Available online at www.sciencedirect.com

ScienceDirect

Procedia Materials Science 5 (2014) 1633 – 1639

Procedia Materials Science

www.elsevier.com/locate/procedia

International Conference on Advances in Manufacturing and Materials Engineering, AMME 2014

Multi Response Optimization of Powder Mixed Electric Discharge Machining of Aluminum/Alumina Metal Matrix Composite Using Grey Relation Analysis

Gangadharudu Talla[a]*, Soumya Gangopadhyay[b], Chandan Kumar Biswas[c]

[a]*Research Scholar, National Institute of Technology, Rourkela-769008, India*
[b]*Assistant Professor, National Institute of Technology, Rourkela-769008, India*
[c]*Associate Professor, Universiti Teknologi Petronas, Ipoh, Malaysia*

Abstract

Electric discharge machining (EDM) is a well-established non-conventional machining process for the machining of electrically conductive and difficult-to-machine materials. But its applications are limited because of slow machining rate and relatively poor surface finish. Powder mixed EDM (PMEDM) is one of the recent advancements in EDM process where the addition of powder particles to the dielectric results in higher machining rate and better surface quality. In this work, Aluminum/Alumina metal matrix composite (MMC), which has many applications in automobile and aero-space industry, was fabricated and machined in EDM by mixing aluminum powder in kerosene dielectric. The effect process parameters (powder concentration, peak current, pulse on time and duty cycle) on two responses namely, material removal rate (MRR) and surface roughness (SR) were measured. A multi response optimization was performed using grey relational analysis (GRA) to find the optimum combination of the process parameters for maximum MRR and minimum SR. The results show that the powder concentration of 6 g/L gives the optimum result for the multi responses.

Selection and peer-review under responsibility of Organizing Committee of AMME 2014

Keywords: Grey relational analysis; Metal matrix composite; Multi response optimization; Powder mixed EDM

* Corresponding author. Tel.: +0-661-246-4506.
E-mail address: gangadhar.talla@gmail.com

Selection and peer-review under responsibility of Organizing Committee of AMME 2014
doi:10.1016/j.mspro.2014.07.351

1. Introduction

EDM has found many applications in die and tool making, automobile, aero-space and surgical equipment manufacturing industries because of its ability to machine any conductive material, irrespective of its strength properties. But, slow machining rate and poor surface finish of the process restrict its applicability in other industries. PMEDM is one of the recent advancements in EDM process where the addition of suitably chosen powder particles to the dielectric results in higher machining rate and better surface quality.

Zhao et al. (2002) concluded that presence of current conducting particles causes electric aberration in the discharge gap. Under the pressure of gap voltage, lots of positive and negative charges gather respectively at the top and bottom of the powders. Discharge breakdown occurs between the powders where the electric field density is highest. Short circuit between the two powder particles causes the redistribution of electric charges. As a result, discharge occurs between these two powders and the other powder particles. This series discharge finally leads to the discharge break down between tool and work-piece. This causes discharge through the entire gap and discharged gaps are enlarged. Larger discharge gap and longer carrier (ions and electrodes) movement routes imply more carriers and larger discharge passage. Additionally, larger discharge gap reduces the pressure of work fluid on the discharge passage and ease the widening of the discharge passage. Larger discharge passage and distribution of powder particles in it prevent the intensive discharge. This even discharge leads to even heat distribution and results in evenly distributed etched cavities. Thus, formation of large and shallow cavities takes place in PMEDM.

Wong et al. (1998) observed mirror like surface for SKH-54 tool steel when Silicon and Graphite powders were added in the dielectric. Experiments of Chern Lin et al. (2001) showed that SiC powder in dielectric reduced the SR and improved the wear resistance for Al-Zn-Mg alloy. Yih-Fong et al. (2005) observed very poor surface finish with copper powder while powders with least particle size produced better surface quality. Cogun et al. (2006) added H_3BO_3 powder particles in kerosene had no significant effect on surface roughness of SAE 1040 steel whereas increase in pulse time increased SR for both graphite and H_3BO_3 powders. Tsai and Chang (2010) used polymer powder (PANI-emer) as additive in dielectric for stainless steel which resulted in poor surface quality. The experiments of Assarzadeh and Ghoreishi (2012) showed an increase in MRR was found when current increased. After a particular peak current, MRR started decreasing. With further increase in peak current, MRR again increased. MRR increased with the increase in pulse duration, reached maximum and decreased thereafter. MRR increased with the increase in duty factor. Kumar and Davim (2011) observed the addition of appropriate amount of Si powder (4 g/L) into the dielectric fluid triplicated the MRR and lowered the SR by 33%. The experimentations of Ojha et al. (2011) concluded that good surface quality was obtainable at low current–tool diameter combination. The effect of duty cycle on the SR value was found to be insignificant. Mai et al. (2012) concluded that the type of powder material used significantly affects the MRR. Carbon Nano Tubes (CNTs), Si, Al, Graphite produced higher MRR in increasing order. SR declined in the same order.

From the literature review, it is understood that PMEDM has a strong potential in improving the machining characteristics of EDM process. However, very few research work has been reported so far in PMEDM of MMC which has, now-a-days, wide engineering applications particularly in in automobile and aerospace industry. Therefore, in order to extend the beneficial aspects of PMEDM in machining of MMCs, the current research work has been undertaken. Here, aluminum powder was mixed in the dielectric to machine Al-Al2O3 MMC. The effects of process parameters namely powder concentration, peak current, pulse on time and duty cycle on MRR and SR were studied.

2. Experimental details

2.1. Fabrication of Al/Al_2O_3 MMC

Aluminum and alumina powders with particle size of 74μm (200 mesh) were used to prepare the work-piece. 80% of aluminum and 20% of alumina powder by weight were mixed thoroughly in a high energy ball mill at 300 rpm for 2 hours. The ball to powder ratio was 10:1. Powders were milled in liquid toluene environment to prevent the agglomeration and oxidation of aluminum powder. Specimens were prepared through powder metallurgy at a compaction pressure of 250 MPa. Acetone was used as lubricant to decrease the die wear. The compacted specimens were then sintered in nitrogen environment, at 500°C for hour and allowed to cool in the furnace for 24 hours. The samples were then heated to 400°C and quenched in iced water. In order to prevent the initiation of natural aging after this quenching, all samples were artificial aged immediately after heat treatment. During this process, samples were heated to 200°C for 30 min and left to cool in the muffle furnace for 8 hours.

2.2. Machining of Al/Al_2O_3 MMC

All the experiments were conducted on an EDM machine (Model LEADER-1, Electronica) wherein a specially mounted tank was used for homogeneous mixing of suspended powder particles during machining to prevent settling. Prepared $Al\text{-}Al_2O_3$ samples and commercial copper were used as work-piece and tool materials, respectively. Al powder particles of size 54µm were mixed in kerosene to form the dielectric media. Powder concentration (C_p), peak current (I_p), pulse on time (T_{on}) and duty cycle (T_{au}) were chosen to be the control parameters. Experiments were conducted using L_{18} orthogonal array by varying the factors at their respective levels. The values of different fixed and control parameters are given in Table 1.

Table 1. Experimental details

Parameter	Description
Work-piece	Al-Al2O3 (φ 25 x 8 mm)
Tool	Copper (φ 12 mm)
Dielectric	Kerosene
Powder	Aluminium (~45 µm)
Flushing pressure	0.5 kg/cm2
Polarity	+Ve
Gap voltage	45 V
Powder concentration	0, 2, 4, 6, 8, 10 g/L
Peak current	1, 2, 3 A
Pulse on time	50, 100, 150 µs
Duty cycle	50, 70, 85 %
Machining depth	mm

2.3. Measurement of responses

Weights of the Al/Al_2O_3 specimens were measured before and after the machining using a high precision weighing balance (Model-VIBRA, SANSUI Electronics). Density of the specimen was found to be 0.0961 g/mm3. Machining time was measured using a stop watch. MRR was calculated using Eq. 1. Three readings of surface roughness values (R_a) were measured for each sample using portable stylus type profilometre (Talysurf, Taylor Hobson).

$$MRR = \frac{W_{wa} - W_{wb}}{t_m \times \rho_w} \tag{1}$$

Where W_{wa} = Weight of the work-piece after machining, W_{wb} = Weight of the work-piece before machining, t_m = Machining time and ρ_w = Density of work-piece.

Fig. 1. Machined work-pieces

3. Optimization using grey relation analysis (GRA)

In many cases, processes parameters cannot be set only for one response, as the objective would be to minimize some responses and maximize some responses simultaneously. Here there is a need for a multi response optimization. The multi response optimization first converts multiple objectives into a single response and optimizes it. In the present work, GRA is used for the multi response optimization of PMEDM process.

Various steps involved in the grey relation analysis are:

3.1 Normalization of different responses

'Higher the better (HTB)' or 'lower the better (LBT)' condition is chosen for each response based on the desired objective. For this experiment HBT and LBT were chosen for MRR and SR respectively.

For HTB, the equation for normalization is:

$$y_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \tag{2}$$

For LTB, the equation for normalization is:

$$y_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \tag{3}$$

Where $y_i(k)$ is i^{th} normalized response value and $x_i(k)$ is observed value for the i^{th} run of the k^{th} response.

3.2 Calculating grey relation coefficient (GRC)

Grey relation coefficient ($\zeta_i(k)$) is calculated using the following equation :

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta_i \Delta_{\max}}{\Delta_i(k) + \zeta_i \Delta_{\max}} \tag{4}$$

Where $\Delta_{\min}$ and $\Delta_{\max}$ are the global minimum and maximum values of normalized values respectively of the k^{th} response. ζ is the distinguishing factor whose value lies between 0 and 1. Its purpose is to expand or compress the range of grey relation coefficient. In this experiment the distinguishing factor considered is 0.5.

3.3 Calculating the grey relation grade (GRG)

Performance of the multi response is evaluated by GRG. It is the weighted summation of all the GRC's and is calculated using the following expression:

$$\gamma = \frac{1}{n}\sum_{i=1}^{n}\zeta_i(k) \tag{5}$$

The calculated GRC and GRA values are given in Table 2.

Table 2. GRG values for the multi response

S.No.	C_p	T_{on}	T_{off}	T_{au}	MRR	SR	GRC for MRR	GRC for SR	GRG
1	2	1	50	70	22.561	9.23	0.396	0.575	0.485
2	2	2	100	85	28.448	9.727	0.489	0.512	0.500
3	2	3	150	50	37.107	10.169	0.746	0.466	0.606
4	4	1	100	50	26.157	8.627	0.448	0.677	0.562
5	4	2	150	70	38.335	8.854	0.806	0.634	0.720
6	4	3	50	85	41.291	9.452	1.000	0.545	0.772
7	6	1	150	85	25.827	7.524	0.442	1.000	0.721
8	6	2	50	50	26.614	7.632	0.455	0.955	0.705
9	6	3	100	70	35.197	7.593	0.668	0.971	0.820
10	8	1	100	85	19.621	8.103	0.362	0.799	0.581
11	8	2	150	50	20.015	8.563	0.366	0.690	0.528
12	8	3	50	70	23.168	9.218	0.404	0.577	0.490
13	10	1	150	70	16.743	9.438	0.333	0.547	0.440
14	10	2	50	85	18.361	10.171	0.349	0.466	0.407
15	10	3	100	50	20.128	10.606	0.367	0.428	0.398
16	0	1	50	50	20.297	10.963	0.369	0.402	0.385
17	0	2	100	70	24.039	11.377	0.416	0.375	0.395
18	0	3	150	85	35.302	12.14	0.672	0.333	0.503

4. Analysis of results

The obtained GRG is considered a single response for the designed experiment and analysis of variance (ANOVA) is carried out in to know which parameters significantly affect the multi objective response. ANOVA is given in Table 3. From the table, it can be observed that only Cp is significant for the optimum multi response. Remaining factors Ip, Ton and Tau were found insignificant.

Fig. 2 shows the main effects plot for GRG. The maximum GRG values were observed at a C_p of 6 g/L, I_p of 3A, T_{on} of 150 μm and a Tau of 85. Hence, the combination of these processes parameter values gives the optimum result for the multi response.

Table 3. ANOVA for GRG

Source	DF	Seq SS	Adj SS	Adj MS	F	P
C_p	5	0.273931	0.273931	0.054786	14.72	0.003
I_p	2	0.016028	0.016028	0.008014	2.15	0.197
T_{on}	2	0.007932	0.007932	0.003966	1.07	0.402
Tau	2	0.007539	0.007539	0.003770	1.01	0.418
Residual Error	6	0.022330	0.022330	0.003722		
Total	17	0.327761				

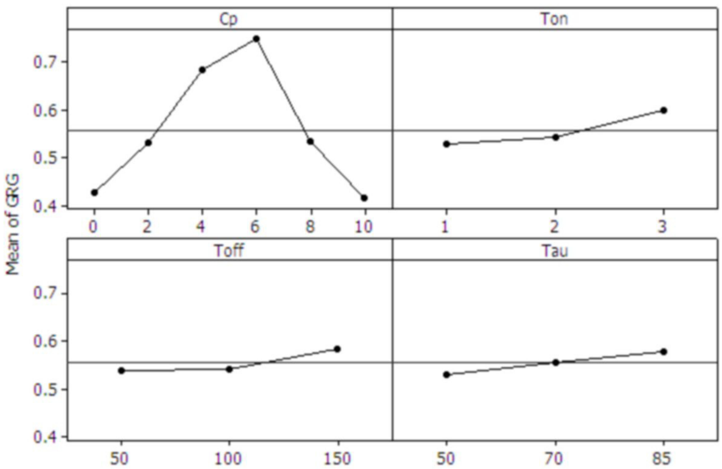

Fig. 2 Main effect plots for GRG

5. Conclusions

The present study investigated the effect of various process parameters on multi responses using grey relation analysis (multi-objective technique) during the PMEDM of Al/Al_2O_3 MMC. Following are some of the conclusions drawn.

- Addition of Al powder particles in the dielectric has increased the MRR and decreased the SR in the EDM of Al/Al_2O_3 MMC.
- For the designed experiment, the maximum MRR (41.291 mm^3/min) was observed at a powder concentration of 4 g/L.
- For the single response SR, the minimum value (7.524 µm) was found at 6 g/L concentration.
- The recommended level of process parameters when MRR (high), SR (low) all are simultaneously considered during PMEDM of Al/Al_2O_3 MMC using Grey relation analysis resulted is observed at a C_p of 6 g/L, I_p of 3A, T_{on} of 150 µm and a Tau of 85%.

References

Assarzadeh, S. and Ghoreishi, M., 2012. A dual response surface-desirability approach to process modeling and optimization of Al_2O_3 powder-mixed electrical discharge machining (PMEDM) parameters, International Journal of Advanced Manufacturing Technology. Article in press.

Cherng Lin, Y., Hwa Yan, B. and Yuan Huang, F., 2001. Surface modification of Al − Zn − Mg aluminum alloy using the combined process of EDM with USM, Journal of Materials Processing Technology. 115, 359–366.

Cogun, C., Ozerkan, B. and Karacay, T., 2006. An experimental investigation on the effect of powder mixed dielectric on machining performance in electric discharge machining, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 220, 1035–1050.

Kumar, H. and Davim, J.P., 2011. Role of powder in the machining of Al − 10%SiC_P metal matrix composites by powder mixed electric discharge machining, Journal of Composite Materials. 45, 133–151.

Mai, C., Hocheng, H. and Huang, S., 2012. Advantages of carbon nanotubes in electrical discharge machining, International Journal of Advanced Manufacturing Technology. 59, 111–117.

Ojha, K., Garg, R. and Singh, K.K., 2011. Experimental investigation and modeling of PMEDM process with chromium powder suspended dielectric, International Journal of Applied Science and Engineering. 9, 65–81.

Tsai, Y.Y. and Chang, C.K., 2010. Effects of polymer particles suspending in dielectric fluid on surface roughness of EDM. Advanced Materials Research. 97-101, 4146–4149.

Wong, Y., Lim, L., Rahuman, I. and Tee, W., 1998. Near-mirror finish phenomenon in EDM using powder-mixed dielectric, Journal of Materials Processing Technology. 79, 30–40.

Yih-Fong, T. and Fu-Chen, C., 2005. Investigation into some surface characteristics of electrical discharge machined SKD-11 using powder-

suspension dielectric oil. Journal of Materials Processing Technology. 170, 385–391.
Zhao, W.S., Meng, Q.G. and Wang, Z.L., 2002. The application of research on powder mixed EDM in rough machining, Journal of Materials Processing Technology. 129, 30–33.