Optimization of Process Parameters of CNC Milling for Aluminium Metal Matrix Composite

Vijay K.Patel[1], Bhupesh Goyal[1], Chinmay Shah[1]

[1]*Assistant Professor, Parul Institute of Technology, Limda, Waghodiya*

Abstract--**Composite materials have many engineering application for manufacturing, packaging, automobile industry etc. For the machining of these composite Materials, many accurate and cost effective machining processes have been used to reduce the machining time and worker timings.The work piece of particulate reinforcement metal matrix composite (PRMMC's) of Aluminium as Matrix material and Alumina (Al_2O_3) and Silicon Carbide (SiC) powder as reinforcement material is prepared by the metal stir casting process with different percentage variation in proposition of Silicon Carbide (SiC) powder to Aluminium matrix. Then the work piece of the composites are carried out for machining on CNC milling to evaluate surface roughness with different process variables which are speed, feed and depth of cut. Analysis of the prepared machining parts is carried out using Design of Experiments(Taguchi technique) with mixed level array of L18 matrix and L6 matrix. For confirmation of analysed result, outcome was tested by ANNOVA method.**

Keywords-- Composite, DOE, ANNOVA, reinforcement, CNC, MMC, CMC, PMC.

I. INTRODUCTION

In modern scenario of development of manufacturing process, with the development of technology, more and more challenging problems are faced by the engineers and technologists in the field of manufacturing. Simultaneously, many new complex geometrical shaped components have been developed to overcome such problems. But some of those components are very difficult to machine due to their complex shapes. Besides machining of those are time consuming and costly for mass production also. So, to achieve higher accuracy with higher rate of production, need of automation and controlled machining processes is raised. As result CNC (Computer numerical controlled) machines are introduced. Periodic metals and their alloys are not capable of full filling every required properties for specified application. But combination of two or more material could be the solution for such issue. So composite materials have been introduced dramatically. Composites are made up of individual materials referred to as constituent materials. There are two main categories of constituent material 1.Matrix 2. Reinforcement. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous.

Classification of Composites:

A. On the basis of matrix material :
   - Metal Matrix Composites (MMC)
   - Ceramic Matrix Composites (CMC)
   - Polymer Matrix Composites (PMC)

B. On the basis of reinforcement material structure :
   - Particulate Composites
   - Fibrous Composites

Manufacturing Techniques of MMC

- Solid state method
- Liquid state method
- Semi-solid state method
- Vapour state method

Design of Experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. A proper design of experiment is essential to obtain maximum information about the process in minimum number of trials for limiting the time and cost involved in experimentation.

Methodology of DOE:

- Comparative Experiment
- Screening Experiment
- Modelling Experiments

Types of DOE:

- Full Factorial
- Fractional Factorial
- Screening Experiments
- Response Surface Analysis
- EVOP
- Mixture Experiments

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr.Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there is intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly. The Taguchi arrays can be derived from software called MINITAB. The arrays are selected by the number of parameters (variables) and the number of levels (states). Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic.

II. EXPERIMENT METHODS

Aluminium alloy 6061 is one of the most extensively used of the 6000 series Aluminium alloys. It is a versatile heat treatable extruded alloy with medium to high strength capabilitie and from [1] For making the composite with high strength, hardness and fracture toughness x6061 matrix is the best.

Composition:

Table I:COMPOSITION of ALUMINIUM ALLOY 6061

Component	Amount (wt. %)
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4 – 0.8
Iron	Max. 0.7
Copper	0.15-0.40
Zinc	Max. 0.25
Titanium	Max. 0.15
Manganese	Max. 0.15
Chromium	0.04-0.35
Others	0.05

Typical properties of Aluminium alloy 6061 include:

- Good toughness
- Good surface finish
- Excellent corrosion resistance to atmospheric conditions
- Good corrosion resistance to sea water
- Can be anodized
- Good weldability and brazability
- Good workability
- Widely available

Physical Properties:

- Density: 2.7 g/cm^3
- Melting Point: Approx. 580°C
- Modulus of Elasticity: 70-80 GPa
- Poissons Ratio: 0.33

Thermal Properties:

- Co-Efficient of Thermal Expansion (20-100°C): 23.5x10^{-6} m/m.°C
- Thermal Conductivity: 173 W/m.K

Electrical Properties:

- Electrical Resistivity: 3.7 – 4.0 x10^{-6} Ω.cm

Among various discontinuous reinforcement material used, silicon carbide is one of the most inexpensive and low density reinforcement available in large quantities.
Silicon carbide powder of 120 mesh by different weight percentage to the aluminium (Al6061) i.e. 5%. 10%, 15% was measured using weighing scale. Silicon Carbide (SiC) powder then first preheated to remove the moisture in it. Alumina (Al_2O_3) powder with 120 mesh was weighted using weighing scale.
From literature review we observed that the between Al2O3and SiC reinforced material Al2O3 reinforced composite material has higher density, hardness and higher tensile and yield strength compare to SiC reinforced composite material. But % increase in properties are less in Al2O3 reinforced material thanSiC reinforced material so we decide to use constant weight percentage of Al2O3 and make variation of 5%,10% and 15% in SiC particle in base matrix.

Manufacturing Process:

Stir Casting: Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibres) is mixed with a molten matrix metal by means of mechanical stirring.

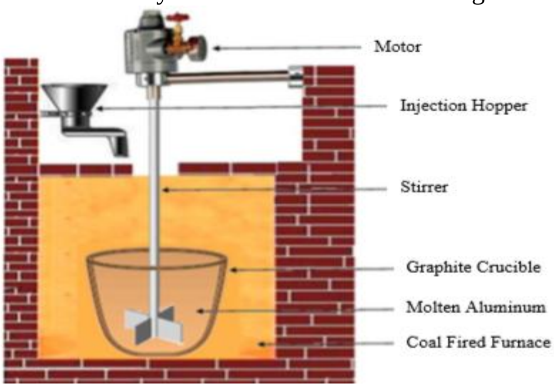

Fig.1 Stir Casting Setup

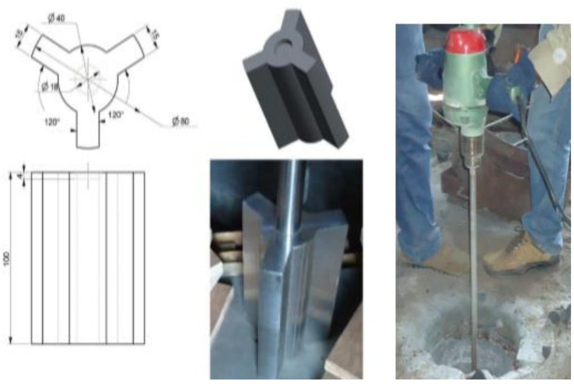

Fig.2 Design and Application of stirrer

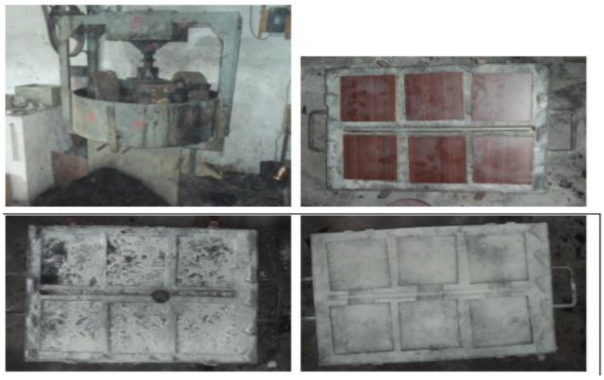

Fig.3 Sand Muller and Preparation of Mould

Fig.4 Pouring of Prepared Composite in Mould and Obtained Casting

Similar method was followed to get a different weight percentage i.e. 5%, 10%, 15% by changing the (Silicon Carbide) SiC particles weight fraction and keeping additional percentage of alumina (Al2O3) constant.

Material Testing:

Work piece are machined on lathe machine to set dimension of test specimen to 110×110×12 mm to perform Hardness test and for CNC Milling work.
Hardness Test Hardness of work piece is on measured on BRINELL's hardness testing machine with 5 mm ball diameter and 250kg load. Test performed for 3 test specimen (Each from different percentage variation).

Table II: HARDNESS VALUE of 5% SiC & 5% Al_2O_3 REINFORCED MATERIAL

Specimen	Inden t Dia.	BHN	Speci men	Indent Dia.	BHN
5a	2.2	62.41	5f	2.4	51.87
5b	2.2	62.41	5g	2.3	56.79
5c	2.3	56.79	5h	2.2	62.41
5d	2.2	62.41	5i	2.3	56.79
5e	2.3	56.79	5j	2.2	62.41
Average Hardness				59.108	

Table III: HARDNESS VALUE of 10% SiC & 5% Al_2O_3 REINFORCED MATERIAL

Specim en	Inden t Dia.	BHN	Specimen	Inden t Dia.	BHN
10a	1.9	84.86	10f	2.15	65.51
10b	2.1	68.84	10g	2.3	56.79
10c	2.2	62.41	10h	2.2	62.41
10d	2.1	68.84	10i	2.2	62.41
10e	2.1	68.84	10j	2.4	51.87
Average Hardness				65.278	

Table IV: HARDNESS VALUE of 15% SiC & 5% Al_2O_3REINFORCED MATERIAL

Speci men	Indent Dia.	BHN	Speci-men	Indent Dia.	BHN
15a	2.2	62.41	15d	2	76.26
15b	2.1	68.84	15e	2.2	62.41
15c	2.15	65.51	15f	2.1	68.84
Average Hardness				67.5	

Table V: HARDNESS VALUE MEASURED in ERDA, VADODARA

Specimen	BHN1	BHN2	Average BHN
5a	61.2	63.3	62.25
10f	68.3	64.2	66.25
15a	68.7	66.3	67.5

CNC Machining & Surface Roughness Test:

CNC milling machine used for making geometry on the specimen.

Table VI: SPECIFICATION ofMTAB CNC XLMILL

Table Size	360mm × 132mm
Travel X Axis	225mm
Travel Y Axis	150mm
Travel Z Axis	115mm
Spindle to Table Distance	70mm to 185mm
Spindle Column	110mm
Spindle Nose Taper	ISO 30
ATC	6 Stations
ATC-Maximum Tool Diameter	16mm
ATC-Maximum Tool Length	40mm
ATC-Direction	Bi Direction
Programmable Spindle Speed	150-4000

Selection of Process and Response Variables of DOE The experiment is seen as a "black box", where only input and output are considered. Following are the process variables which selected for the machining of MMCs.
Process variables:

- Spindle speed
- Feed
- Depth of cut
- Material variation(Percentage amount of filler material is varied in different sets of combinations in MMC)

Response variables •

- Surface finish

Table VII: PROCESS VARIABLES AND THEIR LEVELS FOR DOE

Parameter	Unit	Level 1	Level 2	Level 3
% variation		5%	10%	15%
Spindle Speed	RPM	2000	2400	2800
Depth of Cut	mm	0.2	0.3	0.4
Feed Rate	mm/min	50	60	70

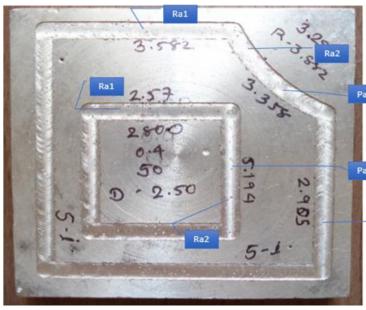

Fig. 5 SURFACE ROUGHNESS NOTATIONS on PLATE

Table : SURFACE ROUGHNESS for SPECIMEN

CODE	Ra1	Ra2	Ra3	Ra Ave
5a	3.113	2.872	3.782	3.255667
5b	4.227	4.287	4.059	4.191
5c	3.577	7.346	2.356	4.426333
5d	2.8516	3.192	3.2543	3.0993
5e	3.562	3.478	3.6059	3.548633
5f	3.598	3.787	3.472	3.619
5g	1.966	2.08	2.716	2.254
5h	3.239	2.58	3.691	3.17
5i	3.582	3.358	2.905	3.281667
10a	3.995	3.186	3.729	3.636667
10d	3.263	3.537	3.506	3.435333
10c	3.846	3.987	3.732	3.855
10g	2.448	1.607	1.995	2.016667
10e	2.427	2.93	2.712	2.689667
10f	3.222	3.199	2.747	3.056
10j	2.004	1.729	2.004	1.912333
10h	2.521	2.579	2.414	2.504667
10i	2.535	2.647	2.392	2.524667
15a	1.995	1.598	1.835	1.809333
15b	1.325	1.643	0.886	1.284667
15c	0.872	0.824	0.821	0.839
15d	3.183	1.9	3.268	2.783667
15e	2.045	2.701	2.333	2.359667
15f	1.151	1.943	1.414	1.502667

DOE for L18 Array

Percentage Variation	Spindle Speed	Depth of Cut	Feed Rate	Surface Roughness	SNRA1	FITS1	RESI1
5%	2000	0.2	50	3.255667	-10.25279955	3.615733389	-0.360066389
5%	2000	0.3	60	4.191	-12.44635322	4.136066556	0.054933444
5%	2000	0.4	70	4.426333	-12.92088167	4.517299889	-0.090966889
5%	2400	0.2	50	3.0993	-9.825272325	2.820611222	0.278688778
5%	2400	0.3	60	3.548633	-11.00122174	3.340944389	0.207688611
5%	2400	0.4	70	3.619	-11.17177166	3.722177722	-0.103177722
5%	2800	0.2	60	2.254	-7.059078234	2.383177889	-0.129177889
5%	2800	0.3	70	3.17	-10.02118524	3.121294389	0.048705611
5%	2800	0.4	50	3.281667	-10.3218902	3.188294556	0.093372444
10%	2000	0.2	70	3.636667	-11.21407071	3.173227833	0.463439167
10%	2000	0.3	50	3.435333	-10.71937683	3.597111167	-0.161778167
10%	2000	0.4	60	3.855	-11.72048765	3.760561167	0.094438833
10%	2400	0.2	60	2.016667	-6.092683834	2.200766833	-0.184099833
10%	2400	0.3	70	2.689667	-8.593970291	2.938883333	-0.249216333
10%	2400	0.4	50	3.056	-9.703066998	3.0058835	0.0501165
10%	2800	0.2	70	1.912333	-5.631270389	1.981116833	-0.068783833
10%	2800	0.3	50	2.504667	-7.974999876	2.405000167	0.099666833
10%	2800	0.4	60	2.524667	-8.044082068	2.568450167	-0.043783167

Table VIII: RESPONSE TABLE for SIGNAL to NOISE RATIOS

Level	%	Spindle	Depth Of Cut	Feed Rate
1	-10.558	-11.546	-8.346	-9.800
2	-8.855	-9.398	-10.126	-9.394
3		-8.175	-10.647	-9.926
Delta	1.703	3.370	2.301	0.532
Rank	3	1	2	4

*Smaller is better

Table IX: RESPONSE TABLE for MEANS

Level	%	Spindle Speed	Depth Of Cut	Feed Rate
1	3.427	3.800	2.696	3.105
2	2.848	3.005	3.257	3.065
3		2.608	3.460	3.242
Delta	0.579	1.192	0.765	0.177
Rank	3	1	2	4

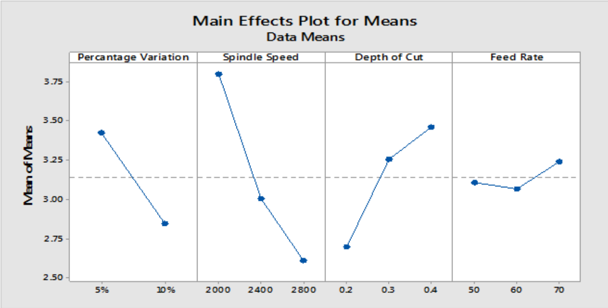

Fig.6 MAIN EFFECT PLOT for MEANS

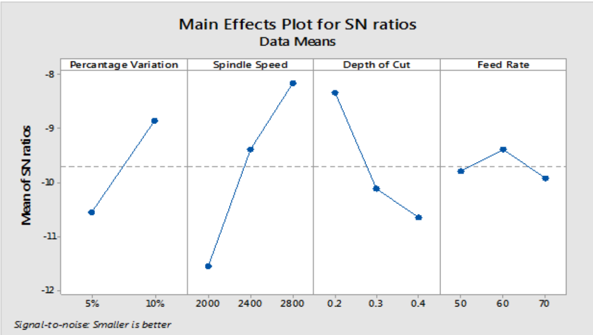

Fig.7 MAIN EFFECT PLOT for SN RATIO

DOE for L6 Array

From L18 experiment we can observe that feed rate has very less contribution about only 1% on surface roughness and ranked last in Taguchi analysis. Spindle speed is having 50% of significance over result and depth of cut is having it at 20%. So we decided to take feed rate as constant (50mm/min) for next phase of experiment. As further said, Spindles speed is having the most significance, 3 levels of it were set for next array. For depth of cut, 2 levels were set for L6 array.

Values of input parameter and output parameters are shown in table below for L6 array.It is clear that all the process variables will not impact same amount of effect on further result of machining. So we will eliminate one process variable in further experiment. But for better assurance, all the factors will be considered during initial stage. After assuringinsignificant effect of any variable it will be eliminated for cost reduction. We can choose levels of remainingvariables after reduction of least effective factor for CNC milling.

Taguchi Design:

Taguchi Analysis: Surface Roughness versus Depth of Cut, Spindle Speed

Table X: INPUT & OUT PARAMETER for L6 ARRAY

%	Depth of Cut	Spindle Speed	Surface Roughness	SNRA2	FITS1	RESI1
15%	0.2	2000	1.994	-5.99450308	2.097666667	-0.103666667
15%	0.2	2400	1.0685	-0.57549053	1.187416667	-0.118916667
15%	0.2	2800	0.9745	0.224363131	0.751916667	0.222583333
15%	0.3	2000	2.8855	-9.204421573	2.781833333	0.103666667
15%	0.3	2400	1.9905	-5.979243638	1.871583333	0.118916667
15%	0.3	2800	1.2135	-1.680795613	1.436083333	-0.222583333

Table IX: RESPONSE TABLE for SIGNAL to NOISE RATIOS

Level	Depth of Cut	Spindle Speed
1	-1.934	-7.021
2	-6.629	-4.816
3		-1.006
Delta	4.695	6.015
Rank	2	1

Table X : RESPONSE TABLE for MEANS

Level	Depth of Cut	Spindle Speed
1	1.311	2.297
2	2.215	1.822
3		1.171
Delta	0.904	1.126
Rank	2	1

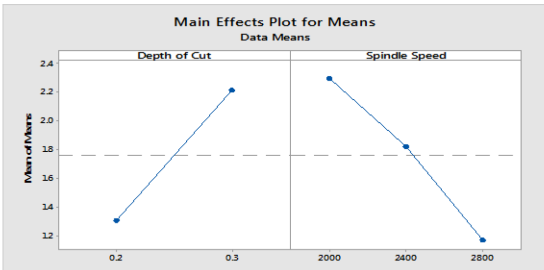

Fig.8 MAIN EFFECT PLOT for MEANS

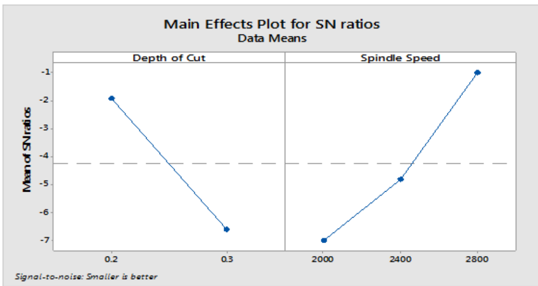

Fig.9 Main Effect Plot for Sn Ratio

CONCLUSION

Within the frame of current research work the following conclusions can be derived.

- SiC and Al2O3 particles can be successfully used as a reinforcing material to produce Metal- Matrix Composite
  MMC) component in aluminum matrix for better strength to weight ratio.
- Experimental result shows that Percentage weight of Sic and Al2O3 influence the hardness of Al/SiC/Al2O3 metal matrix composites. As the percentage weight of of SiCp increases hardness increases.
- From Taguchi analysis conclusions can be drawn out that spindle speed has more effect on surface roughness compared to depth of cut and percentage variation. Feed rate has very less effect on surface roughness.
- From Taguchi analysis we can conclude that with increase in percentage variation and spindle speed of SiC particle surface roughness is decrease.
- From Taguchi analysis we can conclude that with increase in feed rate and depth of cut surface roughness is increases.

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