Optimization of WEDM Process Parameters on Machining of AZ91 Magnesium alloy using MOORA method

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Abstract. Selection of optimum machining parameters in wire electrical discharge machining (WEDM) operations leads to good functional attributes for the machined components and increased productivity. In this present experimental work, the effect and advancement of machining control parameters over kerf and cutting speed in wirecut electrical discharge machining operations were analyzed. Multi objective optimization by ratio analysis (MOORA) applied for optimization of kerf width (KW) and cutting speed (CS). Magnesium AZ91 alloy is selected as work material of dimension 100 x 100 x 10 mm. The analyses were outlined with Taguchi L27 design matrix. WEDM parameters resemble Pulse on time, Pulse off time, current, gap voltage, wire speed & wire tension are considered. The effect of the cutting control parameters on the kerf width and cutting speed is directed by using examination of fluctuation. The parameters corresponding to experiment run number 2 are pulse on duration 106 units (Level 1), pulse off duration 40 units (Level 1), peak pulse current 150 units (Level 2), gap voltage 30 units (Level 2), wire feed 6 units (Level 2) & wire tension 8 units (Level 2) are the best combination to achieve better CS and KW.

Keywords: MOORA, WEDM, Taguchi method, AZ91, kerf width & cutting speed.

1. Introduction
Wire EDM has all the earmarks of being exceptionally encouraging strategy among all non-conventional machining strategies [1]. The industrial growing sectors utilizing Wire EDM technology comes under five main different categories: tool and die, power generation, aerospace, automotive, oil and gas industries. WEDM maintains the largest percentage of share, as much as 50% and ECM about 15% lagging behind laser processes which are 20%. In many application areas which offers several benefits that include better precision, higher cutting rate & controlled material removal and also different types of materials that can be processed. The main aim of Wire EDM users & manufactures is to obtain a better steadiness of the machining process and increased productivity. More colorful materials are produced, and more mind boggling shapes are introduced and regular machining activities achieve their restrictions; the expanded utilization of Wire EDM in assembling keeps on developing at a quickened rate. Wire EDM makers and client accentuate on accomplishment of higher machining profitability with a coveted exactness and surface wrap up. Magnesium composites are combinations of magnesium alloys with other metals, often aluminum, manganese, copper, zinc, silicon rare earths metals and zirconium [2]. Magnesium compounds have hexagonal cross section structure which influences the essential properties of this composite. That is why, alloys of magnesium are mostly used as cast alloys & wrought alloys which has been more extensive. Cast magnesium alloys are utilized for a little parts of present day auto parts, and magnesium square; incredible magnesium is likewise utilized for camera bodies and in focal points segments.

The selection of proper machining variables leads to accuracy, quality and functional attributes of machined component [3]. Kerf width and cutting speed are important objective responses in WEDM operations to obtain high machining performances [4]. Proper selection of control variables
reduces the kerf width and increases cutting speed [5]. The optimal machining variables setting plays a significant role to improve the performance of any machining operation. In real time manufacturing, the decision making process is more difficult due to various interests and values of different decision makers. There is a need for simple, systematic and logical procedure to solve decision-making problems effectively. The MOORA method is one of the Multi criteria Decision Making methods which use statistical procedure for the selection of the best alternative from the given alternatives. This method generates most suitable alternatives by considering both beneficial and non beneficial alternatives and eliminates unsuitable alternative from the given alternatives for strengthening the existing selection procedure. The MOORA method involves lesser computations, comprehensiveness and robustness which can solve multiple number of criteria simultaneously [6]. The overall material grades of magnesium is available, in the research work the grade used to do the research is identified to be AZ91, which had most application in aircraft industry. The material magnesium AZ91 is selected for the process where these metals have good mechanical strength and are conductive. This research work also aims at investigating the main effects of the different Wire EDM control parameters like as wire speed, wire feed, Pulse on and Pulse off time on KW by using the technique named Taguchi. MINITAB version 18.0 software was used so as near optimize the operating variables of Wire EDM for magnesium AZE91.

2. Materials & method

AZ91 Magnesium alloys

The mass fabrication of lightweight metal matrix castings for moderate strength applications requires the make use of of high volume die-casting techniques. The predominant magnesium alloy used for both die as well as sand casting is AZ91, containing approximately 9% aluminum and 1% zinc, which possess excellent casting properties and reasonable strength.

Machining control variables

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 CS and KW were measured after machining for investigation. The scopes of these procedure parameters were chosen on the origin of the pilot tests. The different parameters level and its assignments are exhibited in Table 2.

| Table 1. | Control Variables |
|---------|------------------|
| Symbol  | Process parameter | Level 1 | Level 2 | Level 3 |
| A       | Pulse on time    | 106     | 116     | 126     |
| B       | Pulse off time   | 40      | 50      | 60      |
| C       | Pulse current    | 70      | 150     | 230     |
| D       | Gap Voltage      | 20      | 30      | 40      |
| E       | Wire feed        | 4       | 6       | 8       |
| F       | Wire tension     | 4       | 8       | 12      |

Experimental Design by Taguchi technique

Taguchi approach is a proficient apparatus for the summarize of a great assembling framework. It also effectively solves many difficult problems in manufacturing [7]. 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 variables, that is, Pulse on time (A), Pulse off time (B), current (C), Gap voltage (D), wire feed (E) and wire tension (F) with 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.
Experimental Set Up
Analyses were led on Electronica Sprint cut CNC wire cut electrical discharge machine to think about the cutting speed 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 material and the wire terminal. The dielectric liquid is ceaselessly encouraged into the cutting zone with required weight. The material is getting expelled by a progression of discrete sparkles occurring at the zone to be machined through electro-thermal system. Test set up of the wire electrical release machine is appeared in Figure 1.

Amid machining process little gap kept up between the work and wire material. The wire is held by a stick direct at the upper & lower parts of the work piece. The work example measure utilized as a part of this examination is 100 x 100 x 10 mm rectangular plate. Zinc covered metal brass wire of 0.25 mm diameter was considered for 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 entire 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. The cutting speed has been observed from machine display board.

Methodology
MOORA is the one of the MCDM techniques used to choose best options among a given number of choices [9]. 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 illumining and positioning ideal options all the while.

Step 1: Description of problem and objectives.
In the present analysis, cutting speed& kerf width are selected as non-beneficial attribute.
Step 2: Construction of decision matrix.
The decision matrix which is used to represent the experimental results with respect to various output parameters. The matrix $D_{morn}$ is represented as

$$D_{morn} = \begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n} \\
X_{21} & X_{22} & \cdots & X_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
X_{m1} & X_{m2} & \cdots & X_{mn}
\end{bmatrix}$$

where $X_{ij}$ indicates the experimental result of $i$th alternative on $j$th attribute, $m$ indicates the number of experiments, and $n$ refers to the number of output parameters. The decision matrix 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 $N_{i j}$ is presented in Table 4. The expression used to determine the normalized decision matrix $(N_{i j})$ is given by

$$N_{i j} = \frac{x_{i j}}{\sqrt{\sum x_{i j}^2}} \quad \text{for} \quad i = 1, m; \quad j = 1, \ldots, n, \quad \text{[5]}$$

where $x_{i j}$ and $N_{i j}$ 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 $Y_i$ is the standardized evaluation estimation of i-th elective regarding all characteristics. Table 4 demonstrates the standardized appraisal estimation of chose yield parameters

$$Y_i = \sum_{j=1}^{g} W_j N_{i j} - \sum_{j=g+1}^{n} W_j N_{i j}, \quad \text{[6]}$$

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

$$Y_i = \sum_{j=1}^{g} W_j N_{i j} - \sum_{j=g+1}^{n} W_j N_{i j} \quad (j = 1, 2, \ldots, n), \quad \text{[7]}$$

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

3. Result and discussion
The experimental values cutting speed and kerf width are tabulated in table 2. Table 3 shows the square of $X_i$, normalized matrix for $X_i$ and rank calculated by MOORA method. The normalized CS & KW are multiplied with their corresponding weights. These values are listed in the table 6. The parameters, higher the better (maximum) and smaller the better (minimum) respectively added for rank calculation. The cutting speed observed in the experiment is in the range of from 1.92 to 7.52 mm/min. Similarly the kerf width observed in the experiment is in the range of from 0.32 to 0.374 mm. From these observations, experiment number 2 has the best rank. The parameters corresponding to experiment run number 2 are pulse on time 106 units (Level1), pulse off time 40 units (Level1), peak current 150 units (Level 2), gap set voltage 30 units (Level 2), wire feed 6 units (Level2) and wire tension 8 units (Level2).

**Table. 2 Cutting speed& Kerf width**

| Ex.No. | Pulse on Time | Pulse off Time | Current | Gap voltage | Wire Feed | Wire Tension | CS     | KW    |
|--------|---------------|----------------|---------|-------------|-----------|--------------|--------|-------|
| 1      | 106           | 40             | 70      | 20          | 4         | 4            | 6.32   | 0.323 |
| 2      | 106           | 40             | 150     | 30          | 6         | 8            | 7.52   | 0.32  |
| 3      | 106           | 40             | 230     | 40          | 8         | 12           | 6.89   | 0.321 |
| 4      | 106           | 50             | 70      | 30          | 6         | 12           | 3.47   | 0.33  |
| 5      | 106           | 50             | 150     | 40          | 8         | 4            | 3.49   | 0.332 |
| 6      | 106           | 50             | 230     | 20          | 4         | 8            | 5.51   | 0.337 |
Table 3 Normalized decision matrix & MOORA rank

| Ex.No. | Square of Xi | Normalized Xi | Wj*Xi       | \( \sum_{\max} \) | \( \sum_{\min} \) | Rank |
|--------|--------------|---------------|-------------|----------------|----------------|------|
| CS     | KW           | CS            | KW          | CS             | KW             |      |
| 1      | 39.9424      | 0.104329      | 0.2340      | 0.1788         | 0.11699        | 0.08942 | 0.02757 | 3     |
| 2      | 56.5504      | 0.1024        | 0.2784      | 0.1772         | 0.13921        | 0.08859 | 0.05062 | 1     |
| 3      | 47.4721      | 0.103041      | 0.2551      | 0.1777         | 0.12754        | 0.08887 | 0.03868 | 2     |
| 4      | 12.0409      | 0.1089        | 0.1285      | 0.1827         | 0.06423        | 0.09136 | -0.02712 | 19    |
| 5      | 12.1801      | 0.110224      | 0.1292      | 0.1838         | 0.06460        | 0.09191 | -0.02731 | 20    |
| 6      | 30.3601      | 0.113569      | 0.2040      | 0.1866         | 0.10200        | 0.09329 | 0.00870 | 13    |
| 7      | 3.6864       | 0.106929      | 0.0711      | 0.1811         | 0.03554        | 0.09053 | -0.05498 | 27    |
| 8      | 9.3636       | 0.1089        | 0.1133      | 0.1827         | 0.05664        | 0.09136 | -0.03471 | 23    |
| 9      | 8.0089       | 0.116281      | 0.1048      | 0.1888         | 0.05239        | 0.09440 | -0.04202 | 26    |
| 10     | 37.4544      | 0.119716      | 0.2266      | 0.1916         | 0.11329        | 0.09579 | 0.01750 | 5     |
| 11     | 39.0625      | 0.116281      | 0.2314      | 0.1888         | 0.11570        | 0.09440 | 0.02129 | 4     |
| 12     | 35.7604      | 0.128164      | 0.2214      | 0.1982         | 0.11070        | 0.09911 | 0.01159 | 9     |
| 13     | 16.2409      | 0.139876      | 0.1492      | 0.2071         | 0.07460        | 0.10354 | -0.02894 | 21    |
| 14     | 36.1201      | 0.137641      | 0.2225      | 0.2054         | 0.11125        | 0.10271 | 0.00855 | 14    |
| 15     | 35.7604      | 0.133225      | 0.2214      | 0.2021         | 0.11070        | 0.10105 | 0.00965 | 12    |
| 16     | 9.4864       | 0.113569      | 0.1140      | 0.1866         | 0.05701        | 0.09329 | -0.03628 | 24    |
| 17     | 14.3641      | 0.121104      | 0.1403      | 0.1927         | 0.07016        | 0.09634 | -0.02618 | 18    |
| 18     | 13.5424      | 0.128164      | 0.1362      | 0.1982         | 0.06812        | 0.09911 | -0.03099 | 22    |
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Conclusions
This paper has presented application of MOORA method for the selection of optimal control parameters in machining of AZ91 magnesium alloy using WEDM. The MOORA method, indeed, considers all the attributes along with their relative importance which enables this method to provide not only a better but also an accurate evaluation of the alternatives. As compared to many other MODM methods, this method is found to be simple, logical and robust. This method can simultaneously consider any number of quantitative and qualitative selection of attributes and is able to provide optimum solution quickly as computational time necessary to obtain the solution is reasonably low. MOORA method is employed to select the optimum machining parameters in WEDM machining of AZ91 Magnesium alloy with zinc coated brass wire electrode. From these observations, experiment number 2 has the best rank. The parameters corresponding to experiment run number 2 are pulse on time 106 units (Level 1), pulse off time 40 units (Level 1), peak current 150 units (Level 2), gap set voltage 30 units (Level 2), wire feed 6 units (Level 2) and wire tension 8 units (Level 2). The optimum results are adopted in validation study and the results based on WEDM process responses can be effectively improved.

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|    |    |    |    |    |    |
|----|----|----|----|----|----|
| 19 | 33.4084 | 0.126736 | 0.2140 | 0.1971 | 0.10700 | 0.09855 | 0.00844 | 15 |
| 20 | 35.0464 | 0.123201 | 0.2192 | 0.1943 | 0.10959 | 0.09717 | 0.01242 | 8  |
| 21 | 35.6409 | 0.123904 | 0.2210 | 0.1949 | 0.11051 | 0.09745 | 0.01307 | 7  |
| 22 | 26.7289 | 0.120409 | 0.1914 | 0.1921 | 0.09570 | 0.09606 | -0.00036 | 16 |
| 23 | 35.8801 | 0.132496 | 0.2218 | 0.2015 | 0.11088 | 0.10077 | 0.01011 | 10 |
| 24 | 35.6409 | 0.132496 | 0.2210 | 0.2015 | 0.11051 | 0.10077 | 0.00974 | 11 |
| 25 | 9.8596  | 0.130321 | 0.1163 | 0.1999 | 0.05813 | 0.09994 | -0.04181 | 25 |
| 26 | 24.2064 | 0.138384 | 0.1822 | 0.2060 | 0.09108 | 0.10298 | -0.01191 | 17 |
| 27 | 35.7604 | 0.121801 | 0.2214 | 0.1932 | 0.11070 | 0.09662 | 0.01408 | 6  |