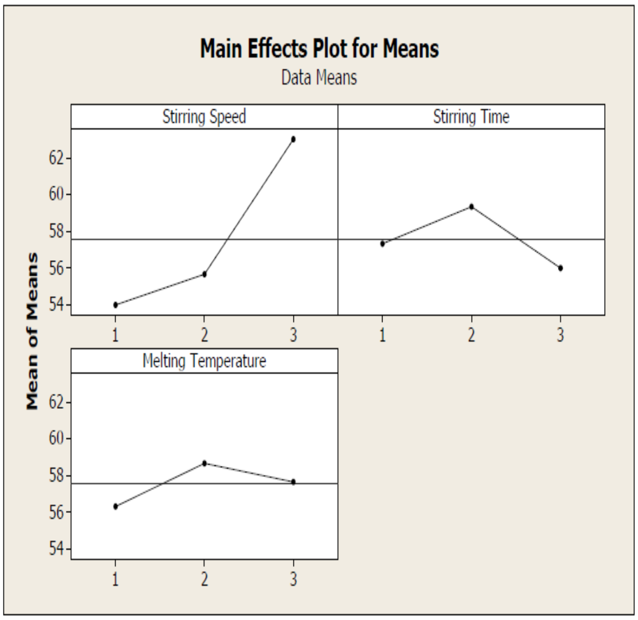

Fig.7: MAIN EFFECTS PLOT FOR MEAN VERSES PARAMETERS

From the above Taguchi's experimental analysis, it is observed that the hardness value for the produced sample increases according to the variation of stirring speed and the hardness value initially increases and then slightly decreases at high stirring time as well as it increases initially in melting temperature and then slightly decreases at high melting temperature. By the SN ratios verses parameters Graph 6.5, we find out that the Stirring speed at 500 rpm and Stirring time of 5 min and melting temperature of 740°c have high influence on obtaining maximum hardness in the produced samples.

CONCLUSION

The Conclusion of the investigation is as follows,

- From the Taguchi's Optimization approach, it is observed that the hardness value for the produced sample increases to the variation of stirring speed and the hardness value of the Stirring time initially increases and then slightly decreases at high stirring time as well as it increases initially in melting temperature and then slightly decreases at high melting temperature.
- The Presence of carbon fibres are observed in the microstructure of the produce specimen.
- And the Stirring speed at 500rpm and Stirring time of 5 min and melting temperature of 740ºc have high influence on obtaining maximum hardness in the produced samples.

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