Journal of Engineering and Applied Sciences 11 (7): 1469-1474, 2016
ISSN: 1816-949X

Micro Electro Discharge Machining of Non-Conductive Ceramic Using Conductive Powder Mix Dielectric Fluid

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Abstract: This study presents the process development and investigation of the Material Removal Rate (MRR) in micro Electro Discharge Machining (micro-EDM) of non-conductive ceramic zirconia using titanium carbide powder mixed with the kerosene dielectric fluid. Experimental investigation is carried out using 1.0 mm diameter copper electrode with two varying parameters; gap voltage and capacitance. The MRR data are analyzed and an empirical model is developed using design expert software. The optimum parameters for maximum MRR are found to be 86 V gap voltage and 1.0 nF capacitance.

Key words: Micro-EDM, Assisting Electrode Method (AEM), zirconia (ZrO_2), Material Removal Rate (MRR), Titanium Carbide (TiC) powder

INTRODUCTION

Currently, micro parts are made of engineering ceramic vastly used in biomedical field to fabricate femoral heads and acetabular cups for total hip replacement for example. In near future, the need for tough, strong and stable bio-inert ceramics should be met by nano structured alumina (Al_2O_3) and zirconia (ZrO_2) based ceramics and composites or by non-oxide ceramics (Chevalier and Gremillard, 2009). However, non conductive ceramics cannot be machined by traditional metallic tools because of their high brittleness and hardness. Hence, non-conventional machining such as chemical machining, abrasive water jet machining, ultrasonic machining, laser beam machining, Electro Discharge Machining (EDM) are used in processing structures from non-conductive ceramic materials (Ting *et al*., 2009).

EDM is a thermal process that uses electrical discharges to erode electrically conductive materials and is capable in machining accurate cavities of dies and molds. Micro Electrical Discharge Machining (micro-EDM) is quite similar with the principle of conventional EDM (Zarepour *et al*., 2007; Das and Joshi, 2010; Schubert *et al*., 2011). Micro-EDM process is based on the thermoelectric energy between the workpiece and an electrode. It is a newly developed method to produce micro-parts in the range of 50-100 μm. Micro-EDM is an efficient machining process for the fabrication of a micro-hole because of its non-contact nature with nearly force free machining. A pulse discharges occur in a small gap between the workpiece and the electrode which removes material from the workpiece through the melting and vaporization (Mahendran *et al*., 2010; Schubert *et al*., 2013; Masuzawa, 2000).

However, in order to apply micro-EDM operation on non-conductive ceramic materials, a new technique known as Assisting Electrode Method (AEM) had been introduced (Mohri *et al*., 1996; Muttamara *et al*., 2009; Ji *et al*., 2012; Fukuzawa *et al*., 2009). In AEM, a conductive layer is applied on top of the non-conductive ceramic in order to produce sparks between the workpiece and the electrode. During the erosion process, Assisting Electrode (AE) will be eroded. High temperature that occurs around the carbonic dielectric fluid will degenerate the polymer chains and creates carbon elements from cracked polymer chains. These carbon elements with combination of conductive debris cover the ceramic surface in order to sustain the conductivity during the erosion process (Muttamara *et al*., 2009; Ji *et al*., 2012; Fukuzawa *et al*., 2004, 2009; Banu *et al*., 2014; Mohri *et al*., 2013). In brief, the material removal process for non-conductive ceramic is assisted by AE and carbon layer generated from the combustion after-effect of spark.

Powder mixed EDM is one of the recent innovations in EDM to enhance the capabilities of EDM process. The presence of powder suspended in the dielectric fluid is a new hybrid material removal process. In this

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technique, fine abrasive powder is mixed into the dielectric fluid of EDM. The added powder significantly affects the performance of EDM process. The electrically conductive powder reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and the workpiece (Furutani *et al*., 2001). As a result, the process becomes more stable thereby improving Material Removal Rate (MRR). Thus, the objective of this paper is to develop process and to investigate the MRR of the non-conductive zirconia to be machined by micro-EDM in the presences of the Titanium Carbide (TiC) powder mix with the kerosene dielectric fluid.

MATERIALS AND METHODS

The process development and the MRR investigation were performed using micro-EDM with multi-process micro machine tools, DT-110 (Mikrotools Inc., Singapore). The machining operation was done using copper electrode (ϕ1.0 mm), TiC powder mix with kerosene dielectric fluid, zirconia plate (20×15×10 mm) as the workpiece and copper foil as the AE. The experimental parameters for process development and the MRR are shown in Table 1.

In process development, two machining setup were used in order to study the machinability of the zirconia by micro-EDM using TiC powder mix with kerosene as the dielectric fluid. Once the process development is determined, detailed experiments for the analysis of MRR was conducted.

As for MRR, Taguchi L9 orthogonal array (Table 2) was used to conduct the experiments using two controlled factors; gap voltage and capacitance. For each of the run, the mass of the workpiece before and after were taken using weighing scale and the machining duration was also recorded in order to calculate the MRR. The results were analyzed using Analysis of Variance (ANOVA) approach and an empirical model was developed.

RESULTS AND DISCUSSION

Process development: The typical experiment set up that usually adopted by researchers in micro-EDM especially for powder mixed dielectric fluid is shown in Fig. 1. Normally, the powder is added into the kerosene dielectric fluid in a separated tank. Then, the powder mixed kerosene is circulated into the operating tank assisted by pump. The nozzle of the hose is directed at the machining area so that the powder additive can be transported and catalyze the machining process. However, the circulated fluid washed away the carbon generated from the cracked polymer chains of the kerosene dielectric fluid. The carbon has the ability to sustain the machining process after the AE is eroded. In other words, the existence of carbon is significant to sustain the machining operation of non-conductive ceramic. In order to withstand the machining operation for a longer time, customized experimental setup had been developed (Fig. 2).

The usage of pump (Fig. 1). was replaced by adding copper lid that act as a pond to trap the carbon that needed in order to maintain the machining operation. Moreover, the copper lid also allows the powder additive to be kept at the plasma region of the machining area in order to catalyze the machining operation. The thickness of the copper lid used is 0.8 (Fig. 3). It is adequate to store enough carbon for the process.

Fabrication of hole on non-conductive ceramic: Adhesive copper foil is adhered on non-conductive ZrO_2 ceramic. It is used to initiate and assist the machining process (Fig. 4a). Copper lid is clamped together with the workpiece on top of the adhesive copper foil. Copper lid is used to trap the carbon and powder additive that helps in maintaining the machining process (Fig. 4b). Copper tool is adjusted at the opening area (pond) of the copper lid before starting the micro-EDM operation (Fig. 4c). As machining process starts, the tool machines the Adhesive Copper foil (AE) first. During this process, carbons produced from the combustion are trapped in the pond (Fig. 4d). Then a small amount of powder additive Titanium Carbide (TiC) is added during the machining process. The powder particles get energized and behave in a zigzag manner between the tool and the workpiece. The grains come close to each other under the sparking area and gather in clusters. The interlocking between the different powder particles takes place due to variation in their shapes and sizes (Fig. 4e). The chain formation helps in bridging the gap between both the electrode and the workpiece. Due to bridging effect, the gap voltage and insulating strength of the dielectric fluid decreases. The easy short circuit takes place which causes early explosion in the gap (Fig. 4f). As a result, the "series of discharges" starts under the electrode area. Since the frequency of discharging increases, a quicker sparking within a discharge takes place which allows rapid erosion from the workpiece surface. At the same time, larger and wider plasma channel are produce due to the existence of the powder (Kansal *et al*., 2007). The electric density decreases; hence sparking is uniformly distributed among the powder particles. Therefore, even and more uniform distribution of the discharge takes place which causes uniform erosion on the workpiece. As a result, MRR increases. Figure 5 shows the SEM image of the machined area on non-conductive ZrO_2 ceramic using the customized machining setup.

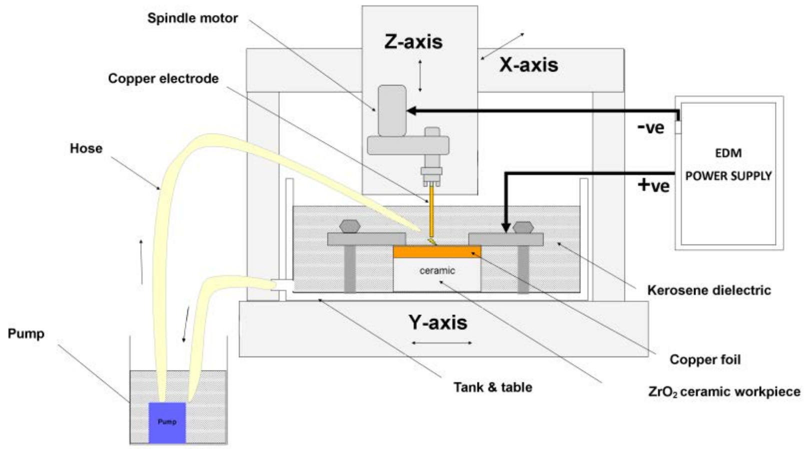

Fig. 1: Typical experimental setup for powder mixed micro-EDM of ZrO_2

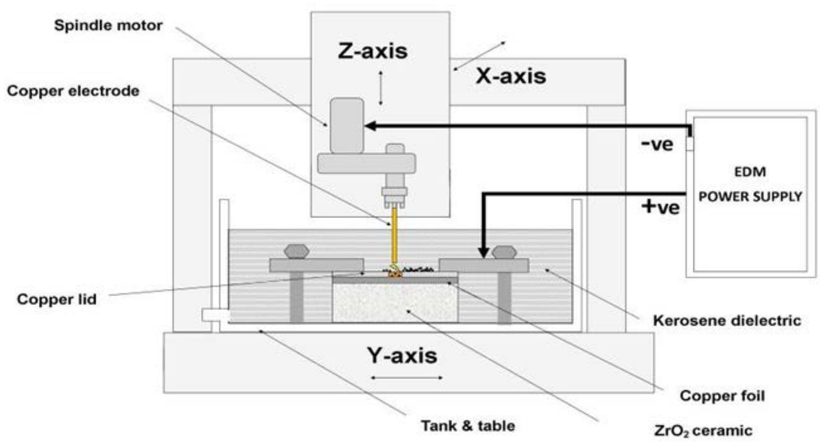

Fig. 2: Customized experimental setup for powder mixed micro-EDM of ZrO_2

Fig. 3: Copper lid (20×20 mm), opening area (2×1.5 mm)

Table 1: Experimental parameters

Controlled parameters	Factors	Levels I	Levels II	Levels III
Gap voltage (V)	V	85.00	90.00	95.00
Capacitance (nF)	C	0.01	0.10	1.00

Fixed parameters; Workpiece = Zirconia (ZrO_2); Dielectric fluid = Kerosene; Tool electrode = Copper (ϕ 1.0 mm); Powder = Titanium carbide (TiC); powder concentration = 10 g/L; Assisting Electrode (AE) = Copper foil (0.06 mm thickness); spindle speed = 300 rpm; threshold gap = 27%; Polarity = Workpiece positive; Depth of cut = 300 µm

Effect of machined area using customized experimental setup: Smaller copper lid pond (about to fit the hole size) allows the machining process to take place for a longer time. As a result, higher machining depth can be achieved. However, it gives bad effect on the surface surrounding the hole. Figure 6ab shows the carbon deposited around the outer hole. The affected surface surrounding the outer hole increases due to the presence of the powder additive which causes larger plasma channel. To overcome such

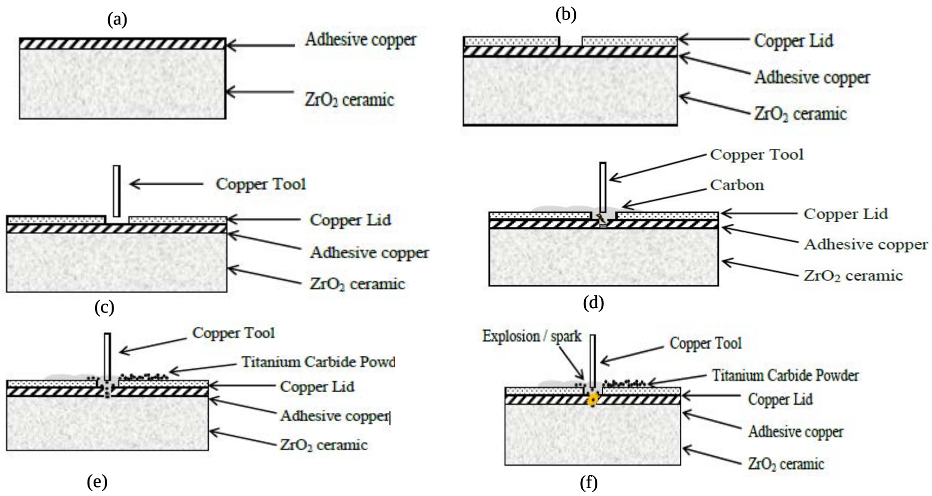

Fig. 4: Steps to fabricate a hole on non-conductive ZrO_2 ceramic

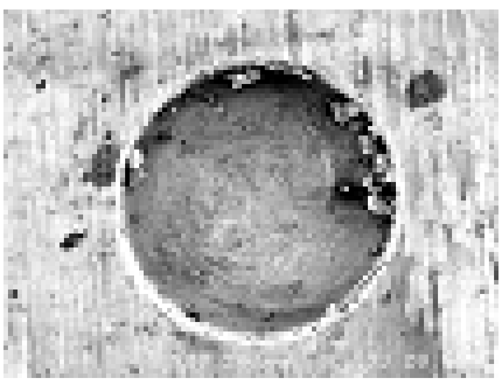

Fig. 5: SEM image of the machined area of ZrO_2 ceramic using customize experimental setup for powder mixed micro-EDM of non-conductive ceramic

problem, the copper lid pond should be designed to bigger tolerance to reduce the deposition of carbon around the outer hole (Fig. 6c). In Fig. 6c, less carbon were deposited around the outer hole since the plasma channel was distributed to a larger space. Even though by replacing the pump with copper lid pond has optimized the MRR of micro-EDM, it also affected the surrounding surface of the outer hole. A lot of carbon can be deposited if small pond is used. However, the carbon can be reduced by enlarging the copper lid pond. This special customized set up should be put into consideration in to obtain high depth of cut and MRR in non-conductive ceramic.

The developed empirical model is shown in Eq. 1. The adequacy of the developed statistical model was checked by the ANOVA. Based on ANOVA, prob. >F-value of

Table 2: Taguchi's L9 orthogonal array design and measured MRR values

Run	Gap voltage (V)	Capacitance (nF)	MRR (mm^3/min)
1	85	0.01	9.317E-05
2	85	0.10	3.830E-04
3	85	1.00	1.773E-03
4	90	0.01	4.170E-04
5	90	0.10	5.747E-04
6	90	1.00	1.724E-03
7	95	0.01	9.195E-04
8	95	0.10	7.360E-04
9	95	1.00	3.130E-04

0.0087 indicates the model is significant. Based on the analysis, the most significant factor is capacitance, C since it gives the most influence on MRR. The interaction effect, VC gives F-values of 21.50 with prob. >F of 0.0057. In column prob. >F, the values with <0.05 indicates the factors are significant. However, values with greater than 0.10 implies the factors are not significant. Hence, it is concluded that gap voltage, V is not significant (prob. >F is 0.1379) but it does affected the MRR when there is an interaction between gap voltage and capacitance.

$$MRR = -5.97\times10^{-3} + 7.17\times10^{-5}\,V + 2.05\times10^{-2}\,C - 2.19\times10^{-4}\,VC \quad (1)$$

Where:

MRR = Material removal rate (mm^3/min)
V = Gap Voltage (V)
C = Capacitance (C)

Figure 6d shows the contour graph of MRR vs. gap voltage and capacitance. The MRR increases when the gap voltage decreases and capacitance increases. However, the MRR gives the lowest value when the gap voltage and capacitance are low. Hence, it can be concluded that capacitance have a strong influence

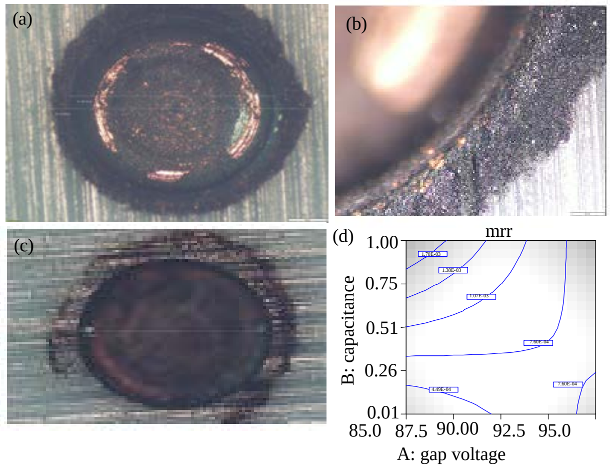

Fig. 6: Carbon deposited at the surface surrounding the hole (optical image); a) whole hole image; b) clearer image; c) less carbon deposited at the surface surrounding the hole (optical image) and d) contour graph for MRR vs. gap voltage and capacitance

on the MRR. The ANOVA-based optimization suggested that the optimum parameters for maximum MRR are found to be 86 V gap voltage and 1.0 nF capacitance.

CONCLUSION

The micro-EDM of non-conductive ZrO_2 ceramic has been successfully conducted using constant concentration of powder mixed TiC dielectric fluid. This study shows that: the customized setup can maximized the MRR of the machined area even though it affected the surrounding surface of the machined area (outer hole). To overcome such problem, the copper lid pond should be designed to bigger tolerance to reduce the deposition of carbon around the outer hole. Based on the ANOVA analysis, the MRR is strongly affected by the capacitance. The model predicts maximum MRR (1.82×10^{-3} mm^{-2}) when 86 V gap voltage and 1.0 nF capacitance are used.

ACKNOWLEDGEMENT

The researchers would like to express their thanks to the Ministry of Education, Malaysia for financial support under Research Grant FRGS14-156-0397.

REFERENCES

Banu, A., M.Y. Ali and M.A. Rahman, 2014. Micro-electro discharge machining of non-conductive zirconia ceramic: Investigation of MRR and recast layer hardness. Intl. J. Adv. Manuf. Technol., 75: 257-267.

Chevalier, J. and L. Gremillard, 2009. Ceramics for medical applications: A picture for the next 20 years. J. Eur. Ceramics Soc., 29: 1245-1255.

Das, S. and S.S. Joshi, 2010. Modeling of spark erosion rate in microwire-EDM. Intl. J. Adv. Manuf. Technol., 48: 581-596.

Fukuzawa, Y., N. Mohri, H. Gotoh and T.A.N.I. Takayuki, 2009. Three-dimensional machining of insulating ceramics materials with electrical discharge machining. Trans. Nonferrous Met. Soc. China, 19: 150-156.

Fukuzawa, Y., N. Mohri, T. Tani and A. Muttamara, 2004. Electrical discharge machining properties of noble crystals. J. Mater. Process. Technol., 149: 393-397.

Furutani, K., A. Saneto, H. Takezawa, N. Mohri and H. Miyake, 2001. Accertation of titanium carbide by electrical discharge machining with powder suspended in working fluid. Precision Eng., 25: 138-144.

Ji, R., Y. Liu, Y. Zhang, F. Wang and B. Cai *et al*., 2012. Single discharge machining insulating Al2O3 ceramic with high instantaneous pulse energy in kerosene. Mater. Manuf. Processes, 27: 676-682.

Kansal, H.K., S. Singh and P. Kumar, 2007. Technology and research developments in Powder Mixed Electric Discharge Machining (PMEDM). J. Mater. Process. Technol., 184: 32-41.

Masuzawa, T., 2000. State of the art of micromachining. CIRP Ann. Manuf. Technol., 49: 473-488.

Mohri, N., Y. Fukuzawa, T. Tani, N. Saito and K. Furutani, 1996. Assisting electrode method for machining insulating ceramics. CIRP Ann. Manufactur. Technol., 45: 201-204.

Mohri, N., Y. Fukusima, Y. Fukuzawa, T. Tani and N. Saito, 2003. Layer generation process on work-piece in electrical discharge machining. CIRP. Ann. Manuf. Technol., 52: 157-160.

Muttamara, A., Y. Fukuzawa, N. Mohri and T. Tani, 2009. Effect of electrode material on electrical discharge machining of alumina. J. Mater. Process. Technol., 209: 2545-2552.

Schubert, A., H. Zeidler, M.H. Oschatzchen, J. Schneider and M. Hahn, 2013. Enhancing micro-EDM using ultrasonic vibration and approaches for machining of nonconducting ceramics. Strojniski Vestnik J. Mech. Eng., 59: 156-164.

Schubert, A., H. Ziedler, N. Wolf and M. Hackert, 2011. Micro electro discharge machining of electrically nonconductive ceramics. AIP. Conf. Proc., 1353: 1303-1308.

Ting, H.T., K.A.A. Hossein and H.B. Chua, 2009. Review of micromachining of ceramics by etching. Trans. Nonferrous Met. Soc. China, 19: 1-16.

Zarepour, H., A.F. Tehrani, D. Karimi and S. Amini, 2007. Statistical analysis on electrode wear in EDM of tool steel DIN 1.2714 used in forging dies. J. Mater. Process. Technol., 187: 711-714.