Optimization of WEDM process parameters using standard deviation and MOORA method

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Abstract. In this present experimental work, the effect and advancement of machining control parameters over kerf and surface quality in wire cut electrical discharge machining operations were analyzed. The hybrid metal reinforced composite was manufactured by process named as stir casting utilizing particulates of graphite & Silicon carbide each in Al6061 combination. The analyses were outlined with Taguchi L27 design matrix. WEDM parameters resemble pulse Pulse on time, current, Pulse off time, gap set voltage, wire tension &feed are considered. The impact of the machining parameters on the kerf width (KW) and surface roughness (SR) is dictated by utilizing examination of fluctuation. MOORA in blend with standard deviation (SDV) was utilized for the enhancement procedure. SDV was utilized to decide the weights that were utilized for normalizing the reactions acquired from the mechanical test outcomes. The parameters corresponding to experiment run number 7 are Pulse on time 108 units (Level 1), Pulse off time 50 units (Level 2), peak current 230 units (Level 3), gap set voltage 50 units (Level 3), wire feed 5 units (Level 3) and wire tension 12 units (Level 3) are the best combination to achieve better surface roughness & kerf width.

Keywords: MOORA, WEDM, SDV, Taguchi method, Hybrid composite, Surface roughness.

1. Introduction

Composite materials had grown rapidly over recent few decades to encompass metal matrix composites, ceramic composites and polymer matrix composites [1-3]. Metal grid composites have pulled in significant consideration because of their capacity to give an extensive variety of microstructures & properties [4]. The underlying philosophy of metal composite design is that an continuous metallic matrix, with its ductility and formability, is combined with the stiffness and load withstanding property of a ceramic or refractory reinforcements to produce material with superior properties [5]. Metal Composites possess good properties over metals alloys with high specific strengths, better properties of metal composite at elevated high temperatures, minimum thermal expansion, very good wear resistance & high structural strength. These properties are predominantly suited to application in an automotive, aerospace and electronic sectors [6-7].

Fabrication, shaping and joining with good surface quality can be done easily [8-9]. The reinforced particles in composites provide strength to the composite and also serve the other additional purposes like heat resistance, thermal conduction, resistance to corrosion & rigidity. The reinforcement particles always possess much stronger and much stiffer properties than the base metals. fibers and ceramics particulates are generally considered as reinforcement particles. The approach used for fabrication of the MMC may be different route[10-11]. The techniques can be labeled into 5 extraordinary categories: (i) Liquid state strategies (ii) solid phase techniques (iii) two segment methods (iv) Deposition techniques (v) In situ methods. In stir cast processing, the reinforced particulates are very well blended right into a nicely molten metallic matrix.

Manufacturing sector is growing rapidly by accommodating technology modernization. The mechanism for machining hard reinforced materials, intricate shapes and contours which are very difficult to cut by conventional methods which created many unconventional methods[12]. CNC wire cut machine was developed in the year 1969. WEDM which involves moving very thin wire electrode continuously. Wire electrode materials such as brass and zinc coated brass wire of diameter ranges from 0.05-0.35 are widely applied in industry. The gap between work and wire electrode is generally ranges from 0.025mm to 0.050mm and is continuously maintained by a computer controlled coordinating system. To achieve better surface quality on the tool as well as in the component, optimum process parameter setting is a very important factor. Machining control parameters are optimized by using different methods for the improvement of the quality. Taguchi method which is widely applied mainly experimental design in manufacturing application. It allows the optimization of parameters in machining by turning, milling, Electro Discharge Machining, wire cut EDM, welding, grinding etc. The optimization is achieved with lesser number of experiments by this overall cost and time is saved.

2. Materials & Method

2.1. Preparation of Hybrid Composite

In this investigation, the hybrid MMC has been created by stir casting process. The crossover composite comprises of 10 wt% SiC and 5 wt% Graphite particulates in metal lattice Al6061 compound. The Al combination of 6xxx arrangement is having the capacity to be used in aviation and car ventures in light of its high quality to-weight proportion and great protection from consumption. Composition of Al6061 composite is appeared in Table 1. Fortifications SiC and graphite in particulate frame are utilized to create the hybrid composite. The easiest and the most savvy technique for fluid state creation is stir casting [19]. Figure1 demonstrates the stircast equipment utilized for manufacture of hybrid composite.

Table 1. Composition of Al6061 alloy

Mg	Si	Fe	Cu	Cr	Al
1.1	0.64	0.48	0.33	0.04	Remaining

Figure 1. Stir casting set up

2.2. Machining Parameters and Response

Machining process parameters in WEDM, Pulse on time, Pulse off time, current, gap voltage, wire speed and wire tension were considered as input parameters. Responses SR and kerf width were measured after machining for investigation. The scopes of these procedure parameters were chosen on the premise of the pilot tests. The levels of different parameters and its assignments are exhibited in Table 2.

Table 2. Three levels of process parameters

Process parameter	Level 1	Level 2	Level 3
Pulse on time (A)	108	117	126
Pulse off time (B)	40	50	60
Pulse current (C)	90	160	230
Gap voltage (D)	10	30	50
Wire speed (E)	3	4	5
Wire tension (F)	4	8	12

2.3. Taguchi's Experimental Design

Taguchi strategy is a proficient apparatus for the outline of a great assembling framework. It also effectively solves some complex problems in manufacturing (Roy 1990).It is a strategy in view of OA tests, which give much decreased change to the try different things with ideal setting of process control parameters. The six control parameters, that is, Pulse on time (A), Pulse off time (B), current (C),Gap voltage (D), wire drum speed (E) and wire tension(F) at three levels were chosen in this examination. The tests were finished by Table 3. This table just speaks to specific level of the different elements of the procedure at which the examinations would be directed. Kerf width ought to be as least as conceivable in the WEDM procedure. Kerf width is an imperative component of the laser cutting procedure that gives the benefit of this innovation contrasted with different strategies for form cutting.

2.4. Experimental Set Up

Analyses were led on Electronica Sprint cut CNC wire cut electrical discharge machine to think about the surface quality and kerf width influenced by the machining parameters at various levels. WEDM is a start disintegration process. The flashes are produced between the work piece and the wire terminal. The dielectric liquid is ceaselessly encouraged into the machining zone with required weight. The material is getting expelled by a progression of discrete sparkles occurring at the zone to be machined through electro-warm system. Test set up of the wire electrical release machine is appeared in Figure 2.

Amid machining process little hole kept up between the work and wire material. The wire is held by a stick direct at the upper and lower parts of the work piece. The work example measure utilized as a part of this examination is 95 x 80 x 8 mm rectangular plate. Zinc covered metal cathode wire of 0.25 mm width was utilized as a part of this investigation. Deionized water was utilized dielectric liquid at room temperature. In the wake of machining, the examples were cleaned with acid after machining. The kerf was measured utilizing profile projector measuring framework. The kerf esteems were measured at six spots spread over the full length of cut. The kerf esteems utilized a part of this examination are the numerical normal of three estimations produced using the example in each cut.

Table 3. Taguchi L27 Orthogonal array

Experimental run	Control factors and levels					
	A	**B**	**C**	**D**	**E**	**F**
1	1	1	1	1	1	1
2	1	1	1	1	2	2
3	1	1	1	1	3	3
4	1	2	2	2	1	1
5	1	2	2	2	2	2
6	1	2	2	2	3	3
7	1	3	3	3	1	1
8	1	3	3	3	2	2
9	1	3	3	3	3	3
10	2	1	2	3	1	2
11	2	1	2	3	2	3
12	2	1	2	3	3	1
13	2	2	3	1	1	2
14	2	2	3	1	2	3
15	2	2	3	1	3	1
16	2	3	1	2	1	2
17	2	3	1	2	2	3
18	2	3	1	2	3	1
19	3	1	3	2	1	3
20	3	1	3	2	2	1
21	3	1	3	2	3	2
22	3	2	1	3	1	3
23	3	2	1	3	2	1
24	3	2	1	3	3	2
25	3	3	2	1	1	3
26	3	3	2	1	2	1
27	3	3	2	1	3	2

2.5. Weight Criteria Calculation using SDV Concept

Standard deviation is connected to this examination for unprejudiced assignment of weights. The significance of weights in illuminating MCDM issues cannot be over stressed. To decide the standard deviation, the range institutionalization was finished utilizing Equation (1) to change diverse scales and units among different criteria into regular quantifiable units so as to figure their weights.

$$X_{ij}^{1} = \frac{X_{ij} - \min\limits_{1<j<n} X_{ij}}{\max\limits_{1<j<n} X_{ij} - \min\limits_{1<j<n} X_{ij}} \quad (1)$$

where max X_{ij}, min $X_{ij}$are the maxima and minimum values of the criterion (*j*) respectively. The Standard deviation (*SDV*) is calculated for every criterion using Equation (2)

$$\mathrm{SDV_j} = \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(X_{ij} - \overline{X_j^i}\right)^2} \quad (2)$$

where *Xj′* is the mean of the values of the j^{th} criterion after normalization and j = 1,2…*n* . After calculating for *SDV* for all criteria, the next step is to determine the weights, W_j of all the criteria considered.

$$w_j = \frac{\mathrm{SDV_J}}{\sum_{j=1}^{n}\mathrm{SDV_J}} \quad (3)$$

where$j$= 1,2,…*n* .

Figure 2. WEDM experimental set up (Electronica Sprint cut)

2.6 MOORA Methodology

MOORA is one of the MCDM techniques used to choose best options among a given number of choices [13-16]. This issue includes different goals or criteria and furthermore struggle with each other. They are advantageous (amplification) furthermore, non-valuable (minimization) targets. MOORA technique considers both advantageous and non gainful targets for illuminating and positioning ideal options all the while [17].

Step 1 *Problem description and establishment of objectives.* In the present work, surface roughness and kerf width are selected as non beneficial attribute.

Step 2 *Construction of decision matrix.* The decision matrix is used to represent the experimental results with respect to various output parameters.

The decision matrix D_{mxn} is represented as

$$D_{mxn} = \begin{bmatrix} X_{11} & X_{12} & \dots & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & \dots & X_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ X_{m1} & X_{m2} & \dots & \dots & X_{mn} \end{bmatrix} \quad (4)$$

where Xi j indicates the experimental result of ith alternative on jth attribute, m indicates the number of experiments, and n refers to the number of output parameters. The decision matrix D27_3 is given in Table 4.

Step 3 Normalization of input data.

Generally, normalization is needed, as the variety and unit of output value may be different from others. The meaning of normalization is converting the original score into a comparable score. The output values presented in the decision matrix are normalized with the help of equation (3). The value of normalized decision matrix N27_3 is presented in Table 4. The expression used to determine the normalized decision matrix (Ni j) is given by

$$N_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij^2}}} \quad \text{for} \quad i = 1,m: j = 1,...,n, \quad (5)$$

where xi j and Ni j are original and normalized score of decision matrix, respectively.

Step 4 Determination of solution.

The standardized scores are included the instance of valuable or amplification objective and subtracted on account of non-helpful or minimization objective. At that point the multi-target streamlining moves toward becoming

where g speaks to the quantity of properties for maximization,(n-g) speaks to the quantity of traits for minimization, and Yi is the standardized evaluation estimation of ith elective regarding all characteristics. Table 4 demonstrates the standardized appraisal estimation of chose yield parameters

$$Y_i = \sum_{j=1}^{g} N_{ij} - \sum_{j=g+1}^{n} N_{ij} \quad (6)$$

Step 5 The attributes being considered are more important than others in practical situations.

To identify the important attribute, it must be multiplied with its relative importance. If relative importance is considered, then the equation is modified as

$$Y_i = \sum_{j=1}^{g} W_j N_{ij} - \sum_{j=g+1}^{n} W_j N_{ij} \ (j = 1,2,...,n), \quad (7)$$

where Wj represents weight of j_{th} attribute and it is calculated by entropy measurement method.

3. Result and Discussion

3.1 Weight Allocation

In this study, the weight allocation for each of the output parameters, that is surface roughness and kerf width. The range of standardized decision matrix is determined using equation (1). Table 4 shows the summary of the range of standardized decision matrix. The standard deviation and weights are calculated using the formula (2) & (3). The calculated weight values are 0.575 for surface roughness and 0.425 for kerf width.

3.2 Result Analysis

Table 5 shows the square of Xi, normalized matrix for Xi and rank calculated by MOORA method. The normalized SR & KW are multiplied with their corresponding weights. These values are listed in the table 6. The parameters, higher the better 9 (maximum) and smaller the better (minimum) respectively added for rank calculation. The surface roughness observed in the experiment is in the range of from 2.252 to 4.256. Similarly, the kerf width observed in the experiment is in the range of from 292 to 327. From these observations, experiment number 7 has the best rank. The parameters corresponding to experiment run number 7 are pulse on time 108 units (Level1), pulse off time 60 units(Level3), peak current 230 units (Level3), gap set voltage 60 units (Level3), wire feed 3 units (Level1) and wire tension 4 units (Level1).

Table 4. Kerf width& Surface roughness

Ex. No.	Pulse on Time	Pulse off Time	Peak Current	Gap set voltage	Wire Feed	Wire Tension	KW	SR
1	108	40	90	10	3	4	0.300	3.56
2	108	40	90	10	4	8	0.300	3.32
3	108	40	90	10	5	12	0.295	3.15
4	108	50	160	30	3	4	0.304	2.59
5	108	50	160	30	4	8	0.312	2.59
6	108	50	160	30	5	12	0.302	2.57
7	108	60	230	50	3	4	0.313	2.36
8	108	60	230	50	4	8	0.316	2.78
9	108	60	230	50	5	12	0.305	2.01
10	117	40	160	50	3	8	0.316	3.43
11	117	40	160	50	4	12	0.310	3.04
12	117	40	160	50	5	4	0.313	3.48
13	117	50	230	10	3	8	0.314	3.22
14	117	50	230	10	4	12	0.312	2.78
15	117	50	230	10	5	4	0.306	3.45
16	117	60	90	30	3	8	0.306	2.55
17	117	60	90	30	4	12	0.304	2.6
18	117	60	90	30	5	4	0.308	2.21
19	126	40	230	30	3	12	0.312	2.28
20	126	40	230	30	4	4	0.320	2.87
21	126	40	230	30	5	8	0.310	3.05
22	126	50	90	50	3	12	0.313	3.01
23	126	50	90	50	4	4	0.322	2.75
24	126	50	90	50	5	8	0.314	3.18
25	126	60	160	10	3	12	0.312	4.23
26	126	60	160	10	4	4	0.314	4.17
27	126	60	160	10	5	8	0.317	3.8

Table 5. Standardized Surface roughness & Kerf width

Ex.No.	Pulse on Time	Pulse off Time	Peak Current	Gap set voltage	Wire Feed	Wire Tension	SR	kerf width
1	108	40	90	10	3	4	0.04896	0.28571
2	108	40	90	10	4	8	0.17281	0.22857
3	108	40	90	10	5	12	0.38306	0.00000
4	108	50	160	30	3	4	0.02016	0.34286
5	108	50	160	30	4	8	0.06048	0.22857
6	108	50	160	30	5	12	0.26786	0.25714
7	108	60	230	50	3	4	0.00000	0.28571
8	108	60	230	50	4	8	0.25634	0.31429
9	108	60	230	50	5	12	0.34274	0.14286
10	117	40	160	50	3	8	0.63652	0.31429
11	117	40	160	50	4	12	0.55300	0.48571
12	117	40	160	50	5	4	0.55012	0.62857
13	117	50	230	10	3	8	0.60484	0.71429
14	117	50	230	10	4	12	0.61636	0.60000
15	117	50	230	10	5	4	0.83813	0.85714
16	117	60	90	30	3	8	0.10369	0.71429
17	117	60	90	30	4	12	0.34850	0.60000
18	117	60	90	30	5	4	0.02880	1.00000
19	126	40	230	30	3	12	0.57316	0.28571
20	126	40	230	30	4	4	0.69412	0.71429
21	126	40	230	30	5	8	0.74309	0.28571
22	126	50	90	50	3	12	0.66244	0.51429
23	126	50	90	50	4	4	0.46083	0.91429
24	126	50	90	50	5	8	0.54724	0.85714
25	126	60	160	10	3	12	0.92454	0.68571
26	126	60	160	10	4	4	1.00000	0.94286
27	126	60	160	10	5	8	0.91590	0.74286

Table. 6 Normalized decision matrix and MOORA rank

Ex. No.	Square of Xi		Normalized Xi		Wj*Xi		∑max -∑min	Rank
	SR	KW	SR	KW	SR	KW		
1	0.09	12.6736	0.186203	0.224511	0.12910	0.07914	-0.2082	23
2	0.09	11.0224	0.186203	0.209375	0.12040	0.07914	-0.1995	19
3	0.087025	9.9225	0.1831	0.198654	0.11423	0.07782	-0.1921	16
4	0.092416	6.7081	0.188686	0.163338	0.09392	0.08019	-0.1741	7
5	0.097344	6.7081	0.193651	0.163338	0.09392	0.08230	-0.1762	9
6	0.091204	6.6049	0.187445	0.162077	0.09320	0.07967	-0.1729	5
7	0.097969	5.5696	0.194272	0.148833	0.08558	0.08257	-0.1682	4
8	0.099856	7.7284	0.196134	0.17532	0.10081	0.08336	-0.1842	11
9	0.093025	4.0401	0.189307	0.12676	0.07289	0.08046	-0.1533	1
10	0.099856	11.7649	0.196134	0.216312	0.12439	0.08336	-0.2077	22
11	0.0961	9.2416	0.19241	0.191717	0.11024	0.08178	-0.1920	15
12	0.097969	12.1104	0.194272	0.219466	0.12620	0.08257	-0.2088	24
13	0.098596	10.3684	0.194893	0.203069	0.11677	0.08283	-0.1996	20
14	0.097344	7.7284	0.193651	0.17532	0.10081	0.08230	-0.1831	10
15	0.093636	11.9025	0.189927	0.217574	0.12511	0.08072	-0.2058	21
16	0.093636	6.5025	0.189927	0.160815	0.09247	0.08072	-0.1732	6
17	0.092416	6.76	0.188686	0.163969	0.09429	0.08019	-0.1745	8
18	0.094864	4.8841	0.191169	0.139373	0.08014	0.08125	-0.1614	2
19	0.097344	5.1984	0.193651	0.143788	0.08268	0.08230	-0.1650	3
20	0.1024	8.2369	0.198617	0.180996	0.10408	0.08441	-0.1885	13
21	0.0961	9.3025	0.19241	0.192348	0.11060	0.08178	-0.1924	17
22	0.097969	9.0601	0.194272	0.189825	0.10915	0.08257	-0.1917	14
23	0.103684	7.5625	0.199858	0.173428	0.09973	0.08494	-0.1847	12
24	0.098596	10.1124	0.194893	0.200546	0.11532	0.08283	-0.1982	18
25	0.097344	17.8929	0.193651	0.266764	0.15340	0.08230	-0.2357	27
26	0.098596	17.3889	0.194893	0.26298	0.15122	0.08283	-0.2341	26
27	0.100489	14.44	0.196755	0.239646	0.13780	0.08362	-0.2214	25

4. Conclusion

In this experimental study, the combined MOORA and SDV method is applied for the estimation of optimum machining parameters to minimize surface roughness and kerf width. The conclusions drawn from this study are as follows:

1. Combined MOORA and SDV method is employed to select the optimum machining parameters in WEDM machining of Al6061/SiC/graphite with brass wire electrode.

2. From these observations, experiment number 9 has the best rank. The parameters corresponding to experiment run number 9 are P_{on} time 108 units (Level1), P_{off} time 50

units (Level 2), peak current 230 units (Level3), gap set voltage 50 units (Level3), W feed 5 units (Level3) and W tension 12 units (Level3).

3. Standard Deviation (SDV) method is also employed to find the relative importance of surface roughness 7 kerf width. The weight ratios are found to be 0.575 for surface roughness and 0.425 for kerf width.

4. The optimum results are adopted in validation study and the results based on WEDM process responses can be effectively improved.

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