Assessment of Surface Roughness in EDM of RHA, Cu and Mg Reinforced Hybrid MMC using L_{27} Taguchi's Orthogonal Array Technique

Ram Narayan Muni, Jujhar Singh, Vineet Kumar, Shubham Sharma, Munish Mehta

Abstract*: The goal of this research is to develop Al alloy 6061 matrix composites of lower cost with higher performance with the using agricultural waste Rice Husk Ash (RHA) as a major reinforcement. The weight percentage of RHA at 6,8 and 10 % is used in the basic matrix of Al6061 alloy. The copper (Cu) and magnesium (Mg) are kept at constant level i.e 3% and 1 % of weight(wt) respectively. The Al-matrix hybrid composites have been developed by stir casting method. The investigation has been made to explore the effect of different weight percentage of RHA reinforced hybrid composite and other machining factors on Surface Roughness(SR) for machining of Al matrix hybrid composites using electric discharge machining (EDM) by Taguchi's approach. An L_{27} Orthogonal Array (OA) for 6 different factors each at 3 stages, has been selected to perform the experiments. Optimal combination of SR-related parameters of machining and the significant parameters has been highlighted. Machined surfaces have been characterised by SEM micrographs

***Keywords* : Al 6061 alloy, Rice Husk Ash, MMC, EDM, SR.**

I. INTRODUCTION

Metal matrix composites (MMCs) have become suitable choice of materials for recent engineering applications such as aerospace, automotive, structural, electrical, wear and thermal. The new generation researchers are now developing the hybrid composites materials by integrating two or more different reinforcements to score over the traditional alloys in terms of high temperature stability, specific modulus, specific strength, wear resistance, etc.

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Aluminium matrix hybrid composites have become new generation of MMCs which have the ability to fulfil the current demands of applications in advanced engineering. Such demands are there due to improvements in tribology and mechanical properties, reduction in fabrication cost. Increasing the numbers of reinforcement particle can enhance mechanical properties of MMC, depending upon the design of reinforcement particles. It can also reduce MMCs costs without significantly changing the material's properties [1-3]. Quality of such materials depends mainly on using the proper mix of reinforcements as few of the manufacturing parameters are correlated with the reinforcement's particles. Kumar NN et al. [4] studied the mechanical behaviour of Al matrix composites using SiC particles as reinforcements and solid Graphite for lubrications. Two type of composites were manufactured using Stir Casting Method, the first one was Al with SiC and graphite and the other was Al with Alumina and solid graphite lubricant. Alaneme KK et al. [5] tested the mechanical properties of AA 6063 hybrid composites using reinforcement SiC and RHA. In the reinforcing process, the mixture of RHA and SiC were in the ratios 1:0; 1:3; 1:1; 3:1 and 0:1. The tensile, specific and yield strength of hybrid composite were increased by increasing the wt% of reinforcing, whereas the fracture toughness was decreased. Prasad DS et al. [6] reported the mechanical properties of Al matrix hybrid composite with RHA and SiC (2, 4, 6, and 8 wt%) in equal ratios. The hybrid composite's hardness and its porosity increased by increasing the volume fraction of reinforcement but density decreased by increasing the content of particle. The yield and ultimate tensile strength (UTS) were increased by increasing the wt% of the reinforcements, while elongations were decreased with increasing the reinforcements. Allwyn J et al. [7] fabricated AA 6061 composites with RHA particles (0, 2, 4, 6 and 8 wt. %) as reinforcement and characterized the fabricated composites. X-ray diffraction patterns and scanning electron microscopy (SEM) RHA reinforced composites indicated uniform RHA distribution and presence across the matrix. RHA particle reinforcement improved the micro hardness and UTS of composites. Madhusudan S et al. [8] studied the mechanical behaviour of Al-Cu composite developed using stir casting process and was compared with the behaviour of alloy having same composition.

The Cu concentration was varied from 5 to 15 wt% and its effect was further analysed. The hardness improved with increasing Cu particulate content in both the cases. Composites reported a 13% decrease in strength and a 15% decrease in strain relative to the alloy. Siddhartha Sarkar et al. [9] studied the fabrication and mechanical properties of the aluminum alloy Al-6061, reinforced by Silicon Carbide and RHA. The composite proportions of RHA and SiC were 1:4, 2:3 and 0:1 with an 8wt.%. Hardness testing, tensile testing, impact analysis, and machinability testing were carried out of the new material to obtain the mechanical characteristics. SEM and EDX were also used to obtain proper characterization of material. The results clearly estimated less than 2.86% porosity of less dense hybrid composites of Al/RHA/SiC. MMCs can be machined by different non-conventional methods such laser cutting and asbrasive water jet but these methods have limitations for linear cutting only. EDM is a modern manufacturing technique used in sophisticated industries which produces high quality products of any form of electrical conductive materials that are difficult to process using traditional methods. Dhar S et al. [10] investigated the different EDM process parameters effect on tool-wear-rate(TWR), MRR, radial-over-cut(ROC) on Al matrix composites (AMC). Full factorial design of three factors with three levels was used for analyzing the results. TWR, MRR and ROC were increased nonlinearly by increasing the electric current. Mohan B et al. [11] used rotary EDM to machine SiC reinforced Al matrix composites and reported that, due to effective flushing the electrode of rotating tube produced higher MRR over the electrode of rotating solid rod. Experimental results confirmed the lower MRR and SR and higher TWR by increasing the volume % of SiC. It has also resulted higher MRR, TWR and lower SR with the increase in rotational speed of the tube electrode. Singh J et al. [12] studied the effects of vibrations on machining of work piece of high carbon high chromium steel using Cu as electrode. The machining parameters such as vibration, amplitude, current, pulse-on time, no load voltage and duty-factor were used to determine the ultrasonic assisted EDM response parameters such as MRR, micro cracks and heat affected layer. The MRR was improved during discontinuous vibrations. Velmurugan C et al. [13] studied parametric effect on SR , MRR and TWR during EDM machining of 10wt.% SiC and 4wt.% graphite particles reinforced Al 6061 metal matrix hybrid composites. Development of mathematical regression models and results were analysed using the MINITAB 17 software. It was found that all factors had significant effect on the response variables.

Narinder et al. [14] reported the parametric effect on different response parameters during EDM of as cast Al matrix composite with 10wt% SiC using brass tool of diameter 2.7 mm. The results had shown the higher MRR and poor surface finish with the high value of current and pulse-on time whereas lower MRR and TWR with higher value of flushing. Sarabjeet S S et al. [15] performed the EDM on three different MMCs 65volume%SiC/A356.2; 10volume%SiC-5vol%quartz/Al and 30volume%SiC/A359 and investigated the optimal machining conditions. The four response parameters such as MRR, TWR, SR and surface integrity were found with optimal machining conditions using TOPSIS for each MMC. It was observed that the MMC with lowest reinforced particle had high MRR and SR. TWR was found highest with Cu-graphite(Gr) electrode. Choudhary R et al. [16] studied the EDM parameter effect on MRR, TWR and SR of Al 6061/14% fly-ash AMC using L_{18} OA. Experiments performed using copper and brass electrodes on EN-35 die-sinking EDM. Analysis of the signal to noise(S / N) ratio and ANOVA was then applied to determine the optimum setting of the EDM parameter. In this experimental study, EDM is performed on newly formed Al matrix hybrid composite and the effect of factors such as percentage of composition of RHA based composite workpiece electrode and other machining parameters on SR with brass as tool electrode are investigated.

II. FABRICATION OF COMPOSITES

For composite development, the Al 6061 alloy with RHA and Cu is chosen as reinforcements and Mg as coupling agent. The hybrid composites are fabricated using two step stir casting method. Using this process, three different hybrid composites are fabricated using 6,8 and 10wt.% of RHA, 3 constant wt.% of Cu and 1 constant wt.% of Mg as reinforcements as shown in Table-I. All the three molten mixture of composite are poured into the cavity to get the cast product.

Table-I: Composites with composition (wt.%)

Symbol	Al6061(wt.%)	RHA (wt.%)	Cu (wt.%)	Mg (wt.%)
W1	90	6	3	1
W2	88	8	3	1
W3	86	10	3	1

Table-II presents the property such as brinell hardness (HRB), UTS (MPa) and impact toughness (J) of unreinforced alloy and newly fabricated hybrid composites. Hardness and UTS of Al matrix hybrid composites are increased with the increase in RHA content and with addition of Cu particle whereas impact toughness are initially increased with the addition of RHA and Cu particle but decreased with the further increase in RHA contents.

Table-II: Property of unreinforced alloy and hybrid composites

Sample	HRB	MPa	J
Al 6061	43	85	3
W_1	54.1	95.2	3.5
W_2	57	97.1	3
W_3	58.1	98.4	2.5

III. EXPERIMENTAL DETAILS

All the experiments are performed on Elektra puls PS35 electric discharge machine as shown in Fig.1. Workpieces with dimension 34 mm as diameter and 10 mm as thickness are prepared from the newly developed hybrid composites with the help of conventional lathe machine.

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Solid cylindrical brass rod with diameter 10 mm are used as tool electrode. Three different RHA and copper reinforced hybrid MMC's material are used as workpiece electrode (Table-I) for this study. EDM oil is used as dielectric, which is circulated using the side injection and debris from the gap is removed by jet flushing.

On the basis pilot study performed, six factors namely percentage of RHA based workpiece electrode(A), discharge current(B), voltage(C), duty factor(D), Pulse on time(E) and flushing pressure(F) with three different levels are presented in Table-III. From the different literature it is clear that poor MRR is found at the current below 5 A and higher surface roughness at the current above 25 A. Values of duty factor and pulse-on time are chosen suitably for Al matrix composites. The voltage and flushing pressure levels are chosen from the machine's availability and also suitable for material. Appropriate OA is chosen for the experiments by measuring total degrees of freedom (DOF). The chosen OA must fulfill the inequality (Ross 1988): the total DOF required for the experiment ≤ total DOF of the OA. For six factors, each at three levels and without interaction, the required DOF is 6×2= 12, as a 3 level parameter has 2 DOF (no. of levels - one). Therefore, an L_{27} OA is selected for the present experimental work as shown in Table-IV.

Table-III: Different factor at 3 levels

Factor(symbol)	Unit	Levels		
		1	2	3
A(W)	---	W1	W1	W3
B(I)	A	5	10	15
C(V)	V	50	65	80
D(T)	%	8	16	24
E(T_{on})	μs	10	20	50
F(P)	Psi	3	5	10

SR of the samples machined by EDM is measured using Mitutoyo talysurf testing instrument having diamond stylus tip with 8mm sampling length. The average surface roughness value in microns is directly obtained from computer interfaced with the machine using tally software for all experiments.

The S/N ratio graphs are then plotted using MINITAB of the obtained response table, which is used to analyse the results. Basically, S/N ratio is classified into three different categories i.e. smaller-the better(LB), nominal-the best(NB), and higher-the better(HB) and the selection depends on response. Here smaller the better category is selected for analysis the surface roughness.

$$(S/N)_{LB} = -10\log_{10}\left[1/n\sum_{i=1}^{n} y_i^2\right]$$

Here, n denotes numbers of experiments and y_i represents the i^{th} experimental value.

Fig.1. Elektra puls PS35 die sinking EDM

Microstructural characterization of machined surface of sample W1 at three different levels of discharge current is carried out using SEM.

IV. RESULTS AND DISCUSSION

A. Optimum response characteristics

The main effects analysis is used to study the trend of the effects of each of the factors. Table-IV presents the observed SR results and their corresponding obtained S/N ratio based on the different inputs parameters combinations using Taguchi's L_{27} orthogonal array. S/N ratio and its response graph is obtained using the Minitab 17 software (Minitab Manual 2010). The obtained S/N response-graph (Fig.2) shows the major effect of RHA on SR. The change of SR for different factors is illustrated in Fig.2. Here the mean of SR value decreases with increasing the RHA content (from 6 wt% to 8 wt%), and further increases with the increasing the RHA content (from 8 wt% to 10 wt%). Therefore, the addition of RHA with certain content can improve the surface finish of EDM machined composites. The S/N response-graph (Fig.2) also indicates the increase in mean SR value with increasing the discharge-current, as the discharge energy is more at its larger value.

The high value of the discharge current thus creates larger and deeper craters on the workpiece electrode, resulting in higher defects in the machined surface with a higher average roughness value. Hence, the best surface is found at 5A of discharge current. From the S/N response-graph, the optimum factor for minimum SR is $A_2B_1C_3D_2E_1F_3$.

Table-IV: Observed SR and their corresponding S/N Ratios

SR NO	A	B	C	D	E	F	SR (microns)	S/N ratio
1	1	1	1	1	1	1	2.85	-9.0969
2	1	1	1	1	2	2	4.01	-12.0629
3	1	1	1	1	3	3	4.33	-12.7298
4	1	2	2	2	1	1	4.5	-13.0643
5	1	2	2	2	2	2	5.63	-15.0102
6	1	2	2	2	3	3	4.45	-12.9672
7	1	3	3	3	1	1	5.85	-15.3431
8	1	3	3	3	2	2	5.74	-15.1782
9	1	3	3	3	3	3	5.18	-14.2866
10	2	1	2	3	1	2	3.55	-11.0046
11	2	1	2	3	2	3	3.25	-10.2377
12	2	1	2	3	3	1	3.31	-10.3966
13	2	2	3	1	1	2	4.16	-12.3819
14	2	2	3	1	2	3	4.42	-12.9084
15	2	2	3	1	3	1	4.07	-12.1919
16	2	3	1	2	1	2	4.33	-12.7298
17	2	3	1	2	2	3	4.47	-13.0062
18	2	3	1	2	3	1	5.72	-15.1479
19	3	1	3	2	1	3	3.46	-10.7815
20	3	1	3	2	2	1	3.71	-11.3875
21	3	1	3	2	3	2	2.15	-6.6488
22	3	2	1	3	1	3	3.9	-11.8213
23	3	2	1	3	2	1	4.66	-13.3677
24	3	2	1	3	3	2	6.09	-15.6923
25	3	3	2	1	1	3	6.42	-16.1507
26	3	3	2	1	2	1	7.85	-17.8974
27	3	3	2	1	3	2	7.90	-17.9525

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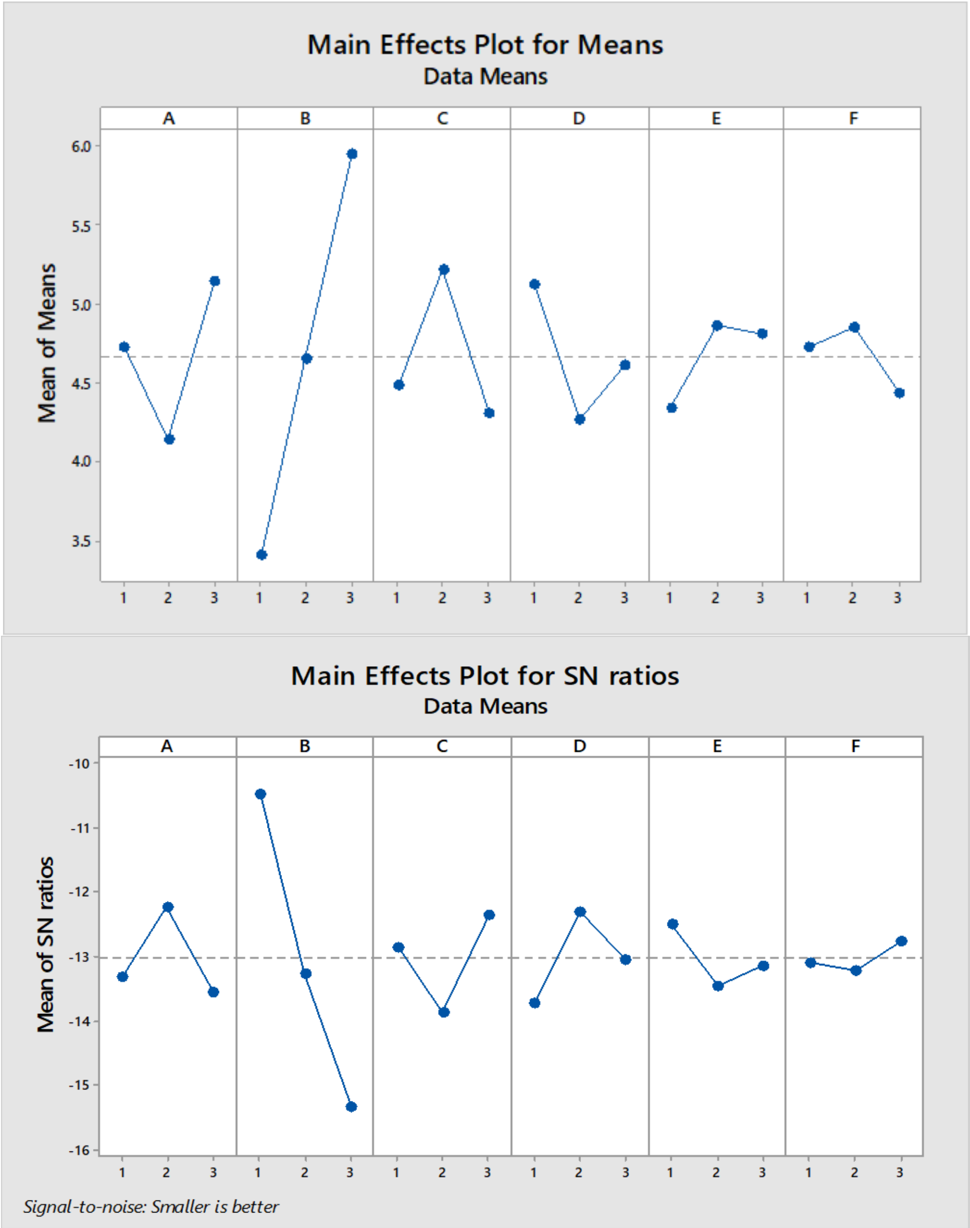

Fig.2. Main effects for means and S/N ratios of SR (microns).

Table-V: Response for S/N ratios

Level 1	A	B	C	D	E	F
1	-13.30	-10.48	-12.85	-13.71	-12.49	-13.10
2	-12.22	-13.27	-13.85	-12.30	-13.45	-13.18
3	-13.52	-15.30	-12.35	-13.04	-13.11	-12.77
Delta	1.30	4.82	1.51	1.40	0.96	0.42
Rank	4	1	2	3	5	6

Table-VI: Response for Means

Level 1	A	B	C	D	E	F
1	4.727	3.402	4.484	5.112	4.336	4.724
2	4.142	4.653	5.207	4.269	4.860	4.840
3	5.127	5.940	4.304	4.614	4.800	4.431
Delta	0.984	2.538	0.902	0.843	0.524	0.409
Rank	2	1	3	4	5	6

Table-VII: ANOVA for SR (microns)

Source	DOF	Seq. MS	Adj. SS	Adj. MS	F	P
Workpiece Electrode (A)	2	4.5522	4.5522	2.2761	4.74	0.027

Discharge Current(B)	2	29.3674	29.3674	14.6837	30.55	0.000
Voltage(C)	2	4.2681	4.2681	2.1341	4.44	0.032
Duty Factor(D)	2	3.3710	3.3710	1.6855	3.51	0.058
Pulse on time(E)	2	1.5252	1.5252	0.7626	1.59	0.239
Flussing Pressure (F)	2	0.8539	0.8539	0.4269	0.89	0.433
Error	14	6.7280	6.7280	0.4806		
Total	26	50.6658				
Sum of squares: SS, Mean square: MS, F ratio: F, P value: P.						

The response table of mean and S/N ratios and means are shown in Table-V and Table-VI respectively. The ANOVA table is also obtained using the Minitab software and is shown in Table-VII. It indicates the importance of the different factors on SR value. The overall result is confirmed at a confidence level of 95%. Three factors such as wokpiece electrode, discharge-current and voltage are found major effect on SR value. The effect of pulse-on time, duty factor, flushing pressure is found minimum on the SR value.

B. Prediction of mean response parameters

Number After finding the optimal condition, the mean response (μ) i.e average value of SR is predicted at this condition. Here estimation of mean value is only from those factors which are more significant. The ANOVA table identifies the significant factors. Since, factors A, B and C are significant (Table-VII) and A_2, B_1 and C_3 are the optimal conditions (Fig.2). Then, the mean response at the optimal condition is estimated [Ross (1996)] as:

$$\mu = \overline{T} + (\overline{A}_2 - \overline{T}) + (\overline{B}_1 - \overline{T}) + (\overline{C}_3 - \overline{T})$$

$$= \overline{A}_2 + \overline{B}_1 + \overline{C}_3 - 2\overline{T}$$

$\overline{T}$ = Overall mean response

$\overline{A}_2, \overline{B}_1, \overline{C}_3$ = mean response values at the optimal levels of significant factors A, B and C respectively.

Predicted mean or optimal value of SR = (A2+B1+C3- 2Tavg) = 2.522 (μm)

C. Analysis of Machined surface

Fig.3 displays the machined surface microstructure of W_1 after EDM process. On the machined surface there are wide no micro holes, gas bubbles and microcrackers. It is found better surface finish comparatively at low level of discharge current. As discharge energy is higher at higher value of discharge-current causing to increase in surface roughness. A thick pool of solidified white layer can be noticed from SEM micrographs as shown in Fig.3. The Fig.3c indicates increase in presence of voids, micro holes, gas bubbles for high discharge energy i.e discharge current of 15 A.

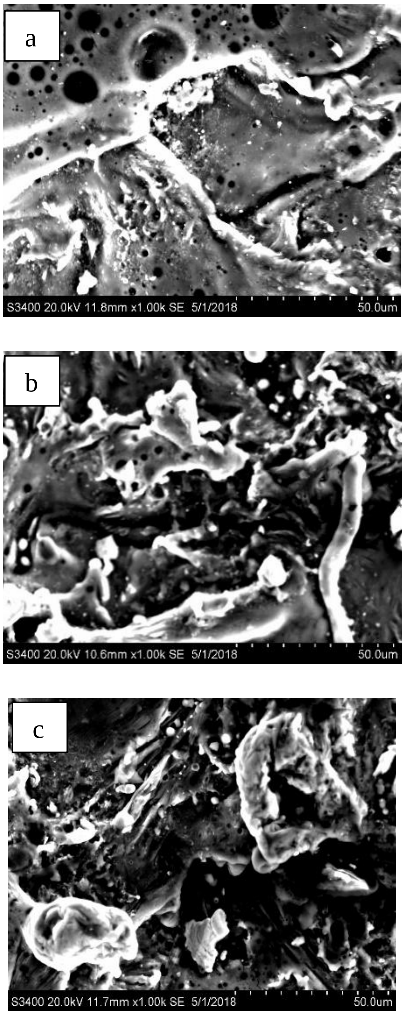

Fig.3. Microstructure of W_1 after EDM at (a) 5A, (b) 10A and (c) 15A

D. Confirmation Experiment

Confirmation experiment has been conducted for better surface finish i.e. lower SR. The experimental value obtained at the optimal setting of parameters is 2.522 mm/min. Therefore, confirmation experiment shows that the error associated with machining is about 2%, which is inacceptable range. Table-VII provides the description of the results showing the expected optimal value of the selected quality characteristics and the experimental value of validation.

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Table- VIII: Summary of results for single response optimization

Quality characteristic	Optimal setting of factors	Significant factors (at 95% confidence level)	Predicted optimal value of quality characteristic	Confirmation experimental value
SR	$A_2B_1C_3$ $D_2E_1F_3$.	A, B, C	2.552 (μm)	2.61 (μm)

V. CONCLUSION

Al-matrix hybrid composite has been developed and successively machined by EDM with varying the parameters and the response of RHA wt% and other factors on the SR has been studied and analysed. Based on the experimental results and review, the following conclusions are drawn.

- SR of machined surface is found minimum at 8 wt.% of RHA, and at 5A current, but increases significantly at 10A and 15A current. The composite with 10wt.% of RHA is found with maximum hardness and UTS but SR of its machined surface is also found maximum.
- The high level of voltage at 80V and flushing pressure at 10 Psi provides lower SR i.e, better surface finish.
- Moderate value of duty factor at 16% and low value of pulse-on time at 20 µs provides lower SR.
- The SEM analysis of composite with 8wt.% of RHA revealed that crater size over machined surface may increase for higher pulse energy.
- The optimum parametric combination to minimize the SR is $A_2B_1C_3D_2E_1F_3$.

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