Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 4, No. 2, April : 2023

EVALUATION OF PROCESS VARIABLES FOR ELECTRICAL DISCHARGE MACHINING OF TZM-MOLYBDENUM SUPERALLOY UTILIZING OFAT METHODOLOGY

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Abstract
Super alloys' extreme hardness and high point of melting make them particularly challenging to manufacture using conventional machining techniques. Certain materials may be easily machined adopting electric discharge machining (EDM), even when utilising soft tools material. The process parameters for machining TZM-Molybdenum superalloy, including peak current, pulse on time, pulse off, and gap voltage, were experimentally adjusted in this study utilising the one factor at a time (OFAT) methodology to optimize the material removal rate (MRR) and tool wear rate (TWR). An experiment is designed using the OFAT approach, which tests each element or cause separately rather than all of them at once. Electrolytic copper was used as the anode materials. To ascertain the impact of every input variable on the machinability of EDM, the collected findings were evaluated. According to the examination of the OFAT methodology, the peak current and pulse on time were responsible for a substantial impact on the rate of removal of material and rate of tool wear.

Keywords: Superalloy, TZM-Molybdenum, OFAT, MRR, TWR.

I. Introduction

Superalloy materials with high hot strengths, high melting points, and high wear resistance are becoming more and more popular in the nuclear reactor, aerospace, and aircraft sectors. Such metals are much more challenging to machine in addition to being tougher, harder, less heat-sensitive, and more corrosion-resistant. Complex forms are extremely difficult to produce with high surface finishes and accuracy levels at reasonable cutting rates using any conventional machining technique, necessitating the development of novel technologies. One of the best non-traditional techniques for producing accurate, high-quality materials at the lowest possible tooling cost is EDM. Superalloys may now be machined easily using the EDM technique.

A high voltage is used in the EDM process to cut through the small gap between both the material and the electrodes tool. In the insulating dielectric that is present in the small gap between the electrode and the workpiece, this high voltage creates an electric field. This led to the concentration of conducting particles suspended in the dielectric at the strongest electrical field points. When the dielectric breaks down and a transient spark discharges through the dielectric fluid, a little quantity of material is removed from the workpiece surface. This happens when the potential difference between the electrode and the workpiece is sufficiently large.

To increase the productivity, precision, and efficiency of the EDM process, several scholars have conducted extensive study in the past. Based on an analysis relating the process variables to the response variables, the appropriate machining settings are chosen to optimise performance parameters such as material removal rate (MRR), tool wear rate (TWR), surface roughness (SR), and radial overcut (ROC) during the EDM process. According to Rajesh Purohit et al. [1], who used grey relational analysis to optimise the EDM parameters for M2 tool steel, the electrode rotation speed is largely influenced by the voltage and spark time output parameters. The Taguchi approach was used by Mahendra M. Ghayatadak et al. [2] to study the EDM behavior of H13 Steel. The outcome showed that MRR and EWR have been strongly impacted by peak current and pulse on time. The WEDM variables upon that surface quality of Ti-6-2-4-2 Alloy were studied by M. P. Garg et al. [3] using response surface approach. D Kanagarajan et al. [4] investigated the electric discharge machining behaviour of WC/30%Co powder metallurgical alloys. The central composite design (CCD) approach was used for the analysis. M. Meignanamoorthy et al. [5] optimized the EDM properties of AA6351-Al_2O_3 composites using a multiobjective optimization technique such as the Taguchi L_9 orthogonal array. In this investigation, they determined that the current is the most important factor that affects the MRR and SR. S. Singh [6] optimized the EDM process with numerous performance criteria using the Taguchi approach in conjunction with a grey relational analysis. The data was acquired using Taguchi's L_{18} orthogonal array, and it was demonstrated that combining the Taguchi approach with grey relational analysis produced beneficial results and increased efficiency. B.K. Tharian et al. [7] used the Taguchi approach to optimise the machining settings for electrical discharge machining of Inconel 718 using cryo-treated graphite electrodes and determined that employing cryo-treated graphite electrodes improves the MRR.

In this case, MRR, surface roughness, and overcut of the EDM process have been optimized using grey relation analysis approaches by Bose et al. The machinability of the Nimonic C263 Super alloy was examined by Renu K. Shastri et al. [9] using several electrode materials, including copper, tungsten, and copper-tungsten. With a goal of consuming less specific energy, the results showed that the copper electrode performs better among the other two electrodes. The most important factor for SEC while milling Nimonic C263 workpiece is pulse on time. Using an electrolytic copper tool, Vaibhav Gaikwad et al. [10] studied the EDM process parameters for cryo-treated NiTi alloys. Taguchi's DOE with an L36 orthogonal array is being utilised for experiments. They claimed that the electrical conductivity of the work piece, gap current, and pulse on time are the key factors influencing the rate of material removal. The ideal parameters were determined using the grey-fuzzy logic approach by Dewangan et al. [11] after they evaluated the surface integrity of the AISI P20 workpiece. The wire cut EDM settings were optimized using a cuckoo search technique by Saravanan et al. [12]. To achieve the ideal machining condition, the multi-objective particle swarm optimization (MOPSO) technique is applied [13, 14].

This investigation used the JOEMARS AZ50-JM322 spark EDM equipment, as indicated in Figure 1. In this investigation, experiments were carried out utilising a 40mm-long electrolytic copper electrode with a 12mm diameter. The workpiece was a TZM-Molybdenum alloy with measurements of 120 mm x 120 mm x 6 mm. In this study, spark EDM was performed using a 12 mm electrode at a depth of 1 mm on the surface of TZM-Molybdenum superalloy under various machining circumstances.

II. MATERIAL

2.1 Work material

Due to its special qualities, such as a higher recrystallization temperature, higher creep strength, and higher tensile strength, TZM-Molybdenum is employed as a workpiece in the current study. TZM alloy is a well-known molybdenum-based alloy with 0.08% zirconium and the remaining molybdenum, 0.5% titanium, and 0.03% carbon. In Table 1, the chemical components of TZM are listed. The abbreviation TZM, which stands for the initials of these three components, stands for titanium zirconium molybdenum alloy. When the temperature hits 1300 °C, the strength of TZM is two times greater than that of pure molybdenum. The TZM Molybdenum alloy obtains a high recrystallization temperature and, as a result, a greater strength at high temperatures [15, 16] by mixing minor quantities of Ti and Zi. The same characteristics, however, provide a significant barrier when using conventional machining techniques. TZM may be used for electric discharge machining since it is conductive. Yet, the same alloy's EDM properties have scarcely ever been condensed.

Industrial Engineering Journal
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TZM was therefore selected as the workpiece material and was formed into thin plates that were 120 mm x 120 mm x 6 mm in size. Table 2 provides a list of TZM's properties.

Figure 1 A pictorial view of the EDM machine along with Fuzzy-controller

Table 1: The chemical formula for TZM- Molybdenum Alloy

Constituent	***Ti***	***Zr***	***C***	***Mo***
% Composition	0.5	0.08	0.02	Balance

Table 2: Physical and Mechanical Properties of TZM- Molybdenum Alloy [17]

Properties	***TZM- Molybdenum Alloy***
Density	10.22 g cm^{-3}
Melting point	2623 °C
Specific heat	305 J K^{-1} kg^{-1}
Thermal conductivity	126 W m^{-1} K^{-1}
Electrical resistivity	6.85 micro-ohm-cm
Coefficient of thermal expansion	5.3 $x10^{-6}$ K^{-1}
Tensile strength	560-1150 MPa
Modulus of elasticity	320 GPa
Elongation at break	<20 %

2.2 Electrode material

The material used for the electrode should be such that when ions impact on it during the machining process, little tool wear will result. Moreover, as EDM is used to produce complex-shaped geometric features, the tool electrode should be simple to build. Electrolytic copper electrode (99.9%) has been chosen as a tool electrode after taking the aforementioned parameters into account. The tests were conducted using a tool that had a 40 mm length and a 12 mm diameter.

2.3 Dielectric oil

The rate of metal removal and tool wear is affected by the dielectric oil choice, which has an impact on the EDM process. For this procedure, the industry is always looking for new and improved dielectric fluids. DEF 92 EDM oil was employed as the dielectric fluid in the current studies, and Table 3 lists some of its characteristics.

Table 3: Characteristics of dielectric used: DEF 92 EDM oil

Properties	***Unit***	***Values***
Viscosity @ 40°C	mm/s^2	2.16
Density @ 15°C	g/cm^3	0.767
Flashpoint	°C	105
Specific gravity	-	0.78
Di- electric strength	K.V	45
Colour	-	Crystal clear
Odour	-	Odourless

2.4. Input and Output parameters

The following input parameters were utilised in the current work:

- Peak current: The largest amount of current that an output is capable of providing for brief periods of time is known as the peak current.
- Pulse on-time: This is the period of time after the dielectric's breakdown voltage is attained and its ionization results in a spark between the electrode and the workpiece.
- Pulse off-time: This is the amount of downtime needed for the dielectric to reionize.
- Gap voltage: The voltage between the workpiece and the electrode is known as the gap voltage.

The output parameters used in the present work are:

- Metal Removal Rate (MRR): MRR is the amount of material removed in one unit of time. Typically, the rate of metal removal is represented in cubic millimeters per minute (mm^3/min).

$$\boldsymbol{MRR}\ (\mathbf{mm^3/min}) = \frac{\mathbf{Wi - Wf}}{\boldsymbol{\rho}\ \mathbf{x\ T}}$$

Where, w_i = the work piece's weights before it is machined

w_f = the work piece's weight following cutting

ρ = material density of the workpiece

T = minutes for machining

- Tool Wear Rate: The weight differential of the electrode before and after the performance trial is used to calculate the tool wear rate.

$$\boldsymbol{TWR}\ (\mathbf{mm^3/min}) = \frac{\mathbf{ti - tf}}{\boldsymbol{\rho}\ \mathbf{x\ T}}$$

Where, t_i = the tool's weights before it is machined

t_f = weights of the tool following machining

ρ = the tool material's density

T = minutes for machining.

III. One factor at a time approach (OFAT)

The execution and data analysis of conventional one factor at a time (OFAT) experiments don't require sophisticated statistical understanding. When conducting studies to establish the major factor settings, the OFAT technique is still used in many businesses [18]. Traditionally, scientists and engineers have changed one component at a time while leaving the others constant when conducting OFAT studies. This variable is changed until the ideal setting is reached. At this point, it is fixed. The second element is then adjusted until the experiment's optimal setting is identified and maintained constant, at which point a repeat of the experiment quickly depletes the available resources. A new factor is introduced and the entire procedure is repeated.

IV. Experimental Procedures

For the initial experiment, TZM-Molybdenum superalloy was employed as the work material, while 12 mm electrolytic copper rod served as the tool-electrode material. The experimentation employed a positive polarity. EDM 92 DEF For the investigation, oil was used as the dielectric fluid. Four parameters were chosen for the initial stage of pilot experiments: peak current, pulse on time, pulse off time, and gap voltage. These factors were examined utilising the "one factor at a time method (OFAT)" on three response characteristics, including MRR and TWR. After considering the outcomes of pilot trials, the precise values of these four electrical parameters as well as their ranges were decided upon. Based on the control panel and machine operating manual, the following settings of the input process parameters were selected for the pilot experiment:

- Peak current : 6, 9, 17, 28, 36 and 50 Amperes
- Pulse on-time : 31, 100, 210, 690, 1550 and 5000 μs
- Pulse off-time : 20, 96, 210, 550, 1550 and 5000 μs
- Gap voltage : 30, 50, 70, 92, 110 and 130 Volts

Following parameters are kept constant at a fixed value during the experiments (As per the machine’s control panel):

- High Voltage: 3
- Servo Sens.: 9
- Flushing Height: 6
- Working Time: 10
- Flushing Two-speed: 1
- Arc Sens.: 3
- Low wear factor: 1

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 4, No. 2, April : 2023

- Electrode Polarity: + (Positive)

V. Results and Discussions

5.1 Effect on Material Removal Rate

Figures 2 to 5 depict how changes in peak current, Ton, Toff, and gap voltage affect MRR. In order to study the effects of different peak current levels on MRR, as shown in Figure 2, the experiment parameters of pulse on-time (100 µs), pulse-off-time (96 µs), and gap voltage (50 V) were held constant. From the figure, it could be seen that as the peak current value rises, so does the rate of machining.

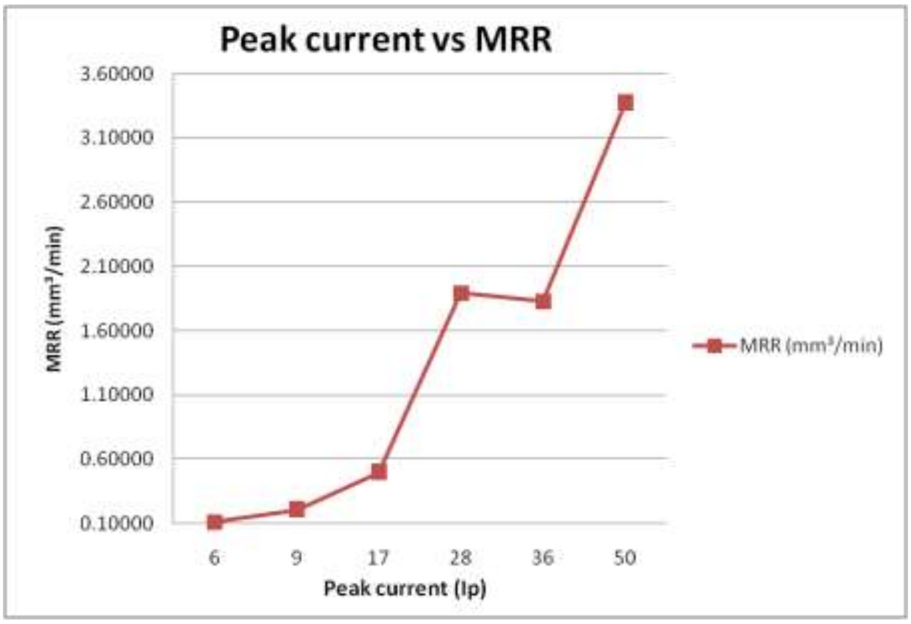

Figure 2 Effect of variation in Peak Current on MRR at pulse on-time = 100 µs, pulse off time = 96 µs, and gap voltage = 50 V

Figure 3 illustrates the effect of the pulse on time, where the time varied from 31 to 5000 µs while the values of current (17A), pulse-off time (96 µs), and gap voltage (50 v) were held constant throughout the experiments. Figures 2 and 3 show that lower values of peak current, or 6 A, and pulse-on-time, or 31 µs, resulted in a lower metal removal rate. Figure 4 illustrates how pulse off-time affects the MRR by demonstrating how the MRR rises as pulse off-time lengthens.

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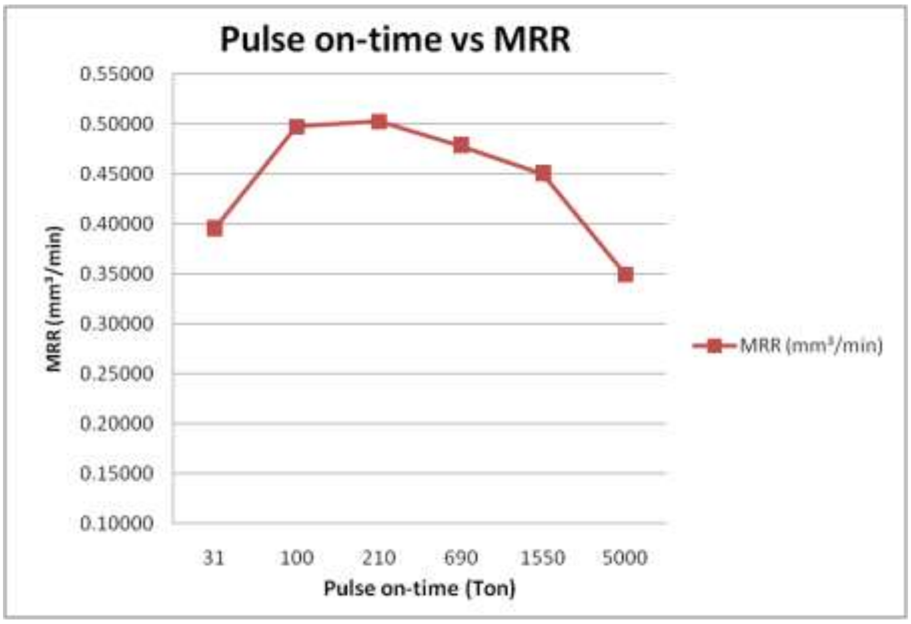

Figure 3 Effect of variation in Pulse-on-time on MRR at pulse off-time = 96 µs, gap voltage = 50, and peak current = 17 A

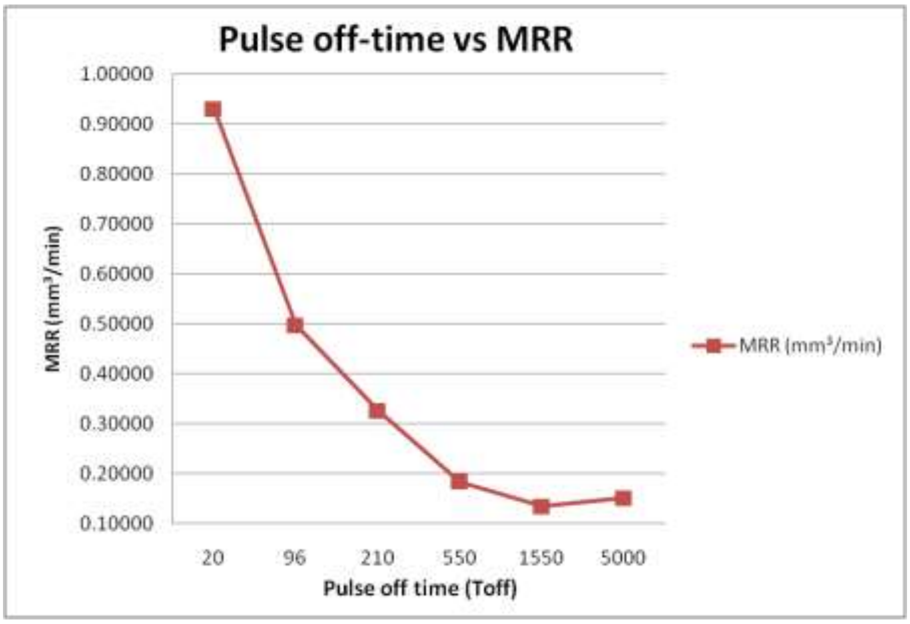

Figure 4 Effect of variation in Pulse-off-time on MRR at pulse-on-time = 100 µs, gap voltage = 50, and peak current = 17 A

Figure 5 depicts the results of the gap voltage and demonstrates how the MRR decreases as the gap voltage rise. Hence, greater gap voltage values are not taken into account for further investigation.

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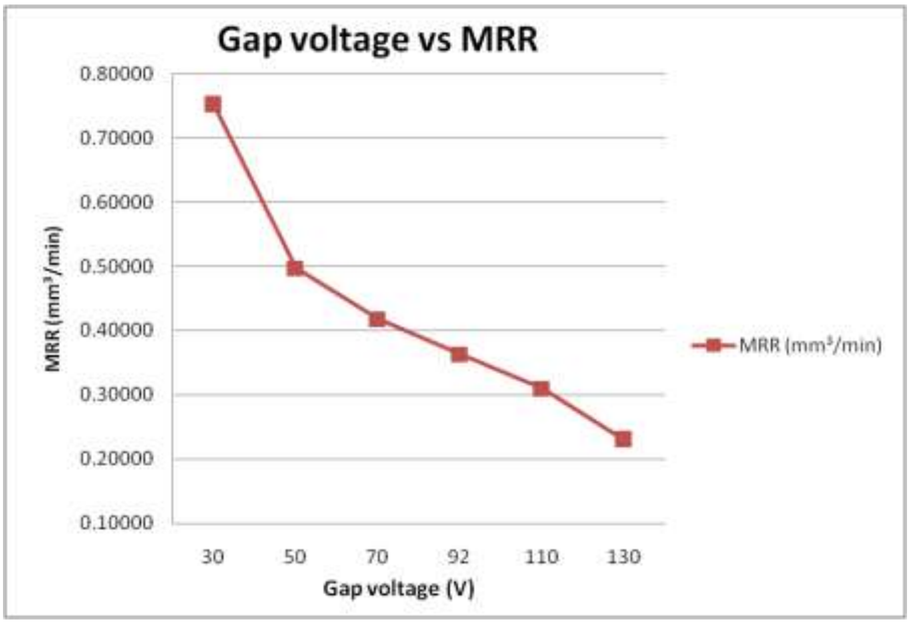

Figure 5 Effect of variation in Gap voltage on MRR at pulse-on-time = 100 µs, pulse off-time = 96 µs, and peak current = 17 A

5.2 Effect on Tool Wear Rate

The effects of changing the peak current, pulse on time, pulse off time, and gap voltage on TWR are shown in Figures 6 to 9. The remaining three parameters Ton 100 µs, Toff 96 µs, and gap voltage 50 V stay constant throughout the trials. TWR was calculated at various values of peak current 6, 9, 17, 28, 36, and 50 amperes. Figure 6 shows that TWR constantly raises as current increases from 6 A to 50 A. According to Figure 7, a greater on-time value has a higher TWR.

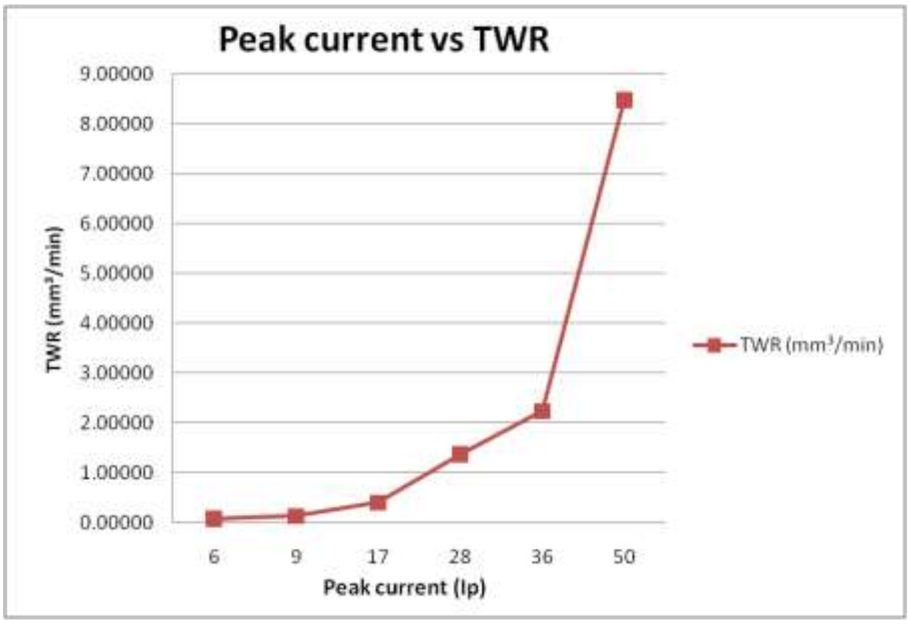

Figure 6 Effect of variation in Peak Current on TWR at pulse on-time = 100 µs, pulse off time = 96 µs, and gap voltage = 50 V

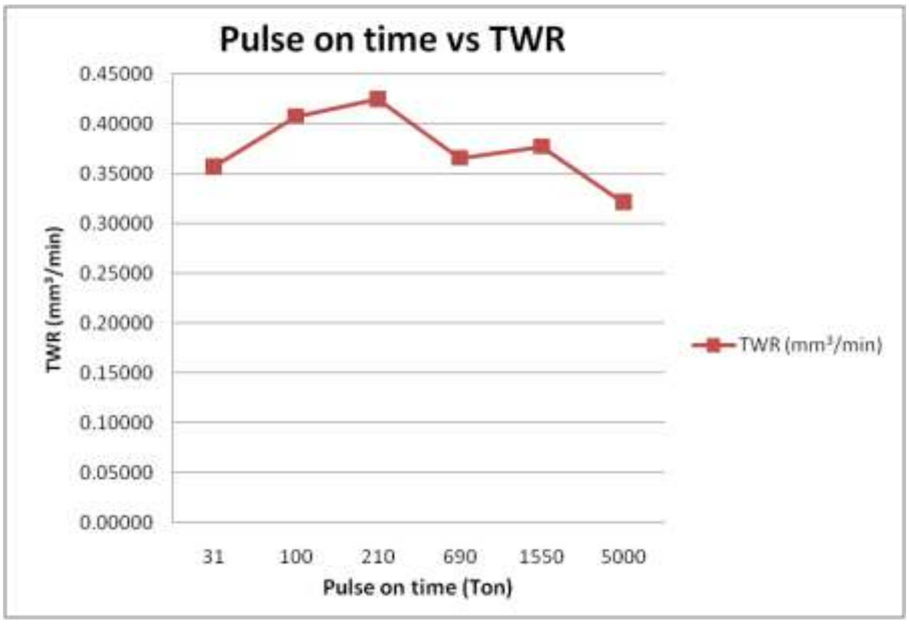

Figure 7 Effect of variation in Pulse-on-time on TWR at pulse off-time = 96 µs, gap voltage = 50, and peak current = 17 A

TWR was shown to be greater at low values of Toff, i.e. 20 µs, but as off-time increased to 5000 µs, the TWR decreased. Nevertheless, in the upper range, TWR decreased because there was enough time for the electrode to cool and for flushing. Figure 9 depicts the result of gap voltage and demonstrates how the TWR decrease as gap voltage rises.

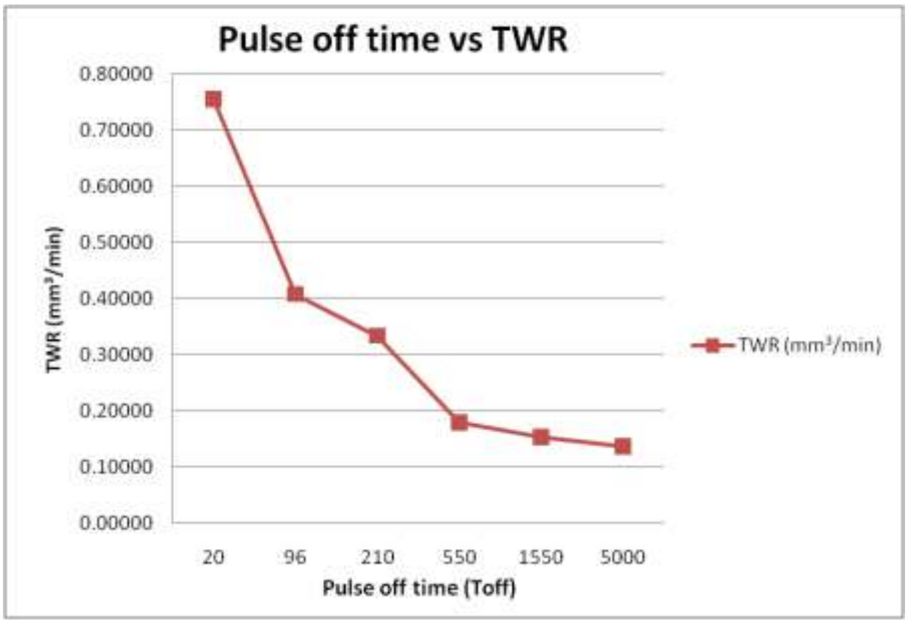

Figure 8 Effect of variation in Pulse-off-time on TWR at pulse-on-time = 100 µs, gap voltage = 50, and peak current = 17 A

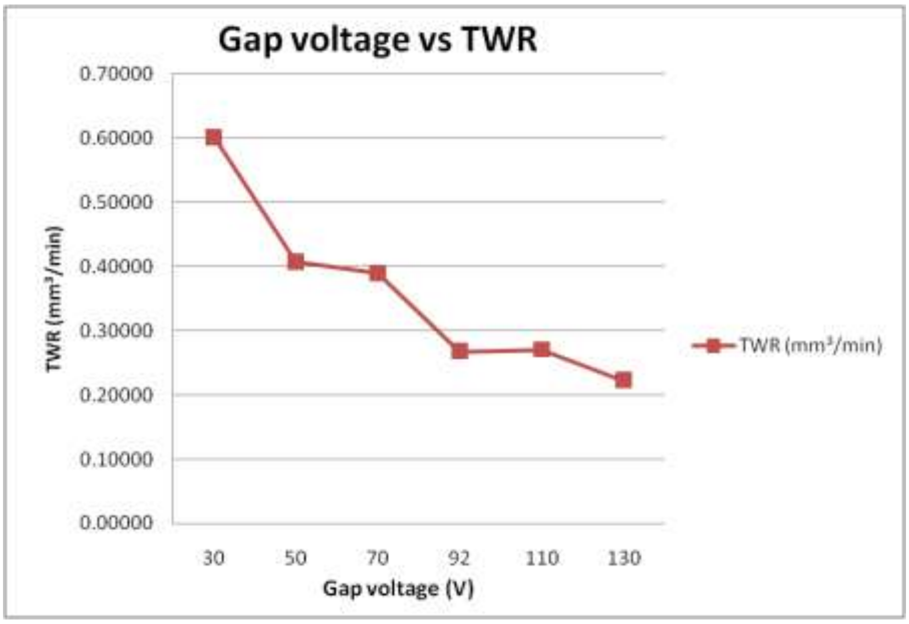

Figure 9 Effect of variation in Gap voltage on TWR at pulse-on-time = 100 µs, pulse off-time = 96 µs, and peak current = 17 A

VI. Conclusions

The impact of different process parameters on the EDM machining properties of TZM- Molybdenum superalloy with the electrolytic copper electrode has been investigated experimentally using the OFAT method. This work has emphasized the effects of peak current, pulse on time, pulse off time, and gap voltage on MRR and TWR. From this experiment, it is possible to make the following observation:

- It has been shown that the rate of material removal increases dramatically with an increase in peak current.
- Peak current (Ip) 50A, pulse on time (Ton) 100 µs, pulse off time (Toff) 96 µs, and gap voltage (V) 50V yield the highest MRR.
- The lowest TWR is obtained when the peak current (Ip) is 6A, the pulse on time (Ton) is 100 µs, the pulse off time (Toff) is 96 µs, and the gap voltage (V) is 50V.
- The optimal MRR and TWR were 3.370 and 0.083 mm3/min respectively.
- Peak current, pulse on time, pulse off time, and gap voltage are ranked 1, 2, 3, and 4, respectively, for both MRR and TWR.

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