Optimization of WEDM Parameters for Super Ni-718 using Neutrosophic Sets and TOPSIS Method

Y Rameswara Reddy[1*], B Chandra Mohan Reddy[2]

[1,2] Department of Mechanical Engineering, Jawaharlal Nehru Technological University, Anantapur, India

yrameswarareddy.mech@jntua.ac.in[1], cmr_b.mech@jntua.ac.in[2]

Abstract— The work presents optimization of process parameters in wire electrical discharge machining process. This paper presents the results of experimental work carried out in Wire Electrical Discharge Machining of Super Ni 718 super alloy. Experiments have been conducted using 8 process parameters such as Pulse on time, Spark gap, Wire feed, Wire tension, flushing pressure, servo speed and peak current at 3 levels for obtaining responses like surface finish, material removal rate and dimensional deviation. The optimal setting of parameters is determined through experiments planned, conducted and analyzed using Neutrosophic sets and TOPSIS method.

Keywords: WEDM, Super Ni 718, Neutrosophic sets, TOPSIS

1. INTRODUCTION

Super Ni- 718 super alloy is an important engineering material with a wide range of applications in a number of engineering fields because of its excellent physical and mechanical properties. Wire electro discharge machining (WEDM) is one of the important non- traditional machining processes which are used for machining difficult to machine material like composites and inter-metallic materials. Wire EDM uses a traveling wire electrode that passes through the work piece. The Wire EDM removes material with electricity by means of sharp erosion. Therefore, this process can be utilized in machine any electrically conducting aterials irrespective of their strength, hardness and toughness.

The selection of optimum machining parameters in Wire EDM is an important step. Improperly selected parameters will resulted in serious problem like short-circuiting of wire. Wire breakage and work surface damage which is imposing certain limits on the production schedule and also reducing productivity. As material removal rate (MRR) Surface roughness (Ra) and dimensional deviation (DD) are most important responses in wire EDM. Various investigations have been carried out by several researchers for improving the above output responses however; the problem of selection of machining parameters is not fully depending on machine controls rather material dependent [4].

Multi criteria decision making (MCDM) method is the multi objective technique that has been used to evaluate the alternatives. The objectives with the highest relative closeness to the positive solution are suggested for optimal combination of input parameters. TOPSIS is a multi-criteria decision making method developed by Yoon and Wang, which involves determinate of the shortest distance to the positive solution and greatest distance from the negative solution.

The Wire Electric Discharge machining (WEDM) parameters were optimized by TOPSIS method. TOPSIS method is broadly accepted by the manufacturing domain for multi-criteria selection [3]. Optimal subsystem selection was evaluated with the help of TOPSIS method in composite product development [5]. In the Inconel 718 the optimal input parameters were determined by using combined TOPSIS and AHP method [8]. The machinabilty has been evaluated in turning operation of titanium using combined TOPSIS and AHP method [6].

An overall performance was obtained for its operational activities in the success of a manufacturing company using TOPSIS and AHP method [9]. Even though TOPSIS is more reliable while dealing with the tangible attributes and in the assessment of number of alternatives, it needs an appropriate procedure to determine the weight criteria of each objective. AHP method has been used to assign the weight of each criterion. AHP provides an effective structured technique based on mathematical concept [1].

With response surface methodology and developed quadratic mathematical model to represent the behavior of WEDM process parameters for the process responses such as MRR, Surface roughness and KERF on D2 tool steel [7]. Optimal machining parameters were determined by the Grey relational grade obtained Grey relational analysis as the performance index for machining parameters in

WEDM for parameters such as Work piece polarity, pulse on time, duty factor open discharge voltage, discharge current, and dielectric fluid were optimized with considerations of multiple performance characteristics including MRR, SR and Electrode wear ration [3].

2. EXPERIMENTAL DETAILS

In the present research work Ultra Cut CNC F2 WEDM Machine was used for the study. A block of Super Ni 718 (Ni 55%, Cr 21%, Mb 3.3%, C 0.045%, Mn 0.35%, Si 0.35%, S 0.01% , Ti 0.052, and balance Fe) with 100mm × 100mm × 10 mm size . The parameter constant during machining are wire/electrode (Zinc coated copper wire, dia 0.25 mm). The 8 input variables were selected after an extensive literature review and subsequent preliminary investigations.

Their limits were set on the basis of capacity and limiting conditions of the WEDM, ensuring continuous cutting by avoiding the breakages of the wire, as listed in Table 1. The most important performance measures in WEDM are Material removal rate (MRR), Surface roughness (Ra) and Dimensional deviation (DD). Taguchi’s L27 orthogonal array is used to evaluate the effect of machining parameters on performance characteristics. Table 2 shows that the experimental data with L27 orthogonal array.

3. METHODOLOGY

Techniques for order preference by similarity to ideal solutions (TOPSIS):

The TOPSIS method was developed by Hwang and Yoon. This method is based on the concept that chosen alternative should have the shortest Euclidean distance from the ideal solution and farthest from the negative ideal solution. The ideal solution is a hypothetical solution for which all attribute values correspond to the maximum attribute values in the data base comprising the satisfying solutions; the negative ideal solution is the hypothetical solution for which all attribute values corresponding to the minimum attribute values in the database. TOPSIS thus gave a solution that is not only closest to the hypothetically best but also farthest from the hypothetical worst.

The procedural steps for the present research work are listed below:

Step 1: The objective and the important evaluation attributes are determined. For this particular problem MRR is considered as a beneficial attribute and (i.e.) maximization, while micro hardness and surface roughness and dimensional deviation are considered as non-beneficial attributes (i.e.) minimization.

Table 1 Process Parameters, Symbols and their Ranges

S. No.	Parameter	Symbol	Level 1	Level 2	Level 3
1	Pulse on time	TON (µs)	105	115	120
2	Pulse off time	TOFF (µs)	50	55	60
3	Corner Servo	CS (Volts)	70	150	230
4	Pressure	WP (Kg/cm2)	5	10	15
5	Wire Feed	WF (m/min)	4	8	12
6	Wire Tension	WT (Kg-f)	4	8	12
7	Spark Gap Voltage	SV (Volts)	20	25	30
8	Servo Feed	SF (mm/min)	2100	2120	2140

Step 2: All the information available is represented in the form of a decision matrix.

Table 2 Experimental Data using L27 Orthogonal Array

Exp. No.	MRR (mm/min)	Ra (µm)	DD (%)
1	0.85	1.62	0.593
2	0.79	1.86	0.457
3	0.69	1.68	0.473
4	1.02	2.34	0.486
5	0.67	1.48	0.368
6	1.03	2.29	0.189
7	0.33	1.7	0.327
8	0.78	2.3	0.129
9	1.01	1.96	0.52
10	0.87	2.76	0.396
11	0.5	1.73	0.57
12	1.04	2.56	0.289
13	0.72	1.72	0.395
14	0.92	2.32	0.287
15	0.78	1.39	0.32
16	0.89	2.2	0.123
17	0.54	1.46	0.533
18	1.02	2.59	0.268
19	0.78	2.32	0.37
20	0.57	2	0.293
21	0.68	2.53	0.697
22	0.68	1.79	0.253
23	0.87	2.03	0.387
24	1	2.12	0.223
25	0.96	1.99	0.249
26	0.95	1.96	0.4
27	0.93	1.91	0.317

Step 3: The normalized matrix $\mathbf{N}_{ij}$ is determined by using the following formula

$$N_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}} \quad (1)$$

Table 3 Normalized Values

MRR (mm/min)	surface Roughness (microns)	Dimensional Deviation (DD) %
0.732	0.832	0.181
0.648	0.657	0.418
0.507	0.788	0.390
0.972	0.307	0.368
0.479	0.934	0.573
0.986	0.343	0.885
0.000	0.774	0.645
0.634	0.336	0.990
0.958	0.584	0.308
0.761	0.000	0.524
0.239	0.752	0.221
1.000	0.146	0.711
0.549	0.759	0.526
0.831	0.321	0.714
0.634	1.000	0.657
0.789	0.409	1.000
0.296	0.949	0.286
0.972	0.124	0.747
0.634	0.321	0.570
0.338	0.555	0.704
0.493	0.168	0.000
0.493	0.708	0.774
0.761	0.533	0.540
0.944	0.467	0.826
0.887	0.562	0.780
0.873	0.584	0.517
0.845	0.620	0.662

Step 4: The weighted normalized decision matrix is constructed by multiplying the normalized decision matrix by its associated weights.

$$W_{ij} = \mathbf{N}_{ij} \times W_j \quad (2)$$

where N_{ij} is the normalized matrix W_j is the weight criteria. The weight (W_j) of each criterion is calculated by AHP method and the detailed procedure is given below.

Determine the relative importance of different attributes with respect to the objective. To do so one must construct a pair-wise comparison matrix. Assuming *N* attributes, the pair-wise comparison of attribute *I* with attribute *j* yields a square matrix ***A*** *N*×*N*, where a_{ij} denotes the comparative importance of attribute *I* with respect to attribute *j*. In the matrix, $a_{ij} = 1$ when *i*= *j* and $a_{ij} = 1/\ a_{ij}$. This can be described as follows:

Table 4 Score and Weights of Objectives

	SCORE	WEIGHTS
MRR	0.4582	0.6303
SR	0.1642	0.2259
DD	0.1045	0.1437

$$A_{N\times N} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & - & - & a_{1N} \\ a_{21} & a_{22} & a_{23} & - & - & a_{2N} \\ a_{31} & a_{32} & a_{33} & - & - & a_{3N} \\ - & - & - & - & - & - \\ - & - & - & - & - & - \\ a_{N1} & a_{N2} & a_{N3} & - & - & a_{NN} \end{bmatrix}. \quad (3)$$

Pair wise comparison matrix:

$$\boldsymbol{A}_{N\times N} = \begin{bmatrix} 1 & 3 & 1 \\ \frac{1}{3} & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}. \quad (4)$$

Table 5 Aggregated Prioritized Matrix

	MRR	**SR**	**DR**
MRR	0.6694	0.2886	0.1757
SR	0.4642	0.3786	0.3786
DR	0.4932	0.4571	0.3700

The relative normalized weight (Wj) of attributes is calculated using neutrosophic sets

Table 6 Decision Maker's Prioritized Matrix in SVNS

Priorities	**MRR**	**SR**	**DD**
MRR	(1.000)	(0.600 0.400 0.200)	(0.500 0.400 0.300)
SR	(0.200 0.60 0.6)	(1.000)	(0.500 0.400 0.400)
DD	(0.300 0.60 0.50)	(0.400 0.600 0.500)	(1.000)

Determine matrix ***A***3 and ***A***4 such that ***A***3 = ***A***1× ***A***2 and ***A***4= ***A***3/***A***2,

where $A_2 = 1/\ [W_1, W_2, \ldots \ldots \ldots, W_N]$.

Table 7 Weighted Normalized Matrix

MRR (mm/min)	surface Roughness (microns)	Dimensional Deviation (DD) %
0.461	0.191	0.025
0.408	0.151	0.059
0.319	0.181	0.055
0.612	0.071	0.051
0.302	0.215	0.080
0.621	0.079	0.124
0.000	0.178	0.090
0.399	0.077	0.139
0.603	0.134	0.043
0.479	0.000	0.073
0.151	0.173	0.031
0.630	0.034	0.100
0.346	0.175	0.074
0.524	0.074	0.100
0.399	0.230	0.092
0.497	0.094	0.140
0.186	0.218	0.040
0.612	0.029	0.105
0.399	0.074	0.080
0.213	0.128	0.099
0.311	0.039	0.000
0.311	0.163	0.108
0.479	0.123	0.076
0.595	0.107	0.116
0.559	0.129	0.109
0.550	0.134	0.072
0.532	0.143	0.093

Step 5: Determination of the positive ideal solution (A**) and the negative ideal solution (A*). These are calculated by using Eq. (5) and Eq. (6):

A**= {(maxWij| j∈J),(minWij| j∈J')}, (5)

A*= {(minWij| j∈J),(maxWij| j∈J')}, (6)

Table 8 POSITIVE IDEAL SOLUTION

MRR (mm/min)	surface Roughness (microns)	Dimensional Deviation (DD) %
0.63000	0.00000	0.00000

J= 1, 2, 3,…, n − where J is associated with the benefit criteria J' = 1, 2, 3,…, n − where J' is associated with the cost criteria.

Table 9 NEGATIVE IDEAL SOLUTION

MRR (mm/min)	surface Roughness (microns)	Dimensional Deviation (DD) %
0.00000	0.23000	0.14000

Table 10 Distance form PIS and NIS

DISTANCE FROM POSITIVE IDEAL SOLUTION	DISTANCE FORM NEGATIVE IDEAL SOLUTION
0.256	0.477
0.275	0.424
0.364	0.334
0.089	0.639
0.401	0.308
0.147	0.639
0.661	0.072
0.280	0.428
0.144	0.619
0.168	0.536
0.510	0.195
0.105	0.661
0.341	0.357
0.164	0.548
0.338	0.402
0.215	0.515
0.496	0.212
0.110	0.646
0.255	0.433
0.447	0.240
0.322	0.391
0.375	0.319
0.209	0.495
0.162	0.607
0.184	0.569
0.172	0.562
0.196	0.542

Step 6: The separation measure is calculated. The separation of each alternative from the positive ideal one is given by:

$S_i^{**} = \Sigma(\mathbf{W}ij – Aj^{**})^2$, j = 1, where i= 1, 2,...,m. (7)

Similarly, the separation of each alternative from the negative ideal one is given by:

$S_i^{*} = \Sigma(\mathbf{W}ij – Aj^{*})^2$, j = 1, where i= 1, 2,...,m. (8)

Step 7**:** The relative closeness is calculated to the ideal solution.

$$c_i^* = \frac{s_i^{**}}{s_i^{**}+s_i^*} \quad (9)$$

The larger the c_i^* value the better is the performance of the alternatives.

Table 11 Relative Correlation Coefficient (RCC)

L1	0.350
L2	0.393
L3	0.521
L4	0.122
L5	0.565
L6	0.187
L7	0.902
L8	0.396
L9	0.188
L10	0.238
L11	0.724
L12	0.137
L13	0.489
L14	0.230
L15	0.457
L16	0.294
L17	0.701
L18	0.145
L19	0.371
L20	0.651
L21	0.452
L22	0.540
L23	0.296
L24	0.210
L25	0.244
L26	0.234
L27	0.266

4. RESULTS AND DISCUSSION

The conformation test for the optimal parameter setting with a selected level was conducted to evaluate the quality characteristics for WEDM of SUPERNI 718. From experiment run (Table 8) shows the lowest closeness coefficient, indicating the optimal process parameter set up of Ton-1, Toff-2,CS-2, P-2,WF-1,WT-1,SV-1,SF-2 has the best multiple performance characteristics among the 27 experiments, which can be compared with results of conformation experiments for validation of results by using Taguchi TOPSIS.

Step 8: Rank the relative closeness value.

Table 12 Ranking Based on RCC

Rank	Exp. No	RCC
1	L4	0.122
2	L12	0.137
3	L18	0.145
4	L6	0.187
5	L9	0.188
6	L24	0.210
7	L14	0.230
8	L26	0.234
9	L10	0.238
10	L25	0.244
11	L27	0.266
12	L16	0.294
13	L23	0.296
14	L1	0.350
15	L19	0.371
16	L2	0.393
17	L8	0.396
18	L21	0.452
19	L15	0.457
20	L13	0.489
21	L3	0.521
22	L22	0.540
23	L5	0.565
24	L20	0.651
25	L17	0.701
26	L11	0.724
27	L7	0.902

Table 13 Response Table for Signal to Noise Ratios

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	9.35	8.297	9.20	9.44	9.313	10.6	8.767	9.87
2	9.86	10.3	11.8	9.72	7.41	9.15	9.79	9.69
3	9.45	10.0	7.60	9.49	11.9	8.84	10.1	9.10
Delta	0.51	2.04	4.2	0.27	4.53	1.82	1.342	0.774
Rank	7	3	2	8	1	4	5	6

Table 14 Response Table for Means

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	0.4027	0.4263	0.3833	0.3538	0.3944	0.3660	0.4397	0.3493
2	0.3794	0.3440	0.3019	0.3876	0.4656	0.3670	0.3609	0.3909
3	0.3627	0.3744	0.4596	0.4034	0.2848	0.4118	0.3442	0.4046
Delta	0.0400	0.0823	0.1577	0.0497	0.1808	0.0458	0.0954	0.0552
Rank	8	4	2	6	1	7	3	5

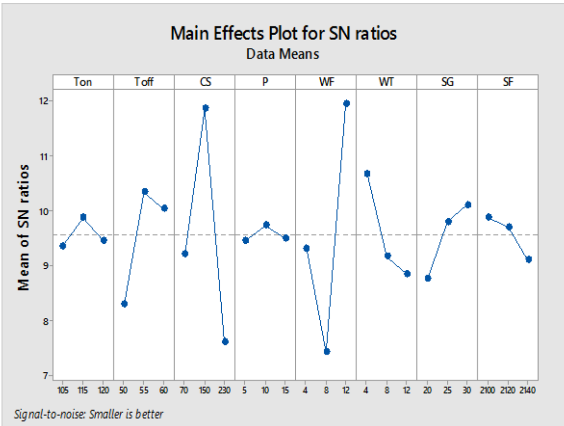

Fig. 1 Main Effects Plot for SN Ratios

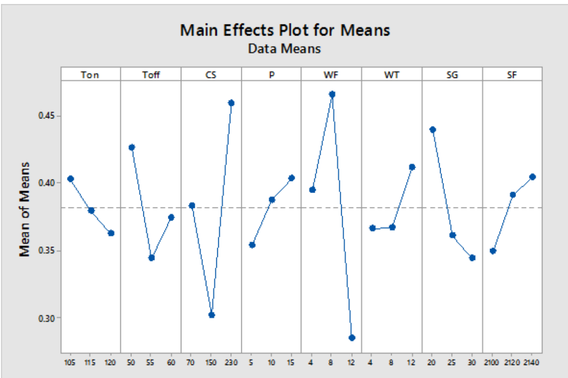

Fig. 2 Main Effects Plot for Means

From Taguchi TOPSIS design optimal are Ton-2, Toff-2, CS-2, P-2, WF-3, WT-1, SG-3, SF-1. The response values obtained from conformation experiment are shown in Table 11. The corresponding improvement in material removal rate is 10.3%, surface roughness and dimensional deviation are 2.84% and 6.9% respectively.

Table 15 Results of Conformation Experiment (TOPSIS)

S. No.	Response Characteristics	Optimal Parameter Combination	Response characteristic values	
			Predicted at 95% of confidence level	Avg. of three Conformation Experiments
1	MRR	A2 B2 C2 D2 E3 F1 G3 H1	0.97	1.07
2	Ra		2.11	2.05
3	DD		0.35	0.326

5. CONCLUSION

The paper represents the selection of optimum process parameters in WEDM process by considering the experimental results for maximizing the material removal rate and minimizing surface roughness and dimensional deviation of the desired work piece. The suggested multi-response approach using TOPSIS and SVNS method in combination with Taguchi's robust design methodology is quite capable for any type of optimization problem involving any number of responses.

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