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Effects of Electrode Polarityon SKD61 Steel Surface Properties in Powder Mixed Electrical Discharge Machining

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Abstract: ***Metal powder oralloy powder is suspended in a suitable dielectric fluid during electrical machining dischagre (EDM)is very effective in improving the productivity and quality of the machined surface. Thus, the researches in this area have been very interesting. This paper introduces the investigated results influencing the electrode polarityon thequality of the machined surface after EDM with powder mixed in dielectric fluid (PMEDM). Titanium powder, SKD61hot die steelandcopper and graphite electrodeswere used for the research. These parameters were selected to evaluate the quality of the machined surface such asand thickness of the heat-affected layer, chemical composition, topography and microhardness.The results showed that the electrode polarity in EDM with titanium powder mixed in oil dielectric fluid can significantly affect thequality of the machined surface.***

Keywords: EDM, PMEDM, Heat-affected layer, Chemical composition, Topography, Microhardness

1. Introduction

Using the traditional processing methods for forming surface moulds is often difficult due to machined surface complex shapes and high mechanical properties of materials. EDM is commonly used to shape the mould surface. This method can be the machined surfaces with complex shapes and materials of any hardness. However, the surface layer of dies after EDM hasthe topography andmetallurgical and physicochemical properties changed significantly and the special machined surface showsa white layer with more microcracks and low toughness. The change of the surface layer that reduces the ability of the working dies is necessary to improve the surface quality of the work product of this type.In practice, the machined surfaceby EDM often requiresfine machining, such as grinding, polishing, etc. to removelayer defect.

The research results showed that, PMEDM is the effective method to eliminate the limitations of EDM. PMEDM can improve the productivity and machining quality of EDM. However, the working principle of PMEDM processis very complex, so it is affected by many technological parameters. Beside the influence of the parameters, such as current, pulse on time, pulse of time, concentration of powder, powder materials, the electrode polarity alsohas significantimpact on the quality of the machined surface. The negative polarity of copper(Φ1 mm) electrode on SKD61 steel machining by EDM with titanium powder mixed in dielectric fluid created the coating hardness of 2000 HV on the surface of the workpeice [1]. Whentungsten powder was mixed in dielectric fluid in EDM with negative polarity copperelectrode also created a surface layer of the steel mould (OHNS, D2 and H13), which increased the microhardnessby 2 times [2].The negative polarity of tungsten (Φ1 mm) electrode was used to evaluate the influence ofaluminum and silicon powder on the thickness of the Inconel 718 steel surface layer affected by the heat pulse [3]. The results showed thataluminum powder gave the smallest affected heat and the highest MRR.Theeffects of electrical parameters onMaterial Removal Rate (MRR), Tool Wear Rate (TWR) and surface roughness (SR) were investigated in machining nickel alloy with aluminum powder mixed in dielectric fluid and reverse electrode polarity [4]. The effect of copperelectrode polarityon the quality of SKD61 steel surface after EDM with aluminum powder was mixed in dielectric fluid was shown [5]. SR has received optimal value with reverse electrode polarity. The influence of the powder Al, Cr, Cu, SiC on SKD11 steel surface in EDM with reverse electrode polaritywas introduced [6]. The results showed that Al powder gaveSR and thickness affected by the minimum heat pulse with positive electrodeand then increased respectively in the materials powder Cr, SiC and Cu. The positive electrode polarity of copper was used to research the effect of Si powder to MRR in AISI D2 steel machining [7]. The results showed that current intensity and powder concentration werethe two parameters having thegreatest impact on MRR. The powder Al, Cr and Al + Cr mixed in dielectric fluid affected the surface quality of steel SKD61 after EDM withCu reverse electrode polarity[8]. The powder of Al, Cr and Al + Cr increased the hardness and strength erosion of the SKD61 steel surface. The smaller particle size leads to smaller surface roughness. The copper electrodepolarityhave little effect on the TWR in EDM with graphite powder mixed in dielectric fluid. The reverse electrode polarity gavesmaller TWR [9]. The influence of the concentration and size of Al powder andelectrode polarityon the MRR, WR and SR in machining 718 stainless steel by EDM was introduced [10]. The results showed that the reverse polarity hadstrong influence on MRR and the negative polarity hadgood impact on WR and SR. The influence of the electrode polarityon MRR, TWR in EDM, Dry-EDM and PMEDM was investigated [11]. The results indicated that the diameter of the

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hole in the Dry-EDM electrode hadsignificant impact onMRR, TWR in both cases of negative polarity and positive polarity. The powder mixed in dielectric fluid had significant impact onMRR and TWR. The negative electrode polarityreducedthe values of the SR of the H13 steel surface after EDM with Al powder mixed in dielectric fluid [12]. EDM with MoS2 powder mixed in dielectricfluid showedthat the MRR increasedby 70% and significantly improved the quality of the machined surface [13].

The results of the research showed that the electrode polarity can affect the quality of the machined surface layer in PMEDM. The results of this review aimat showing the influence of the copper and graphite electrode polaritys on the SKD61 steel surface quality after EDM with titanium powder mixed in dielectric fluid. The properties of the machined surface quality such as heat-affected zone thickness, microhardness, chemical composition and topography were investigated.

2. Exprimental Production

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 material used for the workpiece was SKD61 (Japanese Industrial Standard) hot-die steel that is used extensively for hot-forged dies. 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, 0.018% P, and the balance was Fe. The workpiece dimensions were $45 \times 27 \times 5$ mm^3. Before machining, the raw material had a microhardness of 490–547 HV. The tool materials selected for this investigation were graphite and copper. The two electrodes had the shape shown in Figure 1. Copper and graphite have excellent electrical and thermal conductivity and are the major commercial materials. The powder material chosen for this research was titanium of 45 µm grain sizeas shown in Figure2. Titanium compounds have been applied extensively as the materials for surface modification because of their hardness, abrasion resistance, high melting point and low coefficient of friction. The dielectric fluid used was oil EDM. To avoid the wastage of kerosene oil, a small dielectric circulating system was designed. A tank size of $330 \times 180 \times 187$ mm^3 was made of 3mm thick mild steel with a capacity of 9 litres. The tank was installed in the EDM machine as shown in Figure3 and 4.These parameters for the experimental work were selected on the basis of the results from the previous research. The machining parameters are shown in table 1.

The following material parameters were studied during the course of this experiment: chemical composition and microstructure of surface layer, microhardness of machined surface, SR, and surface appearance. SR was measured using a SJ-301 from Mitutoyo, Japan. After EDM, the samples were cleaned and the cross-section of die-sink surface was machined. An optical microscope was used to research the change in the microstructure of the EDMed surface. The rest of the analysis was carried out on six samples using a scanning electron microscope (SEM, model JSM 6490, JEOL, Japan). The surfaces of the samples were cleaned prior to SEM analysis a different magnifications: 500×, 1000×. To analyze the phase composition of the surfaces, the selected workpieces were analyzed using X-ray diffractometry (XRD) over a 2θ range from 5° to 85° with a model Axiovert 40MAT from Carl Zeiss, Germany. Microhardness was measured on a microhardness tester (model Indenta Met 1106) from Buehler, USA. The chemical compositions of the machined surfaces were analyzed using energy-dispersive X-ray spectroscopy (EDS, model JSM – 6490LA, JEOL, Japan).

Figure 1: Electrodes used in this research

Figure 2: Titanium powder

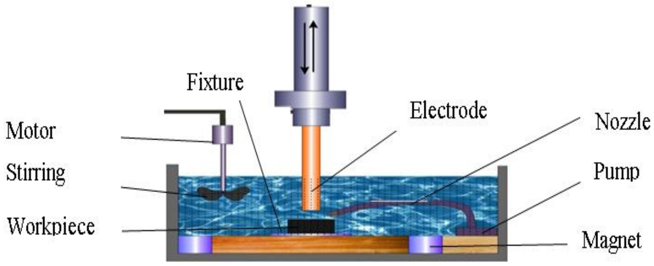

Figure 3: Schematic diagram the experimental setup

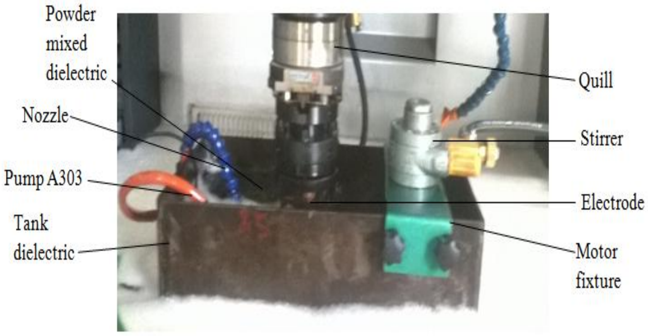

Figure 4: Photograph of the experimental setup

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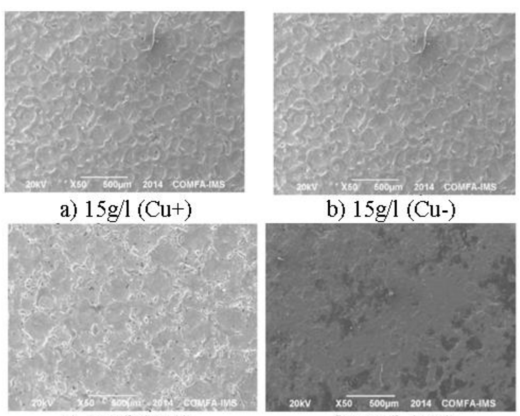
Table 1: Machining conditions

Variable	Set-up
Intensity of discharge(A)	15
Pulse-on time(µs)	50
Pulse-off time(µs)	85
Dielectric	HD-1
Polarity	Positive and negation (EDM process)
Machining time	15'
Voltage of discharge (V)	150
Tool material	Copper, Graphite (Ø25mm)
Flushing	10 liters/min
Powder	Titanium: - grain size 45µm. - concentration15 g/l.

3. Results and Analysis

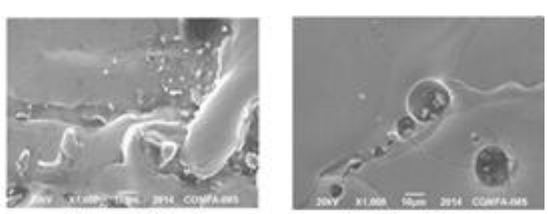
1. Topography of machined surface

Figure 5 was shows that the machined surface topography is a collection of many craters.And the negative electrode polarity helped increase the number of craters and the diameter and depth of the craters was reduced.A lot of microcracks and metal particles appeared on the machined surface in EDM.The adhesion of metal particles on the machined surface was the cause of increased surface roughness. Machined surface with copper electrode created the number of particles andfewermicrocracks than the with graphite electrode.Negative polarity led to the decreased number of metal particles but increased the number of microcracks as shown in Figure 6.Figure 7shows that the negative electrode polarity created surface roughness is smaller than the positive electrode polarity. Copper electrode gave the smallest surface roughness, which led to the reduced time for fine machining.

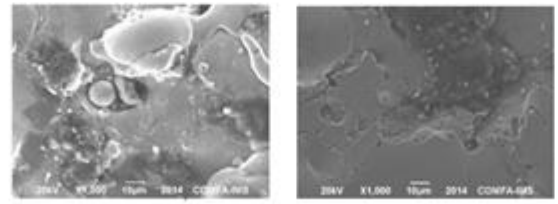


a) 15g/l (Cu+) b) 15g/l (Cu-)
c) 15g/l (Gr+) d) 15g/l (Gr-)

Figure 5. Topography of machined surface



a) 15g/l (Cu+) b) 15g/l (Cu-)



c) 15g/l (Gr+) d) 15g/l (Gr-)

Figure 6. Microstructure of machined surface

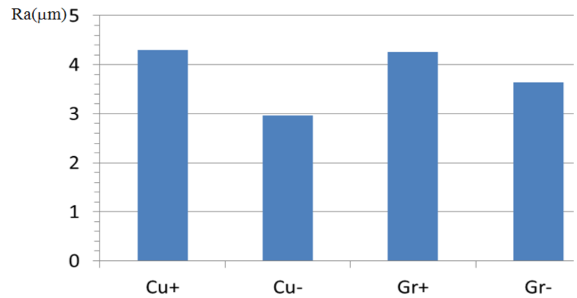
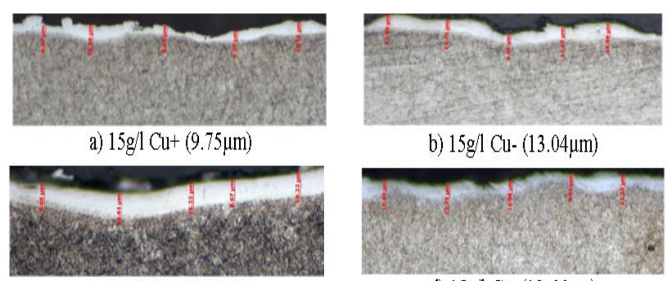


Figure 7. Surface roughness of machined surface

2.White layerof machined surface after PMEDM

Figure 8shows that the white layer appeared on the machined surface after EDM. This layer was formed when the workpiece material was melted but not swept away by the dielectric fluid.And a small amount of electrode and titanium powder melted and evaporatedand adhered to the machinedsurface.The depth of the microcracks was approximately equal to the thickness white layer.The positive electrode created the thickness ofthe white layer wasn't significantly smaller than the negative electrode polarity.Table 2 and Figure 9show that themicrohardness of the white layer was relatively high and the negative electrode polarityled to the microhardness of the greater white layer than the positive electrode polarity.The white layer containing microcracks increased the adhesive lubricant ability,combining with great microhardness significantly enhanced the corrosion resistance of mould materials.



a) 15g/l Cu+ (9.75µm) b) 15g/l Cu- (13.04µm)
c) 15g/l Gr+ (10.61µm) d) 15g/l Gr- (12.66µm)

Figure 8: White layers of machine surface

Table 2:.Microhardness of whitelayers after PMEDM

Electrode material	Polarity	Microhardness of white layer (HV)	
		White layer	Base metal
Cu	+	655.3	526.7
	-	660.2	561.6
Gr	+	650.9	571.9
	-	690.5	598.3

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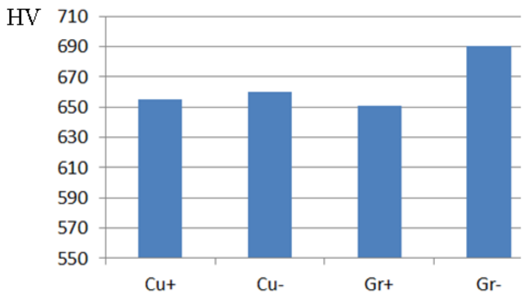
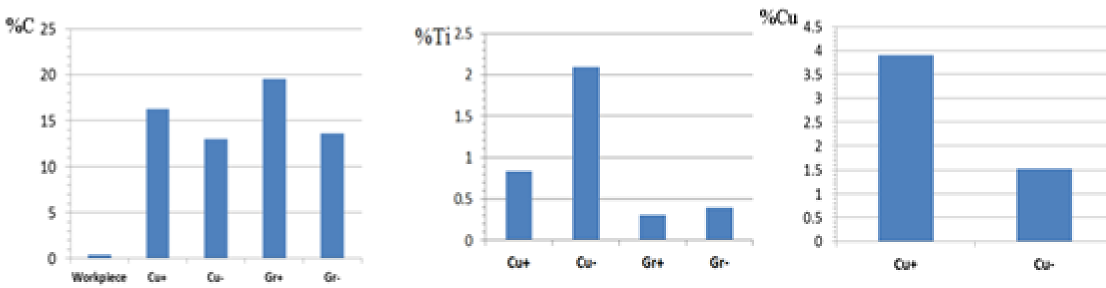


Figure 9: Graph of microhardness of white layers.

Table 3: Chemical composition of machined SKD61 steel.

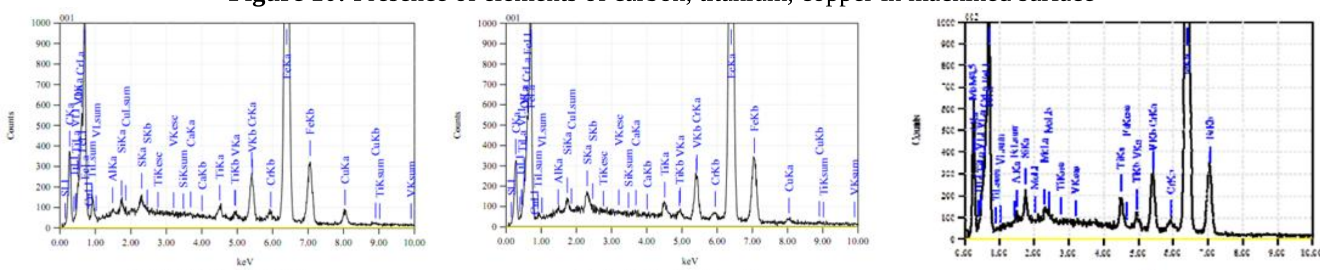
Composition	Before machining (%)	After machining (%)			
		Copper electrode		Graphite electrode	
		+	-	+	-
Carbon	0.40	16.24	12.97	19.58	13.60
Silicon	0.98	0.58	0.56	0.46	0.55
Vanadium	0.83	0.42	0.61	0.36	0.56
Chromium	4.89	4.02	4.13	3.96	4.10
Titanium	0.00	0.84	2.09	0.31	0.39
Copper	0.00	3.90	1.53	0.00	0.00

3. Chemical composition of machined surface



a) %C b) %Ti c) %Cu

Figure 10: Presence of elements of carbon, titanium, copper in machined surface



a) 5g/l (polarity +) b) 5g/l (polarity -) c) Titanium electrode (+) [14]

Figure 11: XRD patterns of machined SKD61 steel

The chemical composition of the white layer significantly altered compared to the base material. Table 3shows that the percentage of carbon in the white layer increased greatly with both electrode materials. The positive electrodes led to the percentage of carbon in the white layerto increase higher, which suggested that the dielectric fluid was destroyed faster and lead to the reduced reliability of the dielectric fluid compared withnegative electrode polarity. The percentage of carbon in machinedsurface increased very high in EDM with graphite electrode, whichalso showed thatthe amounts of electrode material erosion occured during processing. Figure 10 showsthat the positive polarity of the graphite electrode increased the tool wear rate. The percentage of carbon in the white layer would increase the microhardness of the machinedsurface layer. Titanium and copper led to a relatively large amounts of white layer. It was caused by the thermal energy of the electric sparksmelting and evaporating the electrode and powder, entering the white layer of the machined surface. Figure 10 bshows that copper electrode helped titanium powder enter themachined surface in a larger amounts than graphite electrode. And percentage of titanium in the surface layer increased larger in the negative electrode. This led to the lower durability of titanium powder than the reverse electrode polarityand especially in EDM with copper electrode. Titanium and copper elements increased the resistance of abrasion and corrosion of the machined surface. However, titanium and carbon was not combined together to form TiC in both cases of electrode polarity. Figure 10cshows that copper elements entering the machinedsurface in larger amounts in reverse electrode polarity. This indicates that the TWR ofpositive copperelectrode polaritywas larger than the negative electrode polarity. Figure 11shows that the titanium powder mixed in dielectric fluid resulting in thetitanium being evenly distributed rather than EDM with the titanium electrode. This will contribute to the increased resistance of abrasion and corrosion evenly distributed over the surface area of the workpiece. In addition, the results of chemical analysis of the white layershow that the percentage of Mn, Si, V, Cr reduction. This is because titanium, carbon and copper replaced the steel elements in the organization.

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4. Conclusions

In PMEDM, electrode polarity quite strongly influencedthe quality of the machinedsurface: Negative copper electrode polarity would constitute part of the surface topography of the best quality Ramin = 2.97 µm and the least number of microcracks on the machined surface.This indicates that the negative electrode isomers can be the favorable condition in fine machining.The influence of the electrode polarityon the thickness and microhardness of the white layer is not large.In both types of electrode materials, the negative electrode polarity reduced thetool wear rate. This will help improve machining accuracy. And the durability of the dielectric fluid machining time also increases. Also the percentage of the titanium enters the machined surface layer when the negativeelectrode polarity is larger than the positive polarity, which leads to the increased the wear and corrosion resistance of the machinedsurface.

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