Application of Taguchi's Method For Parametric Optimization of Control Parameters For Better Surface Finish

Amresh Kumar[1], Neelkant Grover [2], Alakesh Manna[3]
[2] Associate Professor, Dept of Mechanical Engineering
[3]Professor and Formerly Head, Dept of Mechanical Engineering,
[1]IKG-PTU Jalandhar, CGC College of Engineering, Mohali,Punjab, India
[2]IKG-PTU Campus, Jalandhar,Punjab, India
[3]PEC, University of Technology, Chandigarh, India

Abstract- *Particulate reinforced aluminum-matrix composites employing ceramic reinforcement and acquiescent to inexpensive fabrication processes such as powder metallurgy and casting have led to the application of these materials in automotive and aviation industries.This study is focusedon experimental investigation of the effects of control parameters such as peak current ($_{IP}$), pulse-on time (Ton), pulse-off, time (Toff), wire feed (WF) and wire tension (WT) on surface roughness (SR) during WEDM process of hybrid MMCs which was fabricated using particulates of 10wt.% of SiC , 3% wt.% of Gr, 3% of wt. $Fe_2O_3$and balance of Al Alloy (AA6061) as matrix material. The optimal combination of control parameters for optimum response values has been suggested using S/N Ratios based upon Taguchi's methodology. ANOVA was applied to determine the significant and non significantparameters. The confirmatory experiments indicated the improvement in surface roughness as optimal combination of parameters was selected for experimentation.*

Keywords- AL hybrid MMC, WEDM, Surface Roughness

I. INTRODUCTION

The first MMCs were developed in the 1970s for high-performance applications using continuous fibers and whiskers for reinforcement. Aluminum-matrix composites employing ceramic-particle reinforcement and amenable to inexpensive net shape processes such as casting and extrusion have led to the application of these materials in automotive brakes, drive shafts, and cylinder liners. Recent market forecasts for MMC use suggest the prospect for accelerating growth as the materials are more widely understood and costs decrease, suggesting a bright future for this class of materials [2, 7].Despite the superior mechanical and thermal properties of particulate metal-matrix composites,their poor machinability has been the main deterrent to their substitution for metal parts. Metal matrix composites (MMCs) materials can be machined by many non-traditional methods like water jet and laser cutting but these processes are limited to linear cutting only[3]. Electrical discharge machining (EDM) shows higher capability for cutting complex shapes with high precision and economy for these materials. But many problems and difficulties has been faced in the manufacturing industries during processing of composite material by well-known non-conventional machining method e.g. wire electrical discharge machining (WEDM) of Al/SiC MMC, are irregular material removal rate, high frequency of wire breakage, and very poor surface finish etc. Usually, the selection of appropriatemachining parameters is difficult and relies heavily on theoperators' experience and the machining parameters tablesprovided by the machine-tool builder for the target material. Hence, the optimization of operating parameters is of greatimportance where the economy and quality of a machinedpart play a key role [3,8].Taguchimethods provide an efficient and systematic way tooptimize designs for performance, quality, and cost. Taguchi's methods of parameter design, a confirmation test is usually necessary to remove concerns about the choice of control parameters, experimentaldesign, or assumptions about responses.This paper presents the effectiveness of Taguchi's method to predict optimal combination of control parameters to improve quality features of WEDM process of newly developed Al hybrid MMC.

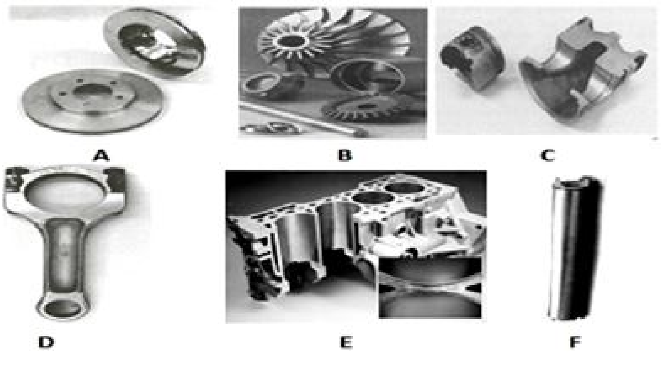
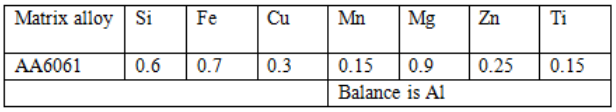


Fig.1 Typical application of Al MMCs

II. WEDM OF ALUMINUM MMC

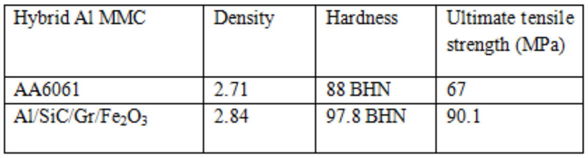
Al based composites are more oftenly used in aerospace and automobile industry and they are usually reinforced by Al_2O_3, SiC, C, B_4C, AlN and Gr etc. [2].The study of WEDM of MMCshas received much attention by many researchers in recent.Manna and Bhattacharyya [3] applied the Taguchi Gauss elimination method to determine the optimal parameters setting during the machining of Al/SiC–MMC. Through experimental findings, it was revealed that the Open-gap voltage was found to be the most significant influencing machining parameters, for controlling the MRR followed by Pulse-on period, meanwhile, surface roughness was found to be affectedsignificantly by wire tension and spark gap voltage setting.Patil and Brahmankar [8] determined the MRR in wire electro-discharge machining of silicon carbide particulate-reinforced aluminium matrix composites using dimensional analysis. This work proposed a semi-empirical model for MRR for WEDM based on thermo physical properties of the work piece and machining parameters such as pulse-on time and average gap voltage. The experimental results showed that increased percentage of ceramic particulates in theMMCresults in declining of MRR. Shandilya et al. [10] undertook a study to determine thewire breakage frequency during WEDM of MMCS.Experimental investigation revealed that wire breakage frequencyincreases withincrease in pulse-on time for all the three selected MMCs.It was shown that wire breakage frequency increases with increase in the SiC.Literature survey on the WEDM of MMCs reveals that machining of composite is not explored to the greater extent. In present work, themachinablity of newly prepared composite prepared using stir casting

Table 1 Chemical composition of AA6061/Al alloy used as metal Matrix (in wt%)



Matrix alloy	Si	Fe	Cu	Mn	Mg	Zn	Ti
AA6061	0.6	0.7	0.3	0.15	0.9	0.25	0.15
				Balance is Al			

Table 2: Property of AA 6061 Aluminium Alloy and Hybrid Al MMC



Hybrid Al MMC	Density	Hardness	Ultimate tensile strength (MPa)
AA6061	2.71	88 BHN	67
$Al/SiC/Gr/Fe_2O_3$	2.84	97.8 BHN	90.1

III. PREPARATION OF COMPOSITE MATERIAL

In this Experimental Investigation, the material fabricated through stir-casting is a hybrid composite, which was used by the other researchers .The commercially available Aluminum alloy is used as the matrix material, while, the reinforcement are used particulates as SiC, Gr,and Fe_2O_3 respectively. An electrical resistance heating muffle furnace is used to prepare melt of the Al alloy. Aluminium alloy was measured and placed in the graphite crucible and was melted to a temperature of 900^0C using an electric furnace. Proper stirring is required to achieve homogeneous distribution of reinforcement particles in the melt. The melt was stirred withthe help of a mechanical stirrer to form a fine vortex for 10-20 minutes [5. The furnace temperature was first raised above the liquid state temperature, cooled down to just below the liquid state temperature to keep the slurry in a semi-solid state. At this stage the preheated SiC, Gr and Fe_20_3 particles were added and mixed mechanically. Moulds (size 40mm diameter ×170 mm long) made of IS-1079/3.15mm thick steel sheet were preheated to 350^0C for 2 h before pouring the molten Al/SiC -MMC.

3.2 Design of experiment

The selection of suitable orthogonal array for the experiments is made by calculation of the total degrees of freedom. This total degree of freedom is determined by levels of design parameters and interaction between design parameters if any once the required degrees of freedom are known, then next step is to select an appropriate orthogonal array tofit the specific task. The selected OA must satisfy the following inequality

Total DOF of the OA ≥ total DOF required for the experiment.

Hence, an L27 OA(a standard three-levelOA)was selected for this experimental work.

3.3 WEDM Experiments

Electronica Sprincut-734 Wire Electrical Discharge Machine (WEDM) is used to study surface roughness affected by machining process variable at different setting of pulse-on time (Ton), pulse-off, time (Toff), spark gap set voltage (SV), peak current (I_P), wire feed (WF) and wire tension (WT).Some of the factors which could affect the performance measures to a little extent,, are kept constant, i.e. flushing pressure (0.833 MPa),Specific resistance of dielectric (1-3 mA), dielectric fluid temperature (25-27 °C), pulse peak voltage setting (100 V), wire type (0.25 mm-diameter brass) .The machined surface roughness is to be measured at three different positions and the average values are to be taken for analyzing the machining performance using surface texture measuring instrument.

3.4. Analysisof Experiments

In the Taguchi method, the term ‘signal’ stands for the desirable value (mean) for the response characteristicand the term ‘noise’ stands for the undesirable value(S.D.) for the outputcharacteristic. The S/N ratio isdefined in mathematical form as following:

Higher- is- better(maximize):

$$\eta = -10\log_{10}\left[1/n\sum_{i=1}^{n} 1/y_i^2\right] \qquad (1)$$

Lower- is- better(minimize):

$$\eta = -10\log_{10}\left[1/n\sum_{i=1}^{n} y_i^2\right] \qquad (2)$$

where η denotes the S/N ratio computed from experimentally observed values. Values (unit: db); y_i represents the experimentally observedvalue of the ith experiment, and n is the repeated number of each experiment. Notably, in L_{27}array,each experiment was conducted three times.

The S/N ratios determined from experimentally observedvalues were statistically studied by ANOVA If the “Model P value” is very small (less than 0.05) then the terms in the model have a significant effect on the response [4].

Table 3: Control Factors and their levels to be used WEDM

S. No.	Input Parameters	Level			Unit
		1	2	3	
1.	A:Peak Current(Ip)	80	100	120	Amp
2.	B:Pulse on -Time (Ton)	.5	.8	1.1	µs
3.	C:Pulse Off -Time (Toff)	12	16	20	µs
4.	D:Wire feed rate (WF)	5	7	9	m/min
5.	E:Wire Tension(WT)	850	1000	1200	Gms
6.	F: Spark gap set voltage(SV)	25	30	35	Volts

Table 4: S/N Ratios for observed response values

Exp No	Pulse Peak Current (Ip)	Pulse On-Time (Ton)	Pulse Off - Time (Toff)	Wire feed rate (WF)	Wire Tension(WT)	Spark gap set voltage(SV	SR	S/N Ratio for SR
1	1	1	1	1	1	1	0.9780	0.19322
2	1	1	1	1	2	2	1.2340	-1.82630
3	1	1	1	1	3	3	1.4560	-3.26323
4	1	2	2	2	1	1	0.9980	0.01739
5	1	2	2	2	2	2	1.2350	-1.83334
6	1	2	2	2	3	3	1.2460	-1.91036
7	1	3	3	3	1	1	1.1234	-1.01069
8	1	3	3	3	2	2	1.6570	-4.38645
9	1	3	3	3	3	3	1.7540	-4.88059
10	2	1	2	3	1	2	1.4500	-3.22736
11	2	1	2	3	2	3	1.5430	-3.76732
12	2	1	2	3	3	1	1.9230	-5.67959
13	2	2	3	1	1	2	1.3400	-2.54210
14	2	2	3	1	2	3	1.4680	-3.33452
15	2	2	3	1	3	1	1.8840	-5.50162
16	2	3	1	2	1	2	1.4560	-3.26323
17	2	3	1	2	2	3	1.2670	-2.05553
18	2	3	1	2	3	1	1.4430	-3.18533
19	3	1	3	2	1	3	1.3450	-2.57445
20	3	1	3	2	2	1	1.5460	-3.78419
21	3	1	3	2	3	2	1.5780	-3.96214
22	3	2	1	3	1	3	0.9670	0.29147
23	3	2	1	3	2	1	1.3460	-2.58090
24	3	2	1	3	3	2	1.6660	-4.43350
25	3	3	2	1	1	3	1.4320	-3.11886
26	3	3	2	1	2	1	1.6530	-4.36546
27	3	3	2	1	3	2	1.4370	-3.14914

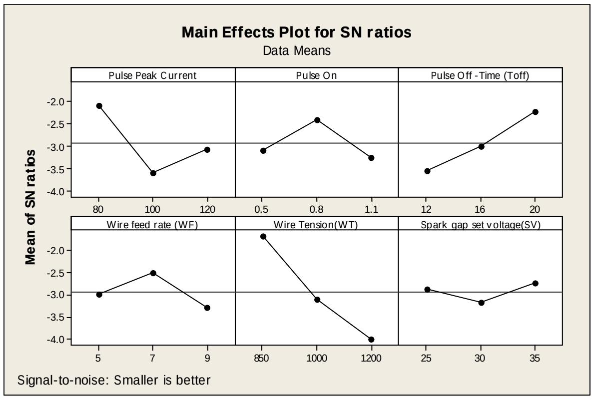


Figure 2: S/N ratios plot for SR

IV. RESULTS AND DISCUSSION

Data analysis is initiated by summarizing the test results of the experiments conducted on the basis of Taguchi’s L_{27} in table 3. For the selected OA experimental design, it is notable that effect of each WEDM parameter at different levels can be separated out the effect of each machining parameter. Therefore, in table, the mean S/N ratio for the selected parameters is presented for their corresponding levels 1, 2 and 3by averaging the experimentallyobtained data.Maximum MRR is achieved for high level of wire feed rate. Surface Roughness of particulate reinforced MMC during wire EDM can be affected by size of particulates, thermo-physical properties of particulates, distribution of discharge energy, and disintegration of particulates from the machined surface and extent of gap contamination. The S/N graphs as presented in fig. show that optimum SR can be achieved for low level of peak current (I_P), pulse-on time (Ton), and pulse-off time. Meanwhile, high level of wire feed rate and spark gap set voltage produces minimum SR. The parametric combination showing the minimum SR for sample 1are as parameter A (level 1, S/N = -2.100) B (level 2, S/N = -2.425), parameter C (level 3, S/N = -2.236), parameter D (level 2, S/N = -2.506), parameter E (level 1, S/N = -1.693), parameter F (level 3, S/N = -2.735)i.e $A_1B_2C_3D_2E_1F_3$. The analysis of variance (ANOVA) is used to recognize the influence of the selected control parameters on the response values such as MRR and SR. The control parameter stand for highest 'Model Fvalue' causes maximum variation in the response characteristics [4]. Correspondingly, the indicator named "P value" decides whether an individual term in the ANOVA model is significant or not. Theresults of ANOVA as shown in table elucidate that SR, pulse peak Current (Ip) and wire tension (WT) is found to be significant while rest of factors found to be non-significant.

Table 5 : S/N Ratios of the levels of control parameters for SR

Level	Pulse Peak Current	Pulse On	Pulse Off - Time (Toff)	Wire feed rate (WF)	Wire Tension(WT)	Spark gap set voltage(SV)
1	-2.100	-3.099	-3.553	-2.990	-1.693	-2.877
2	-3.617	-2.425	-3.004	-2.506	-3.104	-3.180
3	-3.075	-3.268	-2.236	-3.297	-3.996	-2.735
Delta	1.517	0.843	1.317	0.792	2.303	0.446
Rank	2	4	3	5	1	6

Table 6: ANOVA for SR

Source	**DF**	**Seq MS**	**AdjSS**	**AdjMS**	**F**	**P**
A: Pulse Peak Current(Ip)	2	0.24763	0.24763	0.12381	4.62	0.029
B:Pulse on - Time (Ton)	2	0.07386	0.07386	0.03693	1.38	0.285
C:Pulse Off - Time (Toff)	2	0.19882	0.19882	0.09941	3.71	0.045
D:Wire feed rate (WF)	2	0.09703	0.09703	0.04851	1.81	0.200
E:Wire Tension(WT)	2	0.60741	0.60741	0.30371	11.32	0.001
F: Spark gap set voltage(SV)	2	0.01960	0.01960	0.00980	0.37	0.700
Error	14	0.37559	0.37559	0.02683		
Total	26	1.61993				

Table 7: Confirmatory Experiments

Response	Initial machining parameters	Optimal Parametric Combination
	$A_2B_2C_2D_2E_2F_2$.	$A_1B_2C_3D_2E_1F_3$.
Surface Roughness	1.782 µm	1.344 µm

V. CONFIRMATORYTESTS

Since the optimal level of the machining parameters is selected, the confirmation tests are processed to verify theimprovement of performance characteristics. The results of confirmation experiment are compared with the outcome of Taguchi method and initial conditions of design operating parameters. Table 7 shows the compared results of the selected optimal and initial design of machining parameters. The initial design machining parameters are A_2, B_2, $C2$, D_2, E_2, F_2, G_2 and$H2$. The maximum surfaceroughness is greatly reduced from 1.7824 to 1.344 µmand the value will be obviously decreasing as compared withthe results in Table 4. It is shown clearly the above performance characteristicsin the WEDM process are greatly improved through thisstudy.

VI. CONCLUSION

Hybrid metal matrix composites were prepared by stir casting for the purpose of machining them using EDM and analyzing the effect of various machining parameters on the material removal rate and surface roughness. The following findings are reported.

1. Improvement in mechanical properties of the prepared hyrid MMC has been noticed as comparison to base alloy.
2. Control factors such as Pulse peak Current (Ip) , Pulse off time (T_{off}) and wire tension (WT) were significant influencing the Surface roughness.
3. Increase in surface roughness values was noticed for high discharge energy.
4. The optimal parametric combination for surface roughness gap is $A_1B_2C_3D_2E_1F_3$.

REFERENCES

[1] Mangalgiri, P. D., (1999), "Composite materials for aerospace applications," J. Bull Mater Sci., 22(3), pp. 657-664.

[2] Clyne, T. W., (2000), "An Introductory Overview of MMC Systems, Types and Developments, in Comprehensive Composite Materials Vol.3: Metal Matrix Composites," T. W. Clyne (ed.), Elsevier, pp. 1-26.

[3] Manna, A., and Bhattacharyya, B., (2006), "Taguchi and Gauss elimination method: A dual response approach for parametric optimization of CNC wire cut EDM of PRAlSiCMMC," International Journal of Advanced Manufacturing Technology, 28, pp. 67-75.

[4] Phadke,M.S.: Quality EngineeringUsing Robust Design. Prentice- Hall, Englewood Cliffs (2003)

[5] Hashim J., Looney, L., and Hashmi, M. S. J., (1999) , "Metal matrix composites: production by the stir casting method," Journal of Materials Processing Technology, 92-93, pp. 1-7.

[6] Davim, J.P., (2012), Machining of Metal Matrix Composites, Springer London Dordrecht Heidelberg,

New York.

[7] Suresha, S., and Sridhara, B. K., (2010), "Wear characteristics of hybrid aluminium matrix composites reinforced with graphite and silicon carbide particulates,"Composite Science and Technology, 70, pp. 1652-1659.

[8] Nilesh, G. P., and Brahmankar, P. K., (2010_a) , "Some studies into wire electro-discharge machining of alumina particulate-reinforced aluminum matrix composites," Int J AdvManufTechnol, 48, pp. 537–555.

[9] Nilesh, G. P., and Brahmankar, P. K., (2010_b) , "Determination of material removal rate in wire electro-discharge machining of metal matrix composites using dimensional analysis," Int J AdvManuf Technol,51, pp. 599-610.

[10] Shandilya, P., Jain, P. K., and Jain, N. K., (2012), "On wire breakage and microstructure in WEDC of SiC_p/6061 aluminum metal matrix composites," Int J AdvManufTechnol, 61, pp. 1199-1207.