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EDM: Surface Characterization on Machining Tungsten Carbide without and with Vibration

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ABSTRACT

One of the non-traditional machining methods is Electrical Discharge Machining (EDM). The process is based on removing material from a part by a series of repeated electrical discharges between tool called electrode and the work piece with the presence of dielectric. EDM with vibration is one of current research trends. It expand the application of EDM and able to improve the machining performance on difficult to machine materials. This paper presents the surface morphologies resulting from different machining methods, current settings and polarities for work piece surfaces using stereomicroscope and SEM. Cracks, pockmarks and globules are found on higher magnification of the machined surface while machining is conducted without vibration. However, with the introduction of vibration during the machining has reduced the appearance of cracks, pockmarks and globules. The machining was conducted with Sodick A30R EDM machine available in Department of Engineering Design and Manufacture, Faculty of Engineering, Universiti Malaya. The machining used tungsten carbide work piece, copper electrode and current settings of 10A and 8A under positive as well as negative polarities. The amplitude and frequency of vibration selected are 1μm and 400Hz respectively.

Keywords: *copper, EDM, EDM with vibration, surface morphology, tungsten carbide*

Introduction

Machining operations are considered to be the most important process in manufacturing engineering. Even if the machining is not directly involved in the production process, the supporting materials such as moulds, dies, jigs and fixtures, which are used in the production are made by the machining process (Armarego & Brown, 1969). Electrical Discharge Machining (EDM) falls under the non-traditional machining category where the machining technique is based on thermoelectric principle.

The process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of dielectric fluid (Luis et al., 2005). The electrode is moved toward the work piece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric (Bojorquez et al., 2002). Short duration discharges are generated in a liquid dielectric gap, which separates tool and work piece. The material is removed with the erosive effect of the electrical discharges from tool and work piece (Marafona & Chousal, 2006).

The combination of vibration technique with EDM machining was initiated by researchers due to the problem faced during micro-EDM due to the circulation of dielectric and the removal of debris. A few researchers have carried out machining with the application of work piece vibration. The work piece is directly attached to a transducer to secure the vibration. One advantage of work piece vibration instead of tool vibration is that it permits a freer tool system design and much simple and more compact than traditional systems (Egashira & Masuzawa, 1999).

This paper highlights the surface morphologies resulting from machining tungsten carbide without and with vibration in different current settings and polarities using stereomicroscope and SEM. The sample preparation and the experimental setup is also presented.

Materials and Methods

Work piece Material: Tungsten Carbide

According to Ming-Hong Lin (2005), tungsten carbide (WC) is an important tool and die material mostly because of its high melting point (2800^{0}C), high degree of hardness (H_v=22GPa), high modulus of elasticity (696GPa), high fracture toughness (28MPam$^{1/2}$), and good wear resistance over a wide range of temperatures. It is a refractory cermet that has good thermal and chemical stability and is highly desirable because of the combination of its hardness, good abrasion and oxidation resistance, a low coefficient of thermal expansion (5.2μm/m/K) and a certain amount of plasticity.

Many researchers have conducted studies about tungsten carbide on the following topics: the surface integrity, the optimum machining conditions and the application of the work piece in industry (Lee & Li, 2003; Luis & Puertas, 2007; Chen & Hsu, 2003). Using XRF analysis, the composition of tungsten carbide used for the experiment is indicated in Table 1.

Table1: XRF Analysis on Tungsten Carbide

Elements	Concentration (wt%)	Elements	Concentration (wt%)
C	15.000	Ti	2.380
O	9.700	Cr	0.579
Al	1.110	Fe	1.150
Si	0.920	Co	8.150
S	0.160	W	59.490

Electrode Material: Copper(Cu)

Cu is a stable material under sparking condition (McGeough, 1998). It is used for commercial EDM material due to its excellent electrical and thermal conductivity (Li Li et. al., 2001). In machining tungsten carbide material, Cu exhibits the best performance with regard to surface finish compared to copper-tungsten and graphite (Lee & Li, 2001).

Cu is a good electrode materials as it gives good surface finish, low diameteral overcut, high material removal rate (MRR) and less electrode wear when machining hardened tool steel material (Shankar Singh et. al., 2004). According to I. Puertas and C.J. Luis, (2003) based on some cases, the electrodes made of copper it is the most highly recommended material for the EDM of tungsten carbide. It is also recommended that negative polarity for the electrode should be used in order to ensure a much more stable machining process.

Dielectric: Kerosene

Kerosene as the dielectric is very common among the researchers even though it is inflammable, having possibility of fine hazard and will produce solid solubilisation and diffusion of carbon on the machined surface. It is yellowish in colour, smelly and gives very light skin irritation.

Sample Preparation

The work pieces are cut to the dimensions of 25mm x 25mm x 10 mm. The copper (Cu) electrode is 16mm in diameter. The hardness of the work piece is tested using INSTRON Wilson/Rockwell series 600 hardness testing machine. Before and after the machining, all specimens together with the tool are cleaned ultrasonically in alcohol. The surface finish was analyzed using Mitutoyo Surftest SV-600 version 3.0.

Experimental Setup

The experiments are carried out using Sodick A30R EDM machine available in Department of Engineering Design and Manufacture, Faculty of Engineering, Universiti Malaya. The amplitude and frequency of vibration is selected based from the work done by Gunawan et al., (2006) where the 1μm amplitude and 400Hz are employed. Additional equipments are connected and attached to the machine in order to generate the vibration for the work piece. From direct current source, the current is transmitted to a step-down transformer. The power amplifier together with function generator is connected to the transformer and drives the vibration generator device. Then, it shakes the beam connector thus shaking the work piece attached at the end of the beam. The amplitude and frequency generated from the vibrator is monitored by data acquisition device using an accelerometer mounted to the beam. The data acquisition device is installed with Lab View 7.0 programme. Figure 1 shows the overall experimental setup. Details on the experimental condition are listed in Table 2. The positive polarity for this experiment represents the tool is positive and the work piece is negative and vice versa.

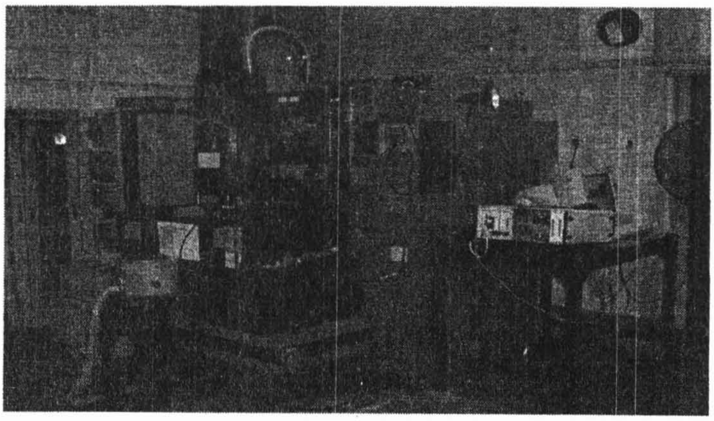


Figure 1: Experimental Setup for EDM with Ultrasonic Vibration

Table 2: Machining Details

Machine	Sodick A30R
Tool	Cu (ø16mm)
Work piece	Tungsten Carbide
Dielectric fluid	Vitol 2, Sodick (Kerosene) [16]
Flushing pressure	50kPa
Voltage	90-120V
Current	10A (high-H), 8A (low-L)
Polarity	Positive (+), Negative (-)

Results and Discussions

Surface Morphology using Stereomicroscope

Figure 2 and Figure 3 presents the tungsten carbide morphology machined without vibration and with vibration respectively. The photograph of the machine surface was captured in 10x and 40x magnification. It can be seen that higher current gives bigger crater. However, no obvious difference between the two machining method can be seen with naked eyes.

Surface Morphology using SEM and EDX – Machining without Vibration

Specimen machined with high current in negative polarity (H-) was selected to be observed under

Scanning Electron Microscope (SEM). Figure 4(a) shows the centre portion of the machined surface under 100x magnification. Selected area from Figure 4(a) was magnified to 500x and shown in Figure 4(b). It can be seen that the surface has pockmarks and small crack.

Pockmarks are formed by entrapped gases escaping from the resolidifying material (Yusuf et al., 2006) Globules of detached metals can be seen on the surface which suggest that portion of metals which are evaporated by sparks form spherical particles due to the cooling effect by dielectrics, fall back on the work piece and get loosely attached. This maybe the debris that is not properly flushed after the vaporisation and deposited on the surface. H.T. Lee and T.Y. Tai (2003) explained that crack formation can be attributed to the presence of thermal stress and tensile stress within the machined component. Thermal stress is produced when the electrode discharges bombard the surface of the sample during the machining process. Tensile stress within the sample is generated because not all of the material which melts during the machining process is swept away from the component's surface by the dielectric. Due to the ingress of carbon, the melted material contracts more than the unaffected parent part during the cooling process, and when the stress in the surface exceeds the material's ultimate tensile strength, cracks are formed. Figure 4(c) shows the machined surface at the edge of the machined area. Crack is not very obvious but the pockmarks together with globules are very distinct.

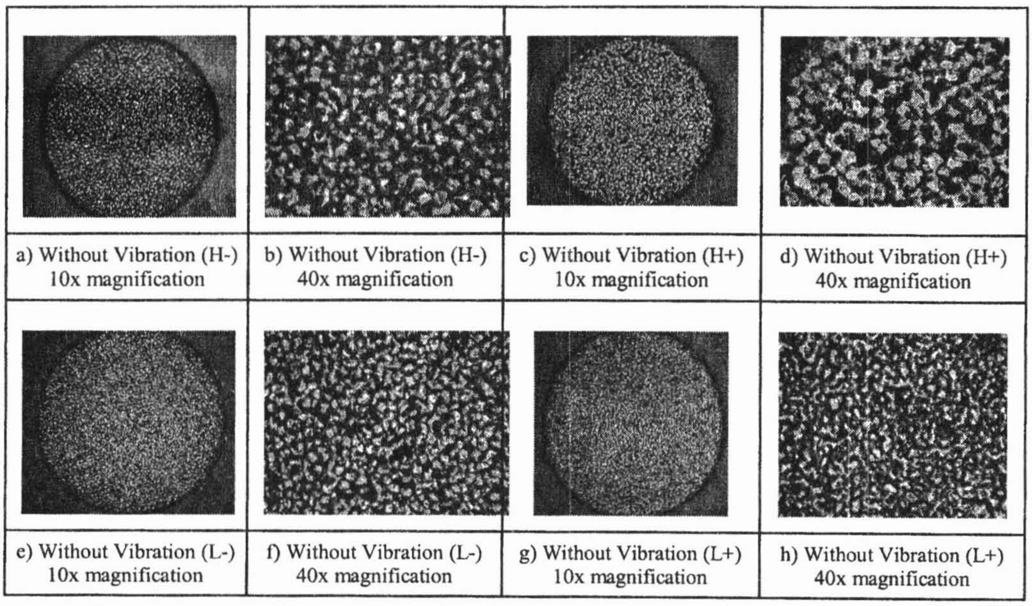


Figure 2: Surface Morphology of Tungsten Carbide Machined without Vibration under Stereomicroscope in 10x and 40x Magnification

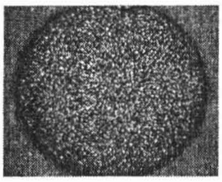
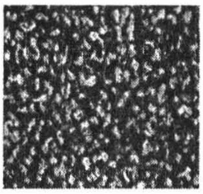
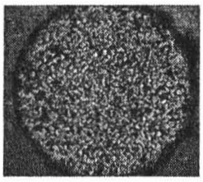
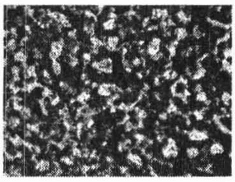
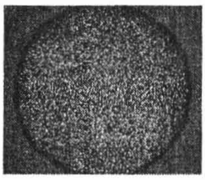
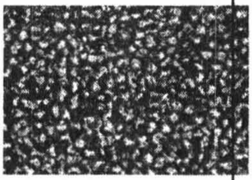
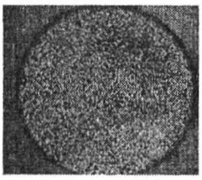
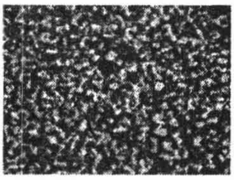
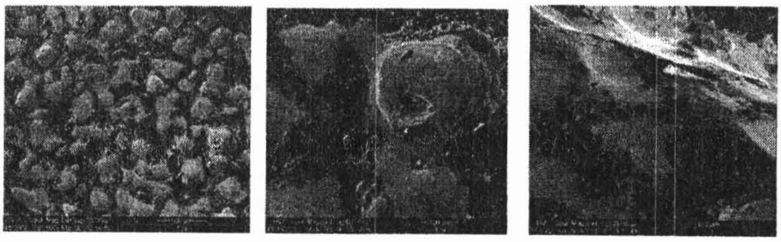
			
a) With Vibration (H-) 10x magnification	b) With Vibration (H-) 40x magnification	c) With Vibration (H+) 10x magnification	d) With Vibration (H+) 40x magnification
			
e) With Vibration (L-) 10x magnification	f) With Vibration (L-) 40x magnification	g) With Vibration (L+) 10x magnification	h) With Vibration (L+) 40x magnification

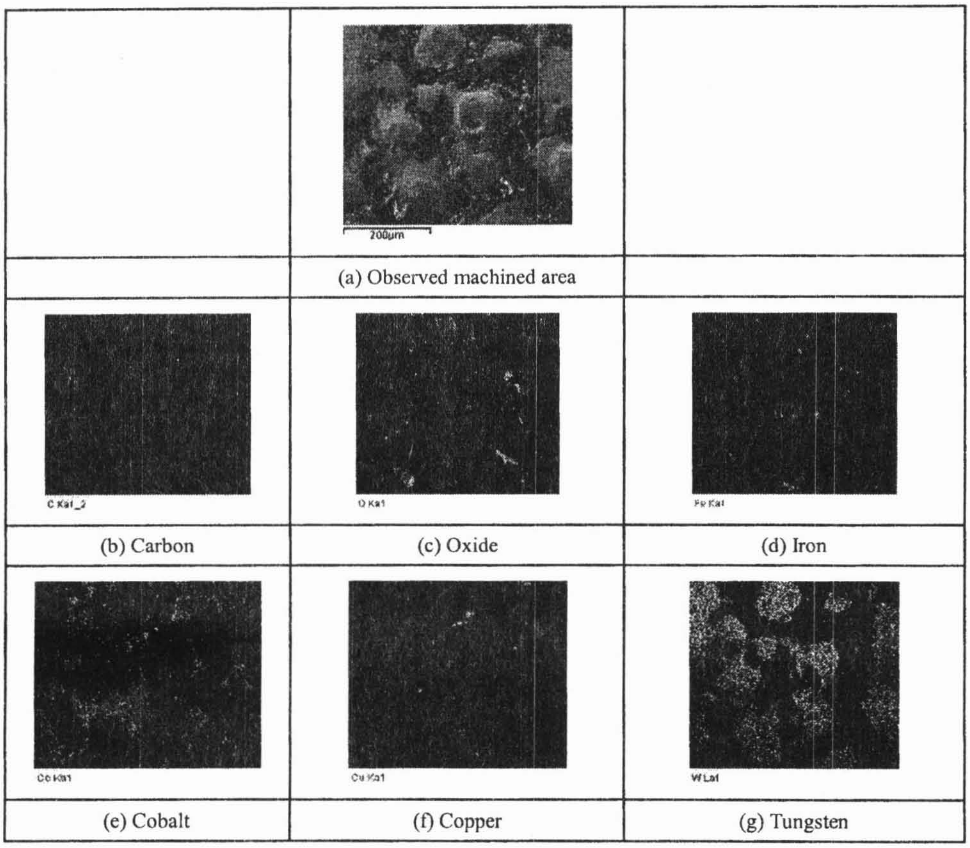
Figure 3: Surface Morphology of Tungsten Carbide Machined with Vibration under Stereomicroscope in 10x and 40x Magnification

EDX mapping was done on selected surface as shown in Figure 5(a). The result shows that there are six major elements found on the machined surface. They are carbon (C), oxide (O), iron (Fe), cobalt (Co), copper (Cu) and tungsten (W) as shown in Figure 5. Carbon is the main element found on the surface with 52.58%. Therefore the black layer seen by naked eyes on the surface is confirmed as carbon layer. Other than that, the percentages of other elements are: cobalt 5.63%, oxide 4.23%, copper 1.80% and iron 0.33%.



(a) (b) (c)

Figure 4: SEM on Tungsten Carbide Machined without Vibration



(a) Observed machined area

(b) Carbon (c) Oxide (d) Iron

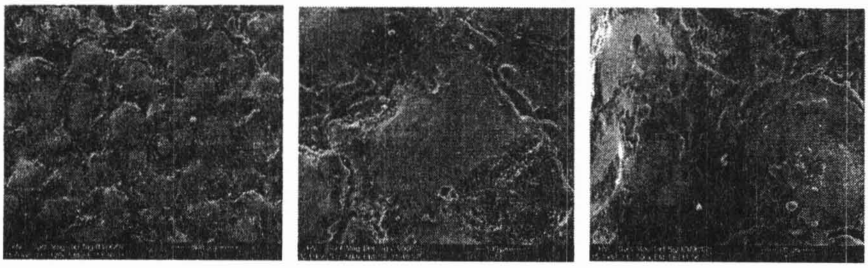
(e) Cobalt (f) Copper (g) Tungsten

Figure 5: Mapping on Tungsten Carbide Work piece Machined without Vibration

Surface Morphology Using SEM and EDX – Machining with Vibration

The SEM image of tungsten carbide machined under H(-) with vibration in 120x and 500x magnification is shown in Figure 6. Figure 6(a) gives the image at the centre of the machined surface while Figure 6(b) shows the magnified image from Figure 6(a). Crack is very difficult to see while pockmarks and globules are scarce. Magnified image captured at the edge of the machined surface is illustrated in Figure 6(c). Flushing is a problem at the edge of the crater. By implementing the vibration during machining, it can reduce pock marks and globules. This is because, the vibrated work piece enhance the removal of debris from the surface during the machining.

Results of surface mapping revealed that there are six elements on the machined surface. The EDX analysis reveals that carbon present is 46.16% followed by tungsten (39.52%). The other elements present are cobalt 7.84%, oxide 4.35%, copper 1.93% and chromium 0.21%.



(a) (b) (c)

Figure 6: (a) Machined Surface at the Centre of the Crater with 120x Magnification (b) Image of Selected Area With 500x Magnification (c) Edge Machined Surface with 500x Magnification

Conclusion

The following observations are made from the results of this study:

i. Machining without and with vibration exhibits nearly the same surface morphology when observed with naked eyes.
ii. Observation with higher magnification shows that machining with vibration reduces the porkmark, crack and globules especially at the edge of the machined surface.
iii. Machining with vibration promotes to reduce the formation of entrapped gases, thermal and tensile stress of the specimen and better flushing of debris.

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