Multi objective optimization of process parameters in WEDM of aluminum hybrid composite using taguchi and topsis techniques

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Abstract. Multi-Criteria Decision Making (MCDM) strategies have gotten much consideration from scientists and professionals in assessing, evaluating and positioning choices transverse over assorted technologies. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) continues on working attractively crosswise over various application territories. This paper proposes the TOPSIS-based Taguchi enhancement way to deal with decide the ideal WEDM process parameter for machining of aluminum hybrid composite using brass wire. The hybrid metal matrix composite was manufactured by stir casting process utilizing particulates SiC and graphite each in Al6061 combination. This experiment was outlined with L27 orthogonal cluster. The test input parameters are Pulse on time, Pulse off time, current, gap voltage, wire speed & wire tension. The impact of the machining parameters on the kerf width (KW) and surface roughness (SR) is expressed by utilizing examination of variation. The parameters corresponding to experiment run number 9 are Pulse on time 108 units (Level 1), Pulse off time 60 units (Level 3), peak current 230 units (Level 3), gap set voltage 60 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: TOPSIS, WEDM, Taguchi method, Hybrid composite, Surface roughness & Kerf width.

1. Introduction

Composite materials had grown rapidly over recent few decades to encompass metal matrix composites, ceramic composites and polymer matrix composites [1-2]. Metal grid composites have pulled in significant consideration because of their capacity to give an extensive variety of microstructures & properties. 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 [3]. 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 [4-5].

Fabrication, shaping and joining with good surface quality can be done easily [6-7]. 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. 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 [8]. CNC wire cut machine was developed in the year 1969. WEDM which involves moving very thin wire electrode continuously. Wire electrode materials such as raw brass, diffused coated 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 program controlled coordinating system. To achieve smooth surface quality on the tool as well as in the component, optimum process parameter setting is a very important. 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 [10]. 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 blend throwing process. The hybrid composite includes 10 wt% SiC and 5 wt% Graphite particulates in metal cross section 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. The weight % piece of Al6061 composite is appeared in Table 1. Fortifications SiC and graphite in particulate frame are utilized to create the hybrid composite. The weight % structure of SiC and graphite are appeared in Table 2. These fortifications have 10–13 micron measure particles of SiC and graphite. The simplest and the most cost effective method of liquid state fabrication is stir casting [19]. Figure 1 shows the stir casting device used for fabrication of hybrid composite.

| Table 1. Composition of Al6061 alloy |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Mg | Si | Fe | Cu | Cr | Al |
| 1.10 | 0.64 | 0.48 | 0.33 | 0.04 | Remaining |

2.2. Machining Parameters and Response

Six information process parameters in WEDM, to be specific, pulse on time, pulse off time, current, gap voltage, the wire drum speed and wire tension were considered their consequences for SR and kerf width while machining the hybrid metal matrix composite. The scopes of these procedure parameters were chosen on the premise of the pilot tests. The levels of different parameters and their assignments are exhibited in Table 2.
2.3. Experimental Design using Taguchi Method

Taguchi strategy is a proficient apparatus for the outline of a great assembling framework. It also effectively solves some complex problems in manufacturing [11]. 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 picked 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 is meant 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. TOPSIS Method

TOPSIS depends on the rule that the picked option ought to have the most limited separation from the perfect arrangement and the most remote separation from the negative perfect arrangement [12-14]. Perfect arrangement is an answer that amplifies the advantage criteria and limits unfavorable criteria, while the negative perfect arrangement boosts the unfriendly criteria and limits the advantage criteria.

2.5. Experimental Set Up

Analyses were led on Electronica Sprint cut CNC wire cut electrical discharge machine to think about the surface finish quality and kerf width influenced by the machining control parameters at various
levels. WEDM is a start disintegration process. The flashes are produced between the work piece and the wire terminal. Dielectric liquid is ceaselessly encouraged into the machining zone with required weight. The material is getting expelled by a progression of discrete sparks occurring at the zone to be machined through electro-thermal 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 machined particles were flushed & carried away by the persistent stream of the dielectric medium. The wire is held by a stick direct at the upper & lower parts of the work piece. The work example measure utilized 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 to a part of this investigation. Deionized water was utilized as 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 as a part of this examination are the numerical normal of three estimations produced using the example in each cut.

2.6. Weight Criteria Calculation using SDV Concept

Standard deviation is connected to this examination for unprejudiced assignment of weights. The significance of the 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.

\[
X_{ij} = \frac{X_{ij} - \min X_{ij}}{\max X_{ij} - \min X_{ij}}
\]

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

\[
X'_{ij} = \frac{X_{ij} - \min X_{ij}}{\max X_{ij} - \min X_{ij}}
\]

where \(X'_{ij}\) is the mean of the values of the \(j^{th}\) criterion after normalization and \(j = 1,2,\ldots,n\). Subsequent to ascertaining for SDV for all criteria, the following stage is to decide the weights, \(W_j\) of the considerable number of criteria considered.

\[
w_j = \frac{SDV_j}{\sum_{j=1}^{n} SDV_j}
\]

Where \(j = 1,2,\ldots,n\).
2.7. TOPSIS Methodology

Procedure for Order Preference by Similarity to Ideal Solution Method (TOPSIS) is one of the MCDM which is utilized to comprehend the sort of basic leadership issue [15-17]. This technique depends on the idea that the picked option ought to have the most limited Euclidean separation from the perfect arrangement, and the most remote from the negative perfect arrangement. The perfect arrangement is a speculative answer for which all describe esteem compare to the most extreme trait esteems in the database containing the fantastic arrangements; the negative perfect arrangement is the theoretical answer for which all credit esteems relate to the base property estimations in the database. TOPSIS along these lines gives an answer that is not just nearest to the speculatively best, that is additionally the most distant from the theoretically most noticeably awful.

Hwang and Yoon created TOPSIS to evaluate the options previously numerous quality basic leadership [18]. TOPSIS considers all the while the separation to the perfect arrangement and negative perfect arrangement in regards to every option and furthermore chooses the most relative closeness to the perfect arrangement as the best option. Generally MCDM was utilized to take care of issue including determination from among a limited number of choices. For a basic leadership issue among the different options TOPSIS is one of the higher potential device [9]. TOPSIS is a basic leadership procedure. It is an objective based approach for finding the option that is nearest to the perfect arrangement. In this strategy, alternatives are evaluated in light of perfect arrangement comparability. In the event that a choice is more like a perfect arrangement, it has a higher review [10].

**Step 1**: Initial step to be followed in TOPSIS strategy is the standardization of execution of various model and the standardized grid is appeared in Table 4. This stage give way to contrasting distinctive foundation by changing over different properties measurement into non dimensional property. Standardize scores or information as takes after:

\[ R_{ij} = \frac{x_{ij}}{\sum x_{ij}^2} \]  

*for i= 1…m; j= 1… n;*

**Step 2**: Apportioning weights for the whole model which are considered for streamlining. The weights considered for this exploration were: surface unpleasantness =0.522, kerf width =0.478. The aggregate of weight ought to be equivalent to one.

**Step 3**: Develop the weighted standardized choice grid as in Table 5. Assume we have weights for every basis wj for j = 1… n.

On duplicating every section of standardized choice lattice by its particular weight the component acquired is:

\[ V_{ij} = W_j R_{ij} \]

**Step 4**: The next step is determination of ideal and negative ideal solution Ideal solution.

*Figure 2. WEDM experimental set up (Electronica Sprint cut)*
Positive ideal solution
\[ A^+ = \{ V_1^+, \ldots, V_n^+ \} \text{ where } V_i^+ = \{ \max (V_{ij}) \text{ if } j \in J; \min (V_{ij}) \text{ if } j \in J' \} \]

Negative ideal solution
\[ A^- = \{ V_1^-, \ldots, V_n^- \} \text{ where } V_i^- = \{ \min (V_{ij}) \text{ if } j \in J; \max (V_{ij}) \text{ if } j \in J' \} \]

**Step 5:** Separation measure determination is the fifth step in TOPSIS method. The value obtained is given below: The separation from the ideal alternative is:
\[ S_i^+ = \left( \sum (V_{ij}^+ - V_{ij})^2 \right)^{\frac{1}{2}} \quad i = 1, \ldots, m \]

Similarly, the separation from the negative ideal alternative as shown below Table 6:
\[ S_i^- = \left( \sum (V_{ij}^- - V_{ij})^2 \right)^{\frac{1}{2}} \quad i = 1, \ldots, m \]

**Step 6:** The relative closeness of a particular alternative
\[ P_i = S_i^- / (S_i^+ + S_i^-) \]

Select the option with \( P_i \) closest to 1

### 3. Result and discussion

Trials were led on Electronica Sprint cut (Electra-Elplus 40A Dlx) CNC WEDM to think about the surface finish and kerf width influenced by the machining parameters at various levels. Table 4 demonstrates surface finish and kerf width estimates. In the wake of machining, the examples were cleaned with \((\text{CH}_3)\text{CO}\). SR (Ra) was estimated utilizing Mitutoyo Surf test SV-2100. On each machined surface, SR was estimated at three spots spread over the whole machined territory. For introduce tests kerf width has been estimated utilizing Nikon profile projector show 6C.

#### 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. Effect of process parameters on surface roughness & kerf width

Table 4 shows the square of \( X_i \) and normalized matrix for \( X_i \) calculated by TOPSIS method. The normalized SR & KW are multiplied with their corresponding weights given in table 5. The parameters, higher the better (maximum) and smaller the better (minimum) respectively added for rank calculation. The surface roughness observed in the experiment is in the range of from 2.01 to 4.17. Similarly the kerf width observed in the experiment is in the range of from 295 to 322 microns. From these observations, experiment number 9 has the best rank. The parameters corresponding to experiment run number 9 are Pulse on time 108 units (Level1), Pulse off time 60 units (Level 3), peak current 230 units (Level 3), gap voltage 50 units (Level 3), wire feed 5 units (Level 5) and wire tension 12 units (Level 3). The observed kerf width and surface roughness values are .305 mm & 2.01 microns for the corresponding experiment number 9. Experiment number 25 has the least rank and the kerf width & surface roughness values are high.
Table 3. Surface roughness & Kerf width

| 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 4. Weighted normalized matrix for Surface roughness & Kerf width

| Ex. No. | Pulse on Time | Pulse off Time | Peak Current | G voltage | Wire Feed | Wire Tension | SR   | kerf width |
|---------|---------------|----------------|--------------|-----------|-----------|--------------|------|------------|
| 1       | 108           | 40             | 90           | 10        | 3         | 4            | 0.1291| 0.0791     |
| 2       | 108           | 40             | 90           | 10        | 4         | 8            | 0.1204| 0.0791     |
| 3       | 108           | 40             | 90           | 10        | 5         | 12           | 0.1142| 0.0778     |
| 4       | 108           | 50             | 160          | 30        | 3         | 4            | 0.0939| 0.0802     |
Table 5. Closeness coefficient values and ranking of alternatives

| Ex.no. | $S^+$ | $S^-$ | $P_i$ | Rank |
|--------|-------|-------|-------|------|
| 1      | 0.0032| 0.0006| 0.1648| 24   |
| 2      | 0.0023| 0.0011| 0.3321| 20   |
| 3      | 0.0017| 0.0016| 0.4812| 17   |
| 4      | 0.0004| 0.0036| 0.8883| 7    |
| 5      | 0.0005| 0.0035| 0.8846| 8    |
| 6      | 0.0004| 0.0037| 0.8978| 6    |
| 7      | 0.0002| 0.0046| 0.9617| 4    |
| 8      | 0.0008| 0.0028| 0.7736| 12   |
| 9      | 0.0000| 0.0065| 0.9989| 1    |
| 10     | 0.0027| 0.0008| 0.2394| 21   |


| 11 | 0.0014 | 0.0019 | 0.5704 | 15 |
| 12 | 0.0029 | 0.0007 | 0.2065 | 23 |
| 13 | 0.0019 | 0.0013 | 0.4084 | 19 |
| 14 | 0.0008 | 0.0028 | 0.7762 | 11 |
| 15 | 0.0027 | 0.0008 | 0.2302 | 22 |
| 16 | 0.0004 | 0.0037 | 0.9050 | 5 |
| 17 | 0.0005 | 0.0035 | 0.8836 | 9 |
| 18 | 0.0001 | 0.0054 | 0.9882 | 2 |
| 19 | 0.0001 | 0.0050 | 0.9774 | 3 |
| 20 | 0.0010 | 0.0024 | 0.7055 | 13 |
| 21 | 0.0014 | 0.0018 | 0.5616 | 16 |
| 22 | 0.0013 | 0.0020 | 0.5948 | 14 |
| 23 | 0.0008 | 0.0029 | 0.7890 | 10 |
| 24 | 0.0018 | 0.0015 | 0.4435 | 18 |
| 25 | 0.0065 | 0.0000 | 0.0010 | 27 |
| 26 | 0.0062 | 0.0000 | 0.0015 | 26 |
| 27 | 0.0042 | 0.0002 | 0.0545 | 25 |

4. Conclusions

In this experimental study, the combined TOPSIS 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 TOPSIS and SDV method is employed to select the optimum machining parameters in WEDM machining of Al6061/SiC/graphite with zinc coated brass wire electrode.

2. From these observations, experiment number 4 has the best rank. The parameters corresponding to experiment run number 9 are Pulse on time 108 units (Level1), Pulse off time 60 units (Level 3), peak current 230 units (Level 3), gap voltage 50 units (Level 3), wire feed 5 units (Level 3) & tension 12 units (Level 3).

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

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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