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Enhanced Material Removal Rate and Surface Quality of H13 Steel in Electrical Discharge Machining With Graphite Electrode in Rough Machining

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Abstract: Enhanced productivity and workpiece surface quality after electrical discharge machining (EDM) is a concern of many researchers. In this study, the effect of powder concentrations on material removal rate (MRR), surface roughness (SR) and topography surface in powder mixed EDM (PMEDM) was investigated. The experimental studies were conducted keeping the various parameters like current, voltage and pulse time constant while using varying concentrations of titanium powder. Experimental research methods were employed to study performance characteristics in the machining of H13 steel using PMEDM with a graphite electrode. The results revealed that the concentration of titanium powder has a powerful influence on the MRR, SR and topography surface in PMEDM.

Keys word: EDM; PMEDM; MRR; H13; titanium powder.

1. INTRODUCTION

Among non-traditional machining methods, EDM has been the most popular application in mechanical engineering technology. This method uses the energy from the sparks generated in the dielectric fluid to melt and evaporate both electrode and machining material. The advantages of this method are the machining of conductive materials with very high hardness and strength. Surfaces with complex shapes can also be machined; this would be difficult using the traditional processing methods. However, the greatest drawback of this method is productivity and also the processing quality is not high. Recently a solution has been proposed to overcome these limitations of EDM and there is a lot of professional interest in this field. There have been many research documents published concerning the use of metals or alloy powders mixed with dielectric fluid and used in EDM.

Some of these powders (copper (Cu), silicon (Si), aluminum (Al), chromium (Cr), tungsten (W), vanadium (V), nickel (Ni), silicon carbide (SiC), aluminum oxide (Al_2O_3) and molybdenum disulfide(MoS_2)), with size <100μm were used and mixed into the dielectric fluid to improve productivity and processing quality in EDM. The powder, when mixed into the dielectric fluid formed a series of electric sparks which discharged in one pulse of EDM as shown in Figure 1 [1]. When the powder was mixed into the dielectric fluid, results showed that MRR increased. Surface roughness and the number of cracks on the surface microstructure reduced with machining and the impact of the thermal layer also reduced. Strength erosion increased and a layered alloy with good mechanical properties formed on the machining surface [2], Figure 2 and 3. Silicon powder when mixed into the dielectric fluid for machining steel H13 enhanced the quality of the machining surface [3]. Aluminum powder with average size mixed into the dielectric fluid for machining steel SKH-51 showed high surface smoothness, but when machining steel SKH-54 resulted in low surface smoothness [4]. The change in the concentration of Al powder mixed with the dielectric fluid had a powerful influence on the quality of the EDM process [5]. The diameter and depth of the craters on the surface when machining using the EDM technique decreased when powder was mixed into the dielectric fluid [6]. Silicon powder and the cross-sectional area of the electrodes both had an effect on the values of surface roughness and the structure of the machining surface [7]. Values of surface roughness ranged from 0.09 to 0.57μm when the surface area of machining varied from 1 to 64 cm^2. Surface roughness, white layer thickness and the shape and depth of the craters are all related to the surface machining area and this has been described by mathematical equations [8]. Al and SiC powders were mixed into the dielectric fluid and surface roughness was selected for analysis [9]. Results from research have found that the technological parameters of quality PMEDM have achieved the best surface machining. Comparing the effect of Cu powder mixed with graphite powder into the dielectric fluid showed that, the graphite powder significantly reduced the tool wear rate (TWR). This enhanced the durability of the electrode and improved machining accuracy [10]. Al powder mixed into the dielectric fluid behaves like pure water for machining a W300 steel mould by EDM [11]. This reduced the thickness of the white layer on the surface machining layer of the workpiece, compared with no powder in the dielectric fluid. Increasing the concentration of powder resulted in a decrease in the white layer thickness. Graphite and nickel powders when introduced into the dielectric fluid in EDM increased MRR while TWR reduced and machining accuracy and surface machining quality increased [12]. When Al powder was added to the dielectric fluid surface roughness values reduced and increasing concentrations of powder led to further surface roughness reduction [13]. When large amounts of tungsten powder (0.25% to 2.89%) were mixed with the dielectric fluid the tungsten migrated to the machining surface and increased the microscopic surface hardness by 100% [14]. This increased the durability of the machining to surface corrosion. The concentration and size of SiC powder mixed into the dielectric fluid influenced MRR, TWR and SR [15]. The productivity and quality of surface machining using PMEDM is higher than just using EDM [16], and the machining time of products is reduced. It is necessary to extend the search of different types of powder materials and investigate their concentration and effect on productivity and quality machining surfaces [17].

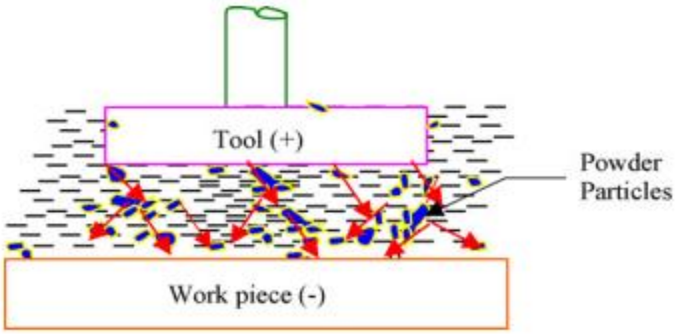

Figure 1. Schematic diagram “series of electric sparks” in PMEDM [1]

These search results show that the PMEDM method is very promising. However, more research is needed for this technology to become acceptable in practical production applications. In this research experiments were carried out using various concentrations of titanium powders in oil dielectric fluid for machining H13 steel moulds by EDM using a graphite electrode in reverse polarity. Material removal rate, surface roughness and surface topography measurements were used to evaluate the influence of the concentration of the titanium powders against efficiency in EDM.

2. Experimental procedure

2.1. Machine EDM, Schematic diagram

The experiments were conducted using the Electrical Discharge Machine model CNC- AG40L of Sodick, Inc. USA at The Central Laboratory of Thai Nguyen University of Technology. The powder was evenly distributed in the dielectric fluid and no powder deposition phenomena were observed. The stirring system as shown in Figure 2. Compressed air motor rotation speed was 100 revolutions/min with the stirring propeller diameter at 105 mm as shown in Figure 3a. The dielectric fluid is supplied to the machining process by an A303 pump from China with a pumping capacity of 600 litres/hour and nozzle diameter (Ø) 8 mm. These parameters as shown in Table 1 were selected based on the instruments used by previous researchers.

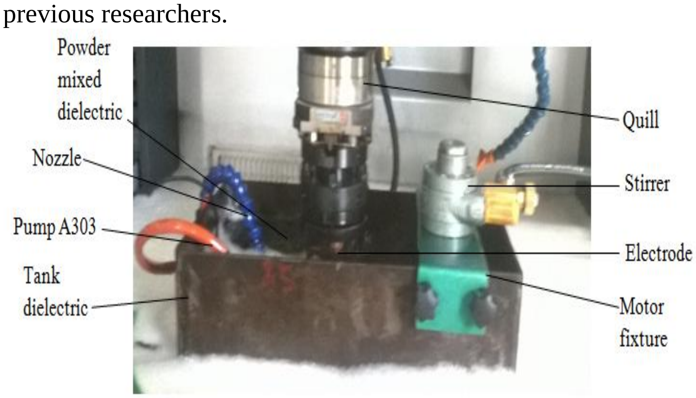

Figure 2. Dielectric tank with along with stirrer

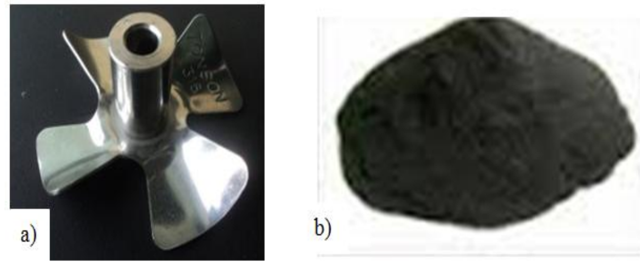

Figure 3.
a) Propeller stirrer b) Titanium powder

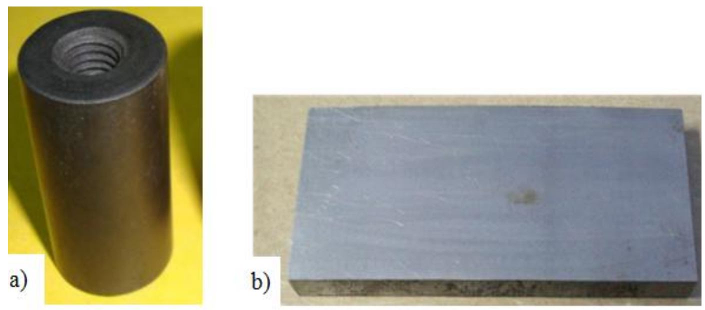

Figure 4.
a) Tool of graphite electrode b) H13 steel workpiece

Table 1. Machining conditions

Variable	Set-up
Intensity of discharge(A)	15
Pulse-on time(μs)	50
Pulse-off time(μs)	85
Dielectric	HD-1
Polarity	Positive (EDM process)
Machining time(min)	2
Voltage of discharge (V)	150
Tool material	Graphite (Ø25mm)
Flushing	10 liters/min
Powder	Titanium: - grain size 45μm. - concentration 0, 5, 10, 15, 20 g/l.

Table 2. Properties of graphite HK - 2 tool electrode

Property	Unit	Value
Chemical composition	%	99,99
Electrical resistivity	μΩ.m	14
Melting temperature	^oC	3675
Density of solid	g/cm^3	1,811
Hardness	HB	10
Size powder	μm	7

Table 3. Mechanical properties of H13 steel

Temperature (^0C)	Density of solid (kg/dm^3)	Specific heat capacity (J/kg.K)	Electrical resistivity ($Ohm.mm^2/m$)	Young's modulus (N/mm^2)	Thermal conductivity (W/m.K)
20	7,80	460	0,52	215.10^3	24,30
500	7,64	550	0,86	176.10^3	27,70
600	7,6	590	0,96	165.10^3	27,50
Liquefaction temperature: 1454^0C			Solidification temperature: 1315^0C		

2.2. Experimental materials

The material used for the workpiece was H13 (Japanese Industrial Standard) hot-die steel which is used extensively for hot-forged dies. Mechanical properties of H13 steel as shown in Table 3. The constituents of the steel, as determined by chemical analysis, were: 0.40% C, 0.47% Mn, 0.98% Si, 0.14% Ni, 4.90% Cr, 0.83% V, 1.15% Mo, 0.016% Co, 0.00012% S and 0.018% P, and the balance was Fe. The workpiece dimensions were 45 × 27 × 5 mm3 as shown in Figure 4b. Before machining, the raw material had a microhardness of 490–547HV. The tool material selected for this investigation was graphite HK-2 as shown in Table 2. The graphite electrode was shaped as shown in Figure 4a. This type of electrode material is widely used in EDM (90%) and especially in rough EDM. Titanium powder with a particle size of 45µm was selected to mix into the dielectric fluid as shown in Figure 3b. The dielectric fluid used was oil HD-1 Electrol.

2.3. Measurement equiment MRR, R_a and topography

The following material parameters were studied during the course of this experiment: Material removal rate, surface roughness, and topography of workpiece surface. Three readings were taken for each work specimen to compute the final, average measurement.

2.3.1. Measurement MRR

Equation 1 was used to determine the MMR value:

$$MRR = \frac{W_i - W_f}{\rho_T . t} .1000 mm^3 / \min \qquad (1)$$

Where

W_i – Initial weight of workpiece material (g)

W_f – Final weight of workpiece material (g)

t – Time period of trails in minutes (t = 15 min)

ρ_T – Density of workpiece material (ρ_T = 7.81g/cc)

Precision balance was used to measure the weight of the workpiece before and after the machining process (model vibra AJ-203 shinko max 200g /d=0.001g, Japan).

2.3.2. R_a and topography tester

Surface roughness was measured using a SJ-301from Mitutoyo, Japan. After EDM, the samples were cleaned of die-sink surface machined. The rest of the analysis was carried out on ten samples using a scanning electron microscope (SEM, model JSM 6490, JEOL, Japan). The surfaces of the samples were cleaned prior to SEM analysis at three different magnifications: 50×, 200×, 1000×.

3. RESULTS AND DISCUSSION

3.1. Variation of MRR

Table 4 and Figure 5 show that when the titanium powder is mixed into the dielectric fluid MRR increases compared with no mixed powder. Increasing the concentration of titanium powder also increases MRR. The MRR increases are explained by the presence of the powder particles in the discharge gap which creates more 'electric spark chains', thereby increasing the spark rate during machining. When the powder concentration increases from 0 to 5g/l, the high graph slope indicates that the MRR increases substantially (212,123%). This large jump can be explained because in addition to increasing the number of electric sparks, the titanium powder with good conductivity and now present in the discharge gap has reduced the strength of the dielectric relaxation solution and energy used to reduce solvent breakdown. This has resulted in an increase in the energy of the electric sparks. As powder concentrations continue to increase, the graph slopes down which similarly leads to MRR reduction. MRRmax= 174.264 mm3/min at a concentration of 20 g/l powder. Increasing the concentration of titanium powder leads to a greater density of powder particles in the electric spark gap. This creates an increase in the number of electric sparks generated during a pulse and dielectric strength is reduced which leads to MRR increasing accordingly. However, if the concentration of titanium powder is too high this can have a negative impact on MRR because of the electrical arc phenomenon and short circuit of the dielectric fluid.

Table 4. Results for MRR

Trial no	W_i (g)	W_f (g)	MRR (mm^3/min)	$\overline{MRR}$ (mm^3/min)	Concentration (g/l)
1	33.397	32.975	32.586	30.089	No
2	31.878	31.447	27.593		
3	30.914	29.127	95.198	93.918	5
4	32.726	31.003	92.638		
5	31.308	29.102	132.586	136.203	10
6	33.329	31.145	139.821		
7	34.411	32.013	153.521	150.672	15
8	31.661	29.232	147.823		
9	32.703	29.919	170.294	174.263	20
10	31.897	29.128	178.233		

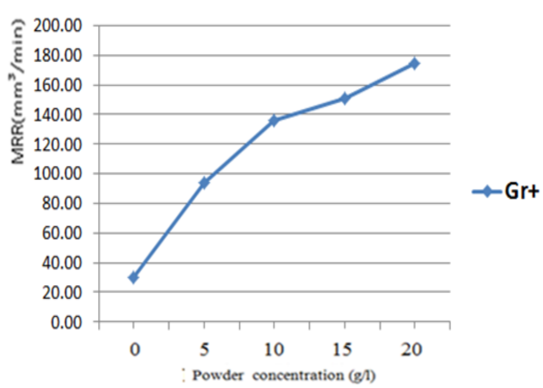

Figure 5. Variation of MRR with titanium powder concentrations

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3.2. Variation of R_a

Surface roughness is the measure of the texture of the surface. Values of surface roughness in roughing machining direct influence to choice of finish machining methods and machining time and if the value is high then the surface is rough and if low then the surface is smooth. Surface Roughness is measured in µm. It is denoted by Ra.

Table 5. Results for R_a

Trial no	Ra (µm)	Concentration (g/l)
1	7.13	No
2	5.69	5
3	4.61	10
4	4.25	15
5	4.18	20

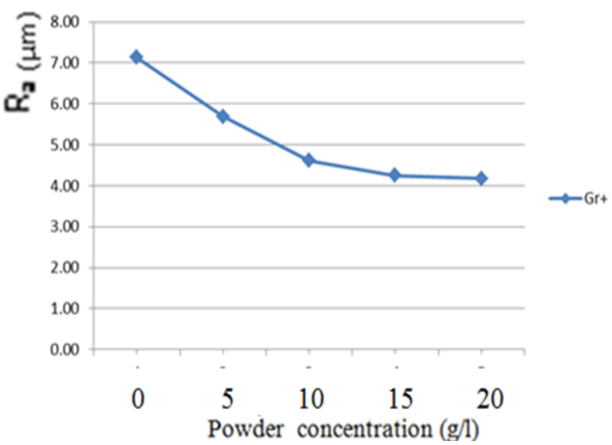

Figure 6. Variation of R_a with titanium powder concentrations

Titanium powder mixed into the dielectric fluid has reduced the SR value of the surface machining as shown in Figure 6. When the powder concentration changes from 0 to 10 g/l the graph is steep with a reduced slope as powder concentration continues to increase. The SR reduction could be due to the powder mix in the dielectric fluid which leads to powder particles in the discharge gap increasing the influence area of sparks, which then reduces the energy of the sparks in the machining process. This creates smaller diameter and depth craters on the machining surface which results in a smoother finish. As the titanium powder concentration continues to increase the number of powder particles in the discharge gap also increases. This increases the number of sparks generated during a pulse, which leads to the energy of each spark decreasing and so the surface roughness values also decrease. Ramin = 4.18µm at concentrations of 20 g/l titanium powder. If Ti concentrations continue to increase short circuits occur making the process unstable and surface roughness increases.

3.3. Variation of topography of surface workpiece

Understanding the surface workpiece after rough machining is very important. Topography and heat affacted zones of machined surface affect the selection chip thickness and methods of fine - finish machining. This may affect the production costs.

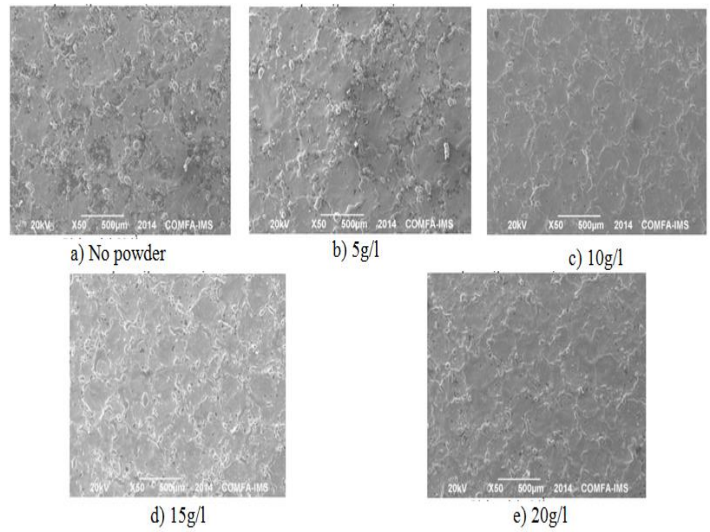

Figure 7. Surface topography of workpiece with titanium powder concentrations

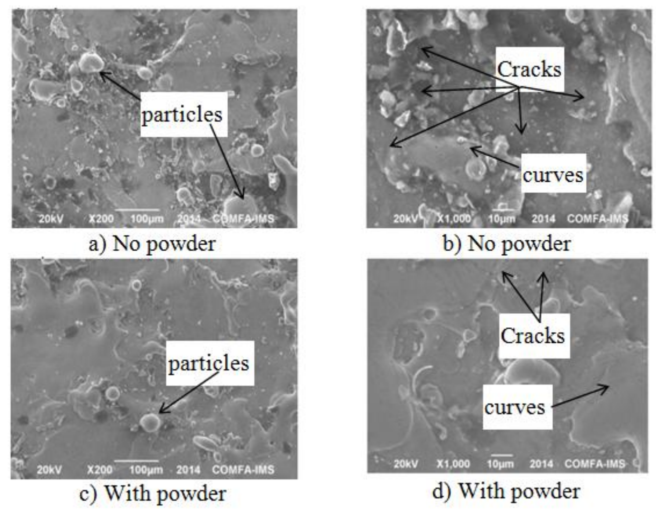

Figure 8. Microstructures of machined surface with titanium powder concentrations
(a), (b) No powder (c), (d) Powder mix in the dielectric
(a) the superimposed craters and (b) the morphology of the debris particles produced
(c) the superimposed craters and (d) the morphology of the debris particles produced

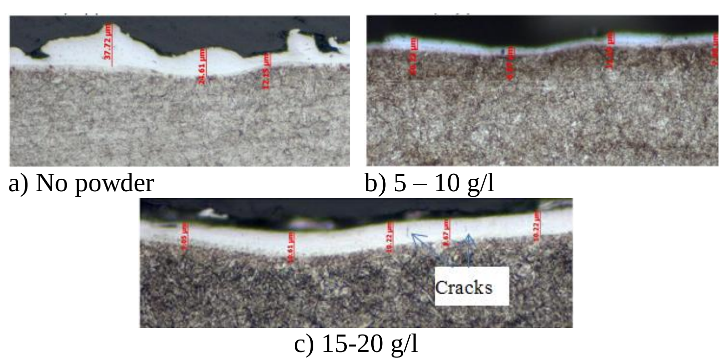

Figure 9. Layers of machine surface with titanium powder concentrations

The final machining surface is created as the sparks melt and vapourise the material in the tiny craters that they produce. As the number of craters increases, so the diameter and depth of the craters decreases in EDM using titanium powder mixed into dielectric fluid. This happens because the powder mixes with the dielectric fluid and increases the number of electric sparks formed and this leads to the reduction in energy of each electric spark. As the concentration of titanium powder mixed into the dielectric fluid increases, so the quality of the surface machining is enhanced.

After EDM surface machining some microscopic cracks may appear. These are caused by the large thermal power heating the workpiece surface which is immediately rapidly cooled by dielectric fluid. The titanium powder mixed into the dielectric fluid reduces the number of microscopic cracks. This is because the effect of the thermal energy of each electric spark on the machining surface is reduced, which results in a reduction of the influence of the heat pulse on the machining surface. There are many metal particles clinging to the machining surface, due to the rapid cooling effect of the dielectric fluid after metal melting and evaporation. These metal particles have not been pushed out of the solvent and remain adhered to the machining surface. The metal particles have a spherical shape, while the craters are oval and curved, due to the surface tension effect created by the dielectric fluid.

Workpiece surface after PMEDM appeared white layer is shown in Figure 9. This white layer thickness smallest at concentrations of powder 5 g/l and 10 g/l. White layer thickness increases with increasing concentration of powder is greater than 10 g/l. However, when the powder appears in the dielectric fluid leads to the shape of the white layer better. Moreover, the depth of the cracks in the white layer is approximately equal white layer thickness.

4. CONCLUSIONS

This research has reviewed some new research directions.

In PMEDM, concentrations of titanium powder mixed in the dielectric fluid have greatly impacted on MRR and SR improvement.

Increased concentrations of titanium powder result in increased MRR and when compared with no powder mixed into the dielectric fluid MRR in PMEDM increased 475.46% at a powder concentration of 20g/l.

Surface smoothness after EDM increased with increasing concentrations of powder. Compared with no powder mixed into the dielectric fluid a concentration of 20 g/l powder decreased SR by 41.34%. Reducing the value of SR leads to reduced machine usage time and increased productivity and profitability.

Using powder mixed dielectric fluid can be an effective method to reduce the thickness of the white layer of the surface machining. However, there should be further research to understand the mechanical properties, microstructure and chemical composition of white layer. Thereby evaluation suitability for the working conditions of this layer in practice. And this is the direction to use or remove them in the next technological steps.

There is a powerful influence of the concentration of titanium powder on MRR while the reduction of SR is negligible (Ramin= 4.18 µm). This showed that PMEDM can be a viable solution to increased machining productivity. However, the price of titanium powder is very high and efficiency could be increased if researchers found other powder materials that have low prices to improve the efficiency in rough machining by EDM. However titanium powder has been quoted by many authors and used to improve the hardness and corrosive resistance of surface machining [18-20] so titanium is preferred for research in the EDM field. The strength of the powder, its even distribution and the powder deposition phenomena in the dielectric fluid also needs to be clarified by those interested in this field.

The heat generated from the electric sparks to the workpiece surface is very large [21, 22]. This greatly influences the chemical composition, structure and working ability of surface machining. Due to the complexity of the characteristics and principles of EDM modelling the influence of heat pulses to the workpiece surface needs to be clarified with further research [23]. In particular, the clear influence of thermal energy pulses to the surface after PMEDM is very complex and this is a necessary new research direction.

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