MCDM Optimization of Parameters for Wire-EDM Machined Stainless Steel using Hybrid RSM-TOPSIS, Genetic Algorithm and Simulated Annealing

Dilip Kumar Bagal, Abhishek Barua, Siddharth Jeet, Pratyashi Satapathy, Dulu Patnaik

Abstract*: In this investigation, the influence of WEDM process constraints on tool wear rate, kerf width, surface roughness of SS 304 grade stainless steel was studied. Fifteen experimental runs were carried out based on Box-Behnken method of Response surface methodology and TOPSIS method was used for finding an optimum parameter setting. From the ANOVA results, pulse ON time was found as most significant factor for tool wear rate, kerf width and surface roughness. Genetic Algorithm and Simulated Annealing was also used for the calculation of the optimum setting along with the forecast of fitness values. It was found that every optimization technique gives similar factor setting.

Keywords: ANOVA, Box-Behnken, Genetic Algorithm, Response surface methodology, TOPSIS method, Simulated Annealing.

I. INTRODUCTION

Stainless steel extensively preferred as a constituent for innumerable goods which are regularly manufactured using numerous processes. Non-traditional machining techniques such as Wire Electrical Discharge Machining have the prospective which can be used for precise machining of stainless steel. Though, it is significant for selection of best arrangement of WEDM constraints for the achievement of optimum machining enactment [1-8]. In this contemporary work, the influence of WEDM process constraints on tool wear rate, kerf width and surface roughness of SS 304 grade stainless steel was studied. Optimization of the machining parameters for SS 304 machining has been done using TOPSIS method. RSM based Box-Behnken experimental design was planned, Genetic Algorithm and Simulated Annealing was also used for the calculation of the optimum setting along with the forecast of fitness values.

II. MATERIAL USED AND EXPERIMENTAL SETUP

SS 304 graded Stainless steel was chosen as work-piece material. Each work piece specimen was cut in 200 mm × 40 mm × 5 mm dimension in the Wire Electrical Discharge Machine. Table I shows the composition of stainless steel.

Table- I: Material configuration of SS 304

Element	% Conc. by weight	Element	% Conc. by weight
Iron	70.32	Molybdenum	0.166
Carbon	0.07	Silicon	0.18
Chromium	18.30	Copper	0.247
Manganese	1.28	Phosphorous	0.034
Sulphur	0.0052	Niobium	0.045
Titanium	0.007	Vanadium	0.044
Nickel	8.02	Aluminum	0.0005

The experimental studies were performed on Electronica Group Ecocut travelling WEDM machine. By utilizing this machine, work piece can be cut in accord with fixed locus. Pulse ON time, current and pulse OFF time with different levels are taken as process parameters in this experimental investigation. Throughout the experiments, frequency setting was retained fix. Fig. 1 and 2 shows the WEDM diagram and work table respectively. The input parameters for WEDM operation is shown in Table II.

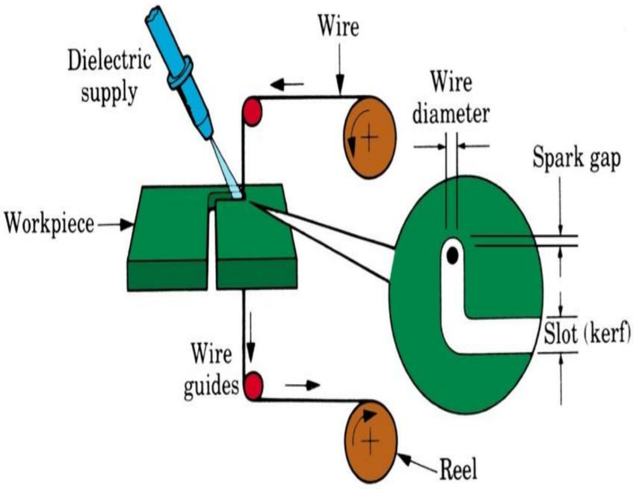

Fig. 1.Schematic of WEDM process

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Fig. 2. Work Table

The surface roughness of each specimen was measured by the Mitutoyo Surface Roughness Tester (model SJ – 400). The stereo-zoom microscope was used for measuring kerf width and tool wear rate was measured using Scanning Electron Microscope.

Table- II: Input parameters

Factors	Symbol	Level 1	Level 2	Level 3
Current	A	1 amp	1.5 amp	2 amp
Pulse ON Time	B	6 µs	7 µs	8 µs
Pulse OFF Time	C	1 µs	2 µs	3 µs

A. Experimental Design using Response Surface Methodology

RSM (Response surface methodology) is a collected works of calculated and numerical methods which are compliant for demonstrating and exploration of difficulties in which output is partial by several input parameters. The investigational values are examined and the scientific model is established which exemplifies the correlation amid the input variable and output response [2]. Equation (1) shows the second-order model which describes the conduct of the method:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i,j=1, i\neq j}^{k} \beta_{ij} X_i X_j + \epsilon \quad (1)$$

Where, Y = consistent output, X_i = response, $X_i X_j$ are squares and collaboration terms in second-order model, respectively. β_0, β_i, β_{ij}, β_{ii} are indefinite regression coefficients, ϵ is error in model [10-14].

B. Technique for order of preference by similarity to ideal solution Method (TOPSIS)

Following are the steps which are used in the TOPSIS method [3, 4, 11, 13, 14]:

Step 1: Decision Matrix formation:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (2)$$

Where, x_{ij} is output relating to x_j.

Step 2: Matrix normalization using Equation (3):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (3)$$

Where, r_{ij} is the normalized value of x_{ij}.

Step 3: Formation of weighted normalized matrix:

$$V = \lfloor v_{ij} \rfloor V = w_j r_{ij} \quad (4)$$

$$D = \begin{bmatrix} y_{11} & y_{12} & . & y_{1j} & y_{1n} \\ y_{21} & y_{22} & . & y_{2j} & y_{2n} \\ . & . & . & . & . \\ y_{i1} & y_{i2} & . & y_{1j} & . \\ . & . & . & . & . \\ y_{m1} & y_{m2} & . & y_{mj} & y_{mn} \end{bmatrix} \quad (5)$$

Here, $\sum_{j=1}^{n} w_j = 1$

Step 4: Determination of positive ideal solution and negative ideal solutions:

a) For positive ideal solution:

$$A^+ = \{(\max_i y_{ij} | j \in J), (\min_i y_{ij} | j \in J | i = 1,2,\ldots,m)\} = \{y_1^+, y_2^+, \ldots\ldots, y_j^+, \ldots\ldots y_n^+\} \quad (6)$$

$$A^+ = \{(\min_i y_{ij} | j \in J), (\max_i y_{ij} | j \in J | i = 1,2,\ldots,m)\} = \{y_1^-, y_2^-, \ldots\ldots, y_j^-, \ldots\ldots y_n^-\} \quad (7)$$

Step 5: Determination of distance measures using Euclidean distance equations:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_j^+)^2} \quad i = 1,2,\ldots\ldots,m \quad (8)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_j^-)^2} \quad i = 1,2,\ldots\ldots,m \quad (9)$$

Step 6: Overall performance coefficient calculation using Equation (10):

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}, i = 1,2,\ldots\ldots, m; 0 \leq C_i^+ \leq 1 \quad (10)$$

C. Genetic Algorithm

It is established on natural advancement process which is utilized to advance answers for complex enhancement issues. A potential answer for an issue might be spoken to by an arrangement of constraints known as qualities which are composed to frame a string, which are alluded as a chromosome. This arrangement of constraints by a specific chromosome is known as genotype which contains the data required to develop a living being known as the phenotype. A wellness work is practically equivalent to the target work in a streamlining issue. The wellness work restores a solitary numerical wellness which is relative to the utility or the capacity of the person which that chromosome speaks to. Following is the algorithm which is used in the GA approach [8, 11, 14].

Algorithm of GA approach

1. Generated of random population of chromosomes.
2. Evaluation of fitness of each chromosome in population.
3. Stop and return the preeminent result in existing population if end situation was satisfied.
4. Creation of new population by repetition of following steps until new population is ample. Two parent chromosomes from population is selected

having great fitness value. Parents cross over was done using crossover probability for producing new offspring. New offspring transmutation was done using mutation probability for every position in the chromosome [8].

5. Usage of new generated population is done for supplementary run of the algorithm.
6. After processing all the above steps, step 2 onwards is repeated.

D. Simulated Annealing Approach

It is a credibility technique which mirrors the way toward tempering (moderate cooling of liquid metal) with a specific end goal to accomplish least unguent esteem in a minimization matter. The cooling occurrence is conceded by governing temperature like constraint using Boltzmann probability distribution. Giving to this dispersal a framework in warm balance at temperature 'T' has its vitality credibility scattered according to Equation (11) [6, 9, 11, 14].

$$P(E) = exp(-\Delta E/kT) \qquad (11)$$

Where, ΔE and k are Boltzmann coefficient and Boltzmann constant respectively.

III. RESULTS AND DISCUSSION

The samples are cut into desired size using WEDM which is shown in Fig. 3. Samples are prepared by using RSM Box Behnken experimental design shown in Table VI. The experimental results are then analyzed using MINITAB 18 software. The experimental results for kerf width, TWR and the surface roughness are tabulated in Table VI.

Fig. 3. Tested Specimen

Table- III: RSM based Box-Behnken design for experimental runs and responses

Run No.	A	B	C	Surface Roughness (µm)	Kerf Width (µm)	TWR (g/min^3)
1	1.0	6	2	2.311	194.609	4.6
2	2.0	6	2	2.575	205.279	3.64
3	1.0	8	2	2.698	206.718	1.29
4	2.0	8	2	2.784	179.122	1.86
5	1.0	7	1	3.597	194.47	2.81
6	2.0	7	1	4.212	179.47	6.05
7	1.0	7	3	3.28	186.533	10.1
8	2.0	7	3	4.631	205.57	5.9
9	1.5	6	1	4.149	209.192	7.05
10	1.5	8	1	3.76	271.93	6.96
11	1.5	6	3	3.25	213.61	2.33
12	1.5	8	3	4.09	210.16	2.09
13	1.5	7	2	4.01	210.07	1.78
14	1.5	7	2	3.66	193.4	5.9
15	1.5	7	2	4.49	177.35	4.3

A. Optimization using TOPSIS method

In TOPSIS, the output responses have been standardized into a solo dimensionless scale between 0 and 1 as shown in Table IV. Here, each response parameters have been hypothetical to equally imperative so all have been allotted with equal significance weight. Table V presents weighted normalized matrix. Positive ideal solution and negative ideal solution are articulated in order to evaluate parting distance which is furnished in Table VI. Lastly, overall performance index (OPI) has been calculated using Equation (10). Mean effect plot for overall performance index has been shown in Fig. 4.

Table- IV: Normalized Output Responses

Run No.	Surface Roughness	Kerf Width	TWR
1	0.164169	0.246678	0.234455
2	0.182922	0.260203	0.185525
3	0.191660	0.262027	0.065749
4	0.197769	0.227047	0.094801
5	0.255523	0.246502	0.143221
6	0.299211	0.227488	0.308359
7	0.233004	0.236441	0.514781
8	0.328976	0.260571	0.300714
9	0.294736	0.265163	0.359327
10	0.267102	0.344686	0.354740
11	0.230873	0.270763	0.118756
12	0.290545	0.266389	0.106524
13	0.284862	0.266275	0.090724
14	0.259999	0.245145	0.300714
15	0.318960	0.224801	0.219164

Table- V: Weighted Output Responses

Run No.	Surface Roughness	Kerf Width	TWR
1	0.0797146	0.0814037	0.0541756
2	0.0630785	0.0858668	0.0603644
3	0.0223547	0.0864688	0.0632479
4	0.0322324	0.0749255	0.0652639
5	0.0486952	0.0813455	0.0843227
6	0.1048420	0.0750711	0.0987398
7	0.1750255	0.0780255	0.0768914
8	0.1022426	0.0859886	0.1085622
9	0.1221713	0.0875036	0.0972629
10	0.1206116	0.1137465	0.0881438
11	0.0403772	0.0893516	0.0761881
12	0.0362181	0.0879085	0.0958798
13	0.0308461	0.0878709	0.0940044
14	0.1022426	0.0808979	0.0857995
15	0.0745158	0.0741843	0.1052568

Table- VI: Positive Ideal solution and negative ideal solution

Type of Ideal Solution	Surface Roughness	Kerf Width	TWR
Positive Ideal Solution	0.05418	0.07418	0.06575
Negative Ideal Solution	0.10856	0.11375	0.51478

Table- VII: Calculated

distance measure and Overall performance coefficient

Run No.	S+	S-	C+
1	0.0157	0.4396	0.9655
2	0.0135	0.4551	0.9712
3	0.0460	0.4953	0.9150
4	0.0353	0.4860	0.9323
5	0.0354	0.4678	0.9297
6	0.0593	0.4119	0.8742
7	0.0552	0.3431	0.8613
8	0.0665	0.4135	0.8614
9	0.0722	0.3936	0.8450
10	0.0500	0.3947	0.8876
11	0.0369	0.4761	0.9282
12	0.1417	0.4794	0.7719
13	0.0547	0.4848	0.8986
14	0.0488	0.4145	0.8948
15	0.0518	0.4421	0.8951

In Fig. 4, the combination of $A_2B_3C_3$ shows smallest value of mean effect plot for the factors A, B and C respectively. Therefore, $A_2B_3C_3$ i.e. current 1.5 amp, pulse ON time 8 µs and pulse OFF time 3 µs is the optimum parameter setting.

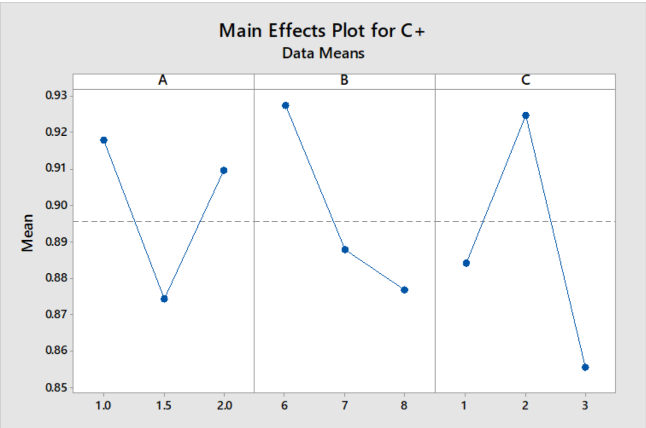

Fig. 4.Main effect plot with factors and their levels

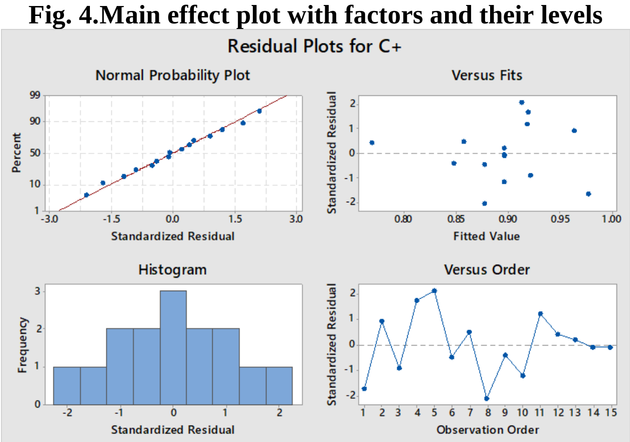

Fig. 5.Residual Plots for overall performance index

B. Most influential factor

Table VIII gives ANOVA results for the output responses using the calculated values from the Overall Performance Index (OPI) of Table VII. As stated by Table VIII, factor B, pulse ON time with 14.6 % of contribution, was found out to be the most important parameters for WEDM followed by factor C, pulse OFF time with 4.58 % and factor A, the current with 0.37 % of contribution if minimization of kerf width, surface roughness and TWR simultaneously considered.

S = 0.0151638, R-sq = 96.74 %, R-sq(adj) = 90.88 %, R-sq(pred)= 48.24 %

Table- VIII: ANOVA result for C^+

Source	DF	Adj SS	Adj MS	F-test	P-test	%
Model	9	0.034	0.003	16.50	0.003	96.74
Linear	3	0.006	0.002	10.01	0.015	19.56
A	1	0.000	0.000	0.57	0.483	0.37
B	1	0.005	0.005	22.42	0.005	14.60
C	1	0.001	0.001	7.03	0.045	4.58
Square	3	0.016	0.005	23.99	0.002	46.89
A*A	1	0.004	0.004	21.60	0.006	14.07
B*B	1	0.000	0.000	2.78	0.156	1.81
C*C	1	0.009	0.009	42.05	0.001	27.40
2-Way Interaction	3	0.010	0.003	15.50	0.006	30.30
A*B	1	0.000	0.000	0.14	0.720	0.09
A*C	1	0.000	0.000	3.36	0.126	2.19
B*C	1	0.009	0.009	43.01	0.001	28.02
Error	5	0.001	0.000			3.26
Lack of Fit	3	0.001	0.000	82.34	0.012	3.23
Pure Error	2	0.000	0.000			0.03
Total	14	0.035				

C. Optimization using Genetic Algorithm and Simulated Annealing

The designing constraints are distinct in the customary optimal arrangement and are resolved with the help of Genetic Algorithm and Simulated Annealing. For the present study, the minimization problem was framed in regular mathematical layout similar to regression equation is shown in Equation (7):

Minimize

$$1.333 - 0.544a - 0.119b + 0.4969c + 0.1467a^2 + 0.01317b^2 - 0.05117c^2 + 0.0058ab + 0.0278ac - 0.04972bc \quad (12)$$

Subjected to constraints:

$1 \leq a \leq 2$

$6 \leq b \leq 8$

$1 \leq b \leq 3$

A Genetic Algorithm and Simulated Annealing was castoff for solving the objective function shown in Equation (12). For Genetic Algorithm, population size of 200 with preliminary population range casing the whole array of values for a, b and c was used for avoiding local minima. The cross over rate of 0.8 used was with uniform mutation function. The optimal parameter setting was acquired by Genetic Algorithm after 96 generations are shown in Fig. 6. For Simulated Annealing, maximum iterations and time limit has been set to infinite. Boltzmann Annealing has been chosen as annealing function. The Initial temperature of the body has been set to 100. The optimum parameter setting was achieved after 3349 generations. The optimum parameters obtained by the Simulated Annealing are shown in Fig. 7.

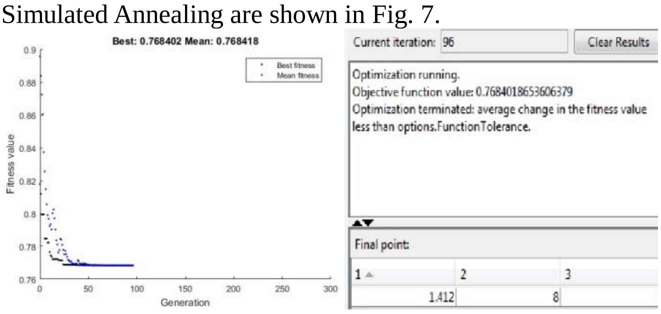

Fig. 6. Variations of the best fitness value and optimal parameters using Genetic Algorithm

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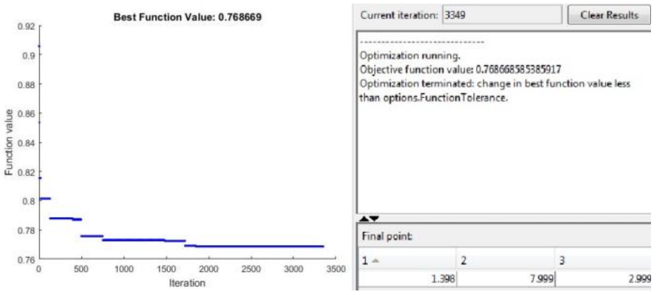

Fig. 7.Variations of the best fitness value and optimal parameters using Simulated Annealing

IV. CONCLUSION

The properties of input parameters i.e. pulse ON time, current and pulse OFF time were studied experimentally throughout SS 304 machining using WEDM process. The TOPSIS method based on the RSM Box-Behnken design was used for optimization of WEDM process constraints. Based on outcomes of this study, following inferences were shown:

1) The best input parameters setting for WEDM using different approaches are shown in Table IX.

Table- IX: Optimal cut parameters using three optimization methods

Algorithm	Current	Pulse ON time	Pulse OFF time
TOPSIS	1.5 amp	8 µs	3 µs
Genetic Algorithm	1.412 amp	8 µs	3 µs
Simulated Annealing	1.398 amp	7.99 µs	2.99 µs

2) Surface roughness, kerf width and tool wear rate increases when pulse ON time tends to rise.
3) From ANOVA analysis, pulse ON time is the most influential parameter than current and pulse OFF time for WEDM process when minimization of kerf width, tool wear rate and surface roughness are concurrently measured.

Both Statistical and Heuristic approach gives similar result when employed for predicting optimum factor setting. Responses like roundness, circularity, cylindricity, machining cost etc. are can be considered for future research in WEDM process.

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