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 ZrB₂+ 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. Precised 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. Precised 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 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 this 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

| LEVELS | FACTOR LEVELS FOR ZrB2-SiC |
|--------|-----------------------------|
|        | Workpiece       | Pulse On Time | Pulse Off Time |
| 1      | 0.14            | 4             | 1              |
| 2      | 0.21            | 7             | 3              |
| 3      | 0.26            | 10            | 5              |

TABLE II

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:
D. Grey Relation Co-Efficient
The grey relation coefficient was calculated as

\[ \varepsilon_i(k) = \frac{\Delta_{\text{min}} + \omega \Delta_{\text{max}}}{\Delta_{\text{mi}}(k) + \omega \Delta_{\text{max}}} \]

Where \( \varepsilon_i(k) \) is the grey relation coefficient of the \( i^{th} \) experiment for the \( k^{th} \) response. \( \Delta_{\text{mi}}(k) = \|y_0*(k) - y_i*(k)\| \), i.e. absolute of the difference between \( y_0*(k) \) and \( y_i*(k) \). \( y_0*(k) \) is the ideal or reference sequence. \( \Delta_{\text{max}} \) is the largest value of \( \Delta_{\text{mi}}(k) \), \( \Delta_{\text{min}} \) is the smallest value of \( \Delta_{\text{mi}}(k) \).

E. Grey Relation Grade
The grey relation grade \( \Gamma_i \) is calculated by averaging the grey relational coefficients corresponding to each experiment

\[ \Gamma_i = \frac{1}{n} \sum_{k=1}^{Q} \varepsilon_i(k) \]

Where, \( Q \) is the total number of responses and \( n \) is the number of output responses. The grey relational grade \( \Gamma_i \) 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 |
| LEVELES | 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 | Pulse Off Time | 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 (µs) | Pulse Off Time (µs) | MRR (mg/min) | TWR (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              |
| 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 |
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       |
### 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      | Grey Relational Grade |
| 1        | 0.321238159 0.166664548 | 0.678762 0.833355452 | 0.424174 0.374999 | 0.399587 |
| 2        | 0.181324085 0.846058033 | 0.818676 1 | 0.379168 0.333333 | 0.356251 |
| 3        | 0.880842694 0.936387092 | 0.119157 0.063612908 | 0.807549 0.887134 | 0.847341 |
| 4        | 0.305709405 0.978367798 | 0.694291 0.021632202 | 0.418659 0.95853 | 0.688594 |
| 5        | 0.159387498 0.978367798 | 0.694291 0.021632202 | 0.418659 0.95853 | 0.688594 |
| 6        | 0.880842694 0.936387092 | 0.119157 0.063612908 | 0.807549 0.887134 | 0.847341 |
| 7        | 0.056990527 0.960561268 | 0.943009 0.039438732 | 0.346498 0.926889 | 0.636694 |
| 8        | 0.243490864 0.756509 | 0.378228687 0.852412969 | 0.621771 0.147587031 | 0.445724 0.772097 | 0.60891 |
| 9        | 0.145038563 0.506361291 | 0.854961 0.493638709 | 0.369014 0.503201 | 0.436108 |
| 10       | 0.373052435 0.421116181 | 0.626948 0.578883819 | 0.443676 0.463442 | 0.453559 |
| 11       | 0.139862312 0.591606401 | 0.860138 0.408393599 | 0.36761 0.550422 | 0.459016 |
| 12       | 0.725399865 0.975825824 | 0.2746 0.024174176 | 0.645494 0.953881 | 0.799688 |
| 13       | 0.145038563 0.506361291 | 0.854961 0.493638709 | 0.369014 0.503201 | 0.436108 |
| 14       | 0.373052435 0.421116181 | 0.626948 0.578883819 | 0.443676 0.463442 | 0.453559 |
| 15       | 0.139862312 0.591606401 | 0.860138 0.408393599 | 0.36761 0.550422 | 0.459016 |
| 16       | 0.725399865 0.975825824 | 0.2746 0.024174176 | 0.645494 0.953881 | 0.799688 |
| 17       | 0.145038563 0.506361291 | 0.854961 0.493638709 | 0.369014 0.503201 | 0.436108 |
| 18       | 0.38858119 0.251909658 | 0.611419 0.748090342 | 0.449875 0.400612 | 0.425244 |
| 19       | 0.290128889 0.166664548 | 0.709871 0.833335452 | 0.413267 0.374999 | 0.394133 |
| 20       | 0.088048036 0.88803874 | 0.911952 0.11196126 | 0.35412 0.817045 | 0.585582 |
| 21       | 0.595838294 0.251909658 | 0.404162 0.748090342 | 0.552998 0.400612 | 0.476805 |
| 22       | 0.341943165 0.994903341 | 0.658057 0.005096659 | 0.431758 0.98991 | 0.710834 |
| 23       | 0.259071381 0.675567814 | 0.740929 0.324432186 | 0.402924 0.606478 | 0.504701 |
| 24       | 1 0.589051716 0.410948284 | 0.041909227 1 | 0.548879 0.774439 | 0.637459 |
| 25       | 0.331590662 0.909670941 | 0.668409 0.090329059 | 0.427932 0.846985 | 0.637459 |
| 26       | 0.077695533 0.980909773 | 0.922304 0.019090227 | 0.351542 0.963224 | 0.657383 |
### 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         | 0.37907             |
| 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 0.25369 | 0.814409 0.764630994 | 0.380399 0.395372         | 0.387866            |
| 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 0.25369 | 0.814409 0.764630994 | 0.380399 0.395372         | 0.387866            |
| 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 |
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 noise 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.
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.

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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