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Experimental investigations on MRR, Surface Roughness and Dimensional Deviation of SuperNI-718 alloy steel in Wire-EDM using Taguchi Method

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Abstract - This study focuses on optimizing of WEDM cutting parameters based on the Taguchi method to maximize Material Removal Rate(MRR), minimize the Surface roughness(SR) and Dimensional deviation(DD). Experiments have been conducted using the L_{27} Orthogonal array in WEDM. Tests are carried out on Superni-718 with brass cutting wire. Each experiment is repeated six times to ensure accurate reading of the output parameters. This statistical methods of Signal to Noise ratio(SNR) is applied to investigate effect of Ton, Toff, CS, P, WF,WT, SG,SF on MRR, Ra and DD. The developed model can be used in the metal machining industries in order to determine the optimum cutting parameter for maximizing MRR, minimizing Ra and DD.

Key words; Wire-EDM, Taguchi technique, MRR, SR & DD.

I. 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 travelling 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 materials irrespective of their strength, hardness and toughness.

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

II. LITERATURE REVIEW

The literature reveals that the Taguchi technique is the most effective modelling tool to study the performance characteristics of either EDM or WEDM process and determine the effect of input variables and their levels. Some of the contributions by Taguchi Technique in Wire EDM are brought-out in the following to decide the (i) Ra and MRR by Parametric optimization [Mahapatra, et al., 2006 (11)]; the number of experiments and Optimization of machining parameters in relation to work piece by orthogonal array method [Ramakrishnan, et al., 2006 (2)]; multi-response optimization by weighted principle component method (PCM) [Liao, et al., 2006 (3)]; multi response signal to noise ratio with principle component analysis (PCA) and also the PCA provides better results than that of constrained optimization, [Gauri, 2006 (4)]; Surface Removal Rate, cutting radius of work piece on machining of Al_2O_3 particle reinforced material (6061) alloy, [Chiang and Chang, 2006 (5)]; precision and accuracy by Taguchi Dynamic Experiments with Fuzzy Logic Analysis by 81.5 %, [Tzeng, et al., 2007 (6)]; the multi objective function with Taguchi based Genetic Algorithm to find that the process parameters can be adjusted to achieve better MRR, SR and cutting width, [Mahapathra, 2007 (7)]; accuracy and surface roughness are established by the measured responses of MRR on Inconal alloy 800 super alloy [Ravindra, et al., 2008 (8)];

Wire-EDM can machine the Die steels also irrespective of the work material and is proved by experimentation on (i) hard die steel with Molybdenum wire as Electrode, [Ravindra, et al. (2008)(9)]; (ii) Die steel with Brass wire as electrode[Kamal Jangra, et al.(2010)(10)], (iii) SUS304 Stainless steel [Abdul Kareem, et al (2011)(11)] and (iv) P20 Die tool steel with Molybdenum wire as electrode and standard performance characteristics such as MRR, SR and Dimensional Error [Bhaskar Reddy, et al. (2012)(12)].

The wire EDM is extended to investigate the effects of input parameters of Alloy materials like (i) Nimonic (C 263) material with uncoated brass wire of 0.25 mm diameter as electrode, [Niladri, et al. (2010)(13)]; Titanium

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Alloy (Ti 6 Al 4v), [Danial Ghodsiyeh, et al. (2012)(14)] and (iii) Nimonic 80A with Brass wire as tool electrode, [Goswami and Jatinder (2012)(15)].

The above literature review number of researchers focused on machining of EDM on different materials but less attempt to Superni 718 material and to optimization.

III. TAGUCHI DESIGN OF EXPERIMENTATION

Taguchi's approach has been built on traditional concepts of Design of Experiments (DOE), such as full factorial, fractional factorial design and orthogonal arrays based on signal –to-noise ratio, robust design and parameter and tolerance designs. DOE is a powerful statistical technique introduced by R.A. Fisher in England in 1920s to study the effect of multiple variables simultaneously.

Since, the present work concentrates on the experimental work; the number of experiments is to be conducted the effect of the individual parameters on the Wire-EDM to be studied. Therefore, the Taguchi technique is chosen and used in the present research work. In order to reduce the total number of experiments "Sir Ronald Fisher" has developed the solution: "Orthogonal Arrays". The orthogonal array is a distillation mechanism by which the engineers can select the experimental process. The array allows the researcher / engineer to vary multiple variables at one time and obtain the effects such that set of variables has an average and the dispersion. Taguchi employs the design of experiments using specially constructed table, known as "Orthogonal Arrays" (OA) to treat the design process, such that the quality is build into the product during the product design stage.

IV. MATERIAL AND METHODOLOGY

The equipment used in the Wire EDM experiment is ULTRA CUT f2 and set up is shown in figure 1. The material used for the present work is Superni-718 alloy steel (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× 10mm size . The parameter constant during machining are brass wire/electrode of diameter 0.25mm. 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. 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.

Fig 1: Experimental setup of WEDDM

4.1 Plan of Experiment based on Taguchi Method:

The pilot experiments were carried by varying the process parameters e.g. pulse on time, pulse off time, spark gap set voltage, peak current, wire feed and wire tension to study their effect on output parameters e.g. cutting rate, surface roughness gap current and dimensional deviation. The ranges of process parameters, different levels of process parameters and their symbols are shown in table 2. With the taguchi method for 8 process parameters with 3 levels are shown in table 3 and the experimental results. Each experiment is repeated six times to ensure accurate reading of the output parameters and the final experimental results with L27 are shown in table 4

Table 2 Process parameters, symbols and their Ranges.

S.No	PARAMERTER	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

Table 3: Process parameters / Control factors and their levels

EXP	TON	TOFF	CS	WP	WF	WT	SV	SF
1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2
3	1	1	1	1	3	3	3	3
4	1	2	2	2	1	1	1	2
5	1	2	2	2	2	2	2	3
6	1	2	2	2	3	3	3	1
7	1	3	3	3	1	1	1	3
8	1	3	3	3	2	2	2	1
9	1	3	3	3	3	3	3	2
10	2	1	2	3	1	2	3	1

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11	2	1	2	3	2	3	1	2
12	2	1	2	3	3	1	2	3
13	2	2	3	1	1	2	3	2
14	2	2	3	1	2	3	1	3
15	2	2	3	1	3	1	2	1
16	2	3	1	2	1	2	3	3
17	2	3	1	2	2	3	1	1
18	2	3	1	2	3	1	2	2
19	3	1	3	2	1	3	2	1
20	3	1	3	2	2	1	3	2
21	3	1	3	2	3	2	1	3
22	3	2	1	3	1	3	2	2
23	3	2	1	3	2	1	3	3
24	3	2	1	3	3	2	1	1
25	3	3	2	1	1	3	2	3
26	3	3	2	1	2	1	3	1
27	3	3	2	1	3	2	1	2

Table 4: Experimental Results:

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

V. RESULTS AND DISCUSSIONS

The effects of individual WEDM process parameters, on the selected response characteristics – MRR, SR and DD. The average value and S/N ratio of each response of response characteristics for each parameter at different levels were calculated from the experimental data. The main effects of Process parameters both for raw data and s/n data were plotted. The response curves (main effects) are used for examining the parametric effects on response characteristics. The most favorable values (optimal settings) of process parameters in terms of mean response characteristics are established by analyzing the response curves . The S/N ratios of response characteristics are given in the table 5.

Table 5: S/N Ratios of Experimental Results

Exp. NO	S/N Ratio for MRR	S/N Ratio for Ra	S/N Ratio for DD
1	-1.411621	-1.41162	-4.1903
2	5.1054501	-2.04746	-5.39026
3	-6.196078	-3.22302	-4.50619
4	0.1720034	0.172	-7.38432
5	-3.478504	-3.4785	-3.40523
6	2.9225607	0.25674	-7.19671
7	-9.629721	-9.62972	-4.60898
8	-2.158108	-2.15811	-7.23456
9	0.0864275	0.08643	-5.84512
10	6.9270595	-1.20961	-8.81818
11	-6.0206	-6.0206	-4.76092
12	1.7981022	0.34067	-8.1648
13	-2.85335	-2.85335	-4.71057
14	4.0279425	-0.72424	-7.30976
15	-8.404328	-2.15811	-2.8603
16	-1.0122	-1.0122	-6.84845
17	-10.17277	-5.35212	-3.28706
18	4.7105689	0.172	-8.266
19	4.6089784	-2.15811	-7.30976
20	-4.882503	-4.8825	-6.0206
21	1.5109392	-3.34982	-8.06241
22	-3.349822	-3.34982	-5.05706
23	-1.209615	-1.20961	-6.14992
24	0	0	-6.52672
25	-0.354575	-0.35458	-5.97706
26	-0.445528	-0.44553	-5.84512
27	-0.630341	-0.63034	-5.62067

5.1 Effects on MRR:

The average values of MRR for each parameter at levels 1,2 and 3 for raw data and S/N data are plotted in figures 2 and figure 3 respectively and shows that material removal rate increases with increasing pulse on time. The Material removal rate decrease with increasing pulse off time. The MRR slightly increases and decreases with increase with corner servo. The MRR decreases with increase in pressure. The MRR slightly decreases and increases with increase wire feed. The MRR decreases with increase in Wire Tension. The MRR increases and decreases with Increase in Spark gap voltage. The MRR increases and decreases with increase in servo feed.

Table 6:Response Table for Signal to Noise Ratios to MRR

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	-2.3815	-2.6625	-1.9371	-1.5387	-2.4230	-2.1169	-2.9941	-1.6263
2	-2.0908	-1.4828	-1.2633	-2.1814	-2.9243	-1.8599	-1.6880	-12.1504

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3	-1.8200	-2.1471	-3.0919	-2.5723	-0.9450	-2.3155	-1.6103	-2.5157
Delta	0.5614	1.1797	1.8286	1.0336	1.9792	0.4555	1.3838	0.8894
Rank	7	4	2	5	1	8	3	6

Table 7: Response Table for Means for MRR

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	0.7967	0.7522	0.8144	0.8433	0.7889	0.8256	0.7522	0.8422
2	0.8089	0.8544	0.8856	0.8000	0.7322	0.8144	0.8333	0.8044
3	0.8244	0.8233	0.7300	0.7867	0.9089	0.7900	0.8444	0.7833
Delta	0.0278	0.1022	0.1556	0.0567	0.1767	0.0356	0.0922	0.0589
Rank	8	3	2	6	1	7	4	5

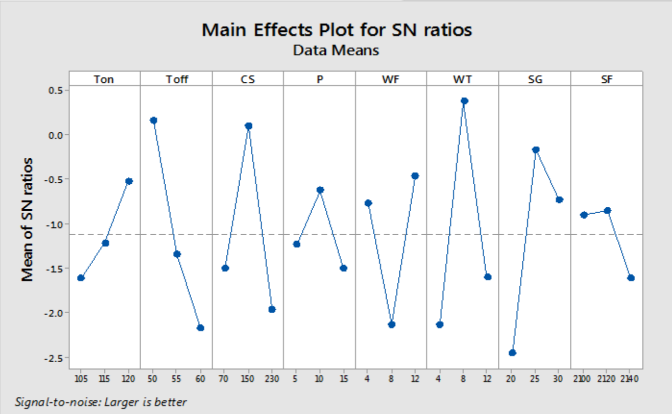

Figure 2: Main Effects Plot for SN ratios for MRR

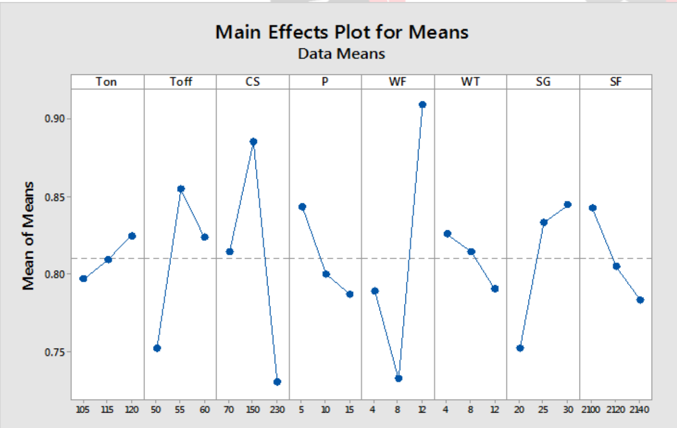

Figure 3: Main Effects Plot for Means for MRR

The significance of process parameters towards material removal rate and the ANOVA was performed and it is found that pressure and servo feed non significant process parameters for MRR. From table 6 and figure 7 wire feed is having maximum influence on material removal rate, pulse on, pulse off, wire tension, spark gap voltage and corner servo time are affecting significantly. From figure 3 the third level of pulse on time(TON3), first level of pulse off time (TOFF1), second of level of corner servo(CS2), second level of flushing pressure (WP2), third level of wire feed (WF3), second level of wire tension (WT2), second level of spark gap voltage(SG2) and second level of servo feed(SF2) provide maximum value of material removal rate. The S/N data analysis Figure 2 also suggests the same level of the parameters (TON3, TOFF1, CS2, WP2, WF3, WT2, SG2, SF2) as the best levels for maximum MRR in WEDM process.

5.2 Effects on SR:

From figures 4 and 5 and shows that the surface Roughness increases with increasing pulse on time. The Surface Roughness decreases with increasing pulse off time. The Ra slightly increases and decreases with increase corner servo. The Ra increases and slightly decreases with increase in pressure. The Ra slightly decreases and increases with increase wire feed. The Ra increases and decreases with increase in Wire Tension. The Ra increases with Increase in Spark gap voltage. The Ra slightly decreases and increases with increase in servo feed.

Table 8: Response Table for Signal to Noise Ratios for Ra

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	-5.529	-6.358	-5.580	-5.157	-6.101	-5.943	-5.750	-5.919
2	-6.114	-5.622	-6.353	-6.420	-5.489	-5.963	-5.963	-5.895
3	-6.285	-5.948	-5.996	-6.352	-6.339	-6.216	-6.216	-6.115
Delta	0.756	0.736	0.772	1.263	0.849	0.596	0.466	0.220
Rank	4	5	3	1	2	6	7	8

Table 9:Response Table for Means for Ra

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	1.914	2.118	1.928	1.828	2.049	2.021	1.970	2.024
2	2.081	1.942	2.113	2.134	1.904	2.098	2.031	1.989
3	2.072	2.008	2.027	2.106	2.114	1.949	2.067	2.054
Delta	0.167	0.176	0.186	0.307	0.210	0.149	0.097	0.066
Rank	5	4	3	1	2	6	7	8

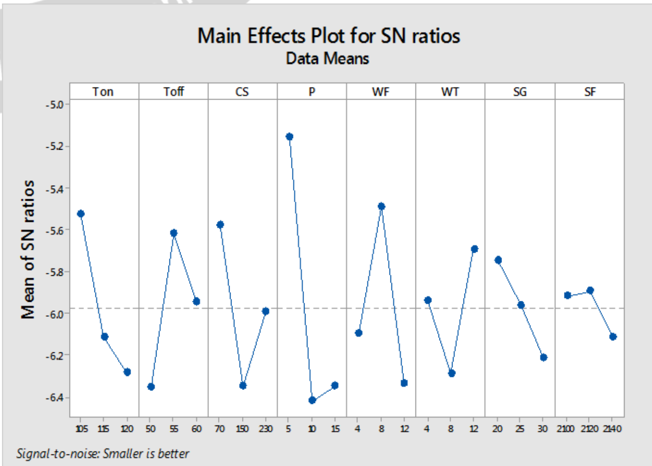

Figure 4: Main Effects Plot for SN rations for Ra

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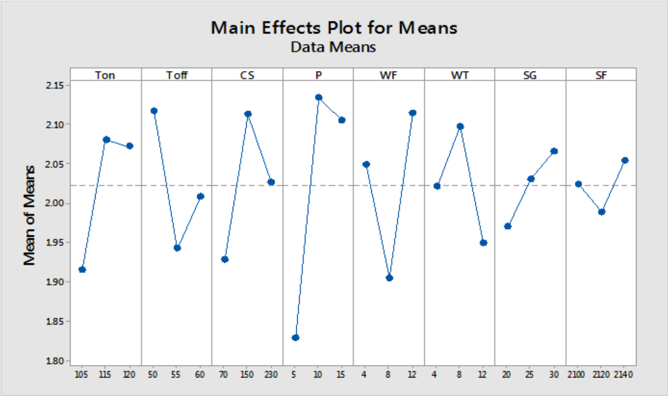

Figure 5: Main Effects Plot for Means for Ra

As surface roughness is the "Lower the better" type quality characteristics from figure 5, it can be seen that the third level of pulse on time(TON3), first level of pulse off time (TOFF1), third level of corner servo(CS3), second level of flushing pressure (WP2), third level of wire feed (WF3), third level of wire tension (WT3), third level of spark gap voltage(SG3) and third level of servo feed(SF3) provide minimum value of surface Roughness. The S/N data analysis Figure 4 also suggests the same level of the parameters (TON3, TOFF1, CS3, WP2, WF3, WT3, SG3, SF3) as the best levels for minimum Ra in WEDM process.

5.3. Effects on DD:

From figures 6 and 7 respectively. Figure 7 show the Dimensional Deviation decreases strongly with increasing pulse on time and then very slightly increases. As pulse off time increases the Dimensional deviation decreases strongly. With increase in corner servo the Dimensional Deviation slightly decreases and then increases. The Dimensional Deviation decreases with increase in pressure. The DD slightly increases and decreases with increase wire feed. The wire tension slightly Decreases and the increases with increase in Wire Tension. The Dimensional Deviation strongly decreases and then slightly increases with Increase in Spark gap voltage. The Dimensional Deviation slightly increases and decreases with increase in servo feed.

Table 10:Response Table for Signal to Noise Ratios for DD

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	8.938	7.110	9.574	8.518	9.720	8.833	7.539	9.982
2	9.736	10.161	9.238	9.662	9.037	10.415	10.893	8.413
3	9.518	10.922	9.380	10.012	9.435	8.944	9.760	9.798
Delta	0.798	3.812	0.336	1.493	0.683	1.582	3.354	1.569
Rank	6	1	8	5	7	3	2	4

Table11:Response Table for Means for DD

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	0.3936	0.4598	0.3678	0.3879	0.3547	0.3737	0.4481	0.3503
2	0.3534	0.3231	0.3627	0.3697	0.3804	0.3450	0.3003	0.3954
3	0.3543	0.3184	0.3709	0.3438	0.3662	0.3827	0.3529	0.3556
Delta	0.0401	0.1413	0.0082	0.0441	0.0258	0.0377	0.1478	0.0451
Rank	5	2	8	4	7	6	1	3

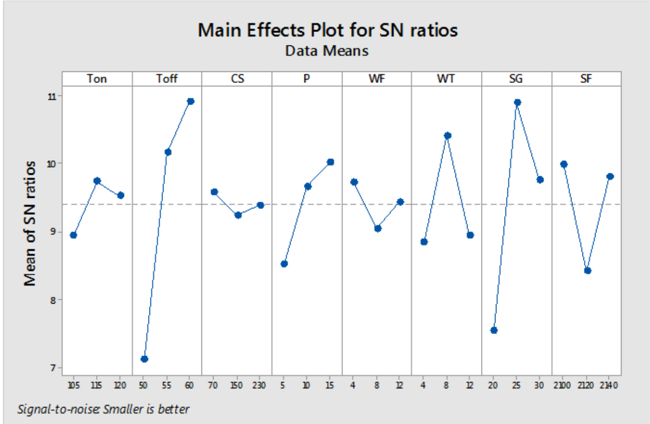

Figure 6: Main Effects Plot for SN Ratios for DD

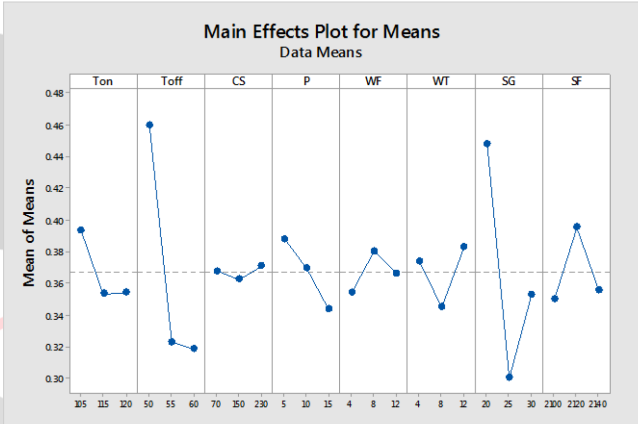

Figure 7: Main Effects Plot of Means for DD

As Dimensional Deviation is the "Lower the better" type quality characteristics from figure 4.7, it can be seen that the first level of pulse on time(TON1), first level of pulse off time (TOFF1), second level of corner servo(CS2), first level of flushing pressure (WP1), second level of wire feed (WF2), first level of wire tension (WT1), first level of spark gap voltage(SG1) and second level of servo feed(SF2) provide minimum value of Dimensional Deviation.

VI. CONFIRMATION EXPERIMENTS

The confirmation test for the optimal parameter setting which is selected levels was conducted to evaluate quality characteristics for WEDM of Superni-718. Once the optimum parameters are selected for response characteristics individually, confirmation experiments are conducted for validation of that optimum values. The Table 4.23 gives the comparison of predicted values with confirmation experimental values.

The response values obtained from conformation experiments MRR is 1.082 mm/min, SR is 2.05 µm and DD is 0.492. the material removal rate shows an increased value of 0.981 to 1.08, SR value reduced to 2.261 to 2.05, DD value is reduced from 0.5295 to 0.492 respectively.

The corresponding improvement in material removal rate is 10.3% , SR and DD were 9% and 7% respectively.

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Table 4.12: Optimal process parameters combination obtained from Taguchi method

S. NO	Response characteristics	Optimal parameter combination	Response characteristic values	
			Predicted at 95 % of confident	Avg. of three conformation experiments
1	MRR	3-1-2-2-3-2-2-2	0.981	1.082
2	Ra	3-1-3-2-3-3-3-3	2.261	2.05
3	DD	1-1-2-1-2-1-1-2	0.5295	0.492

VI. Conclusions

The final conclusions based on the results are presented in the following.

The author, for the first time, has conducted experiments on WireEDM considering SuperNi-718 for same parametric values and compared the performance characteristics in terms of MRR, Surface Roughness and DD.

Form the analysis it is found that, Wire feed is having maximum influence on MRR. Pressure, wire feed, corner servo, pulse off time, pulse on time are affecting SR significantly in order. Servo voltage,, Pulse off time, servo feed, pressure, pulse on time are affecting the DD significantly in the order.

Future Scope

The experiments are conducted in the present on SuperNi-718 alloy steel. This procedure can be extended to other tool steels and composite materials.

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