IMPROVING THE MACHINING QUALITY AND OPTIMISING THE PARAMETERS OF AL 8090 ALLOYS USING MOUTH BROODING FISH ALGORITHM

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Abstract

Aluminium (Al) alloys in aircraft applications requires the use of advanced machining process, which includes Electric Discharge Machining (EDM) for fabrication of aircraft mechanical structures. However, optimization of the parameters of Al is required to avoid variations, which tend to affect the Material Removal Rate (MRR) and Surface Roughness (SR) of machining quality. In this paper, parametric EDM optimization is carried out on Al 8090 using a meta-heuristic algorithm called Mouth Brooding Fish (MBF) algorithm. The Al 8090is used to fabricate the metal matrix composites that consists of an activated charcoal with different reinforcement percentage. The parameters considered for optimization includes peak current, pulse-on and off and Response Surface Method (RSM). The Box–Behnken design is used to implement the RSM through mathematical derivations of Tool Wear Rate (TWR), MRR, and Material Hole Roundness (MHR). Several iterations are established to improve the accuracy of the model. The Al 8090 alloys are tested for Hardness, Density, Ultimate tensile strength and Impact Strength. These methods yields best samples and machining process is performed on it in EDM. Several experiments are carried out using RSM and observations are carried out. The quality of alloys are evaluated in terms of SR and MRR. The optimal solution of MBF is found using weighted sum method with multi-objective function. The optimal results provides the solutions for optimal parametric combination with maximum MRR and minimum SR values. The results of ANOVA analysis proved that the servo speed creates a greater influence to determine the quality of EDM. Finally, the effectiveness of the proposed method is confirmed using confirmatory experiments.

Keywords

Mouth Brooding Fish algorithm, Material Removal Rate, Surface Roughness, Electric Discharge Machining

1.   Introduction

With increasing growth in technology and industry, the development of tough materials finds its application in the areas of nuclear engineering, aerospace and other industries due to its high hardness, strength and heat resistance [2]. The use of Al alloys provides high stiffness, strength, damping, recyclability, machinability, high thermal conductivity, electromagnetic shielding, high electrical conductivity and low melting point [3]. However, these materials are difficult to be machined through existing mechanisms, hence the development of new machining is used that does not provides any contact with the surface.

EDM is considered as a machining process, where the process is of processes is of non-contact type. The use of high frequency (HF) sparks between the work-piece and the tool helps in the removal of materials. During this process, both the work-piece and the tool is immersed in distilled water or kerosene that forms a dielectric bath [1]. Since, it uses anelectro-thermal erosion instead of erosion, there is not contact exist between the surfacesas well it is not limited by the metallurgical properties of sample Al 8090. Hence, it does not pose any limitation on the machining material with toughness and hardness properties for EDM and as long as the material is electrically conductive.

The EDM is controlled through several parameters [4] and variations in these parameters affects directly the performance of EDM. The proper machining method is found through classification of different measures that affects its performance. Such classification helps in providing the conditions and efficiency associated with machining process.Also, it is seen that the selection of parameters are far optimal from the desirable range. Further, the optimization of these parameters is considered time consuming and costly. Different machining mechanism to address various effects are given in Section 2.

These mechanism helps in improving the rate of production and the dependency is reducing using some optimization models adopted specifically on EDM. On other hand, these adoptions can fit only selected materials and poses severe limitation on other environment and material [5]. Therefore, the parametric optimization acquires the characteristics of the entire EDM process using mathematical model. The modelling and analysis of a set of processing variables can be attained using a Design of Experiments over certain response or output variables.

In this paper, parametric EDM optimization is established on Al 8090 through a Mouth Brooding Fish (MBF) algorithm. The parameters required for optimization includes peak current, pulse-on and off and RSM. This method considers Box–Behnken design with

mathematical derivations of TWR, MRR and MHR to implement the RSM. The optimal solution to obtain the optimal parameters is found using multi-objective function. After resolving the effects associated with contradicting parameters, the manufacturing of AL 8939 (properties are given in Table 1) alloys with complex and intricate shapes can be done through EDM in aerospace applications.

Table 1: Mixture of alloys in Al 8090

Alloy of Al 8090	Percentage of materials used in Al 8090
Percentage of Al	94.8
Li	2.45
Cu	1.3
Mg	0.95
Zr	0.12

The outline of the paper is given below: Section 2 provides the related works. Section 3 provides the experimental design and section 4 provides the optimization approach. Section 5 discusses the obtained results. Section 6 concludes the paper.

2. Related works

Various mechanism are used to improve the performance of finding optimal parameters for EDM. Several techniques are identified to improve the accuracy of finding the optimal parameters, few of which related to the present study is discussed below:

Talla et al. (2015) [6] fabricated the EDM process by adding Al powder with kerosene as a dielectric. This method achieves high MRR and low SRR using a multi response optimization through principal component analysis-based grey technique. This helps in determining the optimal settings required to process the parameters to attain high MRR and low SRR within its experimental range.Kuriachen et al. (2015) [7]used micro-wire based EDM to increase the MRR with reduced SRR. This method considers various process parameters like capacitance, gap voltage, wire tension and feed rate on micro-WEDM. The study focussed entirely on Titanium alloys. This method used ANOVA to find the significant factors. The relationship between the output response and process parameters is correlated using fuzzy logic model,

which helps in predicting the process behaviour. In order to handle the problems related with uncertainties, this method uses particle swarm optimization (PSO) algorithm to improve the EDM performance. This hybrid resolves the poor dynamic qualities and inaccuracies related with EDM. Prakash, et al. (2016) [8] used Non-dominated sorting genetic algorithm (NSGA)-II integrated with Taguchi based RSM to improve the optimization of parameters in EDM. This method is used for predicting the optimal parameters of powder mixed EDM. This is used for fabricating the surface of Titanium alloys and the significant parameters is found using ANOVA. Gaitonde, et al. (2017) [9] used differential evolution algorithm to find the optimal parameter or optimise the parameters required for EDM. This method provides minimum SR with high MRR with best combination of pulse on and off time. HCHCr steel using brass electrode is used as a sample material for the study and it uses WEDM to find the characteristics of sample material. It is seen that the material achieves higher roughness and formation of cementite and ferrous oxide is found through XRD analysis.Majumder, A. (2015) [10] used trained neural network to find the relationship between machining performance and process parameters. The simulated annealing, particle swarm optimization and genetic algorithm is then combined with neural network for predicting the optimal parameters required to reduce the SR and increase the MRR. Tripathy& Tripathy (2016) [11] used Taguchi method called TOPSIS and Grey Relational Analysis is used as optimization technique to analyse and find the optimal parameters from Powder Mixed EDM. The dielectric fluid is mixed with conductive powder to improve the machining process on advanced materials mixed with chromium powder.The ANOVA and F-test is used to find the parameters for EDM and optimal sample measurement is carried out using Scanning Electron Microscope (SEM).Selvakumar, G., et al. (2014)used Taguchi method with additive model and Pareto optimality approach is used to find the optimal parameters required to improve the performance of WEDM. The experimental design uses a series of experiments using L9 orthogonal array that offers reduced SR and increased MRR. Gupta& Jain (2014) [13] used Box–Behnken approach with RSM for WEDM for finding the fine-pitch miniature spur gears made of brass. This method uses four parameters namely, pulse-on andoff time, voltage and wire feed rate to analyse the miniature gears. ANOVA is used to find the most significant parameter for optimization. Mohanty et al. (2016) [14] adopted the same Box–Behnken approach with RSM to estimate the parameters and the response rate for finding the parameter is improved using multi-objective particle swarm (MOPSO) algorithm. The parameters for estimation includesdischarge current, open circuit voltage, duty factor, pulse-on-time, tool material and flushing pressure. This method adopts 54 trails on Inconel 718 super alloy to obtain high MRR. Purohit, et al. (2015) [15]used Grey relational analysis with a

L9 orthogonal array to identify the optimal parameters required to improve the EDM parameter selection. This method considers voltage, tool rotation speed and spark time as its parameters for analysis on rotary brass electrode. ANOVA is used to find the significant parameters required to optimise the EDM process. Mohal& Kumar (2017) [16] performed EDM using a promising optimization technique on multiwalled carbon nanotubes with powder particles. Kumar, H. (2015) [17] used similar mirror-like surface finish like Mohal & Kumar (2017) [16] on AISI-D2 die steel by EDM. The parameters considered are peak current, CNT concentrationand pulse duration. Kulkarni, et al. (2018) [19] performed WEDM on Nitinol superelastic alloy using multi performance characteristics optimization. The optimization technique involves Taguchi's utility and Quality loss function to find the optimal parameters that includeswire feed, spark gap set voltage and pulse on and pulse off time. Garg, et al. (2014) [20]performs WEDM on Titanium alloy by considering Box–Behnken design and RSM. Six experiments are conducted to find the optimal parameters that includes pulse on and off time, spark gap set voltage, peak current wire tension and wire feed. Sharma, et al. (2017) [21] performed WEDM on NiTi shape memory alloyusing powder metallurgy technique. This method employs RSM with central composite rotatable design on WEDM. Ray, A. (2016) [22] used gray relational analysis combined with principal component analysis to optimise the process parameters in green EDM. The parameters selected for optimization includes tool wear ratio, process time, aerosol concentration, process energy and dielectric consumption. The experimental runs are carried out using Taguchi (L9) orthogonal array. The PCA determines the weighting values of various performance characteristics. Thereafter, ANOVA finds the significant parameter with reduced SR and increased MRR

3. Experimental Design

The design of experiments is regarded as a research method to sequence the trails to find the relationship between different parameters considered for the given study. These relationship is represented in terms of a mathematical models that is expressed in terms of a response variable i.e. control variables that influences the response variable, the most. The characteristics of output variable is expressed explicitly in terms of characteristics of input variable.

3.1.Response Surface Methodology (RSM)

RSM involves a statistical and mathematical model to analyse the responses associated with optimization technique formulated w.r.t to control parameters [18]. This method is considered very useful if the impacts of these variables does not pose a linear response relationship. This

helps in capturing the characteristics of these control variables or responses through the range of input responses. The RSM is used to optimise the input responses, which can be regarded as a multi-objective problem. The 2ndorder polynomial is used to define the mathematical model, which is given by following expression:

$$U = \lambda_0 + \sum_{i=1}^{n} \lambda_i V_i + \sum_{i=1}^{n} \lambda_{ii} V_i^2 + \sum_{i,j=1,i \neq j}^{n} \lambda_{ij} V_i V_j + \varepsilon \qquad (1)$$

where

U is regarded as the matching response,

V_i is regarded as the independent parameter,

V_i^2 is regarded as the squares,

$V_i V_j$ is regarded as the interaction terms of the input variables,

ε is regarded as the error term,

$\lambda_0, \lambda_i, \lambda_{ii}, \lambda_{ij}$ is regarded as the unknown regression coefficients, which needs to be estimated.

3.2. Box–Behnken design

The Box and Behnken is a quadratic design that needs few experimental trails. The treatment runs required for EDM experimentation is considered as minimum to ensure that the project lies within its scope. The experimentation is made rotatable with three levels in each factor and this ensures that the variance predication is uniform in the design space. The design is realised for MRR, TWR and MHR w.r.t design factors. The factors required for design is given in Table 2 and Table 3, which is very much required for optimizing the parameters using EDM process.

Table 2: Box and Behnken parameters for EDM

Parameters	Values
Base runs	15

Factors	3
Replicates	1
Total runs	15
Total blocks	1
Base blocks	1

Table 3: Design of experiments for EDM

Run order	Current (A)	Pulse on (μs)	Pulse-off (μs)
1	20	6	10
2	30	2	8
3	25	6	8
4	30	10	8
5	30	6	10
6	30	6	6
7	20	6	6
8	20	2	8
9	25	2	6
10	25	10	6
11	25	2	10
12	25	10	10
13	25	6	8
14	20	10	8
15	25	6	8

4. Multi-objective Optimization

There exist several optimization process as discussed in section 2 to improve the parameters required for EDM process.Jahani, E., & Chizari, M. (2018) [23] developed MBF algorithm that pretends the symbiotic interaction approachesaccepted by the organisms for survival and propagation in its ecosystem. The MBF consist of certain process that involves: movement, dispersion and protection of MBF as a pattern in order of finding the optimal parameters required for the given study. The main steps and entire process is given in Jahani, E., & Chizari, M. (2018) [23].

The MBF is a modelled as a multi-objective optimizationfunctiondeveloped using normalization and preferences of various output functions. This method utilises the addition of unitary weights $w_1,..,w_n$over various fitness function and then convertingit into a single objective function, which is given in Eq.(2). The multi-objective optimization is estimated using responses nature and optimization type, which is given in Eq.(2):

$$f(x) = w_1 f_1(x) + w_2 f_2(x) + w_2 f_2(x) \qquad (2)$$

where, $w \in (0,1)$ and these weights are added to unity, which would converge to present the final solution.

5. Results and Discussions

This section discusses various analysis carried out to find the MRR and SR rate and the statistical significant of optimal parameters. This includes MBF optimization analysis to find the MRR and SR. The ANOVA analysis to find the statistical significance of the parameters. The confirmation test is used to confirm the performance development using machine parameters.

5.1.MBF Optimization Analysis

Here two inputs (MRR and SR) and one output (GFRG) fuzzy-logic system is used. Fuzzy inference method achieves fuzzy reasoning with fuzzy ideas for producing a fuzzy price. The grey relational coefficient for MRR and SR are inputs to the fuzzy logic system. The linguistic membership operate Lowest, Low, Medium, excessive and maximum are used to signify the grey relational coefficient (GRC) of enter variables. Likewise the yield grey relational grade is being represented through the membership functions similar to Lowest, Very Low, Medium Low, Low, Medium, and high, better, Medium larger and perfect. The triangular shaped

membership performs which is possessed on this work. A total of 26 numbers of fuzzy ideas are used for this purpose. The rule of fuzzy grade reasoning is shown in Fig. 6. Difference in compositional operation by tracking the fuzzy reasoning yields a fuzzy output. Fuzzy techniques increasingly applied to the research area and no work has been summarized this techniques in 8090 metal matrix composites. From the response analysis given in the table concluded that, that parameter combination A1B3C3D1 had the best performance for all the quality features. The results of MRR and SR is given in Figure 1 – Figure 2, respectively.
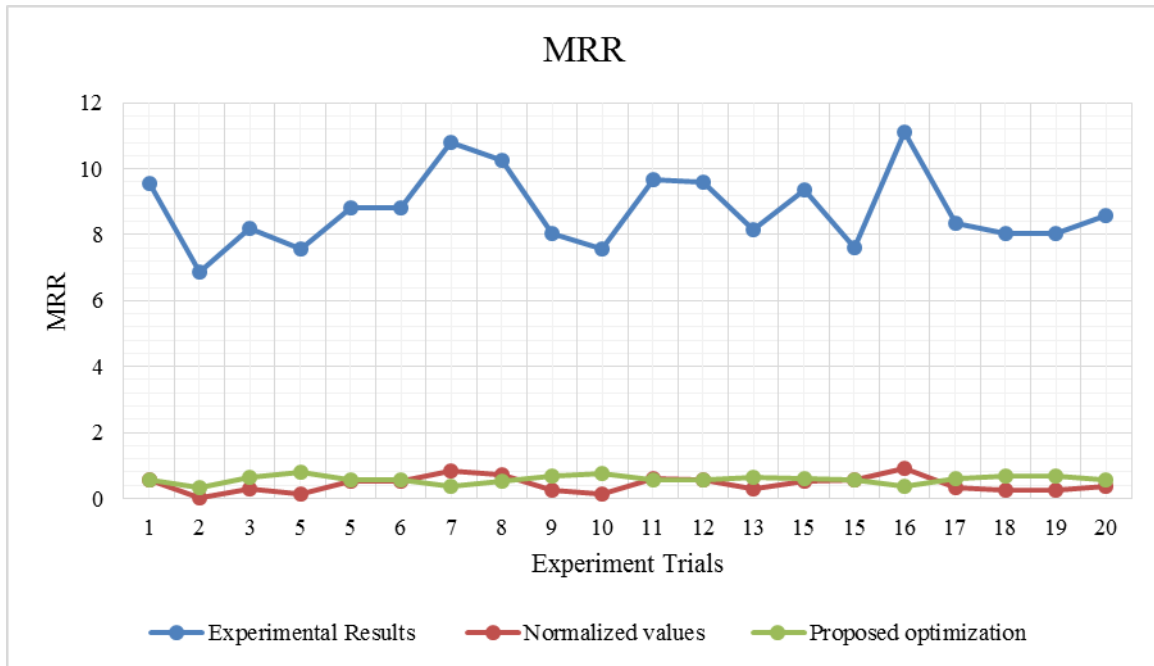

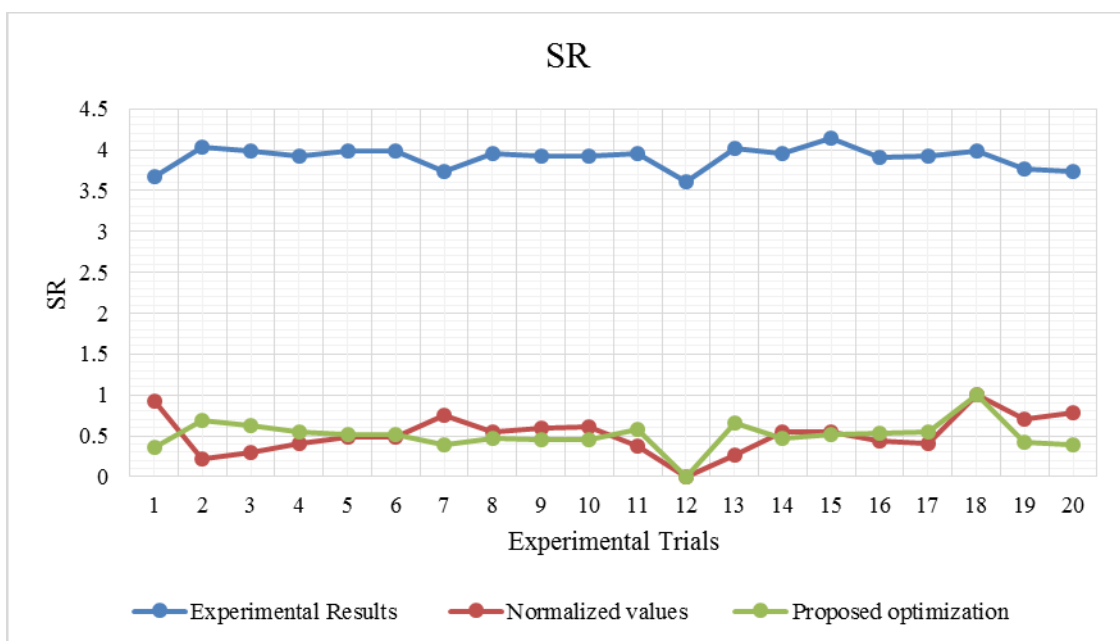Figure 1:Results of MRR between the proposed and experimental results

Figure 2: Results of SR between the proposed and experimental results

5.2.ANOVA analysis

The proposed study uses ANOVA analysis in order to classify the parameters of EDM, which significantly has an enormous impact on its efficiency. The ANOVA analysis includes the sums of squares, degrees of freedom andF-ratio.Also, it shows the proportion of its contribution that determines the important of each characteristicthan the performance characteristics.

The result in Table 4 shows that the cost of servo speed is the most inferencing factor, which is formed from pulse on time. It is seen that each component: servo speed, pulse on, pulse off time and discharge current is diversified in terms of total variance rate.

Table 4: Analysis of variance Results

Source	Df	SeqSS	AdjSS	Adj MS	F	P	Percentage contribution
Current	2	0.01	0.007	0.003	0.6	0.5	3.52
Pulse on	2	0.05	0.005	0.002	5.4	0.6	13.09
Pulse off	2	0.04	0.057	0.028	2.0	0.01	9.97
Servo Speed	2	0.28	0.172	0.086	15.0	0	68.45
Error	18	0.02	0.010	0.005	-	-	
Total	26	0.41	-	-	-	-	

It is found from the result that the servo speed is the highly influencing factor that obtains higher speed to sustain or withhold the tensions of the wire and it has the ability to run at maximum voltage. The result shows that the highly insignificant factor is the discharge current with least significant rate to manipulate the grade strength. Since, the rate of conduction is minimum in EDMwith increasing cutting speed through servo voltage.

On other hand, if the servo speed reduces its speed, the discharge current increases its significant rate and it becomes the most influencing factor in EDM. The Figure 3 shows the

microscopic image of the experiment obtained with optimal parameters with following specification, which is given in Table 4.

5.3.Confirmation Test

The Confirmation Test is used in the present study to confirm the performance development using machine parameters. The comparison of various performance metrics is shown in Table 5 to obtain its highest quality with given machining parameters. The Eq. (3) finds the high quality level of EDM parameters using estimate reasoning grade, where its preliminary designed stages are initial experimental and prediction stages.
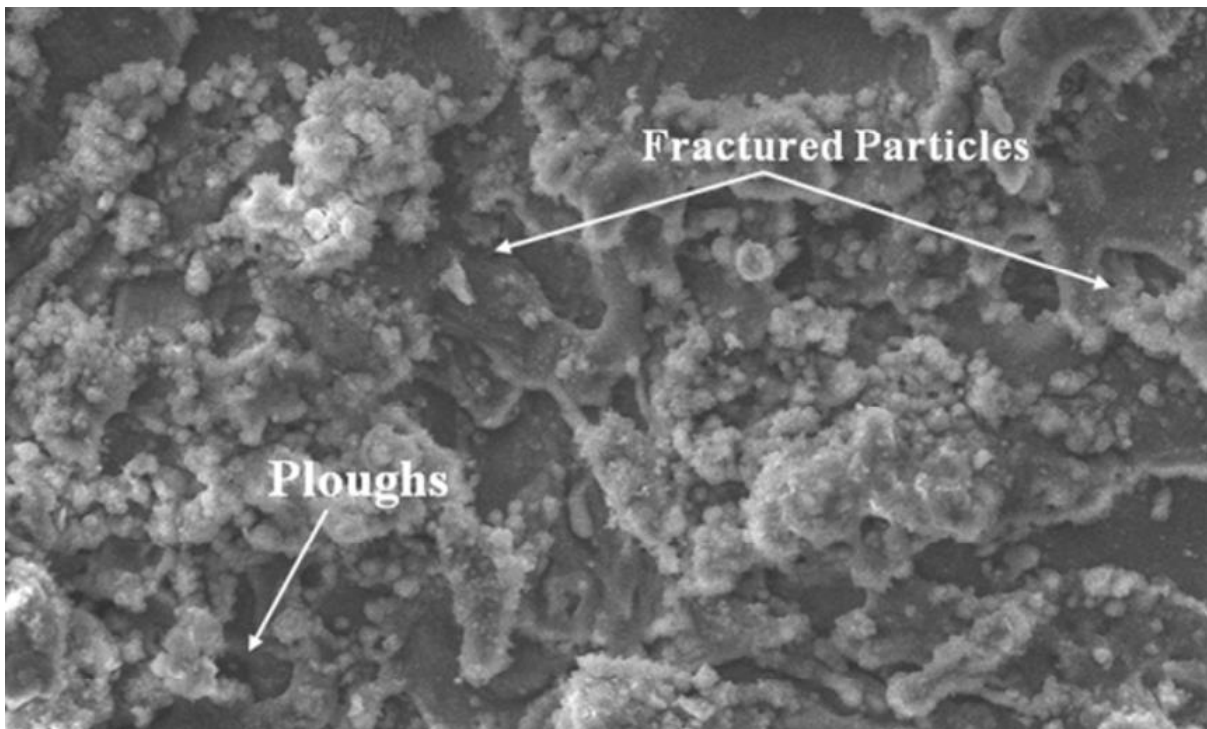
$$\gamma = \gamma_m + \sum_{i=1}^{q}\left(\gamma_i - \gamma_m\right) \qquad (3)$$

Where

γ is considered as the mean of reasoning grade,

γ_m is considered as the final stage reasoning grade and

q is considered as the number of the parameters impacting the output response variables.

Fig. 3. SEM image of optimal parameter

Table 6: Machining Performance Results using optimal factors

	Parameters of Initial Process	Optimal Parameters for Experiment	Optimal Parameters for Prediction
Material Removal Rate(mm^3/s)	0.14366	0.14363	-
Surface Roughness (mm)	311	305	-
Output	0.761	0.806	0.7972
Improvement in output	-	0.045	0.0352

The Table 5 shows that the MRR has increased and SR has lowered with increasing reasoning grade.The most effective design is found by considering the fabricated alloy sample with highest reasoning grade. This clearly shows that the multi-objective optimization has increased the effectiveness of machining approach to a greater extent.

6. Conclusions

In this paper, the EDM machine is conducted successfully on Al 8090 alloys. The mathematical model is developed and analysed after developing a multivariate MBF algorithm. The experiments conducted shows significant improvements in finding the parameters using multivariate optimization techniques, which helps to derive the following conclusions:

- An effective mathematical modelling suiting EDM with reduced trails is modelled with various metrics like MRR, TWR and MHR. The analysis and modelling of these metrics is found to be high relevant or suitable during at characterising the hole. This method can further be applied on other geometries like waviness, cylindricity, etc. to classify the hole pattern.

- The statistical analysis using ANOVA proves that the servo speed is considered to be the influencing factor that effects on the performance on EDM after carrying out the experiments with RSM on the Al alloys. These results of adopted through discharge current, pulse on and off time. On other hand, the MBF algorithm tends to improve the quality of EDM parameters after fabrication. This is recommended on aircraft surfaces.

- The result shows that the optimization of parameters using MBF optimization on MRR and SR achieves high MRR and less SR to generate high quality EDM. The selection of optimal discharge, pulse on and off time, and servo speed, increases the optimal combination of parameters to provide maximum grade strength value (0.773).

- The decision process for material characterization is analysed based on the optimization technique, where the input parameters is sampled to obtain maximum MRR and minimum TWR.

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