Available online at www.sciencedirect.com

ScienceDirect

Procedia Materials Science 5 (2014) 2215 – 2223

Procedia Materials Science

www.elsevier.com/locate/procedia

International Conference on Advances in Manufacturing and Materials Engineering, AMME 2014

Comparison of machining performances using multiple regression analysis and group method data handling technique in Wire EDM of Stavax material

G.Ugrasen[a*], H.V.Ravindra[b], G.V.Naveen Prakash[c], R.Keshavamurthy[d]

[a]Assistant Professor, Department of Mechanical Engineering, BMS College of Engineering, Bangalore, Karnataka-560 019, INDIA
[b]Professor, Department of Mechanical Engineering, PES College of Engineering, Mandya, Karnataka-571 401, INDIA
[c]Professor, Department of Mechanical Engineering Vidya Vardhaka College of Engineering, Mysore, Karnataka-570 002, INDIA
[d]Associate Professor, Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bangalore, Karnataka-560078, INDIA

Abstract

Wire Electrical Discharge Machining (WEDM) is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining processes. This study outlines the development of model and its application to estimation of machining performances using Multiple Regression Analysis (MRA) and Group Method Data Handling Technique (GMDH). Experimentation was performed as per Taguchi's L'_{16} orthogonal array for Stavax (modified AISI 420 steel) material. Each experiment has been performed under different cutting conditions of pulse-on, pulse-off, current and bed speed. Among different process parameters voltage and flush rate were kept constant. Molybdenum wire having diameter of 0.18 mm was used as an electrode. Four responses namely accuracy, surface roughness, volumetric material removal rate and electrode wear (EW) have been considered for each experiment. Estimation and comparison of responses was carried out using MRA and GMDH.

Keywords: WEDM, Ra, VMRR, EW, MRA, GMDH

* Corresponding author. Tel.: +91-80-26603961; fax: +91-80-26614357.
E-mail address: ugrasen.g@gmail.com

doi:10.1016/j.mspro.2014.07.430

1. Introduction

Wire cut EDM (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles irrespective of hardness. WEDM has evolved as a simple means of making tools and dies to the best alternative of producing micro-scale parts with the highest degree of dimensional accuracy and surface finish. Molybdenum wire is used in limited applications which require very high tensile strength to provide a reasonable load carrying capacity in small diameter wire. The effect of process parameters on the electrode wear and the amount of the erosion on wire is to be investigated experimentally in wire EDM. An attempt has been made to estimate wire wear out using multiple regression analysis and group method data handling technique.

Yan, et al, (2013) have discussed the application of micro wire electrical discharge machining (micro wire-EDM) for profile roughing and final dressing of polycrystalline diamond (PCD) wheels using a specific pulse generator. The pulse generator using anti-electrolysis circuitry and digital signal processor based pulse control circuit was developed to suppress damages on the machined surface of PCD while achieving stable machining. In comparison with wire-EDM, micro wire-EDM could achieve better surface quality and smaller thickness of damaged layer for the fabrication of PCD wheels. By applying a specific pulse generator, a PCD wheel with a grinding-edge thickness of 3 µm has been successfully fabricated by micro wire-EDM. Micro wire-EDM could achieve smaller thickness of the damaged layer, better surface quality, less machining time and thinner grinding-edge for the fabrication of PCD wheels than wire-EDM since the former could provide much smaller discharge energy and higher machining accuracy than the latter. The Raman analyses have confirmed the transformation of diamond to non-diamond carbon (sp^2-bonded carbon) had occurred due to the thermal effects during electrical discharge machining. M. Durairaj, et al, (2013) have studied the Grey relational theory and Taguchi optimization technique, in order to optimize the cutting parameters in Wire EDM for SS304. The objective of optimization was to attain the minimum kerf width and the best surface quality simultaneously and separately. In this present study stainless steel 304 is used as a work piece, brass wire of 0.25mm diameter used as a tool and distilled water is used as a die electric fluid. For experimentation Taguchi's L_{16}, orthogonal array has been used. The input parameters selected for optimization are gap voltage, wire feed, pulse on time, and pulse off time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters. The Analysis of Variance resulted that the pulse on time has major influence on the surface roughness (µm) and kerf width (mm) in both the Taguchi optimization method and Grey relational analysis. The objectives such as surface roughness and kerf width are optimized using a single objective Taguchi method and multi objective grey relational analysis and the same has been validated with the experimental results. Sengottuvel.P, et al, (2013) have investigate the effects of various EDM input parameters as well as the influence of different tool geometry on Material Removal Rate (MRR),Tool Wear Rate (TWR) and Surface Roughness (SR) on machining of Inconel 718 material by using copper electrode. Five EDM parameters, namely pulse on time (T_{ON}), pulse off time (T_{OFF}), peak current (A), flushing pressure (P) and electrode tool geometry (G_{eo}), were considered here. Tool geometry of the electrodes was circle (C), square (S), rectangle (R) and triangle (T). Four different levels for the five input parameters were planned as per the L_{16} orthogonal array. The parameters were optimized using multi-objective optimization technique of desirability approach and the significance of each parameter was analyzed by Analysis of Variance (ANOVA). A comparison of the performances of the electrode by desirability approach and ANOVA showed that the current was the most influencing factor, followed by pulse on time and pulse off time. It was also observed that the rectangular tool geometry provided better results as compared to other tool geometries. Validation tests for FLM were carried out and show closer relationship with the experimental results. The proposed fuzzy model provides a more precise and easy selection of EDM input parameters for the required MRR, TWR and SR, thereby to optimize machining conditions and reduce costs. The fuzzy model was shown to be able to predict the experimental results with accuracy of 95%. The validation of fuzzy results with experimental findings proved the high accuracy of the model. Farnaz Nourbakhsh, et al, (2013) have reported an experimental investigation of wire electro-discharge machining (WEDM) of titanium alloy. They have investigated the effect of process parameters including pulse width, servo reference voltage, pulse current, and wire tension on process performance parameters (such as cutting speed, wire rupture and surface integrity). A Taguchi L_{18} design of experiment (DOE) has been applied. All experiments have been conducted using Charmilles WEDM. They have found that the cutting speed increases with peak current and pulse interval. Surface roughness was found to increase with pulse width and decrease with pulse interval. The Analysis of Variance (ANOVA) also indicated that voltage, injection pressure, wire feed rate and wire tension have non-significant effect on the cutting speed. Compared with high-speed brass wire, zinc-coated brass wire results in higher cutting speed and smoother surface finish. Sharma, et al. (2013) have investigated the effect of parameters on metal removal rate for WEDM using HSLA (High strength low alloy steel) as work-piece and brass wire as electrode. HSLA used in cars, trucks, cranes, bridges, roller coasters and other structures that are designed to handle large amounts of stress. It was observed that metal removal rate and surface roughness increases with increase in pulse on time and peak current. Metal removal rate and surface roughness decreases with increase in pulse off time and servo voltage. Wire mechanical tension has no significant effect on metal removal rate and surface roughness. Response Surface methodology (RSM) is used to optimize the process parameter for metal removal rate and surface roughness. RSM is formulating a mathematical model which correlates the independent process parameters with the desired metal removal rate and surface roughness. Prakash, et al. (2013) have investigated the effect of parameters like gap voltage, pulse on time, pulse off time, wire feed and percentage reinforcement on the responses material removal rate as well as surface roughness while machining aluminium alloy (A413)/ flyash / boran carbide hybrid composites using WEDM. They have used Taguchi's L_{27} orthogonal array for experimental work. ANOVA has been used to determine the design parameters significantly influencing the response. They have reported that gap voltage is the most influential parameter which significantly affects the MRR. Gap voltage and wire feed are the most influential parameter which significantly affect the surface roughness.

Sahu, et al. (2013) have proposed an optimization methodology for the selection of best process parameters in multi-response situation. Experiments have been conducted on a die-sinking electric discharge machine under different conditions of process parameters. A response surface methodology (RSM) is adopted to establish effect of various process parameters such as discharge current (I_p), pulse on time (T_{on}), duty factor (τ) and flushing pressure (F_p) on four important responses like material removal rate (MRR), tool wear rate (TWR), surface roughness (R_a) and circularity (r1/r2) of machined component. The data envelopment analysis (DEA) methodology along with average ranked value (ARV) approach has worked satisfactorily and yielded acceptable results as well as finding suitable condition among a large number of alternative processes for generation of a desired quality and productivity in EDM process. Hsu, et al. (2013) presents an experimental investigation of the machining characteristics of Polycrystalline Diamond (PCD) in micro wire electrical discharge machining (μ-WEDM). The Taguchi method was adopted to obtain the optimum conditions of parameter settings for cutting width and material removal rate (MRR). The ANOVA analysis has been used to predict the significant machining parameters according to L_{18} orthogonal array and signal/noise (S/N) ratio. The experimental results reveal that the intensity of open circuit voltage (UHP) affects significantly on the amount of cutting width as well as MRR. Additionally, the cutting width is also directly reduced by higher wire tension and lower flushing pressure. The MRR was increased at greater UHP and peak current (I). Finally, the confirmation experiments show that the cutting width and MRR also depends on the grain size of PCD (1.6μm ~7μm) by the optimum machining conditions. Shanmugam S, et al. (2013) have discussed the numerical modelling of Electro Discharge Machining (EDM) process using moving mesh feature. Coefficient of erosion was defined and found to be constant using analytical equations. This was validated by conducting experiments on electro discharge machining. Then, the machining process was modelled in software using the coefficient of erosion. When the same conditions were applied in the real time machining, the results obtained were in good agreement with that of the software results. The application of software modelling was demonstrated to determine the efficiency of drilling process. A comparison study was performed with the use of conventional and concentric electrode for drilling concentric micro size holes. It was concluded that reduced machining time and perfect concentricity was observed when conventional electrodes were replaced by concentric electrodes. Yet another study was performed to justify the reduction in machining time due to usage of conductivity enhancement rings in the direction of passage of current to enhance current flow by avoiding air gap insulation. Thus, software modelling helps to perform research by predicting machining time without the need of real time experimentation.

2. Experimental work

The experiments were performed on CONCORD DK7720C four axes CNC WED machine. The basic parts of the WED machine consist of a wire electrode, a work table, a servo control system, a power supply and dielectric supply system. The CONCORD DK7720C allows the operator to choose input parameters according to the material and height of the work piece. The WED machine has several special features. Unlike other WED machines, it uses the reusable wire technology. The experimental set-up for the data acquisition is illustrated in the Fig. 1. The WEDM process generally consists of several stages, a rough cut phase, a rough cut with finishing stage, and a finishing stage. But in this WED machine only one pass is used.

The gap between wire and work piece is 0.02 mm and is constantly maintained by a computer controlled positioning system. Molybdenum wire having diameter of 0.18 mm was used as an electrode. The control factors and fixed parameters selected are as listed in Table 1. The control factors were chosen based on review of literature and experts. Each time the experiment was performed, an optimized set of input parameters was chosen. In this study, five machining parameters were used as control factors and each parameter was designed to have four levels denoted I, II, III and IV as shown in Table 1.

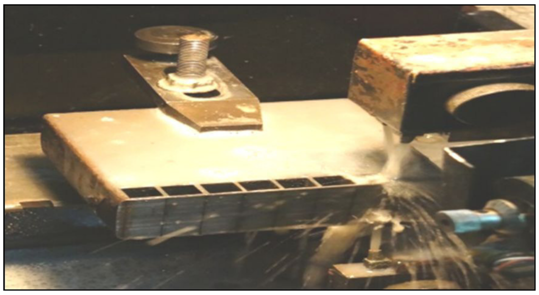

Fig. 1. Experimental Set-up

Table 1. Machining settings used in experiments

		Level			
Control Factors		I	II	III	IV
A	Pulse –on	16	20	24	28
B	Pulse-off	4	6	8	10
C	Current	3	4	5	6
D	Bed speed	20	25	30	35

3. Results and Discussions

3.1 Multiple Regression Analysis

The objective of multiple regression analysis is to construct a model that explains as much as possible, the variability in a dependent variable, using several independent variables. The model fit is usually a linear model, though some timer non linear models such as log-linear models are also constructed. When the model constructed is a linear model, the population regression equation is

$$Y_i = \alpha + \beta_1 X_{1i} + \ldots\ldots\ldots\ldots + \beta_m X_{mi} + e_i \qquad (1)$$

Where Yi is the dependent variable and X_{1i} …………… X_{mi} are the independent variables for i^{th} data point and e_i is the error term. Error term is assumed to have zero mean. This error term is the combined effect of variables that are not considered explicitly in the equation, but have an effect on the dependent variable. The co-efficients α, β_1,……………β_m are not known and estimates of these values, designated as a, b_1…….b_m have to be determined from the sampled data. For this least squares estimation is used, which consists of minimizing.

$$SS = \sum_{i=1}^{n} e_i^{\,2} = \sum_{i=1}^{n} \left(Y_i - a - b_i X_{1i} \ldots\ldots\ldots\ldots - b_m X_{mi}\right)^2 \tag{2}$$

With respect to each of the co-efficients a, b_1…..b_m. This will give k+1 equations from which a, b_1…..b_m. can be obtained. These least squared estimates are the best linear unbiased estimates and hence gives the best linear unbiased estimate of the dependent variable.

$$Y = a + b_1X_1 + b_2X_2 + \ldots\ldots\ldots\ldots + b_mX_m \tag{3}$$

The obtained regression model for estimating surface roughness for EN-31 material is,

$$Ra = 1.59e\text{-}2 \times A - 4.50e\text{-}2 \times B + 1.9e\text{-}1 \times C + 1.64e\text{-}2 \times D + 1.358 \tag{4}$$

The obtained regression model for estimating material removal rate for EN-31 material is,

$$VMRR = 6.41e\text{-}2 \times A - 2.26e\text{-}1 \times B + 7.77e\text{-}1 \times C + 6.52e\text{-}2 \times D + 1.60 \tag{5}$$

The obtained regression model for estimating accuracy for EN-31 material is,

$$Accuracy = -1.25e\text{-}2 \times A + 1.15 \times B + 1.0e\text{-}1 \times C + 2.0e\text{-}2 \times D - 6.5e\text{-}1 \tag{6}$$

The obtained regression model for estimating electrode wear for EN-31 material is,

$$Electrode\ Wear = 2.76e\text{-}1 \times A - 1.46e\text{-}2 \times B + 3.59e\text{-}1 \times C + 1.46e\text{-}2 \times D - 2.068 \tag{7}$$

3.2 Group Method of Data Handling

Group method of data handling (GMDH) is a family of inductive algorithms for computer-based mathematical modelling of multi-parametric datasets that features fully automatic structural and parametric optimization of models. GMDH is used in such fields as data mining, knowledge discovery, prediction, complex systems modelling, optimization and pattern recognition. GMDH algorithms are characterized by inductive procedure that performs sorting-out of gradually complicated polynomial models and selecting the best solution by means of the so-called external criterion.

A GMDH model with multiple inputs and one output is a subset of components of the base function *(8)*.

$$Y(x_1, \ldots\ldots, x_n) = a_0 + \sum_{i=1}^{m} a_i f_i \tag{8}$$

Where f are elementary functions dependent on different sets of inputs, a are coefficients and m is the number of the base function components. In order to find the best solution GMDH algorithm consider various component subsets of the base function *(8)* called partial models. Coefficients of these models estimated by the least squares method. GMDH algorithm gradually increase the number of partial model components and find a model structure with optimal complexity indicated by the minimum value of an external criterion. This process is called self-organization of models. The most popular base function used in GMDH is the gradually complicated Kolmogorov-Gabor polynomial *(9)*.

$$Y(x_1, \ldots\ldots\ldots, x_n) = a_0 + \sum_{i=n}^{n} a_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij} x_i x_j + \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n} a_{ijk} x_i x_j x_k + \ldots\ldots \tag{9}$$

GMDH is also known as polynomialneural networks and statistical learning networks thanks to implementation of the corresponding algorithms in several commercial software products.

3.3 Prediction of response variables of Stavax material

The prediction of responses was carried out using MRA and GMDH, for various training sets of 50%, 62.5% and 75% of data is used in GMDH for up to Level 5. There are three criteria's, viz., regularity, unbiased and combined criteria's is used in GMDH. When the training is completed, it is necessary to check the network performance and determine if any changes need to be made to the training process, network architecture or the data sets.

Fig. 2, Fig. 3 and Fig. 4 shows the comparison of measured and predicted surface roughness, VMRR, accuracy and electrode wear using MRA and GMDH. There are different training datasets viz., 50%, 62.5%, and 75% are used up to Level 5 in GMDH for Stavax material.

Table 2. Machining performances using L'$_{16}$ orthogonal array

Run	Pulse-on (μs)	Pulse-off (μs)	Current (Amps)	Bed speed (μm/s)	Surface Roughness (μm)	VMRR mm^3/min	Accuracy (μm)	Electrode Wear (μm)
1	16	4	3	20	2.392	5.522	5	3.598
2	16	6	4	25	2.384	5.501	6	4.121
3	16	8	5	30	2.526	5.362	10	4.317
4	16	10	6	35	2.792	7.217	12	4.689
5	20	4	4	30	2.631	6.803	4	5.019
6	20	6	3	35	2.641	6.237	7	5.245
7	20	8	6	20	2.843	7.350	9	5.215
8	20	10	5	25	2.891	7.440	11	5.886
9	24	4	5	35	3.317	9.732	6	6.947
10	24	6	6	30	3.281	8.631	8	7.874
11	24	8	3	25	2.476	6.059	9	6.015
12	24	10	4	20	2.253	5.202	12	6.545
13	28	4	6	25	3.024	8.586	4	7.989
14	28	6	5	20	2.786	6.376	7	7.616
15	28	8	4	35	2.582	6.085	8	7.078
16	28	10	3	30	2.448	5.375	12	6.785

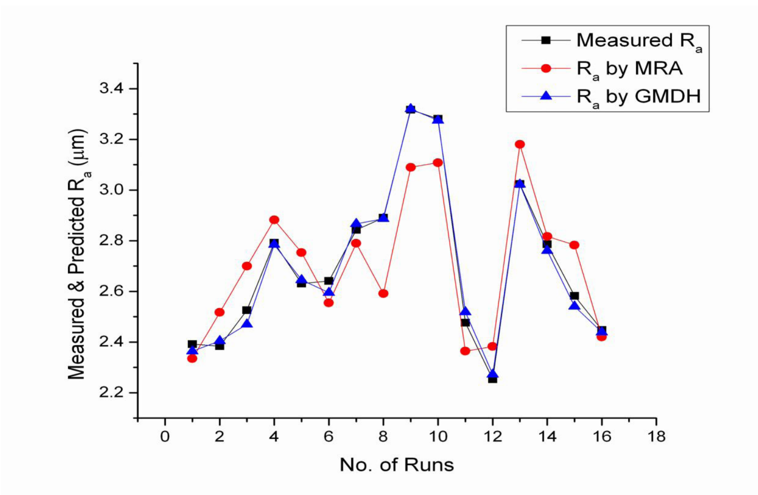

Fig. 2. Comparison of measured and predicted surface roughness using MRA and GMDH

It is observed from the Fig. 2 predicted surface roughness of regularity criteria with 75% of the data set exhibits better correlation with the measured surface roughness than 50% and 62.5% of the data set at Level 5 using GMDH when compared to the MRA.

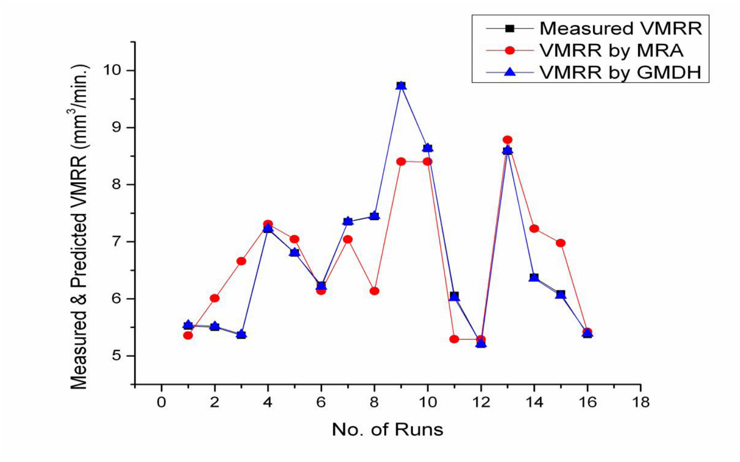

Fig. 3. Comparison of measured and predicted VMRR using MRA and GMDH

From the Fig. 3 predicted VMRR of regularity criteria with 62.5% of the data set exhibits better correlation with the measured VMRR than 50% and 75% of the data set at Level 5 using GMDH when compared to the MRA.

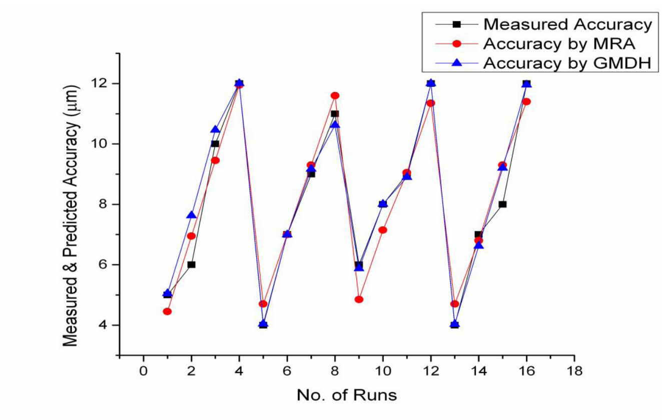

Fig. 4. Comparison of measured and predicted accuracy using MRA and GMDH

It is clearly observed from Fig. 4 predicted accuracy of regularity criteria with 62.5% of the data set exhibits better correlation with the measured accuracy than 50% and 75% of the data set at Level 5 using GMDH when compared to the MRA.

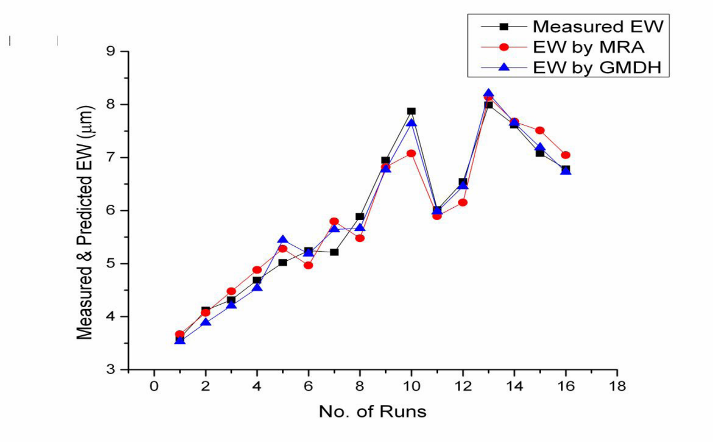

Fig. 5. Comparison of measured and predicted electrode wear using MRA and GMDH

It is clearly observed from Fig. 5 predicted electrode wear of regularity criteria with 75% of the data set exhibits better correlation with the measured electrode wear than 50% and 62.5% of the data set at Level 3 using GMDH when compared to the MRA.

4. Conclusion

This paper has presented an investigation on the estimation and prediction of machining parameters on surface roughness, VMRR, accuracy and electrode wear in WEDM operations. It was found that, each control factors are affecting the response variables to different extent. We have also seen that multiple regression analysis is a preferred tool for estimating the machining performances of Stavax material. Three different criterion functions of GMDH viz., Regularity (RMS), Unbiased and Combined have been tried for estimation of machining performances Stavax.

The results from the GMDH show that the regularity criterion function provides good estimation than the other two functions. Different models of GMDH were built by varying the number of data in the training set to 50%, 62.5% and 75% of the total data. It was found that the least error of estimation and best-fit was found for 75% of data in training set for surface roughness and electrode wear and 62.5% of data in training set for VMRR and accuracy. Comparison of the two theoretical methods for estimation of machining performances, it was found that, GMDH technique has an edge over MRA. Thus, predicted response variables of 62.5% and 75% of data in training set correlates well with the measured response variables. GMDH technique gave better prediction than MRA.

References

E. Weingärtner, K. Wegener and F.Kuster, 2013, "Influence of workpiece circumferential speed in wire electrical discharge machining", Procedia CIRP, 6,238–243.

Farnaz Nourbakhsh, K. P. Rajurkar, A. P. Malshe and Jian Cao, 2013, "Wire electro-discharge machining of titanium alloy", Procedia CIRP, 5, 13–18.

F. C. Hsu, T. Y. Tai, V. N. Vo, S. Y. Chen and Y. H. Chen, 2013, "The machining characteristics of polycrystalline diamond (PCD) by micro-WEDM", Procedia CIRP, 6, 261–266.

Jambeswar Sahu, Chinmaya P. Mohanty and S.S. Mahapatra, 2013, "A DEA approach for optimization of multiple responses in Electrical Discharge Machining of AISI D2 steel", Procedia Engineering, 51, 585–591.

J.A. Sánchez, S. Plaza, R. Gil, J.M. Ramos, B. Izquierdo, N. Ortega and I. Pombo, 2013, "Electrode set-up for EDM-drilling of large aspect-ratio microholes", Procedia CIRP, 6, 274–279.

J. Uday Prakash, T.V.Moorthy and J.Milton Peter, 2013, "Experimental Investigations on Machinability of Aluminium Alloy (A413) / Flyash / B4C Hybrid Composites using Wire EDM", Procedia Engineering, 64, 1344-1353.

K.P. Rajurkar, M. M. Sundaram and A. P. Malshe, 2013, "Review of Electrochemical and Electrodischarge Machining", Procedia CIRP, 6, 13–26.

M. Durairaj, D. Sudharsun and N. Swamynathan, 2013, "Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade", Procedia Engineering, 64, 868–877.

M-T. Yan, G-R. Fang, Y-T. Liu and J-R. Li, 2013, "Fabrication of polycrystalline diamond wheels by micro wire-EDM using a novel pulse generator", Procedia CIRP, 6, 203–208.

Neeraj Sharma, Rajesh Khanna and Rahuldev Gupta,, 2013, "Multi Quality Characteristics Of WEDM Process Parameters With RSM", Procedia Engineering, 64, 710 – 719.

Sengottuvel.P, Satishkumar and Dinakaran.D 2013, "Optimization Of Multiple Characteristics Of EDM Parameters Based On Desirability Approach And Fuzzy Modeling", Procedia Engineering, 64, 1069–1078.

Vignesh Shanmugam S, Krishnaraj V, Jagdeesh K A, Varun Kumar S and Subash S, 2013, "Numerical Modelling of Electro-Discharge Machining Process using Moving Mesh Feature", Procedia Engineering, 64,747–756.