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EFFECT OF SURFACTANTS AND ADDITIVES ON ELECTRICAL DISCHARGE MACHINING OF REACTION BONDED SILICON CARBIDE

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ABSTRACT

In this paper, a comparative study of Electrical Discharge Machining (EDM) on Reaction Bonded Silicon Carbide (RB-SiC) by using different types of surfactants and additives powder has been carried out. The EDM oil type Low Smell (LS) used in the experiment was mixed with different surfactants namely Span 20, Span 80, Span 83 and Span 85. Additives powder that were used to verify the machining performance are Carbon Nanofiber (CNF), Carbon Nano Powder (CNP) and Carbon Powder (CP). These powders are different in terms of size and shape. In this study, the change of material removal rate (MRR), electrode wear ratio (EWR), surface roughness and spark gap was investigated. The result shows that the surfactant and additives added dielectric fluid not only improves MRR and spark gap, but also reduces the EWR. The addition of surfactant might prevent the agglomeration of powders, and caused the powders dispersed well in the dielectric fluid. Therefore, electro discharge frequency will be increased, leading to a higher MRR and spark gap. However, the improvement of surface finish is not significant after addition of surfactant. For comparison, combination of surfactant Span 80 and CNF is more significant in improving machining efficiency of RB-SiC compared to the others type of surfactant and additives.

Keywords: electrical discharge machining, RB-SiC, surfactant, additive.

INTRODUCTION

Silicon Carbide (SiC) is expected to be an important material in manufacturing industries for the next generation low-loss power conventional equipment in lots of applications such as electronic component, chemical, boiler and petroleum industry [1-2]. The selection of this material is based on its excellent material properties for example high thermal and chemical stability, low density, high stiffness, high hardness, high thermal conductivity and low activation [3]. Many types of products can be made from SiC, such as ceramic brake discs for sports cars, seal ring material for pump shaft sealing and components that used in pumps such as valves in oilfield applications. However, due to high hardness, SiC is difficult to be machined with good surface finish and high accuracy. Conventional diamond grinding is used to machine SiC, but the process requires high grinding force and for that cutting edges of diamond grinder is easily worn out which makes the process costly and inefficient [4]. In addition, grinding of SiC is difficult because of its low fracture toughness and making it very sensitive for cracking [4]. Instead of grinding, researchers also tried to cut Reaction Bonded Silicon Carbide (RB-SiC) using diamond cutter, but tool wear still remains main problem although it can produce high material removal rate (MRR) [5].

To overcome the problems during machining of ceramic materials, some researchers conducted Electrical Discharge Machining (EDM). It is based on a non-contact process between workpiece and electrode. The material is removed by series of repeated electrical discharge between material and tool that immersed in dielectric fluid [6]. Zhao *et al.* [1] investigated the EDM behavior of single crystal SiC and found that cutting speed of foil EDM of SiC can be improved by increasing the discharge current and using thinner foil electrode. Lopez *et al*. [7] offered few advantages of EDM machining over other machining process in terms of final shaping and surface finishing of ceramic materials. Even so, there are limitations when EDM applies for ceramic material because most of the ceramic materials are not conductive as the electrical resistivity of these materials is between 100 and 300 Ω cm [8-9]. To overcome the resistivity, many researchers added conductive powder into dielectric fluid viz., Chow *et al*. [10] added SiC powder in dielectric fluid for micro-slit EDM machining and found that SiC powder helped to bridge the electrode and workpiece gap and at the same time accelerated MRR and Jeswani [11] added graphite powder to kerosene and confirmed the improvement in MRR and electrode wear rate (EWR). For machining RB-SiC, Liew *et al.* [12] added Carbon Nanofiber (CNF) into dielectric fluid and found that machining efficiency of RB-SiC improves significantly. However, when high concentration of CNF is used, the CNF tends to agglomerate and might not disperse well. The methods to avoid particles agglomeration in dielectric fluid have been investigated by several groups, such as pump circulation [13] and ultrasonic vibration [14]. Besides that, some researchers also attempted adding surfactant into dielectric fluid [15-17]. Although extensive researches have been carried out using surfactant, however, to date, there is no report on a comparative study of different surfactants and additives in dielectric fluid on low conductivity RB-SiC by conventional EDM process.

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Therefore, in the present work, the effect of four different types of surfactants (Span 20, Span 80, Span 83 and Span 85) and three different types of additives (Carbon Nanofiber (CNF), Carbon Nano Powder (CNP) and Carbon Powder (CP)) on the MRR, electrode wear ratio (EWR), surface roughness and spark gap in EDM were investigated experimentally.

METHODOLOGY

RB-SiC with dimensions of 30 mm x 30 mm x 13 mm and a copper electrode with diameter of 6 mm were used as a workpiece material and tool, respectively. The RB-SiC have electrical resistivity of 1453 Ω cm, Young modulus of 407 GPa and Vickers hardness of around 25 to 35 GPa.EDM oil type Low Smell (LS) was used as a dielectric fluid. Four different types of surfactants namely Span 20, Span 80, Span 83 and Span 85 were used in this study. Table-1 shows the chemical properties of these surfactants.

Three types of additives were used in the EDM oil mixture, such as CNF, CNP and CP. The differences between these three additives are their shape and size. CNF is in the form of cylinder and CNP is in a spherical shape. The size for the CNP is around 20-40 nm whereas CP is around 1-30 µm. Figure-1 shows the Field Emission Scanning Electron Microscope (FE-SEM) micrographs of these three additives. In order to prepare the EDM mixture, the required amounts of surfactant, additive and dielectric fluid were measured separately before being mixed together. Initially, the surfactant and EDM oil were mixed through Labsonic ultrasonic homogenizerfor 5 minutes. Afterwards the additive was added into the mixture and subjected to ultrasonication process again for another 30 minutes. In this study, surfactant concentration was kept constant at 0.6wt%. For comparison, the EDM experiment without surfactant in EDM oil also has been carried out.

Sodick AQ35L die-sinking EDM machine was used to perform hole machining in this experiment. Each experimental trial was performed for duration of 15 minutes. Table-2 shows the experimental conditions. After the hole machining, MRR, EWR, surface finish and spark gap were measured. Average of three measurements for each parameter setting was taken.

Table-1. Chemical properties of surfactants.

Properties	**Span 20**	**Span 80**	**Span 83**	**Span 85**
Chemical formula	$C_{18}H_{34}O_6$	$C_{24}H_{44}O_6$	$C_{33}H_{60}O_{6.5}$	$C_{60}H_{108}O_8$
Molecular weight [g/mol]	346.47	428.60	561.00	957.52
Density [g/ml at 25 °C (lit.)]	1.032	0.986	0.989	0.950
Flash point [°F]	>230	>230	>235.4	>235.4
Relative index	n20/D 1.474 (lit.)	*n*20/D 1.48 (lit.)	n20/D 1.478 (lit.)	n20/D 1.476 (lit.)
HLB Value	8.6	4.6	3.7	1.8
Acid value [mgKOH/g]	≤8	≤8	≤13	≤10
Saponification value [mgKOH/g]	158-170	145-160	149 -160	170-190

Table-2. Experimental conditions of EDM.

Working parameter	**Description**
Workpiece Material	Reaction Bonded Silicon Carbide (RB-SiC)
Electrode Material	Copper
Diameter Electrode [mm]	6
Polarity	Positive (Workpiece) Negative (Tool/electrode)
Voltage [V]	22
Peak Current ,Ip [A]	6
Pulse On Time, T_{on} [µs]	10
Pulse Off Time, T_{off} [µs]	40
Machining Time [min]	15
Additive	Carbon Nanofiber (CNF) Carbon Nano Powder (CNP) Carbon Powder (CP)
Surfactant	Span 20, Span 80, Span 83 and Span 85
Concentration of Surfactant [wt %]	0.6

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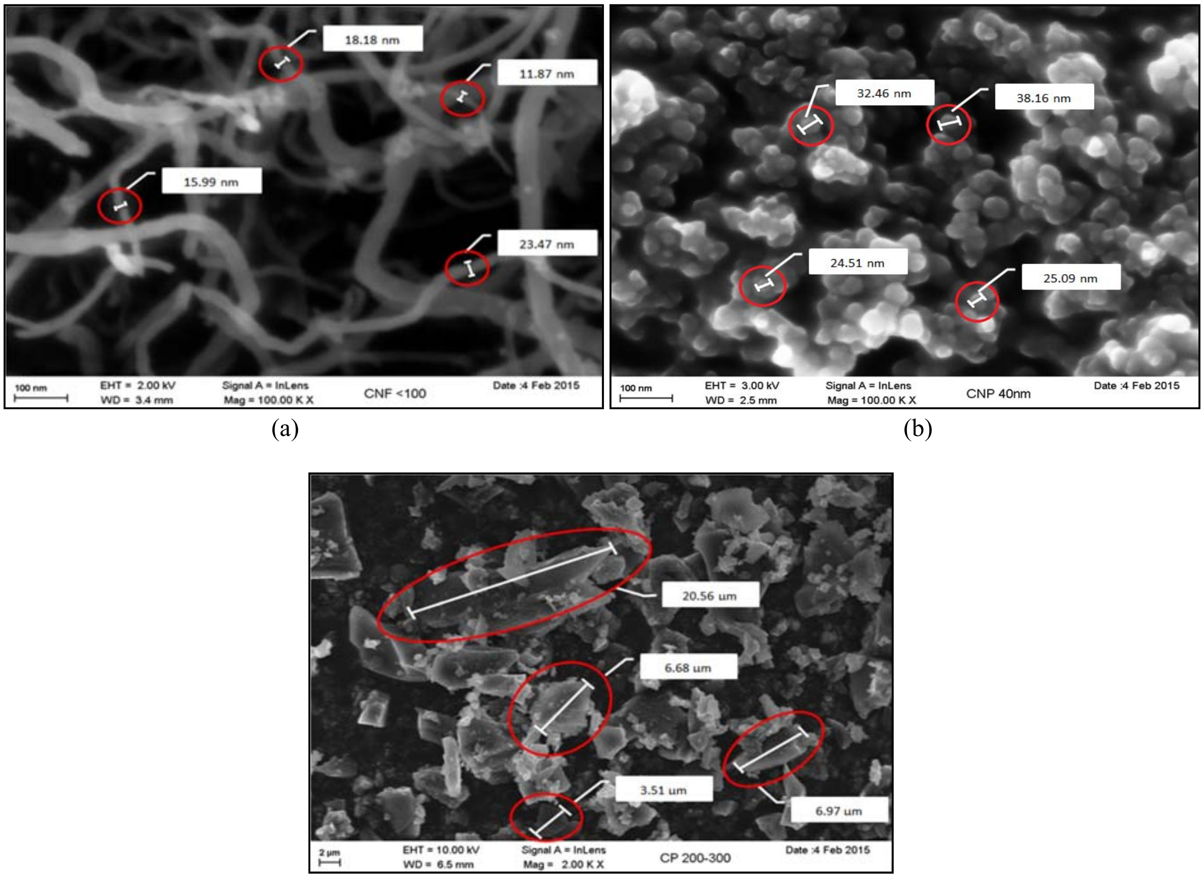

Figure-1. FE-SEM micrographs of different types of additives (a) carbon nanofiber (CNF), (b) carbon nano powder (CNP) and (c) carbon powder (CP).

RESULTS AND DISCUSSIONS

Material removal rate

Figure-2 shows the effect of different types of surfactants for machining RB-SiC with different types of additives. Without the surfactant, the MRR is very low. When the surfactants were added, the MRR improves significantly, especially by using surfactant Span 80. By adding surfactant into dielectric fluid, the conductivity of dielectric fluid, the surface tension, dispersion and dissolubility of particles would be increased, resulting higher material removal rate [17]. Among the additives, addition of CNF into EDM oil increases the MRR rapidly compared to CNP and CP for any type of surfactants. The addition of powder into dielectric fluid helps in bridging the gap between electrode and workpiece, causing higher electro discharge frequency and in turn, higher MRR can be obtained [12, 18]. The cylindrical shape of CNF might easy to interlock which helps to form bridging networks compared to the spherical shape CNP.By comparison, addition of CNP (nano sized) also induced higher MRR compared to the CP which is in micro size. This result is consistent with that reported by Chow et al. [19]. Due to the small machining gap during the EDM process, it is difficult for the large powder to enter the gap between the electrode and workpiece. Therefore, material removal rate is lower by using the micro powder grain size than that of applying nano powder grain size.

Electrode wear ratio

Figure-3 illustrates the effect of different types of surfactants and additives on the electrode wear ratio. It is seen that the EWR is quite high for three additives when surfactant was not added. The EWR dropped when the surfactants were added into dielectric fluid, except for the Span 20 and Span 80 which used the CP as the additive. According to Rehbein *et al.* [20], intense movement of electrons because of small arcs produced during the machining may reverse the direction of the feed to maintain a larger gap and as a consequence, most of the (-ve) ions move easily through the machining gap and results in lower EWR. In terms of additives, it is noticed that EWR is lowest when CNF were added into dielectric fluid compared to CNP and CP. This observation was in good agreement with that reported by Liew *et al*. [12]. The addition of CNF might have prevented the ions produced by the ionization of dielectric fluid hit the tool electrode with high momentum and high energy, which causes rapid erosion of the tool electrode. Moreover, CNP with the smaller size also shows lower EWR compared to the micro

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size CP. This is attributed to the combined effect of a low MRR and a high tool wear by large particles [21].

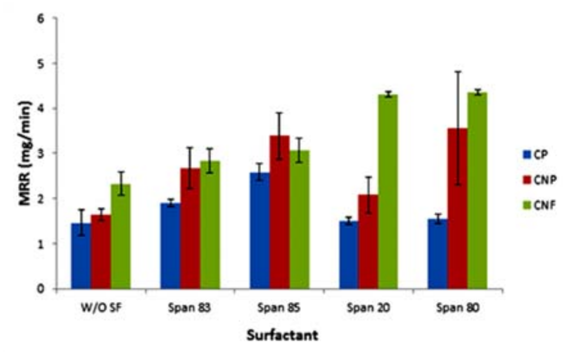

Figure-2. Effect of different types of surfactants and powder on material removal rate (MRR).

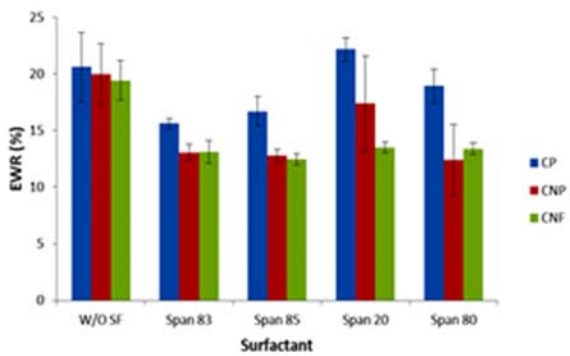

Figure-3. Effect of different types of surfactants and additives on electrode wear ratio (EWR).

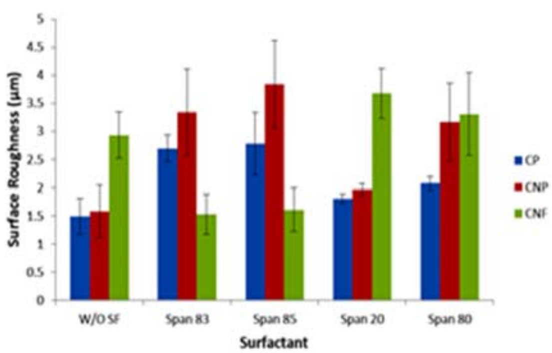

Figure-4. Effect of different types of surfactants and on surface roughness.

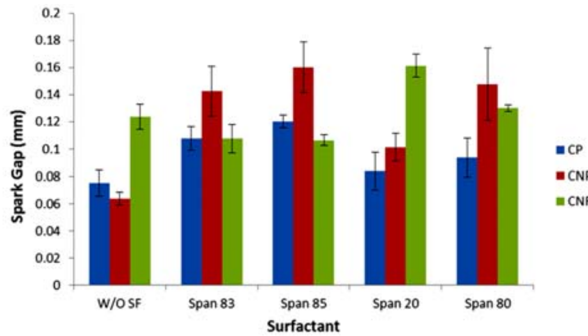

Figure-5. Effect of different types of surfactants and additives powder on spark gap.

Surface roughness

Figure-4 indicates the effect of different types of surfactant and additives on the surface roughness. From the figure, it is clearly seen that the surface roughness is slightly higher when surfactants were added into dielectric fluid, typically by using surfactant Span 85. This result is contradictory with respect to the results of Wu *et al*. [22]. When surfactant is added in the dielectric, the hydrophilic head group will absorb on the surfaces of particles to cause well distribution in the dielectric fluid. Therefore, electrical discharges will be more distributed to perform a better surface roughness on the workpiece. However, in this case, the effect of surfactant in improving surface finish was not significant. By comparing the types of additives, it is seen that also lower surface roughness can be achieved by using CP particles. This might be due to the material is removed little by little (low MRR) by melting and evaporation and cause a decrease in crater size, thus surface finish will be improved.

Spark gap

The effect of different types of surfactants and additives on the spark gap is depicted in Figure 5. When surfactants were used, the spark gap increases significantly. The addition of surfactant might prevent the agglomeration of powders, and cause the powders dispersed well in the dielectric fluid. The addition of powders improves the breakdown strength of dielectric and causes the insulating strength of dielectric fluid to reduce [23]. As a result, a bigger spark gap will be obtained. Moreover, it is worth noting that the highest spark gap could be obtained by using CNF additives and surfactant Span 20. Presumably, when CNF were added into the dielectric fluid, long and thin CNF might be able to bridge the gap between the electrode and workpiece more significantly by interlocking to each other as compared to round-shaped CNP and CP.

CONCLUSIONS

In this study, the effect of different types of surfactants and additives within the EDM oil for machining RB-SiC using the conventional EDM process was investigated and the following conclusions can be drawn:

- Combination of surfactant Span 80 and CNF produce the highest MRR compared to the other types of surfactant and additives.
- The EWR decreases with the addition of surfactant. EWR is lowest when CNF were added into dielectric fluid compared to CNP and CP.
- The improvement of surface finish is not significant with the addition of surfactant into dielectric fluid.
- The highest spark gap can be achieved by using Span 20 and CNF.
- Combination of surfactant Span 80 and CNF is more significant in improving machining efficiency of RB-SiC.

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