International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 9, Issue 4 (JULY-AUGUST 2021), PP. 40-46

INVESTIGATION OF VARIOUS CUTTING PARAMETERS OF EN-31 IN WIRE ELECTRIC DISCHARGE MACHINING PROCESS

Utkarsh Kumar Sharma[1], Maneesh Mishra[2],
Department of Production Engineering
[1]M.Tech (Production Engineering) Scholar, S.R. Institute of Management & Technology, Lucknow
[2]Assistant Professor, S.R. Institute of Management & Technology, Lucknow

Abstract— **Wire electrical discharge machining (WEDM) has tremendously improved the processing of newer and very hard materials, especially used for the aerospace, nuclear, and medical industries. It is the most important Nontraditional machining process which is widely used for machining difficult-to-machine materials like titanium, nimonics, zirconium, etc., with intricate shapes. Using numerical control WEDM, complicated profiles can be easily machined through difficult-to-machine electrically conductive materials. The high degree of accuracy obtained and the fine surface quality make WEDM a very valuable technology in the modern day manufacture.**

EN-31 alloy steel, widely used in automotive and lock industries, is electrically machined in order to study the effects of some important cutting parameters on Metal Removal Rate (MRR), Surface Roughness (Ra), and Overcut. Whereas the Metal Removal Rate determines the economics of machining and rate of production, the Surface Roughness and Overcut denotes the quality of machining and degree of precision respectively. The experimental work during the study has been conducted on an ELECTRONICA SPRINTCUT WEDM machine and deals with the features of rough cutting regime of EN-31 alloy steel.

The present work also highlights the development of mathematical models for correlating the inter-relationships of various WEDM machining parameters such as; pulse on- time (Ton), pulse peak current (Ip), wire tension (T), wire feed rate (F) and water pressure (P) on Metal removal rate, Surface roughness and Overcut while machining EN-31 steel. A second-order polynomial, in terms of machining parameters, was developed for Metal removal rate, Surface roughness and Overcut using Response Surface Methodology (RSM). These models are developed by conducting a designed experiment based on the Rotatable Central Composite Design (RCCD). Mathematical models fitted to the experimental data will contribute towards optimization of process parameters.

Index Terms— **MRR, Surface Roughness (Ra), Rotatable Central Composite Design (RCCD), WEDM etc.**

I. INTRODUCTION

Over the past several decades, researches in the field of material science have led to the development of high strength materials used in technologically advanced industries. These materials and alloys are characterized by their high hardness, high strength, and high temperature resistance. Many of theses materials are very difficult to machine or even unmachinable by conventional means. However, Electrical Discharge Machining (EDM), one of the Nontraditional machining processes, is widely used to machine electrically conductive materials. EDM is a thermo- electric process in which material removal takes place through the process of controlled spark generation. EDM is commonly used in mould and die making industry and in manufacturing automotive, aerospace, nuclear and surgical components. Since there is no mechanical contact between the tool and the workpiece, thin and fragile components can be machined without the risk of damage. Commercially EDM exists in two forms, Die-sinking machines and Wire Cutting machines (Wire EDM).

Sinker EDM consists of a tool and workpiece submerged in dielectric fluid. The electrode (which is reverse of the workpiece cavity) and workpiece are connected to a suitable power supply. The power supply generates an electrical potential between the two parts. As the electrode approaches the workpiece, dielectric breakdown occurs in the fluid, forming plasma channel, and hence a high temperature spark is generated which erodes the material from both the work piece and electrode.

Wire electrical discharge machining (WEDM), also known as wire-cut EDM, applies a thin single-strand metal wire, usually of brass, through the workpiece. Dielectric fluid, typically deionized water, is pumped into the cutting zone. The Wire-cut EDM is typically used to cut thick metallic plates and to make punches, tools, and dies from hard metals that are difficult to machine by other methods.

A. Historical Background

WEDM was first introduced to the manufacturing industry in the late 1960s. In 1969 Agie (Agie Charmilles is the world's leading supplier of Non -Conventional Machines) launched the world's first numerically controlled wire-cut EDM machine. Seibu (SEIBU ELECTRIC & MACHINERY CO., LTD, Fukuoka, Japan) developed the first CNC wire EDM machine 1972 and the first system manufactured in Japan. The development of the process was the result of seeking a technique to replace the machined electrode used in EDM. In 1974, D.H. Dulebohn applied the optical-line follower system to automatically control the shape of the component to be machined by the WEDM process (Jameson, 2001). By 1975, its popularity was rapidly increasing, as the process and its capabilities were better understood by the industry (Benedict, 1987). It was only towards the end of the 1970s, when computer numerical control (CNC) system was initiated into WEDM that brought about a major evolution of the machining process. As a result, the broad capabilities of the WEDM process were extensively exploited for any through-hole machining owing to the wire, which has to pass through the part to be machined.

B. Applications of WEDM

As newer and more exotic materials are developed, and more complex shapes and contours are to be machined, conventional machining operations will continue to reach their limitations and the increased use of the WEDM in manufacturing will continue to grow at an accelerated rate (Newman et al., 2004). Owing to its capability of achieving great dimensional accuracy, surface finish and contour generation features the process has the ability to machine hard, difficult-to-machine materials. Parts with complex, precise and irregular shapes for forging, press tools, extrusion dies, difficult internal shapes for aerospace and medical applications can be made by EDM process.

Wire EDM has been employed for making dies of various types. The process is also used for fabrication of press tools and electrodes for use in other areas of EDM. Wire EDM can also be employed to cut cylindrical objects with high precision.

II. METHODOLOGY

A. THEORITICAL BACKGROUND

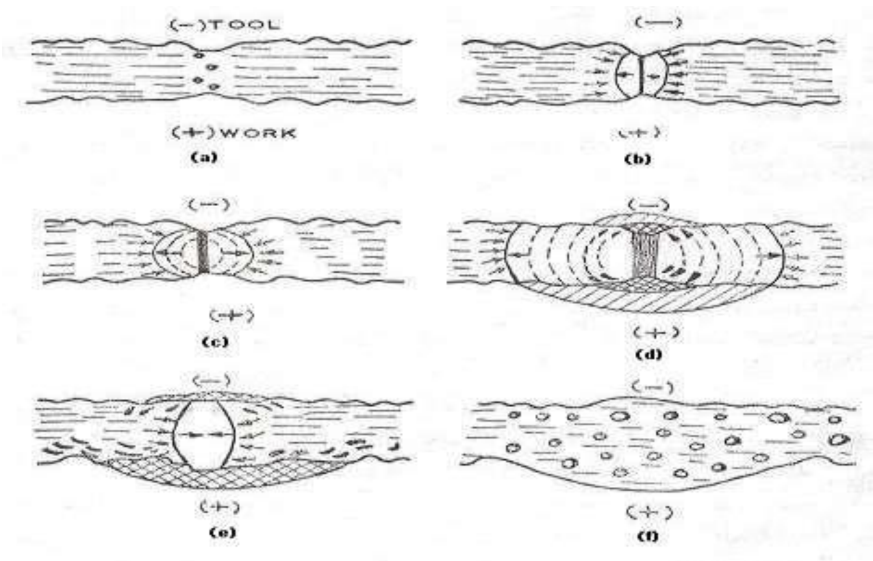
1) Mechanism of Metal Removal in EDM

When a suitable voltage is applied across the electrodes, potential intensity between the closest micro-irregularities builds up. Impurities increase field strength and electrons start leaving the cathode (field emission) and drift towards anode (fig. 2.1a). Collisional ionization at this stage is not expected. However, the dielectric fluid gets heated and a bubble is formed. High pressure vapour (or gas) bubble expands. Within the bubble, Collisional ionization takes place and after sometime, a narrow channel of continuous conductivity is formed (fig. 2.1b).

The plasma channel and the enveloping bubble expand continuously and there is considerable flow of electrons towards anode (fig. 2.1c). Due to increase in the field strength and impact of ions on the electrode surface, its temperature increases and the electron emission changes from field emission to thermal field emission. This increases the temperature further which melts and evaporates certain volume of material.

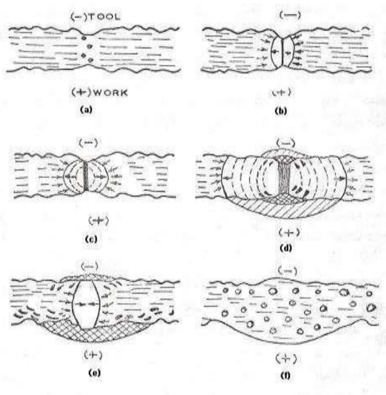
At this stage, some additional factors such as mechanical impact of particles, electrical forces, and pressure waves created due to high temperature gradient cause expulsion of the material from the molten pool (fig. 2.1d). A little (300 – 500 µs) after the discharge terminates, pressure inside the bubble drops abruptly due to its collapse, and some of the molten metal in the molten pool is ejected due to combined hydraulic and thermo-dynamical effects (fig. 2.1e).

Ejected metal is solidifies subsequently and is swept away by the flowing dielectric in the form of debris (fig. 2.1f). After the discharge is over, the dielectric within the gap de-ionizes completely and the channel of conductivity ceases to exist. A fresh discharge may initiate at some other point, where the tool-work gap is minimum.



2) Working principle of Wire-cut EDM

The basic working principle of wire-cut EDM is same as that of die-sinking EDM. In this process, a slowly moving wire travels along a prescribed path and removes material from the work piece. The material is removed by a series of discrete discharges between the wire electrode and the work piece in the presence of dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. Each discharge leaves a crater in the work piece and the tool. The area where discharge takes place is heated to extremely high temperature, so that the surface is melted and evaporated. The eroded particles are flushed away by the flowing dielectric fluid. The mechanism involved in wire-cut EDM process is shown below in fig 2.2.



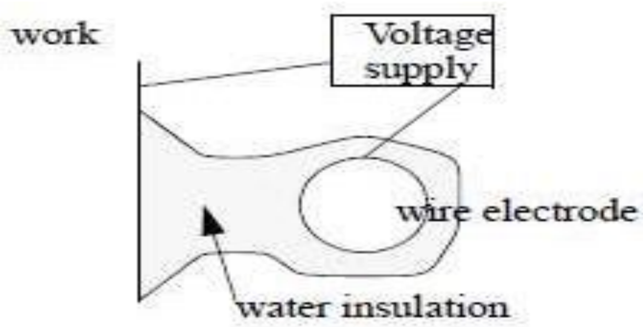


Figure 2.1: Successive stages of discharge

B. Design of Experiments (DOE)

1) DOE principles

Design of Experiments (DOE) refers to planning, designing and analyzing an experiment so that valid and objective conclusions can be drawn effectively and efficiently. In performing a designed experiment, changes are made to the input variables and the corresponding changes in the output variables are observed. The input variables are called factors and the output variables are called response. Each factor can take several values during the experiment. Each such value of the factor is called a level. A trial or run is a certain combination of factor levels whose effect on the output is of interest. It is convenient to represent the high level value of a factor as +1 and the low level value as -1, and transforming all the factors into the same [-1 1] coded range. It is essential to incorporate statistical data analysis methods in the experimental design in order to draw statistically sound conclusions from the experiment.

2) Response Surface Methodology

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes (Myers and Montgomery, 2002). The design procedure of RSM is as follows:

1. Designing a series of experiments for adequate and reliable measurements of the response of interest.
2. Developing a mathematical model of the response surface with the best fittings.
3. Finding the optimal set of experimental parameters that produce a maximum or minimum value of response.
4. Representing the direct and interactive effects of the process parameters through two- and three-dimensional plots.

Consider a process where the response variable (output) y depends on the controllable (input) variables x1, x2, …, xk. The relationship is:

$$y = f(x1, x2, \ldots, xk) \qquad (2.1)$$

The true form of the response variable y is seldom known for a process. In RSM, the true relationship between y and the independent variables is generally approximated by the lower-order polynomial models such as:

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k + \varepsilon$$

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon$$

Where ε represents the statistical error term

Here, the βs are the unknown parameters. These parameters are estimated by first collecting data on the system and then performing statistical model building by using regression analysis. Response surface designs are special types of experimental designs which are commonly used for the data collection phase. Polynomial models are generally linear functions of the unknown βs. Hence linear regression is used for the model building phase.

A linear regression model may be written in matrix notation as:

$$y = X\beta + \varepsilon \qquad (2.3)$$

Where

$$y = (y_1, y_2, \cdots, y_n)^T ,$$

$$X = \begin{pmatrix} 1 & x_{11} & \cdots & x_{1k} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & \cdots & x_{nk} \end{pmatrix}$$

$$\beta = (\beta_0, \beta_1, \cdots, \beta_k)^T \quad , \varepsilon = (\varepsilon_0, \varepsilon_1, \cdots, \varepsilon_n)^T$$

In general, y is an (n x 1) vector of the responses, X is an (n x p) matrix of the levels of the independent variables, β is a (p x 1) vector of the regression coefficients and ε is an (n x 1) vector of random errors, with p=k+1.

The least square estimate of the β parameters is:

$$b = (X^T X)^{-1} X^T y \qquad (2.5)$$

The fitted regression model is:

$$\hat{y} = Xb \qquad (2.6)$$

Where, ŷ is the estimated response based on linear regression model.

3) Central Composite Design

The central composite design (CCD) is one of the most popular classes of designs used for a second-order model. CCD designs comprise a set of two-level factorial points, axial points and center runs. The factorial points contribute to the estimation of linear terms and two-factor interactions. Factorial points are the only points which contribute to estimation of the interaction terms. The axial points contribute to the estimation of quadratic terms. In the absence of axial points, only the sum of the quadratic terms can be estimated. The center runs provide an internal estimate of pure error and contribute towards the estimation of quadratic terms. The CCD has a lot of advantages, one of which is that it enables us to analyze a response surface with a relatively small number of experimental runs.

The number of factorial runs depends on the type of factorial design used and the number of factors. For a full factorial, there are 2k factorial points. The number of axial points is 2k and the number of center runs (nc) depends on the number of factors. For up to four factors, three to five center runs are sufficient. Higher number of center runs is preferable if there are more than four factors.

The axial points lie at a distance of ± α from the center point (zero level for all factors). The value of α generally varies from 1 to √k. In the coded space, axial points are obtained by taking ± α level for one factor and the zero level for all other factors. Thus, there are 2k axial points, two points (one +α and one -α) for each factor. Each factor is varied over five levels: ± α (axial points), ± 1 (factorial points) and the center point.

C. Rotatable Central Composite Design (RCCD)

Rotatable designs belong to a series of central composite designs. In a Rotatable CCD the value of α is chosen so that the variance σ2 (ŷ) is the same for all points at equal distance from the centre of the design. Choosing appropriately the number of the observations at the central point nc (nc can be chosen larger than the minimal value which is 2 to 4), one can obtain almost uniform distribution of the variance within a spherical region of interest. Like central composite design, rotatable design may be subdivided into three parts. They are: factorial points, axial points (or star points) and center runs (to give roughly equal precision for ŷ within a circle of radius 1).

Rotatable designs for any number of variables can be built up from these three components. The value of α must be 2k/4 in order to make the design rotatable. Size of the experiments is reduced in case of variables greater than 5 (k>5), by using a half-replicate of the 2k factorial. With a half- replicate, α becomes 2(k-1)/4. In the present work a uniform precision, rotatable central composite experimental design was used. For k=5 variables, this design consists of 16 factorial runs (half replicate, 2(k-1)), 10 axial runs (2k), and 6 central runs (nc). The distance α is calculated as 2(k-1)/4 so as to obtain rotatability and a five variable central composite design is rotatable if α = ± 2.000.

III. EXPERIMENTAL PROCEDURE

A. Experimental Set-Up

1) Wire EDM Machine

All the experiments have been conducted on a Computer Numerically Controlled (CNC) Wire-cut EDM Machine, ELEKTRA SPRINTCUT, manufactured by ELECTRONICA MACHINE TOOLS Ltd., India. The Elektra Wire-cut EDM comprises of a machine tool, a power supply unit (ELPULS) and a dielectric supply unit. The experimental set-up is shown in fig 2.3.

Figure 2.3: Experimental set-up of wire cut EDM [Courtesy NSIC, Aligarh (India)]

2) Machine tool

The machine tool comprises of a main work table (called as X-Y table), an auxiliary table (called as U-V table) and a wire drive mechanism. The workpiece is mounted and clamped on the main work table. X,Y,U,V axes moves in steps of 1 micron, by means of pulse motors , U &V axes are parallel to X &Y axes respectively. A traveling wire which is continuously fed from wire feed spool is caused to travel through the workpiece and goes finally to the waste-wire box. Along its traveling path, the wire is supported under tension, between a pair of wire guides is stationary whereas the upper wire guide is supported by the U-V table. The upper wire guide can be displaced transversely, along U-V axes; with respect to the lower wire guide .It can also be positioned vertically along Z axis by moving the vertical arm.

3) Power Supply

The power supply unit comprises of Electric pulse generator, motor drives units for X, Y, U, V axes and controller.

4) Dielectric Supply

During machining the machining zone is continuously flushed with water passing through the nozzles on both sides of the workpiece. The spark discharge across the workpiece

–wire electrodes causes ionization of the water which is used as a dielectric medium. It is important to note that ionization of water leads to the increases in water conductivity, it is better to change the water after 50 sparking hours to maintain the conductivity within the required range.

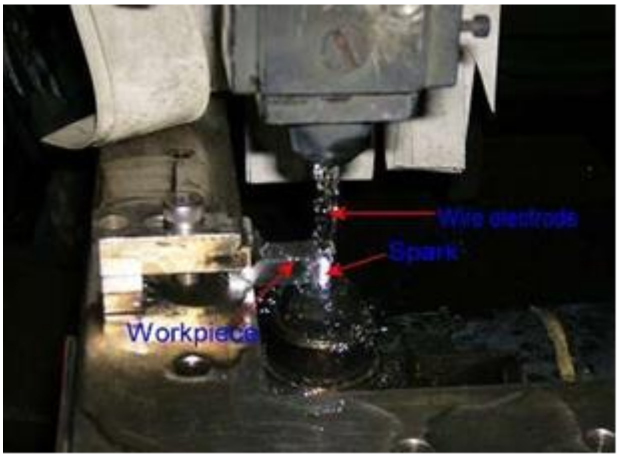
The range and least count of various electrical parameters available on the machine are shown in Table 2.1.

Table 2.1: Range of values available on the Wire EDM machine on which experiments have been conducted

Parameters	***Range***	***In steps of***
Pulse on-time	00-31 µs	1 µs
Pulse off-time	00-63 µs	1 µs
Pulse peak current	10-230 A	5 A
Pulse peak voltage	0-2	1
Wire tension	300-1980 g	120 g
Wire feed	01-15 m/min	1 m/min
Water pressure	3-12 kg/cm^2	1 kg/cm^2
Servo voltage setting	0-99	1
Servo feed setting	0-999	1

5) Experimental Procedure

The test specimens (workpieces) were thoroughly washed in petrol, dried, and accurately weighed on an electronic balance (“ADAIR”, AD-600B) to an accuracy of 0.01 g. These samples were then mounted on the work table in the work holding fixture one by one and properly aligned. Wire electrode is initially kept at the position 8 mm from the free end of the workpiece along its 25 mm length from where the machining starts. The placement of test specimen on the work table is shown in fig 4.3. A constant gap between the workpiece and the wire electrode was maintained during machining by the servo motor. The fixed parameters were set as per given values shown in the table 4.3. The input (or test) parameters were set for each run as per given design of experiments (DOE). All the parameters controlled and monitored during machining by the control panel of the machine unit. Water (dielectric) pressure was monitored by the gauge provided in the flow line of the dielectric. Both top and bottom flushing was used. Length of the machined slot was set to 7 mm. The machining time was recorded with the help of stop watch. Machined samples were cleaned, dried with the help of air blower so that dielectric particles were removed from the machined slot and again weighed for determining the weight of material eroded during the test. The experimental work was carried out at National Small Scale Industries Corp. (NSIC) Ltd., Aligarh, UP (India).



IV. RESULTS

A. Parametric Analysis

In order to study the effect of the input parameters, a designed experiment has been conducted as discussed in earlier Since, the aim is to fit a second order polynomial function using the DOE, hence, a Rotatable Central Composite design has been used which is capable of fitting a second order polynomial function.

B. RCCD Observations

The experimental data obtained from the RCCD runs are shown in Table 6.1. It is interesting to note that when the input parameters were changed, significant changes in the MRR, Ra and Overcut values were obtained. MRR lies in the range of 1.64 - 29.39 mg/min, Ra lies in the range of 1.54 -3.25 µm and the Overcut lies in the range of 30.5 - 53.5 µm.

V. CONCLUSIONS

In this experimental study, the effect of WEDM parameters such as pulse on-time, pulse peak current, wire tension, wire feed rate and water pressure on machining characteristics of EN-31 steel was investigated. Experiments based on the Rotatable Central Composite Design (RCCD) were conducted to develop empirical models of the process. Summarizing the main features of the results, the following conclusions may be drawn:

5.1. WEDM process has proved its adequacy to machine EN-31 steel. The Metal Removal Rate (MRR) lies in the range of 1.64 - 29.39 mg/min, Overcut lies in the range of 30.5 – 53.5 µm and Surface Roughness (Ra) lies in the range of 1.54 – 3.25 µm.

5.2. From the designed set of experiments based on the Rotatable Central Composite Design (RCCD) it was found that the Pulse on-time, Pulse peak current, and Wire tension are the most dominating parameters for Metal removal rate (MRR). Whereas Pulse on-time is the most dominating parameter for Overcut, and Pulse on-time and Pulse peak current are the most dominating parameters for Surface Roughness (Ra).

5.3. The analysis of the response parameters using RSM technique has the advantage of explaining the effect of each working parameter on the value of the resultant response parameter.

5.4. The regression technique is an important tool for representing the relation between machining characteristic and WEDM process input parameters, and the obtained mathematical models, indicate this correlation perfectly.

5.5. Results show that the Rotatable Central Composite Design (RCCD) is a powerful tool for providing experimental diagrams and statistical-mathematical models, to perform the experiments appropriately and economically.

5.6. The variables affecting the Metal removal rate, Overcut and Surface roughness were identified using ANOVA technique. Statistical analysis is carried out and the model adequacy is also checked.

5.7. The pulse on-time parameter has direct effect on the metal removal rate and surface roughness, as we increase the pulse on-time the metal removal rate and surface roughness increases. While Overcut decreases with increase in pulse on-time.

5.8. The pulse peak current parameter has direct effect on the metal removal rate and surface roughness, as we increase the pulse on-time the metal removal rate and surface roughness increases. While Overcut first increases and then decreases with increase in pulse on-time.

5.9. Metal removal rate, Overcut and Surface roughness decreases when the wire tension is increased.

5.10. Wire feed rate has no effect on the metal removal rate and surface roughness. While Overcut decreases when the wire feed rate is increased.

5.11. Metal removal rate and Surface roughness first increases and then decreases with increase in water pressure. While Overcut initially decreases and then increases with increase in water pressure.

5.12. The developed technology setting in the field of wire electrical discharge machining of EN-31 steel will find tremendous potentiality in modern industrial applications for efficient manufacturing of precision jobs. Since EN-31 steel is widely used in automotive and lock industries. Besides the proposed modeling technique can also be utilized for optimizing the machining parameters in WEDM.

VI. Scope for Future Work

Further research might attempt to consider the other performance criteria, such as surface waviness, cutting speed, dimensional shift, wear ratio, etc. as an output parameter (or response). This technique can also be applied for the various conventional machining operations and for machining of advanced materials like composites to improve the performance characteristics simultaneously.

Also an attempt can be made to consider more factors, such as wire/workpiece material, dielectric type, dielectric flow rate, effective wire offset, duty factor, pulse off-time, spark gap voltage, and open circuit voltage can be used as input parameters for further research. The techniques presented in this study might also be carried out for the finishing operation of WEDM process.

The experimental results obtained in this study may be optimized so that a technology table is developed, which will be very useful and may be used as a guideline for machining of EN-31 steel. Apart from experimental work, ample scope exists for theoretical modeling and process simulation in WEDM.

References

[1] Benedict, G.F., 1987. Electrical discharge machining (EDM), Non-Traditional Manufacturing Processes, Marcel Dekker, Inc, New York & Basel, pp. 231–232.

[2] Bhattacharyya, B., Sorkhel, S.K., 1999. Investigation for controlled electrochemical machining through response surface methodology based approach. Journal of Materials Processing Technology, 86, 200–207.

[3] Chiang, K.T., Chang, F.P., 2006. Optimization of the WEDM process of particle-reinforced material with multiple performance characteristics using grey relational analysis. Journal of Materials Processing Technology, 180, 96–101.

[4] Cochran, W.G., and Cox, G.M., 1977. Experimental Designs, Second edition, Asia Publishing House, Bombay, India.

[5] Dauw, D.F., Albert, L., 1992. About the evolution of tool wears performance in wire EDM. Ann CIRP 41(1):221–225.

[6] Ebeid, S.J., Hewidy, M.S., El-Taweel, T.A., Youssef, A.H., 2004. Towards higher accuracy for ECM hybridized with low-frequency vibrations using the response surface methodology. Journal of Materials Processing Technology, 149, 432–438.

[7] Gauri, S.K., Chakraborty, S., 2009. Optimization of multiple responses for WEDM processes using weighted principal components. International Journal of Advanced Manufacturing Technology, 40, 1102–1110.

[8] Gauri, S.K., Chakraborty, S., 2009. Multi-response optimization of WEDM process using principal component analysis. International Journal of Advanced Manufacturing Technology, 41, 741–748.

[9] George, P.M., Raghunath, B.K., Manocha, L.M., Warrier, Ashish M., 2004. Modeling of machinability parameters of carbon–carbon composite-a response surface approach. Journal of Materials Processing Technology, 153–154, 920-924.

[10] Gokler, M.I., Ozanozgu, A.M., 2000. Experimental investigation of effects of cutting parameters on surface roughness in the WEDM process. International Journal of Machine Tools & Manufacture, 40, 1831–1848.

[11] Han, F., Jiang, J., Yu, D., 2007. Influence of machining parameters on surface roughness in finish cut of WEDM. International Journal of Advanced Manufacturing Technology, 34 (5–6), 538–546.

[12] Hascalyk, A., Caydas, U., 2004. Experimental study of wire electrical discharge machining of AISI D5 tool steel. Journal of Materials Processing Technology, 148, 362–367.