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Experimental Investigation and Optimization of Machining Parameter on EDM Process of ZrB2-SiC Composite using Combination of different Tool (W, NB) by Grey Relational Analysis

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Abstract: The machining parameters for the electrical discharge machining process relies heavily on the operators' technologies and experience because of their diverse range. In general, ceramic components are manufactured through powder metallurgy route at net shaped production, but special feature like holes of smaller diameter at different orientation is not possible to produce by this technique. Hence machining becomes inescapable. In this work machinability behaviour of ZrB_2+ SiC during Electric Discharge Machining (EDM) with different tool material is carried out. The input parameters of the GRA are the tool, pulse on time and pulse off time. The output parameters of the model are MRR, TWR, and tool weight wear ratio.
Keywords: EDM, ZrB2-SiC, GRA.

I. INTRODUCTION

Globalization of world market creates a challenging environment in products marketing. Due to high competition induced the manufacture to produce better quality products within short period of time as well as low cost. Précised products could be produced while utilizing the machines at optimum working conditions.

Optimum machining parameters are of great concern in manufacturing environments, where economy of machining operations plays a key role in competitiveness in the market Present manufacturing industries are facing challenges from these advanced materials viz. super alloys, ceramics, and composites, that are hard and difficult to machine, requiring high precision, surface quality which increases machining cost.

To meet these challenges, non-conventional machining processes are being employed to achieve higher metal removal rate, better surface finish and greater dimensional accuracy, with less tool wear Globalization of world market creates a challenging environment in products marketing. Due to high competition induced the manufacture to produce better quality products within short period of time as well as low cost.

Précised products could be produced while utilizing the machines at optimum working conditions. Optimum machining parameters are of great concern in manufacturing environments, where economy of machining operations plays a key role in competitiveness in the market Present manufacturing industries are facing challenges from these advanced materials viz. super alloys, ceramics, and composites, that are hard and difficult to machine, requiring high precision, surface quality which increases machining cost. To meet these challenges, non-conventional machining processes are being employed to achieve higher metal removal rate, better surface finish and greater dimensional accuracy, with less tool wear.

II. LITERATURE REVIEW

The Fuzzy Theory, Artificial Neural Network and Regression Analysis are the most important and major modeling methods, employed in the EDM process modeling [1].

P.S. Kao (2003) proposed a method to optimize the electrochemical polishing of stainless steel by grey relational analysis [2]. Grey relational analysis is applied for the optimization of the wire electric discharge machining process of Al2O3 particle reinforced material (6061 alloy) with multiple-performance characteristics [3].In GRA, when the range of sequences is large or the standard value is large, the function of factors is neglected. The experimental results are normalized in the range of zero and one, the process is called grey relational generating [4]

III.DESIGN OF EXPERIMENTS

A. Taguchi Experimental Design And Analysis

Taguchi's recommends orthogonal array (OA) for laying out of experiments. These OA's are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interaction of interest to the appropriate columns. The use of linear graphs and triangular table suggested by Taguchi makes the assignment of parameters simple. The array forces all experimenters to design almost identical experiments. In the Taguchi method the results of the experiments are analysed to achieve one or more of the following objectives:

1) To establish the best or the optimum condition for a product or process.
2) To estimate the contribution of individual parameters and interactions.
3) To estimate the response under the optimum condition.

In the experiment, Minitab 16 software for Taguchi design was used. In this study, 3 level design (three factors) with total of 9 numbers of experiments to be conducted and hence the OA L9 was chosen

TABLE I
FACTOR LEVELS FOR ZRB2-SIC

LEVELS	Workpiece	Pulse On Time	Pulse Off Time
1	0.14	4	1
2	0.21	7	3
3	0.26	10	5

TABLE III
L9 ORTHOGONAL ARRAY

Array	RUNS	work piece	Pulse on time	Pulse off time
1	1	1	1	1
2	4	1	2	2
3	7	1	3	3
4	5	2	1	2
5	8	2	2	3
6	2	2	3	1
7	9	3	1	3
8	3	3	2	1
9	6	3	3	2

B. Grey Relation Analysis

In the grey relation analysis, experiment data, i.e., measured responses, are first normalized to the range of 0 to 1. This process is called grey relation generation. Based on this data, grey relation coefficients are calculated to represent the correlation between the ideal (best) and the actual normalized experimental data. Overall, grey relation grade is then determined by averaging the grey relation coefficient corresponding to selected responses. The overall quality characteristics of the multi-response process depend on the calculated grey relation grade.

C. Grey Relation Generation

There are three different types of data normalization according to the requirement of Lower the Better (LB), Higher the Better (HB), or Nominal the Best (NB) criteria. The desired quality characteristics for MRR are HB criterion; therefore, the normalization of original sequence of this response was done by using following equation:

$$y_i*(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Where $y_i*(k)$ was the normalized data, i.e. after grey relational generation, $y_i(k)$ was the k^{th} response of the i^{th} experiment, min $y_i(k)$ is the smallest value of $y_i(k)$ for k^{th} response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response. Overcut diameter follows the LB criterion. Accordingly, the normalization of this response is done using following equation:

$$y_i*(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

D. Grey Relation Co-Efficient

The grey relation coefficient was calculated as

$$\varepsilon_i(k) = \frac{\Delta \min + \omega \Delta \max}{\Delta_{oi}(k) + \omega \Delta \max}$$

Where $\mathcal{E}_i$ (k) is the grey relation coefficient of the ith experiment fr the kth response. Δ_{oi} (k)= lly_o*(k) – y_i *(k)ll, i.e absolute of the difference between y_o*(k) and y_i *(k). y_o*(k) is the ideal or reference sequence. Δ max is the largest value of Δ_{oi} (k), Δ min is the smallest value of Δ_{oi}.(k).

E. Grey Relation Grade

The grey relation grade (Ϊi) is calculated by averaging the grey relational coefficients corresponding to each experiment

$$\Gamma_i = \frac{1}{n}\sum_{=1}^{Q} i(k)$$

Where, Q is the total number of response and n is the number of output responses. The grey relational grade Ϊi represents the level of correlation between the reference sequence and the comparability sequence. If higher grey relation grade occurred than the corresponding parameter combination is closer to the optimal setting.

IV. EXPERIMENTAL RESPONSES AND OPTIMIZATION

Based on the selected process parameters levels, L9 Orthogonal Array was selected as shown in Table III and the combinations of machining operations are performed in EDM machine. There are nine experiments required to study the electric discharge machining process parameters by using Taguchi L9 orthogonal array

TABLE III

FACTOR LEVELS FOR ZRB2-SIC

LEVELS	Work piece	Pulse On Time	Pulse Off Time
1	0.14	4	1
2	0.21	7	3
3	0.26	10	5

The level of the variable process parameters selected on the basis of literature review, results of pilot experiments and the set up constraints.

The plan of experiments is made of 9 tests with Workpiece, Pulse On Time, Pulse Off Time as input parameters the response to be studied is material removal rate and overcut is exhibited in Table IV

TABLE IV

Experimental observations using L9 orthogonal array ZrB2-SiC by NB (Niobium)

Ex No	Workpiece	Pulse On Time (µs)	Pulse Off Time (µs)	MRR (mg/min)	TWR (mg/min)
1	0.14	4	1	0.9810	6.6767
2	0.14	7	3	0.9510	0.2903
3	0.14	10	5	0.8308	0.1201
4	0.21	4	3	1.0811	4.6747
5	0.21	7	5	1.0811	4.6747
6	0.21	10	1	0.6306	3.3333
7	0.26	4	5	0.5305	1.0010
8	0.26	7	1	1.5115	6.0060
9	0.26	10	3	1.0010	0.8308

TABLE V

Experimental observations using L9 orthogonal array ZrB2-SiC by W (Tungsten)

Ex No	Workpiece	Pulse On Time	Pulse Off Time	MRR	TWR
		(μs)	(μs)	(mg/min)	(mg/min)
1	0.14	4	1	0.9610	0.1802
2	0.14	7	3	1.5315	0.7007
3	0.14	10	5	0.3604	2.6627
4	0.21	4	3	1.0811	4.6747
5	0.21	7	5	0.6507	6.0060
6	0.21	10	1	0.4505	4.8248
7	0.26	4	5	0.5305	1.0010
8	0.26	7	1	2.0320	0.5806
9	0.26	10	3	1.3313	0.7007

The most valuable use of regression is in making predictions. The general purpose of multiple regressions is to learn more about the relationship between several independent or predictor variables and a dependent or criterion variable.

It can be used for a variety of purposes such as analyzing of experimental, ordinal, or categorical data. The data presented in Table VI have been used to build the multiple regression models.

TABLE VI

L27 ORTHOGONAL ARRAY

Ex No	Workpiece	Pulse On Time	Pulse Off Time
1	0.14	4	1
2	0.14	4	3
3	0.14	4	5
4	0.14	7	1
5	0.14	7	3
6	0.14	7	5
7	0.14	10	1
8	0.14	10	3
9	0.14	10	5
10	0.21	4	1
11	0.21	4	3
12	0.21	4	5
13	0.21	7	1
14	0.21	7	3
15	0.21	7	5
16	0.21	10	1
17	0.21	10	3
18	0.21	10	5
19	0.26	4	1
20	0.26	4	3
21	0.26	4	5
22	0.26	7	1
23	0.26	7	3
24	0.26	7	5
25	0.26	10	1
26	0.26	10	3
27	0.26	10	5

TABLE VII
EXPERIMENTAL RESULTS OF NB

Exp .No	workpiece	Pulse on time	Pulse off time	MRR	TWR
		(µs)	(µs)	(mg/min)	(mg/min)
1	0.14	4	1	0.9810	6.6767
2	0.14	4	3	0.7107	7.9880
3	0.14	4	5	0.3604	1.3313
4	0.14	7	1	2.0621	0.6206
5	0.14	7	3	0.9510	0.2903
6	0.14	7	5	0.4004	3.6737
7	0.14	10	1	1.0911	1.2813
8	0.14	10	3	0.4705	0.4304
9	0.14	10	5	0.8308	0.1201
10	0.21	4	1	0.6406	4.0040
11	0.21	4	3	1.0811	4.6747
12	0.21	4	5	0.6306	3.3333
13	0.21	7	1	1.7618	0.3103
14	0.21	7	3	0.6406	4.0040
15	0.21	7	5	1.0811	4.6747
16	0.21	10	1	0.6306	3.3333
17	0.21	10	3	1.7618	0.3103
18	0.21	10	5	0.6406	4.0040
19	0.26	4	1	1.1111	6.0060
20	0.26	4	3	0.9209	6.6767
21	0.26	4	5	0.5305	1.0010
22	0.26	7	1	1.5115	6.0060
23	0.26	7	3	1.0210	0.1602
24	0.26	7	5	0.8609	2.6727
25	0.26	10	1	2.2923	3.3534
26	0.26	10	3	1.0010	0.8308
27	0.26	10	5	0.5105	0.2703

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TABLE VIII

EXPERIMENTAL RESULTS OF W

Exp .No	workpiece	Pulse on time (µs)	Pulse off time (µs)	MRR (mg/min)	TWR (mg/min)
1	0.14	4	1	0.9610	0.1802
2	0.14	4	3	0.6206	7.8078
3	0.14	4	5	0.4104	4.5746
4	0.14	7	1	0.9610	1.5315
5	0.14	7	3	1.5315	0.7007
6	0.14	7	5	0.5305	0.1201
7	0.14	10	1	1.8218	6.5265
8	0.14	10	3	0.5405	6.3163
9	0.14	10	5	0.3604	2.6627
10	0.21	4	1	0.7007	0.2703
11	0.21	4	3	0.6507	6.0060
12	0.21	4	5	0.4505	4.8248
13	0.21	7	1	2.2322	1.2112
14	0.21	7	3	0.7007	0.2703
15	0.21	7	5	0.6507	6.0060
16	0.21	10	1	0.4505	4.8248
17	0.21	10	3	2.2322	1.2112
18	0.21	10	5	0.7007	0.2703
19	0.26	4	1	1.2513	1.8519
20	0.26	4	3	0.6907	7.8178
21	0.26	4	5	0.5305	1.5516
22	0.26	7	1	2.0320	0.5806
23	0.26	7	3	1.1211	5.8358
24	0.26	7	5	0.2903	3.6737
25	0.26	10	1	0.5405	3.7437
26	0.26	10	3	1.3313	0.7007
27	0.26	10	5	0.3303	0.2202

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TABLE IX
FOR NB

Order No	Normalized Values		Grey Relation Analysis		Grey Relational Coefficient		Grey Relational Grade
	M.R.R	Overcut	M.R.R	Overcut	M.R.R	Overcut	
1	0.321238159	0.166664548	0.678762	0.833335452	0.424174	0.374999	0.399587
2	0.181324085	0	0.818676	1	0.379168	0.333333	0.356251
3	0	0.846058033	1	0.153941967	0.333333	0.764594	0.548964
4	0.880842694	0.936387092	0.119157	0.063612908	0.807549	0.887134	0.847341
5	0.305709405	0.978367798	0.694291	0.021632202	0.418659	0.95853	0.688594
6	0.020705005	0.548341997	0.979295	0.451658003	0.337999	0.525399	0.431699
7	0.378228687	0.852412969	0.621771	0.147587031	0.445724	0.772097	0.60891
8	0.056990527	0.960561268	0.943009	0.039438732	0.346498	0.926889	0.636694
9	0.243490864	1	0.756509	0	0.397928	1	0.698964
10	0.145038563	0.506361291	0.854961	0.493638709	0.369014	0.503201	0.436108
11	0.373052435	0.421116181	0.626948	0.578883819	0.443676	0.463442	0.453559
12	0.139862312	0.591606401	0.860138	0.408393599	0.36761	0.550422	0.459016
13	0.725399865	0.975825824	0.2746	0.024174176	0.645494	0.953881	0.799688
14	0.145038563	0.506361291	0.854961	0.493638709	0.369014	0.503201	0.436108
15	0.373052435	0.421116181	0.626948	0.578883819	0.443676	0.463442	0.453559
16	0.139862312	0.591606401	0.860138	0.408393599	0.36761	0.550422	0.459016
17	0.725399865	0.975825824	0.2746	0.024174176	0.645494	0.953881	0.799688
18	0.145038563	0.506361291	0.854961	0.493638709	0.369014	0.503201	0.436108
19	0.38858119	0.251909658	0.611419	0.748090342	0.449875	0.400612	0.425244
20	0.290128889	0.166664548	0.709871	0.833335452	0.413267	0.374999	0.394133
21	0.088048036	0.88803874	0.911952	0.11196126	0.35412	0.817045	0.585582
22	0.595838294	0.251909658	0.404162	0.748090342	0.552998	0.400612	0.476805
23	0.341943165	0.994903341	0.658057	0.005096659	0.431758	0.98991	0.710834
24	0.259071381	0.675567814	0.740929	0.324432186	0.402924	0.606478	0.504701
25	1	0.589051716	0	0.410948284	1	0.548879	0.774439
26	0.331590662	0.909670941	0.668409	0.090329059	0.427932	0.846985	0.637459
27	0.077695533	0.980909773	0.922304	0.019090227	0.351542	0.963224	0.657383

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TABLE X
FOR W

Order No	Normalized Values		Grey Relation Analysis		Grey Relational Coefficient		Grey Relational Grade
	M.R.R	Overcut	M.R.R	Overcut	M.R.R	Overcut	
1	0.345383387	0.992192	0.654617	0.007807527	0.433044	0.984625	0.708835
2	0.170091148	0.001299	0.829909	0.998700911	0.375966	0.333622	0.354794
3	0.061846645	0.421321	0.938153	0.578679346	0.347668	0.46353	0.405599
4	0.345383387	0.816647	0.654617	0.183353469	0.433044	0.731686	0.582365
5	0.639167825	0.924575	0.360832	0.075425127	0.580833	0.868923	0.724878
6	0.12369329	1	0.876307	0	0.363291	1	0.681646
7	0.78866059	0.167751	0.211339	0.832248594	0.702899	0.375305	0.539102
8	0.128842886	0.195058	0.871157	0.804941736	0.364656	0.383159	0.373907
9	0.036098666	0.669694	0.963901	0.330306455	0.341553	0.602187	0.47187
10	0.21133941	0.980488	0.788661	0.019512322	0.388	0.962441	0.67522
11	0.185591431	0.235369	0.814409	0.764630994	0.380399	0.395372	0.387886
12	0.082496524	0.388817	0.917503	0.611182561	0.352733	0.449971	0.401352
13	1	0.858256	0	0.141743638	1	0.779127	0.889564
14	0.21133941	0.980488	0.788661	0.019512322	0.388	0.962441	0.67522
15	0.185591431	0.235369	0.814409	0.764630994	0.380399	0.395372	0.387886
16	0.082496524	0.388817	0.917503	0.611182561	0.352733	0.449971	0.401352
17	1	0.858256	0	0.141743638	1	0.779127	0.889564
18	0.21133941	0.980488	0.788661	0.019512322	0.388	0.962441	0.67522
19	0.494876152	0.775024	0.505124	0.224976292	0.497451	0.689678	0.593564
20	0.206189814	0	0.79381	1	0.386455	0.333333	0.359894
21	0.12369329	0.814035	0.876307	0.185964639	0.363291	0.728901	0.546096
22	0.896905093	0.940177	0.103095	0.059823064	0.829057	0.893139	0.861098
23	0.427828415	0.25748	0.572172	0.742520493	0.466343	0.402408	0.434376
24	0	0.538356	1	0.461644387	0.333333	0.519943	0.426638
25	0.128842886	0.529262	0.871157	0.470738013	0.364656	0.515072	0.439864
26	0.536072918	0.924575	0.463927	0.075425127	0.518711	0.868923	0.693817
27	0.020598383	0.986996	0.979402	0.013003884	0.337974	0.974651	0.656313

TABLE XI
OPTIMUM LEVEL SELECTION FOR NB

Level	A	B	C
1	0.538111	0.492582	0.632329
2	0.59814	0.629297	0.543815
3	0.556851	0.571223	0.516958
Delta	0.06003	0.136715	0.115371
Rank	3	1	2

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TABLE XII
OPTIMUM LEVEL SELECTION FOR W

Level	A	B	C
1	0.579667	0.450938	0.580793
2	0.525872	0.59437	0.568147
3	0.574064	0.634296	0.530664
Delta	0.053795	0.183358	0.050129
Rank	2	1	3

V. RESULTS AND DISCUSSION

According to Taguchi philosophy the use of loss function to measure the deviation between the experimental value and the desired value which is further transformed into signal-to-noise ratio (S/N). Basically, there are three types of categories in the evaluation of signal-to-noise ratio i.e.

Lower-the-better (LB), higher-the-better (HB) and nominal- the-better (NB) .The objective of paper is to optimize the process parameter for MRR, over cut and for finding MRR higher the better has been taken to calculate the singal to noice ratio .and lower-the-better characteristic has been taken to calculate the other response parameter.

The optimal parameters were chosen based on higher S/N ratio as signal represents desirable value and noise represents undesirable value. Next, statistical analysis of variance (ANOVA) was conducted to study the significance of process parameters on responses based on their P-value and F-value at 95% confidence level.

Fig 6.1 main effect plot MRR for means (W)

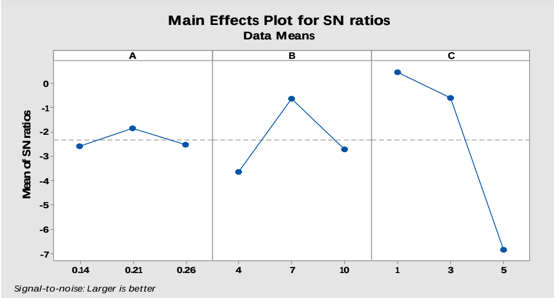

Fig 6.2 main effect plot MRR for SN Ratio (W)

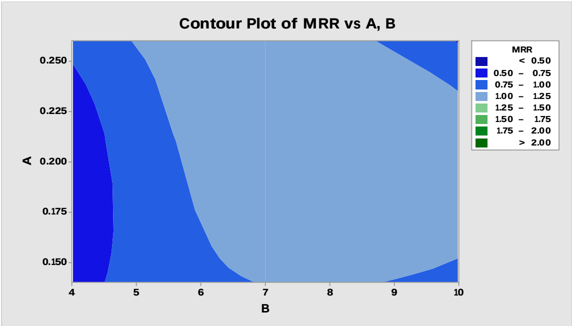

Fig contour plot of MRR vs A, B

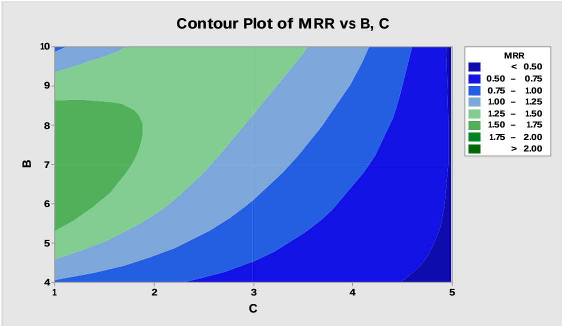

Fig contour plot of MRR vs B, C

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A. Contour plot of MRR vs A, B

In the above figure show the dark blue region is lower metal removal rate and then increasing with light blue so we can say that parameter B from 4 to 6 and parameter A from 0.15 to 0.25 cover small MRR as compare to other region of contour plot.

B. Contour plot of MRR vs B, C

In the above figure show the dark green region is higher metal removal rate and then decreasing with light blue and blue so we can say that parameter B from 5 to 8.5 and parameter C from 1 to 3 cover large MRR as compare to other region of contour plot.

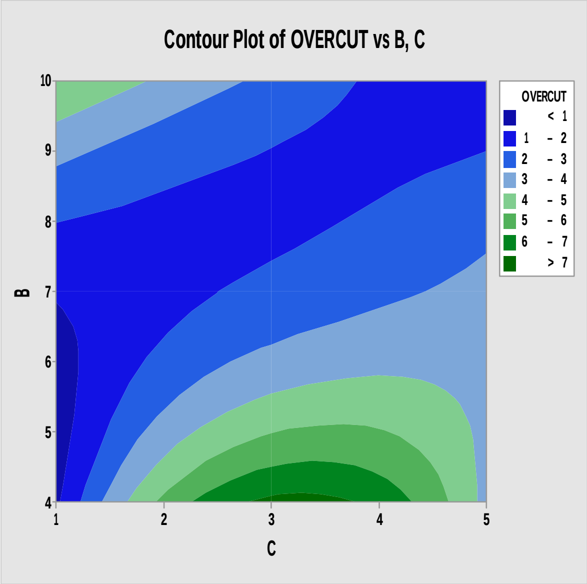

Fig contour plot of OVERCUT vs B, C

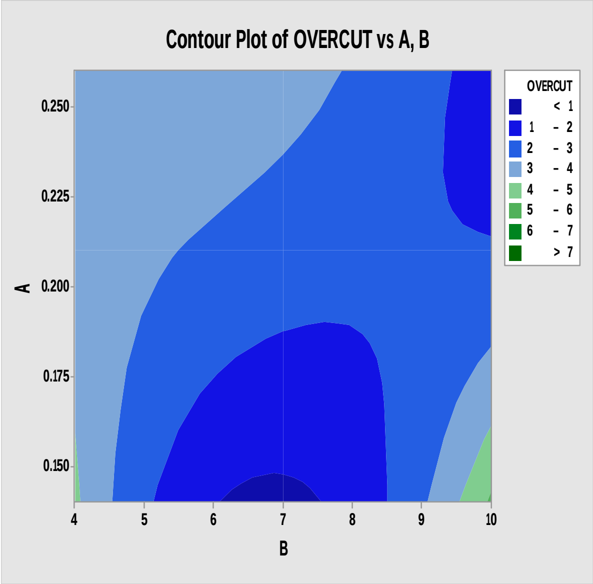

Fig contour plot of OVERCUT vs A, B

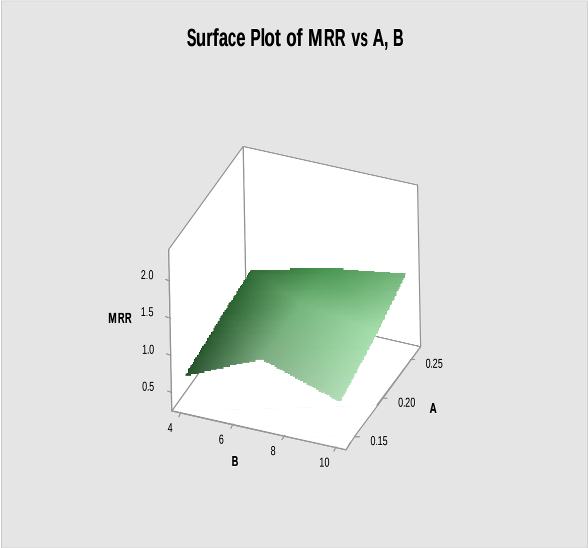

Fig surface plot of overcut VS A,B (NB)

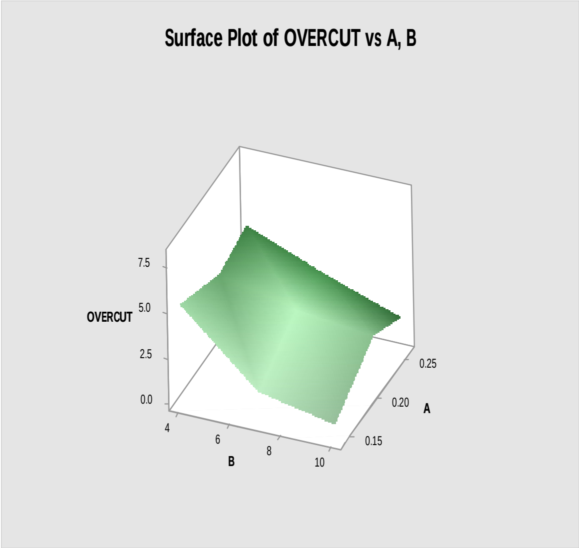

Fig surface plot of overcut VS A, B (NB)

VI. CONCLUSION

The experimental results for optimal settings showed that there was a considerable improvement in the performance characteristics viz., MRR and OC. And using grey technique the optimal parameter of input is A2 B2 AND C1 and the value of MRR and OC is 2.23222.0621(mg/min) and 1.2112(mg/min) respectively for W. and apart from that the optimal result in the case of NB the percentage of SiC in ZrB2 is 14 percentages is the optimum and pulse on time is 7 µs and pulse off time is 1 µs. For this input parameter the response parameter is optimum MRR 2.0621(mg/min) and OC is 0.6206 (mg/min).

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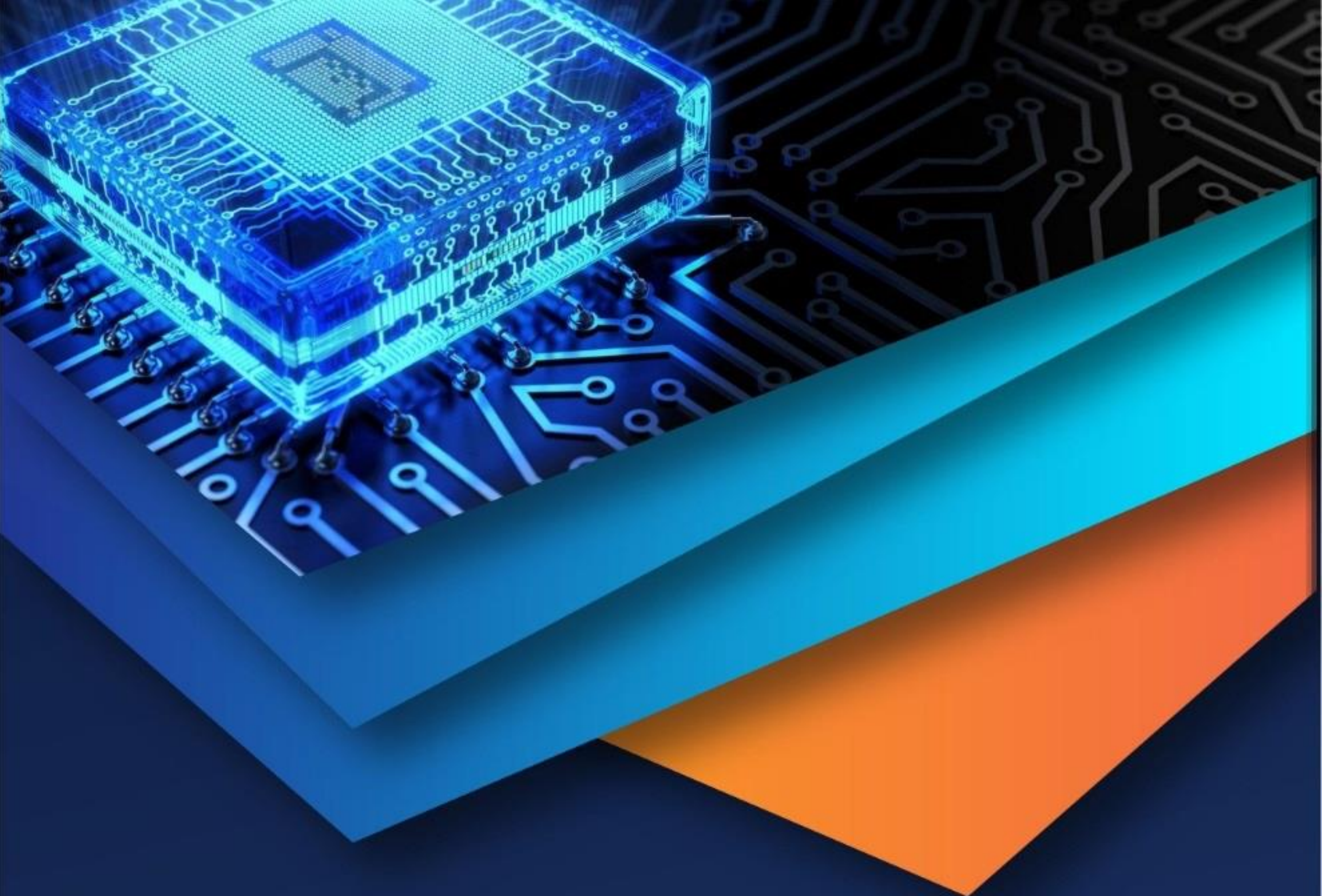

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