International Journal on Emerging Technologies **10**(2): 307-316(2019)

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Mathematical Modelling and Parametric Optimization of EDM for Tool Wear Rate of Hybrid Aluminum Metal Matrix Composite Reinforced with SiC_p and Gr_p

Harish Kumar Garg[1], Rajesh Kumar[1], Alakesh Manna[2] and Shubham Sharma[3]
[1]Sant Longowal institute of Technology, Longowal, Punjab, 148-106, India.
[2]PEC University of Technology, Chandigarh, 160-012, India.
[3]CSIR - Central Leather Research Institute,
Regional centre for extension and development, Kapurthala Road, Jalandhar-144021, Punjab, India.

(Corresponding author: Harish Kumar Garg)
(Received 06 May 2019, Revised 25 July 2019 Accepted 2 August 2019)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Hybrid Aluminum metal matrix composites have become a leading engineering material due to their excellent characteristics and engineering applications. Due to high hardness and abrasive in nature the hybrid Al/(SiC_p + Gr_p)-MMC machining is very difficult by traditional machining because of excessive tool wear. Electrical Discharge Machining (EDM) is one of the most suitable and effective nontraditional machining processes can used to machine such composite. This paper investigates the significant effect of machining parameters like pulse-on time (T-on), pulse-off time (T-off), voltage (V), current (I), Tool Material and workpiece material on tool wear rate (TWR) as considered as are sponse characteristic. The SiC_p and Gr_p of average particle size 75 µm have been used as reinforcement particles in different weight percentages to fabricate the hybrid Al/(SiC_p + Gr_p)-MMC and utilized it as workpiece material for experimental investigations. To machine the fabricated hybrid MMCs, three different electrodes materials such as Steel-304, brass and Copper of Ø12mm each have been used. The design matrix was set for experiments and developed mathematical models based on response surface methodology (RSM) and utilized Design expert 9.0.6 software respectively. Results revealed that the most promising parameter is pulse-on-time followed by pulse-off-time and tool material. Optimal value of TWR 0.347 gm/min was recorded at 30 µs pulse on time, 65 µs pulse off time, 7.0 V gap voltage, and 10 A peak current. To identify the significant parameters of the model the ANOVA technique has been employed. The SEM and EDS images of the machined surfaces have been taken to analyze the machined surface characteristics and elements analysis respectively.

Keywords: Hybrid aluminum metal matrix composite, Electrical discharge machining, Response surface methodology, Tool wear rate.

Abbreviations used: EDM: Electrical Discharge Machining, T-on: Pulse-on time, T-off: Pulse-off time, V: Voltage, I: Current, TWR: Tool wear rate, SiCp: Silicon Carbide, Grp: Graphite, MMCs: Metal Matrix composites, RSM: Response surface methodology, ANOVA: Analysis of variance, SEM: Scanning electron microscope, EDS: Energy-dispersive X-ray spectrometer, WC: Tungsten carbide, CCD: Central Composite Design

I. INTRODUCTION

Al/ (SiC + Grp)-MMC is one of the important hybrid composites among MMCs, which have silicon carbide and graphite particles in an aluminum matrix. The SiC is harder than tungsten carbide (WC) and graphite particles give tall resistance to the wear in the cross-breed composites. One of the researchers has presented various forms of aluminum alloys and their applications and he concluded that 32.2% of the aluminum was consumed in the transport industry in different forms. As of late present-day industry quickly presenting diverse composites due to their one of a kind properties such as moo thickness and exceptionally light weight with high temperature stability, high hardness and toughness, high damping capacity, high corrosion resistance and wear resistance, in arrange to meet the challenges of liberalization and to preserve worldwide competitiveness in the showcase. MMCs (Metal Matrix Composites) are one of the most advanced man-made materials, which are fabricated by mixing of at least two distinct materials or metals [1]. An MMC mainly consists of two phases i.e. matrix phase and reinforcement phase. Matrix phase (consist a metallic alloy) is the basic part of an MMC which is reinforced with the ceramic phase in the form of particles, fibers (short, long, aligned, and continues) orplatelets [2]. MMCs are used in various industries and structural applications due to their superior sets of mechanical, thermal and environmental properties [2]. By adding the reinforcement into various forms and configurations (short, long, aligned, continue and discontinues) the strength and stiffness of prepared MMC sample is directly affected, so to develop a MMC with required characteristics,reinforcement materials in a particular configuration and compositions must be added, because of this advantage the MMCs are also known as Tailor-made materials [3]. When at least two reinforcements (materials) are added into a metallic matrix phase of MMC, then the composite material is called a hybrid metal matrix composite [3]. For this experimental work, Al 6061 has been used as a matrix phase, whereas SiC_p and Gr_p have been reinforced into three different compositions using the stir casting method [4]. Sic is avery hard ceramic material whereas Gr is very soft. By reinforcement of SiC_p and Gr_p into matrix alloy the "coefficient of friction", "hardness" and many other properties of developed MMC have been improved [2]. The properties and applications of Sic and Gr (reinforcements) are shown in the following table 1 [5].

Table 1: Characteristics and Applications of Sic and Gr reinforcements.

Reinforcements	Properties	Applications
Silicon Carbide (SiC)	Low density	Seal, bearing
	High strength	Ball valve parts
	Low thermal expansion	Hot gas flow lines
	High thermal conductivity	Heat exchangers
	High hardness	Turbine components
	High elastic modulus	
Graphite (Gr_p)	High thermal stability	Refractories
	Electrical conductivity	Batteries
	Good lubricants	Brake linings
	Good corrosion resistance	Lubricants

EDM is a non-conventional method of machining processes, used in modern manufacturing industries due to their effectiveness and economical approach [6]. EDM is mainly used to machine very hard material, alloys (electrically conductive) to any shapes.

Machining parameters (pulse-on time, pulse-off time, voltage, current, tool material, and workpiece material) at 3 levels have been selected through pilot study for our desired response (TWR). Aim of this experimental work is to investigate the significance of process parameters on tool wear rate and to optimize their values during EDM of newly fabricated hybrid MMCs.

Bhanrdare *et al.* (2014) studied the various fabrication processes to develop an AMC (Aluminum matrix composite) and examined that Stir casting is the best and most economical method/process to fabricate a particulate reinforced metal matrix composite [8]. Balaji *et al.* (2015) developed an Aluminum metal matrix composite with improved tribological properties by reinforcing the SiC_p through the stir casting process and inspect the uniform distribution of SiC_p through micro-structure analysis of developed samples [9]. Barenji *et al.* (2016) reported the optimum machining parameters during the electric discharge machining of AISI D6 tool steel. RSM was employed to speculate the optimal condition for maximum MRR and minimum TWR [10]. Goplakamman *et al*. (2012) reported the interaction effect of process parameters on output responses (SR, TWR) and the author also examined that at higher values of pulse-off time and voltage, TWR decreases [11]. Muthuramalingam *et al.* (2015) determined the various electrical process parameters of EDM and also analyzed the empirical relationship between process parameters to find out the best optimum parametric combination in the EDM process so that they can improve the efficiency of the machining process [12]. Qingfeng *et al.* (2014) reported that by improving the properties of electrolyte, lower tool electrode wear can be achieved in EDM and ECM [13]. Balasubramaniam *et al.* (2014) reported an experimental investigation on lower tool wear and surface roughness using RSM to optimize the process parameters. SEM images had been carried out (before and after the machining) to study the microstructure of tools and workpieces [14].

Younis *et al*. (2015) diagnosed the effect of different tool electrode material on electric discharge machining of the steel surface and reported that residual stress is produced in electrodes resulting in high surface roughness and high tool wear rate [15]. U.K. Garg *et al.* (2008) applied Response surface methodology to optimize the ideal process parameters and also analyzed the final results by using mathematical models [16].

Kumar Mishra et al. (2016) has investigated the effects of WEDM machining parameters viz. pulse on time, pulse off time, spark gap set voltage, peak current, wire tension and wire feed on cutting rate, surface roughness, gap current and dimensional deviation during machine of hot die steel, H-11. The experiments were planned and conducted by employing response surface methodology (RSM). Desirability functions approach has been used for simultaneous optimization of performance measures. The machining parameters values were optimized by taking single objective and multi objective function using design expert software.7.0.0 [20].

Kumar Ravinder *et al.* (2017) studied to investigate the influence of input variables (current, duty factor, tool speed and flushing pressure) on surface roughness produced during the electric discharge hole grinding (EDHG). A comparative analysis was also performed between the hole surface produced by the EDD and the EDHG process. The electric sparks used in the EDHG process thermally soften the work material and this softening of material is advantageous in the grinding action. Current was identified to be the key factor affecting the SR of the hole. Duty factor has very little influence during the EDHG process [21].

Periyasamy *et al.* (2019) studied an optimization of friction stir welded (FSW) process parameters (Pin diameter, tool offset and tilt angle) of an aluminium alloys using central composite design in Response surface methodology (RSM). Two types of aluminium alloys were utilized (AA7075-T651 and AA6061) to deliberate the influence of FSW machining parameters on the micro-hardness and ultimate tensile strength of aluminium alloy joints [22].

II. MATERIAL PREPARATION

A. Fabrication of Al-based hybrid MMC

It has been a big challenge to prepare a metal matrix composite with uniform distribution of reinforcement phase and without any microstructure defects. As per requirements, the reinforcement phase has been added into the matrix phase in proper weight composition [2]. Aluminum 6061 is used as a matrix phase, whereas the silicon carbide particles and graphite particles (average size of 75µm each) are utilized as reinforcements. The SiC_p and Gr_p have been reinforced into three different compositions, shown in Table 2.

Table 2: Compositions of SiC_p and Gr_p for three samples.

Reinforcement fillers used	Al MMC-1	Al MMC-2	Al MMC-3
Gr_p	3%	5%	8%
SiC_p	10%	15%	20%

B. Testing of developed samples and electrodes

To confirm and check the uniform distribution of reinforcements (SiC_p and Gr_p) and examined the microstructure of developed samples through scanning electron microscopy (SEM) has been done for each sample, and the same has been done to study the microstructure of electrodes before and after machining. The SEM images of three different composites samples are conducted at the same resolutions are shown in figure.1a-c, and figure.2a-c shown the electrodes SEM images (before machining) at an equal magnification level.

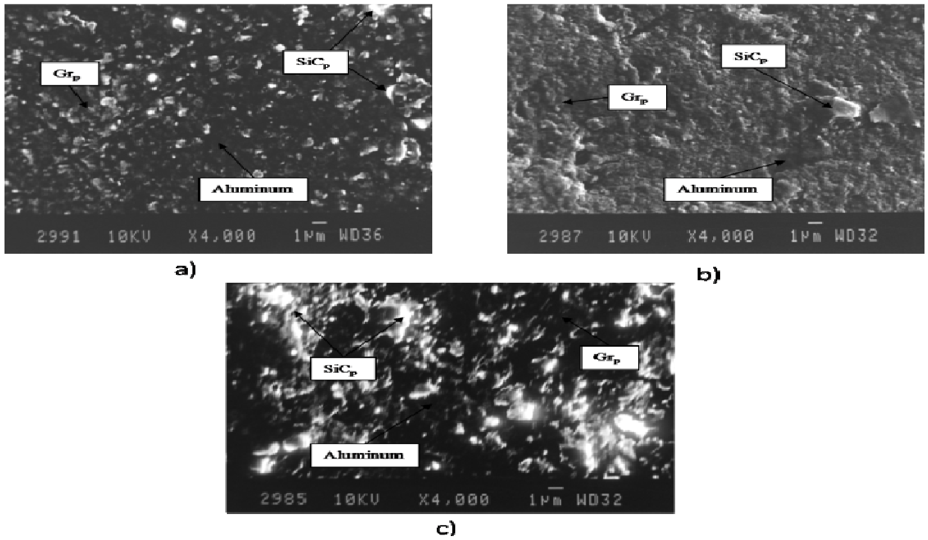


Fig.1. SEM images of three fabricated composites, a) Al MMC-1 (SiCp10% and Grp3%), b) Al MMC-2 (SiCp15% and Grp5%) and c) Al MMC-3 (SiCp20% and Grp8%).

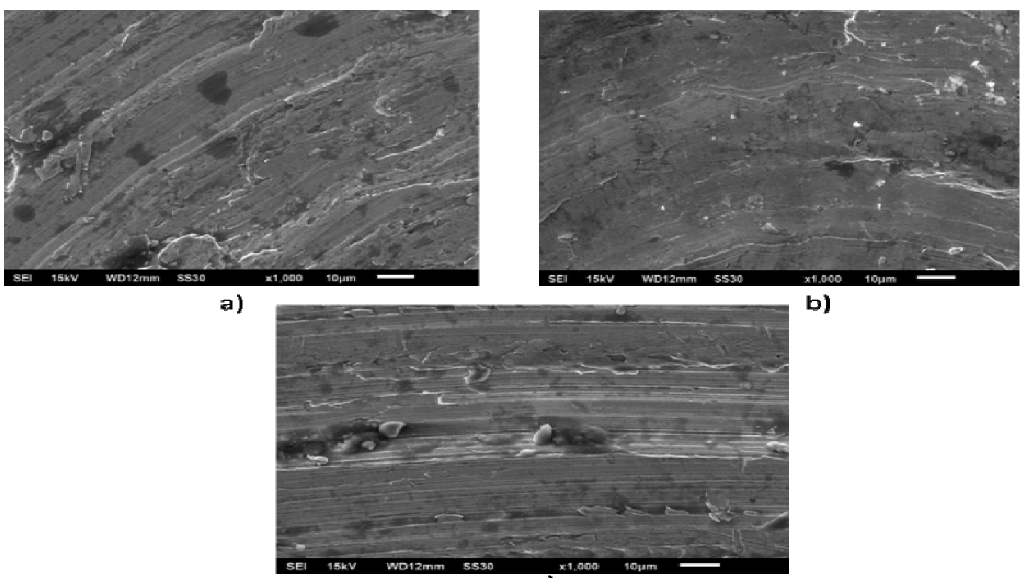


Fig. 2. SEM images (before machining) of three electrodes, a) Steel-304, b) Brass and c) Copper.

III. EXPERIMENTAL WORK

The experiments sheet has been planned for six process parameters each at three levels. The selected machining parameters and their levels are shown in table 3. The designed experiments were performed on the Oscar Max Die-Sinking EDM machine (Taiwan made).

Table 3: Selected machining parameters and their levels.

	Machining parameters						
		Pulse-on time	Pulse-off time	Voltage	Current	Tool	W/p
	Symbols	**T-on**	**T-off**	**V**	**I**		
	Units	**(µs)**	**(µs)**	**(V)**	**(A)**		
Levels	Level 1	30	30	6	10	Steel-304 (-1)	Al MMC-1 (-1)
	Level 2	60	60	7	12	Brass (0)	Al MMC-2 (0)
	Level 3	90	90	8	14	Copper (1)	Al MMC-3 (1)

A. The calculation for TWR (Tool Wear Rate)

To calculate the tool wear rate during EDM the specimen, the weight of the tool was measured before and after machining for each experiment and the time of machining was also recorded. Weighing machine used for recording weight of tool has 0.001g least count and can measure 1000g maximum.

$$\mathrm{TWR} = \frac{\mathrm{Mtbm} - \mathrm{Mtam}}{\mathrm{tm} \times \rho t} \frac{\mathrm{mm}^3}{\mathrm{min}} \quad (1) \quad [10\text{-}11]$$

Where,

Mtbm = mass of tool before machining

Mtam = mass of tool after machining

tm = machining time

ρt = density of tool

B. Response Surface Methodology

The experimentation involved investigation of EDM of Al/ (SiCp+ Grp)-MMC with an objective of minimization of TWR. Six process parameters were selected for investigating their effect on response characteristics of the EDM process. For these experiments, a Face-centered CCD scheme, a popular variant of the central composite design involving three levels for each parameter, has been used to plan the experiments. It is one of the most effective second-order designs capable of handling linear, quadratic, and interaction terms in process modelling. In this experimental work, 52 experimental trials are used to form the design matrix.

The 52 experimental trials were conducted as per the design matrix in random order to avoid any systematic error creeping into the system as shown in table 4. In each trial, the response characteristics viz. MRR, SR and TWR were measured.

Table 4: Measured value of output response during EDM.

Run	Pulse on time (µs)	Pulse off time (µs)	Gap Voltage (V)	Peak Current (A)	Tool Material	W/p Material	TWR (gm/min)
1	0.000	0.000	0.000	0.000	0.000	0.000	0.0144
2	0.000	0.000	0.000	0.000	0.000	0.000	0.0142
3	0.000	0.000	0.000	0.000	0.000	0.000	0.0143
4	0.000	0.000	0.000	0.000	0.000	-1.565	0.0180
5	0.000	0.000	-1.565	0.000	0.000	0.000	0.0159
6	1.000	-1.000	-1.000	-1.000	1.000	-1.000	0.0390
7	1.000	1.000	-1.000	-1.000	-1.000	-1.000	0.0195
8	0.000	0.000	0.000	-1.565	0.000	0.000	0.0117
9	-1.000	1.000	1.000	-1.000	-1.000	-1.000	0.0080
10	0.000	-1.565	0.000	0.000	0.000	0.000	0.0362
11	1.000	-1.000	1.000	-1.000	1.000	1.000	0.0353
12	0.000	0.000	0.000	0.000	0.000	0.000	0.0143
13	-1.000	-1.000	-1.000	1.000	1.000	-1.000	0.0392
14	1.000	-1.000	1.000	1.000	1.000	-1.000	0.0493
15	0.000	0.000	0.000	0.000	0.000	0.000	0.0141
16	1.000	1.000	-1.000	1.000	-1.000	1.000	0.0295
17	-1.000	1.000	-1.000	1.000	1.000	1.000	0.0222
18	0.000	0.000	0.000	0.000	1.565	0.000	0.0240
19	0.000	0.000	1.565	0.000	0.000	0.000	0.0147
20	-1.000	1.000	1.000	1.000	1.000	-1.000	0.0210
21	0.000	0.000	0.000	0.000	0.000	0.000	0.0145
22	-1.000	1.000	1.000	-1.000	1.000	1.000	0.0089
23	0.000	0.000	0.000	1.565	0.000	0.000	0.0323
24	-1.000	1.000	-1.000	-1.000	-1.000	1.000	0.0082
25	1.000	1.000	1.000	-1.000	1.000	-1.000	0.0207
26	-1.000	1.000	1.000	1.000	-1.000	1.000	0.0225
27	1.000	-1.000	-1.000	1.000	-1.000	-1.000	0.0472
28	1.000	-1.000	1.000	-1.000	-1.000	-1.000	0.0325
29	1.000	-1.000	-1.000	-1.000	-1.000	1.000	0.0349
30	0.000	0.000	0.000	0.000	0.000	0.000	0.0142
31	1.000	1.000	-1.000	1.000	1.000	-1.000	0.0297
32	-1.000	-1.000	1.000	1.000	-1.000	-1.000	0.0335
33	-1.000	-1.000	1.000	-1.000	1.000	-1.000	0.0205
34	-1.565	0.000	0.000	0.000	0.000	0.000	0.0062
35	0.000	0.000	0.000	0.000	-1.565	0.000	0.0208
36	1.000	1.000	1.000	-1.000	-1.000	1.000	0.0204
37	0.000	0.000	0.000	0.000	0.000	1.565	0.0193
38	-1.000	1.000	-1.000	-1.000	1.000	-1.000	0.0070
39	0.000	0.000	0.000	0.000	0.000	0.000	0.0144
40	-1.000	-1.000	1.000	1.000	1.000	1.000	0.0377
41	1.000	1.000	-1.000	-1.000	1.000	1.000	0.0207
42	-1.000	1.000	-1.000	1.000	-1.000	-1.000	0.0185
43	1.000	1.000	1.000	1.000	-1.000	-1.000	0.0287
44	1.565	0.000	0.000	0.000	0.000	0.000	0.0250

45	1.000	-1.000	1.000	1.000	-1.000	1.000	0.0455
46	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	0.0210
47	1.000	1.000	1.000	1.000	1.000	1.000	0.0333
48	-1.000	-1.000	-1.000	1.000	-1.000	1.000	0.0368
49	-1.000	-1.000	1.000	-1.000	-1.000	1.000	0.0173
50	-1.000	-1.000	-1.000	-1.000	1.000	1.000	0.0223
51	1.000	-1.000	-1.000	1.000	1.000	1.000	0.0518
52	0.000	1.565	0.000	0.000	0.000	0.000	0.0119

IV. MATHEMATICAL MODELS

The tool wear rate prediction model has been developed using RSM based CCD method. Equation2 reflects the quadratic regression model developed based on RSM for correlating the TWR with machining parameters after eliminating the non-significant terms.

TWR (gm/min) = [+7.94422 +0.020148 x on time -0.047621 x off time -0.55279 x voltage -0.88887 x current -0.033390 x tool -0.15730 x w/p -4.40972E-005 x on time x off time -8.20833E-004 x on time x current +5.41667E-004 x on time x tool -1.43750E-004 x on time x w/p +1.81875E-003 x off time x voltage -8.20833E-004 x off time x current -1.12917E-003 x off time x tool +8.22917E-004 x off time x w/p +5.31250E-003 x voltage x current +3.87500E-003 x voltage x tool +8.84375E-003 x current x tool +0.011625 x current x w/p +3.69302E-005 x on time2 +2.66910E-004 x off time2 +0.025480 x voltage2 +0.047807 x current2 +0.20001 x tool2 +0.10856 x w/p2…]

By increasing the pulse-on time and current the thermal heat energy and the strike rate of charged particles is increased respectively, causes to increase the volume of molten metal of electrodes and leads to a higher TWR.

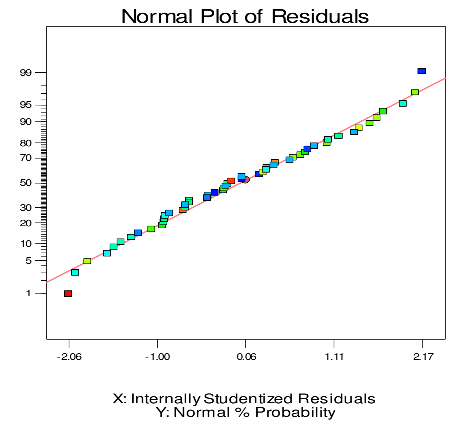
The ANOVA (Analysis of variance) is employed to check out the second-order mathematical model of the above equation, and the result is shown in the following table 5. In this model, the value of "Prob.>F" is less than 0.0500 which indicates that the model is "Significant". Table 5 shows the ANOVA for the reduced quadratic model for tool wear rate by selecting the backward elimination procedure to automatically reduce the terms that are not significant.

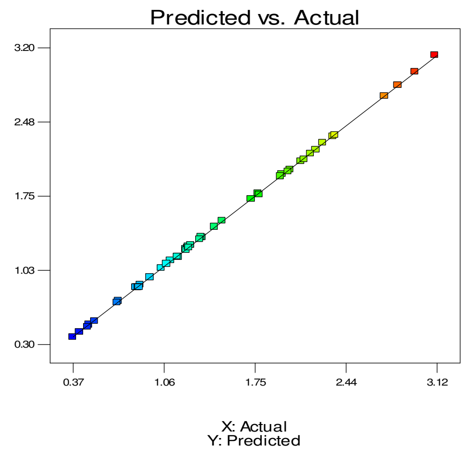
Interaction effects of most of the input parameters are significant as shown in table 5 and figures 3 (a) to (c). The normal probability plot indicates that whether the residuals follow a normal distribution or not. If the residuals follow a normal distribution, maximum number of points should fall on a straight line. If the residuals are lying outside the straight line, it means not completely following the normal distribution. Figure 3 (a) shows the normal distribution plot for residuals. It infers that the residuals fall on a straight line implying that the residuals are distributed normally. Residuals versus the predicted response plot for tool wear rate are shown in Figure 3 (b). For assumption of constant variance to be true, the plot should be a random scatter. The figure reveals no obvious pattern or unusual structure, indicating the validity assumption to be true. The value of "Prob. > F" for lack-of-fit is 0.1022 >> 0.05, that indicates that the lack of fit is still insignificant.

The R^2 value, which is the measure of proportion of total variability explained by the model, is equal to 0.9999 ≅1, is invariably desirable. The adjusted R^2 value is equal to 0.9998; it is particularly useful when comparing models with different number of terms. The result shows that the adjusted R^2 value (0.9998) ≅R^2 value (0.9999).

Table 5: ANOVA table for the reduced quadratic model (response: TWR in gm/min).

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	24.50	24	1.02	8932.41	< 0.0001	significant
A-on time	4.85	1	4.85	42439.86	< 0.0001	
B-off time	7.83	1	7.83	68536.30	< 0.0001	
C-voltage	0.020	1	0.020	173.72	< 0.0001	
D-current	5.74	1	5.74	50229.39	< 0.0001	
E-tool	0.15	1	0.15	1348.10	< 0.0001	
F-w/p	0.019	1	0.019	170.07	< 0.0001	
AB	0.050	1	0.050	441.12	< 0.0001	
AD	0.078	1	0.078	679.30	< 0.0001	
AE	8.450E-003	1	8.450E-003	73.95	< 0.0001	
AF	5.951E-004	1	5.951E-004	5.21	0.0306	
BC	0.095	1	0.095	833.76	< 0.0001	
BD	0.078	1	0.078	679.30	< 0.0001	
BE	0.037	1	0.037	321.37	< 0.0001	
BF	0.020	1	0.020	170.69	< 0.0001	
CD	3.612E-003	1	3.612E-003	31.62	< 0.0001	
CE	4.805E-004	1	4.805E-004	4.21	0.0501	
DE	0.010	1	0.010	87.62	< 0.0001	
DF	0.017	1	0.017	151.39	< 0.0001	
Residual	3.085E-003	27	1.143E-004			
Lack of Fit	2.650E-003	20	1.325E-004	2.13	0.1544	not significant
Pure Error	4.349E-004	7	6.212E-005			
Cor. Total	24.50	51				
Std. Dev.	0.011		R-Squared		0.9999	
Mean	1.42		Adj. R-Squared		0.9998	
C.V. %	0.75		Pred. R-Squared		0.9994	
PRESS	0.014		Adeq. Precision		371.688	





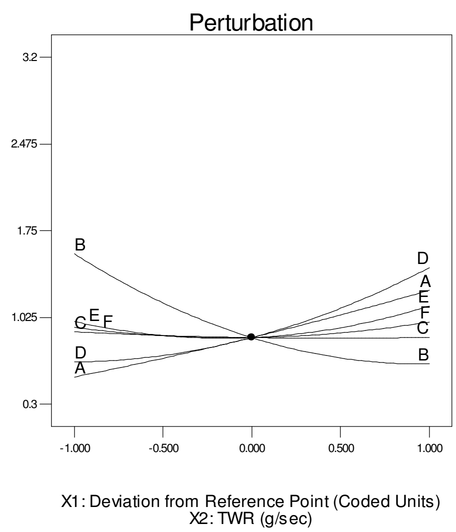


Fig. 3. (a) Normal probability plot of residuals (b) Actual Vs predicted response (c) Perturbation plot.

Adequate precision value is equal to 371.688, which actually is signal to noise ratio; a ratio greater than 4 is desirable, which indicates adequate model discrimination.

A. One parametric effect on TWR

Tool wear rate is a function of EDM input parameters. From the following figures (4 and 5) it is clear that TWR increases with increase in pulse on time whereas decreases with increase in pulse off time while Figure 6and Fig. 7, revealed that, with the increase in peak current TWR increases and tool material have little effect on TWR.

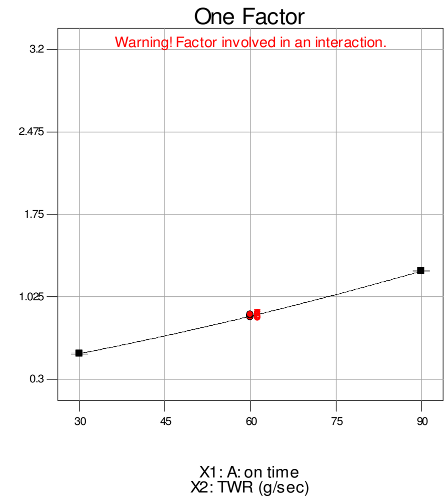


Fig. 4. Effect of pulse on Time (Ton) on TWR.

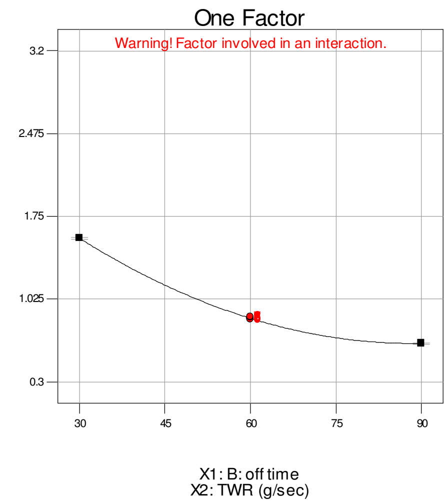


Fig. 5. Effect of pulse off Time (Toff) on TWR.

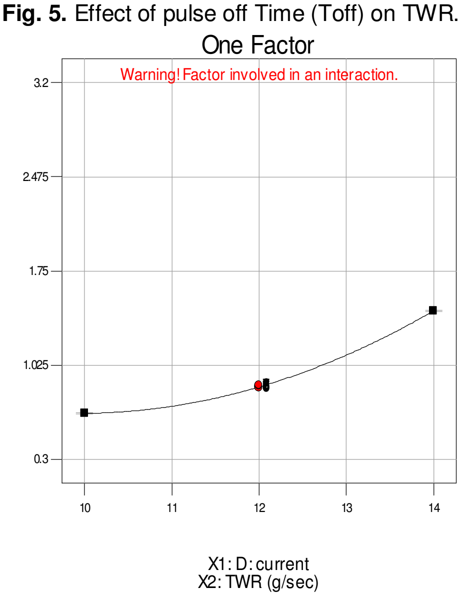


Fig. 6. Effect of current on TWR.

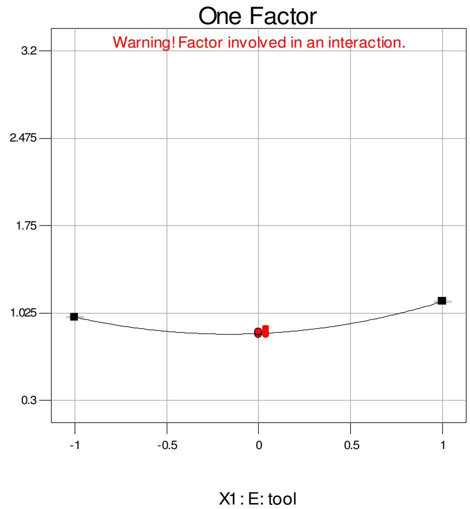


Fig. 7. Effect of tool material on TWR.

B. Parametric interaction effects on TWR

There is a significant effect of the interaction of process parameters on TWR.

As per Figure 8, it is clear that for with an increase in on time and decrease in pulse off time TWR increases. At higher values of pulse off time and lower values of pulse on time TWR is minimum.

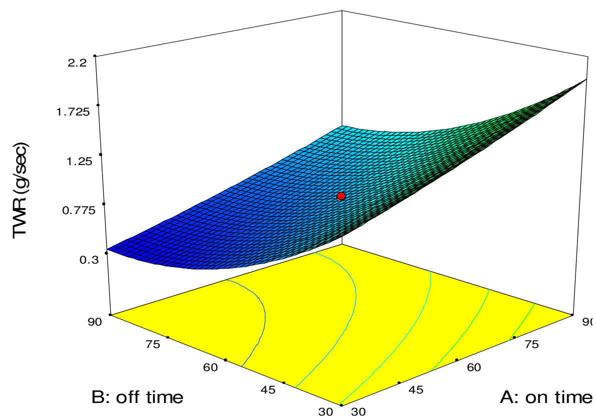


Fig. 8. Interaction effects of Pulse on time and pulse off time on TWR.

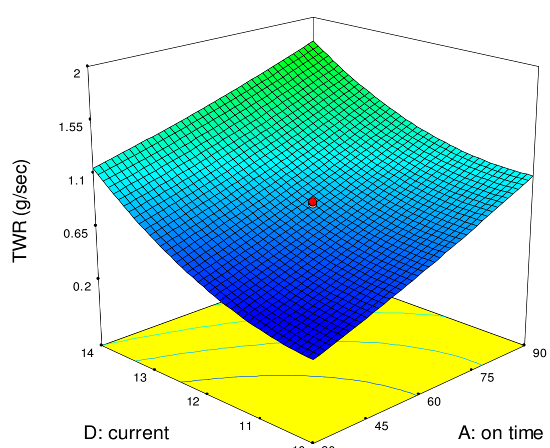


Fig. 9. Interaction effect of Pulse on time and Current on TWR.

From Fig. 9, it is clear that TWR is increasing with an increase in pulse on time and current. TWR is higher at extreme levels of pulse on time and current.

Fig. 10 reflects that TWR is high at higher values of pulse on time but the tool material has little effect on TWR.

Fig. 11 reflects that TWR is high at higher values of pulse on time but the workpiece material has little effect on TWR.

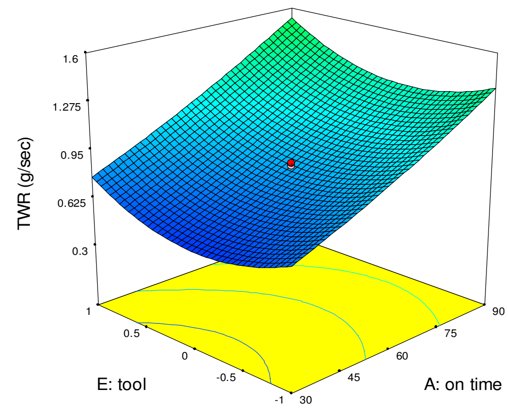


Fig. 10. Interaction effect of Pulse on time and tool material on TWR.

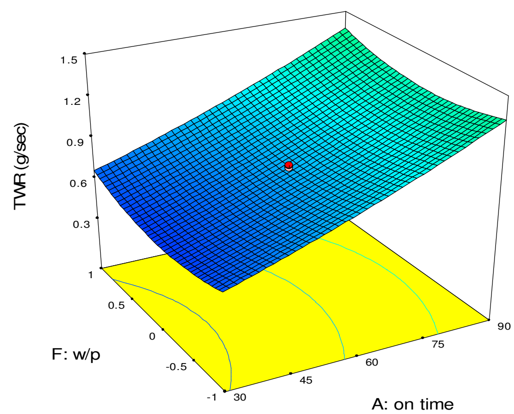


Fig. 11. Interaction effect of Pulse on time and Workpiece material on TWR.

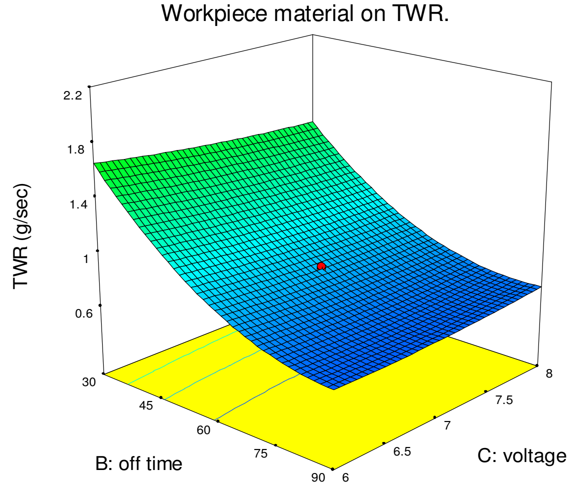


Fig. 12. Interaction effect of Pulse off time and voltage on TWR.

Fig. 12 shows that pulse off time is having an inverse relationship with TWR, as TWR is high at low values of pulse off time, whereas, the voltage has no significant effect on TWR.

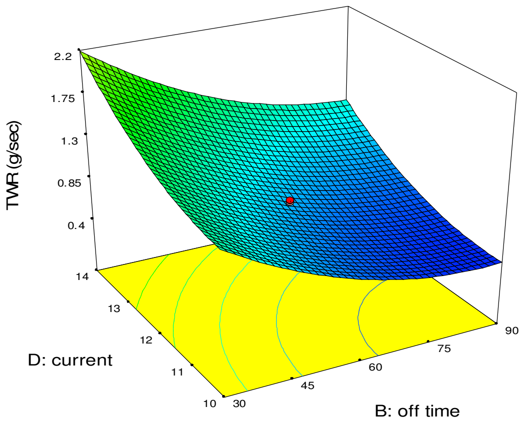


Fig. 13. Interaction effect of Pulse off time and current on TWR.

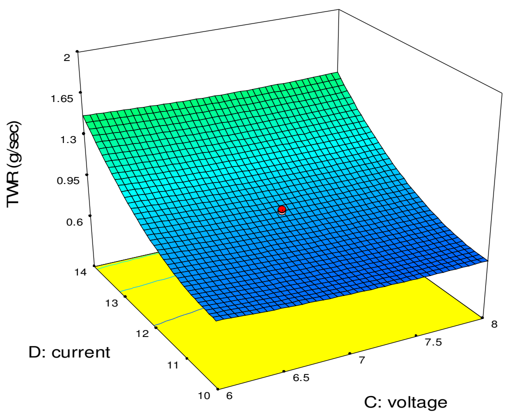


Fig. 14. Interaction effect of current and voltage on TWR.

Fig. 13 represents that TWR is increasing with an increase in current. Whereas, with increase in pulse of time tool wear rate is less.
From Fig. 14, it is clear that voltage does not have anysignificant effect on TWR. Whereas there is almost direct linear relationship between TWR and current. TWR is increasing with an increase in current.

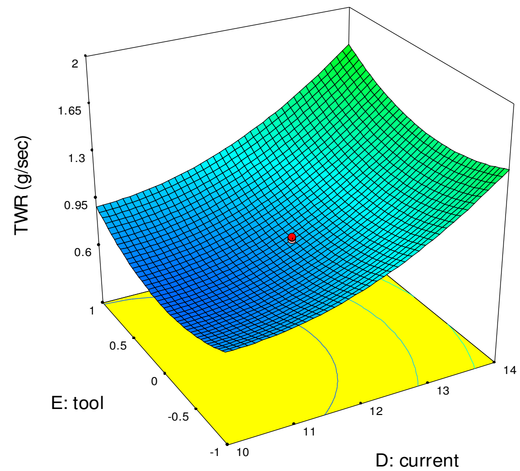


Fig. 15. Interaction effect of tool material and current on TWR.

Fig. 15 reveals that current plays a dominant role in the tool – current interaction as the TWR increases with an increase in current value, whereas, tool material has little effect on TWR.

C. Single objective optimization for TWR

EDM is a sophisticated process to cut any shape in a conductive material, for a quality surface finish tool should have retained its strength. A low TWR will contribute to higher surface finish. So, it is desirable to have low TWR to minimize the overall cost of the product as shown in table 6.Table 7 illustrates single objective optimization for TWR using the Desirability Approach.

Table 6: Single objective optimization for TWR showing influence of selected parameters and their corresponding levels/ranges where our response variable is most desirable.

Constraints						
Lower	**Upper**	**Lower**	**Upper**			
Name	**Goal**	**Limit**	**Limit**	**Weight**	**Weight**	**Importance**
on time	is in range	30	90	1	1	3
off time	is in range	30	90	1	1	3
voltage	is in range	6	8	1	1	3
current	is in range	10	14	1	1	3
tool	is in range	-1	1	1	1	3
w/p	is in range	-1	1	1	1	3
TWR (g/min)	minimize	0.37	3.11	1	1	5

Table 7: Single objective optimization for TWR using the Desirability Approach.

S.No.	Pulse on time	Pulse off time	Voltage	Current	Tool	W/P	TWR (gm/min)	Desirability	
1	30.9672	64.3224	7.45169	10.0431	0.165494	0.946082	0.00782	1.000	Selected
2	30.0072	66.4558	7.64691	10.6329	0.316431	-0.36722	0.00821	1.000	
3	37.1202	82.2857	7.31357	11.4622	-0.25618	0.18471	0.00884	1.000	
4	32.7919	88.954	7.83243	10.2526	0.167034	0.784104	0.00890	1.000	
5	37.0313	79.8364	7.92506	10.0802	0.559466	-0.39770	0.00912	1.000	

Table 8: Confirmatory experiment for TWR.

S. No.	Pulse on time	Pulse off time	Voltage	Current	Tool	W/P	MRR (g/min) Predicted	Exp.	% age Error
1	30	65	7	10	1	1	0.00782	0.00801	2.42

Table 9: Tool-wear rate percentage.

Electrode (code)	TWR percentage (%)
Brass (0)	75%
Steel-304 (-1)	45%
Copper (1)	38%

From Table 7, we can predict that TWR of 0.347 g/min can be achieved if we set to pulse on-time 30 µs, pulse off time 65 µs, Voltage 7V, current 10 A, cooper as a tool and third material as process parameters.
The predicted value by desirability approach has been checked with confirmatory experimentation, and the result is followed in table 8.Table 9 shows percentage tool-wear rate.

V. CONCLUSIONS

The main focus of this experimental work, is to investigate the signification/impact of selected parameters and their levels/ranges where our response variable is most desirable. The desirability approach was employed for this single objective optimization. The 3-D graphs have been generated for analyzing the effect of process parameters using the Design expert 9.0.6 software. The experimental study has led to the following conclusions during machining of Al/ (SiC + Gr)-MMCs through EDM.

1. The most promising parameter is pulse on time followed by pulse off time and peak current. Optimal value of TWRwas recorded as 0.00801 gm/min at 30 µs pulse on time, 65 µs pulse off time, 7.0 V gap voltage, and 10 A peak current.
2. Pulse-on-time, pulse-off-time and peak current are found to be most significant factors affecting response output, whereas, gap voltage and workpiece material have little effect on responses i.e. on TWR.
3. The quadratic regression models for TWR were developed followed by validity experiments. Validity experiments confirmed that the predicted results by developed models for the selected responses are in good agreement with experimental results. The developed models can be effectively used to predict the output response for given set of input parameters in advance.
4. The pulse-on-time and peak current both are the significant parameters that directly affected (increases) the tool wear rate for all three different electrode materials.
5. The TWR is minimum at high level of pulse-off-timebut the gap voltage has a constant effect on TWR.
6. From three different electrode materials (Steel-304, Brass, and Copper), it is identified that the Brass electrodehas high TWR as compare to other two electrodes used for experiments.

ACKNOWLEDGMENT
The authors are thankful to Dr. Umesh Garg of Adesh Institute of Engineering and Technology, Faridkot (India) for his valuable suggestions in RSM and help in simulation work.

Declaration of conflict of interest: The authors declare that they have no conflict of interest.
Funding: The author doesn't receive any research funds or grant from any organization.

Ethical approval: This article does not contain any studies with human participants or animals performed by the author.

REFERENCES

[1]. Kumar, A., Saini, G., Bains, H.S. and Manna, A., (2015). Mechanical behavior of particle reinforced Aluminum matrix composite-A review. *National conferences on mechanical engineering (NCME-2015),* pp: 297-301.
[2]. Alman, D.E., (2001). Properties of metal matrix composites. *U.S department of energy*, Vol. **21**: 838-858.
[3]Johny James, S., Venkatesan, K., Kuppan, P. and Ramanujam, R., (2014). Hybrid aluminium metal matrix composite reinforced with SiC and TiB_2. in: *Procedia Engineering*, Vol. **97**: 1018-1026. DOI: 10.1016/j.proeng.2014.12.379.
[4]. Singh, J., and Chauhan, A.,(2016). Characterization of hybrid aluminum matrix composite for advanced application-A review. *Journal of Materials Research and Technology*, Vol. **5**(2): 159-169.
[5]. Kiliçkap, E., Çakir, O., Aksoy, M. and Inan, A., (2005). Study of tool wear and surface roughness in machining of homogenised SiC-p reinforced aluminium metal matrix composite. *Journal of Materials Processing Technology*, Vol. 164-165: 862-867.
[6]. Velmurugan, C., Subramanian, R., Thriugnanam, S.and Anandavel, B. (2011). Experimental investigation on machining characteristics of Al6061 hybrid metal matrix composite processed by EDM. *International Journal of Engineering, Science, and Technology*, Vol. **3**: 87-101.
[7]. Chomsamuts, K. and Somkiat, J. (2012). Optimization parameters of tool life material using the Taguchi approach and Response surface methodology. *International Journal of computer science*, Vol. **9**: 120-125.
[8]. Bhandare, R.K.G. and Sonawane, P.M.,(2014). Preparation of aluminum metal matrix composite using stir casting method. *International journal of engineering and advanced technology*, Vol. **3**: 148-155.
[9]. Balaji, V., Sateesh, N. and Hussain, M.M. (2015). Manufacturing of Aluminum metal matrix composite (Al 7075-SiC) by stir casting technology. *Materials today proceedings*, Vol. **2**(4-5): 3403-3408.
[10]. Barenji, R.V., Pourasl, H.H. and Khojastehnezhed, V.M., (2016). Electric discharge machining of AISI D6 tool steel: Prediction and modeling of the material removal rate and tool wear ratio. *Precision Engineering*, Vol. **45**: 435-444.
[11]. Gopalakannan, S., Senthilvelan, T. and Ranganathan, S., (2012). Modeling and optimization of EDM process parameters on machining of Al7075-B4C MMC using RSM. in: *Procedia Engineering*, Vol. **38**: 685-690.

[12]. Muthuramalingam, T. and Mohan, B., (2015). A review on influence of electrical process parameters in EDM process. *Archives of civil and mechanical engineering*, Vol. **15**(1): 87-94.
[13]. Yin, Q., Wang, B., Zhang, Y., Ji, F. and Liu, G., (2014). Research of lower tool electrode wears in simultaneous EDM and ECM. *Journal of Materials Processing Technology*, Vol. **214**: 1759-1768.
[14]. Balasubramanian, P. and Senthilvelan, T., (2014). Optimization of Machining Parameters in EDM Process using Cast and Sintered Copper Electrodes. *Procedia Materials Science*, Vol. **6**: 1292-1302.
[15]. Younis, M.A., Abbas, M.S., Gouda, M.A., Mahmoud, F.H. and Abd Allah, S.A., (2015). Effect of electrode material on electrical discharge machining of tool steel surface. *Ain Shams Engineering Journal*, Vol. **6**: 977-986.
[16]. Garg, U.K., Kaur, M.P., Garg, V.K. and Sud, D., (2008). Removal of Nickel (II) from aqueous solution by adsorption on agriculture waste biomass using a response surface methodological approach. *Bioresource Technology*, Vol. **99**(5): 1325-1331.
[17]. Olmez, T., (2009). The optimization of Cr(VI) reduction and removal by electrocoagulation using response surface methodology. *Journal of Hazardous Materials*, Vol. **162**(2-3): 1371-1378.
[18]. Garg, U.K., Kaur, M.P., Sud, D. and Garg, V.K., (2009). Removal of hexavalent chromium from aqueous solution by adsorption on treated sugarcane bagasse using a response surface methodological approach. *Desalination*, Vol. **249**(2): 475-479.
[19]. Singh, K. and Garg, H.K., (2015). Comparison of Tool Material Performance on HYBRID Material for surface Roughness. *International Journal on Emerging Technologies*, Vol. **6**(2): 139-144.
[20]. Kumar, A., Singh, H. and Garg, H.K., (2016). Optimization of Material Removal Rate (MRR) and Surface Roughness (SR) while Turning of Hybrid Aluminium Metal Matrix Composite on CNC Lathe Using Response Surface Methodology (RSM). *International Journal on Emerging Technologies*, Vol. **7**(1): 117-125.
[21]. Kumar, R., Singh, A. and Singh, I., (2017). Electric discharge hole grinding in hybrid metal matrix composite. *Material and Manufacturing processes*, Vol. **32**(2): 127-134.
[22]. Periyasamy, Y.K., Perumal, A.V. and Kunnathur, B., (2019). Optimization of process parameters on friction stir welding of AA7075-T651 and AA6061 joint using response surface methodology. *Materials Research* Express, 6, 096558. DOI: https://orcid.org/0000-0002-7175-5705.

How to cite this article: Garg, H.K., Kumar, R., Manna, A. and Sharma, S. (2019). Mathematical Modelling and Parametric Optimization for Tool Wear Rate of Hybrid Aluminum Metal Matrix Composite Reinforced with SiC_p and Gr_p. *International Journal of Emerging Technologies*, **10**(2): 307–316.