

Effects of WEDM Process Parameters on Surface Roughness and Material Removal Rate of Brass Alloy

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Abstract—The aim of this investigation is to study the effect of process parameters of Wire Electrical Discharge Machining (WEDM) on surface roughness (R_a) and material removal rate (MRR) of brass alloy. Different machining parameters like pulse-on time, pulse-off time, peak current and servo voltage were used for conducting the experiments. Chemical analysis of the workpiece material revealed that it was a brass alloy with an average Cu content of around 58.7 %. The surface roughness tester was used for the measurement of surface roughness and MRR was calculated by weight loss method. Experimental results showed that machining parameters have significant effect on R_a and MRR. The MRR improved with increasing pulse on time and current but the surface quality was adversely affected. The study gives useful insights to select the suitable machining conditions to improve the WEDM performance of brass alloy.

Keywords—WEDM; Brass alloy; surface roughness; material removal rate; Machining Parameters

I. INTRODUCTION

Wire Electrical Discharge Machining (WEDM) is an advanced non-traditional machining process used for the manufacturing of electrically conductive materials with high dimensional accuracy and good surface quality. Material is removed by a series of controlled electrical discharges between a continuously moving wire electrode and the workpiece without direct contact. Each spark generates a very high localized temperature, inducing melting and partial vaporization of the workpiece material. The dielectric fluid removes the molten material and cools the machining zone, reestablishing the insulating conditions for the subsequent discharges [1]. Figure 1 shows a schematic diagram of wire EDM.

The stability of electrical discharges and efficient removal of debris strongly influence the machining performance, particularly the surface roughness (R_a) and material removal rate (MRR). Therefore, pulse-on time (T_{on}) and pulse-off time (T_{off}) are among the most important machining parameters affecting discharge energy and surface quality. WEDM is widely used in aerospace, automotive, biomedical, and precision engineering

applications due to its high precision and capability to machine complex conductive materials [3-6].

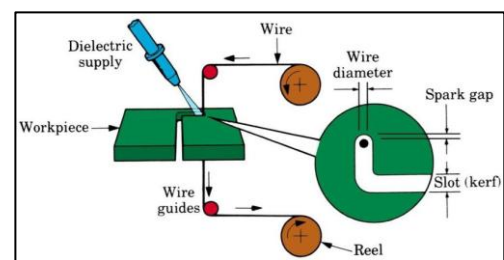


Fig. 1. Schematic diagram of wire EDM [2]

Brass are widely used in industrial applications due to their good machinability, corrosion resistance, and electrical conductivity. However, machining of brass alloy using WEDM requires proper selection of process parameters to achieve better machining performance and surface quality [7].

The [8] studied the optimization of WEDM parameters for brass machining. The objective of this study was to investigate the effect of discharge current, voltage, wire speed and wire tension on the machining performance. The results showed that the material removal rate increases with the increase of discharge current, but simultaneously the spark gap increases and the surface roughness decreases with the increase of the workpiece thickness. Moreover, it was found that the brass wire of 90% Cu and 10% Zn exhibited the best machining performance and surface quality.

The [9] study optimized the WEDM process of Inconel 718 using zinc diffused coated brass wire to maximize material removal rate (MRR) and minimize kerf width and surface roughness (R_a). It was found that the pulse-off time was the most significant parameter affecting the machining quality because it was responsible for dielectric deionization. The optimum conditions were found at $P_{on} = 140 \mu s$, $P_{off} = 50 \mu s$, $SV = 60 V$, and $WT = 5 kg$.

The effect of discharge current, pulse-on time (P_{on}), and pulse-off time (P_{off}) on the machinability of Inconel 718



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during WEDM has been investigated [10]. The results show that the material removal rate (MRR) increases with increase in discharge current and Ton, but the surface roughness also increases due to the increase in discharge energy. Increasing P_{off}, however, helped to improve the surface quality by reducing surface roughness. The best machining conditions were found to be 2 A discharge current, 40 μ s P_{on}, and 9 μ s P_{off}.

The [11] investigated the surface roughness (Ra) during WEDM of aluminum matrix composites reinforced with silicon carbide (SiC) and molybdenum disulfide (MoS₂). Analyzing the impact of important WEDM process parameters on surface quality and machining performance was the primary goal of the study. The findings showed that pulse-off time had the biggest impact on surface roughness.

The [12] study was conducted to evaluate the effect of WEDM parameters on the machining performance of AISI 1012 steel. The results showed that pulse-on time has the maximum effect on increasing the MRR and surface roughness, and the surface finish was improved with higher pulse-off time at the expense of machining efficiency.

Most of the previous WEDM studies have focused on optimizing the machining parameters for different materials, but not much attention has been paid to evaluating the variation in surface roughness between the two machined surfaces of brass under the same cutting conditions. Therefore, further study is needed to understand the effect of pulse-on and pulse-off times on surface quality and material removal behavior of brass.

II. MATERIALS AND METHOD

A. Workpiece Material

The workpiece material used in this work was a brass alloy. The chemical composition analysis confirmed that the alloy consists of about 58.7% copper, and the rest is mainly zinc with trace elements. Table (1) displays the alloy's chemical composition. The specimens were circular discs with a diameter of 100 mm and a thickness of 10 mm.

Table 1. Chemical Composition of Brass

Element	Fe	Cu	Zn	Pb
Composition (%)	0.4	58.7	38.2	2.5

B. WEDM Machine

HighTech EDM machine model DK77H, made in China shown in Fig. 2 used in this study. Available at the Department of Mechanical Engineering, University of Mosul.

Mechanical fixtures were used for mounting the workpiece on the machine, as shown in Fig. 3. The molybdenum wire with a diameter of 0.18 mm was used for the cutting procedure, and its chemical composition is illustrated in Table 2.



Fig. 2. Wire cut EDM for experimental

The dielectric medium of dielectric fluid and deionized water was used during the cutting process. The chemical composition of the dielectric medium is listed in Table (3). The dielectric fluid was mixed with deionized water in a 1:40 ratio, as stated in the machine producer's catalogue. Machine settings were taken from the computer screen, as shown in Fig. 4, where they were set.

Table 2. Chemical Composition of Wire Cut Material

Element	Composition (%)
Mo	99.95
Ni	0.0006
Mg	0.0006
Fe	0.001
Pb	0.0006
Al	0.003
Bi	0.006
Si	0.003
Ca	0.0006
Cu	0.0006
C	0.001
O	0.005
Sb	0.0006
P	0.001

Table 3. Chemical Composition of Dielectric Fluid

Name of compound		
H ₂ O,	Polyethylene Glycol	
(PEG-400),	Glycerol	
Sodium lauryl sulfate (SLS),		
Polysorbate 20 (Tween 20)		
Mineral oil, Olive oil, Castor oil		
NaNO ₂ , Zn salts		

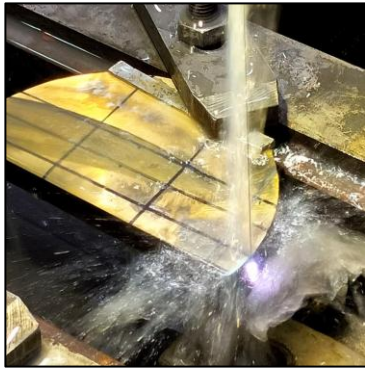


Fig. 3. The workpiece mounted on the machine.

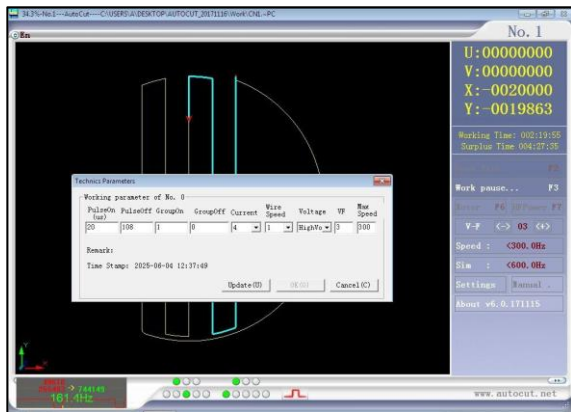


Fig. 4. Operating machine settings.

C. Machining parameters

The following parameters were changed:

- 1) Pulse-on time (T_{on})
- 2) Pulse-off time (T_{off})

The following parameters were unchanged:

- 1) High Voltage: 36 V
- 2) Table speed with workpiece: 300HZ
- 3) Vibration Factor, V-F speed: 3
- 4) Drum speed: 1200 RPM
- 5) Servo Rate (Gap): 0.05 mm
- 6) Current: 4 A
- 7) Wire tension: 11.32 N. As shown in figure 5.

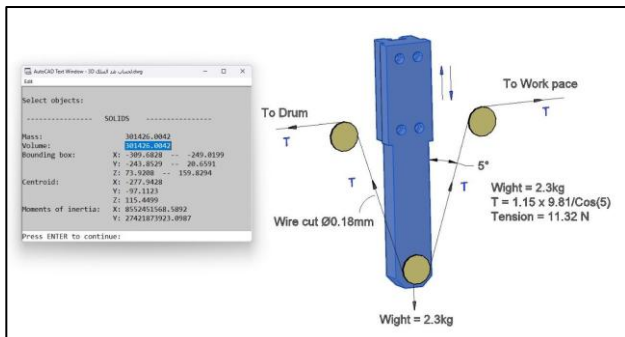


Fig. 5. Tension of wire

For each of the five lines, the material was cut into three pieces. Pulse off time P_{off} was varied for each pass in Figure 6, while pulse on time P_{on} was constant.

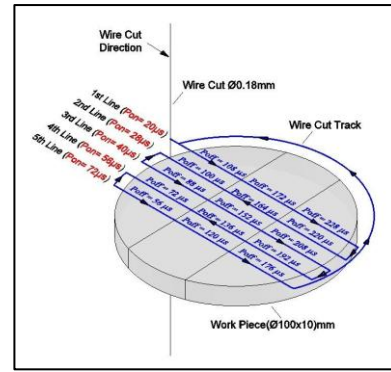


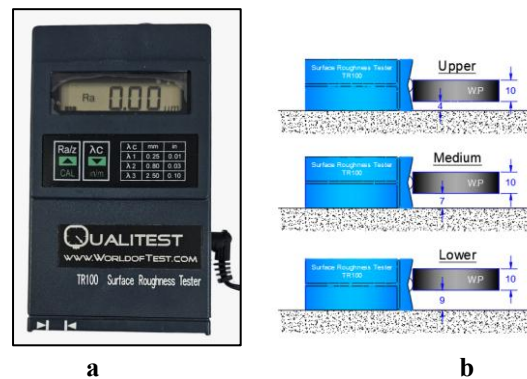
Fig. 6. size of materials with machine parameters

D. Measuring Surface Roughness

Surface roughness (R_a) was measured using the surface roughness tester model (Qualities) as shown in Figure (7a). The measurements were performed using a cut-off length (λ_c) of 2.50 mm and an evaluation length of 5.0 mm. Each specimen was measured three times (upper, medium, and lower), and the mean value was recorded, as illustrated in Figure (7b).

The Roughness Average, or R_a : The surface roughness parameter most commonly used in research and engineering applications. It is the arithmetic mean of the absolute deviations of the surface profile from the mean line within the measured sample's evaluation length.

Mean Roughness Depth (R_z): Is the average height difference between the five highest peaks and the five lowest valleys over the measured sampling length. It displays the vertical separation between the highest and lowest points on the surface profile, and R_z eventually yields higher quantities than R_a due to its distinct focus on valley-to-peak differences rather than the usual standard deviation.

Fig. 7 a- Surface Roughness Tester – TR100 (Qualitest), b- three different positions to measuring (R_a) for each section part

E. Material Removal Rate (MRR)

The material removal rate (MRR) equation was used to evaluate machining efficiency by determining the amount of material removed per unit time [13].

$$MRR \left(\frac{mm^3}{min} \right) = \left[\frac{W_{before} - W_{after}}{\rho \cdot t(min)} \right] * 10^9 \quad (1)$$

Where:

W_{before} : Weight before cutting (kg)
 W_{after} : Weight after cutting (kg)
 ρ : Density (kg/m^3)
 t : time (sec)

Figure 8 shows a theoretical calculation of weight. The volume of the brass specimen before and after the cutting process was calculated using the AutoCAD Mass Properties tool. The equivalent weights before and after cutting were then calculated by multiplying each calculated volume by the density of brass.

Density of brass alloy (kg/m^3) = 8500 kg/m^3

Disk Volume Before = 79485.1216 mm^3

Disk Volume After = 78520.3316 mm^3

Weight before cutting = 0.675 kg

Weight after cutting = 0.667 kg

The theoretical approach was chosen because the removed material volume was very small and therefore the weight measurement by direct weighing was impacted by measurement errors, whereas the calculations based on the geometric dimensions and the density of the material give more reliable and consistent results.

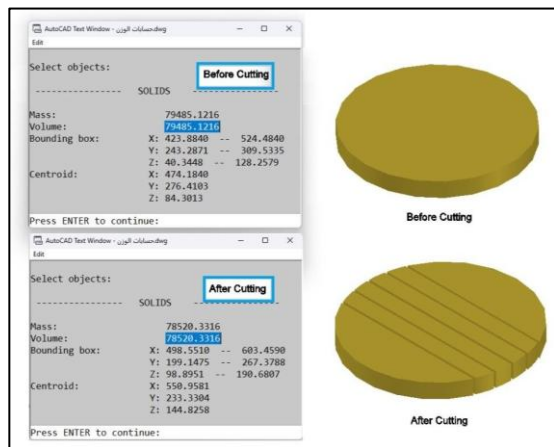


Fig. 8. Theoretical calculation of the workpiece weight

F. Hardness Test

Hardness of brass specimen was measured by hardness machine, as shown in figure 9, available at Metallurgy Laboratory, Department of Mechanical Engineering, University of Mosul. The hardness measured was 53 HRB at load 100 kg and ball diameter $1/16$ ".



Fig. 9. Hardness tester machine

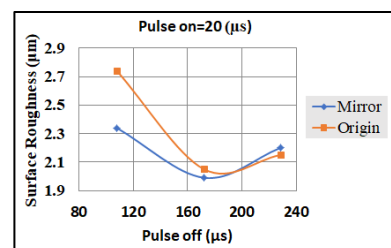
III. RESULTS AND DISCUSSION:

1. Effect of WEDM Parameters on Surface Roughness

Experimental results show that pulse-on time has a significant effect on the surface roughness of brass alloy. Table (4) shows the surface roughness (R_a) measurement results for the brass alloy under different machining conditions. The results revealed that the increase of pulse-on time (P_{on}) increased surface roughness. That is due to the fact that the discharge energy is higher for longer pulse durations and therefore more thermal energy is generated at the machining zone. Thus, more material is melted and vaporized, leading to deeper and wider ablation craters, which contribute to surface irregularities and to the measured surface roughness. The results show that the difference in surface roughness between the two cutting surfaces stems from the direction of wire motion and the uneven distribution of spark energy. The wire origin side generally has more stable discharges and better debris flushing. The mirror side tends to deposit molten particles and debris. Figure 8 shows the trend of surface roughness on the two sides of wire cutting with different pulse-off values at a constant pulse-on for each case.

Table 4. Surface Roughness (R_a , R_z) Measurement

P_{on} (μs)	P_{off} (μs)	R_a (μm)		R_z (μm)	
		Mirror	Origin	Mirror	Origin
20	108	2.34	2.74	17.733	20.9
20	172	1.99	2.056	14.866	15.6
20	228	2.206	2.156	15.466	14.833
28	100	2.69	3.196	20.8	23.4
28	164	2.12	2.35	18.1	21.2
28	220	2.756	2.436	18.333	18.2
40	88	3.116	3.473	24.433	24.366
40	152	2.226	2.496	18.8	15.666
40	208	2.756	2.63	19.566	20.2
56	72	3.466	3.723	21	26.8
56	136	2.366	2.63	17.133	19.2
56	192	2.99	2.78	25.6	17.033
72	56	3.57	4.02	32.233	26.333
72	120	2.596	2.97	18.266	19.7
72	176	3.273	2.826	23.5	22.633



(a)

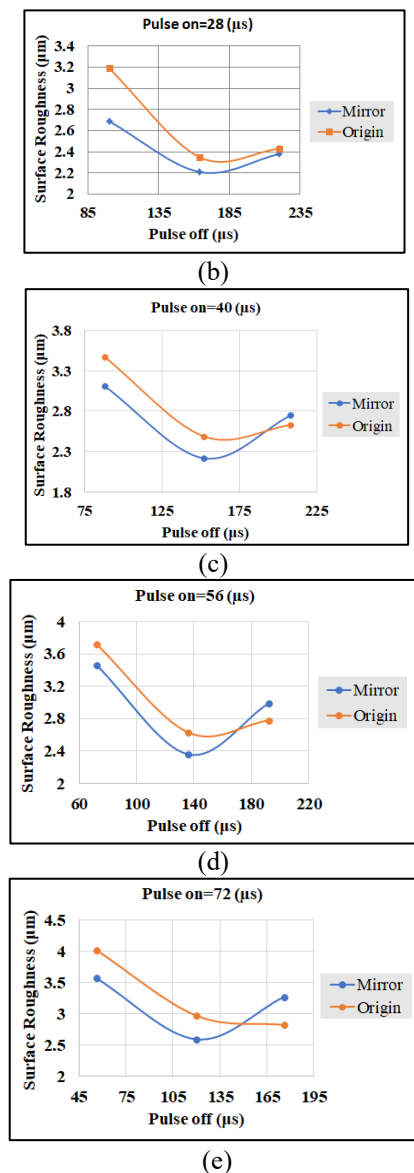


Fig. 8 (a-e) the behavior of surface roughness on two sides of wire cutting with different pulse off at constant pulse on for each case

2. Effect of WEDM Parameters on Material Removal Rate

Table (5) shows material removal rate (MRR) measurement for the brass alloy. Figure 9 shows the effect of pulse on time and pulse off time on the surface roughness, material removal rate and machining time, it was observed that the material removal rate (MRR) decreased with increase in machining time. This is due to the more eroded and molten debris accumulates in the machining gap over longer machining times, which leads to a decrease in the stability of the discharge and the efficiency of the energy transfer and therefore to a decrease in the rate of material removal. It is observed that the surface roughness (Ra) increases with increase in machining time. This behavior is explained by the accumulation of thermal energy and the long action of the electrical discharges that favor the formation of larger molten craters that give a rougher machined surface.

The histogram analysis shows that the optimum machining condition to maximize the material removal rate (MRR) of the investigated brass alloy was at a pulse-on time (P_{on}) of 28 μs and a pulse-off time (P_{off}) of 100 μs with a maximum MRR of 10.568 mm^3/min with a corresponding machining time of 89.05 min. The excellent machining performance can be attributed to the optimum trade-off between the discharge energy in pulse-on period and dielectric recovery in pulse-off period.

These conditions generated sufficient thermal energy to allow the effective melting and vaporization of the work piece material. The chosen pulse-off time provided sufficient debris removal and dielectric deionization for stable spark generation during the machining process. Therefore, this combination of machining parameters gave the best conditions to maximize the MRR of the investigated brass alloy under the present experimental conditions. [3,14].

The above parameters provided maximum machining productivity. The optimum conditions for surface roughness are not necessarily the same as for the maximum MRR, which indicates that there is a trade-off between machining productivity and surface integrity in the WEDM process.

Table 5. Material Removal Rate Measurement

P_{on} (μs)	P_{off} (μs)	Time total (min)	MRR. (min^3/min)
20	108	131.3425	7.16582
20	172	345.5135	2.723993
20	228	541.7877	1.737168
28	100	89.05263	10.56877
28	164	244.7387	3.845637
28	220	371.0526	2.536504
40	88	86.37838	10.89597
40	152	215.9459	4.358389
40	208	331.1171	2.842428
56	72	74.21053	12.68252
56	136	259.1351	3.631991
56	192	415.5789	2.264736
72	56	65.67123	14.33164
72	120	302.3243	3.113135
72	176	459.6986	2.047377

I. CONCLUSION

- There is a discernible difference in surface roughness between the two cutting surfaces, and surface roughness rises with increasing pulse on time (P_{on}). The difference between the two machined surfaces is due to the difference in the movement of the wire and the direction of the flow of the dielectric during the cutting process that leads to secondary discharges and hence the formation of a rougher surface than the other surface.

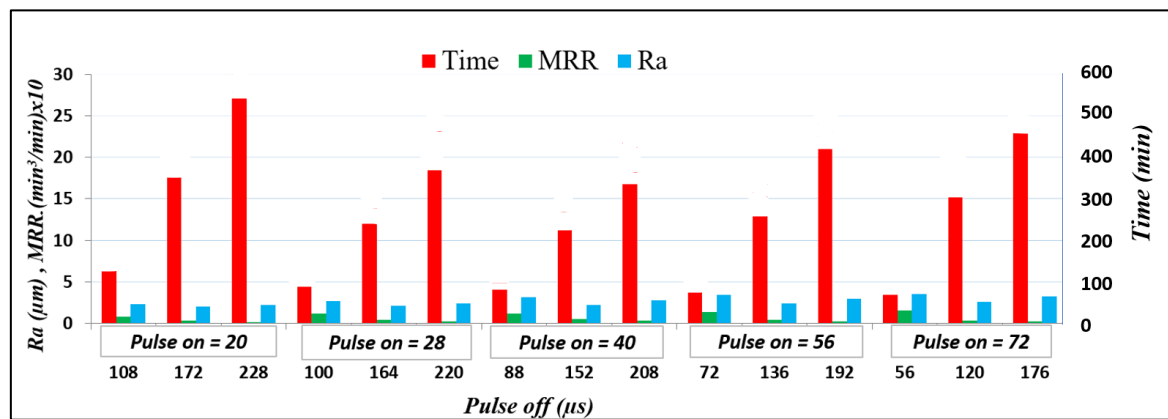


Fig. 9. Effect of pulse on time and pulse off time on the surface roughness, material removal rate and machining time

- The surface roughness of brass increased with increasing pulse-on time due to higher discharge energy, which produced larger and deeper craters on the machined surface. Increasing pulse off time improved debris removal and stabilized the discharge process, which led to less surface roughness.
- The original side's minimum surface roughness value was $2.056 \mu\text{m}$, while the mirror cutting side's minimum value was $1.99 \mu\text{m}$ at ($P_{\text{on}} = 20 \mu\text{s}$ and $P_{\text{off}} = 172 \mu\text{s}$).
- The results indicated that the MRR is inversely proportional to the machining time. Higher machining time results in lower MRR, whereas shorter machining time results in higher material removal rate, this is due to the accumulation of debris in the discharge gap that causes unstable sparks and reduces the effective energy required for material removal. (The minimum MRR = 1.7372 at a time = 541.7877).
- The results show that for various fixed pulse-on times (P_{on}), pulse-off time (P_{off}) significantly affects surface roughness (Ra) and material removal rate (MRR). To attain the best possible balance between surface quality and machining efficiency, a proper combination of P_{on} and P_{off} is required.

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