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Multi-response Optimization of Wire Electrical Discharge Machining Process Parameters for Al7075/Al_2O_3/SiC Hybrid Composite Using Taguchi-based Grey Relational Analysis

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Abstract

To understand how various process parameters in wire electrical discharge machining (WEDM) affect surface quality metrics such as surface roughness and kerf width, Using an L27 orthogonal array, researchers looked at a hybrid metal matrix composite made of Al7075 alloy, 7.5% aluminum oxide (Al_2O_3), and 7.5% silicon carbide (SiC) nanoparticles and a technique that used inert gas assistance during the electromagnetic stir casting procedure. Process parameter values that provide the optimum machined qualities were determined using Taguchi-based Grey relational analysis (GRA), a multi-response optimization approach. Pulse on time, pulse current, pulse off time, and wire drum speed all had a role in the machining of the hybrid composite, but the analysis of variance showed that they were significantly important in the following order: 50.02%, 39.50%, 4.58%, and 2.75%. An improved Grey relational grade was found in a confirmation test performed at the ideal parameter setting, proving the validity of GRA.

Keywords

Wire electrical discharge machining, Surface roughness, Analysis of variance, Grey relational analysis, Hybrid composite, Kerf width, Taguchi

Introduction

A flexible alloy of metals is combined together with a couple of exceptionally strong as well as harder reinforcement elements to form composites composed of metal matrix components (MMCs). These primed metal matrix composites offer enhanced characteristics and are significant within industries like aerospace, defense, and automotive [1, 2]. Manufacturing such MMCs using conventional methods live challenging outstanding close to the coarseness for the additives. Non-conventional manufacturing methods, highly flexible most efficient way to machine such substances is WEDM. WEDM can shape intricate profiles and geometry regardless of material hardness. WEDM manufacturing evaluations of performance comprise the MRR (material removal rate), SR (Surface roughness), and kerf width [3, 4]. Minimal SR enhances the quality of the item, but higher MRR lowers manufacturing charges. Excellent finishes improve component tiredness, deterioration, and overall resilience to wear. Finishing component dimensions depend on kerf width or cutting width [5].

Traditional machining of MMCs significantly differs from machining other metals due to matrix and reinforcement alternation, necessitating specific tools and methods [6]. Examined cutting forces and surface quality in Al/SiC composite machining with varying cutting speeds. Researchers found CBN tools outperformed CN tools but experienced rapid wear [7]. optimizing WEDM included analyzing cutting variables' impact on material removal and kerf.

ANOVA (Analysis of variance) showed voltage and pulse duration's significant effect, enhancing WEDM performance [8]. Practical equations for assessing surface conditions in AISI D2 metal cutting showed that higher pulse current and duration create thicker recast layers. Finer finishing occurs with lower pulse energy, reducing surface damage. However, careful parameter selection is vital for improved WEDM results [9]. Comparing fatigue data of specimens machined at various speeds to parent metal revealed slight reductions in fatigue life but consistent results across speeds. Microhardness and roughness saw marginal increases unaffected by speed changes. WEDM introduced a hard recast layer, affecting hardness and roughness. Variations in cutting speed had minimal influence on fatigue life and surface characteristics, highlighting machining process stability [10]. L27 Taguchi method optimized WEDM for a two-dimensional steel tool. ANOVA showed that current, pulse length, and flow speed maximize MRR and SR. A genetic algorithm determined optimal parameters [11]. CNC WEDM optimized Inconel® 718 parameters (MRR and SR) with pulse, delay, wire speed, and ignition. Turning SKD 11 used L27 orthogonal array, ANOVA highlighted optimal parameters, surpassing initial results [12, 13]. optimizing AA-1050/H22's tensile strength and percentage enlargement through friction stir welding demonstrated increased strength and reduced elongation, emphasizing improvement potential using GRA and the Taguchi method in weld quality [14]. Optimizing WEDM parameters for Incoloy® 800 super alloy enhanced MRR, corner radius, and kerf width. Break electrical energy had the most significant impact, contributing 45.60% to overall performance. The selected variable settings led to improvements of MRR by 7.74%, kerf width by 8.64%, and SR by 6.34% compared to the initial parameters, yielding the highest Grey relational grade [15]. WEDM behavior on D2 steel, assessing six variables' impact on MRR, kerf width, and SR. Using an L27 orthogonal array and GRA, the most favorable parameter combination was identified for optimal outcomes [16]. Optimized WEDM variables for tungsten carbide-cobalt composite, improving MRR and SR. Significant impact of taper angle and pulse on time on GRG (Grey relationship grade) with minimal error percentages of 2.2% and 0.35%, respectively [17]. Taguchi and GRA optimized laser micro-drilling for zirconium oxide ceramic, achieving 16.29%-hole taper and 8.77% HAZ width improvement [18]. Optimized high-speed steel WEDM using L27 orthogonal array and mathematical modeling. The NSGA-2 algorithm in Minitab improved results, with a 61% deviation in confirmatory tests [19].

Only a limited number of studies have investigated the machining of composites in existing literature. Therefore, the purpose of this research is to improve WEDM progression variables using multiple responses of a recently made Al7075/SiC/Al_2O_3 compound. To achieve this, minimum GRA is engaged into honestly incorporate this WEDM for best machining character, including SR also kerf width. By utilizing Minitab15, ANOVA was conducted while found its significant impact of every variable on multi-performance attributes. Moreover, substantiation investigation be carried out to validate its most favorable combination of procedural parameters calculated by means of GRA and Taguchi.

Experimentation

Methods for making hybrid composites

In this study, an electromagnetic stir casting process helped by an inert gas was used to make hybrid MMCs. This mixture compound consisted of nano Al_2O_3 = 7.5 wt.% and SiC = 7.5 wt.% incorporated into an Al7075 alloy matrix. The Al7075 alloy, which belongs to the 7xxx series, holds significant potential for purpose in the aerospace and automotive industries due to its favorable combination ratio in the form elevated stiffness to density also corrosion confrontation. Al7075 be primarily a zinc alloy, with zinc constituting the maximum weight percentage (5.65 wt.%) after the base metal, aluminum. The addition of zinc enhances the alloy's ductility, formability, wet ability, and corrosion resistance. Other alloying consists of elements present include the metals magnesium, copper, and chromium in silicon, which is titanium, which is along with iron. Table 1 shows its mass percentage of Al7075 alloy. The hybrid composite was fabricated using SiC/Al_2O_3 nano reinforcements into fine granular form, with particle sizes ranging from 20 to 40 µm [1-5].

Measurements and reactions in machining

For the purpose to investigate how it affects SR and kerf breadth of four input process parameters, namely pulse on time, pulse off time, pulse current, and wire drum speed, WEDM of the hybrid composite was conducted. Those levels for procedural variables are determined based on preliminary experiments. Its specific levels and corresponding designations of the various parameters can be found in table 2.

Taguchi experimental design

The Taguchi philosophy has been a great approach in support of the intent of greater worth manufacturing methods. It utilizes investigations using orthogonal arrays to minimize variance by identifying the optimal settings for procedure regulation variables. The on-time (A), off-time (B), current (C), and rotational velocity (D) of the wire drum were chosen as the four control parameters. Each parameter was tested at three different levels using an L27 array orthogonal. This investigational design, as shown at table 3, represents its specific levels of each parameter for the conducted experiments. It is important to note that this table does not contain any observed data but rather serves as a guide for the experiment's design. The collected data was analyzed using Minitab 19 software, which facilitated the analysis of the results and provided insights into

Table 1: Al7075 alloy chemical make-up.

Fe (wt.%)	Ti (wt.%)	Si (wt.%)	Mg (wt.%)	Cr (wt.%)	Cu (wt.%)	Zn (wt.%)	Al
0.48	0.19	0.36	2.51	0.27	1.78	5.65	Remaining

Table 2: The quantities correspond to the technique's variables.

Syb.	Procedural variables	Level-1	Level-2	Level-3
A	T_{ON} (µs)	4	8	12
B	T_{OFF} (µs)	2	4	6
C	Current (A)	45	65	85
D	Speed (m/min)	4	6	8

Table 3: Optimization table.

Exp. No. Con	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	10	21	22	23	24	25	26	27
A	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3
B	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3	1	1	1	2	2	2	3	3	3
C	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
D	1	2	3	2	3	1	3	1	2	1	2	3	2	3	1	1	3	1	1	2	3	2	3	1	3	1	2

that outcome for the different parameter levels happening the organization presentation. By employing this Taguchi method and utilizing software analysis tools, this study aimed to minimize the manufacturing procedure and also improve output product excellence.

WEDM set-up for experimental process

WEDM is a non-contact material removal process that efficiently erodes workpieces through controlled sparking between a wire electrode and the workpiece (Figure 1). Dielectric fluid continually flushes away eroded particles, making WEDM ideal for machining hard materials. The wire is precisely controlled, and a guide secures it both above and below the workpiece. Each experiment uses a fresh wire segment. The resulting kerf width determines part accuracy. A Taguchi L27 orthogonal arrays experimental design, converted into signal-to-noise ratios, was used to optimize the process parameters, aiming to minimize variation and enhance performance. Table 4 presents SR and kerf values as a function of S/N ratio.

$$\left(\frac{S}{N}\right)_{SB} = -10\log\left[\frac{1}{n}\sum_{i=0}^{n} y_i^2\right] \tag{1}$$

Equation 1 helps to calculate S/N ratio for SR and kerf width presented in table 5. The i^th^ experiment result and n represent the repetition count for that experiment. The S/N ratio values are then used to calculate grey relational coefficients (GRCs). The conventional Taguchi method is effective in optimizing a single objective function but cannot effectively address multi-objective optimization problems. Deng's Grey system theory, which addresses issues with limited, inadequate, and uncertain information, has been validated as a valuable approach. In this study, GRA is employed to optimize machining characteristics of SR and kerf width for a newly developed hybrid composite using WEDM. The study demonstrates that GRA is a superior method for optimizing various response characteristics in diverse domains.

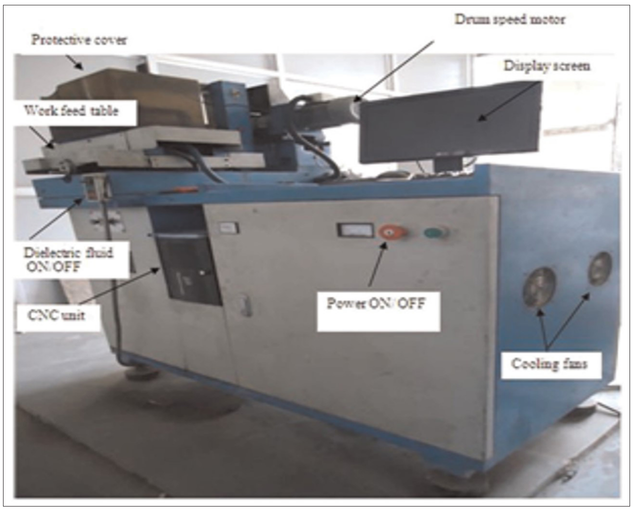

Figure 1: WEDM photographic view.

Theory of GRA

It is an advanced methodology that assists in the identification and ranking of crucial factors within a system. Its particular strength lies in evaluating the independence of variables. This analysis encompasses a spectrum of scenarios, rang-

Table 4: SR and kerf values as a function of S/N ratio.

Exp. No.	SR (μm)	SNRA1	Kerf (mm)	SNRA1
1	2.596	28.284	0.228	247.16
2	3.222	210.16	0.265	248.46
3	4.025	212.1	0.281	248.97
4	2.217	26.913	0.227	247.12
5	3.099	29.821	0.273	248.72
6	3.594	211.11	0.260	248.3
7	2.183	26.778	0.230	247.23
8	2.807	28.962	0.250	247.96
9	3.068	29.734	0.269	248.6
10	3.853	211.71	0.242	247.68
11	4.93	213.84	0.279	248.91
12	5.317	214.51	0.296	249.43
13	3.478	210.83	0.245	247.78
14	4.158	212.38	0.286	249.13
15	4.784	213.6	0.280	248.94
16	3.431	210.71	0.239	247.57
17	4.208	212.48	0.285	249.1
18	4.454	212.98	0.297	249.46
19	4.165	212.39	0.267	248.53
20	4.735	213.51	0.300	249.54
21	5.606	214.97	0.314	249.94
22	3.869	211.75	0.282	249.01
23	4.327	212.72	0.303	249.63
24	5.017	214.01	0.291	249.28
25	3.89	211.78	0.284	249.07
26	4.19	212.42	0.277	248.85
27	4.496	213.06	0.298	249.48

Table 5: S/N ratios were normalized, and the coefficients and average grey relational quality score were computed.

Exp. No.	GRA-SR			GRA-Kerf width			GRA
	SNRA1	Normal	GRC_{sr}	SNRA1	Normal	GRC_{kf}	
1	28.2841	0.18379	0.37988	247.159	0.01355	0.33637	035813
2	210.161	0.41275	0.45987	248.465	0.47706	0.48879	0.47433
3	212.098	0.64909	0.5876	248.974	0.65776	0.59365	0.59063
4	26.9128	0.01647	0.33704	247.121	0	0.33333	0.33519
5	29.8211	0.37132	0.443	248.723	0.56873	0.5369	0.48995
6	211.111	0.52868	0.51476	248.3	0.41835	0.46226	0.48851
7	26.7777	0	0.33333	247.235	0.04047	0.34258	0.33795
8	28.9624	0.26654	0.40537	247.959	0.29747	0.41579	0.41058
9	29.7343	0.36073	0.43888	248.596	0.52324	0.5119	0.47539
10	211.714	0.60229	0.55698	247.676	0.19722	0.3838	0.47039
11	213.839	0.86158	0.78318	248.912	0.63574	0.57854	0.68086
12	214.511	0.94352	0.8985	249.426	0.81805	0.73319	0.81584
13	210.824	0.4938	0.49691	247.783	0.2352	0.39532	0.44611
14	212.375	0.68294	0.61195	249.127	0.71212	0.63461	0.62328
15	213.597	0.83205	0.74856	248.943	0.64677	0.58601	0.66728
16	210.707	0.47946	0.48994	247.567	0.15878	0.37279	0.43137
17	212.483	0.69612	0.62198	249.097	0.70132	0.62604	0.62401
18	212.977	0.75641	0.67241	249.455	0.82844	0.74454	0.70848
19	212.391	0.68481	0.61336	248.53	0.50024	0.50012	0.55674
20	213.508	0.82118	0.73658	249.542	0.85942	0.78054	0.75856
21	214.974	1	1	249.939	1	1	1
22	211.749	0.60649	0.55959	249.004	0.66871	0.60147	0.58053
23	212.721	0.72513	0.64527	249.629	0.89009	0.81979	0.73253
24	214.011	0.88253	0.80976	249.278	0.76554	0.68099	0.74526
25	211.777	0.60998	0.56179	249.066	0.69049	0.61766	0.58972
26	212.424	0.68884	0.6164	248.85	0.61357	0.56406	0.59023
27	213.059	0.76637	0.68154	249.484	0.8388	0.7562	0.71887

ing from situations where no information is accessible, resulting in the absence of a solution, to cases where all information is available, leading to a single, definitive solution. Grey system analysis, when applied to situations with incomplete information, offers a range of feasible solutions. Rather than aiming to discover that absolute most excellent result, GRA offers methods to identifying satisfactory results that are suitable for current global problems [20-23].

$$GRG_{(average)} = 0.5816$$

Data normalization

In GRA, aspects often have different dimensions and a significant difference in magnitude. To address this, experimental data is initially normalized to a range from 0-1, the development of grey relations. Furthermore, quantifies its variation among its investigational also idyllic rate. Optimization criterion within GRA depends on its importance of quality characteristics and can be classified into three categories: 'larger-the-better', 'smaller the superior', also nominal is best. This particular examination, achieving minor values for SR, also better machining performance comes at kerf width, thus, that 'smaller is best criterion was selected entire investigation. Here kerf width also SR considered were smaller considered. Table 6 displays the normalized SR and kerf width values that were calculated [23, 24] using equation 2.

$$X_{ij} = \frac{\max Y_{ij} - Y_{ij}}{\max Y_{ij} - \min Y_{ij}} \quad (2)$$

The GRC, denoted as j_{ij}, is utilized to quantify the association between reference data and the actual experimental normalized data. To calculate the GRC (j_{ij}), the following formula, as described by GRC [8, 19], can be employed.

$$\varepsilon_{ij} = \frac{\Delta_{min} + \varepsilon\Delta_{max}}{\Delta_{ij} + \varepsilon\Delta_{max}} V \tag{3}$$

The expression D_{ij} represents the absolute difference between the reference data or best data (X_{oj}) and the actual experimental data (X_{ij}). D_{min} corresponds to the maximum value of D_{ij}, while D_{min} corresponds to the minimum value of D_{ij}. The coefficient j_{ij}, known as the distinguishing or identification coefficient, assumes values between 0 and 1. Typically, a value of 0.5 is chosen for the distinguishing coefficient to align with practical requirements. The calculated GRCs with kerf width also SR are presented in table 6. No units are mandatory for the data in table 6, which solely current this computed ranges for the S/N ratio, the normalized ranges, also GRCs for SR also kerf width. Its maximum normalized range, which is 1, is observed in trial digit is 21, whereas its smallest range of 0 is associated with trial digit 7.

Following its computation of its GRC, the Overall GRG is determined using equation 4 for each quality characteristic. A weighting method is then utilized to integrate these individual GRG values and obtain a single overall GRG. GRG (g_i) in favor of its i^{th} trial preserve exist premeditated as a described in regenerate response [21].

$$\gamma_i = \frac{1}{m}\sum w_j \varepsilon_{ij} \tag{4}$$

In the given context, m represents this excellent uniqueness numbers, while W_j denotes - delay aspects with the j^{th} reactions. Its final process outcome measure with multiple responses relies on the computed overall GRG. In this case, a value of 0.5 is chosen for j when calculating the GRG. The GRG results are determined by assigning equal weighting ratios to its superiority uniqueness for kerf width also SR. The current approach transforms the optimization problem with numerous reaction progression keen on a situation where a solitary reaction is optimized, using the overall GRG as the objective function. Using the Taguchi approach, one may determine the best set of parameters to maximize global GRG. Results from the GRG are shown in table 6.

Results and Discussion

Response-based ANOVA

The study used ANOVA to analyze GRG values in Minitab 19 software to determine the impact of four main process parameters on the machining of the hybrid composite. The results showed that pulse on time, pulse off time, pulse current, and wire drum speed all had a significant effect on the machining process. Pulse on time was the most influential parameter, contributing the highest percentage (50.02%) to both SR and kerf width. The other parameters were pulse off time (4.58%), pulse current (39.50%), and wire drum speed (2.75%). The response table for the mean values of GRG is presented in table 7, which shows the average GRG value for each combination of parameters at different levels. Pulse on time received the highest rank, followed by discharge current, pulse off time, and wire drum speed. The graph for pulse-off time shows a positive effect, indicating that increasing its value leads to a decrease in both SR and kerf width. The results suggest that pulse on time, pulse current, and wire drum speed have a negative effect on GRG, indicating that both SR and kerf width increase as these parameters increase.

Process variables and their impact

This ANOVA analysis reveals to every 4 progression variables-that are wire drum speed, pulse on time, pulse off time, pulse current, and pulse duration all play crucial roles. At WEDM procedure, substance for detached beginning this exterior through sparkle wearing down. elevated values for pulse current also pulse on time result in a higher sparkle period with higher concentration, delivering a greater quantity energy discharge to this material exterior. The leads to an increased melting with specimen as per one park, resulting in larger, more extensive impacts, ultimately leading to an increase in SR.

On the other hand, this barrel velocity with wire has the pessimistic consequence depended by overall GRG, implying

Table 7: The GRG signifies response table.

Level	T_{ON}	T_{OFF}	A	WDS
1	0.4401	0.6339	0.4562	0.5457
2	0.6075	0.5676	0.5983	0.5754
3	0.6969	0.543	0.69	0.6235
Delta	0.2569	0.091	0.2338	0.0778
Rank	1	3	2	4

Table 6: S/N ratio (GRG) ANOVA.

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	*p*	% Con.
T_{ON}	2	75.434	75.4344	37.7172	334.4	0	50.02
T_{OFF}	2	6.911	6.9107	3.4554	30.64	0.001	4.58
A	2	59.57	59.5696	29.7848	264.07	0	39.5
WDS	2	4.151	4.1512	2.0756	18.4	0.003	2.75
T_{ON} 3 T_{OFF}	4	0.58	0.5796	0.1449	1.28	0.373	0.38
T_{ON} 3 A	4	2.004	2.004	0.501	4.44	0.052	1.33
T_{ON} 3 WDS	4	1.473	1.4729	0.3682	3.26	0.095	0.98
Res. Error	6	0.677	0.6767	0.1128			0.45
Total	26	150.799					

that SR also kerf width enhances wire velocity increases. A larger velocity with wire facilitates more efficient washing out the fragments than with the GAP, which in turn increases the kerf width. Additionally, it increased wire speed throws in into constituent part come away, creating larger craters also empty space, by this means escalating SR.

The GRG improves as the pulse off time rises, implying that the GRG becomes less sensitive to changes in the pulse rate, SR and kerf width decrease. It happens a longer pulse-OFF time results in fewer ejections occurring within a specific time period. As a result, there are fewer spark-induced craters and fewer molten droplets formed on the surface, leading to reduced kerf width and also SR.

Best possible feature estimations

The objective is to establish what values of design parameters will provide the best measurable gains in performance. These optimum values of the overall GRG are predicted based on the selected levels of significant parameters. From the response graph (Figure 2), In this considerable progression constraints also its corresponding most favorable intensities were identified while A_1, B_1, C_1, and D_1. Specifically, this corresponds to a 4 m, 6 m, 2 m, and 4 m/min, respectively that are pulse on, pulse off, current, and drum speed. To estimate that signify for the reaction attribute (mGRG), the appropriate computation methods are [20].

$$\grave{\imath}_{\mathrm{GRG}} = \mathrm{GRG} + (A_1 - \mathrm{GRG}) + (B_3 - \mathrm{GRG}) + (C_1 - \mathrm{GRG}) + (D_1 - \mathrm{GRG})$$

Where, GRG is the overall means of GRG (0.5816); μ_{GRG} = 0.4403 + 0.5435 + 0.4564 + 0.5459 – 3(0.5816) = 0.2401 (Table 8).

This expression may be used to determine 95% confident intervals (CI) given an anticipated average of this authorization investigation.

$$(CI)_{CE} = \sqrt{F_{\alpha}(1, f_e) V_e \left[\frac{1}{\eta_{eff}} + \frac{1}{R} \right]} \tag{5}$$

Based on table 7, the CI was computed as follows: where F_a is the 95% CI F value, f_e is the degrees of freedom for an error of magnitude 6, and t is the standard deviation. This computed average has 8 degrees of freedom (2 + 2 + 2 + 2) from the aggregate of 27 experiments. The overall formula for determining that true effectiveness variety number replicates (η_{eff}) is:

$$\eta_{eff} = \frac{1}{1 + Total\ degree\ of\ freedom\ of\ means} \tag{6}$$

Consequently, η_{eff} = 27/(1 + 8) = 3. There will be one confirmed R experimentation specimen. The CI with a 95% confidence level (a = 0.05) for the F ratio is 5.99. Thus, CI_{CE} equals 60.2317. mMRR = 0.2405 is supposed to be the average of GRG. The most beneficial estimate for GRG, at 95% CI, is mentioned.

$(\mu_{GRG} - CI_{GE}) < \mu_{GRG}\ (\mu_{GRG} + CI_{GE})\ (0.241 - 0.2315)\mu_{GRG} <$

$(0.2401 - 0.2315)0.087 < \mu_{GRG} < 0.4720$

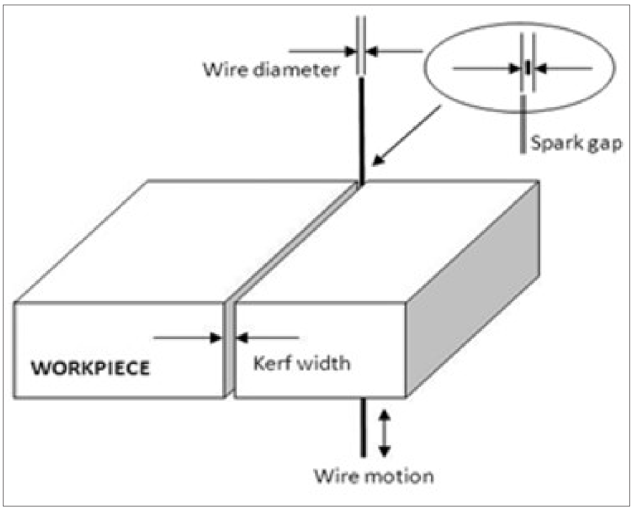

Figure 2: WEDM kerf width specifications.

Table 8: Reaction when operating conditions are ideal.

Exp. No.	Ra (μm)	Kerf width (mm)	Exp. value GRG	CI
1	2.185	0.229	0.33654	0.0087\mGRG\0.4720
2	2.189	0.229	0.33676	0.0087\mGRG\0.4720
3	2.186	0.229	0.3366	0.0087\mGRG\0.4720

Verification procedure

To guarantee the best Taguchi orthogonal array machining combination of design parameters is reliable, a confirmation test was performed. Three further experiments have been run by adjusting the process variables dialed on perfection. It shows the results of a comparison between the GRG that was predicted (using equation 4) and the GRG that was measured (using the best achievable permutation for machining variables) in an experiment. Its predicted range of 0.2401 is found to be in excellent agreement with the experimental value of 0.33655. From the preliminary aspect set into optimum progression variables configuration, there is 0.09601-point rise in GRG (Figure 3). It is important to note that this method improves not just SR but also kerf width, two key performance aspects of the WEDM process.

Conclusions

In the fabrication of nanocomposites MMCs using WEDM, various performance measures, such as SR and kerf width, were fine-tuned through a Taguchi-based GRA. Those investigations led to these relevant recommendations:

- At a pulse-on time of 4 milliseconds, a pulse-off time of 6 milliseconds, a pulse current of 2 A, along with a wire drum speed of 4 m/min, the best values of SR were determined to be 2.187 micrometers and 0.229 millimeters, respectively.
- According to ANOVA, all four process parameters were statistically significant for the entire GRG.
- Pulse on time made up 50.02% of the total GRG,

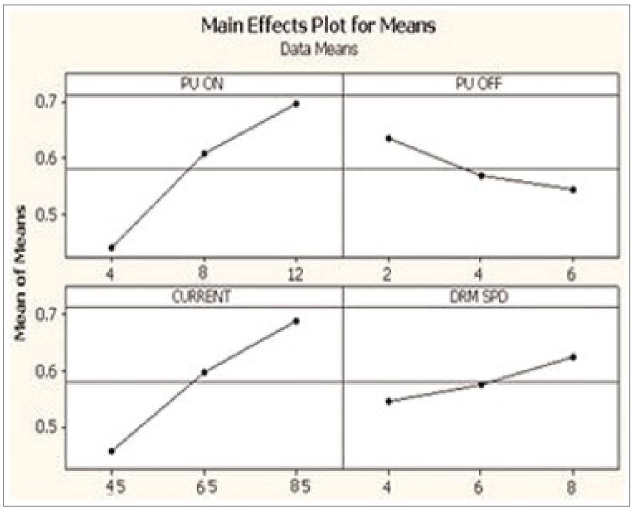

Figure 3: Ways in which process variables affect GRG.

followed in descending order by 39.50% of pulse current, 4.58% of pulse off time and 2.75% wire drum speed.

- When the process parameters were set to their sweet spot (0.0087 mGRG 0.4720), the confirmatory test indicated that the total GRG improved.

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None.

Conflict of Interest

None.

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