Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings XX (2016) XXX–XXX

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

PMME 2016

Wire electrical discharge machining characteristics of AA6061/cenosphere aluminium matrix composites using RSM.*

A. Dey[a], V.R.Reddy Bandi [b], K.M.Pandey[c,]*

[a,c]Dept. of Mechanical Engineering, NIT Silchar, Assam, 788010 India
[b]Dept. of Mechanical Engineering,Gitam University,Hyderabed,India

Abstract

This paper reports experimental investigations of the effect of machining parameters (pulse-on time, pulse-off time, wire speed) on the performance measure like cutting speed (CS) or feed, kerf width(KW) and surface roughness(SR) during wire electrical discharge machining (WEDM) of newly prepared compo casted AA6061/ cenosphere AMCs. Box Behnken of response surface methodology is employed to analyse the effects of significant machining parameters on the performance characteristics. ANOVA analysis was imposed to investigate the influence of process variables and their interactions. Further, a second order quadratic mathematical model has been developed in order to estimate the performance characteristics. The analysis reveals that pulse on time and percentage of reinforcement were found to be the most significant factors affecting all the three responses.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: Compo casting, Wire EDM, RSM, ANOVA analysis.

1. Main text

Now a day, Metal matrix composites have tremendously increasing demand in thermal management areas, as well as in sports and recreation. Aluminium based Metal matrix composites (AMC) are gaining significant interest in

* Corresponding author. Tel.: +919435173130; fax: +0-000-000-0000 .
E-mail address: kmpandey2001@yahoo.com

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

high-tech structural and functional applications including aerospace, defence, automotive and sports equipment manufacturing industries, due to their interesting mechanical and material properties such as high strength, high stiffness, damping capacity, reduced density and improved abrasion and wear resistance capacity compared to monolithic alloy [1-3]. However, the influence properties that associated with the MMCs feature a lot of challenges in machining on it. Since hardness, toughness and impact resistance of the MMCs were increasing after adding of reinforcing materials, so it is difficult to be machined of those composites in traditional machining processes due to the abrasive nature of the reinforced particles [4,5]. However, several investigators have made an effort to apply different non-conventional machining methods like abrasive water jet, laser cutting and electric discharge machine (EDM) to machine MMCs [6,7]. But these processes showed certain disability like unable to linear cutting and required elaborate preparation of preshaped electrode (tool). However, few researchers have been reported that the wire electrical discharge machining (WEDM) process can be overcome those limitations and exhibited better machining performances and economical tool in the machining of composite materials [8]. WEDM is a specialized non-conventional machining process which is mainly used for the machining of any electrical conductive materials irrespective of their material hardness and strength. It can be capable to producing intricate and complicated shapes with fine finish and extremely high accuracies. The most important measures of performance in Wire EDM process are cutting rate, surface roughness and kerf width [9]. Wire EDM is a controlled thermal erosion machining process where electric energy is transformed into thermal energy and generates a series of electric spark for processing the electric conductive workpieces. However, WEDM is a modification of the traditional EDM process where the tool electrode in this machine is simply a thin wire. In this process, there is no direct contact between the work piece and the wire, and therefore, it eliminates the mechanical stresses during machining [10]. However, literatures on the machining of cenosphere reinforced Al MNCs are scarce in general and investigations on the WEDM characteristics in particular.

Hence, in this study an attempts have been made to investigate the machinability of newly prepared composted AA6061/ cenosphere AMCs by developing a mathematical model and examine the effects of process parameters on the performance measures of the prepared MMC using Box Beken (27) of response surface methodology(RSM). Consequently, the quantitative mathematical models have been developing to study the effects of pulse on time (Ton), Pulse off time(Toff), wire speed (m/mm) and percentage of reinforcement (Wt. %) on the performance characteristics like cutting speed(CS), kerf width (kw) and surface roughness (SR) by using RSM approach [10].

Nomenclature

WDEM	Wire electro discharge machining
RSM	Response surface methodology
ANOVA	Analysis of variance.
CS	Cutting Speed
KW	Kerf width
SR	Surface roughness

2. Experimental design

Response surface methodology (RSM) is a collection of mathematical and statistical techniques utilization for modelling and optimizing the response characteristics, which incorporates quantitative independent variables (Cochran and Cox, 1962). The quality characteristic of the system is explained by a second order polynomial quadratic model also called regression model as shown in Eq.1. The coefficients of regression model can be approximated from the experimental data by 'Design Expert 10.0' software.

$$Y = C_0 + \sum C_i X_n + \sum d_i X_i^2 \pm \varepsilon$$

The experiments were designed in the present work based Box Behnken 27 technique. The DOE full factorial design with all factors combination at two levels (high, +1, and low, - 1) are considered which composed of eight star points, and six central point's (coded level 0), corresponds to an α value of 1. The DOE includes 27 experimental trial at four distinct process variables. Table 1 shows both actual and coded values of all the machining parameters and their feasible ranges. The experimental design layout in the coded form that was espoused in this analysis is shown in Table 2.

Table 1. wEDM Machining parameters with their levels.

Parameters	Labels	Levels		
		-1	0	+1
Wt. percentage, Wt.%(A)	A	0	4	8
Pulse on time, T_{on} (µs)	B	12	16	20
Pulse off time, T_{off}(µs)	C	46	49	52
Wire Speed (m/mm)	D	4	6	8

Table 1. Design layout and experimental results.

Run	Factor 1 A:Wt.% %	Factor 2 B:Ton microsec.	Factor 3 C:Toff Microsec.	Factor 4 D:Wspeed m/min	Response 1 CS mm/min	Response 2 KW µm.	Response 3 SR (µm)
1	4	16	46	8	5.1	95.131	3.10
2	8	16	49	4	6.26	100.88	3.246
3	8	12	49	6	6.94	105.413	3.13
4	4	20	46	6	7.20	111.174	3.26
5	0	16	49	8	7.10	107.107	3.423
6	8	16	49	8	7.00	104.933	8.93
7	0	16	52	6	7.077	104.867	3.31
8	4	16	49	6	7.47	106.656	3.146
9	8	16	46	6	7.40	110.733	3.103
10	4	16	49	6	4.81	93.603	3.2
11	4	20	52	6	5.89	98.041	3.313
12	0	20	49	6	6.504	103.143	3.033
13	0	12	49	6	6.866	108.171	3.193
14	0	16	49	4	6.637	106.895	2.996
15	4	12	46	6	6.057	100.351	3.033
16	4	20	49	4	6.44	103.39	3.306
17	4	16	52	4	6.884	104.257	2.923
18	4	16	52	8	6.87	108.191	3.283
19	4	12	52	6	4.03	92.603	3.07
20	0	16	46	6	4.97	96.041	3.08
21	4	12	49	4	6.25	100.143	3.2
22	4	16	46	4	6.866	106.083	3.40
23	8	20	49	6	6.496	105.252	2.95
24	4	16	49	6	6.022	95.335	3.306
25	4	20	49	8	6.228	99.714	3.29
26	4	12	49	8	6.808	101.807	2.923
27	8	16	52	6	6.79	106.484	3.293

3. Results and discussion

3.1. Modeling of CS, KW and SR

The model fit summary prescribed that the second order quadratic model is significant statistically for the analysis of CS, KW and SR. The analysis results for quadratic models are shown in ANOVA Tables 3–5. The model F value implies that the model is significant. The Probability F value has greater than the given F value for the models term are less than 0.05 implies that the developed models are appraised to be statistically significant and it is desirable as it indicates that the model terms have a significant influence on the performance characteristics. The obtains response model have better fits with actual data, when the multiple regression co efficient R^2 approaches to unity. It exists the less the deviation between the actual and predicted values. Moreover, the value of adequate precision (AP) in present model, which compares the span of the predicted value at the design point to the mean prediction error, is fairly above 3. This represents the adequate model discrimination. These developed models propose grater values of the determination coefficients (R^2) and adequate precision (AP) at the same time. The process of backward elimination eradicates the insignificant factors to alter the fitted quadratic response surface models. These insignificant quadratic model terms can be eliminated and the test of lack of fit reveals to be insignificant, as it is desired. The absolute quadratic models of response surface equations obtained by using backward elimination technique are shown in Eqs. (2)- (4) as given below. This obtained model can be employing for navigate the design space as the ratio of adequate precision illustrates an adequate signal.

The ultimate response surface equations for CS, KW and SR are:

Cutting speed:

$$CS = +6.58-0.44*A+0.91*B-0.25*C+0.27*D+0.19*AB-0.041*AC-0.035*AD+0.044*A^2-0.15*B^2-0.067*C^2-0.31*D^2 \quad (2)$$

Kerf width:

$$KW=+101.78-1.86*A+5.18*B-2.88*C+2.66*D-0.24*AB-0.39*AC+0.39*AD+0.52*A^2-0.027*B^2-0.16*C^2+1.23*D^2 \quad (3)$$

Surface roughness:

$$SR= +3.05+0.051*A-0.032*B-0.092*C+0.029*D+0.079*AB-1.000E-002*AC-0.017*AD-0.17*BC+0.14*BD+0.023*CD+0.086*A^2-0.019*B^2+0.015*C^2+0.096*D^2 \quad (4)$$

Table3. The ANOVA results for CS.

ANOVA for Response Surface Quadratic model (Aliased)

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	16.64	11	1.51	58.85	< 0.0001	significant
A-Wt.%	*0.56*	*1*	*0.56*	*21.83*	*0.0003*	
B-Ton	*7.71*	*1*	*7.71*	*300.15*	*< 0.0001*	
C-Toff	*0.54*	*1*	*0.54*	*20.84*	*0.0004*	
D-Wfeed	*0.70*	*1*	*0.70*	*27.13*	*0.0001*	
AB	*0.26*	*1*	*0.26*	*10.01*	*0.0064*	
A^2	*0.012*	*1*	*0.012*	*0.45*	*0.5122*	
B^2	*0.049*	*1*	*0.049*	*1.92*	*0.1859*	
D^2	*0.22*	*1*	*0.22*	*8.38*	*0.0111*	
Residual	0.39	15	0.026			
Lack of Fit	*0.35*	*12*	*0.029*	*2.36*	*0.2601*	*not significant*
Pure Error	*0.037*	*3*	*0.012*			
Cor Total	17.02	26				

Table 4. The ANOVA results for TWR.

ANOVA for Response Surface Quadratic model (Aliased)

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	740.12	11	67.28	138.34	< 0.0001	significant
A-Wt.%	*10.09*	*1*	*10.09*	*20.74*	*0.0004*	
B-Ton	*248.81*	*1*	*248.81*	*511.57*	*< 0.0001*	
C-Toff	*71.84*	*1*	*71.84*	*147.71*	*< 0.0001*	

D-Wfeed	*65.75*	*1*	*65.75*	*135.19*	*< 0.0001*	
AC	*1.26*	*1*	*1.26*	*2.59*	*0.1282*	
AD	*1.09*	*1*	*1.09*	*2.25*	*0.1547*	
A^2	*1.59*	*1*	*1.59*	*3.27*	*0.0905*	
D^2	*3.44*	*1*	*3.44*	*7.08*	*0.0178*	
Residual	7.30	15	0.49			
Lack of Fit	*7.02*	*12*	*0.59*	*6.47*	*0.0753*	*not significant*
Pure Error	*0.27*	*3*	*0.091*			
Cor Total	747.41	26				

Table 5. The ANOVA results for SR.

ANOVA for Response Surface Quadratic model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.47	14	0.034	1.36	0.0001	significant
A-Wt.%	*0.032*	*1*	*0.032*	*1.28*	*0.0001*	
B-Ton	*0.012*	*1*	*0.012*	*0.50*	*0.0007*	
C-Toff	*0.10*	*1*	*0.10*	*4.07*	*0.0015*	
D-Wire speed	*0.010*	*1*	*0.010*	*0.41*	*0.0021*	
BC	*0.11*	*1*	*0.11*	*4.54*	*0.0546*	
BD	*0.080*	*1*	*0.080*	*3.24*	*0.0971*	
A^2	*0.040*	*1*	*0.040*	*1.61*	*0.2288*	
D^2	*0.049*	*1*	*0.049*	*1.96*	*0.1868*	
Residual	0.30	12	0.025			
Lack of Fit	*0.29*	*10*	*0.029*	*21.55*	*0.0451*	*significant*
Pure Error	*2.738E-003*	*2*	*1.369E-003*			
Cor Total	0.77	26				

3.2. Effect of machining parameter on cutting speed.

It is evident from the Fig. 1(a) that the cutting rate increases with the increasing pulse-on-time for all the composite samples. With increasing pulse-on-time more material removal takes place due to increasing duration of sparking. However, unreinforced AA6061 alloy composite exhibited the highest cutting speed compared to the both reinforced composites. It is due to the fact that fly ash particles are thermally and electrically nonconductive and therefore presence of fly ash reduces melting and vaporization of the composites. As a result, it obstructs cutting speed during machining process. Fig. 1(b) plots the cutting speed versus the pulse-off-time for the various wt.% of fly ash reinforced AMCs. It is evident from the figure that the cutting rate decreases with the increasing pulse-off-time for all the three composite samples due to the fact that on increasing the time gap between the two consecutive sparks the process of erosion of material becomes slow. Fig. 1(c) depicts the plots of cutting speed versus the wire feed for the various wt.% of fly ash reinforced AMCs. It is observed that there is no significant influence of wire feed on cutting speed for all the composite samples. Hence, it is recommended to keep the wire feed in a medium level so as to reduce the wastage of wire as higher feed causes more wire consumption as well as more cost of fabrication.

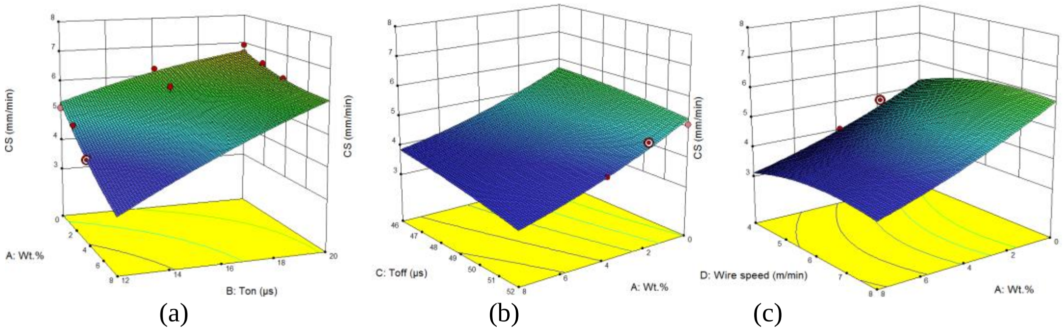


Fig. 1. (a), (b) and (c) shows the response surface graph of CS for AA 6061-cenosphere AMCs.

3.3. Effect of the machining parameters on kerf width.

Fig. 2(a) plots the kerf width versus the pulse-on-time for the various wt.% fly ash reinforced AMCs. It reveals that as the pulse-on-time increases the kerf width of the composites also increased in order to discharge energy of the machining surface is high. The narrowest kerf width is found in reinforced composites where it became thinner as the fly ash content is increased. It indicates that the thermally and electrically nonconductive fly ash particulates barricade the machining process compared to the conductive AA6061 aluminium alloy. Fig. 2(b) plots the kerf width versus the pulse-off-time for the various wt.% of fly ash reinforced composite samples. It is found from the Fig. 2(b) that the kerf width decreases with the increasing pulse-off-time for all the three composite samples. When the pulse-off-time is high, the discharge energy of the machining surface is low, which create very shallow craters and because of this the kerf width is less at higher value of pulse-off-time. Fig. 2(c) shows the plots of kerf width against the wire feed for the various wt.% of fly ash reinforced AMCs. It was seen from the figure that as the wire feed increases, the kerf width is also increased. Which caused as the wire feed increases more machining is done on the same area leading to more material removal thus increasing the kerf width.

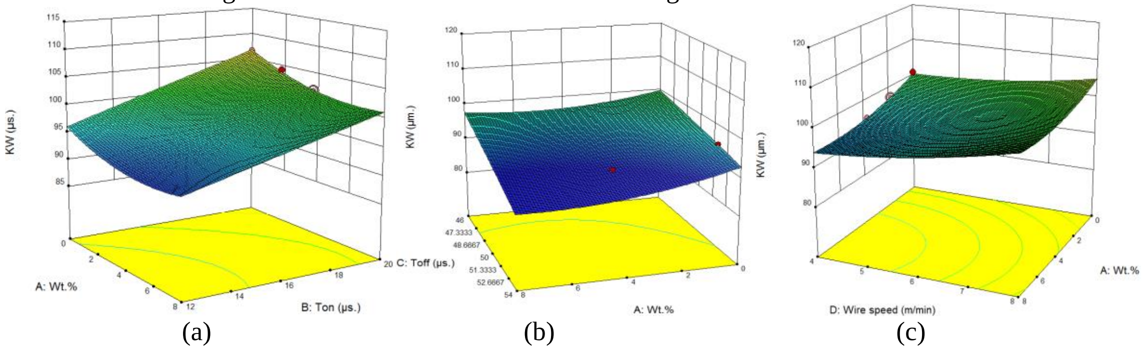
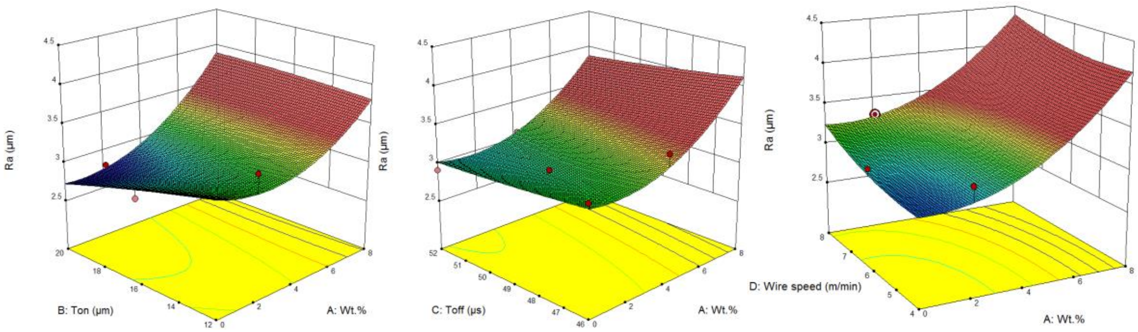


Fig. 2. (a), (b) and (c) shows the response surface graph of KW for AA 6061-cenosphere AMCs.

3.4. Effect of machining parameter on surface roughness.

Fig. 3(a) plots the surface roughness against pulse-on-time for various wt.% of fly ash reinforced AA6061 alloy composites. It has been observed from the figure that as pulse-on-time increases the roughness of the machined surface of the composites increases significantly due to the increased size of the craters produced on the machined surface, so deteriorated the surface integrity. Fig. 3(b) plots the surface roughness versus the pulse-off-time for the various wt.% fly ash reinforced composite samples. From Fig. 3(b) it is seen that as the pulse-off-time increases the roughness of the machined surface decreases. That's because, at high pulse-off-time, cooling time and flushing time will increase, which tends to spill out comparatively more amount of debris through the machining zone and avoiding the resolidificaion of the molten material on the machine surface. The plots of surface roughness versus the wire feed for the various wt.% of cenosphere reinforced AMCs are depicting in fig.3(c). It was obtained from the figure that surface roughness increases with the increase in wire feed and the trend is almost linear. But the effect is very small.



(a) (b) (c)

Fig. 3. (a), (b) and (c) shows the response surface graph of SR for AA 6061-cenosphere AMCs.

4. Conclusions

Wire electro discharge machining(WEDM) of cenosphere fly ash reinforced AA6061 alloys prepared by compo casting processing route have been attempts in this study. Effects of significant processing parameter on the machining responses are evaluated by developing a mathematical model using response surface methodology approach and the following conclusions have been made.

- The predicted values of R^2 for CS, KW and SR match reasonably well with the experimental values.
- The two main significant factors that affect the CS are pulse on time(Ton) and percentage of reinforcements (Wt.%). The CS increases with an increase in pulse on time and decreases drastically with the increase of Wt.%.
- The pulse on time and Wt.% have statistical significance on both KW and SR. The influence of $T_{off,}$ and wire speed on SR are not that much significant.
- There are no significant effects observed on kerf width with the changes of cenosphere contents in the AMCs.
- The SR decreases with an increase in pulse on time(T_{on}) whereas with wire speed it increases slightly.

References

[1] M K Surappa, Aluminium matrix composites: Challenges and opportunities, Sadhana Vol. 28, Parts 1 & 2, February/April 2003, pp. 319–334.

[2] Himanshu Kalaa, Merb K.K.S, Sandeep Kumar, A Review on Mechanical and Tribological Behaviors of Stir Cast Aluminum Matrix Composites. Procedia Materials Science 6 (2014) 1951 – 1960.

[3] Ashok Kumar B, Murugan N. Metallurgical and mechanical characterization of stir cast AA6061-T6–AlNp composite. Mater Des 2012; 40:52–8.

[4] Quan, Y.M.; Zhou, Z.H. Tool wear and its mechanism for cutting SiC particle-reinforced aluminium matrix composites. Journal of Materials Processing Technology **2000**, *100* (1), 194–199.

[5] J.M. Monaghan, P. O'Reilly, the drilling of an Al/SiC metal–matrix composite, Journal of Materials Processing Technology 33 (4) (1992) 469–480.

[6] Hamatami G, Ramulu M, Machinability of high temperature composites by abrasive water jet. ASME J Eng Mater Technol 112(4):381–386

[7] Muller F, Monahan J, Non-conventional machining of particle reinforced metal matrix composites. J Mater Process Technol 118:278–285.

[8] Ho KH, Newman ST, Rahimifard S, Allen RD (2004) State of the art in wire electrical discharge machining (WEDM). Int J Mach Tools Manuf 44:1247–1259

[9] Sreenivasa Rao M, Venkaiah, Review on Wire-cut EDM process, International Journal of Advanced Trends in computer Science and Engineering. Vol.2, No.6, pages: 12-17 (2013).

[10] David Raja Selvam J., Robinson Smart D.S., Dinaharan I., Microstructure and some mechanical properties of flyash particulate reinforced AA6061 aluminum alloy composites prepared by compocasting. Materials and Design 49 (2013) 28–34.