OPTIMIZING WIRE EDM for Al7075/Al_2O_3/SiC HYBRID COMPOSITE: A MULTI-RESPONSE APPROACH WITH TAGUCHI-BASED GREY RELATIONAL ANALYSIS

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Abstract

In order to comprehend the impact of different process parameters in wire electrical discharge machining (WEDM) on surface quality metrics such as surface roughness and kerf width, Researchers used an L27 orthogonal array to investigate a hybrid metal matrix composite consisting of Al-7075 alloy, 7.5% Al_2O_3, and 7.5% SiC nano particulates. They also examined a strategy that included the usage of inert gas support during the electromagnetic stir casting operation. The optimal machined characteristics were established by analysing process parameter values using Taguchi-based grey relational analysis, which is a multi-response optimisation technique. The machining of the hybrid composite was influenced by pulse on time, pulse current, pulse off time, and wire drum speed. However, the analysis of variance revealed that their significance followed this order: 50.02% for pulse on time, 39.50% for pulse current, 4.58% for pulse off time, and 2.75% for wire drum speed. The confirmation test conducted at the optimal parameter setting demonstrated an enhanced grey relational grade, hence validating the effectiveness of grey relational analysis.

Keywords: WEDM, Ra, analysis of variance, grey relational analysis, hybrid composite, kerf width, and Taguchi

Introduction

Metal matrix composites (MMCs) are formed by combining a pliable alloy of metals with a pair of very robust and rigid reinforcing elements. Primed metal matrix composites possess improved properties and are particularly important in sectors such as aerospace, defence, and automotive. Producing metal matrix composites by standard procedures is difficult due to the proximity of the additives' coarseness. Wire machining using electrical discharge is the most efficient and very versatile technology for machining substances that are not conventionally manufactured. Wire Electrical Discharge Machining (WEDM) is capable of forming highly detailed profiles and geometries, irrespective of the hardness of the material. Performance assessments in WEDM production include measurements of Material Removal Rate (MRR), Surface Roughness (SR), and Kerf Width. Reducing surface roughness to a minimum improves the overall quality of the item, while increasing the material removal rate (MRR) reduces the cost of production. Superior surface treatments enhance the durability, fatigue resistance, and overall ability to withstand wear and tear of the component. The final dimensions of the component are determined by the kerf width, which refers to the width of the cut made during the manufacturing process.

Literature Survey

Machining Metal Matrix Composites (MMCs) varies greatly from machining ordinary metals because to the alternating matrix and reinforcement, requiring specialised equipment and processes. The user's text is "[6].". Investigated the cutting pressures and surface quality during the machining of Al/SiC composites at different cutting speeds. Researchers discovered that CBN tools had superior performance compared to CN tools, however they also suffered significant wear at a fast rate [7]. The optimisation of Wire Electrical Discharge Machining (WEDM) involves the analysis of the influence of cutting factors on material removal and kerf. The analysis of variance (ANOVA) revealed that both voltage and pulse length had a substantial impact on improving the performance of wire electrical discharge machining (WEDM)[8]. The empirical equations used to evaluate surface conditions in AISI D2 metal cutting demonstrated that increasing both the pulse current and duration results in the formation of thicker recast layers. Lowering the pulse energy results in a more precise finishing process, which minimises surface damage. Nevertheless, meticulous parameter selection is crucial for enhanced EDM outcomes[9]. When comparing the fatigue data of specimens machined at different speeds to the parent metal, it was found that there were small losses in fatigue life. However, the findings were similar across all speeds. The microhardness and roughness had minimal increases that were not influenced by variations in speed. EDM implemented a rigid restructuring layer, which impacted the level of hardness and roughness. The impact of changes in cutting speed on fatigue life and surface properties was found to be negligible, emphasising the need of maintaining stability in the machining process [10]. The L27 Taguchi approach was used to optimise the Wire Electrical Discharge Machining (WEDM) process for a two-dimensional steel tool. The analysis of variance (ANOVA) revealed that the variables of current, pulse duration, and flow speed had a significant positive impact on maximising material removal rate (MRR) and surface finish (SF). An ideal set of parameters was discovered using a genetic algorithm[11]. Optimised parameters for CNC WEDM of Inconel® 718 include pulse, delay, wire speed, and ignition, with a focus on maximising material removal rate (MRR) and achieving a desired surface roughness (Ra). The use of SKD 11 in the L27 orthogonal array resulted in improved outcomes, as shown by the ANOVA analysis which identified the best parameters. These findings exceeded the earlier results reported in references [12,13]. Enhancing the tensile strength and percentage enlargement of AA-1050/H22 by Friction Stir Welding (FSW) The study used grey relational analysis and the Taguchi technique to assess weld quality, highlighting the possibility for improvement via enhanced strength and lower elongation[14]. Optimising the settings of Wire Electrical Discharge Machining (WEDM) for the Incoloy® 800 super alloy to improve the pace at which material is removed, as well as to boost the corner radius and kerf breadth. The most substantial influence on performance was from the disruption of electrical energy, which accounted for 45.60% of the total effect. The chosen variable configurations resulted in a 7.74% increase in MRR, an 8.64% reduction in kerf width, and a 6.34% improvement in Ra, compared to the baseline parameters. This led to the attainment of the highest grey relational grade [15]. An investigation was conducted to analyse the behaviour of Wire Electrical Discharge Machining (WEDM) on D2 steel. The study aimed to evaluate the influence of six factors on Material Removal Rate (MRR), kerf width, and Surface Finish (SF). The ideal parameter combination for achieving the best results was determined using an L27 orthogonal array and grey relational analysis[16]. Enhanced the parameters of Wire Electrical Discharge Machining (WEDM) for the tungsten carbide-cobalt composite, resulting in increased Material Removal Rate (MRR) and Surface Roughness (SR). The taper angle and pulse on time have a significant effect on GRG, resulting in minimum error percentages of 2.2% and 0.35%, respectively[17]. Taguchi and Grey Relational Analysis An optimised laser micro-drilling technique was used to drill holes in zirconium oxide ceramic, resulting in a 16.29% reduction in hole taper and an 8.77% decrease in heat-affected zone (HAZ) width compared to previous methods [18]. Utilised L27 orthogonal array and mathematical modelling to enhance the efficiency of high-speed steel WEDM. The use of the NSGA-2 algorithm in Minitab led to enhanced outcomes, exhibiting a 61% deviance in confirmatory tests[19].

The present literature has only explored a limited number of studies on the machining of composites. Therefore, the goal of this study is to improve the WEDM process by using a new compound called Al-7075/SiC/Al_2O_3 and its many responses. In order to accomplish this, a little bit of grey relational analysis is used to effectively integrate this WEDM for optimal machining performance, including both surface roughness and kerf breadth. By using Minitab 15, an ANOVA analysis may be performed to determine the significant influence of each variable on several performance metrics. Furthermore, a substantiation inquiry should be conducted to evaluate the optimal combination of procedural parameters calculated using GRA and Taguchi.

2.1.The components and procedures

2.2.1 Methods for Making Hybrid Composites

To create a hybrid metal matrix composite (MMC), the current investigation used an electromagnetic stir casting technique with an inert gas as support. The mixed composition comprises nano- Al_2O_3 and SiC, with a weight percentage of 7.5% each, integrated into an Al7075 alloy matrix. The Al7075 alloy, classified under the 7xxx series, has substantial promise for utilisation in the aerospace and automotive sectors owing to its advantageous ratio of high stiffness to density as well as its resistance to corrosion. Al-7075 is mostly a zinc alloy, with zinc comprising the highest weight percentage (5.65 wt%) after the basic metal, aluminium. Zinc improves the alloy's capacity to be stretched without breaking, its ability to be shaped, its ability to be wetted by liquids, and its ability to resist corrosion. The alloy contains other elements such as magnesium, copper, chromium, and titanium, in addition to silicon and iron. Table 1 displays the mass percentage of the Al-7075 alloy. To make the hybrid composite, SiC/ Al_2O_3 nanoparticles were mixed into very small, fine grains that were between 20 and 40 µm in size. The range of numbers is from 1 to 5.

Table 1 Al7075 alloy chemical make-up.

Element	**Fe**	**Ti**	**Si**	**Mg**	**Cr**	**Cu**	**Zn**	**Al.**
Wt.%	0.48	0.19	0.36	2.51	0.27	1.78	5.65	remaining

2.2.2 Measurements and reactions in machining

To investigate the impact on surface roughness (SR) and kerf width of a hybrid composite, the WEDM process was performed using four input process parameters: pulse on time, pulse off time, pulse current, and wire drum speed. The values for procedural variables will be chosen according to early tests. The particular levels and related designations of the different parameters may be seen in Table 2.

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

Syb.	**Procedural variables**	**Level-1**	**Level-2**	**Level-3**
A	TON (µs)	4	8	12
B	TOFF (µs)	2	4	6
C	Current (A)	45	65	85
D	Speed(m/min)	4	6	8

2.2.3 Taguchi Experimental Design

The Taguchi philosophy has shown to be a very effective way in promoting desired production practises. The method employs research utilising orthogonal arrays (OA) to reduce variation by determining the ideal settings for controlling process variables. The four control parameters used were the on-time (A), off-time (B), current (C), and rotating velocity (D) of the wire drum. An L27 orthogonal array was used to examine each parameter at three distinct levels. The investigative design, as shown in Table 3, depicts the precise values of each parameter for the performed tests. It is crucial to emphasise that this table lacks any actual observed data and instead functions as a blueprint for the experiment's structure. The data was analysed using Minitab 19 software, which enabled the examination of the findings and offered insights into the outcomes for the various parameter levels in the organization's presentation. This research aims to optimise the production process and enhance the quality of the final product by applying the Taguchi technique and software analytic tools.

Table 3 Optimization Table

Ex. 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

WEDM Set-up for Experimental Process

Wire Electrical Discharge Machining (WEDM) is a material removal method that involves controlled sparking between a wire electrode and a workpiece, resulting in efficient erosion of the workpiece. It is a non-contact process. WEDM is useful for cutting hard materials because the dielectric fluid constantly removes eroded particles. The wire is meticulously regulated, and a guide ensures its stability both above and below the workpiece. Every experiment employs a new wire section. The precision of the part is determined by the breadth of the resultant kerf. The process parameters were optimised using a Taguchi L27 OA experimental design, which was transformed into signal-to-noise ratios. The objective was to decrease variance and improve performance.

Fig.1. WEDM Photographic view.

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

Equation 1 is used to determine the signal-to-noise ratio (S/N) for the parameters of SR and kerf width, as shown in Table 4. The i-th experiment result and n denote the number of repetitions for that experiment. The signal-to-noise (S/N) ratio measurements are then used to compute grey relational coefficients (GRCs). The classical Taguchi approach is efficient in optimising a single objective function but lacks effectiveness in addressing multi-objective optimisation situations. Deng's grey system theory, designed to tackle challenges arising from restricted, insufficient, and ambiguous data, has been confirmed as an effective methodology. This work uses GRA (Grey Relational Analysis) to maximise the machining properties of surface roughness (SR) and kerf width for a recently created hybrid composite via the application of WEDM (Wire Electrical Discharge Machining). The research showcases that GRA is an exceptional technique for enhancing different response attributes in a wide range of fields.

Theory of Grey Relational Analysis

This approach is designed to help identify and prioritise important aspects inside a system. Its main advantage is in assessing the autonomy of variables. This study covers a range of scenarios, from circumstances with no accessible information, resulting in no solution, to instances with complete knowledge, leading to a single, conclusive conclusion. Grey system analysis, when used in scenarios characterised by insufficient data, provides a variety of viable options. Instead of striving to uncover the utmost optimal outcome, GRA provides approaches for discerning adequate outputs that are appropriate for prevailing global issues GRG(average) = 0.5816[22,23].

Data normalization

Grey relational analysis (GRA) involves elements that often exhibit distinct dimensions and substantial variations in scale. In order to tackle this issue, the experimental data is first normalised within a range of 0-1, leading to the emergence of grey relations (GRG). Moreover, it measures the extent of its fluctuation between its experimental and ideal levels. The optimisation criteria in GRA are determined by the significance of quality attributes and may be categorised into three groups:

'larger-the-better', 'smaller-the-superior', and 'nominal-is-best'. In this research, the focus was on producing low surface roughness and improved machining performance.

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

Ex.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

The criteria of "smaller is best" was used throughout the whole inquiry, with a specific emphasis on the kerf width. Additionally, the kerf width and surface roughness were taken into account. Table 5 presents the computed normalised SR and kerf width values [23,24] using equation (2).

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

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

$$\varepsilon_{ij} = \frac{\Delta_{min} + \varepsilon\Delta_{max}}{\Delta_{ij} + \varepsilon\Delta_{max}} V \qquad (3)$$

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_{max} 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 Grey Relational Coefficients (GRCs) with kerf width also surface roughness are presented into table-6. No units are mandatory for the data in this table, which solely current this computed ranges for the S/N ratio, the normalized ranges, also grey relational coefficients for surface roughness 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.

Table 5. S/N ratios were normalised, 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

$$\gamma_i = \frac{1}{m}\sum w_j \, \varepsilon_{ij} \qquad (4)$$

Following its computation of its GRC, the Overall grey relationship Grade (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 (gi) in favor of its i^{th} trial preserve exist premeditated as a described in regenerate response [21].

In the given context, m represents this excellence 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 grey relationship grade (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 surface roughness. 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 maximise global GRG. Results from the GRG are shown in Table 6.

Table.6. S/N ratio (GRG) analysis of variance.

Sourse	**DF**	**Seq. SS**	**Adj. SS**	**Adj. MS**	**F**	***p***	**% Con.**
TON	2	75.434	75.4344	37.7172	334.4	0	50.02
TOFF	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
TON 3 TOFF	4	0.58	0.5796	0.1449	1.28	0.373	0.38
TON 3 A	4	2.004	2.004	0.501	4.44	0.052	1.33
TON 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					

Conclusions while Analysis

Response-based ANOVA

The research used ANOVA analysis in Minitab 19 software to examine the GRG values and determine the impact of four primary process factors on the cutting of the hybrid composite. The findings indicated that the pulse on time, pulse off time, pulse current, and wire drum speed all had a noteworthy impact on the machining process. The pulse on time had the greatest impact, accounting for the largest proportion (50.02%) of both SR and kerf. The remaining settings were pulse off time (4.58%), pulse current (39.50%), and wire drum speed (2.75%). The mean values of GRG are shown in Table 7, presenting the average GRG value for each combination of factors at various levels. The variables of pulse on time, discharge current, pulse off time, and wire drum speed were all ranked the highest. The graph depicting the pulse-off time has a favorable impact, suggesting that augmenting its magnitude results in a reduction in both SR and kerf breadth. The findings indicate that increasing the pulse on time, pulse current, and wire drum speed have a detrimental impact on GRG. This implies that both SR and kerf width will rise when these parameters are raised.

Process Variables and Their Impact

The ANOVA study demonstrates that the four progression factors, namely wire drum speed, pulse on time, pulse off time, pulse current, and pulse length, all have significant impacts. During the process of wire electrical discharge machining, material is removed by the erosion caused by sparks. Increased pulse current values lead to a longer duration of sparkling with a higher density, resulting in a larger amount of energy being released onto the surface of the material. This phenomenon causes the specimen to melt more, according to one study, resulting in bigger and more widespread effects, eventually leading to an increase in SR.

However, the use of wire in barrel velocity presents a negative outcome that is contingent upon the overall grey relational grade (GRG). This suggests that both surface roughness and kerf breadth contribute to an increase in wire velocity. A higher velocity of the wire promotes enhanced removal of fragments due to the presence of the GAP, hence leading to an increase in the breadth of the kerf. Moreover, it resulted in an enhanced velocity of wire fragmentation, leading to the formation of more extensive craters and vacant areas, thereby intensifying the overall unevenness of the surface.

The performance of the GRG is enhanced with an increase in the pulse-off time, indicating a reduced sensitivity of the GRG to variations in the pulse rate, SR, and kerf width. It has been shown that an increase in the duration of the pulse-OFF time leads to a decrease in the number of ejections that occur within a given time interval. Consequently, a decrease in spark-induced craters and molten droplet formation occurs on the surface, resulting in a reduction in both kerf width and surface roughness.

The best possible feature estimations

The goal is to determine which values of design parameters will provide the most significant improvements in performance that can be quantified. The estimated ideal values of the overall grey relationship grade (GRG) are based on the specified levels of relevant factors. Based on the response graph (Figure 2), the most advantageous intensities corresponding to the significant progression limitations were determined as A1, B1, C1, and D1. More precisely, these values correspond to a pulse duration of 4 milliseconds, pulse interval of 6 milliseconds, current of 2 Amperes, and drum speed of 4 metres per minute. In order to determine the implications for the response attribute (mGRG), it is necessary to use the right computational approaches[20].

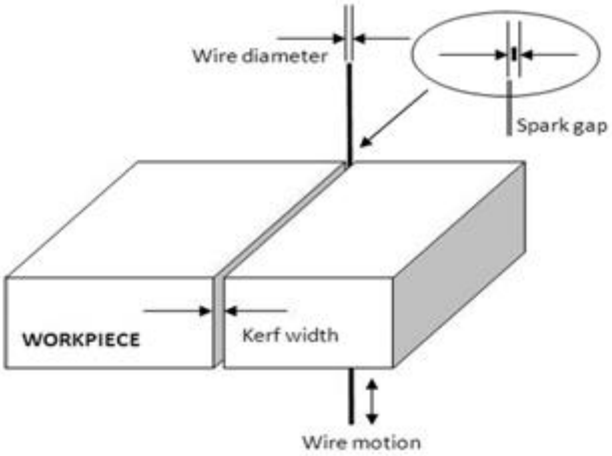

Fig.2. WEDM kerf width specifications.

$$\mu_{GRG} = \mathrm{GRG} + (\mathrm{A}_1 - \mathrm{GRG}) + (\mathrm{B}_3 - \mathrm{GRG} + (\mathrm{C}_1 - \mathrm{GRG}) + (\mathrm{D}_1 - \mathrm{GRG})$$

Where $GRG\ is\ the\ overall\ means\ of\ GRG$ (0.5816);

$$\mu_{\mathrm{GRG}} = 0.4403 + 0.5434 + 0.4564 + 0.5459 - 3(0.5816) = 0.2401(Table8).$$

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

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

Table 7. The GRG signifies response table.

Level	TON	TOFF	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

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

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

Consequently, $\eta_{eff} = 27/(1 + 8) = 3$. There will be one confirmed R experimentation specimen. The confidence interval 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, mentioned

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

Verification Procedure

A confirmation test was conducted to ensure the reliability of the optimal Taguchi OA machining combination of design parameters. Three further experiments have been conducted by finely tweaking the process factors. Table 8 presents the average GRG mean value. This displays the outcomes of a comparison between the projected GRG, determined using equation (4), and the observed GRG, obtained from the optimal permutation of machining variables in an experiment. The anticipated range of 0.2401 is in great agreement with the observed result of 0.33655. Based on the initial conditions and the optimal setting of the variable, there is a 0.09601 increase in GRG. It is crucial to acknowledge that this procedure enhances both surface roughness (SR) and kerf width, which are two critical performance factors in the Wire Electrical Discharge Machining (WEDM) process.

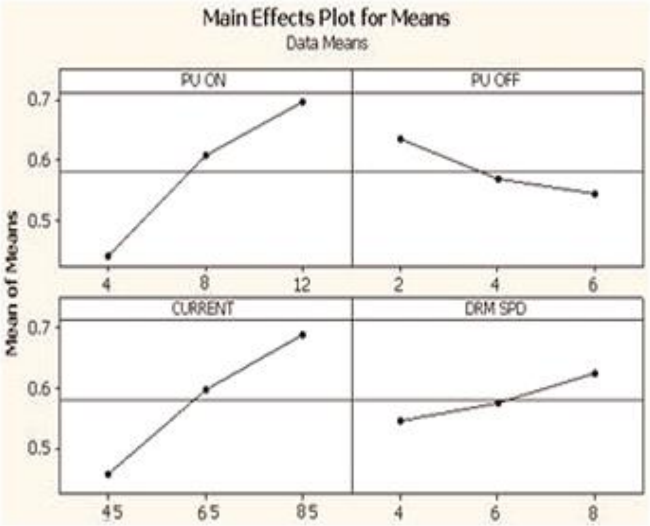

Fig. 3. Ways in which Process Variables Affect GRG.

Table 8. Reaction when operating conditions are ideal.

Ex. number	Ra (µm)	Kerf width (mm)	Ex. 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

CONCLUSIONS

In the fabrication of nano composites metal matrix composites (MMC) using Wire Electrical Discharge Machining (WEDM), various performance measures, such as SR and kerf width, were fine-tuned through a Taguchi-based Grey Relational Analysis (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 amperes, along with a wire drum speed of 4 meters per minute, 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 percent of the total GRG, followed in descending order by 39.50 % of pulse current, 4.58% of pulse off time and 2.75% wire drum speed.
- Fourth, when the process parameters were set to their sweet spot (0.0087 mGRG 0.4720), the confirmatory test indicated that the total GRG improved.

REFERENCES:

1. Amirkhanlou S, Niroumand B. 2010. Synthesis and characterization of 356-SiCp composites by stir casting and compocasting methods. Trans Nonferrous Met Soc China 20: s788-s793. https://doi.org/10.1016/ S1003-6326(10)60582-1.
2. Rao DS, Ramanaiah N. 2017. Evaluation of wear and corrosion properties of AA6061/TiB2 composites produced by FSP technique. JMin Mater Charac Eng 5(6): 353-361. https://doi.org/10.4236/jmmce.2017.56029.
3. Kannan C, Ramanujam R, Balan ASS. 2018. Machinability studies on Al 7075/BN/Al2O3 squeeze cast hybrid nanocomposite under different machining environments. Mater Manuf Process 33(5): 587-595. https:// doi.org/10.1080/10426914.2017.1401718.
4. Arumugam K, Sathiyamoorthy V, Kingston JJ, Akiraman K, Senthilkumar V, et al. 2018. Studies on wear behaviour of aluminium 6061alloy reinforced with B4C & mica particulates hybrid metal matrix composite. Int J Eng Technol 7: 349-352.
5. Chelladurai SJS, Murugesan T, Rajamani T, Anand S, Asok SJP, et al. 2019. Investigation on mechanical properties and tribological behaviour of stir cast LM13 aluminium alloy based particulate hybrid composites. Materialwissenschaft und Werkstofftechnik 50(7): 864-874. https://doi. org/10.1002/mawe.201800116.
6. Hung NP, Loh NN and Venkatesh VC. Machining of metal matrix composites. In: Jahanmir S, Ramulu M and Koshy P (eds) Machining of ceramics and composites. New York: Marcel Dekker, 1999, pp.295–298.
7. Looney LA, Monaghan JM, Really PO, et al. The turning of an Al/SiC metal-matrix composite. J Mater Process Tech 1992; 33: 453–468.
8. Tosun N, Cogun C and Tosun G. A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method. J Mater Process Tech 2004; 152: 316–322.
9. Guu YH and Hocheng H. Improvement of fatigue life of electrical discharge machined AISI D2 tool steel by TiN coating. Mater Sci Eng A: Struct 2001; 318: 155–162.
10. Jeelani S and Collins MR. Effect of electric discharge machining on the fatigue life of Inconel 718. Int J Fatigue 1988; 10: 121–125.
11. Mahapatra SS and Patnaik A. Parametric optimization of wire electrical discharge machining (WEDM) process using Taguchi method. J Braz Soc Mech Sci 2006; XXVIII(4): 422–429.
12. Ramakrishnan R and Karunamoorthy L. Modeling and multi-response optimization of Inconel 718 on machining of CNC WEDM process. J Mater Process Tech 2008; 207: 343–349.
13. Tzeng C-J, Lin Y-H, Yang Y-K, et al. Optimization of turning operations with multiple performance characteristics using the Taguchi method and grey relational analysis. J Mater Process Tech 2009; 209: 2753–2759.
14. Aydin H, Bayram A, Esme U, et al. Application of grey relation analysis and Taguchi method for the parametric optimization of friction stir welding process. Mater Tech. nol 2010; 44(4): 205–211.

15. Kumar VM, Babu SA, Venkatasamy R, et al. Optimization of the WEDM parameters on machining Incoloy800 super alloy with multiple quality characteristics. Int J Eng Sci Tech 2010; 2(6): 1538–1547.
16. Datta S and Mahapatra SS. Modeling, simulation and parametric optimization of wire EDM process using response surface methodology coupled with grey-Taguchi technique. Int J Eng Sci Tech 2010; 2(5): 162–183.
17. Jangra K, Grover S and Aggarwal A. Simultaneous optimization of material removal rate and surface roughness for WEDM of WC-Co composite using grey relational analysis along with Taguchi method. Int J Ind Eng Com- put 2011; 2: 479–490.
18. Ganguly D, Acherjee B, Kuar AS, et al. Hole characteristics optimization in Nd:YAG laser micro-drilling of zirconium oxide by grey relation analysis. Int J Adv Manuf Tech 2012; 61: 1255–1262.
19. Kumar K and Agarwal S. Multi-objective parametric optimization on machining with wire electric discharge machining. Int J Adv Manuf Tech 2012; 62: 617–633.
20. Ross PJ. Taguchi techniques for quality engineering. New York: McGraw-Hill, 1996.
21. Phadke SM. Quality engineering using robust design. Eng- lewood Cliffs, NJ: Prentice Hall, 1989.
22. Deng J. Control problems of grey system. Syst Control Lett 1982; 5: 288–294.
23. Kung CY and Wen KL. Applying grey relational analysis and grey decision-making to evaluate the relationship between company attributes and its financial performance: a case study of venture capital enterprises in Tai- wan. Decis Support Syst 2007; 43: 842–852.
24. Chiang Y-M and Hsieh H-H. The use of the Taguchi method with grey relational analysis to optimize the thin- film sputtering process with multiple quality characteristic in color filter manufacturing. Computer Ind Eng 2009; 56: 648–661.