Effect of Current and Pulse-on Time on Material Removal Rate and Surface Roughness of Tungsten Carbide in Electric Discharge Machine Die-sinking

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ABSTRACT

The focus of manufacturing for tungsten carbide applications often demands a smooth surface quality as the result of the Electric Discharge Machine (EDM) die-sinking process, especially in the manufacture of die and mold with tungsten carbide material processed using a die-sinking EDM machine. The purpose of this study is to analyze the effect of electric current and pulse-on time on the Material Removal Rate (MRR) and surface roughness of tungsten carbide. Through the experimental method, the parameters varied, namely electric current 17 A, 20 A, 23 A, and pulse-on time 30 µs, 55 µs, and 80 µs. MRR was calculated through weight loss. Surface roughness was obtained from a surface roughness tester and a Scanning Electron Microscope for surface morphology. The results showed that the highest material removal rate was 1.509 mm^3/min at 23 A and 30 µs, and the lowest material removal rate was 0.262 mm^3/min at 17 A and 80 µs. The highest surface roughness value was 4.278 µm at 23 A and 80 µs. The lowest surface roughness value was 2.166 µm at 17 A and 30 µs. The tungsten carbide surface topography results are crater, globule, crack, and porous. The greater the current used, the higher the MRR value and surface roughness. Meanwhile, the greater the pulse-on time used, the MRR value decreases, and the surface roughness increases.

Keywords: *Current, EDM, MRR, pulse-on time, roughness, SEM, tungsten carbide*

I. Introduction

Electric Discharge Machine (EDM) die-sinking is a non-conventional machining process that is widely used in the manufacturing industry. The working principle of a EDM die-sinking machine is a jump of electric sparks in material processing that occurs in the electrode gap with the workpiece [1]. EDM die-sinking machines are commonly used to work very hard metals that cannot be worked using conventional machines [2]. One material that has a very high hardness level is tungsten carbide [3].

In recent years, tungsten carbide has been widely used in the manufacturing industry as cutting tools, dies, and molds because it has the advantage of resistance to wear and very high temperatures [4]. Tungsten carbide has a very high hardness level with a Vickers hardness value of up to 2600 and has a scale rating of about 9 on the Mohs scale, so conventional machining processes cannot be performed properly [5].

Some of these tungsten carbide applications often demand a smooth surface quality as the end result of the EDM die-sinking process [6]. Moreover, in the manufacture of dies and molds with tungsten carbide, which are processed using an EDM die-sinking machine, the

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final result of the surface of the mold cavity determines the product of the mold, therefore surface roughness is very important in the EDM die-sinking process of tungsten carbide [7].

In the current research, surface roughness is related to the Material Removal Rate (MRR) produced on EDM die-sinking machines [8], [9]. Bodukori conducted an MRR analysis and surface roughness on Ti-6Al-4V ELI Titanium Alloy using the EDM die-sinking process. The results showed that increasing the current formed a large and deep crater, resulting in lower surface quality. MRR increased with increasing current strength, and pulse on time had a second effect. Taguchi optimization analysis on MRR and surface roughness in the EDM die-sinking material 17-PH Steel. Process parameters such as current strength and pulse on time significantly affect MRR and surface roughness [10]. In contrast, pulse-off time shows the least significant effect compared to other parameters [11]. The effect of current and pulse-on time on bulk metallic glass (BMG) to MRR showed that increasing the current will result in a higher MRR value and surface roughness, then increasing pulse-on time results in a lower MRR value and higher surface roughness value [12]. Based on previous research, current and pulse-on time affected MRR and surface roughness during EDM die-sinking machining. This study aims to analyze the current and pulse-on time on tungsten carbide during EDM die-sinking machining to contribute more information, especially on the use of tungsten carbide.

II. Material and Methods

Workpiece used was a cylindrical tungsten carbide with a diameter of 10 mm and a length of 75 mm. The electrode used to scrape the workpiece is a copper (Cu) cylinder with a diameter of 15 mm and a length of 100 mm. The surfaces of the workpieces and electrodes were polished using sandpaper to make it easier to determine the reference points between the workpieces and ensure the surface roughness level of each experiment. The C-TEK ZNC 320 EDM machine was used in this study by varying the current and pulse-on time. During the EDM die-sinking machining process, the workpiece gap and electrodes were submerged by Chevron HONILO 409 dielectric fluid. EDM die-sinking machining parameters are shown in Table 1.

Table 1. Parameter of EDM die-sinking

Parameter	Value	Unit
Depth of cut	0.2	mm
Current	17, 20, 23	A
Pulse on time	30, 55, 80	μs
Pulse off time (μs)	4	μs
Gap Voltage (V)	40	V
Jumping	8	mm

MRR was obtained by collecting a mass of the workpiece before and after the EDM die-sinking process was measured using the Optima OPD-E204 digital balance and the working time of the EDM die sinking process. After the three data have been collected, the material removal rate data can be determined by Equation (1).

$$MRR = \frac{W_1 - W_2}{\rho t} \quad (1)$$

where MRR is a Material Removal Rate (mm^3/min), W1 and W2 are the mass of the workpiece before and after machining, respectively, and ρ is the density of the workpiece (0.01563 g/mm^3). A surface roughness tester (Mitutoyo SJ 301) was used to measure the surface roughness value of the workpiece after die-sinking EDM machining. A scanning Electron Microscope (SEM FEI Inspect-S50) was used to evaluate the surface morphology of tungsten carbide after machining.

III. Results and Discussions

1. Effect of Current on MRR and Surface Roughness

The current in the EDM die-sinking machine is used to generate electric sparks that are used to remove the workpiece. The experimental results are shown in Figure 1 by a graph of increasing current to MRR.

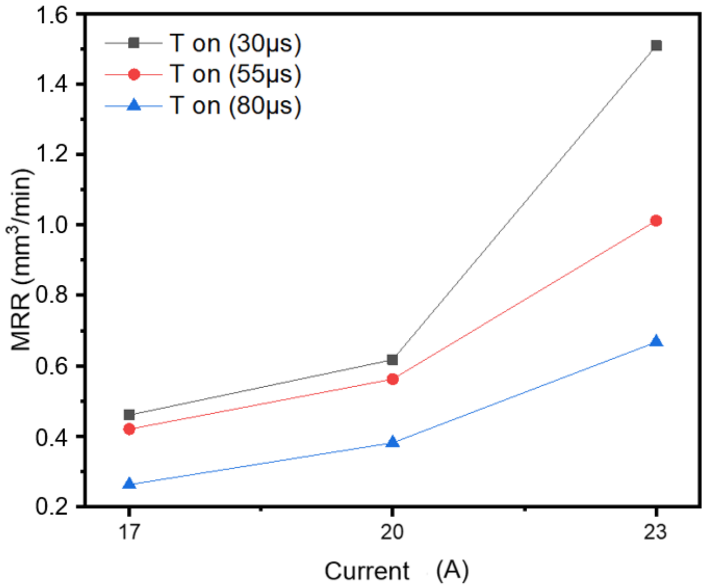


Fig. 1. Effect of Current on MRR

Based on Figure 1, at the current of 17 A with a pulse on time of 30 µs, the MRR is 0.460 mm^3/min. The value of the MRR increases with increasing current with the same pulse-on time until it reaches the highest MRR (1.509 mm^3/min) when using a current of 23 A and a pulse-on time of 30 µs. The greater the current used, the higher the material removal rate obtained. The increase in MRR value also occurs in other current parameters with the same pulse-on time. The highest MRR value was obtained at a current of 23 A, while the lowest MRR value was at 17 A. An increase in amperage is proportional to the increase in MRR. A larger current in the EDM die-sinking process can produce more spark energy between the gap of the workpiece and the electrode resulting in a high-temperature rise [13]. The increase in temperature can melt and vaporize the material quickly to form a crater [14].

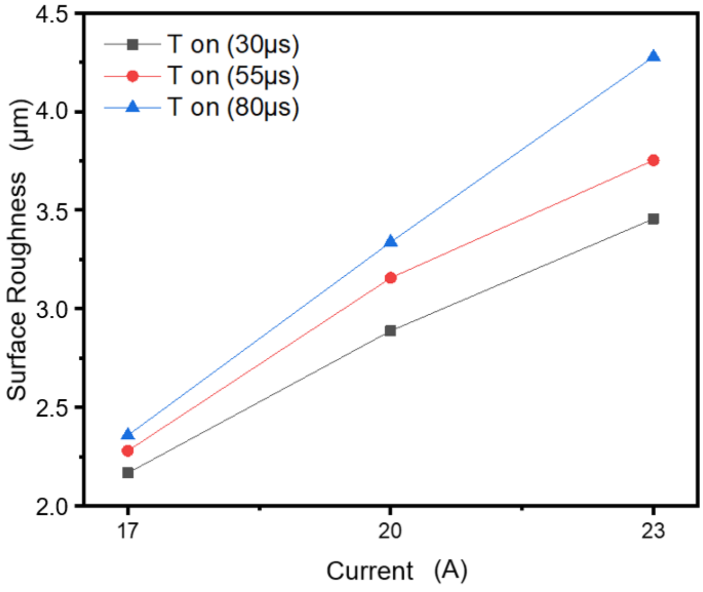
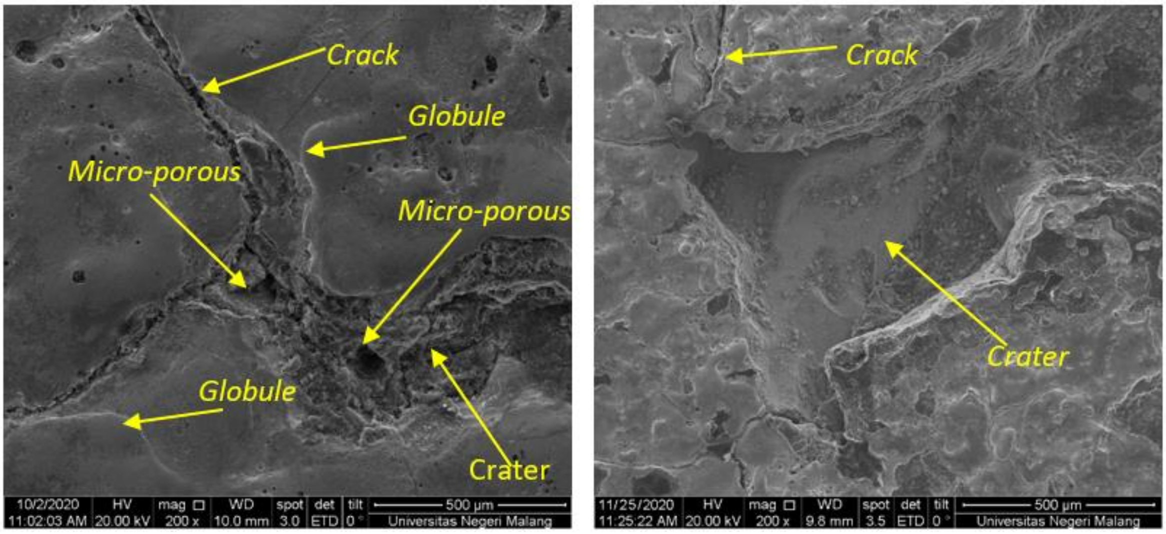


Fig. 2. Effect of current on surface roughness

The experimental results for surface roughness are shown in Figure 2. At a current of 17 A with a pulse-on time of 30 μs, the surface roughness value of 2.166 μm. The average surface roughness (Ra) value increases with increasing current with the same pulse-on time until the highest surface roughness (Ra) (4.278 μm) at 23 A and pulse-on time 80 μs. The higher the current used in the EDM die-sinking machining process, the higher the surface's average roughness (Ra) value so that the quality of the tungsten carbide material surface decreases. An increase in current strength will result in an increase in surface roughness value. After all, an increase in current causes larger craters to form, reducing the surface finish. Good surface quality occurs when the current is low [15].



(a) (b)

Fig. 3. Surface morphology of tungsten carbide at (a) lowest MRR (b) highest MRR

The surface morphology of tungsten carbide that yields the lowest and highest MRR is shown in Figure 3. Figure 3 (a) and (b) show the SEM results at 500x magnification showing the craters, cracks, and porous. Craters are formed from the material removal process when the current generates heat energy and then melts and vaporizes the workpiece [8]. The use of high currents causes the formation of larger craters, can reduce surface quality results, and impact high roughness values. The size of the crater at the highest and lowest MRR is different due to the use of high current, which produces more spark energy [16]. Globules are residual machining particles attached to the surface of the workpiece that is not washed away by the dielectric fluid. Figure 3 (a) shows the surface topography of the lowest MRR, and the globules appear smaller. In Figure 3 (b) the surface topography of the highest MRR, the globules formed appear larger and thicker. The use of high current followed by the use of low pulse-on time causes the melting of the workpiece material to occur faster, or the resulting material removal rate is higher so that the formation of multi-layered globules, in this case with the formation of larger and thicker globules which increases in surface roughness value. In morphology, cracks appeared on the surface [8]. During the machining process, the heat from the spark melts the material's surface, then the melted surface layer is quickly cooled by the dielectric liquid and solidifies again. Because the solidification process is followed by volume shrinkage on the surface of the workpiece, then from this volume shrinkage causes tensile stress, and cracks on the surface of the workpiece are caused by tensile stress that exceeds the material's ultimate tensile strength [17]. Figure 3 shows that the porous is formed because when the heat from the electric sparks generated during the machining process causes the workpiece to melt, at that time, the gas dissolves into the liquid metal. The dielectric liquid quickly cools the liquid metal. The gas that does not escape from the liquid metal is trapped in the material and hardens again [17].

2. Effect of Pulse-on Time on MRR and Surface Roughness

During the EDM die-sinking process, pulse-on time is an electric current discharge cycle between the workpiece gap and the electrode. A graph of the increase in pulse on time to MRR from the experimental results is shown in Figure 4.

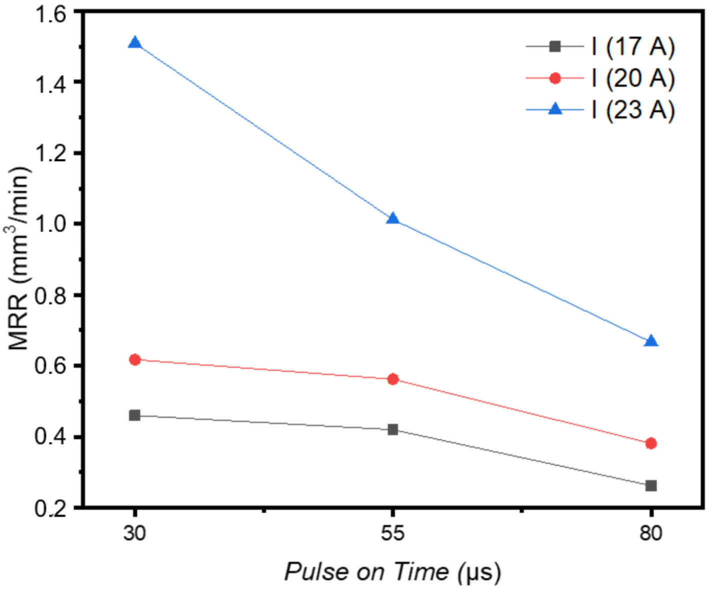


Fig. 4. Effect of pulse-on time on MRR

At a pulse-on time of 30 μs with a current of 17 A, the MRR value is 0.460 mm^3/min. The highest MRR value is obtained using a low pulse-on time of 30 μs, while the lowest

MRR value is obtained using the highest pulse-on time of 80 µs. The MRR value decreases as the pulse-on time increases with the same current. This is because by increasing the pulse on time, the plasma channel formed at the gap between the workpiece and the electrode continues to expand so that when the electric sparks jump, it will inhibit the transfer of heat energy to the surface of the workpiece to erode the workpiece [9] through the dielectric liquid that is able to clean the debris on the surface of the workpiece. As a result, the particles formed from the melting on the surface of the workpiece are not washed away properly. Therefore, the resulting MRR value decreases [18]. In addition, using a lower or shorter pulse-on time will cause more debris between the workpiece gap and the electrode to be removed by the dielectric liquid during the same pulse-off time, resulting in higher MRR values.

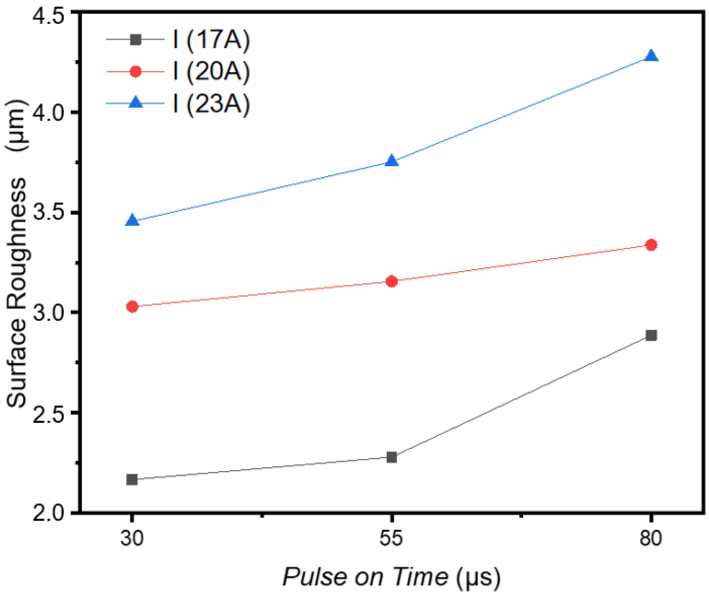


Fig. 5. Effect pulse on time to surface roughness

The graph shows the effect of pulse-on time on roughness in Figure 5. The resulting average surface roughness (Ra) value varies from a range of 2.166-4.278 µm. At a pulse-on time of 30 µs with a current of 17 A produces an average surface roughness value (Ra) of 2.166 µm. This surface roughness value will continue increasing along with the pulse-on time. At a pulse-on time of 55 µs and a current of 17 A, the average surface roughness value (Ra) increased to 2.279 µm, as well as a pulse-on time of 80 µs with a current of 17 A which increased the surface roughness value by 2.887 µm. The average surface roughness value (Ra) increases at other larger pulse-on-time values with the same current value. The lowest average surface roughness (Ra) value occurs when using a pulse on time of 80 µs and a current of 17 A of 2.166 µm, while the highest average surface roughness (Ra) value is 4.278 µm, which is at a pulse on time of 80 µs and 23 A. The higher the pulse-on time used in the EDM die-sinking machining process, the higher the average surface roughness value (Ra) so that the quality of the tungsten carbide material surface decreases. The electric sparks during the EDM die-sinking process last longer, so the greater the heat energy for melting and vaporizing the material, thus the larger and deeper the crater produced, resulting in high surface roughness.

IV. Conclusions

Experiments were conducted on the effect of current and pulse-on time on MRR and surface roughness of tungsten carbide during EDM die-sinking machining. Based on the results, an increase in electrical current caused an increase in MRR value and surface roughness. Increased pulse-on time affects the low MRR value and high surface roughness. In tungsten carbide surface morphology, crater, globule, crack, and porous were found.

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