International Journal of Advanced Research in IT and Engineering
ISSN: 2278-6244

OPTIMIZATION OF MACHINING PARAMETERS OF EN24 ALLOY STEEL ON WEDM USING RSM

Sandeep Malik*

Abstract: *Due to the technological development of mechanical and production industries, the demands for materials having high hardness, toughness, strength and impact resistance are increasing. Wire EDM machines are used to cut all conductive material of any hardness or toughness or that are difficult or impossible to cut with conventional methods. The machines also specialize in cutting complex contours or fragile geometries that would be difficult to be produced using conventional machining parameters. Wire electrical discharge machining process is a highly complex, time varying & stochastic process. The process output is affected by large number of input variables. Therefore a suitable selection of input variables for the wire electrical discharge machining (WEDM) process relies heavily on the operators technology & experience because of their numerous & diverse range. The problem of arriving at the optimum levels of the operating parameters has attracted the attention of the researchers and practicing engineers for a very long time. WEDM is extensively used in machining of conductive materials when precision is of prime importance. Rough cutting operation in wire EDM is treated as challenging one because improvement of more than one performance measures viz. Metal removal rate (MRR), surface finish & cutting rate are sought to obtain precision work. This paper reviews the effects of various input parameters on the performance parameters i.e. material removal rate, surface finish etc.*

Key Words: *WEDM, Process parameters, Response Surface Methodology*

---

*Research Scholar in Mechanical Engg. Deptt. UIET,MDU, Rohtak

1. INTRODUCTION

Wire Electric Discharge Machining (WEDM) is a non-traditional process of material removal from electrically conductive materials to produce parts with intricate shapes and profiles. This process is done by using a series of spark erosion. These sparks are produced between the work piece and a wire electrode (usually less than 0.30 mm diameter) separated by a dielectric fluid and erodes the work piece to produce complex two and three dimensional shapes according to a numerically controlled pre-programmed path. The sparks produce heating and melt work piece surface to form debris which is then flushed away by dielectric pressure. During the cutting process there is no direct contact between the work piece and the wire electrode. The wire electrical discharge machining (WEDM) has become an important non-traditional machining process because it can machine the difficult-to-machine materials like titanium alloys and zirconium which cannot be machined by conventional machining processes.

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. The development of new advanced engineering materials and the need to meet demand for precise and flexible prototype and low-volume production of components have made wire electrical discharge machining (WEDM) an important manufacturing process.

The basic mechanism of metal removal in WEDM is identical to conventional EDM. Instead of moving electrode (as in EDM), the electrode in this process is a moving wire of copper or brass. A vertically oriented wire is fed into the work piece continuously travelling from a supply spool to a take up spool. For this purpose a hole is pre-drilled in the work piece, through which the wire electrode will pass. A constant gap between tool and work piece is maintained with the help of computer controlled positioning system. This system is used to cut through complicated contours especially in difficult-to-machine materials. This process gives a high degree of accuracy and a good surface finish.

WEDM equipment first appeared in the early 1960s, and performed simple machining utilizing the phenomenon of electrical spark. The first five-head WEDM arrived in the United States in December, 1980. In today's WEDM it is possible to program wire to follow a complex path in two axes. Hence, it is possible to use this machine tool for making dies for stamping fine blanking and extrusion as well as 2-D through holes. It is possible to tilt the wire in position other than perpendicular to X and Y axes. It is possible to perform 3-D cutting using WEDM in which two additional axes have been introduced. The drive motors which tilt the wire towards the front or back and left or right are controlled by the programmed commands in CNC WEDM. Fig 1.1 shows the Schematic diagram of WEDM.

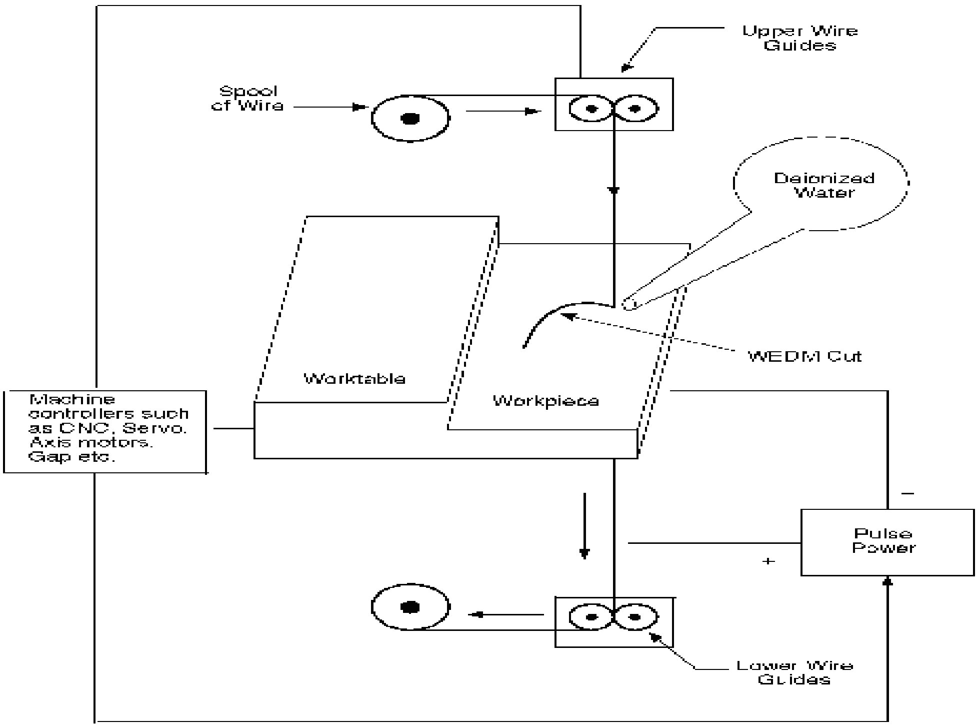


Fig 1.1 Schematic diagram of WEDM

1.1 Mechanism of Material Removal in WEDM Process

The mechanism of metal removal in wire electrical discharge machining mainly involves the removal of material due to melting and vaporization caused by the electric spark discharge generated by a pulsating direct current power supply between the electrodes. In WEDM, negative electrode is a continuously moving wire and the positive electrode is the work piece. The sparks will generate between two closely spaced electrodes under the influence of dielectric liquid. Water is used as dielectric in WEDM, because of its low viscosity and rapid cooling rate (Lok and Lee, 1997). No conclusive theory has been established for the complex machining process. However, empirical evidence suggests that the applied voltage creates an ionized channel between the nearest points of the work piece and the wire electrodes in the initial stage.

In the next stage the actual discharge takes place with heavy flow of current and the resistance of the ionized channel gradually decreases. The high intensity of current continues to further ionize the channel and a powerful magnetic field is generated. This magnetic field compresses the ionized channel and results in localized heating. Even with sparks of very short duration, the temperature of electrodes can locally rise to very high value which is more than the melting point of the work material due to transformation of the kinetic energy of electrons into heat. The high energy density erodes a part of material from both the wire and work piece by locally melting and vaporizing and thus it is the dominant thermal erosion process.

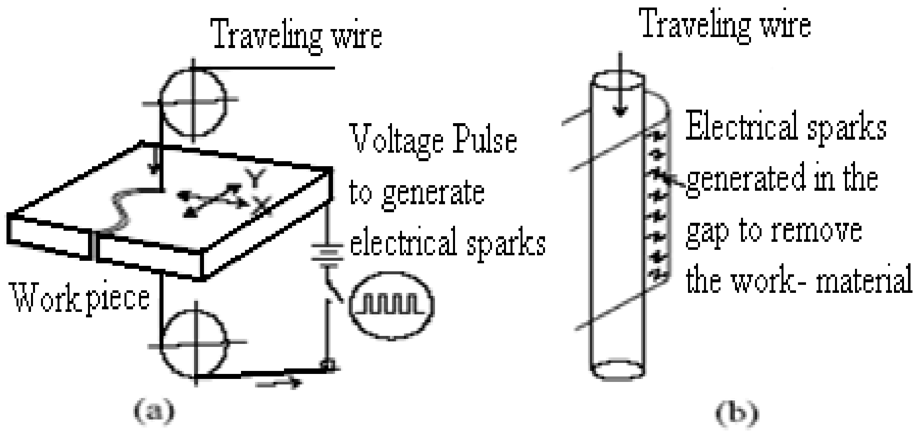


Fig 1.2 Close up view of gap and electric spark

1.2 Factors Affecting Material Removal Rate

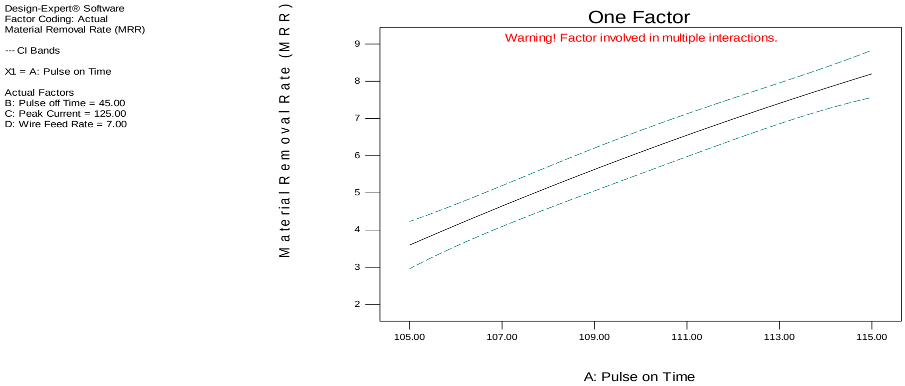
The effect of some important input parameters on material removal rate (MRR), surface roughness and accuracy is discussed below.

1.2.1 Discharge Current

The discharge current is a measure of the power supplied to the discharge gap. A higher current leads to a higher pulse energy and formation of deeper discharge craters. This increases the material removal rate (MRR) value. Similar effect on MRR is produced when the gap voltage is increased.

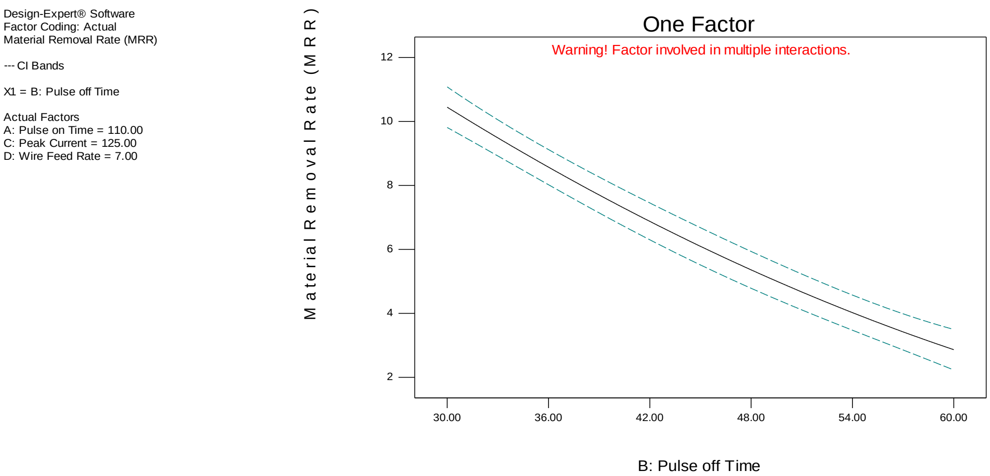
1.2.2 Pulse-on Time (P_{on})

Machining takes place only during the pulse-on time. When the wire electrode is at negative potential, material removal from the anode (work piece) takes place by bombardment of high energy electrons ejected from the wire surface. At the same time positive ions move towards the cathode. When pulses with small on times are used, material removal by electron bombardment is predominant due to the higher response rate of the less massive electrons. However, when longer pulses are used, energy sharing by the positive ions is predominant and the material removal rate decreases. When the electrode polarities are reversed, longer pulses are found to produce higher MRR.



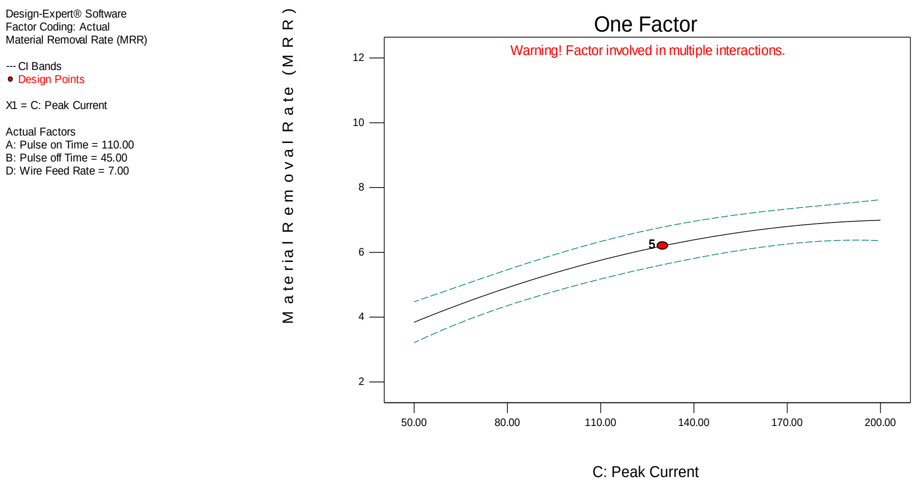
1.2.3 Pulse-off Time (P_{off})

A non-zero pulse off time is a necessary requirement for WEDM operation. Discharge between the electrodes leads to ionization of the spark gap. Before another spark can take place, the medium must de-ionize and regain its dielectric strength. This takes some finite time and power must be switched off during this time. Too low values of pulse-off time may lead to short-circuits and arcing. A large value on the other hand increases the overall machining time since no machining can take place during the off-time. The MRR is found to depend strongly on the spark frequency. When high frequency sparks are used lower values of MRR are observed. It is so because the energy available in a given amount of time is shared by a larger number of sparks leading to shallower discharge craters.



1.2.4 Peak Current (I_p)

Peak current is one of the primary input parameters of a WEDM process and the amount of current used is measured using ammeter during the process. In discharge machining, usually very high currents are not used as they often lead to high heat which damage of the work surface, the depth of the recast layer, work piece might become hardened than its parent material and so on. In the other words, the stronger the discharge current, the higher will be the metal removal rate, over-cut and surface roughness, but decreased the rate electrode wear. Therefore, it is a must to select an appropriate value of current in order to minimize electrode wear and to keep the current density within tolerable limits before machining can be start.



1.2.5 Wire Feed (WF)

Wire feed is the rate at which the wire-electrode travels along the wire guide path and is fed continuously for sparking. The wire feed range available on the present WEDM Machine is 1–15 m/min in steps of 1m/min. It is always desirable to set the wire feed to maximum. This will result in less wire breakage, better machining stability and slightly more cutting speed.

1.2.6 Flushing Pressure of Dielectric

Apart from the electrical parameters, pressure of the dielectric may have an effect on the process performance during WEDM. Velocity of the dielectric jet is directly proportional to the inlet dielectric pressure. A high velocity gas jet would lead to better flushing of debris from the discharge gap thus improving the MRR values. Forced flow of dielectric also helps in reducing the time required for recovery of dielectric strength of the medium since fresh and previously non-ionized medium is continuously supplied to the gap. This leads to higher process stability. Also, it is found that the dielectric strength of dielectric is dependent on the pressure and increases with an increase in the pressure.

1.2.7 Wire Tension Setting

This is the gram equivalent load with which the continuously fed wire is kept under tension so that it remains straight between the wire guides. While the wire is being fed continuously appropriate wire tension avoids the wire deflection from its straight path. The wire deflection is caused due to spark induced reaction forces and dielectric pressure.

2. OBJECTIVE OF THE PRESENT WORK

1. Experimental determination of the effects of the various process parameters viz pulse on time, pulse off time, spark gap set voltage, peak current, wire feed and wire tension on the performance measures like material removal rate, surface roughness in WEDM process
2. Optimization of the performance measures using Response Surface Methodology (RSM)
3. Modelling of the performance measures using response surface methodology (RSM)
4. Confirmation of the experiment using Design of Experiment Technique

3. WORK PIECE MATERIAL

The work material selected for the study was EN24 alloy steel with high tensile strength, shock resistance, good ductility and resistance to wear. The EN24 alloy steel is required to be heated to a temperature of 9000C to 9500 for hardening and followed by quenching in a oil medium. It is then tempered with temperature of 2000 to 2250 °C and obtains a final hardness of 45 to 55 HRC. EN24 is a medium-carbon low-alloy steel and finds its typical applications in the manufacturing of automobile and machine tool parts.

Chemical composition of the EN24 Steel is given in following table : -

Constituent	C	Si	Mn	Cr	Ni	Mo
% Composition	0.35 to 0.45	0.10 to 0.30	0.50 to 0.70	0.9 to 1.4	1.3 to 1.8	0.2 to

4. LITERATURE REVIEW

Mustafa Ilhan Gokler and Alp Mithat Ozanozu present the experimental study to select the most suitable cutting and offset parameter combination for the wire electrical discharge machining process in order to get the desired surface roughness value for the machined workpieces. A series of experiments have been performed on 1040 steel material of thicknesses 30, 60 and 80 mm, and on 2379 and 2738 steel materials of thicknesses 30 and 60 mm. *M.T. Antar, S.L. Soo, D.K. Aspinwall, D. Jones and R.Perez* made a brief review of recent minimum damage EDM pulse generator developments, experimental data is presented for workpiece productivity & integrity when WEDM Udimet 720 nickel based super alloy and Ti-6Al-2Sn-4Zr-6Mo titanium alloy, using Cu core coated wires (ZnCu50 and Zn rich brass). Up to a 70% increase in productivity was possible compared to when using uncoated brass wires with the same operating parameters. Surfaces measuring 0.6 ìm Ra, with near neutral residual stresses and almost zero recast were produced following two trim passes.

Fuzhu Han, Jun Jiang and Dingwen Yu gives the journal on Influence of machining parameters on surface roughness in finish cut of WEDM, according to them Surface roughness is significant to the finish cut of wire electrical discharge machining (WEDM). This paper describes the influence of the machining parameters (including pulse duration, discharge current, sustained pulse time, pulse interval time, polarity effect, material and dielectric) on surface roughness in the finish cut of WEDM. Experiments proved that the surface roughness can be improved by decreasing both pulse duration and discharge current. When the pulse energy per discharge is constant, short pulses and long pulses will result in the same surface roughness but dissimilar surface morphology and different material removal rates. The removal rate when a short pulse duration is used is much higher than when the pulse duration is long. *S. S. Mahapatra and Amar Patnaik* studied optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method, Wire electrical discharge machining (WEDM) is extensively used in machining of conductive materials when precision is of prime importance. Rough cutting operation in WEDM is treated as a challenging one because improvement of more than one machining performance measures viz. metal removal rate (MRR), surface finish (SF) and cutting width (kerf) are sought to obtain a precision work. Using Taguchi.s parameter design, significant machining parameters affecting. *Kapoor et al. [2010]* presented a study on different Wire electrodes which are being used in the industry and some high performance electrodes have been observed. It has been investigated that wire electrode contribute directly to cutting speed and dimensional 22 accuracy. Some of the electrodes studied are copper, brass and coated wire electrodes. It has been observed that for different materials different metal wire electrodes are preferred as they offer better response parameters such as better surface roughness, higher MRR etc. Composite wires have replaced zinc coated wires. Wires having higher tensile strength offer breakage resistance and can be obtained at the expense of fracture toughness. Copper clad wires are used for tall work pieces. High performance wires offer better productivity but with certain limitations such as cost, flaking etc., also they cannot be used all WEDM machine. *Patil and Brahmankar [2010]* investigated electrical and non electrical process parameters for machining metal matrix composite. The metal matrix composite chosen for this experiment is reinforced aluminium matrix composite and wire used is a brass wire of 0.25 mm diameter. Process parameters that have been chosen were reinforcement percentage current, pulse on-time, off time, servo reference voltage, maximum feed speed, wire speed, flushing pressure and wire tension whereas the response parameters were cutting speed surface roughness, and kerf width. Taguchi design methodology has been used to study the effect of performance parameters on the response parameters. It has been observed that WEDM is a good process to machine metal matrix composites and reinforcement percentage current and pulse on time have significant effect on cutting rate, surface roughness, and kerf width. Wire breakages have been observed for higher cutting speeds and also wire shifting leads to deterioration of the machined surface. *Datta and Mahapatra* proposed a quadratic mathematical model and conducted experiments by taking six WEDM process parameters: discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate. Experiments were carried out on D2 Tool Steel using a Zinc coated Copper wire electrode. The response parameters noticed for each experiment were MRR, Surface Roughness and Kerf. A statistical analysis has been carried for each result and responses have been utilized to fit the quadratic model which represents the above said six parameters. Grey based Taguchi technique has been utilized to evaluate optimal parameter combination to achieve maximum MRR, minimum roughness value and minimum width of cut. It has been found out that for continuous quality improvement Grey based Taguchi method is a very reliable method to predict optimal parameter values and all the parameters involved in the experimentation are independent of each other.

5. RESPONSE SURFACE METHODOLOGY (RSM)

Response surface methodology (RSM) is defined as a collection of mathematical and statistical methods that are used to develop, improve, or optimize a product or process. The method was introduced by Box and Wilson in 1951. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. It comprises statistical experimental designs, regression modelling techniques, and optimization methods. Most applications of RSM involve experimental situations where several independent (or control) variables potentially impact one or more response variable. The independent variables are controlled by the experimenter, in a designed experiment, while the response variable is an observed output of the experiment. Fig.5 illustrates the estimated relationship between a response variable and the two independent variables x_1 and x_2.

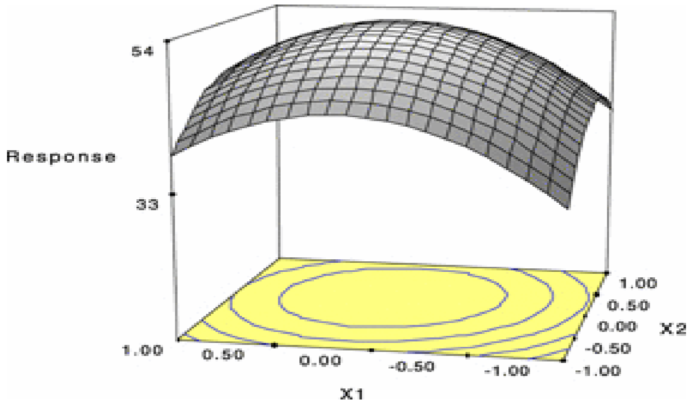


Fig. 5 An example of a response surface.

In many applications of RSM, a sequential process is performed. At the start, a researcher may have numerous control factors that are being studied. In order to determine initially which of these factors has an impact on the response variable, a screening design is often performed. This will potentially reduce the number of factors that need to be investigated in further experimentation. A researcher hopes to eliminate unimportant factors before investing time and money in a more elaborate experiment (i.e., second-order design). An existing screening design can also be augmented with additional design points in order to estimate a second-order (or response surface) model. Another potential step in RSM is the method of steepest ascent. This is an optimization technique that will allow one to move iteratively toward an optimum set of experimental conditions. This is often implemented when the researcher is initially experimenting in a suboptimal region. It would not be very prudent to invest in a large and perhaps costly experiment unless one feels that the region of optimum is either inside the design region or very close to the periphery. After a region of interest has been defined, a second-order (or response surface) design is used to estimate a second-order model. This provides an approximation of the true response surface over the region of interest, allows the optimum operating conditions to be chosen, and permits one to gain a better understanding of the estimated response surface.

The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process. This performance measure or quality characteristic is called the Response. The input variables are sometimes called Independent Variables, and they are subject to the control of the scientist or engineer. The field of response surface methodology consists of the experimental strategy for exploring the space of the process or independent variables, empirical statistical modelling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the values of the process variables that produce desirable values of the response.

6. REFERENCES

1. Y.S. Tarng, S.C. Ma, L.K. Chung, Determination of optimal cutting parameters in wire electrical discharge machining, Int. J. Mach. Tools Manuf. 35 (129) (1995) 1693–1701.
2. Y.S. Liao, J.T. Huang, H.C. Su, A study on the machining-parameters optimization of wire electrical discharge machining, J. Mater. Process. Technol. 71 (1997) 487–493.
3. Y.K. Lok, T.C. Lee, Processing of advanced ceramics using the wire-cut EDM process, J. Mater. Process. Technol. 63 (1–3) (1997) 839–843.
4. J.T. Huang, Y.S. Liao, W.J. Hsue, Determination of finish-cutting operation number and machining parameters setting in wire electrical discharge machining, J. Mater. Process. Technol. 87 (1999) 69–81.
5. M. Rozenek, J. Kozak, L. DabroVwki, K. LubkoVwki, Electrical discharge machining characteristics of metal matrix composites, J. Mater. Process. Technol. 109 (2001) 367–370.

6. N. Tosun, C. Cogun, An investigation on wire wear in WEDM, J. Mater. Process. Technol. 134 (3) (2003) 273–278.
7. S.H. Lee, S.H. Lee, Optimization of cutting parameters for burr minimization in face-milling operations, Int. J. Prod. Res. 41 (3) (2003) 497–511.
8. T.R. Lin, Optimization technique for face milling stainless steel with multiple performance characteristics, Int. J. Adv. Manuf. Technol. 19 (2002) 330–335.