EFFECT OF COMPOSITIONS TITANIUM NITRIDE IN COPPER-BASED SINTERED ELECTRODE DURING ELECTRICAL DISCHARGE MACHINING OF TUNGSTEN CARBIDE

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ABSTRACT

This research studies the effect of compositions Titanium Nitride (TiN) element in copper-base electrode powder sintered during electrical discharge machining process on tungsten carbide (WC-Co). The impact study of Material Removal Rate (MRR), Electrode Wear Ratio (EWR) and surface roughness (Ra). In the experimental variables, include that current, voltage, on-time and off-time, respectively. Analyze the distribution of element using technique AFM and laser optical imaging techniques. The results showed that surface quality of workpieces and electrodes formed after spark, electrode material Cu80%, Ni3%, TiN17% yielded the highest MRR 0.0038 mm³/min, EWR lowest at 113.33% and surface roughness is 1.183μm. Moreover, experiment was found that the effectiveness of the process is evaluated by Scanning Electron Microscopy (SEM). However, TiN composition with copper-based approximate due to high melting point are influencing preferably improvement of MRR increase and reduce EWR.

KEYWORDS: Titanium Nitride (TiN), Compositions, EDM, Tungsten Carbide & Surface Roughness

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1. INTRODUCTION

Tungsten carbide (WC-Co) is the important material, so it is widely used to produce mold in industry since it has high hardness, high wear resistance and high melting point. With these qualities, it is suitable to apply to mold area [1-2]. However, because of its qualities, it cannot be deformed with mechanical machining methods. Thus, Electrical Discharge Machine or EDM is widely used [2-4]. The problem of machining with EDM happens because of EDM principle: releasing the electricity discharge via electrode. This is because the melting point of electrode and the workpiece are different and that results in the limited machining efficiency, which consists of workpiece material removal rate, electrode wear ratio and surface workpiece quality. Besides, it normally has a micro crack on the workpiece after EDM machining because tungsten carbide is the compound of WC and Co, which Co is the tungsten particles binder [2]. During the EDM machining process, the Co particles, which have low melting point would melt and come off before WC melting. As a result, there is a micro crack and pores over the area [3]. However, many researchers studied in area application such as H. K. Kansal et al. [5] studied Powder Mixed Electric Discharge Machining (PMEDM), the result found that the process becomes more stable, thereby, improving the Material Removal Rate (MRR) and surface finish. S. K. Ho et al. [6] studied of powder metallurgy.

(PM) compacted electrodes for electrical discharge surface alloying/modification of Ti-6Al-4V alloy include Al, Cr, Ti, TiC/Ni, WC/Co, Cr/Ni, Ni/Co, Ni/Mn, Ni/Fe, Ni/Si, Cu/W, Cu/Mn, Cu/Co and TiC/WC/Co and other literature relevant to this research. The experiments were found that surface modification by particle with sintering electrode and all layers were in general discontinuous, however those produced with negative polarity were more uniform, especially when using solid electrodes. Li Liet al.[7] had studied about EDM performance of TiC/copper-based sintered electrodes with could conclude a detail of this research that each material has its pros and cons on machining performance. Titanium Carbide (TiC) is an extremely hard refractory material with high melting temperature, high thermal shock and abrasion resistance [7]. It is mainly used in powder metallurgical parts including cutting tool tips, dies, wear parts, and resistant coatings. According to this problem, the researcher regarded the importance of electrode materials application which had similar quality to melting point of workpiece that helped to reduce the limitation of machining efficiency [7,11]. With this application, it studied powder metallurgy between copper-base(Cu) and Titanium Nitride(TiN) composition in different percentage via sintering process. At present, powder metallurgy is used extensively in electrode production. Therefore, the main factor of WC-Co machining is to consider the suitable parameter for applying to electrode material [4,7]. The article applied percentage of TiN to pressed copper-base powder in order to increase the efficiency of tungsten carbide material machining and studied the quality of test workpiece surface and electrode surface with electrical discharge machining process. Result could be applied to the further work to develop the method to suit the relevant industries.

2. EXPERIMENTAL METHODS

2.1 Materials and Equipments

Experiment materials is a composite of tungsten carbide grade 90WC and 10Co. The main ingredients include WC 90%, Co 10%, and other elements, which is a material that conducts electricity well, Hardness and high wear resistance and also widely employed in mold and tool applications. However, machining has a difficult done is not suitable for processing by a conventional machining process. Currently, which can be processed by the non-traditional base on EDM process. Tungsten carbide material with physical properties as shown in Table 1. The electrode materials was copper-base variation sintered with composition TiN variation level elements at TiN 17%, TiN 12%, TiN 9%, TiN 7%, and TiN 4% and Nickel (Ni) fixed element at 3%, respectively. The compositions are shown in Table 2. The properties of Cu-TiN electrode are shown in Table 3. The processes the powder metallurgy with hydraulics press machine with pressure 22 MPa, after process conducted sintering with an electric furnace at a temperature of 28, 350 and 1100 °C respectively, due to rate increases temperatures were 5, 10 and 20 degrees celsius per minute [7]. Moreover, machining workpiece by using turning with a diameter of 9mm and long 45mm.

Table 1: Physical Properties of Tungsten Carbide

Properties	Tungsten carbide
Melting point(°C)	2,800
Density (g/cm ³)	15.7
Thermal expansion (°C)	5×10^{-6}
Electrical resistance(nΩ·m)	52.8
Hardness (HRA)	87.4
Elastic modulus(Gpa)	648

Table 2: The Compositions Ratio of Cu-TiN Electrode

Electrode Type	Composition Ratio (%)		
	Cu	Ni	TiN
1	80	3	17
2	85	3	12
3	88	3	9
4	90	3	7
5	93	3	4

Table 3: Properties of Cu-TiN Electrode

Powder	Cu	TiN	Ni
Purity (%)	99.00	99.90	99.90
Density (g/cm ³)	8.96	5.22	8.88
Melting Point (°C)	1083	2930	1455
Electric Resistivity (Ohm-cm)	1.70E-06	6.00E-03	6.40E-06
Thermal Conductivity (W/m-K)	385	19.2	60.7

Figure 1: Illustration of Electrical Discharge Machining.

Table 4: Experiment Conditions

Parameters	Details
Cu-TiN electrode (%)	TiN 17%, TiN 12%, TiN 9%, TiN 7%, TiN 4%
Diameter of electrode(mm)	9
On – time(μs)	2
Off – time (μs)	2
Polarity (+,-)	(-)
Current(A)	3
Circuit voltage(V)	150
Dielectric	DielMs7000
Flushing	Flow rate 1.5 lpm

2.2 Experiment Procedure

The experiment was carried out on EDM machine of computer numerical control ARISTECH EDM CNC 430 model. The material electrodes of copper-based and titanium nitride mixtures of TiN17%, TiN 12%, TiN9%, TiN 7%, and TiN 4% were used. The condition of EDM spark was 1 mm of depth and 9 mm of diameter electrode on the material surface of tungsten carbide composite 90WC-10Co, diameter sized 25 mm and 2 mm of thickness. The experimental conditions are shown in Table 4. The EDM process was carried out under DielMs7000 EDM Fluid of fluid dielectric hydrocarbon. The cooling and removing of debris were done by the flushing through the 6 mm of diameter tube with the flow rate of 15 lpm. The duty factor was defined as the ratio of on-time discharge current to the total time of one spark cycle (on-time + off-time). The results of the experiment were assessed in terms of the Material Removal Rate: MRR. The MRR was measured from the removed amount per time unit, i.e. cubic millimeter per minute [8-9]. The electrode wear ratio:EWR was analyzed in one dimension, which was measured from the wear ratio of the electrode to the depth of the workpiece. The surface roughness was measured in terms of the arithmetic mean surface roughness: Ra against the DIN EN ISO 4288:1998 standard by using surface roughness on Mahr Pocket Surf PS1 and 3D measuring laser microscope.

The surface of the EDMed workpiece was analysed by using the Scanning Electron Microscope (SEM) and Energy Dispersive Spectrometer (EDS), respectively. Surface quality analysis of test specimen with the lowest and highest surface roughness values and check surface electrode that effect the best quality of the surface and the worst by Atomic Force Microscopy (AFM) and 3D laser microscopy for analysis of characteristic surface electrode affecting to good surface quality and bad surface quality of EDMed workpiece.

3. RESULTS AND DISCUSSIONS

3.1 Material Removal Rate (MRR) and Electrode Wear Ratio (EWR)

Results of testing the machining with EDM of each Cu-TiN electrode ratio on tungsten carbide workpiece with different factors and conditions considering test result from MMR and EWR are shown as the graph in Figure 2. It was found that electrode Cu80%, Ni3% and TiN17% had the highest MRR, which was 0.0038 mm³/min and had the lowest EWR, which was 113.33% because the particles in the electrode captured and melted homogeneously. However, it depended on the appropriately Cu quantity to physical and mechanical quality this type of electrode. Moreover, it was the result of transferring Ni to Ti while burning in sintering process that finally resulted in porosity, density and electrode conductivity which were different based on the ratio that resulted in MRR and EWR of electrode depended on the parameter used in the experiment [10-11]. However, the low melting point of Cu increases the electrode wear ratio.

Figure 2: The Relationship Result of MRR and EWR on Electrode Composition.

3.2 Surface Roughness (Ra)

Surface roughness value that occurred from the EDM spark of Cu-TiN electrode on tungsten carbide surface of the test workpiece (Figure 3) showed the comparison of the test workpiece profiles after sparking with different electrode compounds by magnifying with surface roughness average value by surface machine tester and show the graph position from the measurement as shown in Figure 4 also show the surface roughness graph of the specimen at sparked Cu-TiN electrode in composition was found that. The lowest surface roughness value was 1.183 μm when sparked with electrode Cu80%, Ni3% and TiN17% and the highest surface roughness value was 1.550 μm , when sparked with electrode Cu93%, Ni3% and TiN4%. This was because the qualities of electrode that were appropriately to release electricity and energy accumulation while sparking made the EDM spark cycle stronger [10,14]. Moreover, the higher temperature was different depending on the compound ratio of each Cu-TiN, that is the ratio Cu small quantity and TiN that has a lot of element, may affect surface roughness of the test specimen to a minimum value when compared with the electrode at the rate of other ingredients. It affected the high and low average surface roughness on tungsten carbide material differently [12-13].

Figure3: The Comparison of Workpiece Surface Profiles EDMed with Different Electrode.

Figure 4: Surface Roughness of EDMed by Variation Cu-TiN.

Figure 5: Result of Surface Roughness Lowest and Highest Measured by AFM

Figure 5 shows the surface quality of the specimen (WC-Co) measured by atomic force microscopy (AFM) for the best and the roughest surface of the workpiece. Results found that the good quality surface or the lowest surface roughness had the low curve and quite smooth surface, noticing from the increasing graph at the positions shown in Figure 5 a) I-II and III which is surface roughness shows 3D of surface EDMed with electrode Cu80%, Ni3%, TiN17%. Comparing to the highest roughness surface, which was very different, the surface was rough with deep large holes. Most surfaces were high and low differently as shown in Figure 5 b) which was the surface EDMed with electrode Cu93%, Ni3%, TiN4%. This was the reason of the high surface roughness value [14-15]. This may cause the influence of the electrode and parameters used in sparking which is the main factor in the experiment.

3.3 Characteristic of Surface Workpiece and Electrode

The study on Cu-TiN electrode compound affecting MRR, EWR and surface roughness average value and the test of sparking with tungsten carbide workpiece showed that composition ratio of copper-base electrode with low Cu and high TiN was the best electrode for EDMed. The evaluation of overall efficiency of surface quality after sparking with scanning electron microscope (SEM) indicated that electrode Cu80%, Ni3%, TiN17% provided the lowest roughness to the test workpiece as shown in Figure 6 a) (I). The surface was quite smooth with micro crack and pores all over the crack. The electrode surface from the inconsistent melt of surface had pores and bits all over the surface (Figure 6 b) (II) and shows characteristic roughness from analysis of surface roughness using laser optical imaging techniques at position III.

Figure 6: Characteristic of EDMed Surface Workpiece at Lowest and Highest Roughness.

Figure 6 showed the test workpiece surface that had the highest surface roughness. When sparking with electrode Cu93%, Ni3%, TiN4%, the surface had large crack with holes and pores and had higher convexity than the surface with low roughness as shown in Figure 6. Electrode had micro crack and the surface melted inconsistently which affected the rough surface according to the particles of each types of electrode as shown in Figure 6 b). Since the electricity used in the sparking process, which was the main factor of the EDM process, it affected the surface of test workpiece and electrode that had different composition rates of TiN, which was the particles that has higher melting temperature than the particles of other composition [16-17]. The occurrence of micro-cracking on surface workpiece (WC-Co) caused by factor used in the spark such as duty factor, voltage, current, polarity electrode, on/off time and other factors which causes crack with porosity on the specimen surface, therefore affect the surface roughness and surface roughness quality as mentioned above.

Table 5: Elements on Tungsten Carbide Surface

Element	Weight (%)	Atomic (%)
C	25.53	81.64
Co	5.51	3.59

Cu	0.90	0.55
W	68.06	14.22
Totals	100.00	100.00

Figure 7: Analysis of Elements on Surface.

The analysis result on the element quantity on the test surface that had lowest surface roughness by sparking with electrode Cu80%, Ni3%, TiN17% applying energy dispersive spectrometer: EDS shown in Table 5 and the graph in Figure 7. Lots of element C were found covering the surface of test workpiece. This was because the particles of C was the result from the reaction between workpiece, electrode and dielectric from spark process. Moreover, there was Cu which was the compound of electrode came off to the surface of workpiece as it had low melting point, thus, it melted while sparking and came off on the surface of test workpiece [18].

3.4 Characteristic Internal Structure and Electrode Section

The study on Cu-TiN electrode compound affecting to performance of EDM process consist of MRR, EWR and surface roughness average value and the test of sparking with tungsten carbide workpiece. Moreover, showed internal structure and electrode section at lowest and highest density, which is shown in Figure 8 and Figure 9, respectively.

(I) Internal structure 3D

(II) Section electrode

a) Electrode Cu93%Ni3%TiCN4% (Lowest)

(I) Internal structure 3D333D3

(II) Section electrode o

b) Electrode Cu80%Ni3%TiN17% (Highest)

Figure 8: Characteristic Internal Structure and Electrode Section of Lowest and Highest Density

Figure 9: Analyze the Distribution of Element using Technique EPMA-Mapping of Electrode

4. CONCLUSIONS

In this paper, the effect of compositions titanium nitride in copper-base electrode sintered during electrical discharge machining of tungsten carbide was studied. The experimental results can be concluded as follows.

- Electrode material composition at Cu80%, Ni3%, TiN17% had the highest MRR, 0.0038mm³/min, the lowest EWR, 113.33% and the lowest surface roughness, 1.183 µm. Moreover, copper-based and TiN having good properties of thermal, electrical conductivity and improvement high melting point. These are influencing preferably to reduce EWR, and increase MRR. However, the low melting point of Cu increases the electrode wear ratio.

- The surface of tungsten carbide had micro crack and pores all over the test workpiece of surface. The surface of electrode Cu-TiN had bits that resulted from the inconsistent melt and a crack from the binding of particles in the electrode. For the surface of the test specimen and the surface of the electrode with different characteristics of flatness and roughness, which depends on the sparking efficiency of the materials used in the experiment from the analysis with AFM and laser optical imaging techniques.
- The surface of test workpiece sparked with electrode Cu80%, Ni3%, TiN17% had the particles of C and Cu on workpiece tungsten carbide surface, which is resulted from the reaction while sparking and distribution on area EDMed.

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