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The influence of process parameters on quality indicators in powder mixed EDM using titanium for SKD61 die steel

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Abstract
In the current context, an attempt is being made to improve the electrical discharge machining process by using powder particles in a suitable combination. To improve the quality of such procedures, the process parameters should be optimised. In this study, the influence of technological parameters on the quality parameters in PMEDM using titanium was determined. Technological parameters including current, pulse-on-time, pulse-off-time, and powder concentration were used for the survey. The Taguchi method was used in this study. 5 quality indicators were used in the study.
Keywords: *SKD61, die steel; PMEDM; Taguchi.*

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I. INTRODUCTION

Electrical discharge machining (EDM) utilises the thermal energy generated by electrical discharge sparks to attack the machined surface continuously and repeatedly. During the machining operation, the materials in the work piece and electrode are melted and evaporated [1]. Allowing the deionization of the pressurised dielectric medium ejects the resolidified particles from the machining zone [2]. Additionally, it may influence the thermal and electrical conductivity of the plasma generated in the machining zone. The dielectric medium's characteristics can affect both the formation of craters and microcracks and the thickness of the white layer [3]. To establish the surface layer's quality, the roughness (R_a), hardness (HV), average white layer thickness (WLT), and heat impacted zone were measured (HAZ). As a result, the cost of machining has grown dramatically, as has tool material wear [4]. As a result, optimising the surface layer quality throughout the EDM process continues to be a difficulty. Numerous variables, such as electrical settings, electrode materials, and dielectric fluid, can affect the EDM process's surface quality. Numerous parameters, such as current (I), pulse-on time (T_{on}), and pulse-off time (T_{off}), all influence the surface quality during the EDM process. Additionally, these variables can impact the recast layer's depth [5]. The EDM procedure of removing the WLT layer from the machining surface is time consuming. Reduce the depth of the WLT to increase the surface quality. Electrical resistivity and thermal conductivity of the insulating medium might potentially affect surface performance evaluations during the EDM process [6]. Additionally, the machined workpiece's surface quality is determined by the tool wear rate (TWR), which is greatly influenced by the specific gravity, tensile strength, electrical conductivity, and melting temperature of the electrode materials. In EDM operations with low surface quality, water-diluted dielectric fluid is more productive than oil-diluted dielectric fluid [7]. The diameter of the crater is mostly determined by the nature of the dielectric medium. Microcracks vary in length and distribution depending on the heat conductivity of the workpiece [8]. However, fabricating electrodes with complicated shapes with these materials is extremely difficult. Powder mixed EDM (PMEDM) can be used to eliminate microfractures and voids in the WLT [9]. The electrode material and composition of the powder used with the dielectric fluid during the PMEDM process may affect the machined surface's WLT [10]. During the EDM process, a stronger tool electrode can provide a smoother surface with a higher surface hardness. Additionally, the particle size of the powder material may affect the depth of the WLT, which in turn affects the high voltage of the machined surface during the EDM process [11]. Powder particle size has a significant effect on the capabilities of machined specimens to withstand high voltage [12]. In comparison to standard EDM, PMEDM considerably lowers particle adherence and small fractures [13]. It was revealed that the particle size of the powders mixed with the dielectric medium has an effect on the PMEDM process's efficacy[14].

II. EXPERIMENTAL METHODOLOGIES

2.1. Choice of workpiece and process factors

Due to its importance in the creation of complex form hot stamping dies for manufacturing applications, the present study selected SKD61 die steel specimens with a sample size of 45x27x10 mm as the workpiece specimens. The machining trials were performed using an AG40L electrical discharge machine (Sodick, USA) equipped with a powder mixing stirrer configuration similar to that shown in Figure 1. The particles had an average diameter of 45 µm and were mixed with HD-11 oil dielectric fluid at a flushing pressure of 10 l/min and with the tool electrode polarised positively. We used a copper (Cu) tool electrode with a 22 mm diameter. Experiments were conducted using the process parameter combinations shown in Table 1. The process variables were chosen to represent the process parameters at their maximum, medium, and minimum values. HD-1 dielectric fluid was employed, since it has frequently been utilized in Vietnam for current pulse processing.Two stirring vanes were turned in opposite directions at a speed of 200 rev/min to ensure that the titanium powders were distributed uniformly throughout the dielectric. A solvent pump was employed to maintain a constant flow rate of 24 l/min into the processing chamber. The material removal rate (MRR), the tool wear rate (TWR), the surface roughness (R_a), the micro hardness (HV), and the white layer thickness (WLT) were all used as quality indicators in this experiment. The weights of the workpiece and electrode were determined precisely using a digital weighing scale with an accuracy of 0.001 g and a standard deviation of 10 mg (Model: Vibra AJ-203 SHINKO, Japan). The surface roughness (R_a) was evaluated using a 0.8 mm cut off length contact probe profilometer (SJ-210) (MITUTOYO, JAPAN). Three measurements were obtained for each test sample, and the average of the three values was utilised. The surface morphology was determined using a JEOL-6490 scanning electron microscope (SEM) and a Carl Zeiss Axiovert 40MAT optical microscopy (OPM). The hardness (HV) was evaluated using a 0.5 kg applied stress on an Indenta Met 1106 microhardness tester (Buehler, USA).

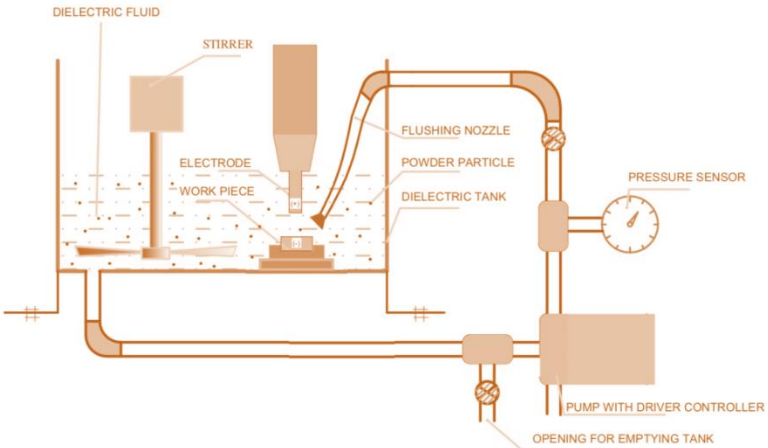

Figure 1. Experimental Scheme used in the present study

Table 1. Selection of process parameters

Process parameters	Symbol	Unit	Variables
Peak-current	I	A	1, 2, 3
Pulse on-time	T_{on}	µs	18, 25, 37
Pulse off-time	T_{off}	µs	18, 25, 37
Powder concentration	C	g/l	3, 4, 5

III. RESULTS AND DISCUSSION

In this investigation, SKD61 die steel specimens were machined using the PMEDM method according to the experimental design described in the preceding section, and the findings are summarised in Table 2. Three measurements were obtained for each test sample, and the average of the three values was utilised.

Table 2. Quality measures matrix in PMEDM process

Exp. No	I (A)	T_{on} (µs)	T_{off} (µs)	C (g/l)	MRR (mm^3/min)	TWR (mm^3/min)	R_a (µm)	HV (HV)	WLT (µm)
1	1	18	18	3	12.623	0.519	0.605	911.9	12.72
2	1	25	25	4	13.54	0.506	0.488	978.8	15.7
3	1	37	37	5	17.195	0.451	0.368	918.9	15.766
4	2	18	25	5	18.077	0.753	0.816	1090.6	18
5	2	25	37	3	16.542	0.641	1.04	900.1	19.6
6	2	37	18	4	17.871	0.842	0.943	1047.6	18.8
7	3	18	37	4	20.366	1.029	1.136	1380.8	19.06
8	3	25	18	5	20.435	1.164	0.983	1090	21
9	3	37	25	3	19.194	1.626	1.28	980.5	19.72

3.1 Effect of I on performance measures

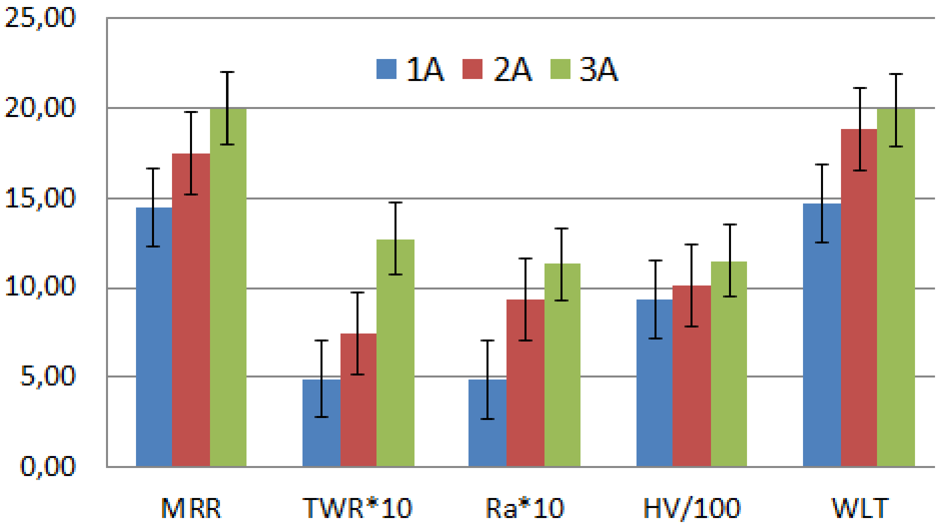

Figure 2. Effect of I on performance measures

Figure 2 shows the influence of I on the quality parameters in PMEDM using titanium powder. The change of I led to the quality parameters being changed quite strongly, and the increase of I led to the value of the quality indicators being increased accordingly. The cause of the increase in WLT could be because the amount of workpiece-powder-electrode adhered to the surface of the workpiece was also increased with the increase of I. R_a of the machined surface was also increased by I due to the increase of the size of the craters on the surface of the workpiece.The increase in HV can be attributed to the increased penetration of Titanium powders and Carbon into the machined surface.MRR, TWR, R_a and WLT were significantly altered with an increase of I, and HV was slightly altered.

3.2. Effect of T_{on} on performance measures

The influence of T_{on}on MRR, TWR, R_a, HV and WLT in PMEDM using titanium powder is shown in Figure 3. The increase in T_{on} led to an increase of MRR, TWR and WLT. But the increase of these quality indicators was not significant. This was due to an increase in the energy of the sparks in the PMEDM under T_{on} = 18 - 37 µs. However, the increase in spark energy was not significant. R_a was changed very little by T_{on} change. The hardness of the machined surface (HV) after PMEDM was reduced by the increase of T_{on} has resulted in a decrease in the amount of titanium powder entering the machined surface. Of the four quality parameters investigated, the change of T_{on} = 18 - 37 µs led to the highest increase in WLT. The largest increase of WLT with T_{on} = 18 - 25 µs, this could be due to the increased adhesion of electrode material, workpiece and powder to the machined surface. In general, the change of T_{on}, it led to the quality indicators in PMEDM being slightly affected.

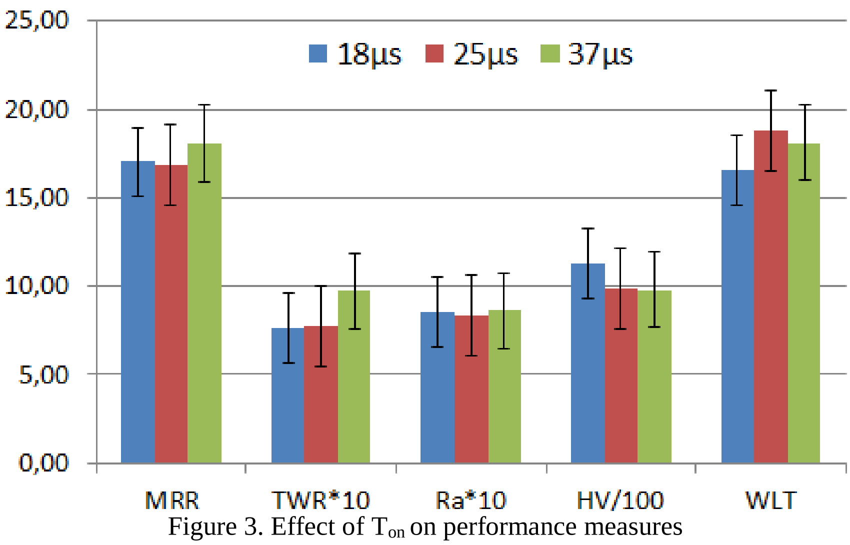

Figure 3. Effect of T_{on} on performance measures

3.3. Effect of T_{off} on performance measures

The T_{off} in PMEDM affects the process of chips, powders and dielectric fluid being ejected from the gap at discharge,after they are impacted by sparks. Figure 4 showed that the change of quality parameters (MRR, TWR, R_a, HV and WLT) was not significant with the increase under T_{off} = 18 - 37 µs. MRR, TWR and R_a were slightly increased, and MRR increased by 6.8%.The reason may be that the increased T_{off} led to a more stable machining process. Therefore the useful energy in machining was increased. The HV of the surface layer was increased. This was also the cause of the increase in WLT.

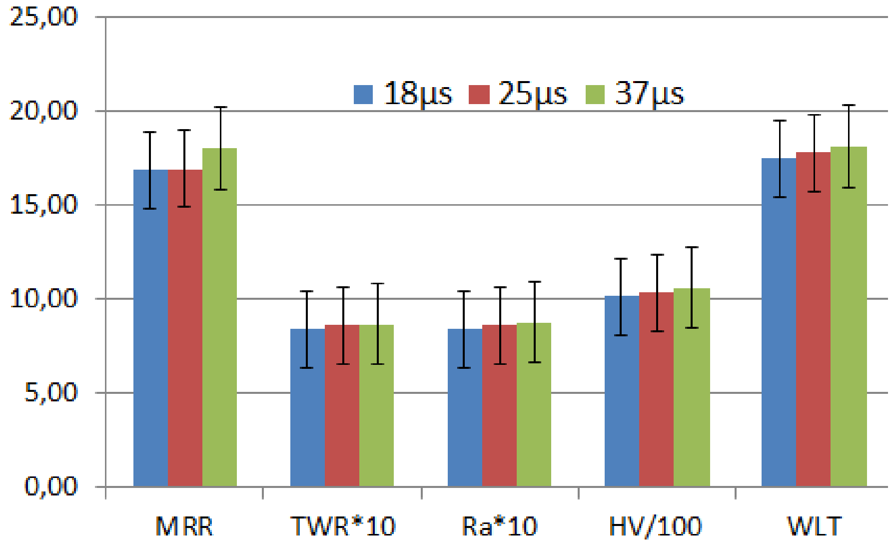

Figure 4. Effect of pulse off time on performance measures

3.4. Effect of titanium powder concentation (C) on performance measures

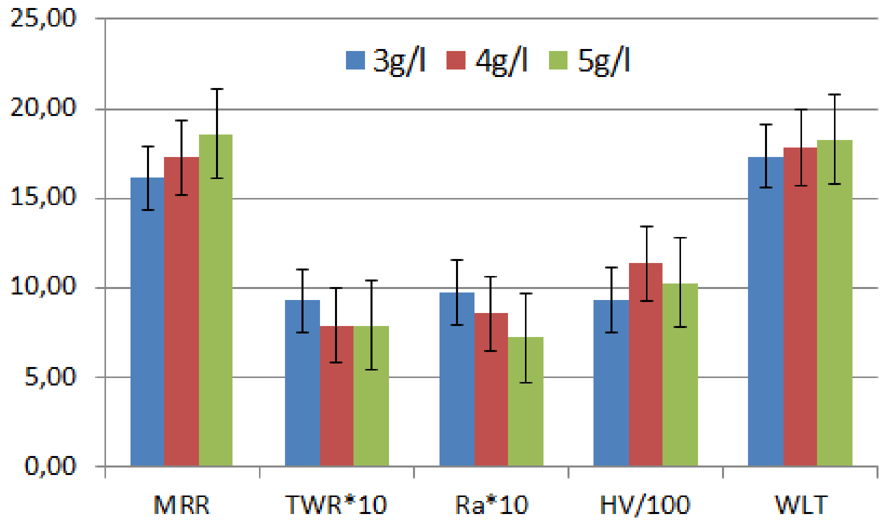

Figure 5. Effect of titanium powder concentration on performance measures

The addition of powder to the dielectric fluid increased the number of sparks and decreased the energy required to break down the dielectric fluid, hence increasing useable energy. Figure 5 illustrates the influence of titanium powder mixed with dielectric fluid on the EDM processing of SKD61. Increases in C = 3-5g/l resulted in a 15.2 percent rise in MRR. TWR and Ra were decreased by 15.0% and 25.91%, respectively. The reason for this could be that the number of sparks increases, resulting in a drop in the energy of each spark. The rise in powder concentration resulted in an increase in powder accessing the workpiece surface layer following PMEDM, and WLT increased marginally (5.23 percent) at C = 5g/l. The hardness of the surface layer was changed insignificantly (≈ 10.73%), and the HV was maximum at C = 4 g/l. However, the value of powder concentration is too high, it will lead to more occurrence of short circuit phenomenon. Hence the machining process is not stable. It can negatively affect the improvement of quality indicators in PMEDM.

IV. CONCLUSIONS

- Technological parameters have a significant influence on quality indicators.
- The graphs show that I is the most influential parameter and Toff is the smallest effect.
- Powder concentration has a very positive influence on quality parameters in EDM.
- Due to the importance of spark energy in the PMEDM process, the peak current is a more prominent factor.
- Titanium particles can significantly improve surface performance during PMEDM-based machining.

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