The effect of alumina powder in dielectric on electrical discharge machining parameters of aluminum composite A413-Al₂O₃ by the Taguchi method, the signal-to-noise analysis and the total normalized quality loss

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Abstract

The machining capability of metal composites is different compared to other materials because of their specific physical and mechanical properties. The aluminum composite A413 reinforced with Alumina powder is one of the materials which causes rapid erosion of the tool if traditional machining methods are employed. In this research, the electrical discharge machining experiments were conducted using the Taguchi method. After analysis of variance (ANOVA) using simultaneous analysis of total normalized quality loss (TNQL), and signal-to-noise ratio (S/N) of outputs, the effect of each parameter such as current intensity, voltage, pulse on-time and pulse off-time have been investigated. These parameters are influential on material removal rates, surface roughness, and tool wear ratio of electric discharge machining in two cases of with alumina powder and without alumina powder in dielectric. The outcomes of this research indicate that the use of Alumina powder 3 g/L in kerosene dielectric averagely reduces the material removal rate by 7.8%, increases the surface roughness by 8.8%, and decreases the tool wear ratio by 1.3%. Also, the results of analysis of total normalized quality loss and signal-to-noise ratio of the experiment have been shown as the first level of voltage (A_1), the first level of current intensity (B_1), the first level of pulse on time (C_1), and the third level of pulse off time (D_3).

Keywords: Electric discharge machining, Aluminum composite 413, Alumina powder

Introduction

The electrical discharge machining is considered as a state-of-the-art machining technique and a technique capable of machining a broad range of conductive materials. Two metal electrodes, one in a predetermined manner and the other a piece of work, are immersed in a dielectric fluid. Based on the collision of ions and electrons with the workpiece and tool, the temperature reaches about 8000 °C to 12,000 °C, which results in the evaporation of super heavy metal and consequently, the removal of the material (Hourmand, Farahany, Sarhan, & Noordin, 2015). Due to the high costs of this machining process and the need to reduce the cost of these products, several studies have been carried out on setting optimal machining parameters for an electric discharge process (Satpathy, Tripathy, Senapati, & Brahma, 2017). Application of the surface analysis method for investigation of the effect of input parameters such as current, voltage, pulse on-time

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Table 1 Physical and mechanical properties of aluminum 413 (Data, 2003)

Detailed composition											
Si	Fe	Cu	Mg	Mn	Ni	Zn	Sn	Ti	Others	Total	Al
11.0–13.0	1.3	1.0	0.10	0.35	0.50	0.50	0.15	-	-	0.25	Balance

Mechanical properties					
Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation (% in 51 mm)	Hardness (BHN)	Shear strength (MPa)	Fatigue strength (MPa)
290	130	3.5	80	170	130

Physical properties					
Density (g/cm³)	Melting range (°C)	Specific heat (J/kg·°C)	Coefficient of thermal expansion (µm/m·K)	Thermal conductivity (W/m·K)	Electrical conductivity (%IACS)
2.66	574-582	963	21.6	121	31

and pulse off-time of material removal rate, tool wear, and surface roughness of 7075 aluminum composite has indicated that the material removal rate initially increases by an increase in the pulse on-time, however, further increase of the pulse on-time will ultimately give rise to a reduction in the material removal rate (Gopalakannan, Senthilvelan, & Ranganathan, 2012). The results of the research on electrical discharge machining parameters of C1023 nickel base alloy suggests that the current and pulse on-time are the most influential parameters. To diminish the tool wear to the lowest possible value, the minimum amount of the pulse on-time and current intensity should be selected. Furthermore, the best result is obtained when the pulse on-time is high for the case of high current intensity and when it is low for the case of low current intensity (Ayesta, 2013). The outcomes of a study regarding analysis of gap changes, plasma channel changes and plasma electromagnetic changes of the electric discharge process demonstrated that plasma evaporation oscillation in the electric evacuation machining process is a mixed process and is activated by various factors such as the electric gap zone, the magnetic gap zone, the plasma channel conductivity, dielectric pressure, and geometry of gap. Also, the role of fluctuating pulses in the improvement of the electric discharge machining efficiency is very pronounced (Wei, Di, Wang, & Wang, 2016). In a study of the relative electric discharge milling process on AISI 304 stainless steel, the effect of air spray rate, current, voltage, and velocity of electrode rotation on the material removal rate, the wear rate, and the surface roughness were investigated. The research showed that the material removal rate enhances by rise in air spray, current, voltage, and velocity of the tool rotation. The surface roughness showed a decreasing trend by reduction of the current intensity as well (Shen, Liu, & Sun, 2016). The outcomes of the application of the Taguchi method in scrutinizing the influential parameters of the electrical discharge machining of AZ31 magnesium alloy proved that the pulse on-time is the most crucial parameter in the surface roughness among other effective parameters such as voltage, current and pulse off-time (Razak, Abdul-Rani, Rao, Pedapati, & Kamal, 2016). In another study, the surface roughness of AISI 4340 steel was examined by the electric discharge machining using a tungsten copper electrode and the residual stress of EDM was also measured by the X-ray method. The results indicated that generally speaking, the material removal rate and surface roughness raise by an increase in current. On top of that, the growth of cracks increases by a rise in the current intensity (Rizvi & Agarwal, 2016). Investigations about the electric discharge machining on A413-Al_2O_3

Fig. 1 XRD composite aluminum compound reinforced with 5% Al_2O_3
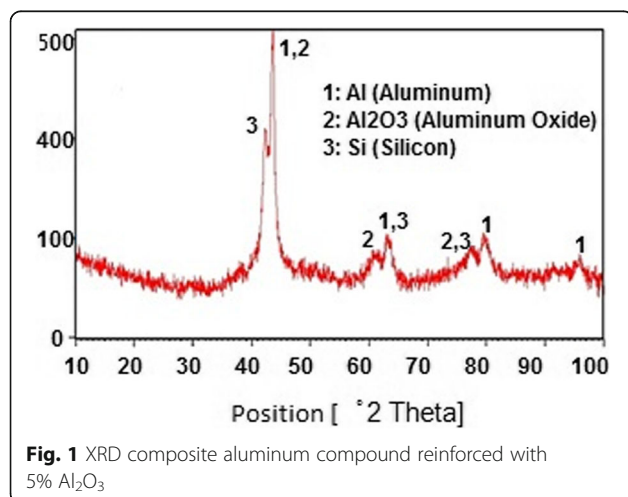
Table 2 Regulatory parameters on each test stage

Factors	Regulatory levels		
Taguchi-related levels	1	2	3
Voltage (V)	80	250	80
Current (A)	10	15	20
Pulse-on time (µs)	35	50	100
Pulse-off time (µs)	30	70	200

Table 3 Taguchi test parameters

Test number	Voltage	Current	Pulse-on time	Pulse-off time
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	1`	1	3	2
8	1`	2	1	3
9	1`	3	2	1

metal matrix composites obviously verify that no research has so far been conducted on this type of composite which proves the uniqueness of this study. The novelty of this research is to investigate how the presence of alumina powder in dielectric will impact output parameters such as the material removal rate, the surface roughness, and the tool wear during the electric discharge process of aluminum composite A413-Al_2O_3 by the Taguchi method. In addition, after analysis of variance (ANOVA) using the simultaneous analysis of the total normalized quality loss (TNQL) and the signal-to-noise ratio (S/N) of the outputs, the effect of each input parameters such as voltage, current intensity, pulse-on time and pulse-off time are scrutinized in two dielectric cases of with alumina powder and without alumina powder.

Materials and equipment
Materials which were used in this study are aluminum composite workpiece, copper tools, and dielectric, as follows:

A413 Alloys have a wide range of high-pressure applications for instance in sensitive hydraulic cylinders, pressure lids and containers, and so on. Also, with its excellent

anti-abrasive and heat treatment, it is a great option for employment in abrasive applications. Table 1 presents the percentage of elements and some of the physical and mechanical properties of this alloy. Aluminum base composites are broadly used in a variety of applications. Adding Al_2O_3 powder to aluminum composite by reducing the main component of aluminum alloy and replacing it with aluminum oxide, enhances the toughness while it prohibits the hardening and curbs the fracture. Moreover, adding Al_2O_3 powder to aluminum base material improves the fatigue strength and abrasion resistance (Ramnath, 2014).

As shown in the XRD test results (Fig. 1), each of these peaks represents a crystalline plan. The uniformity of curve peaks and the repetition of these particles in regular states confirm the presence of Al_2O_3 powder in the aluminum matrix 413 of the experiment workpiece.

The electrode used in this study is pure copper (99.9%) with a diameter of 10 mm and a height of 150 mm.

In this research, two types of kerosene dielectric and kerosene dielectric with a combination of alumina powder have been employed. In the case of dielectric with a combination of alumina powder, 3 g/L alumina powder is added to the kerosene according to the designed experiment.

The spark machine TEHRAN EKRAM model is used for this research. In order to calculate the material removal rate and tool wear rate, an accurate laboratory scale (AND GR-300 model) by a precision of 0.001 g is used. The mass of the electrode (tool) and workpiece are measured before and after machining. At the end of the machining operation, Ra values of machined places on the workpieces are measured using a roughness meter (MAHR M300-RD18 model) which has one-micron precision.

Methodology
In this research, four parameters of voltage, current intensity, pulse-on time, and pulse-off time are taken into

Table 4 The experimental results of aluminum composite A413 reinforced by 5% Al_2O_3 powder in two cases of with and without powder in dielectric

| Experiment number	Kerosene dielectric (the first test)			Kerosene dielectric containing 3 g/L alumina powder (the second test)		
	MRR	SR	TWR	MRR	SR	TWR
1	1.223	4.892	0.0311	1.053	4.195	0.0215
2	1.987	9.165	0.0338	1.814	8.443	0.0231
3	2.438	11.938	0.0260	2.269	10.977	0.0162
4	0.814	4.346	0.0341	0.847	3.531	0.0256
5	4.933	8.807	0.0246	3.841	8.231	0.0184
6	2.488	8.337	0.0374	3.015	7.846	0.0329
7	1.578	4.487	0.0238	1.423	3.734	0.0132
8	0.777	9.026	0.0326	0.657	8.924	0.0239
9	4.791	12.941	0.0349	4.599	11.752	0.0258
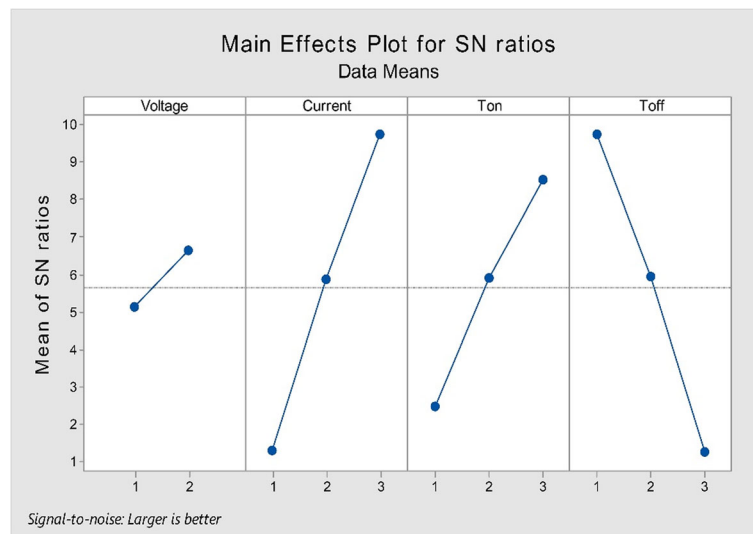
Fig. 2 Effects of input parameters of the first test on material removal rate

consideration as input parameters. Furthermore, based on the adjustable parameters of the spark machine TEHRAN EKRAM, the voltage parameter has 2 levels and the other parameters have 3 levels (according to Table 2). Hence, the repeating levels method is employed for the voltage factor. The impact of input parameters of electric discharge machining on the material removal rate, the workpiece surface roughness, and the tool wear rate in the presence of kerosene with alumina powder and kerosene without alumina powder is investigated using the Taguchi method which is present in Minitab@17 software. According to the presence of four factors (input parameters) as well as the existence of three levels for each factor, the Taguchi method presents an L9 array as shown in Table 3. The time of each test is considered to be 5 min and the components are completely washed by acetone at the end of each test stage and before measuring the mass of the electrode and

workpiece. Then after drying, they are measured by an accurate laboratory scale.

To ensure the accuracy of the adjustment parameters on the spark machine, an oscilloscope is used to fine-tune the pulse-on time and pulse-off time. Moreover, a multimeter is used to adjust the voltage and current of the spark machine. Ultimately, the roughness of the machined workpiece surfaces is measured and recorded by a roughness measurement device.

The material removal volumetric rate (MRR) in cubic millimeters per minute (mm³/min) can be calculated as follows (Baskar, 2016):

$$\mathrm{MRR} = \frac{(W_1 - W_2)}{\rho_w \times t} \times 10^3 \qquad (1)$$

where w_1 and w_2 are the weight of the workpiece before and after the machining, respectively, ρ_w is the density of the workpiece, and t is machining time in minutes.
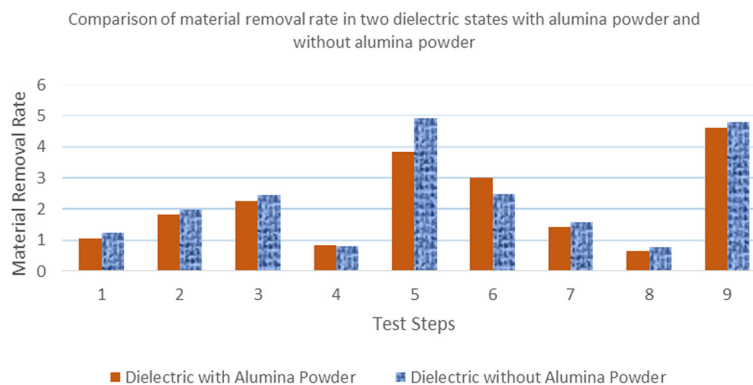

Fig. 3 Comparison of the material removal rate in experiments of the first and the second tests

Table 5 Results of the material removal rate variance analysis for the first test Parameter

	Degrees of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	F value	P value	Degree of impact (rank)
Voltage	1	0.751	0.751	2.802	0.1380	4
Current	2	32.902	16.451	7.358	0.0002	1
Pulse-on time	2	3.486	1.743	6.537	0.0311	3
Pulse-off time	2	8.434	4.217	22.896	0.0243	2

The tool wear ratio (TWR) is also calculated in terms of cubic millimeters per minute (mm³/min) as follows (Baskar, 2016):

$$\text{TWR} = \frac{(T_1 - T_2)}{\rho_T \times t} \times 10^3 \qquad (2)$$

where T_1 and T_2 are the weight of the tool before and after the machining, respectively, ρ_T is the density of the electrode, and t is machining time in minutes.

After the experiments, the output parameter values of MRR, SR, and TWR are presented according to Table 4.

In order to perform the S/N analysis, the values of the material removal rate are calculated by Eq. 3 (the bigger, the better) and the values of the surface roughness and the tool wear rate are calculated by Eq. 4 (the smaller, the better) (Daneshmand, Neyestanak, & Monfared, 2008).

$$S/N = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \qquad (3)$$

$$S/N = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n}y_i^2\right) \qquad (4)$$

where n is the number of trials or measurements and y_i is the measured value.

By considering the fact that the material removal rate, the surface roughness, and the tool wear rate have various units, they have to be normalized in order to simultaneously optimize them. For this purpose, the data for each output must be subdivided into the maximum value of the same output and normalization operation. Subsequently, in order to estimate the normalized total value of the parameters and the simultaneous S/N ratio of the outputs, they are weighted based on the importance of the outputs (according to Eq. 5), and using the Eq. 6, the sum of the normalized parameters is estimated. It should be noted that in this research, by virtue of the higher importance of material removal rate than the surface roughness and the higher importance of the surface roughness compared to the tool wear rate, the coefficient weight of the material removal rate considered to be 0.5, surface roughness considered to be 0.3, and tool wear rate considered to be 0.2.

$$\text{TNQL}i = \sum Wy \\ = (0.5\,\text{MRR} + 0.3\,Ra + 0.2\,\text{TWR}) \qquad (5)$$

$$\text{MSNR}i = -10\log(\text{TNQL}i) \qquad (6)$$

After calculation of the mean value of MSNR, according to the Taguchi approach and MSNR[1] values, the average MSNR value for each input parameter in its different levels is calculated as follows (Daneshmand, Kahrizi, LotfiNeyestanak, & Monfared, 2014):

$$\eta_0 = \eta m + \sum(\eta i - \eta m) \qquad (7)$$

where the values of η_i and η_m are the S/N ratio for each step and the mean ratio of S/N for all steps, respectively. Finally, the maximum value for each input parameter is considered as the optimal value (Daneshmand et al., 2014).

Results and discussion

In this section, the investigation of S/N and variance analysis of output parameters has been performed.

Analysis of the material removal rate results

According to the diagrams of Fig. 2, the current intensity and the pulse-off time have the largest slope and thus, have the greatest impact. As current increases, the temperature of the workpiece surface will increase as well due to a rise in the sparking energy. Therefore, it

Table 6 Results of the material removal rate variance analysis for the second test

Parameter	Degrees of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	F value	P value	Degree of impact (rank)
Voltage	1	0.716	0.716	3.418	0.1069	4
Current	2	7.190	3.595	26.323	0.0011	1
Pulse-on time	2	1.598	0.799	3.478	0.0993	3
Pulse-off time	2	5.484	2.742	16.618	0.0036	2

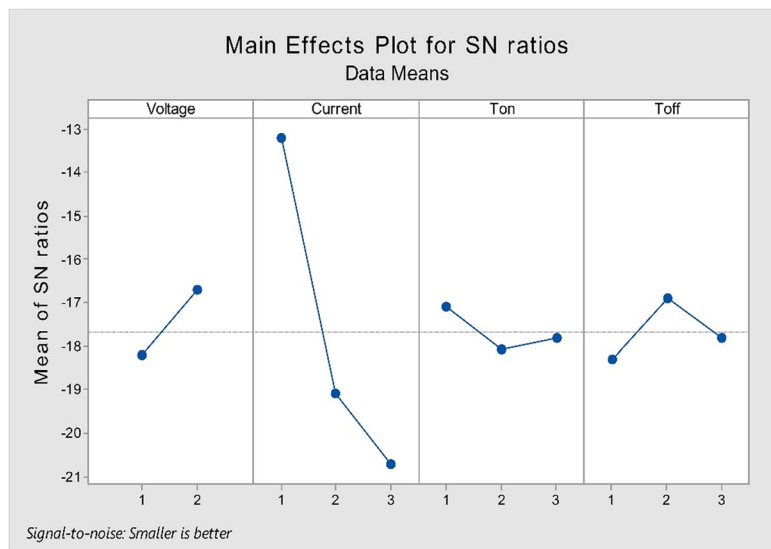
[1]Multi signal-to-noise ratio

Fig. 4 Effects of the input parameters of the first test on the surface roughness

gives rise to an increase of melting and evaporation of the machining zone so that the material removal rate increases. By elevation of the current intensity and pulse-on time, the number of positive ions which hit the workpiece surface grows. Hence, the energy of the spark goes up. By further elevation of the current intensity and the pulse-on time, the S/N curves tend upward. However, the energy density in the machining area lessens because of the accumulation of workpiece swarf in the machining area. This results in a reduction of the gradient of the material removal slope.

According to Fig. 3, the material removal rate in the case of the kerosene dielectric with 3 g/L of alumina powder is less than the kerosene dielectric without powder. Its reason stems from the fact that the powder in dielectric reduces the energy of the spark. That is why it diminishes the material removal rate.

The variance analyses are presented in Tables 5 and 6 for a 95% confidence level in the first and the second tests with a P value less than 0.05. The current intensity, pulse-off time, pulse-on time, and voltage are known as the critical and important influential parameters during the process, respectively.

Analysis of the surface roughness results

According to the diagrams of Fig. 4, the current intensity has the biggest slope and consequently has the largest effect. Thereafter, the pulse-on time and the pulse-off time and ultimately the voltage are the most effective parameters. A rise in the current intensity and the pulse-on time leads to an activation of the positive ions and consequently an increase in the spark energy and more severe bombardment of the ions to the workpiece surface. The bottom line is that quantity of the holes on the surface increases causing more surface roughness. Furthermore, by
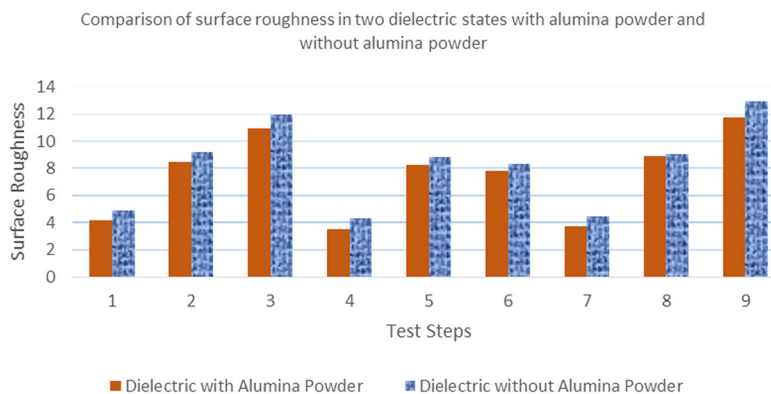

Fig. 5 Comparison of the surface roughness in experiments of the first and the second tests

Table 7 Results of the surface roughness variance analysis for the first test

Parameter	Degrees of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	*F* value	*P* value	Degree of impact (rank)
Voltage	1	4.981	4.981	6.293	0.0405	2
Current	2	65.833	32.916	36.268	0.0005	1
Pulse-on time	2	3.107	1.554	1.627	0.2725	4
Pulse-off time	2	3.825	1.913	2.029	0.2123	3

further increase of the pulse-on time, the flow density and input thermal flux of the surface are reduced because of the expansion of the plasma channel. Thus, the depth of pits lessens and so does the surface roughness.

In Fig. 5, the sparks have been dispersed with less intensity on the workpiece surface by virtue of the electrical resistance and non-conductivity of the aluminum oxide powder. These factors slightly roughen the surface of the workpiece in a dielectric-powder machining case versus the other case without powder in dielectric.

The variance analyses are presented in Tables 7 and 8 which are in fact the variance analysis tables of the first and the second tests, respectively. These tables reflect the fact that for a 95% confidence level with a *P* value less than 0.05, the effects of current intensity, voltage, pulse-off time, and pulse-on time, respectively, are the most critical and crucial effective input parameters during the process.

Analysis of the tool wear ratio results
As shown in Fig. 6, the graph of the pulse-on time has the largest slope suggesting the greatest impact on this parameter. Given that the workpiece has a negative charge and the electrode has a positive charge, an increase in the pulse-on time results in a rise in the diameter of the plasma channel. Hence, the attack of the positive ion on the workpiece surface overcomes the invasion of the electron to the electrode. Thus, by an increase of the pulse-on time to about 50 μs, the wear of the tool is significant; however, after that, the tool wear decreases swiftly.

As shown in Fig. 7, in the machining case with the powder present in the dielectric, the tool wear rate of the electrode diminishes by means of reduction of the ignition energy.

The variance analyses presented in Tables 9 and 10 are considered for a 95% confidence level with a *P* value less

than 0.05. The effects of the pulse-on time, current intensity, voltage, and pulse-off time are respectively the most critical and important influential parameters during the process in the first test, and the pulse-on time, voltage, current intensity, and pulse-off time are the most crucial and critical effective parameters during the process, respectively, in the second test.

Multi signal-to-noise ratio (MSNR) analysis
By simultaneous use of the analysis of the total normalized quality loss and signal-to-noise ratio of the outputs, the influence of each input parameters has been examined on influential parameters such as the material removal rate, the surface roughness, and the tool wear ratio of the electric discharge machining in the two cases of with the alumina powder and without the alumina powder in the dielectric.

Aluminum composite 413 reinforced with 5% Al_2O_3–kerosene dielectric
The results of the S/N ratio analysis and normalized outputs are presented in Table 11. The maximum values of S/N ratio have been grayed out in the table.

The outcomes of normalization and simultaneous S/N ratios analysis of the output parameters are presented in Table 12. Note that the weight ratio of the material removal rate is 0.5, the weight ratio of the surface roughness is 0.3, and the weight ratio of the tool wear rate is 0.2.

Based on the average of MSNR values for each input parameter at different levels (Table 13), the final upshot of the analysis is shown as the first level of voltage (A_1), the first level of current intensity (B_1), the first level of pulse-on time (C_1), and the third level of pulse-off time (D_3). The maximum values of each level have been grayed out in the table.

Table 8 Results of the surface roughness variance analysis for the second test

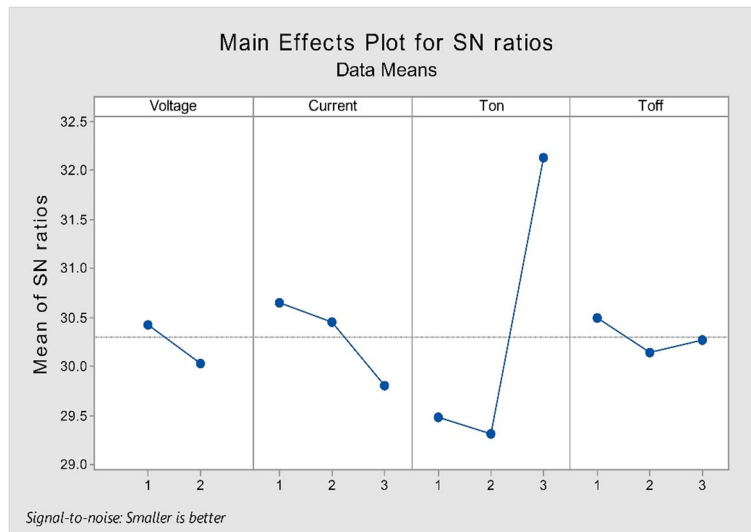| Parameter	Degrees of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	*F* value	*P* value	Degree of impact (rank)
Voltage	1	4.311	4.311	4.293	0.0770	2
Current	2	65.667	32.833	22.059	0.0017	1
Pulse-on time	2	1.350	0.675	0.553	0.6021	4
Pulse-off time	2	3.271	1.636	4.385	0.3224	3

Fig. 6 Effects of the input parameters of the first test on the tool wear ratio

Aluminum composite 413 reinforced with 5% Al₂O₃– kerosene dielectric with 3 g/L Al₂O₃ powder

The results of the S/N ratio analysis and normalized outputs are presented in Table 14. The maximum values of the S/N ratio have been grayed out in the table.

The results of normalization and simultaneous S/N ratios analysis of the output parameters are given in Table 15 presuming the weight ratio of the material removal rate equals to 0.5, the weight ratio of the surface roughness equals to 0.3, and the weight ratio of the tool wear rate equals to 0.2.

According to the average of MSNR values for each input parameter at different levels (Table 16), the final upshot of the analysis is presented as the first level of voltage (A_1), the first level of current intensity (B_1), the first level of pulse on time (C_1), and the third level of pulse off time (D_3). The maximum values of each level have been grayed out in the table.

Conclusion

The purpose of this research was to scrutinize the effect of alumina powder on the electrical discharge machining parameters of the aluminum composite A413-Al₂O₃ by both the Taguchi method and the simultaneous use of the S/N analysis and total normalized quality loss (TNQL). It is concluded that the current intensity has the greatest impact on the material removal rate such that when it increases, the material removal rate will increase, too. Also, when the pulse-on time and voltage increase, the material removal rate increases initially, however, with further increase of these parameters, the material removal rate decreases finally. On top of that, the current intensity is the most influential parameter on the surface roughness. With a rise in the current intensity, the surface roughness increases promptly. By an elevation of the voltage and pulse-off time, the surface roughness
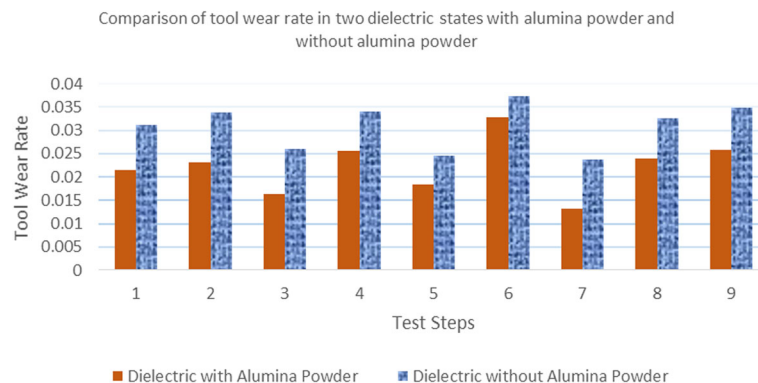

Fig. 7 Comparison of the tool wear ratio in experiments of the first and the second tests

Table 9 Results of the tool wear ratio variance analysis for the first test

Parameter	Degrees of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	*F* value	*P* value	Degree of impact (rank)
Voltage	1	0.00051	0.00051	10.302	0.0164	3
Current	2	0.00162	0.00081	8.809	0.0148	2
Pulse-on time	2	0.00170	0.00849	14.631	0.0049	1
Pulse-off time	2	0.00034	0.00017	2.292	0.1822	4

Table 10 Results of the tool wear ratio variance analysis for the second test

Parameter	Degrees of freedom (DF)	Sum of squares (SS)	Mean of squares (MS)	*F* value	*P* value	Degree of impact (rank)
Voltage	1	0.00500	0.00500	18.433	0.0284	2
Current	2	0.00371	0.00185	18.188	0.0359	3
Pulse-on time	2	0.02412	0.02060	26.581	0.0010	1
Pulse-off time	2	0.00029	0.00014	3.070	0.1207	4

Table 11 Results of the S/N ratio analysis and normalized outputs of the first test

Experiments	S/N Ratio Analysis			Normalized Outputs		
	MRR	**SR**	**TWR**	**MRR**	**SR**	**TWR**
1	1.749	13.790	30.1447	0.126	0.620	0.9284
2	5.962	19.243	29.4216	0.430	0.865	0.9061
3	7.740	21.539	31.7005	0.558	0.968	0.9763
4	1.785	12.762	29.3449	0.129	0.574	0.9037
5	13.861	18.897	32.1812	1	0.850	0.9911
6	7.916	18.420	28.5425	0.571	0.828	0.8790
7	3.960	13.039	32.4684	0.286	0.586	1
8	2.197	19.110	29.7356	0.159	0.859	0.9158
9	13.609	22.239	29.1434	0.982	1	0.8975

Table 12 Normalization of the results and the simultaneous S/N ratio analysis of the output parameters in the first test

Experiment no.	TNQL	MSNR
1	0.4347	3.6178
2	0.6558	1.8324
3	0.7649	1.1638
4	0.4172	3.7962
5	0.9531	0.2086
6	0.7098	1.4889
7	0.5187	2.8509
8	0.5202	2.8385
9	0.9704	0.1307
MSNR mean		1.9920

Table 13 Average of MSNR values for each input parameter at different levels in the first test

Input Parameters	Average of MSNR values for each input parameter and at different levels		
	Level 1	Level 2	Level 3
Voltage (A)	2.6300	1.5098	1.8362
Current (B)	6.2810	0.8956	1.2006
Pulse On-Time (C)	3.9613	1.7754	0.2394
Pulse Off-Time (D)	0.0268	2.1883	3.8146

Table 14 Results of the S/N ratio analysis and normalized outputs of the second test

Experiments	S/N Ratio Analysis			Normalized Outputs		
	MRR	SR	TWR	MRR	SR	TWR
1	0.452	12.455	33.3512	0.034	0.582	0.8872
2	5.175	18.530	32.7277	0.390	0.866	0.8706
3	7.118	20.810	35.8096	0.537	0.972	0.9526
4	1.440	10.958	31.8352	0.109	0.512	0.8469
5	11.690	18.309	34.7036	0.882	0.855	0.9232
6	9.586	17.893	29.6560	0.723	0.866	0.7889
7	3.063	11.443	37.5885	0.231	0.535	1
8	3.645	19.011	32.4320	0.275	0.888	0.8628
9	13.253	21.402	31.7676	1	1	0.8451

Table 15 Normalization of the results and the simultaneous S/N ratio analysis of the output parameters in the second test

Experiment no.	TNQL	MSNR
1	0.3690	4.3296
2	0.6290	2.0133
3	0.7507	1.2453
4	0.3773	4.2337
5	0.8823	0.5440
6	0.7792	1.0833
7	0.4759	3.2246
8	0.5765	2.3919
9	0.9690	0.1367
MSNR mean		2.1336

Table 16 Average of MSNR values for each input parameter at different levels in the first test

Input Parameters	Average of MSNR values for each input parameter and at different levels		
	Level 1	Level 2	Level 3
Voltage (A)	3.3210	1.5939	1.4859
Current (B)	7.5207	0.6820	1.8019
Pulse On-Time (C)	3.5376	2.1165	0.7467
Pulse Off-Time (D)	0.7431	2.0540	3.6036

decreases and by more increase in the pulse-off time (more than 70 μs), the surface roughness increases with a gentle rate again. Moreover, by an increase in the pulse-on time up to 50 μs, the roughness elevates initially and then decreases afterward. In inspecting the effects of the input parameters on the tool wear rate, the pulse-on time has the greatest influence. By a rise in the voltage and current, the tool wear rate increases and also by a rise in the pulse-on time up to 50 μs, the rate of the tool wear increases gently initially and then increases rapidly. It is also observed that the material removal rate declines by adding 3 g/L aluminum oxide powder in the kerosene dielectric which in turn causes a reduction in the surface roughness and the tool wear rate compared to the case of the kerosene dielectric without powder.

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