Development of Aluminum 6061-Sic Composite and It's use in Manufacturing of Dovetail by Single Response Optimization of Hardness and Surface Roughness by Taguchi Method in Stir Casting

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Abstract

Aluminum alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion resistance and wear, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties of these materials and relatively low production cost make them a very attractive candidate for a variety of applications both from scientific and technological viewpoints. In the present investigations an attempt has been made on the study of performance characteristics of Al 6061 reinforcing with varying SiC content composite for varying process parameters. The composite is prepared by stir casting process in an electric melting furnace. The experimental study is performed varying weight % of Silicon carbide powder, pouring temperature and stirring time. The methodology based on orthogonal array Taguchi's analysis of variance (ANOVA) and signals to noise ratio (S/N Ratio) were employed to optimize the performance characteristics like Hardness and Surface roughness of developed Al 6061-SiC composite.

Keywords: Aluminum Metal Matrix Composite, Stir Casting, Reinforcement Silicon Carbide, Taguchi Method, ANNOVA, Hardness, Surface Roughness, Orthogonal Array, Signal to Noise ratio

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I. INTRODUCTION

Now days with the modern development need of developments of advanced engineering materials for various engineering applications goes on increasing. To meet such demands metal matrix composite is one of reliable source. Composite material is one of the reliable solutions for such requirement. In composites, materials are combined in such a way as to enable us to make better use of their parent material while minimizing to some extent the effects of their deficiencies. The simple term 'composites' gives indication of the combinations of two or more materials in order to improve the properties. In AMC one of the constituent is aluminum, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminum and serves as reinforcement, which is usually nonmetallic and commonly ceramic such as SiC, Al2O3,B4C etc.[2,4,8]

Al 6061 is quite a popular choice as a matrix material to prepare MMCs owing to its better formability characteristics. It is widely used in numerous engineering applications including transport and construction where superior mechanical properties such as tensile strength, hardness etc. are essentially required. [12, 13, 14, 15]

Aluminum engine blocks, suspension components, body panels, and frame members are increasingly common, in addition of the use of magnesium in components. Combining or replacing these efforts with the use of advanced Metal Matrix Composites (MMCs) not only to reduce mass, but also improve reliability and efficiency. It also offers unique opportunities to tailor materials to specific design needs. These materials can be tailored to be light weight and with various other properties including High specific strength and specific stiffness, High hardness and wear resistance, low coefficients of friction and thermal expansion, high thermal conductivity, high energy absorption and a damping capacity. In addition to these properties, new MMCs are being developed with self-healing, self-cleaning and self-lubricating properties, which can be used to enhance energy efficiency and reliability of automotive systems and components. [1, 3, 7, 9]

The hardness and surface roughness as output parameters and optimization of process parameters for maximum hardness and minimum surface roughness should be investigated experimentally and the obtained results should be interpreted and modeled statistically to understand closely the mechanical properties of developed composite. In this study, the effect of the stir casting process parameters and their levels of significance on the hardness and surface roughness are statistically evaluated by using analysis of variance (ANOVA). The settings of process parameters were determined by using Taguchi experimental design method. [5, 6, 20, 21]

II. EXPERIMENTAL DETAILS

A. Material and Methods:

For the fabrication process aluminum alloy, 6061 is used as matrix metal that has been reinforced with SiC particles of 60-90 µm. The reinforcement percentage is varied in the range of 0%, 5% and 10% by weight. The chemical composition of the matrix material Al 6061 is given below.

Table - 1
Chemical Composition of Al 6061. By Wt % [1, 17, 19]

Elements	*Percentage*
Al	*Balance*
Mg	*0.8 - 1.2*
Si	*0.4 - 0.8*
Fe	*Max 0.7*
Cu	*0.15 - 0.40*
Zn	*Max 0.25*
Ti	*Max 0.15*
Mn	*Max 0.15*
Cr	*0.04 - 0.35*

Table -2
Properties of Al 6061[1, 17, 19]

Melting Point	*Approx 580˚C*
Modulus of Elasticity	*70-80 GPa*
Poisson's Ratio	*0.33*
Density	*2.7 g/cm^3*

Silicon carbide is used as reinforcement particle. It is a compound of silicon and carbon with chemical formula SiC. It is used in abrasives, refractories, ceramics, and numerous high performance applications. Silicon carbide is composed of tetrahedral of carbon and silicon atom with strong bonds in the crystal lattice. This produces a very hard and strong material. It has characteristics like low density, high strength and thermal conductivity, low thermal expansion and high hardness. [23]

Table - 3
Properties of Silicon Carbide [17, 19]

Melting Point	*2200-2700˚C*
Hardness (Kg/mm^2)	*2800*
Density(g/cm^3)	*3.1*
Coeff. of thermal expansion	*4.0 (µm/m˚C)*
Fracture toughness	*4.6 MPa*
Poisson's Ratio	*0.14*
Colour	*Black*

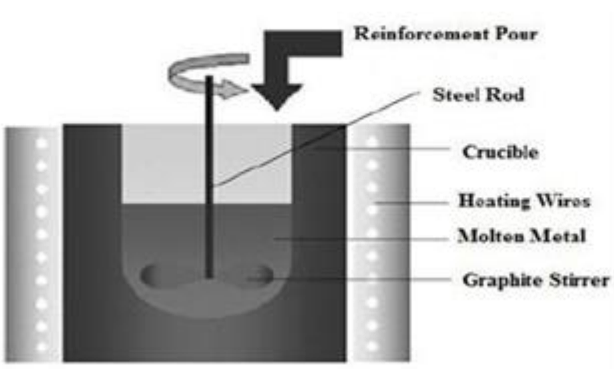

Fig. 1: Graphical representation of stir casting [16, 18]

The fabrication process of Al 6061-SiC composites were carried out by stir casting process. The graphical representation of the experimental set up for making of these composites was shown in figure 1. Approximately 1 Kg of alloy in solid form (hexagonal rod) was melted at 820˚C in the resistance furnace. Preheating of reinforcement silicon carbide at 800˚C was done for one hour to remove moisture and gases from the surface of the particulates. The reinforcement particles were sieved by sieve shaker. Preheated reinforced particles were added with a spoon into the melt manually. After addition of reinforcement, stirring was continued for 20-40 seconds for proper mixing of prepared particles in the matrix. The composite slurry was then reheated to a fully liquid state and stirring is carried out. The final temperature was controlled to be around 750˚C. The melt was kept in the crucible for approximate half minute in static condition and then it was poured in the mould.

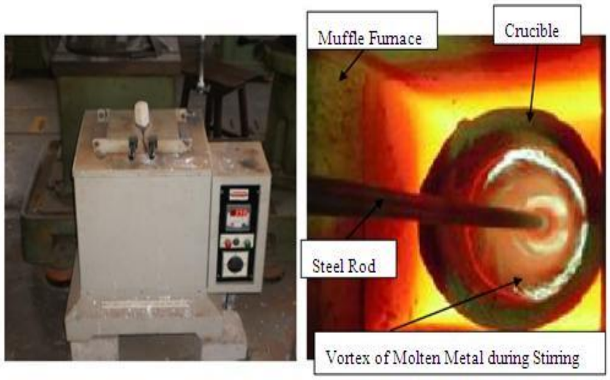

Fig. 2: Muffle furnace and Preparation of samples in muffle furnace

Fig. 3: Synthesis of Al alloy with SiC composite using Stir casting route [As cast Dovetail]

Fig. 4: Finished product for Micro hardness, Surface roughness and Microstructure [After machining Dovetail]

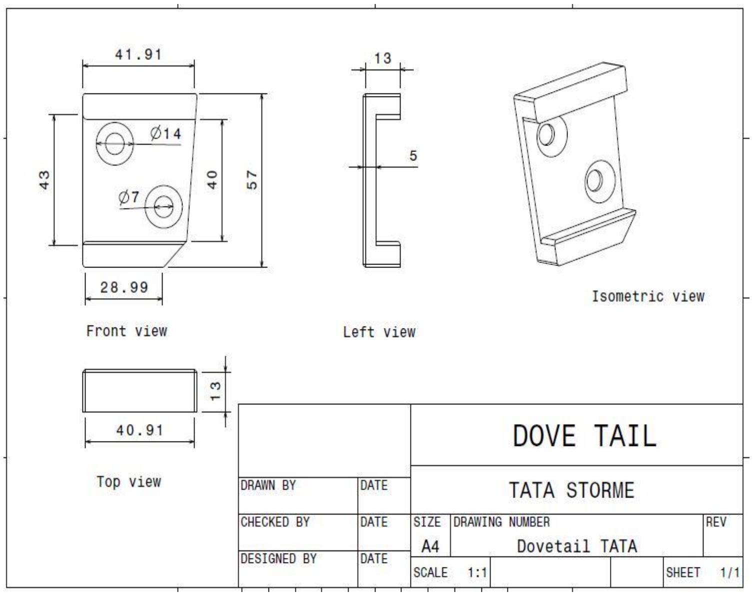

Fig. 5: Catia Drawing of Dovetail [Automobile Part]

B. Finding Critical Function Parameters [10, 16, 19]

Function parameters are nothing but control parameters. Parameters which really affect the response of uncontrollable parameters such as Hardness, Surface roughness, Microstructure etc. are known to be critical function parameters. In stir casting route, there are many factors affecting for mechanical and physical properties of developed composite. Reinforcement of SiC wt %, pouring temperature, Stirring time, Particulate preheat temperature, Stirring speed are few of effecting parameters.

For this research work, hardness and surface roughness is used as response variables. The more effective variable for these responses is selected. Hence SiC wt%, Pouring temperature and Stirring time are the variables which are most effective for the response of hardness and surface roughness.

C. Defining Levels of Critical Parameters:

In this research work, three factors are selected. Levels indicate variation in the factors used for research work. Three levels of each parameter are selected for experimentation. These three levels are as follows.

Table – 4
Levels of Critical Parameters

Sr. No.	*Factors*	*Levels*
1	*SiC wt.%*	*0%,5%,10%*
2	*Pouring Temperature(˚C)*	*660,710,760*
3	*Stirring Time (second)*	*20,30,40*

These levels decided from manufacturers control plan and present casting procedure of stir casting.

D. Design of Experiment:

Design of experiment is technique used for experimentation. Various forms of DOE viz. Response surface method, Taguchi method, and Factorial design method are used for experimentation. For this research Taguchi technique is used. In experimentation, according to Taguchi design of L9 array, total 9 trials are experimented.

E. Analysis of Samples by Simulation Method:

Now when design is created according to Taguchi technique and all experimental trials are carried according to Taguchi experimentation plots, samples are segregated for testing. This includes measurement of Hardness (in BHN) using Brinell Hardness Testing machine, Surface roughness (Ra value in µm) using surface roughness tester as per the tagging applied to the samples.

F. Finding Optimal Solution:

After Experimentation carried, all the results obtained are plotted according to their trial numbers. Analysis of optimal solution is based on requirement. There are three conditions at which we get optimal solution.

- Larger is better = -10log 10 (sum $(1/Y^2)$/n)
- Nominal the better = -10log 10 (Y^2)
- Smaller the better = -10log 10 (sum (Y^2/N))

For this research work, Larger the better condition is used for response variable hardness needs to maximize to get good results. And Smaller the better condition is used for response variable surface roughness needs to minimize to get good results.

G. Validation:

It is very necessary to validate obtained results. Results which we get experimentally are true or not is unknown part. Hence validation gives evidence behind every experimental result. Validation can be either way. One way, is comparing both experimental and analytical result. Other way is to set target value and experimenting other value to ensure not to cross targeted value.

H. Conclusion:

Conclusion is based on result obtained and validation part. Conclusion is what we have observed with results and graph obtained. It tells about effect and contribution of input parameters on response value.

III. EXPERIMENTATION

A. Design of Experiments:

The experimental layout for the process parameters using the L9 orthogonal array was used in this study. This array consists of three control parameters and three levels, as shown in table III. In the Taguchi method, most all of the observed values are calculated on the 'higher the better' and the 'smaller the better'. Thus in this study, the observed values of hardness were set to maximum as desired values and surface roughness were set to minimum desired values. [5]

Table – 5
Indicates the scheme of experiment and levels

Control Parameters	Levels			Observed Values
	1	2	3	
SiC Wt.% (A)	0	5	10	1]Hardness in BHN 2] Surface roughness in µm
Pouring Temperature (B)	660	710	760	
Stirring Time (C)	20	30	40	

Table – 6
Taguchi L9 orthogonal array

Trail No.	A = SiC wt %	B = Pouring Temperature	C = Stirring Time
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

B. Response Variable Selected:

In the present study, the following two parameters have been use as response variables; Hardness and Surface roughness (hardness is measured in BHN and surface roughness measured in µm)

C. Hardness Measurement:

In this current study hardness is measured using Brinell Hardness Testing Machine with 500 Kgf (Load) × 10 mm Ball. Range of hardness on desired surface of the part is measured.

D. Surface Roughness Measurement:

Surface roughness tester is used for measuring arithmetic roughness (Ra) value in µm. after machining of the Dovetail automobile part the desired surface of the part were checked under roughness tester. Mean value of Ra is calculated by avearaging three roughness values.

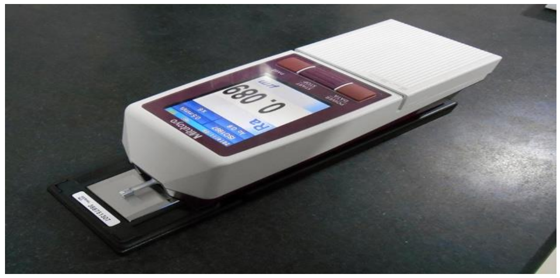

Fig. 6: Surface Roughness Tester [Mitutoyo]

E. Observed Response Values:

According Taguchi design all the experiments should be carried. Brief procedure how response values are obtained are given in (C and D). Results obtained after experimentation and testing are as shown in table VII.

IV. RESULTS AND DISCUSSION

A. Determination of Optimal Process Parameters for Hardness:

In this section, we will discuss calculation procedure and results obtained by applying Taguchi method. L9 orthogonal array is used to determine the optimal process parameters. The results are reported in S/N ratio and ANOVA analysis. In Taguchi method, there are three performance characteristics such as higher-is-better, nominal-is-better and lower-is-better. Here higher-is-better characteristics are used to find the optimal process parameter for hardness. [22] The Hardness and S/N ratio for hardness is listed in table VII.

Table - 7
Observed values of Hardness and its S/N ratio

Trial	*A*	*B*	*C*	*Hardness in BHN*	*S/N ratio for Hardness(dB)*
1	*1*	*1*	*1*	*30.00*	*29.54243*
2	*1*	*2*	*2*	*30.5*	*29.68600*
3	*1*	*3*	*3*	*31.00*	*29.82723*
4	*2*	*1*	*2*	*65.00*	*36.25827*
5	*2*	*2*	*3*	*66.50*	*36.45643*
6	*2*	*3*	*1*	*67.00*	*36.52150*
7	*3*	*1*	*3*	*90.50*	*39.13297*
8	*3*	*2*	*1*	*95.00*	*39.55447*
9	*3*	*3*	*2*	*102*	*40.17200*

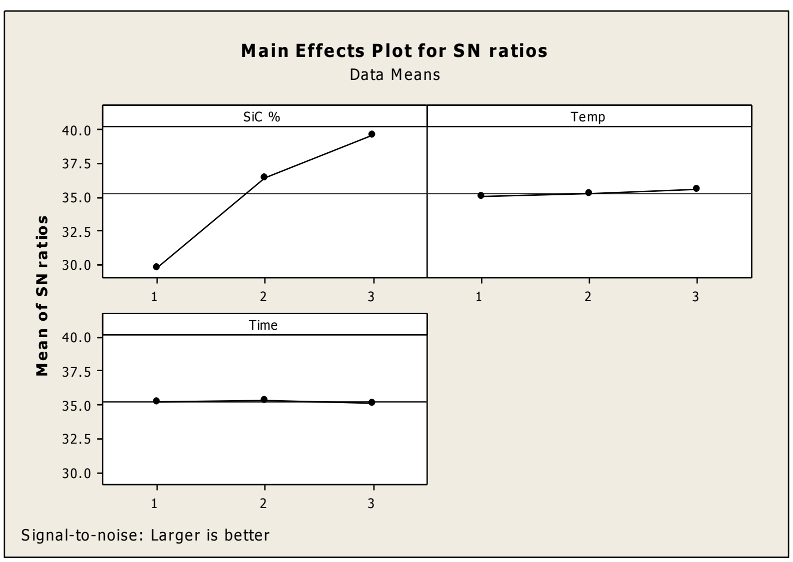

Fig. 7: Means of S/N ratio graph for Hardness

Above graph is obtained from table VII. Hence from above figure it is clear that, best combination obtained for hardness if SiC wt. % of level-3, Pouring Temperature of level-3, and Stirring time of level-2.

B. Analysis Means of S/N Ratio for Hardness:

As the experimental design is orthogonal, so it is possible to separate out the effect of each process parameter at different levels.

Table - 8
Means of S/N ratio for Hardness

Level	SiC wt. %	Pouring Temp.	Stirring Time
1	29.69	34.98	35.21
2	36.41	35.23	35.37
3	39.62	35.51	35.14
Delta	9.93	0.53	0.23
Rank	1	2	3
Total Mean of S/N ratio 35.24 dB			

From S/N ratio of Hardness in table VII, the mean of S/N ratio for hardness, the optimal process parameters are obtained such as SiC wt.% at level-3, Pouring Temperature at level-3, and Stirring time at level-2 (refer table VIII).

C. ANOVA for Hardness:

The purpose of the ANOVA is to find the statistical significance of process parameters on the response shown in table IX. From table, it is found that values of P for all input parameters are greater than 0.05. Hence according to F Value SiC wt % is most significant effect on Hardness. [22]

Table - 9
ANNOVA for Hardness

Source	DF	Adj. SS	Adj.MS	F-Value	P- Value	%Contribution
SiC %	2	6420.70	3210.33	329.26	0.003	98.92
Temp	2	35.20	17.60	1.80	0.357	0.54
Time	2	15.20	7.60	0.78	0.563	0.23
Error	2	19.50	9.80			0.31
Total	8	6490.5				

D. Determination of Optimal Process Parameters for Surface Roughness (Ra):

In this process, S/N ratio for surface roughness is obtained based on response of surface roughness, 'Lower is better' criteria is choose for surface roughness. Results obtained are plotted in tabular form, which is given in table X.

Table – 10
Experimental results of Surface roughness and its S/N ratio

Trial	A	B	C	Surface Roughness in µm	S/N ratio for SR(dB)
1	1	1	1	1.610	-4.13652
2	1	2	2	1.625	-4.21707
3	1	3	3	1.590	-4.02794
4	2	1	2	1.605	-4.10950
5	2	2	3	1.630	-4.24375
6	2	3	1	1.625	-4.21707
7	3	1	3	1.595	-4.05521
8	3	2	1	1.615	-4.16345
9	3	3	2	1.620	-4.19030

V. ANALYSIS MEANS OF S/N RATIO FOR SURFACE ROUGHNESS

Similarly, the S/N ratio for surface roughness is calculated. Here, lower-is-better characteristics are used to find the optimal process parameter for surface roughness (Ra). From the means of response of S/N ratio for Ra from table X, the optimal process parameters are obtained such as SiC wt. % of level-1, Pouring temperature of level-1 and Stirring time of level-3.

Table - 11
Means of S//N Ratio for surface roughness

Level	SiC wt. %	Pouring Temp.	Stirring Time
1	-4.1272	-4.1004	-4.1723
2	-4.1901	-4.2081	-4.1723
3	-4.1363	-4.1451	-4.1090
Delta	0.0629	0.1077	0.0633
Rank	3	1	2
Total Mean of S/N ratio -4.1512 dB			

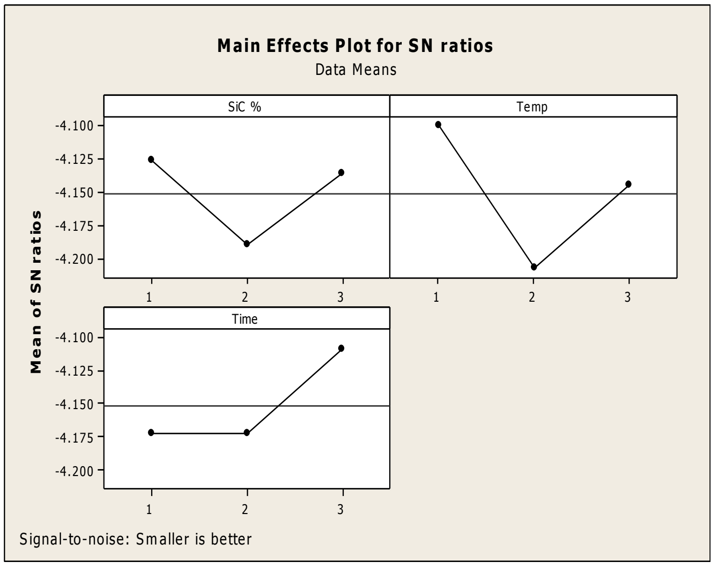

Fig. 8: Means of S/N ratio graph for Surface Roughness

From the above graph, it is clear that, Surface Roughness with lower value is better results for good combination. Hence, from above figure we conclude that, SiC wt. % of level-1, Pouring temperature of level-1 and Stirring time of level-3 are best combination result.

E. ANOVA for Surface Roughness (Ra):

ANOVA for surface roughness (Ra) is listed in the table XII. From the table it is clearly found that pouring temperature with highest contributing parameter for surface roughness. Therefore, pouring temperature is the most significant parameter for Ra followed by stirring time and SiC wt. %. [22]

Table - 12
ANNOVA for Surface Roughness (Ra)

Source	*DF*	*Adj. SS*	*Adj.MS*	*F-Value*	*P- Value*	*% Contribution*
SiC %	*2*	*0.000364*	*0.000182*	*0.54*	*0.648*	*23.3933*
Temp	*2*	*0.000740*	*0.000370*	*1.38*	*0.420*	*47.5578*
Time	*2*	*0.000412*	*0.000206*	*0.62*	*0.617*	*26.4781*
Error	*2*	*0.00004*	*0.00002*			*2.5708*
Total	*8*	*0.001556*				

VI. CONCLUSIONS

This paper has presented an application of parameter design of Taguchi method in the optimization stir casting process parameters. The following conclusions can be drawn based on the experimental results of this study:

1) According to results obtained by parameter optimization of Hardness is Silicon Carbide (SiC) weight percentage with 3rd level, pouring temperature with 3rd level and Stirring time with 2nd level. Silicon Carbide (SiC) is most significant effective parameter for hardness compare to pouring temperature and stirring time.
2) According to responses of S/N ratio for Surface roughness Silicon Carbide with 1st level, pouring temperature with 1st level and stirring time with 3rd level is best combination of result. Pouring temperature is most significant effective parameter for surface roughness, followed by stirring time and silicon carbide weight percentage.
3) According to ANOVA table for Hardness, SiC wt. % is most significant effective parameter for Hardness.
4) According to ANOVA table for Surface roughness, pouring temperature is most significant effective parameter for surface roughness.
5) One more conclusion we can draw from fig.7 if SiC wt. % of reinforcement in Aluminum metal matrix is increases hardness is increases.

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