Optimization of the EDM Parameters on the Surface Roughness of DIN 1.2767 Tool Steel Using Taguchi Method

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Abstract.

Manufacturing processes affect surface properties, as a result, they significantly affect the component lifetime. In Electric Discharge Machining (EDM), the component surface is subject to high localized thermal energy that produces changes in surface quality such as surface hardness, roughness, surface crack density and white layer thickness. In the present paper, Taguchi method and ANOVA has been implemented to obtain the optimal EDM process parameters affecting on DIN 1.2767 tool steel surface. The process parameters were electrode materials (B2, NSS), discharge current (6, 12 and 25 A), pulse on time (50, 200 and 800 µs) and pulse off time (50, 200 and 800 µs). From the results, it was found that the discharge current has the highest influence on surface roughness followed by pulse on time and the influence of electrode material and pulse off time were insignificant. The optimal surface finish can be achieved at low discharge current and long pulse on time and pulse off time and utilize B2 electrode. Scanning Electron Microscopy (SEM) images revealed the alterations in the surface roughness and surface crack density.

Keywords: EDM, Taguchi, steel, NSS, B2, Surface roughness

1. Introduction

EDM is among the unconventional manufacturing techniques that have a major role in the manufacture of complex geometrical shapes and mechanical properties that are difficult to machine in conventional methods (Ho & Newman, 2003). Also, the achievement of accurate dimensions and improvement in the surface finishing of hard materials and advanced engineering materials greatly contributed to the spread of this technology (Selvarjan, Manohar, Jayachandran, Mouri, & Selvakumar, 2018). EDM application seems to be flourishing swiftly for the manufacture of moulds, punches and dies. Those have well-established application in manufacturing of components of aerospace, automotive, surgical, marine, nuclear, and petroleum (Mahajan, Sidhu, & Devgan, 2020). Electric discharge machining removes metal by a series of rapidly repetitive electrical discharges (sparks) between the tool and the workpiece submerged in a dielectric fluid. Each spark causes localized temperatures high enough to melt or vaporize a small amount of material. A large number of sparks occur in a very short time creating melted pool that partially ejected in a form of liquid globules and not ejected molten metal is re-solidified and leaves a tiny hemispherical crater which produces and forms the surface textures and affecting surface integrity (Black & Kohser, 2012; Groover, 2010; Guitrau, 1997). The volume of melted material based on the discharge energy. As a result of the discharge energy increases, the surface roughness and the recast layer increase (Boujelbene, Bayraktar, & Wissem, 2009).

Several previous studies were interested in studying the effect of the input factors on the responses to achieve the best performance of the EDM by conducting practical experiments, analyzing the results, and using mathematical and statistical methods. (Arunkumar, Rawoof, & Vivek, 2012) investigated the effect of process parameters on the performance of EN31(air hardened steel) based on Taguchi Orthogonal Array (OA). The results show that the Ra is influenced by electrode material, flushing pressure, Ip and Ton. In addition, the variation in Ra varies erratically for all electrodes (copper, aluminum and EN-24) but the minimum variation produced by copper electrode. Also, it was found that the minimum Ra can be achieved at low values of Ip. (Janardhanan et al., 2016) studied the effect of EDM process parameters on SR in Inconel 825 Alloy, applied L_{16} OA based in Taguchi to design the experiments and optimize the process parameters and ANOVA to identify the contribution of each parameter. The results revealed that Ip has the highest contribution 82.31% followed by Ton 13.51% and Toff 0.89%. (Chandramouli & Eswaraiah, 2018) applied L_{27} Taguchi method to determine the influence of process parameters and optimization of 17-4 PH steel in EDM, and copper tungsten electrode was used. The machining parameters are Ip (9,12,15A), Ton (50, 100, 200 µs), Toff (20, 50, 100 µs), and lift time (10,20, 50 µs). Results showed that the Ip and Ton have significant influence on surface roughness (SR) while Toff has a lower influence than Ip and Ton. The optimal combination of SR is (Ip 9A, Ton 200µs, Toff 20µs, and lift time 10µs). The highest percentage contribution of the parameters is Ton (83.55%) followed by Ip (7.5%), lift time (0.75%) and the least Toff (0.507%). There is slight interaction effect between parameters for SR. (Sanjeev Sharma, Rajdeep Singh, & Sandeep Jindal, 2015) studied the influence of machining parameters in EDM of EN 31 Die Steel. Taguchi method and ANOVA were applied to optimize the machining parameters. The parameters ware Ip (10,15,20A), Ton (30, 60, 90 µs) and Toff (15,30, 45 µs). The results revealed that Ip is the most significant factors effects on Ra with a contribution of 74.30% followed by Ton 12.67% and Toff 6.30%. Optimum combination of parameters which produce the minimum Ra is Ip 10A, Ton 60µs and Toff 45µs. (Ahmad & Lajis, 2013) experimentally investigated Inconel 718 at higher peak current (20, 30, 40A) and pulse duration (200, 300, 400µs) and concluded that the minimum surface roughness (Ra) achieved at low value of peak current and short pulse-on time. (Patil & Jadhav, 2016) studied the machining parameters in EDM and observed that the SR increases with increase of Ip and Toff, whereas long Ton reduces the SR. (Jamwal, Vates, & Aggarwal, 2017) reviewed papers and observed that the higher intensity of the spark produces the higher material removal rate but it affects the surface quality. SR increases with the higher values of Ip. It is also found in the study that higher values of Toff increase the surface quality.

Hamid & Lajis, 2012 experimentally investigated the machining performance in EDM machining of AISI D2 hardened steel. The process parameters Ip (20, 32, 40A) and Ton (400, 500, 600µs). The results revealed that the lowest surface roughness obtained at the lowest Ip and longest Ton.(Habib, 2014) optimized machining parameters of DIN 2714 hot work tool steel using Taguchi method. The machining parameters for copper electrode are Ip (1,4,6A), Ton (50,100,150 µs), Toff (40,50,60 µs) and the V (40,50,60). It is reported that Ton is the most significant factor affecting SR with contribution 86.33% followed by Ip 7.51% then Toff 4.7%. High Ip and long Ton produce deeper and wider craters on the EDM machined surface. (Mahajan et al., 2020) studied the performance of different copper and copper-based electrodes used in EDM process and mentioned that at utilizing a copper electrode and brass electrode SR is comparatively high at higher values of discharge current. (Guu, 2005) revealed that a higher discharge energy causes a poorer surface quality. To avoid excessive machined damage, low Ip and short Ton should be used. In this present study, the DIN 1.2767 tool steel was EDM machined with two copper-based electrodes to obtain the optimal process parameters for minimum SR applying Taguchi L_{18} OA. In this study, Taguchi method and ANOVA has been implemented to obtain the optimal EDM process parameters affecting on DIN 1.2767 tool steel surface. The process parameters were electrode materials (B2, NSS), discharge current (6, 12 and 25 A), pulse on time (50, 200 and 800 µs) and pulse off time (50, 200 and 800 µs).

2. Experimental work and methodology

2.1 Materials and experimental setup

Tool steel DIN 2767 (45NiCrMo16) was utilized as a workpiece. This material has wide application in the industry for example cutting tools, cutlery punches, bending tools, embossing tools, cold hobbing tools, pressure bars, cold shear knives, plastic moulds, billet shear knives hot press tools, drawing jaws due to its good mechanical properties such as high toughness, good through-hardenability, high impact strength and pressure resistance. The chemical composition of DIN 2767 is shown in Table 1. The size of each workpiece is 50mm X 25mm X 12mm, the surface was milled and finish ground before performing the EDM experiments. The initial surface roughness slightly affecting workpiece surface roughness after EDM machining (Hadad, Bui, & Nguyen, 2018). However, kerosene was used in experiments as a dielectric and copper alloys as electrodes. Kerosene and copper electrodes are currently at peak use in EDM (Vishwakarma, Yadav, Kumar, & Krishhna, 2017). Two different electrodes-based copper – namely, NSS and B2 – with 15 mm diameter and 100 mm height were used to machine the workpieces. These electrodes have physical properties that are suitable for use in EDM. Electrodes physical properties such as thermal conductivity, melting point and electrical resistivity (or electric conductivity) would affect the roughness value of the surface (Fikri, Romlie, & Aminnudin, 2017). Table 2 presents the chemical properties of the electrodes and Tables 3 and 4 present their chemical properties. Before performing experiments, surfaces of electrodes are prepared by polishing on silicon carbide paper with different grit sizes in this sequence, 150, 240, 320, 400, 600 and 800. The experiments were carried out on the FURKAN M25A sinker electrical discharge machine with lateral flushing. The lateral flushing is constant at pressure 0.25 bar. The tool electrode was the negative polarity and the workpiece was the positive polarity during the EDM process. The optimal SR was determined for copper tool electrodes under negative polarity (Amorim & Weingaertner, 2007).

Table 1 Chemical composition (wt %) of DIN 1.2767

Element	C	Si	Mn	Cr	Mo	Ni	Fe
Weight (%)	0.45	0.25	0.35	1.35	0.25	4.05	Balance

Table 2 Chemical Composition: Nss (CuNi2SiCr)

Element	Si	Mn	Cr	Ni	Fe	Pb	Cu
Weight (%)	0,65	0,10	0,35	2,5	0,15	0,02	Balance

Table 3 Chemical Composition B2 (CuBe2)

Element	Ni	Be	Co	Fe	Cu
Weight (%)	0,30	1,95	0,30	0,20	Balance

Table 4 Physical properties of the electrodes

	Density g/cm³	Electrical conductivity MS/m	Thermal conductivity W/m K	Melting temperature range °C
B2	8.3	≥ 16	120-170	870-980
NSS	8.81	≥ 23	190-240	1020-1040

2.2 Materials and experimental setup

At the selection of machining parameters and their levels, the machinability and previous studies were considered. The process parameters and levels are listed in the Table 5.

Table 5 Control Factors and levels

Factor	Unit	Level 1	Level 2	Level 3
Tool Material		B2	NSS	
Ip	A	6	12	25
T_{on}	µs	50	200	800
T_{off}	µs	50	200	800

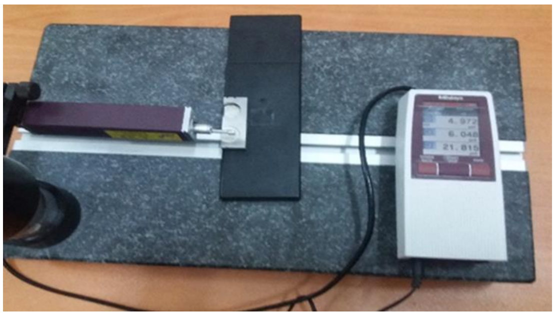
Experiments were planned and conducted according to the Taguchi`s L18 OA. Taguchi optimization technique is widely applied in optimizing process parameters of EDM (Sanghani & Acharya, 2014). Taguchi has presented a combined measure focus on identifying factors that affect mean response and detect factors that affect variability of the response. Optimization in Taguchi technique means identifying the best levels of control factors that minimize the variance. In Taguchi's technique signal to noise ratio (S/N ratio) is implemented to determine the effect of input factors on the output. The S/N ratio is a combined measure of mean and variance (Krishnaiah & Shahabudeen, 2012). Computing S/N ratio based on the condition of optimization. The best levels of process parameters are those that maximize the S/N ratio. For surface roughness, minimum surface roughness is preferable, in S/N ratio "smaller-is-better" that denotes by Equation 1.

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

2.3 Surface roughness (SR)

In EDM, the surface of the workpiece is subjected to electric sparks, which contribute to form a tiny crater. These craters create the surface roughness of the workpiece. Surface roughness is an important performance measure that affected by EDM machining factors since it affects mechanical properties of the workpiece such as fatigue strength and wear resistance. There are many different roughness parameters in use such as Arithmetic mean value of roughness (Ra), the mean square root value (Rq) and Mean Roughness Depth (Rz). Three distinct measurements were taken at different locations using Mitutoyo digital surface roughness tester as shown in Figure 1. and the average surface roughness was calculated.

Fig. 1. Measuring surface roughness of EDMed workpieces



3. Result and discussion

As can be seen from Table 6, the minimum surface roughness (1.618µm) was obtained at combination of parameters E1A1B3C3 and the maximum surface roughness (10.88 µ) at E1A3B3C2. We note from the table also that when machining with the parameters A1B3C3 for both electrodes, the lowest value for the surface roughness can be achieved.

Table 6 Experimental results

Sq.	Control factors	Tool	Ip	T_{on}	T_{off}	Ra
1	$E_1A_1B_1C_1$	B2	6	50	50	3.846
2	$E_1A_1B_2C_2$	B2	6	200	200	2.801
3	$E_1A_1B_3C_3$	B2	6	800	800	1.618
4	$E_1A_2B_1C_2$	B2	12	50	200	4.745
5	$E_1A_2B_2C_3$	B2	12	200	800	7.557
6	$E_1A_2B_3C_1$	B2	12	800	50	2.422
7	$E_1A_3B_1C_3$	B2	25	50	800	5.785
8	$E_1A_3B_2C_1$	B2	25	200	50	9.199
9	$E_1A_3B_3C_2$	B2	25	800	200	10.888
10	$E_2A_1B_1C_1$	NSS	6	50	50	5.791
11	$E_2A_1B_2C_2$	NSS	6	200	200	4.025
12	$E_2A_1B_3C_3$	NSS	6	800	800	2.723
13	$E_2A_2B_1C_2$	NSS	12	50	200	5.349
14	$E_2A_2B_2C_3$	NSS	12	200	800	8.694
15	$E_2A_2B_3C_1$	NSS	12	800	50	4.132
16	$E_2A_3B_1C_3$	NSS	25	50	800	6.095
17	$E_2A_3B_2C_1$	NSS	25	200	50	10.224
18	$E_2A_3B_3C_2$	NSS	25	800	200	10.608

Figure 2 depicts the main effect plot on Ra. The optimal surface finishes achieved at process parameters E1A1B3C3, which can be obtained by maximum values of the mean of S/N ratio. The SR value is minimum if the value of Ip at the lower level and Ton and Tof at high levels. From Figure 2. and Table 7, it is clear that Ip is the most effecting process parameter and playing as main factor for minimizing Ra tracked by Ton then electrode material and the least was Toff. Ra increases sharply as a result of the increase of Ip. The surface roughness increases due to increase discharge energy (Kalyon, 2020). In addition, it is observed that Ra increases initially, when Ton increases from 50 µs to 200 µs, while tends to decrease, when Ton increases from 200 µs to 800 µs. However, the trend of Toff is similar to Ton, where Ra increases when Toff increases from 50 µs to 200 µs and tend to decrease when

Toff increases from 200 µs to 800 µs. An excessive Ton creates an expansion of the electric plasma channel, which results in a reduction in both the SR and the MRR (Lee, Hsu, & Tai, 2004).

Fig. 2. Signal-to-noise graph for surface roughness

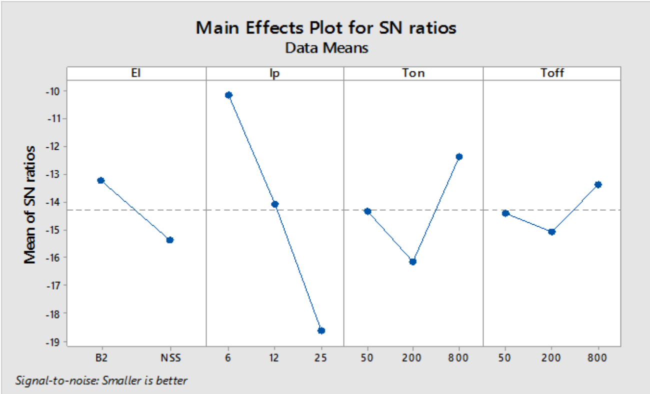


Figure 3 illustrates six interaction plots for various two-parameters interactions between electrode material, Ip, Ton and Toff. In the interaction plot if the lines are parallel, the interaction effect does not exist. The strength of the degree of interaction is distinguished by the degree of non-parallelism between the lines (Krishnaiah & Shahabudeen, 2012). It is observed that, no interaction effect between electrode material and other parameters, and this may be caused by the convergence of the physical properties. While there are strong interactions between other parameters (Ip, Ton, Toff) which is obvious that the significant change on the surface roughness as a result of the effect of one parameter depends on the level of the other parameters. This clears the complex relationship between the parameters and their combined effect on the responses.

Fig. 3. Interaction plot for Ra

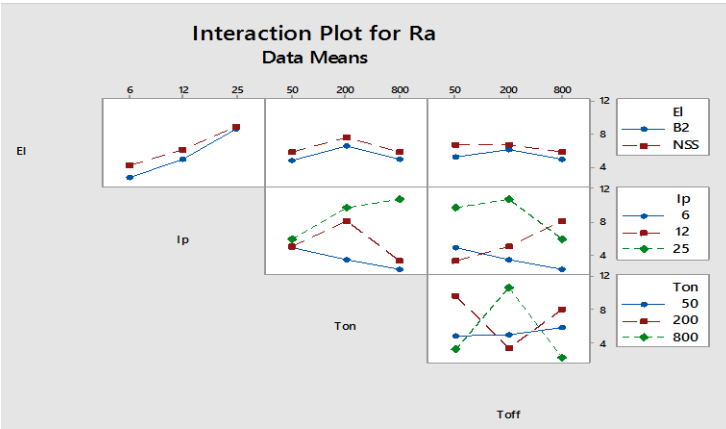


Table 7 S/N response table for SR

Level	Electrode	Ip	T_{on}	T_{off}
1	-13.21	-10.15	-14.33	-14.40
2	-15.35	-14.07	-16.14	-15.06
3		-18.61	-12.36	1.07
Delta	2.14	8.46	3.79	1.70
Rank	3	1	2	4

Figures 4 and 5 show effect of Ton and Toff on the surface roughness and surface crack density. Where it is noticed in the case of process parameters E2A1B1C1 that the surface roughness is higher but the cracks are less compared to the second case when the Ton and Toff increased as in process parameters E2A1B2C2. Also as shown in Figure 5. at machining with process parameters E2A1B1C1 the Ra was 5.791µ whereas the process parameters E2A1B2C2 the Ra was 4.025µ.

Fig 4. SEM Micrograph at process parameters E2A1B1C1

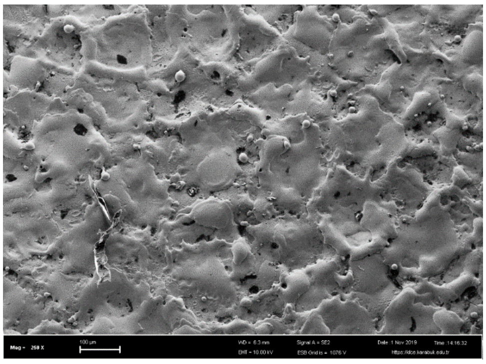
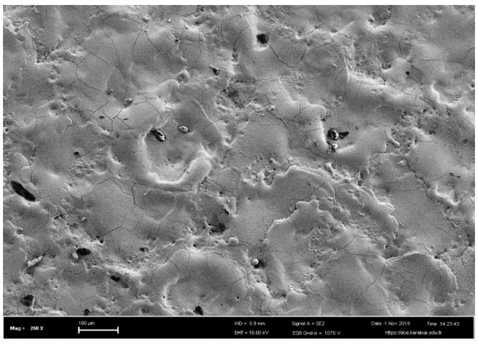


Fig. 5. SEM Micrograph at process parameters E2A1B2C2



4. Conclusion

In the present study, the optimum set of the EDM performance parameters was determined to improve the surface finish quality. The Taguchi L18 OA and ANOVA were adopted for planning the experiments, optimizing and analyzing results. Pulse current and pulse-on time have the highest effect interactively on Ra yielding a wide range from 1.618 to 10.888μm. The Ra sharply increased due to increase of Ip, whereas the value of Ra increases initially with an increase of Ton and Toff and then tends to decrease. Also it observed that a strong interaction between Ip, Ton and Toff and no interaction between electrode materials and other parameters. In addition, SEM images show the increase of SCD as a result of increase of both Ton and Toff. However, for achieving minimum surface roughness, the optimum parametric combination is Ip = 6A, Ton = 800μs, Toff = 800 μs and using B2 tool electrode.

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