PRODUCTION ENGINEERING ARCHIVES 2022, 28(1), 50-55

# PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN 2353-7779 (online)

Exist since 4th quarter 2013
Available online at https://pea-journal.eu

# Effect of different wire materials on WEDM performance of Bio-compatible material

**Gaurav Kumar Pandey[1,*], Praveen Bhai Patel[2], Abhishek Kumar[3], Ramendra Singh Niranjan[2], Vikas Katiyar[2], A K Chandra[2]**

[1] AIT, Kanpur, U.P India
[2] UIET, CSJMU, Kanpur, U.P India; pbpatel@csjmu.ac.in (P.B.P.); rammendra@csjmu.ac.in (R.S.N.); vikas2504@gmail.com (V.K.); abhishekchandra@csjmu.ac.in (A.K.C.)
[3] NIT Patna, Patna, Bihar, India; abhisheksiddhartha.ab@gmail.com
*Corresponding author e-mail: gaurav.pandey12@gmail.com

**Article history**
Received 06.08.2021
Accepted 22.11.2021
Available online 07.02.2022

**Keywords**
WEDM
MRR
SR
Ti-6Al-4V

**Abstract**
The present experimental investigation aims to analyse the effect of various machining parameters, such as pulse peak current (Ion), pulse on time (Ton), pulse off time (Toff) and spark voltage (SV) on the surface roughness (SR) and material removal rate(MRR) by using continuous traveling of both wire electrode (i.e. brass wire and zinc-coated brass wire). The present work also analyses the effect of types of wires, such as brass wire and zinc-coated brass wire used during machining of Titanium alloy (Ti-6Al-4V) on Surface roughness (SR) and material removal rate (MRR). This work studies the correlation between various response parameter such SR and MRR by using same machining parameter by for both wires.

DOI: 10.30657/pea.2022.28.06 JEL: L69, M11

## 1. Introduction

Improved mechanical properties of advanced, smart and composite materials pose challenges for their processing. Therefore, these aspects attract researchers to respond to such challenges. In this regard, advance machining process are becoming alternative solutions for the processing of such materials. WEDM is an electro-thermal, non-contact advanced processing method which is used for machining of hard and electrically conductive materials such as matrix composite metals, aluminium, and titanium alloy to produce a complex shape with precision and accuracy. Titanium alloy (grade 5) used as biocompatible material has the greatest influence on surface quality to its compatibility, hence, an improvement in a machined surface is required to enhance the utility.

## 2. Literature review

Prasad et al. (2014a, 2019b) performed an experimental investigation to obtain the effect of various machining input parameters such as $I_P$, $T_{ON}$, $T_{off}$, and SV. on various response machining parameters such as surface integrity, MRR during WEDM machining of Ti-6Al-4V by using brass wire of .25 mm diameter. This investigation confirmed that machining characteristics such as MRR and SR are significantly affected by IP and Ton, whereas Toff and SV are less significant. With an increase in IP and Ton, MRR increases. In other words, the key factor for obtaining higher MRR is high peak current, whereas surface integrity decreases with increase in IP and Ton. Therefore, it can be concluded that both MRR and surface integrity are associated with parameters IP and Ton.

Kuriakose, and Shanmugam (2013) investigated the influence of various process parameters, such as time between two pulses, injection fluid pressure, pulse duration, machining servo-voltage, ignition pulse current, wire tension, and wire-speed by conducting an experiment according to Taguchi's orthogonal array (L-18) to analyse the metallurgical change on each Titanium alloy surfaces of obtained from WEDM machining by using zinc-coated brass wire on different machining parameters. The experiment reveals that, from a metallurgical point of view, process parameters such as wire-speed, wire tension, the time between two pulses, injection fluid pressure and pulse duration have greater significance on WEDM machining surfaces.

Naurbakhsh and Rajurkar (2013) conducted an experimental investigation to analyses the effect of various machining parameters such as IP, SV, pulse gap width, wire tension by designing an experiment based on Taguchi's L-18 orthogonal array to check various response machining parameters such as surface integrity, machining speed and wire rupture on WEDM of Titanium alloy by using both wires such as brass wire and zinc-coated brass wire. This investigation revealed that machining speed is significantly affected by peak current, pulse gap width, and time between two pulses by using both wires on WEDM of Titanium alloy. During machining of Ti-6Al-4V by using both wires on WEDM, surface integrity is significantly affected by IP, pulse gap width, and wire tension. Wire rupture in the machining of titanium alloy by using both wires on WEDM is significantly affected by pulse gap width and time between two pulses and wire breakage.

Basil et al. (2012) aims to study the influence of various process parameters in WEDM machining by using a continuous traveling of wire-electrode made of brass, copper or tungsten either coated or non-coated of thickness 0.3 mm such as pulse on and pulse off time SVs and dielectric pressure on response parameters such as surface integrity of titanium alloy. The experiment is a design based on DOE with every factor into two levels and by using ANOVO analyses with a 10% confidence level to determine the significant factors and establishing a mathematical relationship between various machining parameters and surface roughness. The experiment result revealed that the most significant factor to determine surface roughness is pulse on time, pulse off time, and machining servo voltages.

Alias et al. (2012a , 2012b) conducted an experimental investigation to study the influences of the feed rate of a continuous traveling of wire-electrode made of brass non-coated of thickness 0.25 mm in WEDM machining while various other process parameters such as ignition pulse current, SVs, wire tension, and wire-speed are kept constant on a fixed value to identify its effect on response parameters such as surface integrity, kerf width, and MRR in the machining of titanium alloy. The study revealed that the most significant factor to determine the surface integrity is high feed rate while wire tension and machining servo voltages influence the most. The most significant factor in the determining of kerf width is high feed rate while ignition pulse current, wire-speed, and wire tension influence the most. The most significant factor in the determining of MRR is low feed rate while ignition pulse current, SV, and wire tension influence the most.

Arikatla and Mannan (2017) aims to optimize the machining parameters by performing an experimental investigation to study the effect of various machining parameters written as a pulse on and off time, servo reference voltage, input machining power and reference wire tension on various outcomes variables written as MRR, kerf-width, surface topography and integrity in the machining of Titanium alloy with WEDM by using surface response methodology. The variance analysis is a design based on ANOVO analyses with a 10% confidence level to determine the effects of significant factors on experimental performance and also establishing a mathematical relationship between various machining parameters and surface roughness for response parameters. This investigation disclosed that kerf-width is significantly increased with increased pulse on and off time, input machining power, reference wire tension, and SV. The MRR is significantly increased with an increased Ton, IP however MRR is significantly decreasing with an extended increased pulse on and off time, input machining power, wire tension, SV. Surface roughness is significantly increased with an increase in pulse on time and input machining power whereas surface roughness significantly decreases with an increase in wire tension and reference servo-voltage.

Chavan and Karthikeyan (2018) optimize the influence of various machining parameters viz. pulse on and off time, input machining power and reference servo-voltage by performing an experiment investigation by using grey relation analysis for multi-performance machining characteristics to determining the effects of these output machining parameters such as SR and MRR. They disclosed that MRR and surface roughness is significantly affected by Ton. MRR increased with an increased Ton and input machining power whereas surface roughness is significantly increased with a decrease in Ton and input machining power. However, MRR and SR have insignificant effect by increasing or decreasing values of SV and Toff.

Ghodisiyeh et al. (2012) aims to optimize cutting parameters of WEDM machining of titanium alloy using deionized water as a dielectric and continuous run of zinc-coated brass wire of diameter 0.25 mm as an electrode. The experimental investigation was based on central composite design method to obtain the influences of three control factors such as Ton, Toff time, SV and IP on the performance of various response machining parameters such as SR, MRR. ANOVO analyses with a 10% confidence level are used to establish a mathematical relationship between various machining parameters and response parameters. It has been disclosed that the most dominating factors for both MRR and Surface integrity are IP and Ton.

Kumar (2013) explored the influences of various process parameters such as Ton and Toff, wire feed and wire tension, reference current and machining servo-voltage by designing an experiment investigation based on Box –Benkhen's approach to analyses their effects on various response parameters such as surface characteristics, wire wear ratio, and MRR on each Titanium alloy surfaces of obtained from WEDM machining by using zinc-coated brass wire on different machining parameters. The study revealed that the most significant factor to determine the surface integrity and wire wear ratio is reference current and pulse on-time. In determining wire rupture is significantly affected by high reference current and frequency of spark. The most influencing factor for determining SR is IP and Ton. SR will be increased with increase IP and Ton.

Pandey and Yadav (2020 a,b) illustrate the effect of vibration on die- sinking EDM on Titanium alloy and Aluminium metal matrix composite materials. In their study they showed the optimized machining parameters by using PCA based GRA method.

## 3. Experimental Setup

The experimental investigation for machining is carried out on Electronica eurocut Mark I CNC Wire cut EDM as shown in Fig. 1. Titanium alloy (grade-5) is taken as work-piece material whose chemical properties are given in Table 1. The work-piece dimensions is taken as 15 mm x 10 mm x 5 mm. The experiments were planned by taking one of the tool of design of experiment. Taguchi's L-9 orthogonal array was used design the experiment for study the effect of various machining parameters such as IP, $T_{ON}$, Toff and spark voltage (SV) on response machining parameters such as cutting speed, surface roughness (SR), and MRR on WEDM of Titanium alloy grade 5 (Ti-6Al-4V) by using continuous traveling of both wire such as brass wire and zinc-coated brass wire of thickness 0.25 mm acts as an electrode and distilled water is used as a dielectric fluid while keeping another parameter constant such as dielectric water pressure (WP), wire tension (WT), wire feed rate (WF) and servo feed rate (SF). Based on the literature review, various input parameters such as IP, Ton, Toff and SV have a significant role on SR and MRR. Hence these control parameters have been used in present study to evaluate output parameters like MRR and SR. The three different input parameters are shown in Table 2. The response variable such as SR is being measured by using TESA- rugosurf 90-G and MRR is calculated by using this formula-

$$\mathbf{MRR = Cutting\ Speed \times Width \times Height} \qquad (1)$$

Table 3 and table 4 show the properties of Brass wire and Zinc coated brass wire electrode respectively. Table 5 shows L-9 orthogonal array bases experimental table for Ti-6Al-4V titanium alloy for Brass and Zinc coated brass wire electrodes.

**Table 1.** Chemical Composition of Titanium Alloy (Grade -5)

| Chemical Composition | Al | V | Pb | Fe | Ti |
|---|---|---|---|---|---|
| % Mass | 6.61 | 4.20 | 1.09 | 0.11 | Balance |

**Table 2.** Three levels of Machining process parameters

| Symbols | Control Parameter | Units | Levels | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| A | Peak Current | Amp. | 11 | 12 | 13 |
| B | Pulse-On Time | µsec | 106 | 110 | 114 |
| C | Pulse-Off Time | µsec | 52 | 56 | 60 |
| D | Spark Voltage | Volt. | 30 | 40 | 50 |

**Table 3.** Chemical properties of Brass wire

| Chemical Composition | Cu | Al | Tin | P | Fe | Pb | Zn | Ni |
|---|---|---|---|---|---|---|---|---|
| % | 56.7 | 0.03 | 0.02 | 0.02 | 0.1 | 03 | 39.85 | 0.08 |

**Table 4.** Chemical properties of Zinc coated Brass wire

| Chemical Composition | Cu | Al | Tin | P | Fe | Pb | Zn | Ni |
|---|---|---|---|---|---|---|---|---|
| % | 53.8 | 0.13 | 0.12 | 0.08 | 0.14 | 2.5 | 43 | 0.16 |

**Table 5.** L-9 orthogonal array based experimental table for Ti-6Al-4V titanium alloy for the Brass wire and Zinc coated Brass electrode

| Exp. No. | Ip (amp) | Ton (µs) | Toff (µs) | SV (volts) |
|---|---|---|---|---|
| **1** | 11 | 106 | 52 | 30 |
| **2** | 11 | 110 | 56 | 40 |
| **3** | 11 | 114 | 60 | 50 |
| **4** | 12 | 106 | 56 | 50 |
| **5** | 12 | 110 | 60 | 30 |
| **6** | 12 | 114 | 52 | 40 |
| **7** | 13 | 106 | 60 | 40 |
| **8** | 13 | 110 | 52 | 50 |
| **9** | 13 | 114 | 56 | 30 |


**Fig. 1.** Experimental setup used for the machining

## 4. Results and discussion

During the experimental investigation, the most influencing process parameters that significantly affect the performance of MRR is $I_P$, $T_{ON}$ and $T_{off}$ in the machining of titanium alloy by using both wires such as brass wire and zinc-coated brass wire in WEDM machining. Other machining parameters such as servo voltage (SV) have inconsiderable significance in MRR using both wires. Table 6 and Table 7 show the experimental results obtained after conducting experiments.

### 4.1. Effect on MRR

Figure 2 and Figure 4 illustrate the main effect plot of MRR. These plots represent the effect of process parameters on MRR. The MRR of titanium alloy grade 5 increase significantly with the increase in $I_P$ and $T_{ON}$ and decreases with $T_{off}$ using both wires. The maximum MRR is obtained when IP and pulse on time is maximum while keeping pulse off time minimum for both wires. The reason for the maximum MRR is due to an increase in discharge energy as IP and Ton increase the intensity and duration of sparking. When there is an increase in pulse off time then the duration of sparking reduces, hence the number of discharges reduces, which results in lower cutting speed. Figure 6-9 illustrate the comparison of experimental results for MRR of both the wires used for machining of Ti-6Al-4V alloy. The figures show that MRR of titanium alloy using continuous traveling of zinc-coated brass wire is bigger than by using brass wire, which results from a coating of zinc over the brass wire reducing its melting point, this reduction in melting point increases the spark formation and also decreases ionization-time coating of zinc over the brass wire provides more tensile strength to wire. Higher tensile strength causes high temperature and heat resistance and produces uniform discharge characteristics in zinc-coated brass wire. This higher tensile strength and uniform discharge characteristics in zinc-coated wire improve the MRR of work material The optimum material removal condition for both wires occur, when IP was at level 3, pulse on time is at level 3 and pulse off time is at level 1.

### 4.2. Effects on SR

Figure 3 and Figure 5 illustrate the main effect plot of SR. These plots represent the effect of process parameters on SR. The SR of titanium alloy grade 5 increases significantly with the increase in IP and $T_{on}$ and increases with Toff using both wires. The minimum SR is obtained when pulse IP and Ton is minimum while keeping Toff at level 2 for both wires. When there is a decrease in IP and Ton, then the duration of sparking reduces, hence the number of discharges reduces, which results in lower surface roughness. The maximum surface roughness is found when IP and Ton is maximum for both wires. The reason for maximum SR is due to an increase in discharge energy, as pulse IP and Ton increases, it creates large craters. The optimum machining conditions for SR for both wires is found when IP was at level 1, Ton is at level 1 and Toff is at level 2. Figures 10-13 illustrate the comparison of experimental results for SR of both the wires used for machining of Ti-6Al-4V alloy. The figures show that SR of titanium alloy using continuous traveling of zinc-coated brass wire is smaller than when using brass wire, hence smoother surface obtained, resulting from a coating of zinc over the brass wire providing more tensile strength to wire. Higher tensile strength leads to high temperature and heat resistance and produces uniform discharge characteristics in zinc-coated brass wire.

**Table 6.** Experimental results for Ti-6Al-4V titanium alloy for Brass wire

| Exp. No. | Ip (amp) | Ton (µs) | Toff (µs) | SV (volts) | SR (µm) | MRR (mm³/s) |
|---|---|---|---|---|---|---|
| **1** | 11 | 106 | 52 | 30 | 2.004 | 2.870 |
| **2** | 11 | 110 | 56 | 40 | 2.097 | 3.238 |
| **3** | 11 | 114 | 60 | 50 | 2.313 | 3.524 |
| **4** | 12 | 106 | 56 | 50 | 1.854 | 1.583 |
| **5** | 12 | 110 | 60 | 30 | 2.354 | 3.626 |
| **6** | 12 | 114 | 52 | 40 | 2.580 | 6.680 |
| **7** | 13 | 106 | 60 | 40 | 2.854 | 8.137 |
| **8** | 13 | 110 | 52 | 50 | 2.952 | 8.990 |
| **9** | 13 | 114 | 56 | 30 | 3.125 | 9.410 |

**Table 7.** Experimental results for Ti-6Al-4V titanium alloy for Zinc coated Brass electrode

| Exp. No. | Ip (amp) | Ton (µs) | Toff (µs) | SV (volts) | SR (µm) | MRR (mm³/s) |
|---|---|---|---|---|---|---|
| **1** | 11 | 106 | 52 | 30 | 1.956 | 2.945 |
| **2** | 11 | 110 | 56 | 40 | 1.987 | 3.287 |
| **3** | 11 | 114 | 60 | 50 | 2.215 | 3.657 |
| **4** | 12 | 106 | 56 | 50 | 1.841 | 2.426 |
| **5** | 12 | 110 | 60 | 30 | 2.327 | 3.820 |
| **6** | 12 | 114 | 52 | 40 | 2.476 | 6.762 |
| **7** | 13 | 106 | 60 | 40 | 2.838 | 8.248 |
| **8** | 13 | 110 | 52 | 50 | 2.903 | 9.061 |
| **9** | 13 | 114 | 56 | 30 | 3.081 | 9.534 |

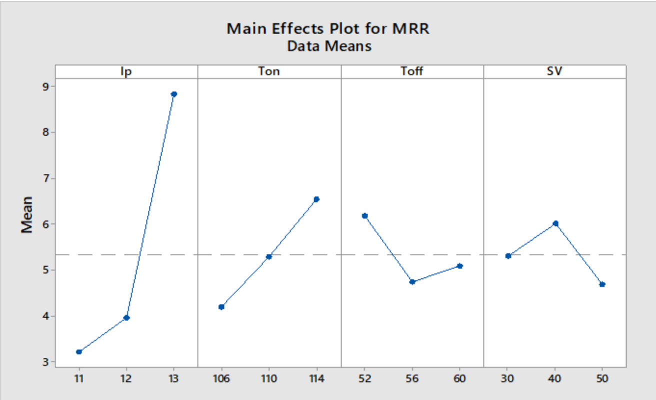


**Fig. 2.** Main effect plot for MRR for Brass wire


**Fig. 3.** Main effect plot for SR for Brass wire

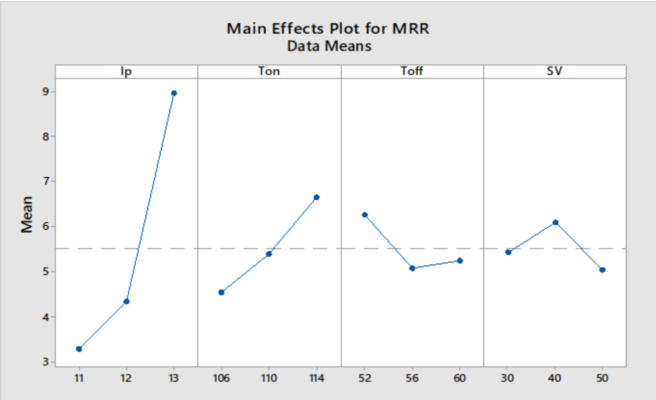


**Fig.4.** Main effect plot for MRR for Zinc coated Brass wire


**Fig. 5.** Main effect plot for SR for Zinc coated Brass wire

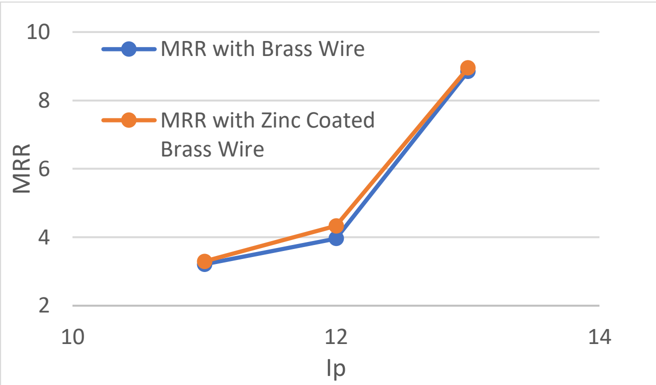


**Fig. 6.** Effect of pulse current (Ip) on MRR

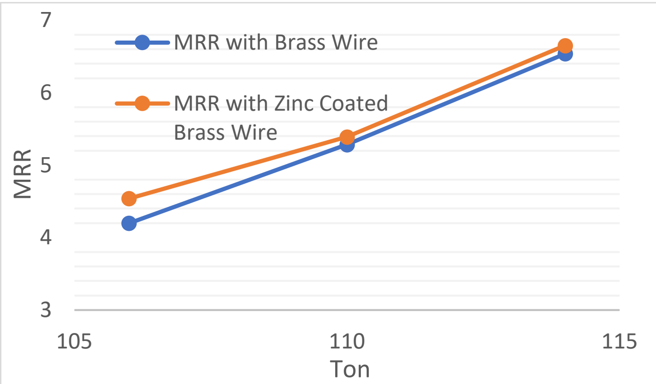


**Fig. 7.** Effect of pulse on time (Ton) on MRR

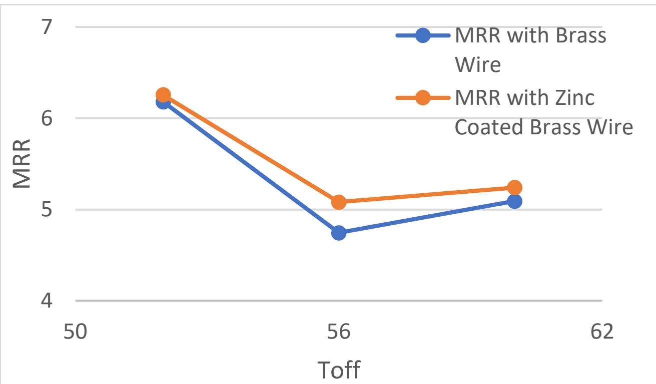


**Fig. 8.** Effect of pulse off time (Toff) on MRR

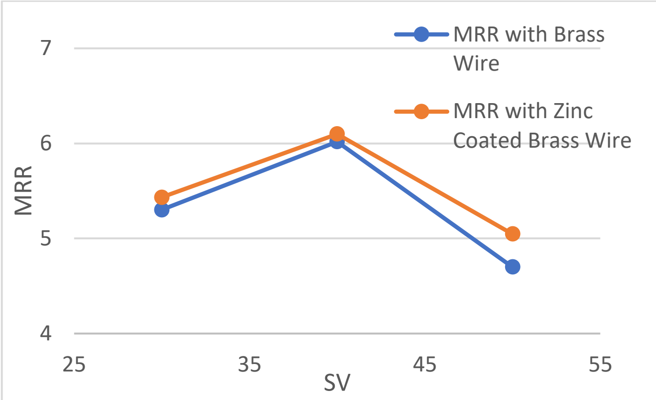


**Fig. 9.** Effect of spark voltage (SV) on MRR

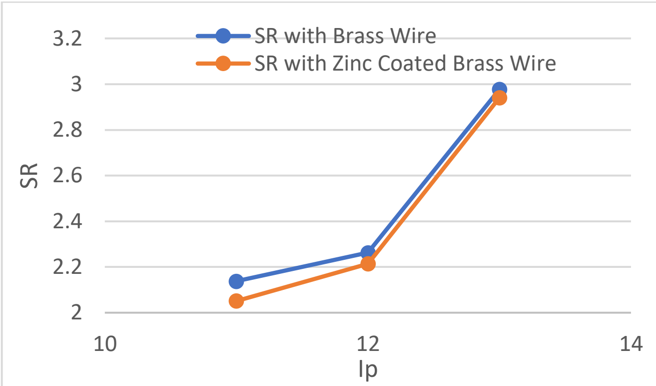


**Fig. 10.** Effect of pulse current (Ip) on SR

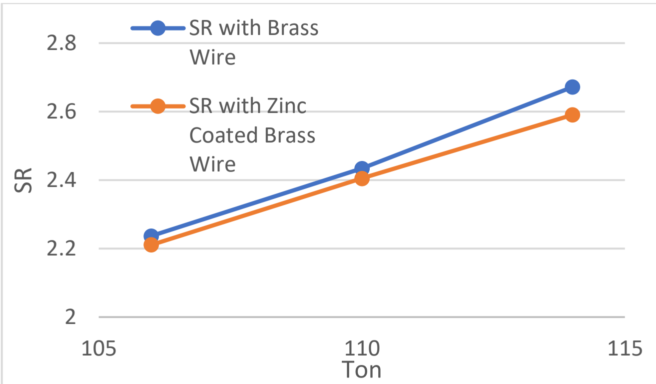


**Fig. 11.** Effect of pulse on time (Ton) on SR

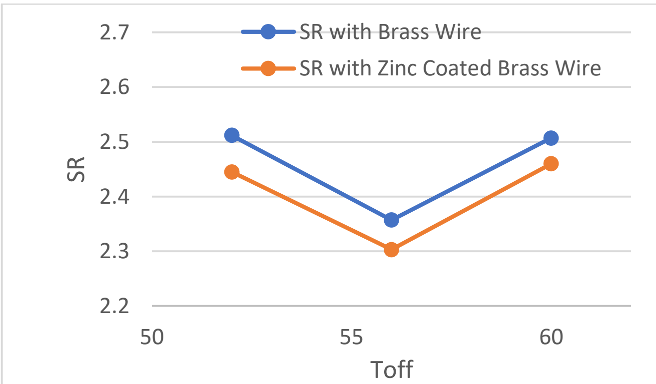


**Fig. 12.** Effect of pulse off time (Toff) on SR

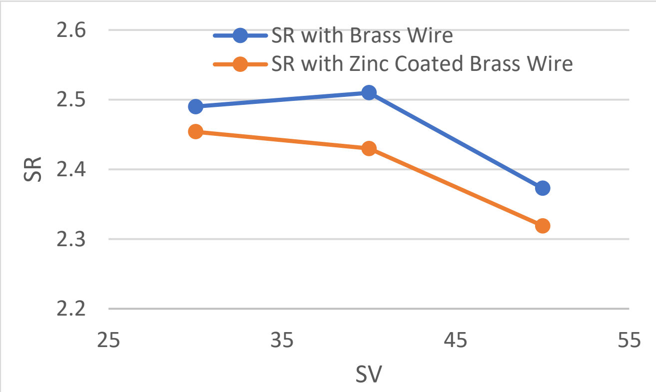


**Fig. 13.** Effect of spark voltage (SV) on MRR

## 5. Summary and conclusion

This experimental investigation of WEDM machining of titanium alloy (Ti-6Al-4V) by using both wires such as brass wire and zinc-coated brass wire disclosed that the most dominating process parameter that significantly influences the performance of cutting speed is IP and pulse on time and pulse off time. The maximum cutting speed is obtained when IP and pulse on time is maximum while keeping pulse off time minimum for both wires.

The cutting speed in the machining of titanium alloy using continuous traveling of zinc-coated brass wire is bigger than by using brass wire.

This experimental investigation disclosed that the most significant process parameter that influences the performance of surface integrity in the machining of titanium alloy (Ti-6Al-4V) in WEDM machining by using both wires such as brass wire and zinc-coated brass wire is IP and pulse on time. The maximum surface roughness is found when IP and pulse on time is maximum for both wires.

The surface roughness of titanium alloy using continuous traveling of zinc-coated brass wire is less than by using brass wire hence smoother surface obtained by using zinc-coated brass wire.

In WEDM machining of titanium alloy, the cutting speed and surface roughness have inverse related between them as maximum cutting speed obtains when IP and Ton is maximum for both wire whereas smoother surface is obtained when IP and Ton is minimal for the both wires.

## Reference

Prasad, A.V.S., Koona, R., Datta, G.L., 2014. An Experimental Study of Wire EDM on Ti-6Al-4V Alloy. International Conference on Advances in Manufacturing and Materials Engineering, 5, DOI: 10.1016/j.mspro.2014.07.517

Prasad, A.V.S., Koona, R., Verma, A., Kumar, P.J., Rao, S.K., 2019. Optimization Of Material Removal Rate. Surface Roughness in Wire-EDM By Using Desirability Function Analysis, International Journal of Innovative Technology and Exploring Engineering, 8(6), 20-24.

Kuriakose, S., Shunmugam, M.S., 2004. Characteristics Of Wire-Electro Discharge Machined Ti6Al4V Surface, Journal of Materials Letters, 58, 2231-2237, DOI: 10.1016/j.matlet.2004.01.037

Nourbakhsh, F., Rajurkar, K.P., 2013. Wire Electro-Discharge Machining of Titanium Alloy. The First CIRP Conference on Biomanufacturing CIRP, 5, 13-18, DOI: 10.1016/j.procir.2013.01.003

Kuriachen, B., Paul, J., Mathew, J., 2012. Modelling Of Wire Electrical Discharge Machining Parameters Using Titanium Alloy (Ti-6Al-4V). International Journal of Emerging Technology and Advanced Engineering, 2(4), 377-381.

Alias, A., Abdullah, B., Mohd Abbas, N., 2012. Wedm: Influence of Machine Feed Rate in Machining Titanium Ti-6al-4v Using Brass Wire and Constant Current (4A), International Symposium on Robotics and Intelligent Sensor, 41, 1812-1817, DOI: 10.1016/j.proeng.2012.07.388

Alias, A., Abdullah, B., Mohd Abbas, N., 2012. Influence of Machine Feed Rate in Machining Titanium Ti-6al-4v Using Brass Wire and Constant Current (6A), International Symposium on Robotics and Intelligent Sensor, 41, 1806-1811, DOI: 10.1016/j.proeng.2012.07.387

Arikatla, S.P., Mannan, K.T., 2017. Parametric Optimization In Wire Electrical Discharge Machining Of Titanium Alloy Using Response Surface Methodology. Materials Today: Proceedings, 4(2), 1434-1441, DOI: 10.1016/j.matpr.2017.01.165

Chavan, U.M., Karthikeyan, R., 2018. Experimental Investigation for Optimum Process Parameters on MRR And Surface Roughness of Titanium Alloy Grade 5 Using Wire Cut EDM Machine. International Journal for Research in Engineering Application and Management, 4 (7), 64-69, DOI: 10.18231/2454-9150.2018.0896

Danial, G., Davoudinejad, A., Mohammad Hassan, H., Navid, H., Golshan, A., 2013. Optimizing Finishing Process In Wedming Of Titanium Alloy (Ti-6Al-4V) By Brass Wire Based On Response Surface Methodology. Research Journal of Applied Sciences, Engineering And Technology 5(4), 1290-1301, DOI: 10.19026/RJASET.5.4864

Kumar, Jatinder, 2012. Prediction of Surface Roughness in Wire Electric Discharge Machining (WEDM) Process Based on Response Surface Methodology. International Journal of Engineering And Technology, 2(4), 708-712.

Pandey, G.K., Yadav, S.K.S., 2020. Multi-Response optimization of Vibration Assisted Electrical Discharge Drilling Process using PCA based GRA approach. 22(4), 2901-2915, DOI: 10.1016/j.matpr.2020.03.424

Pandey, G.K., Yadav, S.K.S., 2020. Multi-Objective optimization of Vibration Assisted Electrical Discharge Drilling Process using PCA based GRA method. 26(2), 2667-2672, DOI: 10.1016/j.matpr.2020.02.561

## 不同线材对生物相容性材料线切割加工性能的影响

**關鍵詞**
WEDM
MRR
SR
Ti-6Al-4V

**摘要**
本实验研究旨在分析各种加工参数，如脉冲峰值电流 (Ion)、脉冲开启时间 (Ton)、脉冲关闭时间 (Toff) 和火花电压 (SV) 对表面粗糙度 (SR) 的影响。 通过使用两个电极丝（即黄铜丝和镀锌黄铜丝）的连续移动来提高材料去除率（MRR）。 目前的工作还分析了钛合金（Ti-6Al-4V） 加工过程中使用的黄铜线和镀锌黄铜线等线材类型对表面粗糙度 (SR) 和材料去除率 (MRR) 的影响。 这项工作通过对两条线使用相同的加工参数来研究各种响应参数（例如 SR 和 MRR）之间的相关性。