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The Effect of Edm Die-sinking Parameters on Material Removal Rate of Beryllium Copper Using Full Factorial Method

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Abstract: The effect of electrical discharge machining (EDM) die-sinking parameters on material removal rate (MRR) of Beryllium Copper (BeCu) was studied. EDM die-sinking is one of the important non-traditional machining processes and it is widely accepted as a standard machining process in the manufacturing of forming tools to produce mould and die. The appropriate parameters were selected to study the influence of operating parameters of BeCu on MRR. Electrolytic copper was selected as electrode with positive polarity. The experiment was done using SODICK AQ35L EDM machine. Two level approach of full factorial design of experiment was applied to design the experimental and the data was analyzed by using analysis of variance (ANOVA) and the optimal combinations of the process parameters were predicted. It is found that peak current was the most significant factor affecting the MRR. Further, pulse on time and pulse off time must be combined with other factors in order to influence the machining characteristics. Finally, machine voltage shows less significant factor for the EDM die-sinking process on BeCu.

Key words: EDM die-sinking · Material removal rate · Full factorial · Beryllium copper · Process optimization

INTRODUCTION

Electrical Discharge Machining (EDM) die-sinking is one of the most popular non-traditional material removal processes and has become a basic machining method for the manufacturing industries especially in mould and die making [1-7]. Machining at critical area such as machining at deep slot, micro hole and pocketing having sharp edge, EDM die-sinking is the most preferred method rather than using conventional machining [8-12].

It was known that Beryllium Copper (BeCu) is used in mould and die making for its high strength as well as good electrical and thermal conductivity. According report by Sagar [13], BeCu alloys usually used as an insert in mould to remove heat from the plastic as quickly as possible. The faster the mould can transfer heat out of the molten plastic and solidify it, the faster the mould can be run. It will reduce the cycle time that equates to reduced manufacturing cost. Since BeCu has a great function in mould making, the best combination of machine parameters should be studied to produce an optimum result on the EDM die-sinking machining process.

It was noticed that various EDM die-sinking machining parameters influence material characteristics such as material removal rate, electrode wear rate and surface roughness. The setting possible combination of those parameters was difficult to produce optimum surface quality [14-17]. Therefore, a comprehensive study using design of experiment (DOE) of the effect of EDM die-sinking parameters such as peak current, machine voltage, pulse duration and interval time on the machining characteristic is greatly significant and could be necessity [18-23].

In this study, the effect of machining parameters on machining characteristics, i.e., material removal rate of BeCu alloys in EDM die-sinking was studied.

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Table 1: Experimental parameters setting for EDM die-sinking

Factor		Parameter -------- Low (-1)	Level -------- High (+1)
A	Peak Current (A)	5	30
B	Machine Voltage (V)	10	45
C	Pulse On Time (µs)	5	200
D	Pulse Off Time (µs)	10	300

Further, the design of experiment using Full Factorial was used to investigate the influence of EDM die-sinking parameters on machining characteristic of BeCu.

Experimental Set-Up: BeCu was used as a workpiece material for this study and electrolytic copper with size 12 mm (width) x 12 mm (length) x 32 mm (height) was selected as electrode. Bridge Port milling machine with maximum speed 4200 rpm was used to prepare the electrode and workpiece samples. The size of BeCu workpiece was 50 mm (width) x 50 mm (length) x 5 mm (height). SODICK AQ35L EDM machine was selected to perform the machining and peak current, machine voltage, pulse on time and pulse off time were selected as the parameters set-up. Kerosene oil was used as dielectric fluid while machining characteristics to be investigated were material removal rate (MRR) and surface appearance. Mitutoyo weighing scale was used to get the weight of workpiece for calculation of MRR. Further, surface crater was captured by Mitutoyo digital imaging microscope. With the help of design expert software to analyze the result, full factorial design was selected and analysis of variance (ANOVA) was employed to evaluate the data.

Table 1 shows the selected parameters performed for this study with working levels. The design of experiment (DOE) of the design factor in Full Factorial method was employed for experimental design. Four factors and two levels were used in this experiment.

There are 16 running processes and 2 centre points were performed from the equation of full factorial design. The equation of full factorial design is stated in Equation 1.

$$\text{Full Factorial Equation} = 2^k \quad (1)$$

where k denotes as the number of factors, i.e., peak current, machine voltage, pulse on time and pulse off time, being investigated in this experiment and 2 is the level of experiment, i.e., low (-1) and high (+1). The analysis of ANOVA is employed in order to indicate the mathematical models of EDM machining characteristic using design expert software version 6.

RESULTS AND DISCUSSIONS

Material Removal Rate: Table 2 shows the summarization of the data that was collected for this experiment. The measurements of weight were taken by using weighing scale while the time of processes were taken from the screen monitor of machine after each machining.

Table 2: Experimental data collection of MRR

Run	Factor A Peak Current (A)	Factor B Machine Voltage (V)	Factor C Pulse On Time (µs)	Factor D Pulse Off Time (µs)	MRR (g/min)	Remarks
1	17.5	27.5	102.5	155	0.1549	Centre point
2	5	10	200	10	0.0293	
3	30	10	5	10	0.1250	
4	17.5	27.5	102.5	155	0.1493	Centre point
5	5	10	5	10	0.0063	Lowest MRR
6	30	10	5	300	0.1463	
7	5	10	200	300	0.0185	
8	30	45	200	300	0.1431	
9	30	45	200	10	0.1347	
10	30	10	200	300	0.1141	
11	30	45	5	300	0.1538	
12	5	45	200	10	0.0129	
13	30	45	5	10	0.1565	
14	30	10	200	10	0.1613	Highest MRR
15	5	45	5	300	0.0136	
16	5	10	5	300	0.0160	
17	5	45	5	10	0.0387	
18	5	45	200	300	0.0331	

Table 3 ANOVA analysis for material removal rate

Response: MRR

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	0.058	5	0.012	225.04	< 0.0001	significant
A	*0.056*	*1*	*0.056*	*1082.48*	*< 0.0001*	
B	*4.796E-004*	*1*	*4.796E-004*	*9.24*	*0.0113*	
BC	*4.666E-004*	*1*	*4.666E-004*	*8.98*	*0.0121*	
ACD	*2.576E-004*	*1*	*2.576E-004*	*4.96*	*0.0478*	
BCD	*1.014E-003*	*1*	*1.014E-003*	*19.53*	*0.0010*	
Curvature	8.593E-003	1	8.593E-003	165.47	< 0.0001	significant
Residual	5.713E-004	11	5.193E-005			
Lack of Fit	*5.556E-004*	*10*	*5.556E-005*	*3.54*	*0.3932*	*not significant*
Pure Error	*1.568E-005*	*1*	*1.568E-005*			
Cor Total	0.068	17				

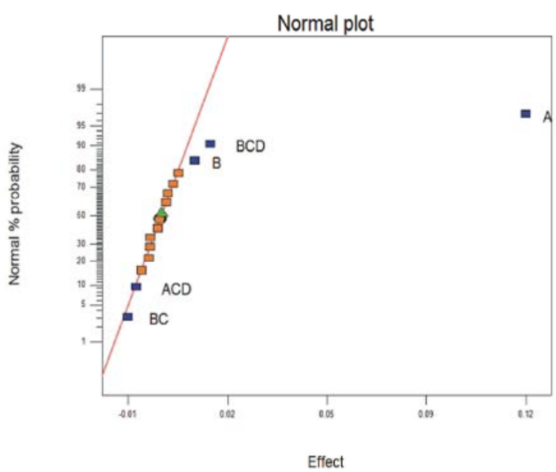


Fig. 1: Normal probability plot for material removal rate

It is found that sample 14 shows the highest MRR with 0.1613 g/min while sample 5 shows less MRR with 0.0063 g/min. As seen in Equation 2, the MRR value was determined using this equation.

$$MRR = \frac{wa - wb}{tm} \text{ (g/min)} \quad (2)$$

where:

Wa = Material weight before machining

Wb = Material weight after machining

tm = Machining time

Analysis of Variance (ANOVA) for MRR: The Analysis of Variance (ANOVA) is to be carried out to examine the influence of process parameters on the machining characteristic of BeCu. Based on ANOVA analysis of MRR in Table 3, it can be seen that the model is significant with probability, Prob>F value between 0.0001 to 0.0478 less than 0.05. It shows that Factor A peak current, Factor B machine voltage and interaction between Factor BC, ACD and BCD are significant at 99 percent.

Figure 1 is clearly support the ANOVA analysis identified the significant factor where Factor A peak current is the most far away from normal plot following by Factor B machine voltage. From the analysis, it shows that the most significant parameter in EDM die-sinking process of BeCu is peak current rather than the machine voltage.

Factor C pulse on time and Factor D pulse off time must be combined with Factor A peak current and Factor B machine voltage to influence the MRR as shown in Figure 1. It shows that Factor C pulse on time and factor D pulse off time cannot stand alone as compare to Factor A peak current and Factor B machine voltage.

Figure 2 shows one factor plot with centre point parameters; Factor A peak current 17.5 A, Factor B machine voltage 27.50 V, Factor C pulse on time 102.50 µs and Factor D pulse off time 155 µs. Based on main effects for MRR, it shows that when peak current increases the value of MRR is also increased dramatically. Meanwhile, the increasing of value MRR in machine voltage is almost flat. It means that factor A peak current is the most significant factor for MRR.

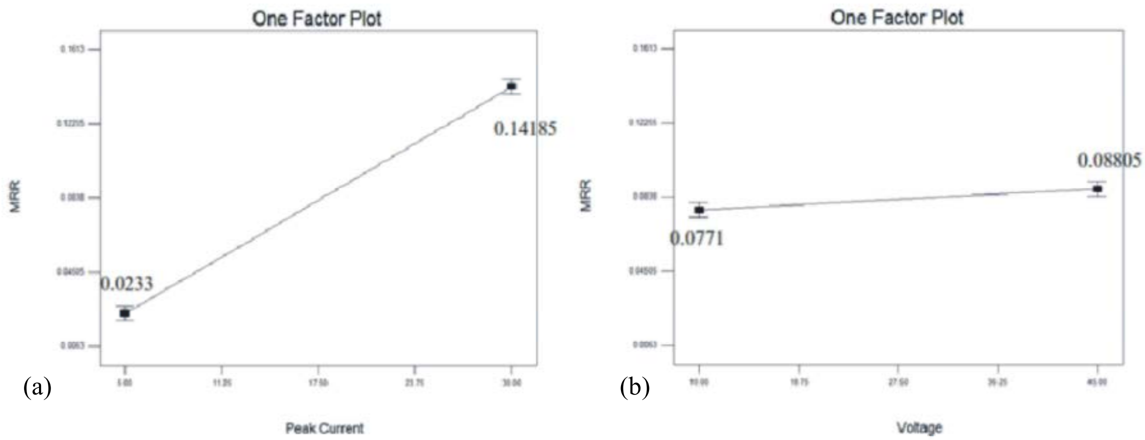


Fig. 2: One factor plot (a) Factor A peak current and (b) Factor B machine voltage dependence of material removal rate

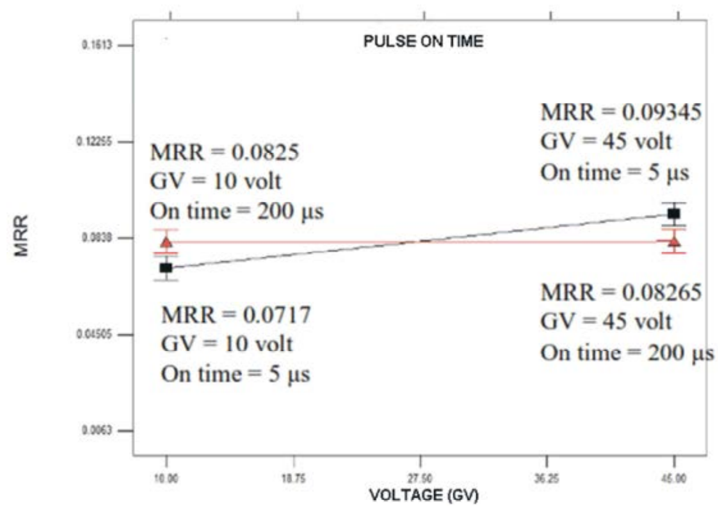


Fig. 3: Interaction graph of Factor B machine voltage and Factor C pulse on time for material removal rate

Based on Figure 3, interaction between Factor B machine voltage and Factor C pulse on time is significant with respect to MRR. In order to get a maximum value of MRR which is 0.09345 g/min, the Factor B machine voltage is set at high level 45 V and Factor C pulse on time is set at low level 5 µs. Meanwhile, for minimum value of MRR which is 0.0717 g/min, both of Factor B machine voltage and Factor C pulse on time is set at low level value which is 10 V and 5 µs respectively.

Verification of Mathematical Model: Verification of mathematical models for each response was performed in order to ensure whether the predicted value that given by software is correct or not. Calculation was carried out using the equation given by software. The calculation was based on the parameters used in the confirmation test in running on sample 2 as shown in Table 2.

Verification on MRR equation in term of coded factor generated by design expert software is shown in Equation 3.

$$MRR = 0.083 + 0.059 \text{ x } A + 5.475\text{x}10^{-3} \text{ x } B - 5.475\text{x}10^{-3} \text{ x } B \text{ x } C - 4.013\text{x}10^{-3} \text{ x } A \text{ x } C \text{ x } D + 7.963\text{x}10^{-3} \text{ x } B \text{ x } C \text{ x } D \quad (3)$$

where:
Factor A = -1, B = -1, C = +1, D = -1

Hence;

$$MRR = 0.083 + 0.059 \text{ x } (-1) + 5.475\text{x}10^{-3} \text{ x } (-1) - 5.475\text{x}10^{-3} \text{ x } (-1) \text{ x } (+1) - 4.013\text{x}10^{-3} \text{ x } (-1) \text{ x } (+1) \text{ x } (-1) + 7.963\text{x}10^{-3} \text{ x } (-1) \text{ x } (+1) \text{ x } (-1)$$

$$MRR = + 0.083 - 0.059 - 0.005475 + 0.005475 - 0.004013 + 0.007963 \quad MRR = 0.0279 \text{ g/min}$$

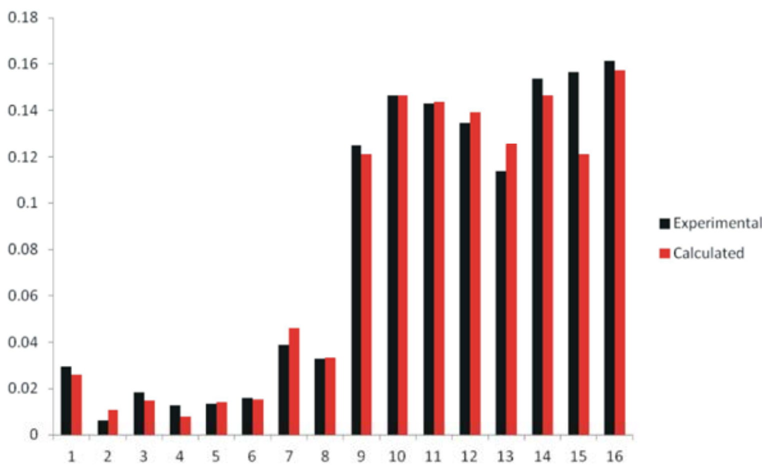
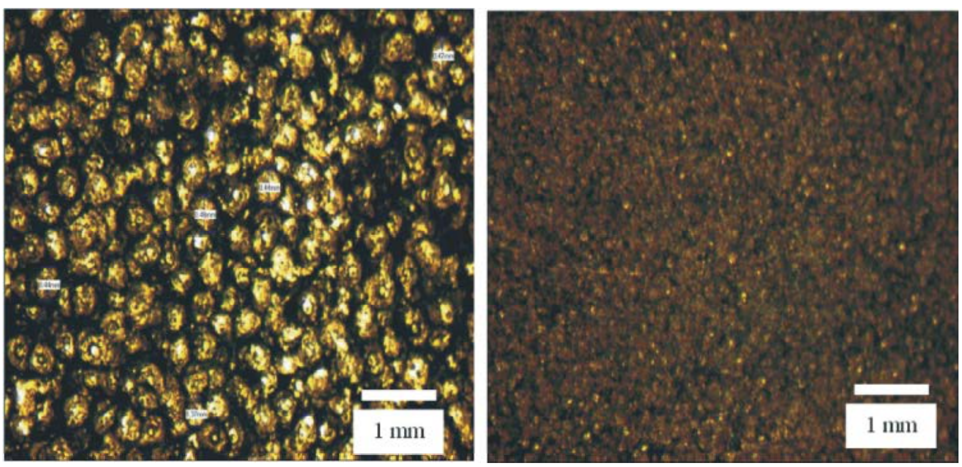


Fig. 4: Experimental (black) and calculated (red) for material removal rate



(a) (b)

Fig. 5: Surface texture and crater size (a) the highest and (b) the lowest of material removal rate

Percentage of difference between calculated value and experimental value of MRR is 5% as indicated in Equation 4. It is confirmed that mathematical model generated by Design Expert software is reliable and acceptable.

$$\text{Percentage different} = \frac{Experimental_{MRR} - Calculated_{MRR}}{Esperimemtal_{MRR}} \text{ x } 100$$

$$\text{Percentage different} = \frac{0.0293\text{-}0.0279}{0.0293} \text{ x } 100 = 5\%. \quad (4)$$

Confirmation differential between calculated and experimental is plotted as shown in Figure 4. It is found that the graph height of experimental and calculated MRR shows similar trend. It is confirmed that experimental result is acceptable.

Surface Appearance of Machining Characteristics: Peak current was considered as most significant factor to MRR while machine voltage and interaction between machine voltage and pulse on time were less significant factor. It also shows that MRR value is the highest at the biggest value of discharge current. Unfortunately, when discharge current is high, the spark density and discharge power are more, subsequently causing a large crater depth on workpiece surface, which result rough surface as similar result indicated by Krishna [24]. Figure 5(a) and Figure 5(b) show the surface texture and crater size between the highest and the lowest MRR of specimen. It is found that the highest MRR of running sample was number 14 and the lowest MRR of running sample was number 5. The image of workpiece surface was enlarge 230 times magnification.

CONCLUSIONS

In this study, the performance of EDM die-sinking parameters on machining characteristic that is MRR of Beryllium Copper was investigated. The machine voltage is the less significant factor, while peak current is the most significant factor. The higher value MRR can be obtained with combination of high level setting of peak current and pulse on time. The changes of peak current and pulse on time have contributed to a great influence of MRR. It can be concluded that a storage spark with higher energy is produced when increasing peak current, subsequently more heat is generated and substantial quantity of heat utilized in material removal.

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REFERENCES

1. Amorim, F. and W. Weingaertner, 2004. "Die-sinking electrical discharge machining of a high-strength copper-based alloy for injection molds," Journal of the Brazilian Society of Mechanical Sciences and Engineering, XXVI(2): 137-144.
2. Prabhu, S. and B. Vinayagam, 2009. "Effect of graphite electrode material on EDM of AISI D2 tool steel with multiwall carbon nanotube using regression analysis," International Journal of Engineering, 1: 93-104.
3. Yan, B. and S. Chen, 1994. "Characteristics of SKD11 by Complex Process of Electrical Discharge Machining Using Liquid Suspended with Alumina Powder," Journal of the Japan Institute of Metals, 58(9): 1067-1072.
4. Ekmekci, B., O. Elkoca and A. Erden, 2005. "A comparative study on the surface integrity of plastic mold steel due to electric discharge machining," Metallurgical and Materials Transactions B, pp: 36.
5. Yih-Fong, T. and C. Fu-Chen, 2005. "Investigation into some surface characteristics of electrical discharge machined SKD-11 using powder-suspension dielectric oil," Journal Of Materials Processing Technology, 170(1): 385-391.
6. Curodeau, A., M. Richard and L. Frohn-Villeneuve, 2004. "Molds surface finishing with new EDM process in air with thermoplastic composite electrodes," Journal Of Materials Processing Technology, 149(1): 278-283.
7. Yan, B., Y. Lin, F. Huang and C. Wang, 2001. "Surface modification of SKD 61 during EDM with metal powder in the dielectric," Materials Transactions-JIM, 42(12): 2597-2604.
8. Chow, H., B. Yan, F. Huang and J. Hung, 2000. "Study of added powder in kerosene for the micro-slit machining of titanium alloy using electro-discharge machining," Journal of Materials Processing Technology, 101(1): 95-103.
9. Wansheng, Z. and W. Zhenlong, 2002. "Ultrasonic and electric discharge machining to deep and small hole on titanium alloy," Journal of Materials Processing Technology, 120(120): 101-106.
10. Kunleda, M., Y. Miyoshi and T. Takaya, 2003. "High speed 3D milling by dry EDM," CIRP Annals - Manufacturing Technology, 52(1): 147-150.
11. Gao, C. and Z. Liu, 2003. "A study of ultrasonically aided micro-electrical-discharge machining by the application of workpiece vibration," Journal of Materials Processing Technology, 139(1-3): 226-228.
12. Katz, Z. and C. Tibbles, 2005. "Analysis of micro-scale EDM process," The International Journal of Advanced Manufacturing Technology, 25(9-10): 923-928.
13. Sagar, P., 2001. "EDMing Beryllium Copper: An Introduction," Modern Machine Shop, 2001. [Online]. Available: http://www.mmsonline.com/articles/e. [Accessed: 15-Apr-2013].
14. Wong, Y., L. Lim, I. Rahuman and W. Tee, 1998. "Near-mirror-finish phenomenon in EDM using powder-mixed dielectric," Journal of Materials Processing Technology, 79(1-3): 30-40.
15. Wu, K., B. Yan, F. Huang and S. Chen, 2005. "Improvement of surface finish on SKD steel using electro-discharge machining with aluminum and surfactant added dielectric," International Journal of Machine Tools and Manufacture, 45(10): 1195-1201.
16. Kruth, J.P., L. Stevens, L. Froyen and B. Lauwers, 1995. "Study of the White Layer of a Surface Machined by Die-Sinking Electro-Discharge Machining," CIRP Annals - Manufacturing Technology, 44(1): 169-172.

17. Yan, B., H.C. Tsai and F.Y. Huang, 2005. "The effect in EDM of a dielectric of a urea solution in water on modifying the surface of titanium," International Journal of Machine Tools and Manufacture, 45(2): 194-200.
18. Dalai, H., S. Dewangan and S. Datta, 2012. "A case study on quality and productivity optimization in electric discharge machining (EDM)," in 14^{th} International Conference in Advanced Materials and Processing Technology, pp: 1-10.
19. Lee, S. and X. Li, 2001. "Study of the effect of machining parameters on the machining characteristics in electrical discharge machining of tungsten carbide," Journal of Materials Processing Technology, 115(3): 344-358.
20. Lajis, M., H. Radzi and A. Amin, 2009. "The implementation of Taguchi method on EDM process of tungsten carbide," European Journal of Scientific Research, 26(4): 609-617.
21. Ghoreishi, M. and J. Atkinson, 2002. "A comparative experimental study of machining characteristics in vibratory, rotary and vibro-rotary electro-discharge machining," Journal of Materials Processing Technology, 120(1-3): 374-384.
22. Kansal, H., S. Singh and P. Kumar, 2005. "Parametric optimization of powder mixed electrical discharge machining by response surface methodology," Journal of Materials Processing Technology, 169(3): 427-436.
23. Shabgard, M., M. Seyedzavvar and S.N.B. Oliaei, 2011. "Influence of Input Parameters on the Characteristics of the EDM Process," Journal of Mechanical Engineering, 57(09): 689-696.
24. Rao, G., S. Satyanarayana and M. Praveen, 2008. "Influence of Machining Parameters on Electric Discharge Machining of Maraging Steels–An Experimental Investigation," in Proceeding of World Congress on Engineering, II: 1-6.