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Application of Signal-to-Noise (S/N) Ratios and ANOVA for the Prediction of Optimal Designs of Multiple Performance Characteristics

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Abstract

In present days, Aluminum based particulate reinforced metal matrix composites have high applications in aerospace, automobile, chemical and transportation industries because of their improved strength, high elastic modulus and increased wear resistance over conventional base alloys. In the present work aluminium metal matrix composite (LM24 + SiC (5%)) is taken as the work piece and the experiments were conducted on CNC-wire electric discharge machine. The experiments were planned as per the taguchi's standard L27 OA for the selected process parameters of P_{on}, P_{off} and I_p at three different levels. Taguchi's Signal-to-Noise ratios and ANOVA are employed for the optimization of output characteristics. The results concluded that P_{on} and P_{off} are the major influencing parameters for material removal rate and surface roughness respectively. Finally, the optimal designs for the responses were predicted and they found to be more accurate and adequate.

Keywords: *Material Removal Rate (MRR), Surface Roughness (Ra), S/N ratios, ANOVA*

INTRODUCTION

Aluminium based alloys are substantially used non ferrous materials in the field of engineering because of their extensive attributes such as high strength to weight ratio, good ductility, corrosion resistance, availability and low cost. However, softnessand poor in wear resistance of these materials affects many practical applications hence there is a need of overcomethis by reinforcing hard ceramic particles like SiC, Al_2O_3 and B_4C in aluminium and its alloys to produce a discontinuous reinforced metal matrix composite.Aluminum based particulate reinforced metal matrix composites have high applications in aerospace, automobile, chemical and transportation industries because of their improved strength, high elastic modulus and increased wear resistance over conventionalbase alloys.Surface roughness is an index of product quality as it influencesthe tribological houses, fatigue strength, corrosion resistance and aesthetic appeal of the completed product. That allows you to obtain optimal aggregate of technique parameters the manufacturing industries have resorted to the use of guide based information and operators revel in. however, this traditional exercise may additionally leads to improper floor exceptional and decrease in the productivity because of sub-best use of machining capability. This may purpose excessive production price and coffee product pleasant. Further to the floor high-quality, the fabric elimination price (MRR) is likewise a critical feature and is usually acceptable. Hence, there may be a need to optimize the method parameters in a systematic manner to attain the desired output traits/responses by means of using experimental strategies and statistical models. Dr. Taguchi hired design ofexperiments (DOE), which is one of the most important and efficient tools of total quality management (TQM) for designing high quality systems at reduced cost. Taguchi emphasizes on the fact that Quality provides robustness and immune to the uncontrollable factors in the manufacturing state. This approach helps to reduce the number of experimental trials when the numbers of process parameters are more.

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EXPERIMENTAL DETAILS

In the present work, aluminium metal matrix composite (LM24 + SiC (5%)) is taken in the form of plate having dimensions of 200x70x7 mm3 for the experiments. The plate is machined on a five axis CNC-wire electric discharge machine (ULTRACUT 843). A brass wire of 0.25 mm (Grade H) and distilled water (at 25˚C and 5 Kg/cm2) are used as an electrode and di-electric fluid respectively. The selected process parameters with their levels and the planned L27 orthogonal array (OA) for the experiments are given in the tables 1 and 2.

Table 1.*Process Parameters and Their Levels*

Parameter	Level-1	Level-2	Level-3
P_{on}, µs	100	105	110
P_{off}, µs	45	50	55
I_p, amp	10	11	12

Table 2.*L27 OA*

S.No.	P_{on}	P_{off}	I_p
1	100	45	10
2	100	45	11
3	100	45	12
4	100	50	10
5	100	50	11
6	100	50	12
7	100	55	10
8	100	55	11
9	100	55	12
10	105	45	10
11	105	45	11
12	105	45	12
13	105	50	10
14	105	50	11
15	105	50	12
16	105	55	10
17	105	55	11
18	105	55	12
19	110	45	10
20	110	45	11
21	110	45	12
22	110	50	10
23	110	50	11
24	110	50	12
25	110	55	10
26	110	55	11
27	110	55	12

DESIGN OF EXPERIMENTS

Design of experiments is a statistical toolused for conducting the experiments, to analyze the data available and to makevaluable conclusions from the analysis.The objective of design of experiments (DOE) is to set the optimal conditions of process parameters that affect the performance characteristics. A Taguchi design or an Orthogonal Array (OA), is a method of designing experiments that usually requires only a fraction of the full factorial combinations. Taguchi designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. Taguchi techniques have been used widely in engineering and scientific community because they are easy to adopt and apply for users with limited knowledge in statistics. An orthogonal array provides a set of well-balanced experiments in which factor levels are weighted equally across the entire design. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor. ANOVA is a statistical decision making tool, used to analyze the experimental data, for detecting any differences in the response means of the factors being tested. ANOVA is also needed for estimating the error variance for the factor effects and variance of the prediction error. In general, the purpose of analysis of variance is to determine the relative magnitude of the effect of each factor and to identify the factors significantly affecting the response under consideration (objective function). The change in average response produced by a change in the level of a factor is called "Main Effect" of that factor. The main effects plot displays the response means for each factor level in the sorted order. The points (response means) in the plot are located with respect to a reference line drawn at the overall mean of the response data and connected by a line.

- When the line is horizontal (parallel to x-axis), then there is no main effect present. Each level of the factor affects the response in the same way, and the response mean is the same across all factor levels.
- When the line is not horizontal, then there is a main effect present. Different levels of the factor affect the response differently. The steeper the slope of the line, the greater the magnitude of the main effect.

RESULTS AND DISCUSSIONS

After machining the performance characteristics of material removal rate and surface roughness are measured and tabulated in table 3. The responses were analyzed using higher the better and lower the better characteristics which are proposed by taguchi. The response mean tables obtained are given in the tables 4 and 5.

***Table 3**. Experimental Results of Responses*

S.No.	MRR	R_a
1	0.5237	1.1947
2	0.5282	1.2094
3	0.5647	1.2743
4	0.6358	1.0582
5	0.6680	1.0668
6	0.7206	1.1152
7	0.8095	0.9418
8	0.8731	0.9561

9	0.8788	0.9816
10	0.3823	1.4551
11	0.3986	1.5008
12	0.3999	1.5178
13	0.4793	1.2501
14	0.5021	1.3361
15	0.5455	1.3643
16	0.6302	1.0769
17	0.6667	1.0971
18	0.6706	1.1061
19	0.2519	1.5267
20	0.2725	1.6186
21	0.2727	1.6394
22	0.3727	1.3305
23	0.4129	1.3754
24	0.4144	1.4488
25	0.4948	1.2240
26	0.4956	1.2343
27	0.4979	1.3022

Table 4.*Response Table for Means of MRR*

Level	P_{on}	P_{off}	I_p
1	0.6892	0.3994	0.5089
2	0.5195	0.5279	0.5353
3	0.3873	0.6686	0.5517
Delta	0.3019	0.2692	0.0428
Rank	1	2	3

Table 5. *Response Table for Means of R_a*

Level	P_{on}	P_{off}	I_p
1	1.089	1.437	1.229
2	1.300	1.261	1.266
3	1.411	1.102	1.306
Delta	0.322	0.335	0.077
Rank	2	1	3

The response mean values are drawn on main effect plots and shown in the figures 1 and 2. From the main effect plots, the optimal combinations of process parameters for achieving high material removal rate and low surface roughness is obtained at

For MRR:
Pon: level-1, 100 μs
Poff: Level-3, 55 μs
Ip: Level-3, 12 amp
For R_a:
Pon: level-3, 110 μs
Poff: Level-1, 45 μs
Ip: Level-3, 12 amp

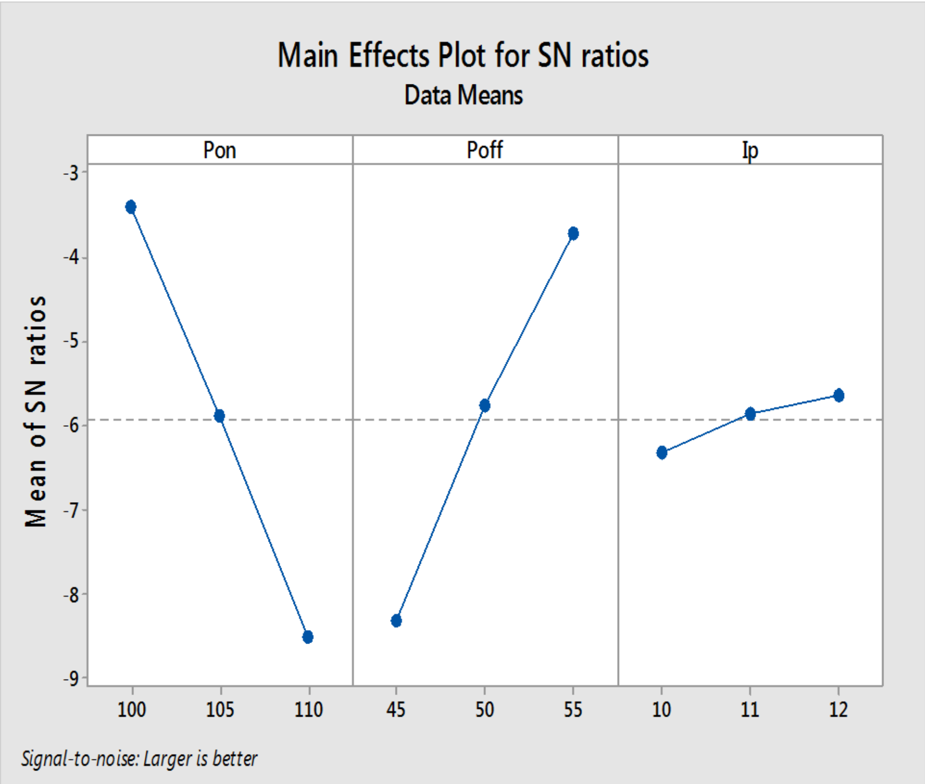

Fig 1. *Main Effect Plot for S/N Ratios of MRR*

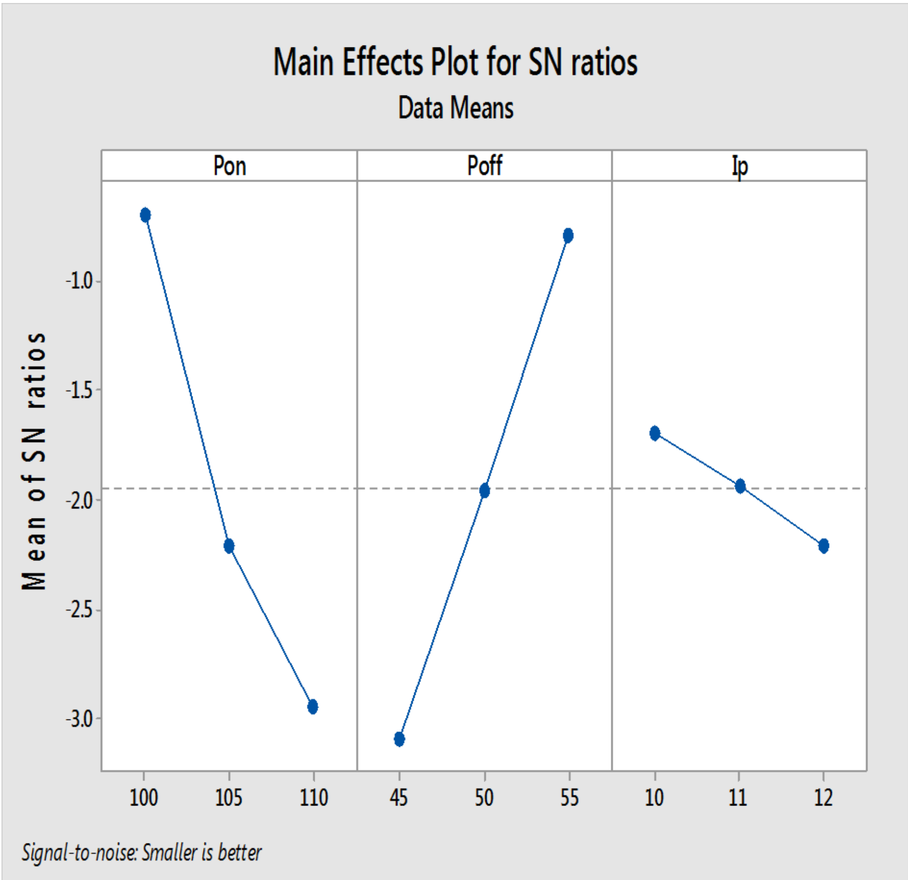

Fig 2. *Main Effect Plot for S/N Ratios of* R_a

Analysis of variance is employed to find the significance and the contribution of each process parameter on the performance characteristics. ANOVA results of material removal rate and surface roughness are given in the tables 6and 7. From the results it is found that P_{on} and P_{off} are the major influencing parameters for MRR and R_a respectively. The residual plots were drawn and shown in the figures3 and 4.

Table 6. *Analysis of Variance of MRR*

Source	DF	Adj SS	Adj MS	F	P
P_{on}	2	0.412224	0.206112	358.03	0.000
P_{off}	2	0.326302	0.163151	283.40	0.000
I_p	2	0.008381	0.004190	7.28	0.004
Error	20	0.011514	0.000576		
Total	26	0.758421			

S = 0.0239934, R^2 = 98.48%, R^2(Adj) = 98.03%, R^2(Pred) = 97.23%

Table 7.*Analysis of Variance of R_a*

Source	DF	Adj SS	Adj MS	F	P
P_{on}	2	0.48316	0.241579	197.60	0.000
P_{off}	2	0.50609	0.253047	206.98	0.000
I_p	2	0.02659	0.013293	10.87	0.001
Error	20	0.02445	0.001223		
Total	26	1.04029			

S = 0.0349655, R^2 = 97.65%, R^2(Adj) = 96.94%, R^2(Pred) = 95.72%

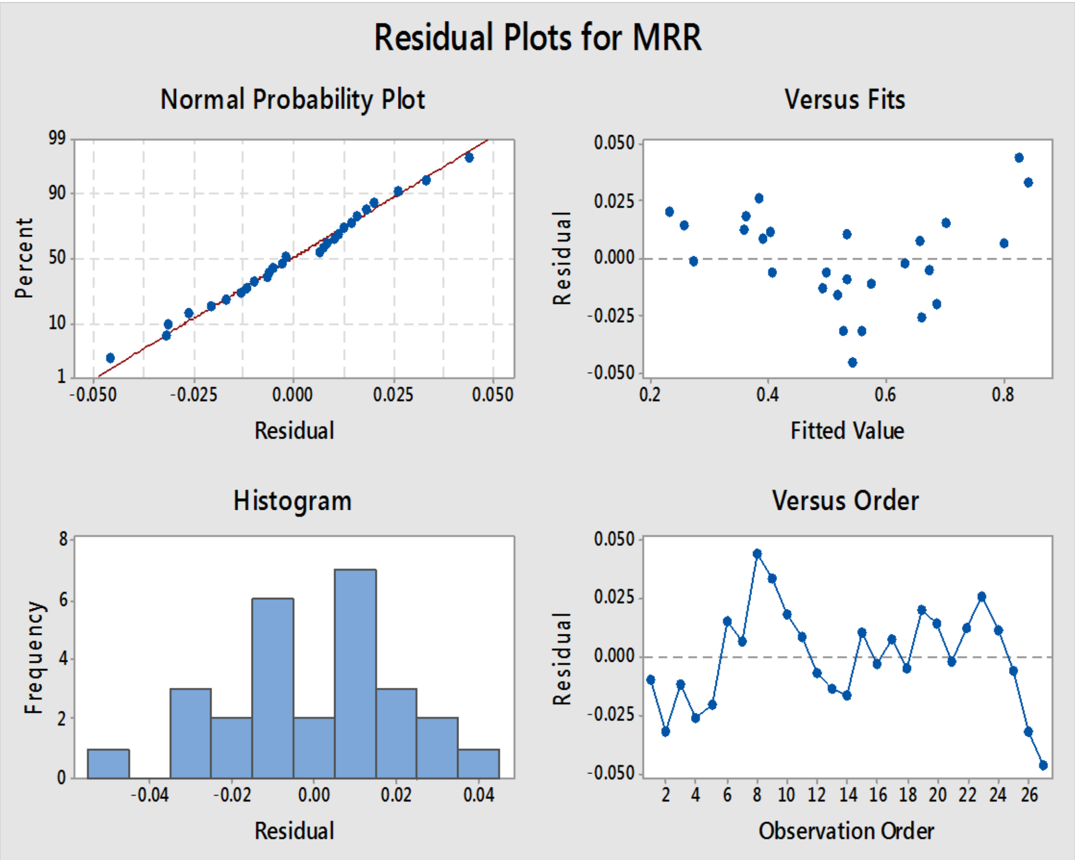

Fig 3. *Residual Plots for MRR*

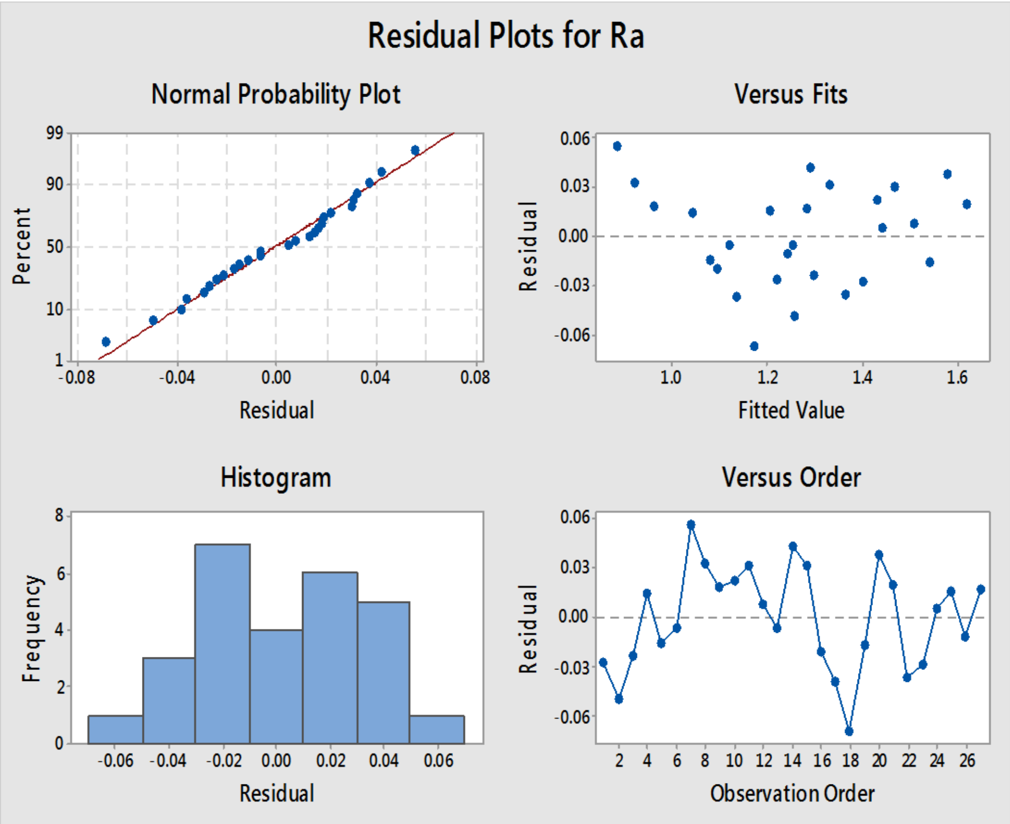

***Fig 4.** Residual plots for R_a*

Prediction of optimal designs

Optimal designs are predicted for the performance characteristic based on the estimated averages by considering the first most influencing process parameters.

For MRR

μ_{A1B3} = A1+B3-T

= 0.6892+0.6686-0.5319 = 0.8259

Confidence interval

$$(CI) = \sqrt{\frac{(F_{95\%,1,dof error} * V_{error})}{\eta_{efficiency}}}$$

$$where, \eta_{efficiency} = \frac{N}{1 + dof}$$

$\eta_{efficiency}$ = 27/(1+2+2) = 5.4

V_{error} = 0.000576

F95%,1,20 = 4.3512

$$CI = \sqrt{\frac{4.3512 * 0.000576}{5.4}} = 0.0214$$

The predicted optimal range of MRR

$\mu_{A1B3} - CI \leq \mu_{A1B3} \leq \mu_{A1B3} + CI$

$0.8045 \leq \mu_{A1B3} \leq 0.8473$

For R_a

μ_{A1B3} = A1+B3-T

= 1.437+1.411- 1.2667= 1.5813

Confidence interval

$$(CI) = \sqrt{\frac{(F_{95\%,1,dof error} * V_{error})}{\eta_{efficiency}}}$$

$$where, \eta_{efficiency} = \frac{N}{1 + dof}$$

$\eta_{efficiency}$ = 27/(1+2+2) = 5.4

V_{error} = 0. 001223

F95%,1,20 = 4.3512

$$CI = \sqrt{\frac{4.3512 * 0.001223}{5.4}} = 0.0313$$

The predicted optimal range of R_a

$\mu_{A1B3} - CI \leq \mu_{A1B3} \leq \mu_{A1B3} + CI$

$1.55 \leq \mu A1B3 \leq 1.6126$

CONCLUSIONS

- The optimal combination of process parameters for material removal rate is obtained at
  P_{on}: level-1, 100 µs
  P_{off}: Level-3, 55 µs
  I_p: Level-3, 12 amp

- The optimal combination of process parameters for surface roughness is obtained at
  P_{on}: level-3, 110 µs
  P_{off}: Level-1, 45 µs
  I_p: Level-3, 12 amp
- Analysis of variance results concluded that P_{on} and P_{off} are the major influencing parameters for MRR and R_a respectively.

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