*Materials Science Forum*
*ISSN: 1662-9752, Vol. 900, pp 127-130*
*doi:10.4028/www.scientific.net/MSF.900.127*

*Submitted: 2017-03-09*
*Accepted: 2017-03-23*
*Online: 2017-07-14*

# Performance of Electrical Discharge Milling and Sinking in Micro Graphite Powder Mixed Dielectric

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**Keywords:** Electrical Discharge Machining, Powder Mixed EDM, Powder mixed dielectric, Graphite Powder.

**Abstract.** Electrical discharge machining (EDM) is a non-conventional machining technique that is well-known for use in fabricating dies and molds owing to machinability of high hardness materials. Although the electro-thermal mechanism of EDM offers many advantages over other available machining methods, its sluggish nature limits the wide application of such machines for mass production. In this research, adding graphite powder to dielectric is proposed to improve EDM performance factors. Material removal rate (MRR) and average surface roughness (Ra) have been monitored and evaluated after addition of graphite powder to dielectric in electrical discharge milling and sinking. It is found that the presence of powder particles in dielectric fluid enhances the MRR steadily up to ~11 and ~17% for milling and sinking process, respectively. Moreover, the highest enhancement if Ra is ~31% at 1g/l graphite powder concentration for electrical discharge milling and up to ~11% for sinking process. Field emission scanning electron microscopy (FESEM) is used to inspect the machined surfaces. The surfaces machined with graphite powder mixed appear significantly unlike the surfaces machined in pure dielectric. Adding powder to dielectric is found to increase the machined surface hardness by ~26%, from 240 to 302 HV.

## Introduction

Among all non-conventional machining methods, the EDM mechanism provides the most suitable conditions for machining difficult–to-cut materials. The capability to fabricate complex shape components, eliminate mechanical stress, and remove vibration and chatter are other essential features of EDM [1, 2]. Selecting an appropriate dielectric is an influential aspect in EDM as well. Powder-mixed EDM (PMEDM) is among the most highly practiced methods [3], whereby a specific concentration of powder is mixed with dielectric. In discharge gap, the powder suspended in dielectric is subjected to heat caused by plasma. The powder material properties directly impact EDM performance and workpiece mechanical properties. The influence of several powder materials on EDM has been evaluated, including graphite, silicon, aluminum, silicon carbide, chromium, copper, titanium, tungsten, molybdenum sulphide, boron carbide, titanium carbide and crushed glass. The most popular powder material seems to be graphite owing to its low cost. In this research, the influence of adding graphite powder to dielectric is evaluated. The EDM process is investigated in terms of MRR, Ra and surface hardness. Furthermore, FESEM is used to assess the surface micrographs.

## Methodology

Sodick die sinking EDM was upgraded with an external dielectric circulation system. As schematically illustrated in [4], a smaller machining chamber was built with a holder inside to manage workpiece stability during the experiments. In the system, a pump controlled the suction of dielectric through a filter from the machining chamber and then flushed it out from the nozzle into the machining gap, where direct flushing was implemented. This circulation system was designed mainly to reduce the amount of powder required during the experiments as well as to prevent the powder from entering the default EDM filtration system. AISI D2 tool steel and copper were the materials of choice for the workpiece and tool, respectively. Machining was done with 100 µs discharge duration, 30 µs charging duration, 2 A peak current, 120 V for 8 minutes, with tool having a rotary motion at 200 rpm, graphite powder of 1 µs diameter was used to prepare graphite powder mixed dielectric. Two main factors of EDM, namely MRR and Ra were investigated. MRR is the removed weight from workpiece over time. The machined surface properties were evaluated by measuring Ra using a surface roughness profilometer and micro-hardness using a micro-hardness tester. Furthermore, FESEM images of the machined surface were inspected.

**Results and Discussion**

First, the process performance was investigated in terms of MRR and surface roughness, which are two of the main performance factors of EDM. Fig. 1 and Fig. 2 indicate the MRR and Ra for machined surface in pure and graphite powder mixed dielectric in electrical discharge milling and sinking. Fig. 1 indicates that MRR increased steadily up to 6 and 11% after adding 1 and 2.5 g/l of powder to dielectric, respectively. This enhancement was mostly due to the bridging effect and discharge dispersion during discharge [5]. Bridging effect occurs when voltage is applied between tool and workpiece and powder particles in discharge gap arranged themselves as chains connecting the electrodes, which eventually led to increasing discharge frequency [6, 7]. This causes multiple discharge paths between tool and workpiece from a single input pulse, which dispersed the energy and created multiple surface craters [8]. For more than 2.5 g/l of powder, MRR is expected to increase up to a certain level, then the MRR will drop due to the energy decrease caused by excessive powder concentrations, where the process also became unstable owing to the occurrence of short circuits [9].

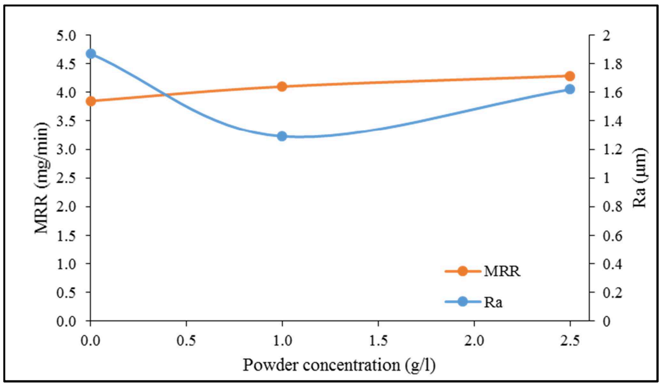


Figure 1. MRR and Ra for surfaces machined with electrical discharge milling in pure oil and 1 and 2.5g/l graphite powder-mixed oil dielectric

Apparently, the presence of graphite powder in discharge gap contributed not only in increasing the MRR but also reducing the Ra at both 1 and 2.5 g/l concentrations. At 1 g/l graphite powder concentration, the highest improvement of approximately 31% was recorded, followed by 2.5 g/l with about 13% reduction in Ra. After the optimum powder concentration, the surface quality decreased again due to the problem of powder settling and the bridging effect. Powder settling on the machined surface can cause more concentrated discharge energy and the accumulation of carbon on the workpiece surface, ultimately deteriorating the surface quality.

Contrasting Figs 1 and 2, shows that rotation of spindle significantly affects the EDM performance. Under the same machining condition, electrical discharge sinking results in lower MRR in compared with electrical discharge milling. However, the MRR and Ra of both processes enhanced after addition of powder to dielectric. According to Fig 2, contribution of 2.5 g/l of graphite powder to dielectric has led to 17% increase in MRR, where at 1 g/l, the MRR did not experience any improvement. The $R_a$ also demonstrated to be improved and the enhancement of around ~11% was found to be the highest at 1 g/l of graphite powder concentration followed by ~9% improvement at 2.5 g/l.

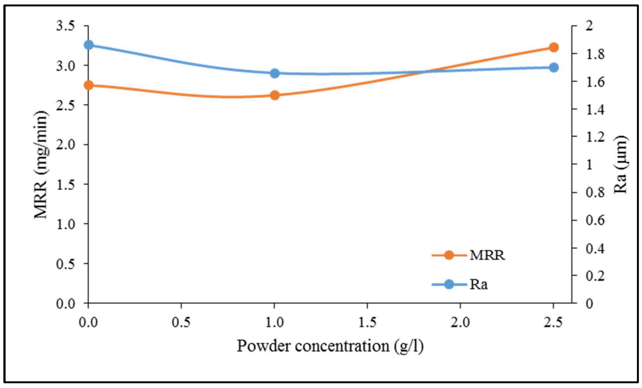


Figure 2. MRR and Ra for surfaces machined with electrical discharge sinking in pure oil and 1 and 2.5g/l graphite powder-mixed oil dielectric

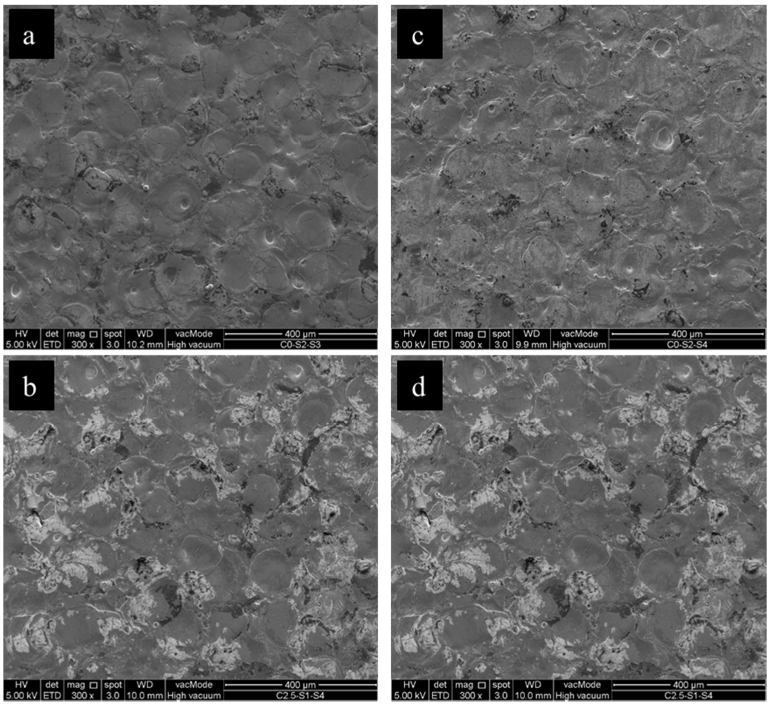


Figure 3. Surfaces machined with electrical discharge milling in (a) oil and (b) 2.5g/l graphite-mixed oil dielectric; and electrical discharge sinking in (c) oil and (d) 2.5g/l graphite-mixed oil dielectric

The micrographs of the machined surface were obtained using FESEM for milling and sinking in pure oil and graphite powder-mixed dielectric which is illustrated in Fig. 3. A visual inspection of the surface micrographs indicates that the surface changes after adding powder to dielectric. The white colour parts on the machined surface are likely formed as a result of surface modification at high plasma temperature when graphite powder was present in the gap. In carburization, a source of carbon, such as a graphite powder or gaseous phase containing carbon, is diffused into steel components and increase the hardness of entire surface [10]. In this regard, the surface micro-hardness was measured for the samples machined in die-sinking process in pure oil and 2.5 g/l of graphite powder. It was observed that micro-hardness increased by ~26% from ~240 HV to ~302 HV after adding 2.5 g/l graphite powder to dielectric due to diffusion of carbon atoms into the surface at high temperature of plasma.

## Conclusion

In this research, addition of graphite powder to dielectric was proposed to improve two EDM performance factors in electrical discharge milling and sinking processes. After investigating the MRR and Ra of electrical discharge milling and sinking process, it was found that in almost all selected machining conditions, these factors improve after adding powder to dielectric. The existence of powder particles in dielectric fluid improve the material removal rate (MRR) steadily up to ~11% and 17% after addition of 2.5 g/l of graphite powder to dielectric in electrical discharge milling and sinking process, respectively. Moreover, Ra of the surface machined with electrical discharge milling decreased the most by ~31% at 1 g/l, whereas Ra dropped by the max by ~11% for surface machined with electrical discharge sinking. The surfaces machined with 2.5 g/l of graphite-mixed powder indicated the increase of about ~26% in surface hardness compared with surface machined in pure dielectric.

## Acknowledgements

The authors acknowledge the financial support of University Malaya Research Grant no. PG016-2013B from the University of Malaya, Malaysia.

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