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Research Paper

Comparing and Investigating the Effect of Input Parameters on External Parameters in Parts of Different Materials in EDM Operation Using Taguchi Method

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Abstract

The correct selection of input parameters in the electric discharge machining (EDM) process leads to improvements in the material removal rate (MRR), dimensional accuracy of the parts, quality of the surface finish, and reduction of tool wear. The main goal of the research was to investigate the type and extent of the influence of input on output parameters in EDM operations. Experimental data and the contribution of parameters were obtained using the Taguchi test design with three levels. The tool used was made of copper. Samples were selected from three types of alloy steel: 4340, Ti6Al-4V, and AISI D2 steel. The test variables included maximum current (Ip), gap voltage (Vg), and duty factor (DF). In these experiments, Ip values of 5, 10, and 15 amps, Vg values of 25, 50, and 75 volts, and DF values of 0.3, 0.6, and 0.9 were selected. The number of machining operations was 81 tests, and the L9 orthogonal array related to the Taguchi approach used for Design of Experiments (DOE) reduced the number of machining operations from 81 to 27 tests. The results indicated that the current parameter of 5 amps had the highest effect on surface roughness (SR) in samples of AISI4340 steel. The current of 15 amps had the greatest impact on MRR, while the duty factor (DF) of 0.6 played the highest role in electrode wear rate (EWR). Maximum Ip contributed 36.77%, Vg contributed 31.03%, and DF contributed 32.18% to EWR.

Keywords

EDM, Surface Roughness, MRR, EWR, Taguchi Method

1. Introduction

Machining, in simple words, is a change in the appearance of the workpiece by applying energy and cutting to achieve desired surfaces and new shapes. The energy sources used can be mechanical, chemical, electrical, thermal, or a combination of them. Meanwhile, mechanical energy can be called the oldest energy used in the machining of parts, in both conventional and non-conventional machining methods. Non-conventional or Modern machining methods are methods in which chipping is done non-mechanically so that tools and workpieces do not have physical contact with each other [1].

The electrical discharge machining (EDM) process is a modern machining process that is used to machine parts made of conductive materials, which cannot be machined using a conventional machining process, and even if it is possible, it will not be economically feasible. The energy source in the EDM process is electro-thermal. Since this process suffers from a low MRR, many studies have been done to make this process as efficient as possible in different countries. Tool wear is another problem that has a significant impact on surface quality in this process. In short, it can be said that the EDM process is a thermal process in which thermal energy is produced through electrical discharge in a small channel called the plasma channel. At the end of the discharge due to high heat, the destruction of the plasma channel occurs, so a small part of the workpiece melts. The molten pool is formed so that a part of this melt is thrown out in the form of droplets and the rest of it is re-frozen and causes the re-casted layer on the surface of the workpiece. In addition, the very high heat generation due to the concentration of intense thermal energy during the ON–Time (t_{ON}) of the EDM process, creates a heat-affected zone (HAZ). This is done under the re-casted layer on the surface of the workpiece. Despite many studies that have been done to improve the process, it is still necessary to do more research in this regard [2]. Selvarajan et al. [3] investigated the effect of EDM parameters on MRR, EWR, and geometrical errors of aluminum material. Important machining parameters such as current (I_p), pulse OFF –Time (t_{OFF}), t_{ON}, fluid pressure, and spark gap are considered using the Taguchi orthogonal array (L_{18}). With the help of average effective graphs, MRR, EWR, cylindricity, as well as out of roundness of the part have been checked.

The results of optimization of MRR and SR during EDM of ultra-fine-grained Al6082, indicate that the SR resolution and MRR are significantly affected by these parameters. The MRR increases with the discharge current and decreases with the duration of the t_{OFF} and t_{OFF} [4]. Research titled Experimental Investigation and optimization of MRR and EWR in the machining of aluminum-boron carbide (Al-B4C) nanocomposite using EDM process indicated that the MRR increases with the increase in current while, the EWR decreases [5].

Optimization of the effect of input parameters on MRR, EWR, and SR in EDM of A356 nano-composite reinforced by alumina is done by HajHosseini et.al [6]. The effect of input parameters of EDM on A356 nano-composite reinforced by 3.5% alumina (Al_2O_3) was examined and optimized by the Taguchi technique. The input parameters of these experiments consisted of voltage, current intensity, t_{ON}, and t_{OFF}. It was concluded that the most influential parameter on the MRR was the t_{OFF}. EWR happened due to the current intensity, and the t_{ON} caused the deterioration of the SR. The contribution percentage of the input parameters in the total variance for voltage, current intensity, t_{ON}, and t_{OFF} were found to be 12.98, 20.96, 5.47, and 60.60, respectively.

The impact of input factors on the MRR of Inconel 718 has been investigated by Kumar, R., & Singh, [7]. L_9 orthogonal array related to the Taguchi approach used for the design of the experiment (DOE). They concluded that the t_{ON}, is the most affecting factor and consequently t_{OFF}, $I_{p,}$ and V_g are the main factors.

The effect of EDM input parameters on A356 nanocomposite reinforced with 6% SiC has been investigated by Rahmani et al. [8]. V_g, I_p, t_{ON}, and t_{OFF}, have been considered as input parameters. The results of variance analysis showed that I_p is the most important parameter due to having the highest share percentage (62.06%). The next influential parameters were V_g, t_{ON}, and t_{OFF}, with participation percentages of 20.7, 9.19, and 8.05 respectively.

EDM is one of the advanced machining processes that can be used to machine metal matrix composites. In this regard, the discharge I_p is the only effective factor on the MRR, and the highest MRR can be achieved [9].

Motevasseli, et al. [10] have investigated the parameters affecting surface integrity and MMR during EDM of HARDOX-400 steel. It was observed that with the increase of the discharge I_p, the EWR increases. However, this happens with a gradual reduction rate. On the other hand, increasing the ratio of t_{ON}, to t_{OFF}, caused the reduction of the the MRR. Furthermore, it was observed that by increasing both the discharge I_p and the t_{OFF}, a thicker white solid layer will be formed. This can be more susceptible to cracking. Therefore, this will be harmful to the integrity of the workpiece.

Jafari et al. [11] have predicted the effect of parameters on the surface quality of steel workspace (CK45) that will take place in EDM. This prediction of the relationship between EDM parameters and surface quality provides a practical tool for making appropriate decisions about process control parameters.

In a study conducted by Aghdeab & Salman [12], the amount of MRR and SR for AISI L2 tool steel has been investigated. The results show that the SR increases with increasing I_p and t_{ON}, this has no effect when increasing the t_{OFF}. The best SR occurs when current low and t_{ON}, are used. On the other hand, MRR increases with increasing I_p and increasing t_{ON}. Meanwhile, MRR decreases with increasing t_{OFF}.

Heydari et al. [13] investigated the increase in wear resistance of copper electrodes in EDM using a very fine grain structure. Tool wear is a serious problem in EDM that significantly affects the machining process and dimensional accuracy. The results show that the electrode volumetric wear and the electrode wear ratio are reduced by using copper tool electrodes with very fine grain microstructures (UFG). Heydari et al. also found out in their research that one of the basic problems of the EDM process is EWR. To increase the resistance of pure copper against EWR during the mentioned process, a very fine structure in the range of nano and several hundred nanometers was used. The results showed that the EWR decreases with the reduction of the size of the crystal structure of the copper electrode. However, the MRR almost remained almost constant and did not change much.

Optimizing the variables of the EDM process is a complicated task due to a large number of parameters. The changes that are applied to one parameter will affect the whole process in a complicated way. To be able to predict surface roughness, material removal rate, and tool wear rate for a given EDM parameter, the influence of EDM parameters on the process outputs must be analyzed. For this purpose, experimental techniques are usually pursued to investigate surface quality, material removal rate, and tool wear rate. To design the experiment and obtain the necessary experimental data, the Taguchi method was used, and for the participation of the parameters, statistical analysis with a mini-tab was conducted. The goal of this study is to determine the effect of the process parameters (Ip, V_g, DF, and workpiece material) on the EDM performance measures (SR, MRR, and TWR) by the copper tool. The study also attains the best set of process parameters that achieve optimal performance. As a result, providing information about EDM for alloy steel 4340, Ti6Al-4V, and AISI D2 steel, improving the EDM machinability and enhancing the application of EDM in manufacturing.

2. Materials and methods

The process of removing material from the surface of the workpiece in the EDM operation is carried out by controlling a series of electric sparks. In this process, when the electrical discharge occurs between the two points of the anode (workpiece) and the cathode (tool), a lot of heat is generated in the machining zone. This leads to the melting and vaporization of materials due to the generation of sparks. Therefore, to improve the efficiency of the process, it is necessary to immerse both parts and tools in a dielectric fluid. This fluid is usually made of hydrocarbons or mineral oils. The schematic of the EDM process is shown in Figure 1. To operate, it is necessary to design and prepare the parts and tools.

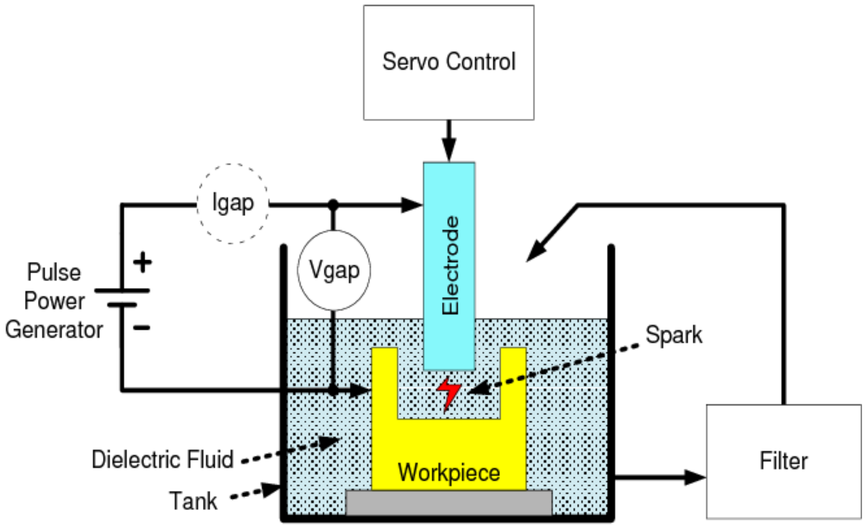

Figure 1. Schematic of Electrical Discharge Machining (EDM) [2]

2.1 Design and preparation of tool

Three electrodes (tools) with the same dimensions and properties were selected from copper, and machining operations were carried out using lathes and grinding machine to achieve the required dimensions and finishing. The dimensions of this tool are presented in Figure 2.

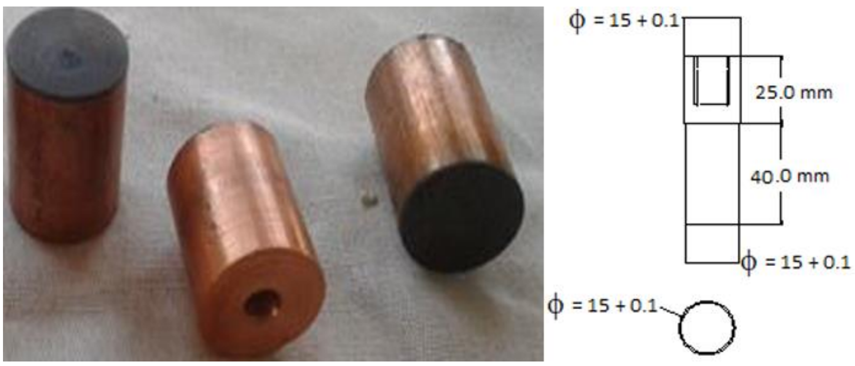

Figure 2. Dimensions and shapes of tools used in the EDM

It should be noted that this length depends on the number of times that sharpened the tool. After each machining step, due to the erosion of the electrode, it is necessary to grind its surface again. Since the length of the machined electrode is short to use in the EDM operation, a stem is used to connect it to the device's body. For this reason, a hole with a diameter of 5.8 mm is created at the end of the tools, and inside it is tapped using an M10 tap to connect to the thread stem. The physical properties of copper, which was selected as a tool, are presented in Table 1. The material used as a tool must have good properties such as suitable electrical and thermal conductivity, low wear rate, and ease of machining, and also have a low cost and should be easily available. Since copper alloy has the mentioned properties, it was selected for this purpose. Copper has an FCC crystal structure and its appearance is reddish-yellow. And when it is subjected to polishing, it turns into a shiny metallic luster. All copper alloys have corrosion resistance against water and steam. In this regard, the electrical and thermal properties of copper are presented in Table 2.

Table 1. Physical properties of copper tools used in this research [14]

Properties	Value	Properties	Value
state	Solid	boiling point	2562 °C,
Density (close to room temperature)	8.96 $g \cdot cm^{-3}$	heat of fusion	13.26 $kJ \cdot mol^{-1}$
Liquid density at the melting point	8.02 $g \cdot cm^{-3}$	heat of vaporization	4.300 $kJ \cdot mol^{-1}$
melting point	1083 °C	heat capacity	440.24 $J \cdot mol^{-1} \cdot K^{-1}$

Table 2. Electrical and thermal properties of copper tools used in this research [14]

Properties	Value	Properties	Value
heat of fusion	134 J/g	Electrical conductivity	5.9×10^{7} S/m
heat of vaporization	3630 J/g	electrical resistance	1.7×10^{-8} mΩ
Heat of sublimation at 1026°C	3730 J/g	Magnetic mode	non-magnetic
Thermal conductivity	401 W/m.K		

2.2. Design and preparation of samples

In this research, the samples were selected from three different materials, comprising AISI 4340 alloy steel, Ti6Al-4V, and AISI D2 steel. AISI 4340 steel is a medium carbon or low carbon alloy steel known for its strength in relatively large industrial sectors. It is also one of the types of nickel chrome molybdenum steel. Alloy steel 4340 is generally supplied in the hardened tensile range of 930 - 1080 MPa. Alloy steel 4340 has good impact resistance as well as wear resistance in rigorous conditions. This material is often used where other alloy steels do not have the required strength and is also an excellent choice for highly stressed parts. Chemical compositions are presented in Table 3 [15].

Table 3. Chemical composition of AISI 4340 alloy steel [15]

Percent	Phosphorus (P)	Molybdenum (Mo)	Silicon (si)	Carbon (C)	Manganese (Mn)	Chromium (Cr)	Nickel (Ni)	iron (Fe)	Sulfur (S)
Max.	---	0.2	0.15	0.38	0.65	0.7	1.65	9.1	---
Min.	0.010	0.3	0.35	0.43	0.9	0.9	2	9.27	0.010

Ti6Al-4V alloys that simultaneously contain alpha and beta phases are called alpha-beta titanium alloys. Ti6A4V alloy is the most widely used alpha-beta titanium alloy. In this alloy, aluminum leads to the stability of the alpha phase and vanadium causes the stability of the beta phase. Ti6A4V is a grade 5 alloy for titanium alloys. Its chemical composition and mechanical and physical properties are presented in Tables 4 and 5, respectively [16].

AISI D2 steel is one of the cold-work alloy steels of steel 2379 (SPK-NL). It is made of high carbon and chromium, which has very high wear resistance. This steel can be hardened in the air.

Table 4. Chemical compositions of Ti6Al-4V [16]

chemical element	C	Mo	Zr	Sn	Al	V	Si
Percent	0.369	0.005	0.0028	0.0625	48.5	22.4	0.0222
chemical element	Ti	No	Cu	Fe	No	Cr	
Percent	90	0.0386	<0.02	0.112	<0.0010	0.0099	

Table 5. Mechanical and physical properties of Ti6Al4V [16]

Specification	Value	Specification	Value
Density (kg/m^3)	4.43×10^3	ultimate tensile strength (MPa)	950
Tensile yield strength (MPa)	880	Modulus of elasticity (GPa)	8.113
Thermal conductivity (W/(m.K))	17	Poisson's ratio	0.342
Heat capacity (J/kg.K)	526		

Chemical compositions and mechanical and physical properties of AISI D2 steel are presented in Tables 6 and 7. The remarkable object about D2 steel is that this steel does not have high machinability. If simple alloy steel with 100% machining strength is considered, D2 steel will have 50% strength [17].

Table 6. Chemical composition of AISI D2 steel [17].

Chemical compounds	C	Cr	Co	Si	Mn	Mo
Weight percent	1.6 – 1.4	11-13	0/1	0.6	0.6	1.20 – 0.7
Chemical compounds	V	S	Cu	No	P	
Weight percent	1.10	0.03	0.25	0.03	0.03	

Table 7. Mechanical and physical properties of AISI D2 steel [17]

Specification	Value	Specification	Value
Poisson's ratio	0.3-0.27	Nope hardness (converted from Rockwell hardness C)	769
Impact without Izod gap	J 77	Vickers hardness	748
Elastic modulus (gigapascal)	210 - 190	hardness, Rockwell C	62
Density (kg/m^3)	10007.7	Melting point (°C)	1421

A raw piece for each sample was prepared from alloy steel 4340, Ti6Al-4V, and AISI D2 steel with dimensions of 350 × 80 × 5 mm. To prepare the parts, first, the cutting process was done on these samples. The cutting operation was done with a crank saw, then the face grinding operation was done on both sides of the cut samples. To obtain a surface with the desired quality, the grinding operation was done by a horizontal axis grinding machine. At the end, the prepared samples were numbered by punch. Before starting the machining operation, it was necessary to check the flatness of the parts using a cast iron surface plate and an indicator clock.

2.3 Electric Discharge Machine

The device used in this research is the A30 CNC Die Sinking EDM, which has excellent performance for normal machining as well as polishing operations. The image of this device can be seen in Figure 3.

Figure 3. Image of the A30 CNC Die Sinking EDM used in this research

It produces the desired surface quality of approximately less than 0.08 micrometers in terms of (Ra). The minimum wear of the electrode is around 0.05%, it is equipped with a 50-amp controller. The maximum machining efficiency with this device is around 500 mm^3/min. The device has three simultaneous control axes and its movement dimensions in X×Y×Z axes are equal to 300×212×272 mm. The dimensions of the work holder are 600 × 400 mm and the dimensions of the work tank on the table are 990 × 640 × 410 mm.

2.4 Machining parameters and performing operations

The test inputs should be performed to draw a suitable comparative diagram and observe the process of changing the outputs of machining operations. The tests were carried out by an EDM with a copper tool on samples of alloy steel 4340, Ti6Al-4V, and AISI D2 steel.

In this experiment, the L9 orthogonal array related to the Taguchi approach was used for DOE, to reduce the number of machining operations. The test variables include the I_p, V_g, and DF. In these tests, the I_p of 5, 10, and 15 amps, was selected. The V_g of 25, 50, and 75 volts, and the DF of 0.3, 0.6, and 0.9 have been selected as shown in Table 8. According to the definition, the number of machining operations is 3 × 3 × 3 × 3 = 81 tests, and by using the Taguchi operation design, the number of machining operations has been reduced from 81 to 27 tests. The input and output data obtained from the machining operation with an EDM on samples of alloy steel 4340, Ti6Al-4V, and AISI D2 steel are given in Table 9.

Table 8. Test design table with Taguchi algorithm

(Ip)			(Vg)			(DF)			Workpieces (samples)		
(a1)	(a2)	(a3)	(b1)	(b2)	(b3)	(c1)	(c2)	(c3)	(d1)	(d2)	(d3)
5	10	15	25	50	75	0.3	0.6	0.9	AISI4340	Ti6Al-4V	AISI D2

Table 9. Samples of alloy steel 4340, Ti6Al-4V, and AISI D2 steel with copper tools

S.No.	(Ip)	(Vg)	(DF)	SR (R_{amean})			MRR (g/min)			EWR (g/min)		
				4340	Ti6Al	D2	4340	Ti6Al	D2	4340	Ti6Al	D2
1	5	25	0.3	0.50	0.51	0.72	1.79	1.09	1.26	0.39	0.69	0.49
2	5	50	0.6	0.59	6.22	0.85	1.94	1.49	1.70	0.28	0.71	0.37
3	5	70	0.9	0.49	12.5	0.71	2.03	1.71	1.91	0.64	0.82	0.72
4	10	25	0.6	3.13	7.22	3.98	4.21	3.68	3.98	0.41	1.23	0.48
5	10	50	0.9	4.66	9.98	4.90	4.91	4.28	4.57	0.55	1.99	0.64
6	10	70	0.3	3.27	6.41	3.80	5.93	5.51	5.79	0.71	2.23	0.81
7	15	25	0.9	3.99	7.39	4.45	3.91	3.22	3.67	0.39	1.84	0.52
8	15	50	0.3	5.65	6.71	6.16	5.54	4.97	5.21	0.31	1.68	0.47
9	15	70	0.6	5.55	10.49	8.89	6.87	6.21	6.68	0.33	2.38	0.39

3. Discussion and conclusion

The output parameters include SR, MRR, and EWR of parts made of AISI4340, Ti6Al-4V, and AISI D2 steel, which are obtained in the machining operation with an EDM with a copper tool. These will be discussed in the following passages.

3.1 Surface roughness (SR) of different samples

The total average SR of 9 rows for AISI4340 steel is equal to 27.83 µm and their average, which is the sum of the number, is equal to 3.0922 µm. The amount of signal to noise (S/N) which is obtained based on equation (1) is calculated for all L_9 rows and then their sum is indicated by the letter L_3.

$$S/N = -10\, log\, MSD$$

$$\frac{S}{N} = -10\ log\ [(R_{a1}^2 + R_{a2}^2 + R_{a3}^2)/3] \tag{1}$$

Therefore, by dividing the sum by the number of 9, their average is obtained. Table 10 shows the S/N value of each row, the sum, and the average for the AISI4340 steel sample. Therefore, the total average SR of 9 rows for Ti6Al-4V is equal to 65.43 µm, and their average, which is the sum of the number, is equal to 7.27 µm.

Table 10. S/N ratio, total, and average for AISI4340 steel sample. Ti6Al-4V and AISI D2 steel

S/N	L1	L2	L3	L4	L5	L6	L7	L8	L9	Sum	Average
AISI4340	6.0194	4.5771	6.1948	-9.911	-13.368	-10.29	-12.01	-15.04	-14.88	-58.725	-6.525
Ti6Al-4V	-7.994	-15.85	-21.93	-17.17	-19.98	-16.13	-17.37	-16.53	-20.41	-153.41	-17.04
AISI D2	2.852	1.406	2.974	-11.99	-13.84	-11.59	-12.96	-15.79	-18.97	-77.90	-8.65

While the total average roughness of 9 rows for AISI D2 steel is equal to 34.46 µm and their average, which is the sum of the number, is equal to 3.828 µm. Figure 4 shows the graphs of the S/N ratio for SR, for a piece of AISI4340 steel, and Figure 5 shows the contribution of input parameters, including I_p, gap voltage, and DF. In the graphs of Figure 4, the parameter with the highest value will be the most effective. In this regard, the I_p, V_g, and DF were input parameters in the machining operation of parts made of AISI4340 steel, Ti6Al-4V, and AISI D2 steel, and among these three parameters, the current of 5 amps had the highest effect on the SR of AISI4340. As can be seen from Figure 4, the voltage of 25 volts after the current of 5 amps can be effective in creating the SR, while the duty factor has no effect in creating roughness. For SR, the less is better strategy is always used because the goal is to create a surface with less roughness. Figure 5 shows the contribution of the input parameters, this contribution for AISI4340, is as follows: The I_p of 79.27, the V_g is 19.10, and the DF of 1.63%.

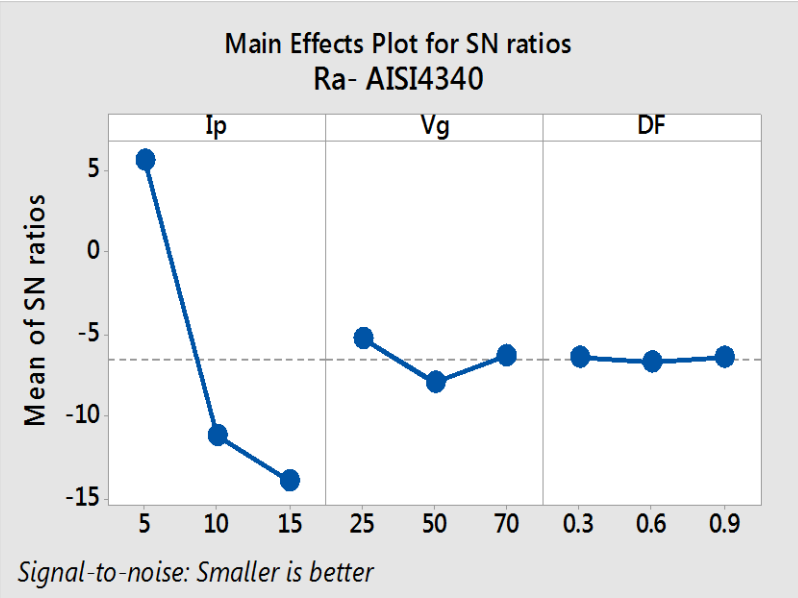

Figure 4. S/N ratio graphs for I_p, V_g and DF, in creating SR for AISI4340 workpiece

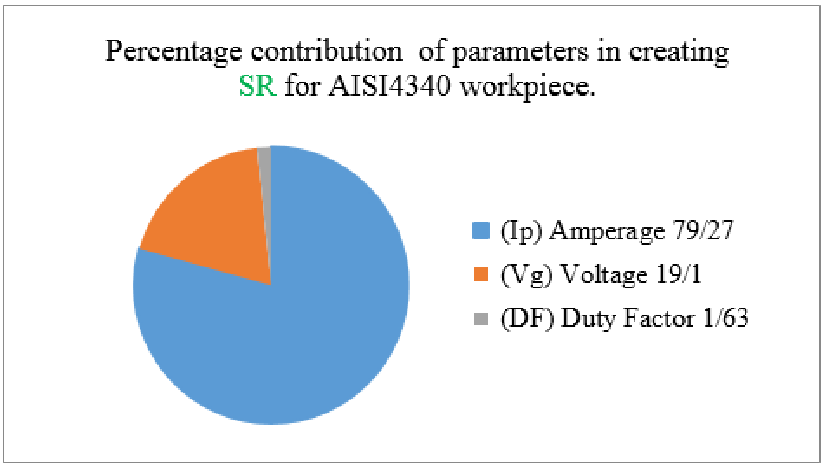

Figure 5. Percentage contribution of I_p, V_g and DF, parameters in creating roughness for AISI4340 workpiece

In this operation, for Ti6Al-4V material, among these three parameters, the duty factor with 0.3, the voltage of 25 volts, and the current of 5 amperes respectively have the highest effect on creating SR (Figure 6). As realized in Figure 7, according to the strategy of less is better, I_p of 14.94, V_g of 39.79, and DF of 45.25% have donated to the creation of SR.

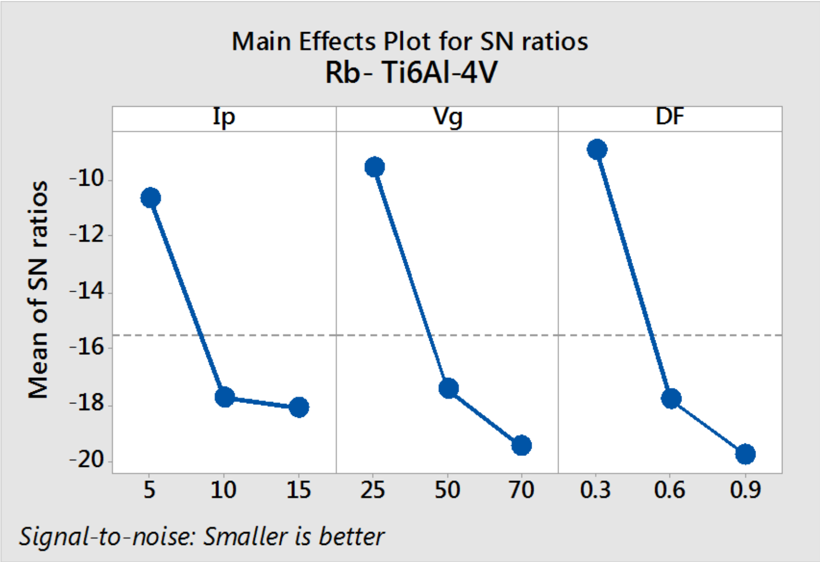

Figure 6. S/N ratio graphs for (Ip), (Vg), and (DF) in creating SR for Ti6Al-4V workpiece

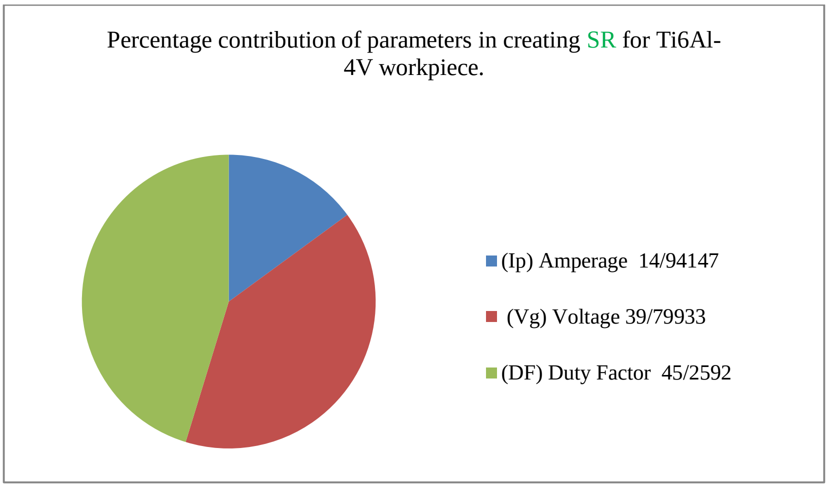

Figure 7. Percentage contribution of (Ip), (Vg), and (DF) parameters in creating roughness for Ti6Al-4V workpiece

Figure 8 shows the graphs of the S/N ratio for AISI D2 steel. In this regard, the current of 5 amps had the highest effect on creating SR.

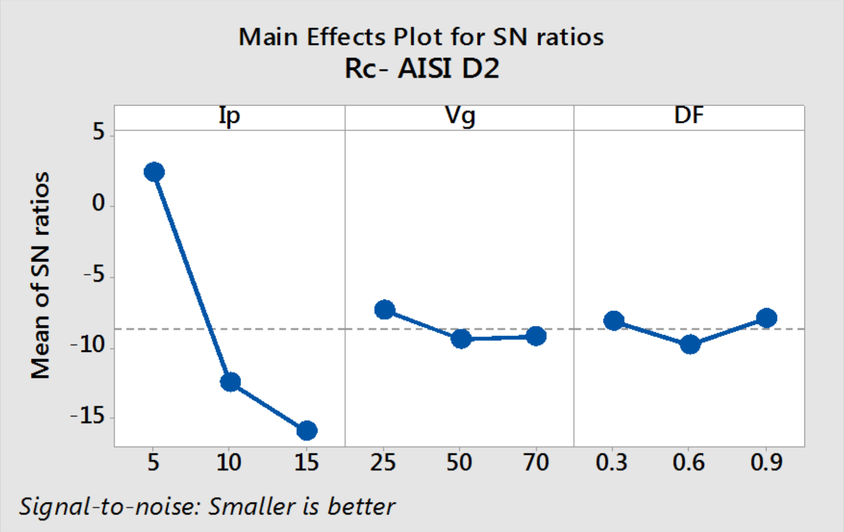

Figure 8. S/N ratio graphs for I_p, V_g, and DF, in creating SR for AISI D2 steel workpiece

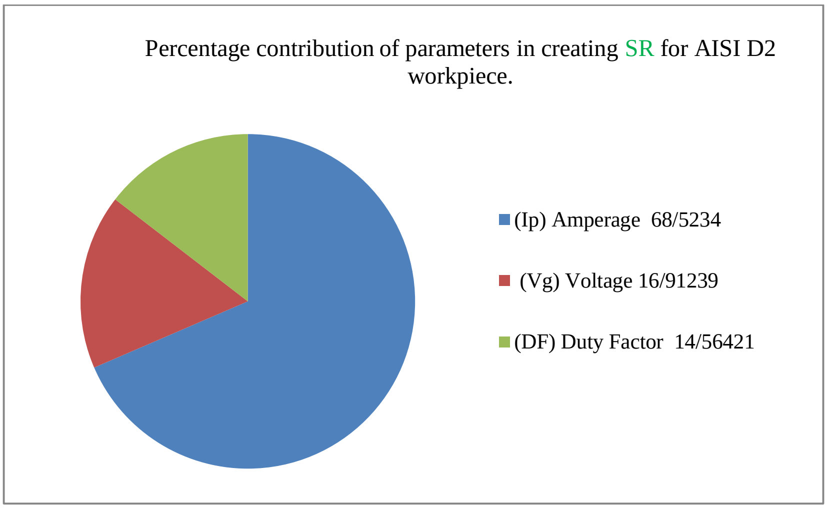

Figure 9. Percentage contribution of I_p, V_g, and DF, parameters in creating roughness for AISI D2 steel workpiece

While the other two parameters, voltage and duty factor, have the least effect. The degree of influence of the input parameters comprises the I_p, V_g, and DF, respectively. The percentage of participation of each of the input parameters in creating the SR is presented in Figure 9. In this regard, the contribution of I_p, 68.52%, V_g 16.91%, and DF 14.56% were in creating SR.

It is observed from ANOVA for SR that as the discharge current increases from 10A to 15A, the SR slightly decreases nonlinearly. The amount of heat energy supplied to remove the material is controlled by the discharge current. So as the discharge current increases, the bombarding impulsive force of electrons also increases. In the case of negative polarity, the bombardment of electrons takes place from the workpiece to the electrode. This resulted in the deposition of material on the machined surface causing a reduction of SR. The SR is higher at 15A as the amount of material deposited is less. When the discharge current at 15A, the larger impulsive force produces deeper and greater craters are deposited with more amount of material, hereafter the SR is lower. The t_{ON} controls the duration of time for which the current is allowed to flow per cycle. T_{OFF} is the least significant factor and shows minimum contribution as far as SR is concerned. This is because no material is removed from the workpiece as there is no discharge current supplied. It is observed that as the t_{OFF}, increases, the SR is improved by a very small amount. At minimum t_{OFF}, the dielectric fluid gets less time to de-ionize and flush away the debris. As the t_{OFF}, further increases, the dielectric fluid gets sufficient time to de-ionize and to flush away the debris. Thus the stability of the machining process is enhanced and therefore SR is improved.

3.2 Material removal rate (MRR) for different samples

The graphs presented in Figure 10 show the S/N ratio for MRR from parts made of AISI4340 steel, Ti6Al-4V, and AISI D2 steel. Here, the parameter with the highest value is considered the most effective parameter. In this regard, the I_p, V_g, and DF, were the input parameters in this operation. Among these input parameters, the current of 15 and 10 amps had the highest impact on the MRR for a piece of AISI4340 steel, and subsequently voltage as much as 70 volts can be effective in creating the MRR, while the duty factor of 0.3 will have a very small effect on the MRR. As seen in Figure 11, the I_p, of 59.03%, the V_g of 27.50%, and the DF of 13.46% contributed to the MRR.

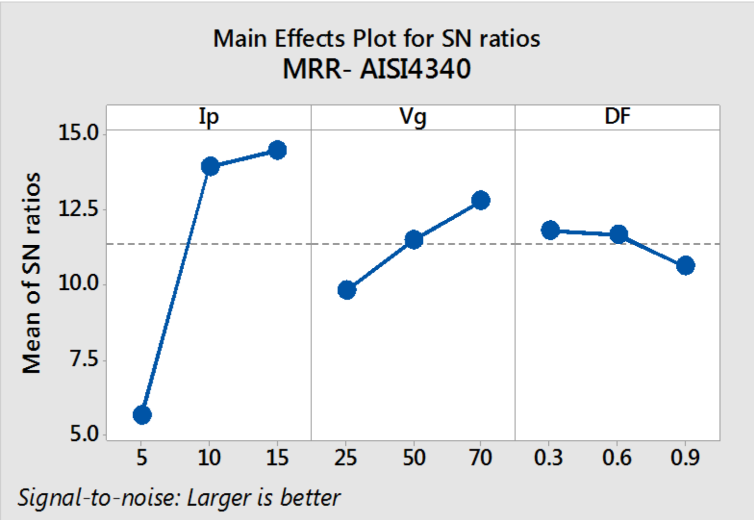

Figure 10. S/N ratio graphs for I_p, V_g, and DF, in creating MRR for the AISI4340 workpiece

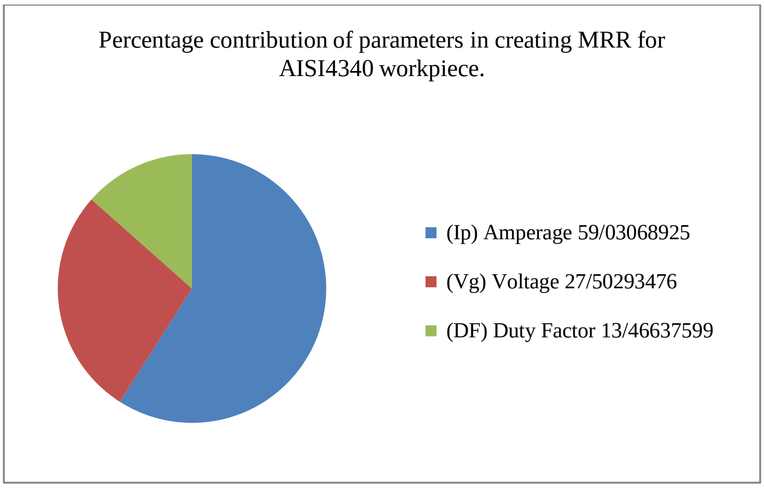

Figure 11. Percentage contribution of I_p, V_g, and DF, parameters in creating MRR in AISI4340 steel

The graphs presented in Figure 12 show the S/N ratio for the MRR in a Ti6Al-4V piece, and the parameter with the highest value is considered the most effective parameter. In this regard, among the input parameters for a piece of Ti6Al-4V, the I_p with 15 and 10 amps have the highest effect on the MRR, Subsequently the voltage of 70 volts can be effective in creating the MRR. While the duty factor of 0.6 can have a very minor effect on the MRR. It is seen that 1 rank should be given to current, because current is most significant for MRR, followed by electrode shapes and t_{ON}, t_{OFF}, and DF are less significant. The results of the researchers confirm this issue [18].

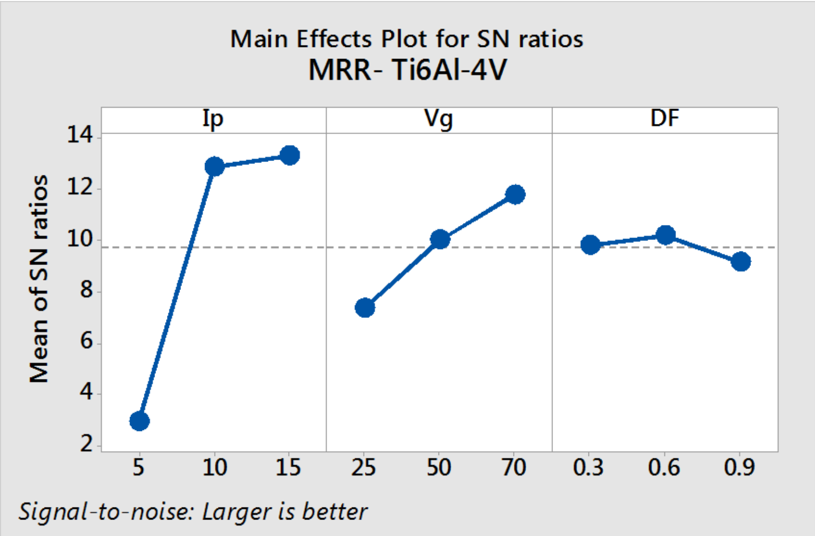

Figure 12. S/N ratio graphs for I_p, V_g, and DF, in creating MRR for Ti6Al-4V workpiece

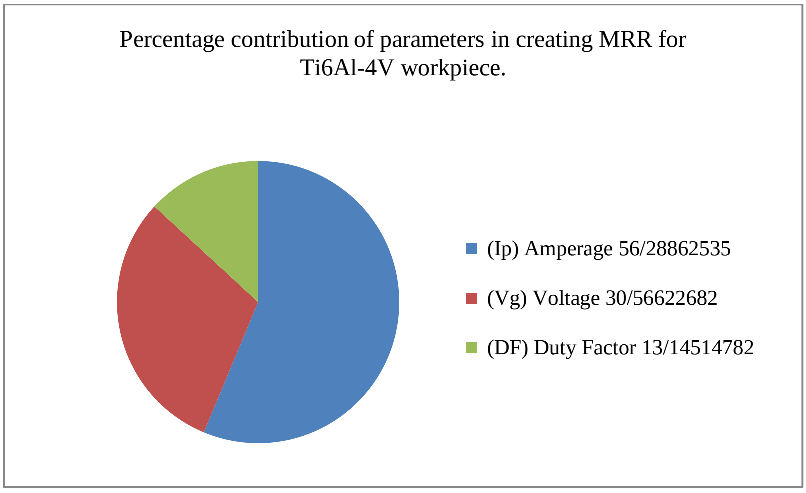

Figure 13. Percentage contribution of I_p, V_g, and DF, parameters in creating MRR for Ti6Al-4V

To determine the response of the S/N ratio to check the MRR of Ti6Al-4V material, the bigger is better strategy is used. Since the goal is to remove a larger volume of material from the part in less time. It can be seen in Figure 13, the percent contribution of each of the input parameters in creating the MRR. The amount of participation in this regard is I_p = 56.28%, the V_g = 30.56%, and the DF = 13.14%.

The S/N ratio for MRR for AISI D2 steel is shown in Figure 14, and the parameter with the highest value is considered to be the most effective parameter. In this regard, the I_p with 15 and 10 amps have the highest effect on the MRR. Subsequently, the V_g of 70 volts can be effective in creating the MRR. While the DF of 0.6, can have a small effect on the MRR.

According to the obtained data, the participation percentage of each of the input parameters in creating the MRR for AISI D2 steel can be seen in Figure 15. The amount of participation attained is The I_p = 58.19%, the V_g = 29.77%, and the DF = 12.03%.

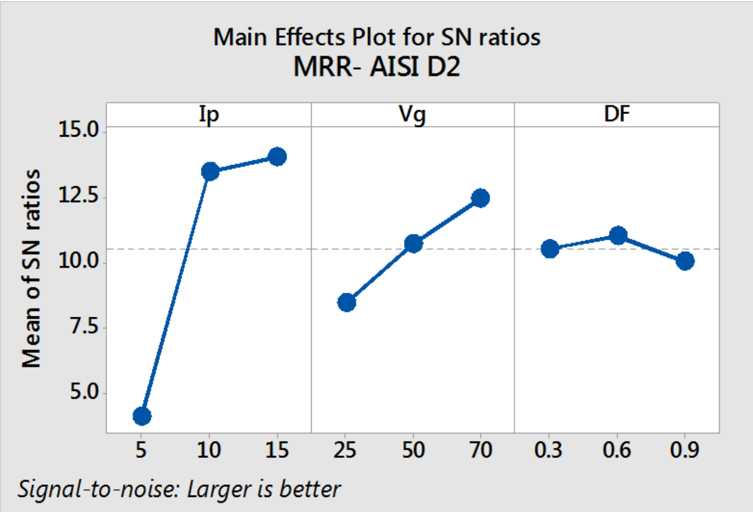

Figure 14. S/N ratio graphs for I_p, V_g and DF, in creating MRR for AISI D2 steel workpiece

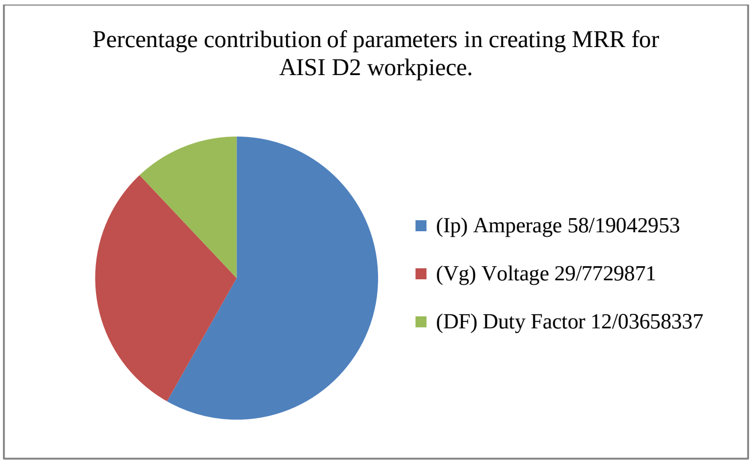

Figure 15. Percentage contribution o I_p, V_g and DF, parameters in creating MRR for AISI D2 steel

During EDM processes, the influence of various machining parameters like DF, I_p, V_g, and material of the tool has vital results on MRR. The I_p is directly proportional to MRR within the variation of one to 5A. This can be expected as a result of a rise in I_p produces sturdy spark that produces the upper temperature, inflicting a lot of material to soften and erode from the workpiece. However, with an increase in I_p from 5A to 10A, MRR will increase slightly. It should be noted that MRR decreases monotonically with the rise in DF. It is a standard undeniable fact that the spark energy will increase with t_{ON} and hence, MRR will increase with t_{ON}. It is evident that with higher t_{ON}, the plasma shaped between the buried conductor gap really obstructs the energy transfer and therefore reduces MRR. It is also observed that the MRR values increase, up to a certain value, and then MRR values decrease as the supply current values increase. This is expected because an increase in I_p produces a strong spark, which produces a higher temperature, causing more material to melt and erode from the workpiece. On the other hand, the low MRR at the high I_p region is considered to be related to inferior discharge due to insufficient cooling of work material. As mentioned in the above paragraph, it is evident that the MRR values decrease, up to a certain value, and then increase as the t_{ON} values increase. While, in the case of the t_{OFF}, it is not so, since as the t_{OFF} increases the MRR values decrease, which is expected. The t_{ON} controls the duration of time for which the current is allowed to flow per cycle. The MRR is directly proportional to the amount of energy supplied during this period. Thus it is the most significant factor as far as contribution and significance are concerned. As the t_{ON}, increases the MRR also increases almost nonlinearly. T_{OFF} is the least significant factor and shows minimum contribution. This is because no material is removed from the workpiece as there is no discharge current supplied. It is observed that as the t_{OFF}, increases the MRR is improved by a very small amount. At minimum t_{OFF}, the dielectric fluid gets less time to deionize and flush away the debris. As the t_{OFF}, increases the dielectric fluid gets sufficient time to de-ionize and to flush away the debris. Thus the stability of the machining process is enhanced and hereafter MRR is improved.

3.3 Electrode wear rate (EWR) of different workpieces

Tool wear is one of the output parameters that must be carefully examined because excessive tool wear leads to affecting the dimensional accuracy of the part as well as its surface quality. In addition, it increases the machining time, which causes an increase in the cost of the produced workpieces. The graphs presented in Figure 16 show the S/N ratio of EWR for the AISI4340. As mentioned in the subjects of SR and MRR, in this case, the parameter with the lowest value is considered to be the most effective parameter. In this regard, the I_p of 10 amps, the DF of 0.9, and the V_g of 70 volts were the input parameters in this operation for AISI4340 steel. Among these three parameters, the duty factor of 0.6 and the Ip of 15 amps, play the highest role in the EWR. Subsequently, the V_g of 50 volts can be effective in creating the electrode wear rate (Figure 16). As shown in Figure 17, I_p of 36.77%, V_g of 31.03%, and DF of 32.86% contributed to the EWR.

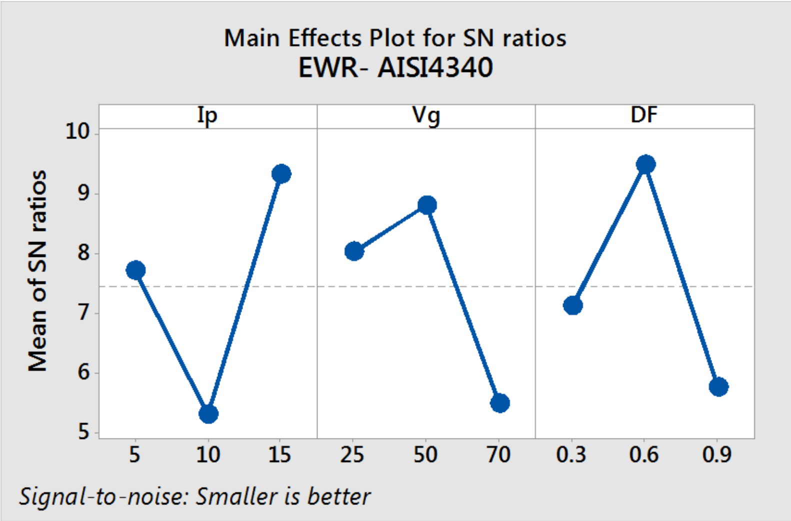

Figure 16. S/N ratio graphs for I_p, V_g, and DF, in creating EWR for the AISI4340 workpiece

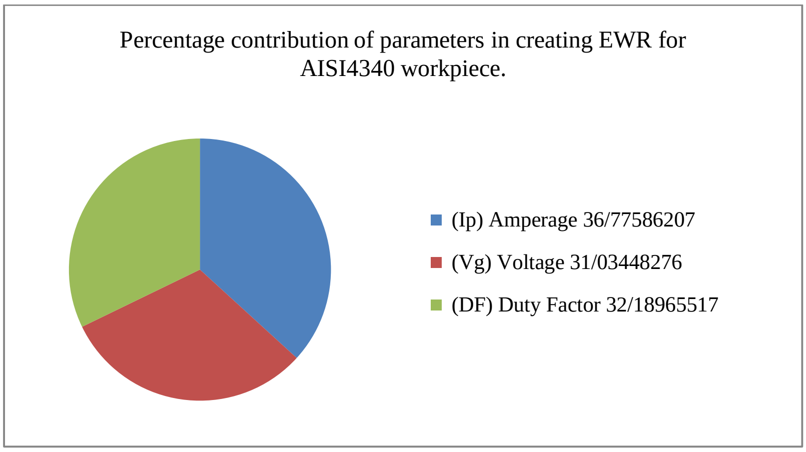

Figure 17. Percentage contribution I_p, V_g, and DF, parameters in creating EWR in AISI4340 steel

The graphs presented in Figure 18 show the S/N ratio for the EWR. In this case, the parameter with the lowest value is considered to be the most effective parameter.

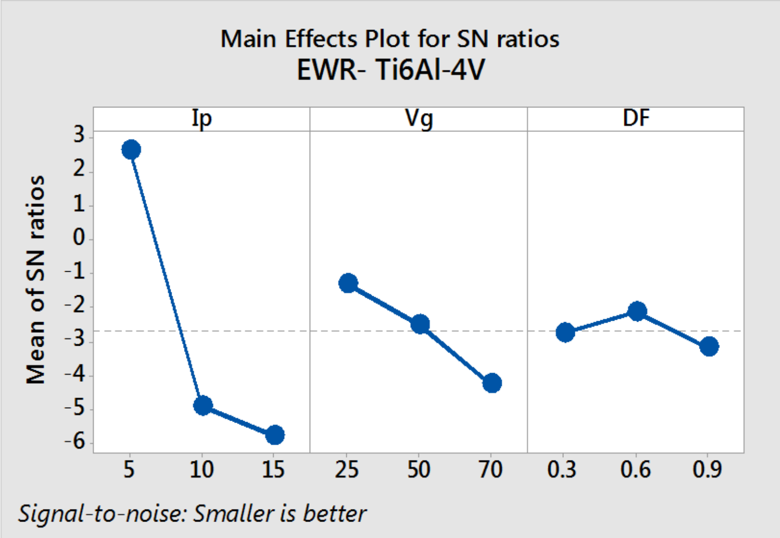

Figure 18. S/N ratio graphs for for I_p, V_g and DF, in creating EWR for Ti6Al-4V, workpiece

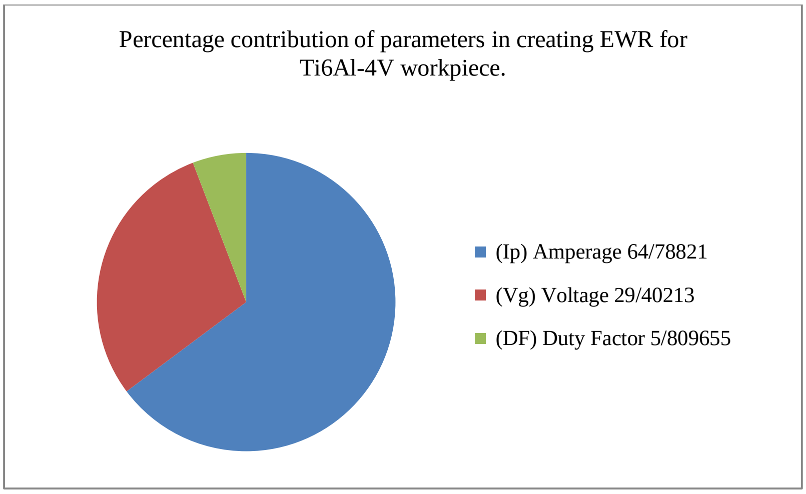

Figure 19. Percentage contribution of I_p, $V_{g,}$ and DF, parameters in creating EWR in Ti6Al-4V

In this regard, the I_p, V_g, and DF, were the input parameters in this operation for workpieces made of Ti6Al-4V, and among these three parameters, the Ip of 15 amps plays the highest role in the EWR. Subsequently, the Vg of 70 volts and the DF of 0.9 can be effective in creating the EWR.

According to the average response for the EWR in Ti6Al-4V, it is necessary to use the strategy of “less is better”. Since the goal is to increase the life of the tool, reduce the production time, and finally reduce the cost. The contribution percentage of each of the input parameters in creating the EWR can be seen in Figure 19. In this regard, the contribution of the Ip of 64.78%, 29.40%, and the DF of 5.80% for the EWR of Ti6Al-4V was gained.

The graphs presented in Figure 20 show the S/N ratio for the EWR in AISI D2 steel. As mentioned in the subject of SR and MRR, in this case, the parameter with the lowest value is considered to be the most effective parameter.

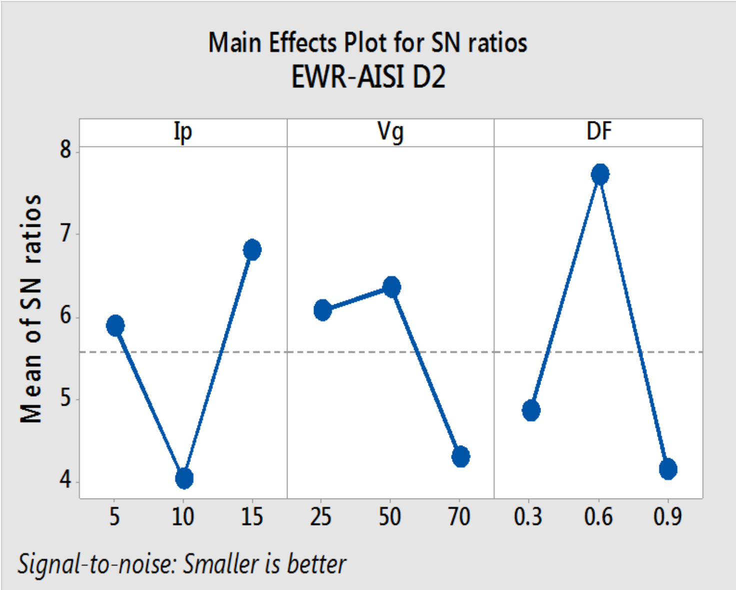

Figure 20. S/N ratio graphs for I_p, V_g, and DF, in creating EWR for AISI D2 steel, workpiece

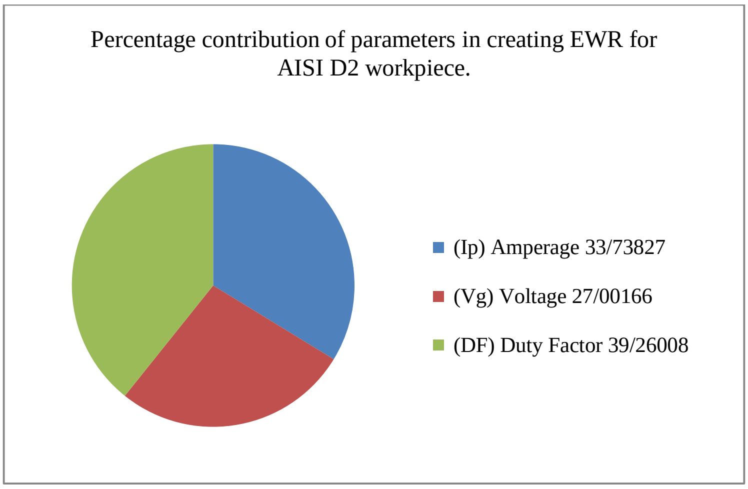

Figure 21. Percentage contribution of I_p, V_g, and DF, parameters in creating EWR in AISI D2 steel

In this regard, the DF of 0.9, the I_p of 10 amps, and the V_g of 70 volts respectively, play the highest role in EWR. The average response for the EWR in AISI D2 steel is that the less is better strategy is used because the goal is to reduce the tool wear in a certain time to increase the tool life and reduce the production time. According to the obtained data, the contribution percentage of each of the input parameters in the EWR can be seen in Figure 21. In this regard, the participation of Ip of 33.73, Vg of 27.00, and DF of 39.26% in the EWR was noted.

In general, electrode wear is mainly due to high-density electron impingement generated during machining from work and electrode materials. In the copper electrode, the EW increases as the I_p is increased due to its low melting point. From this figure, it can be noticed that the EWR increases as the supply current (I) increases. The result also demonstrated that the EW decreases as the t_{ON} increases. Finally, the EWR values increase, up to a certain value, and then EWR values decrease as the t_{OFF} values increase. The minimum EWR was obtained when the interaction effect of t_{ON}, and t_{OFF}, influences the most. The results of the researchers confirm this issue [19].

4. Conclusion

In this research, the experiments were carried out using the EDM with a copper tool on samples of alloy steel 4340, Ti6Al-4V, and AISI D2 steel. To reduce the cost and time of machining and performing operations, the algorithm can be used. The desired results can be obtained with less number of tests. In this research, Taguchi's algorithm has been used to reduce the number of machining operations. The test variables include the I_p, V_g, and DF. In these tests, the I_p of 5, 10, and 15 amps and the V_g of 25, 50, and 75 volts, and the DF of 0.3, 0.6, and 0.9 have been chosen. L9 orthogonal array related to Taguchi approach used for DOE, to reduce the number of machining operations from 81 to 27 tests. In this section, the results of SR, MRR, and EWR for different samples are presented.

A: Surface Roughness (SR)

The S/N ratio for determining the SR in samples of AISI4340 steel showed that the current parameter of 5 amps had the highest effect on the SR. A voltage of 25 volts after a current of 5 amps can be effective in creating roughness. The duty factor does not affect creating roughness. The degree of influence of the input parameters includes the I_p, V_g, and DF, respectively. The percentage of each input parameter in the creation of SR, including current, with a maximum of 79.27 %, and the DF with 1.63 % had the lowest impact.

Samples Ti6al-4V, showed that all three parameters of 5 amps, voltage of 25V, and DF of 0.3 were involved in roughness respectively. The percentage of parameters' participation is 45.45% for DF, the voltage at 39.27%, and the current at 14.94 %.

The surface roughness of AISI D2 steel showed that the 5 amps' current played the most role in the creation of roughness. While the other two parameters had no role. The percentage of parameters participation is 68.52% for Ip, the voltage at 16.91%, and the duty factor at 14.56%, respectively.

B: Material Removal Rate

The S/N ratio for determining the MRR of AISI4340 steel showed that the Ip parameter 15 and 10 amps as well as the voltage of 70V had the highest impact on the MRR. The percentage of each of the input parameters in MRR indicated that the current had a maximum of 59.03 % and the DF with 13.46 % had the lowest impact.

The S/N ratio for determining the MRR of Ti6al-4V showed that the Ip parameter of 15 and 10 amps as well as the voltage of 70V had the highest impact on the MRR. The percentage of participation in the creation of MRR is that the Ip of 56.28 % had the highest impact. While the DF of 13.14 % had the lowest impact.

The S/N ratio for determining the MRR of AISI D2 steel indicated that the Ip of 15 and 10 amps as well as the voltage of 70V had the highest impact on the MRR. The percentage of each of the input parameters in the formation of MRR, including the Ip of 58.19 % is the highest, and the DF with 12.03 % was the lowest.

C: Electrode Wear Rate

The S/N ratio for determining the electrode wear rate of AISI4340 steel showed that the DF of 0.6, Ip of 15 amps, and voltage of 50V, respectively, had the highest impact on the EWR. The percentage of participation of the input parameters in the creation of SR including Ip at 36.77%, the DF at 32.18%, and the voltage at 31.03 % had the highest impact.

The S/N ratio for determining the EWR of Ti6al-4V steel indicated that the 5A current parameter had the highest effect on the electrode wear rate and the other two parameters had no effect. In this regard, the percentage of each of the input parameters in the creation of SR including Ip at 64.78%, Vg at 29.40%, and DF at 5.80 % were the highest participation.

The S/N ratio for determining the wear rate of the tool of AISI D2 steel showed that the DF of 0.6, Ip of 15 amps, and voltage of 50V had the highest impact on the electrode wear rate. In this regard, the percentage of each of the input parameters in the creation of EWR includes the DF at 39.26%, the Ip at 33.73%, and the Vg at 27%.

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