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Optimization of WEDM Parameters for SUPER Ni-718 Using GRA with Neutrosophic Sets

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Abstract

This paper presents a study that investigates the effect of the WEDM process parameters on the surface roughness, MRR and DD of the Super Ni 718 supper alloy. Twenty seven experimental runs based on an orthogonal array of Taguchi method are performed and grey relational analysis with SVNS for weightages is applied to determine an optimal WEDM parameter setting. Surface roughness, MRR and DD are selected as the quality targets. An optimal parameter combination of the WEDM process is obtained using Grey relational analysis with SVNS. By analyzing the Grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets can be found and the ranks are obtained.

Keywords; WEDM , Neutrosophic sets, TOPSIS, Super Ni 718 super alloy.

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.

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.

LITERATURE REVIEW:

Experiments with wire EDM on reciprocating dry sliding pin on plate revealed that the Zro2-WC composite exhibits better tribological characteristics over Zro2-TicN and Zro2-TiN, [Liao, et al., 2004 (1)]. The optimization of EDM Process with multiple quality characteristics and better surface finish and less MRR are achieved by experimentation on the High Chromium-High Carbon Die-Steel and confirmed that the usage of Fuzzy Logic in the Taguchi Method is also very much useful, [Puri and Deshpande, 2004 (2)]. Further, the experimental results revealed that very low wire tension in machining of composites whereas a high flushing rate and a high wire speed were required to prevent wire breakage, [Yan, et al., 2005 (3)].

A new concept of specific discharge energy (SDE) is presented. It is observed that the materials having close values of SDE demonstrate very similar machining characteristics, if they are machined under the same machining conditions, [Liao, et al., 2004 (4)]. Therefore, the process performance is improved by silver coating on work piece material [Jerzy Kozak, et al., 2004 (5)] and it is proved that the Zinc coated Brass Wire gives better performance than brass wire in terms of lower frequency of the breakage of wire, [Kumar, et al., 2011 (6)]. The hardness of material matrix will not affect whereas the recast layer on the Wire EDM surface has to be mechanically removed to improve the pipe-coupling efficiency and prevent the formation of the deformation cracks during expansion process, [Lin, et al., 2005 (7)]. Tests have been conducted on various materials to study the effect of spark cycle and pulse on time of Wire EDM Micro features so as to understand the root cause for the material fracture mechanism, [Miller, et al., 2005 (8)].

The analysis has been formulated using multiple regression method to study the effect of pulse-on time and pulse-peak current, on the surface roughness. The surface roughness of the test specimen increases two variables increased. The developed model was validated by experimentation within 7% levels of error [Kalyanasri, et al., 2007 (9)]. An experimental determination method of the convective heat transfer coefficient in wire electro-discharge machining (WEDM) is introduced. A special device is developed to measure the average temperature increment of the wire after a period of short circuit discharges, and the thermal load imposed on the wire is also tracked and recorded. The wire vibration influenced the steadiness of erosion, kerf width, MRR and therefore, the selection of proper wire tension is necessary to obtain better process performance, [Puri and Bhattacharya, 2003 (10)]; hence the quality of the surface could be improved by the proper wire tension and wire lag implementation, [Puri and Bhattacharya, 2003 (11)]. Accordingly, experiments are conducted to investigate and suggest the methods for suitable form and position of the wire electrode, [Mingqi, et al., 2005 (12)]. Then based on the thermal model of the wire, the convective coefficient is calculated accurately. The influence of the kerf and the effect of the coolant flushing pressure on the convective coefficient are studied, [Gang Cheng, et al., 2007 (13)].

It was observed that, the factor servo-voltage has the largest effect on all the response variables irrespective of the materials used in the experiments conducted on three materials (viz., Hot Die Steel, Oil Hardened Non-sinking Steel, and Mild Steel) to optimize the process parameters, [Ravindra, et al., 2008 (14)] and also while machining AI / SiCp metal matrix composites using the wire EDM [Patil, et al., 2008 (15)]. Further, it is established that the surface finish of composite material is found to be better with increased % of SiC reinforcement. The Stress analysis is modeled with FEM for comparison between the models consisting of machining with 30 degrees Taper Angle and proved that it is possible safely to work in the Plastic Region with maximum value of Von-Mises Stresses in WEDM, [Sanchez, et al., 2008 (16)].

MATERIAL:

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. .

Figure 3.1: Experimental setup of WEDDM

METHODOLOGY

Grey relational coefficient and grey relational grade

In grey relational analysis, the measure of the relevancy between two systems or two sequences is defined as the grey relational grade. When only one sequence, $x_0(\text{k})$, is available as the reference sequence, and all other sequences serve as comparison sequences, it is called a local grey relation measurement. After data pre-processing is carried out, the grey relation coefficient $\xi_i(\text{k})$ for the k^{th} performance characteristics in the i^{th} experiment can be expressed.

$$\xi_i(\text{k}) = \frac{\Delta_{\min} + \zeta\,\Delta_{\max}}{\Delta_{oi}(\text{k}) + \zeta\,\Delta_{\max}} \qquad \text{………….. Eq. (4.1)}$$

where, Δ_{oi} is the deviation sequence of the reference sequence and the comparability sequence.

$$\Delta_{oi} = \|x_0^*(\text{k}) - x_i^*(\text{k})\|$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \left\|x_0^*(\text{k}) - x_j^*(\text{k})\right\|$$

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left\|x_0^*(\text{k}) - x_j^*(\text{k})\right\|$$

$x_0^*(\text{k})$ denotes the reference sequence and $x_i^*(\text{k})$denotes the comparability sequence. $\zeta$is distinguishing or identification coefficient:$\zeta \in [0, 1]$ (the value may be adjusted based on the actual system requirements). A value of ζ is the smaller and the distinguished ability is the larger.

$\zeta = 0.5$ is generally used. After the grey relational coefficient is derived, it is usual totake the average value of the grey relational coefficients as thegrey relational grade. The grey relational grade is definedas follows:

$$\gamma i = \left(\frac{1}{n}\right)\sum_{k=1}^{n} \zeta_i(\text{k}) \qquad \text{………….. Eq. (4.2)}$$

However, in a real engineering system, the importance of various factors to the system varies. In the real condition of unequal weight being carried by the various factors, the grey relational grade defined as

$$\gamma i = \left(\frac{1}{n}\right)\sum_{k=1}^{n} w_k \zeta_i(k) \sum_{k=1}^{n} w_k = 1 \ldots\ldots\ldots\ \text{Eq. (4.3)}$$

where w_k denotes the normalized weight of factor k.

The grey relational grade γi represents the level of correlation between the reference sequence and the comparability sequence. If the two sequences are identical, then the value of grey relational grade is equal to 1. The grey relational grade also indicates the degree of influence that the comparability sequence could exert over the reference sequence. Therefore, if a particular comparability sequence is more important than the other comparability sequences to the reference sequence, then the grey relational grade for that comparability sequence and reference sequence will be higher than other grey relational grades.

Neutrosophic Sets

The concept of neutrosophic set developed by is a more general platform which generalizes the concept of the classic set, fuzzy set, intuitionistic fuzzy set, and interval valued intuitionistic fuzzy sets. In contrast to intuitionistic fuzzy sets and also interval valued intuitionistic fuzzy sets, indeterminacy is characterized explicitly in the neutrosophic set. A neutrosophic set has three basic components such that truth membership, indeterminacy membership and falsity membership, and they are independent. However, the neutrosophic set generalizes the above mentioned sets from philosophical point of view and its functions $TA(x)$, $IA(x)$ and $FA(x)$ are real standard or nonstandard subsets of $]0^-,1^+[$ and are defined by $TA(x):X\to]0^-,1^+[$, $IA(x):X\to]0^-,1^+[$ and $FA(x):X\to]0^-,1^+[$. That is, its components (x),(x),$F(x)$ are non-standard subsets included in the unitary nonstandard interval $]0^-,1^+[$or standard subsets included in the unitary standard interval [0, 1] as in the intuitionistic fuzzy set. Furthermore, the connectors in the intuitionistic fuzzy set are only defined by $T(x)$ and $F(x)$ (i.e. truth-membership and falsity-membership), hence the indeterminacy $I(x)$ is what is left from 1, while in the neutrosophic set, they can be defined by any of them (no restriction) [16].

Single Valued Neutrosophic sets

A single valued neutrosophic set has been defined in [25] as follows:

Let X be a universe of discourse. A single valued neutrosophic set A over X is an object having the form A= {⟨x, (x), (x), (x)⟩: $x \in X$}

Where $u_A(x):X\to[0,1]$, $w_A(x): X\to[0,1]$ and $v_A(x): X\to[0,1]$ with $0\le u_A(x) + w_A(x) + v_A(x) \le 3$ for all $x \in X$. The intervals (x), (x) and (x) denote the truth- membership degree, the indeterminacy-membership degree and the falsity membership degree of x to A, respectively.

Complement of Neutrosophic set

The complement of a neutrosophic set A is denoted by A^c and is defined as $T_{A^c}(x)$={1+} $\ominus T_A(x)$, $I_{A^c}(x)$={1+} $\ominus I_A(x)$ and $F_{A^c}(x)$={1+} $\ominus$ $F_A(x)$ for all $x\in X$.

Geometric Aggregation operator

Let A_k (k=1,2,…,n) ∈ SVNS(X). The single valued neutrosophic weighted average operator is defined by

$$F_w = \left(A_1, A_2, \ldots\ldots A_n\right) = \sum_{K=1}^{n} W_k A_k = \left(1 - \prod_{K=1}^{n}\left(1 - u_{AK}(x)\right)^{wk}\right), \prod_{k=1}^{n}\left(W_{AK}(x)\right)^{wk}$$

Eq - 4.5

where ω_k is the weight of A_k (k=1,2,…,n), $\omega_k\in[0,1]$ and $\Sigma\omega_k$=1. Especially, assume $\omega_k=1/n$ (k=1,2,…,n), then $F\omega$ is called an arithmetic average operator for SVNSs.

Score Function

Let A = (a, b, c) be a single valued neutrosophic number, a score function K of a single valued neutrosophic value, based on the truth-membership degree, indeterminacy-membership degree and falsity membership degree is defined by

$$K(A) = \frac{1 + a - 2b - c}{2}$$

Where $K(A) \in [-1, 1]$.

The score function K is reduced the score function proposed by Li ([8]) if b=0 and a+c≤1.

It is clear that if truth-membership degree a is bigger, and the indeterminacy-membership degree b and falsity membership degree c are smaller, then the score value of the SVNN A is greater.

EXPERIMENTAL ANALYSIS BY GRA WITH SVNS:

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 1.

Table 5.1 : 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

Experimental Data:

Superni-718 super alloy as work piece brass cutting wire and work is carried out on a Wire EDM machine(ULTRA CUT f2). The experimental parameters measured are Cutting rate, Surface roughness and dimensional deviation. The experimental data using L27 orthogonal array is shown in table 2.

Table 5.2: 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

Table 5.3: Normalized Values

Exp.NO	MRR	SR	DD
1	0.385211	1.577518	0.181185
2	0.325211	1.402336	0.418118
3	0.225211	1.533723	0.390244
4	0.555211	1.051971	0.367596
5	0.205211	1.679708	0.573171
6	0.565211	1.088467	0.885017
7	-0.13479	1.519124	0.644599
8	0.315211	1.081168	0.989547
9	0.545211	1.329343	0.308362
10	0.405211	0.745401	0.52439
11	0.035211	1.497226	0.221254
12	0.575211	0.891387	0.710801
13	0.255211	1.504526	0.526132
14	0.455211	1.066569	0.714286
15	0.315211	1.745401	0.656794
16	0.425211	1.154161	1
17	0.075211	1.694307	0.285714
18	0.555211	0.869489	0.747387
19	0.315211	1.066569	0.569686
20	0.105211	1.300146	0.703833
21	0.215211	0.913285	0
22	0.215211	1.453431	0.773519
23	0.405211	1.278248	0.54007
24	0.535211	1.212555	0.825784
25	0.495211	1.307445	0.780488
26	0.485211	1.329343	0.517422
27	0.465211	1.365839	0.662021

Table 5.4: Decision Maker's Prioritized Matrix in SVNS

Priorities	MRR	SR	DD
MRR	(1.0 , 0, 0)	(0.60, 0.40 , 0.20)	(0.50, 0.40, 0.30)
SR	(0.2, 0.6, 0.6)	(1.0, 0, 0)	(0.5, 0.4, 0.4)
DD	(0.3, 0.6, 0.5)	(0.4, 0.6, 0.5)	(1.0, 0, 0)

Table 5. Aggregated Prioritized Matrix

	MRR	SR	DD
MRR	0.6694	0.2886	0.1757
SR	0.4642	0.3786	0.3786
DD	0.4932	0.4571	0.3700

Table 5. 6: Score and Weights of objectives

	SCORE	WEIGHTS
MRR	0.4582	0.6303
SR	0.1642	0.2259
DD	0.1045	0.1437

Table 5.7: Weighted Normalized Matrix

Exp. No	MRR	SR	DD
1	0.242683	0.362829	0.025366
2	0.204883	0.322537	0.058537
3	0.141883	0.352756	0.054634
4	0.349783	0.241953	0.051463
5	0.129283	0.386333	0.080244
6	0.356083	0.250347	0.123902
7	-0.08492	0.349399	0.090244
8	0.198583	0.248669	0.138537
9	0.343483	0.305749	0.043171
10	0.255283	0.171442	0.073415
11	0.022183	0.344362	0.030976
12	0.362383	0.205019	0.099512
13	0.160783	0.346041	0.073659
14	0.286783	0.245311	0.1
15	0.198583	0.401442	0.091951
16	0.267883	0.265457	0.14
17	0.047383	0.389691	0.04
18	0.349783	0.199982	0.104634
19	0.198583	0.245311	0.079756
20	0.066283	0.299034	0.098537
21	0.135583	0.210055	0
22	0.135583	0.334289	0.108293
23	0.255283	0.293997	0.07561
24	0.337183	0.278888	0.11561
25	0.311983	0.300712	0.109268
26	0.305683	0.305749	0.072439
27	0.293083	0.314143	0.092683

Table 5. 8: Quality Loss Function

Exp. No	MRR	SR	DD
1	0.757317	0.637171	0.974634
2	0.795117	0.677463	0.941463
3	0.858117	0.647244	0.945366
4	0.650217	0.758047	0.948537
5	0.870717	0.613667	0.919756
6	0.643917	0.749653	0.876098
7	1.084917	0.650601	0.909756
8	0.801417	0.751331	0.861463
9	0.656517	0.694251	0.956829
10	0.744717	0.828558	0.926585
11	0.977817	0.655638	0.969024
12	0.637617	0.794981	0.900488
13	0.839217	0.653959	0.926341
14	0.713217	0.754689	0.9
15	0.801417	0.598558	0.908049
16	0.732117	0.734543	0.86
17	0.952617	0.610309	0.96
18	0.650217	0.800018	0.895366
19	0.801417	0.754689	0.920244
20	0.933717	0.700966	0.901463
21	0.864417	0.789945	1
22	0.864417	0.665711	0.891707
23	0.744717	0.706003	0.92439
24	0.662817	0.721112	0.88439
25	0.688017	0.699288	0.890732
26	0.694317	0.694251	0.927561
27	0.706917	0.685857	0.907317

Table 5.9: Grey Relational coefficients, Grey Relational Grade with Rank

Exp. No	GRC MRR	GRC SR	GRC DD	GRG	Rank
L1	0.9079	0.96328	0.92226265	0.931149	11
L2	0.8822	0.92773	0.94348562	0.91782	18
L3	0.8426	0.95414	0.94093824	0.912546	20
L4	0.9894	0.86395	0.9388786	0.930756	12
L5	0.8351	0.9853	0.95791101	0.926088	13
L6	0.9947	0.87019	0.98830202	0.951059	2
L7	0.7251	0.95113	0.96470588	0.880324	26
L8	0.8781	0.86893	0.99892512	0.915324	19
L9	0.9842	0.91368	0.93353424	0.943815	6
L10	0.9168	0.81494	0.95332535	0.89502	23
L11	0.7762	0.94665	0.92578449	0.882886	25
L12	1	0.83757	0.97109021	0.936219	8
L13	0.8541	0.94814	0.95348837	0.918572	16
L14	0.9398	0.86644	0.97142857	0.925886	14
L15	0.8781	1	0.96587563	0.947996	4
L16	0.9259	0.88163	1	0.935829	9
L17	0.7893	0.98853	0.93150685	0.903115	21
L18	0.9894	0.83409	0.97465478	0.932728	10
L19	0.8781	0.86644	0.957582	0.900711	22
L20	0.7994	0.90817	0.9704142	0.892667	24
L21	0.8388	0.84107	0.90666667	0.862176	27
L22	0.8388	0.93782	0.97721696	0.917943	17
L23	0.9168	0.90409	0.95479452	0.925227	15
L24	0.9791	0.89206	0.98238196	0.951178	1
L25	0.959	0.90954	0.97790249	0.948829	3
L26	0.9542	0.91368	0.95267384	0.940168	7
L27	0.9445	0.92065	0.96637782	0.943852	5

Table 5.10: Response Table for Signal to Noise Ratios Larger is better

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	-0.6959	-0.8844	-0.6754	-0.6138	-0.7484	-0.6876	-0.8012	-0.6684
2	-0.7283	-0.6056	-0.6486	-0.7750	-0.7793	-0.7425	-0.6589	-0.7252
3	-0.7256	-0.6598	-0.8257	-0.7610	-0.6221	-0.7197	-0.6897	-0.7562

Table 5.11: Response Table for Means

Level	Ton	Toff	CS	P	WF	WT	SG	SF
1	0.9232	0.9035	0.9253	0.9319	0.9177	0.9241	0.9124	0.9262
2	0.9198	0.9327	0.9283	0.9150	0.9144	0.9184	0.9271	0.9201
3	0.9203	0.9271	0.9097	0.9164	0.9313	0.9208	0.9239	0.9170

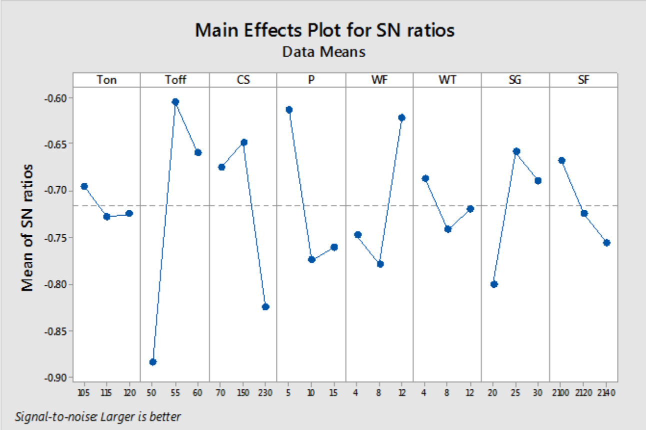

Figure 5.1: Main effects plot for SN ratios

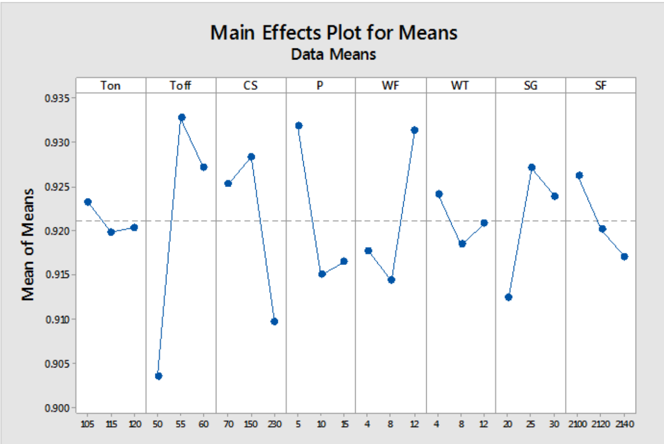

Figure 5.2: Main effects plot for means

CONFROMATION TEST

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 5.8) shows the highest grey relational grade, indicating the optimal process parameter set up of Ton-2, Toff-3,CS-1, P-1,WF-2,WT-2,SV-3,SF-1 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 GRA.

Table 5.12: Results of conformation experiment (GRA)

S. No	Response characteristics	Optimal Parameter Combination	Response characteristics values	
			Predicted at 95% of confidence level	Avg. of three Conformation Experiments
1	MRR	A1B2C2D 1E3F1G2H1	0.934	1.043
2	Ra		1.804	1.68
3	DD		0.43	0.39

CONCLUSIONS

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

I. Experiments conducted on WireEDM considering SuperNi-718 for same parametric values and compared the performance characteristics in terms of MRR,Surface Roughness and DD.

II. Form the analysis it is found that, highest grey relational grade, indicating the optimal process parameter setup of Ton-2, Toff-3,CS-1, P-1,WF-2,WT-2,SV-3,SF-1 has the best multiple performance characteristics among the 27 experiment.

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