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Optimization of hole overcut in electrical discharge machining of newly engineered Al-22%SiC metal matrix composite

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Abstract

In view of widespread demand of engineered metal matrix composites particularly in automobile, electricity, aviation industries; the achievement of desired form is a really tough challenge. This work addresses on predictive optimization of hole overcut in electrical discharge machining of newly engineered Al-22%SiC MMC using response surface methodology. Machining trials are performed under varied process conditions (flushing pressure, discharge current, pulse-off-duration, gap voltage, pulse-on-duration) according to Box-Behnken design. Using desirability function analysis of RSM, the optimum cutting solution was preferred at 1.16 V, pulse-off-time of 11μs, discharge current of 8.38 amp and flushing pressure of 0.5 kgf/cm^2. The predicted hole overcut was found as 0.2497 mm. The Al-SiC MMC machining data would be beneficial to the industry.

Keywords: Al-22%SiC MMC; EDM; Overcut; RSM

1. Introduction

In recent years, the demand of hard and brittle materials is increasing in many fields, especially in aerospace field, medical device and optical industry. One of the main issues for manufacturing with today's technology is ensuring the specified product in an effective and the most economical way. In the present scenario, MMCs have expanded their different industrial applications to attain high levels of efficiency because of their unique characteristics (high specific strength, excellent resistance to thermal distortion, wear & corrosion, and light-weight than traditional materials) [1]. From commercial production point-of-view, the conventional machining processes are incompetent in terms of machining of aluminum-based MMC within an acceptable tolerance limit. In fact, these MMCs can often be difficult-to-machine due to possession of increased reinforcement strength and hardness. Owing to highly flexible manufacturing versatility, electrical discharge machining is the most common non-traditional machining method exercised for removal of extremely hard materials effectively with complex-integrate shape in the manufacturing for miniaturization of given developments within the province of aerospace, defense, automobile, electronic, and nuclear industries. It employs a thermoelectric source of energy to cut electrically conducting materials irrespective of hardness. The process of material removal by controlled erosion via a series of pulsating electric sparks causes melting and vaporization of metal to produce almost a stress-free finished surface [2].

Despite everything, in view of the complex-dynamic performance of the EDM mechanism including its strong links in consequence of the different variables, achieving the high production efficiency from technologically-economic perspective is important. Various factors that influence the cutting phenomena during EDM are: dielectric flushes (dielectric fluids & its flushing pressure), electrode & workpiece materials, electro-spark variables (voltage, discharge current, pulse duration, frequency), and others. Proper machining criteria for optimum process efficiency is still a difficult task, as modern technical approach enables significant progress in decision making. [1]For this reason, researchers have approached various statistical [3-13] and computational [14-18] methods in their works for predictive optimization in EDM process with a view to control

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and to minimize the dimensional deviation machined part without compromising the surface quality.

Table 1. Literature overview

Ref.	Electrode materials	Workpiece material	Process parameters	Dielectric medium	Machining characteristics	Technique
[19]	Copper, brass, stainless steel	Al6061-SiC MMC	Current intensity, pulse duration, duty cycle	Kerosene	MRR, Ra, EWR	RSM
[20]	Copper	Al/SiC MMC	Peak current, pulse on time, gap voltage, volume fraction of SiC in Al matrix	Kerosene	MRR, Ra, EWR, OC	RSM
[21]	Copper	Al-Mg_2Si MMC	Voltage, current, duty factor, pulse on time	Paraffin	MRR, EWR	RSM
[22]	Copper	Al–SiC MMC	Voltage, peak discharge current, pulse off time, pulse on time,	Kerosene	MRR, Ra, EWR	RSM
[23]	Copper	Aluminium-multiwall carbon nano tube MMC	Machining-on time, total depth of cut, discharge current, voltage,	Kerosene	MRR, Ra, EWR	Taguchi method, RSM

As per with existing literature till due, only one study [1] have explored on Al-22%SiC based MMC machining via EDM. In view of machined hole overcut was not intensively highlighted in absence of surface roughness, MRR, electrode wear rate. Though, literatures related to application of response surface methodology for predictive optimization in hard turning are available in large numbers [19-23] as presented in Table 1, unfortunately there has been no systematic study. In perspective to fill the research gap as stated above, this work focused on machined hole overcut during electric discharge machining of newly engineered Al-22%SiC metal matrix composite under the influence of cutting parameters (flushing pressure, gap voltage, pulse-on-time**,** discharge current, pulse-off-time). Predictive optimization of hole overcut in EDM employing response surface methodology in order to improve the dimensional deviation of machined part.

2. Experimental setup and procedure

A newly engineered Al-22%SiC metal matrix composite of circular plate (size: 65mm diameter and 5 mm thickness) is chosen as work material to perform machining trials on a high accuracy electrical discharge machine (ECOWIN, MIC 432CS). Domestically available ecofriendly, bio-degradable vegetable oil and brass rod (size: diameter of 9mm) are respectively chosen as dielectric medium and electrode material during machining. During experimental trials at each parameter settings, CMM device manufactured by ZEISS (model: MC850) embedded with the stylus probe was employed for measurement of machined hole overcut (OC). The number of machining trial were designated according to Box-Behnken design, considered based on RSM which is associated with five control factors each of having three levels namely discharge current (5, 10, 15 Amp), gap voltage (1, 1.5, 2 V), pulse-on-time (100, 200, 300 µs), flushing pressure (0.2, 0.4, 0.6 kgf/cm^2), pulse-off-time (10, 20, 30 µs). BBD is a three levels DOE since it has no points at the vertices of the experimental domain like CCD. It might be useful if the points in the corners of a cube indicate levels that cannot be assessed or exorbitantly costly due to physical process constraints. In contrast to the popular CCD, BBD has excellent symmetry and rotatability and also develops minimum experimental executions and provides maximum information. In this design, the treatment combinations are at the midpoints of the edges of the cube and at the centre, as shown in Figure 1. Experimental layouts results consisting of forty-six runs are presented in Table 2.

Table 2. Experimental plan layout and results

Trial no.	Machining process parameters					Machining response
	DC (Amp)	GV (V)	T_{ON} (μs)	T_{OFF} (μs)	FP (kgf/cm^2)	OC (mm)
1	10	2	200	20	0.60	0.3102
2	10	2	300	20	0.40	0.322
3	15	1	200	20	0.40	0.3756
4	5	2	200	20	0.40	0.3578
5	10	1.5	300	20	0.60	0.3067
6	10	1.5	200	30	0.20	0.3307
7	10	1	200	10	0.40	0.2596
8	15	2	200	20	0.40	0.3542
9	10	1	100	20	0.40	0.3096
10	10	1.5	300	10	0.40	0.2726
11	10	1.5	100	30	0.40	0.2829
12	10	2	200	30	0.40	0.2894
13	10	1.5	200	20	0.40	0.2964
14	10	1.5	300	30	0.40	0.3212
15	10	1.5	100	20	0.60	0.281
16	10	1	200	20	0.60	0.3249
17	5	1.5	200	20	0.20	0.3066
18	10	1	200	20	0.20	0.3266
19	10	2	200	20	0.20	0.3297
20	15	1.5	300	20	0.40	0.3577
21	15	1.5	200	20	0.20	0.3876
22	10	1	200	30	0.40	0.389
23	10	1.5	100	10	0.40	0.2979
24	10	1	300	20	0.40	0.2745
25	10	1.5	200	20	0.40	0.3019
26	5	1	200	20	0.40	0.3203
27	15	1.5	200	20	0.60	0.3318
28	10	1.5	200	20	0.40	0.2995
29	10	1.5	200	20	0.40	0.3008
30	10	1.5	200	20	0.40	0.2984
31	5	1.5	200	30	0.40	0.3587
32	10	1.5	200	10	0.60	0.2978
33	10	1.5	100	20	0.20	0.3184
34	10	1.5	200	30	0.60	0.3097
35	5	1.5	100	20	0.40	0.3217
36	5	1.5	200	10	0.40	0.2719
37	5	1.5	200	20	0.60	0.3437
38	10	1.5	200	20	0.40	0.2984
39	15	1.5	200	10	0.40	0.3704
40	15	1.5	100	20	0.40	0.3432
41	10	1.5	300	20	0.20	0.3025
42	15	1.5	200	30	0.40	0.3579
43	10	1.5	200	10	0.20	0.312
44	10	2	100	20	0.40	0.2934
45	10	2	200	10	0.40	0.3787
46	5	1.5	300	20	0.40	0.3182

Figure 2 illustrates the graphical presentation of the method followed for machining setup and analysis of experimental results.

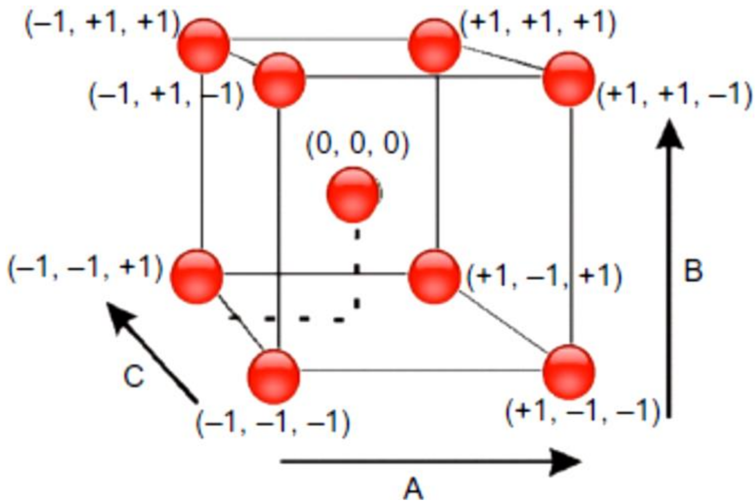

Fig. 1. A graphical representation of Box-Behnken design

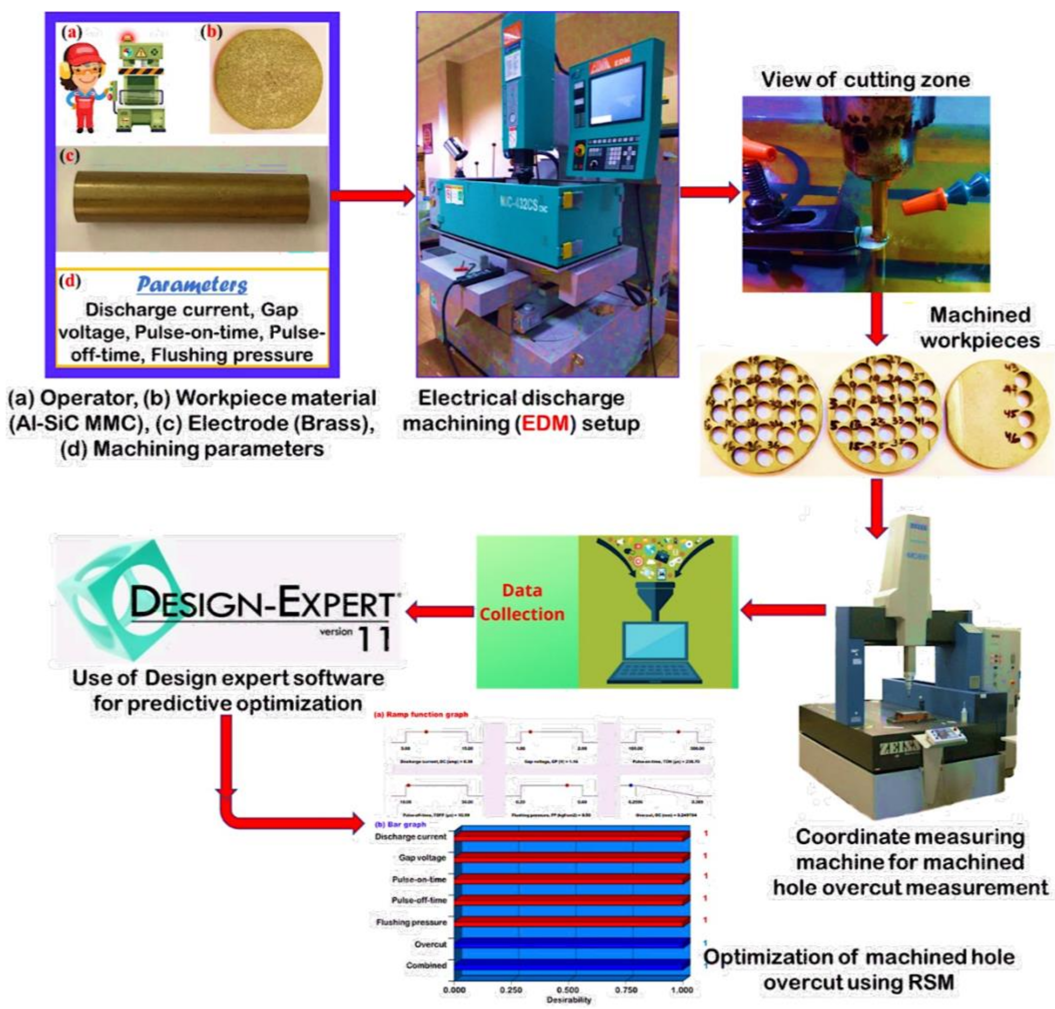

Fig. 2. Schematic presentation of machining setup and methodology followed for experimental investigation process

3. Parametric analysis on machined hole overcut

The influence of machining variables on overcut, OC was examined by employing three-dimensional surface response plot. It is evident from Figure 3a that EDM with increasing discharge current degrades surface finish for the most part which may be because of increased current density and spark energy, which clearly agrees with the previous studies [2,17,24]. The influence of peak current contributes to increase in discharge energy per spark, and accordingly transferred considerable thermal energy to machined upper surface which in comparison to the subsurface leads to more material evaporation and consequently uneven dimensional deviations of hole leading to increasingly overcut (refer, Figure 4). The selected cutting conditions enlisting maximum geometric shape deformation of hole occurs at FP= 0.4kgf/cm^2; T_{on}= 200µs; T_{off}= 20µs; GV= 1V.

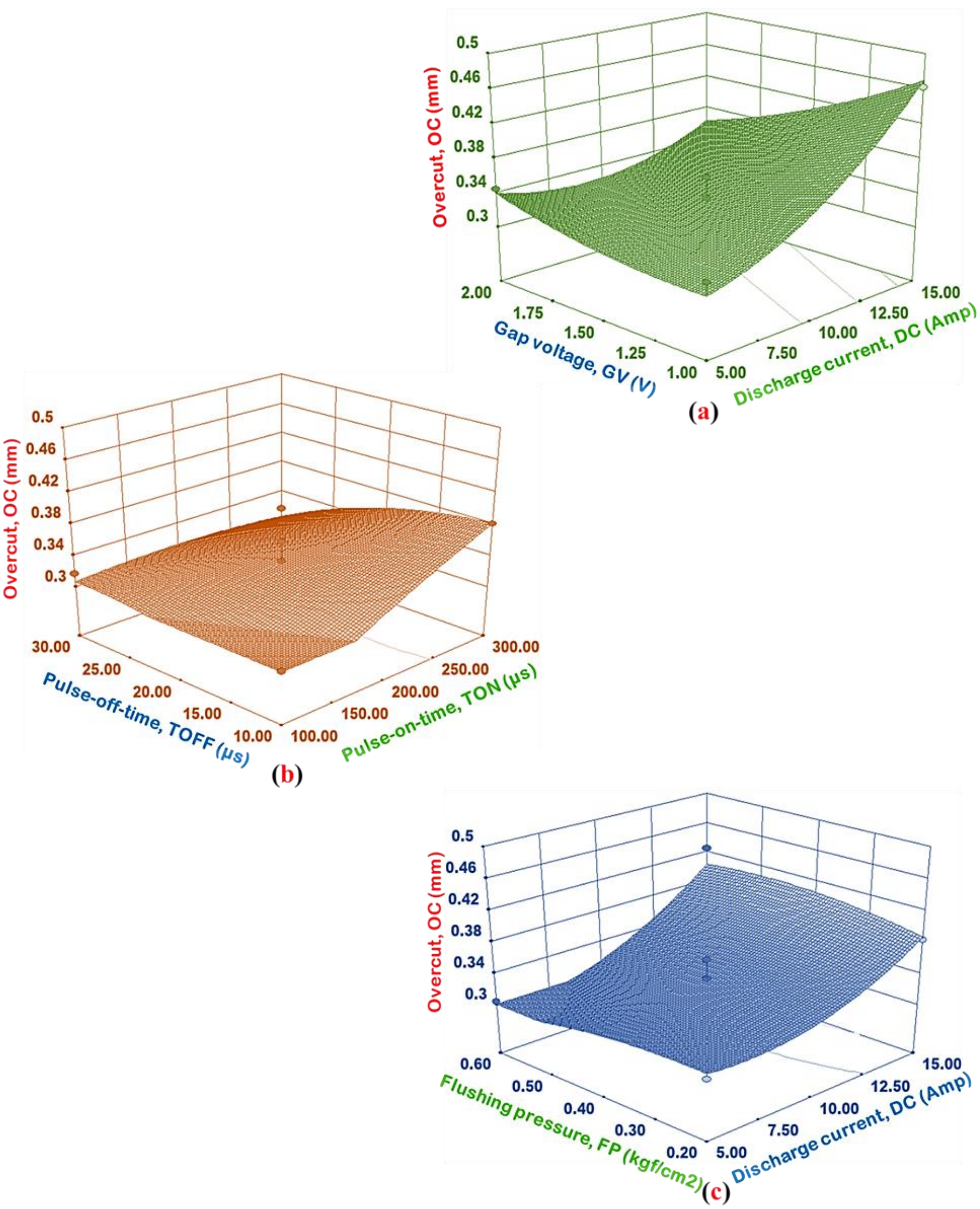

Fig. 3. 3D response plot for overcut under the interaction effects of process parameters: (a) GV-DC, (b) $T_{on} - T_{off}$, (c) DC-FP

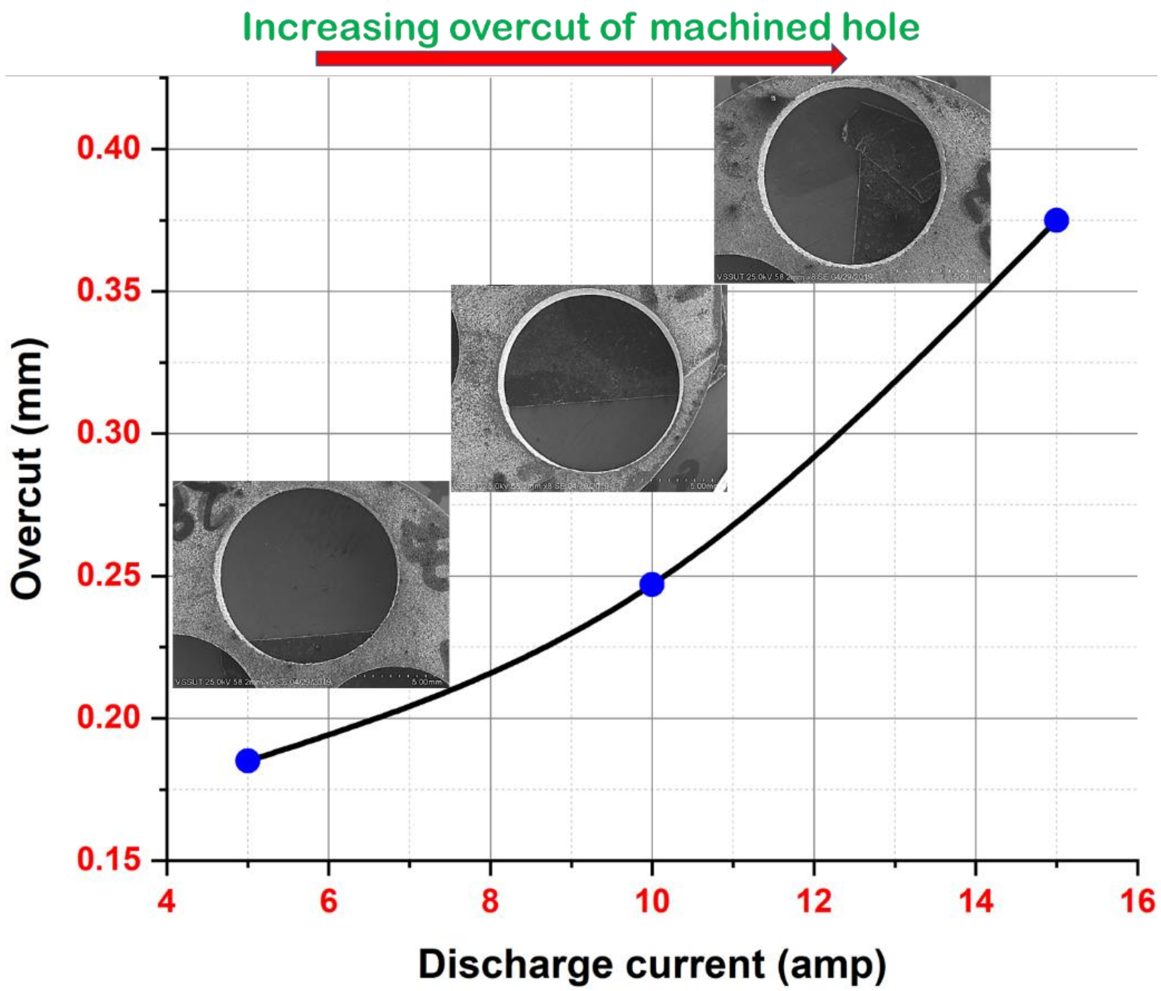

Fig. 4. Dimensional deviation of EDMed hole quality under varied discharge current

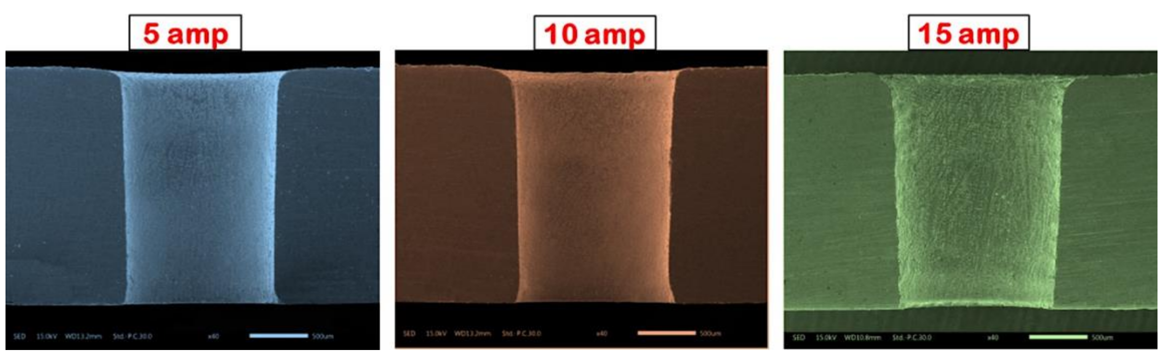

Fig. 5. Effect of discharge current on machined inside hole wall quality at FP= 0.4kgf/cm^2; T_{OFF}= 20μs; GV= 1V; T_{ON}= 200μs.

Figure 5 presents the SEM micrographs illustrating the sectional view of side wall of machined hole at varying discharge peak current. It is to be noted that machining with lower peak current, the side wall surface of hole formed on Al-22%SiC MMC is recommendable than that obtained at higher peak current. This is attributed to lower degree of tool electrode wear as result of limited current density during pulse-on-duration at low discharge current when it compared with high DC value. It is also evident that with the increase in discharge current of 5 to 15 Amp, hole taper rises progressively. This can be explained by the fact heat energy per unit area might lead to a high weary tool leading the tool electrode tip shape to be deteriorated. Therefore, a geometric deviation of the hole as an increasing hole taper is produced. From 3D response graph for overcut (Figure 3b), it is to be noted that OC is increasing with the increase of pulse-on-duration. The reason for that the availability of energy for removal of material in a specified duration is participated with a smaller extent by substantial numbers of sparks at higher pulse-on-duration. Therefore, exploiting uneven deeper-larger crater marks at the wall edge of the machined hole (due to increased MRR) and results in increased overcut. In addition, lesser amount of metal is removed through smaller pulse-on-time and approached to better surface finish by reason of moderate thermal damage to the machined component which develops improved hole accuracy. The forced circulation of the dielectric leads to marginal improvement in hole dimensional deviation because of decrease overcut. From Figure 3c, it was deduced that overcut decreased with flushing pressure as it avoids short circuiting and stagnation of flushing fluid during EDMing.

4. Optimization using response surface methodology

Recent past, one of the best suitable technique of optimization for multi-objective and multiple responses in the metal cutting process is the desirability function analysis. Basically, it is based on multicriteria decision making. Desirability is an objective function that translates each response in the scale ranging from zero outside of the limits to one at the goal. The variables result undesirable response, if the value is 0 while the value 1 is the best performance (i.e., highly desirable) for the studied variables. After the desirability functions are established for each different response variables depending on its objectives, an overall desirability function is established, which is obtained by combining the geometric mean of distinctive desirability function. Once of the overall desirability is established, it can be used for optimal solution of predictors or responses. The Present work deals with desirability optimization methodology for minimization machined hole overcut. Such task for the predicting the optimal solution to the response (OC) was obtained using standard statistical software package Design Expert 11. For solving the optimization problem, the individual desirability function for the abovementioned output is stated as [25],

$$d_i = \begin{cases} 1 & if\ y_i \leq l_i \\ \left[\frac{u_i - y_i}{u_i - l_i}\right] & if\ l_i \leq y_i \leq u_i \\ 0 & if\ \ y_i \geq u_i \end{cases} \tag{1}$$

whereas, the overall desirability can be expressed as,

$$D = \left(\prod_{i=1}^{N} d_i\right) \tag{2}$$

l_i and u_i are the lower and upper observation estimates of studied output. N denotes number of response variables and y_i implies predicted value for the i^{th} response.

The RSM optimization results for OC are presented in Table 3. The optimum solution having maximum desirability value (i.e., approaches to 1) were sorted out on ramp function plot, as shown in Figure 6a. Optimal settings are indicated as points on each ramp graph which results in maximum desirability value. A bar plot is shown in Figure 6b that presents the individual desirability value of 1. As seen from Figure 6, the optimum cutting solution is preferred at pulse-on-duration of 238.7 µs, discharge voltage of 1.16 V, pulse-off-duration of 11µs, discharge current of 8.38 Amp and flushing pressure of 0.5 kgf/cm^2. The hole overcut of value 0.2497 mm was found at the optimum parametric machining conditions.

Table 3. RSM optimization results for overcut

No.	DC (Amp)	GV (V)	T_{on} (μs)	T_{off} (μs)	FP (kgf/cm^2)	OC (mm)	Desirability
1	8.38	1.16	238.7	11	0.50	0.24970	1
2	7.45	1	103.64	10	0.54	0.26069	0.992
3	11.76	2	100	28.83	0.27	0.26520	0.957
4	10.55	2	134.49	30	0.27	0.27063	0.915
5	12.62	2	226.93	30	0.49	0.28074	0.839
6	10.77	1.52	100	18.60	0.6	0.28101	0.835
7	11.36	2	239.03	29.93	0.6	0.28335	0.816

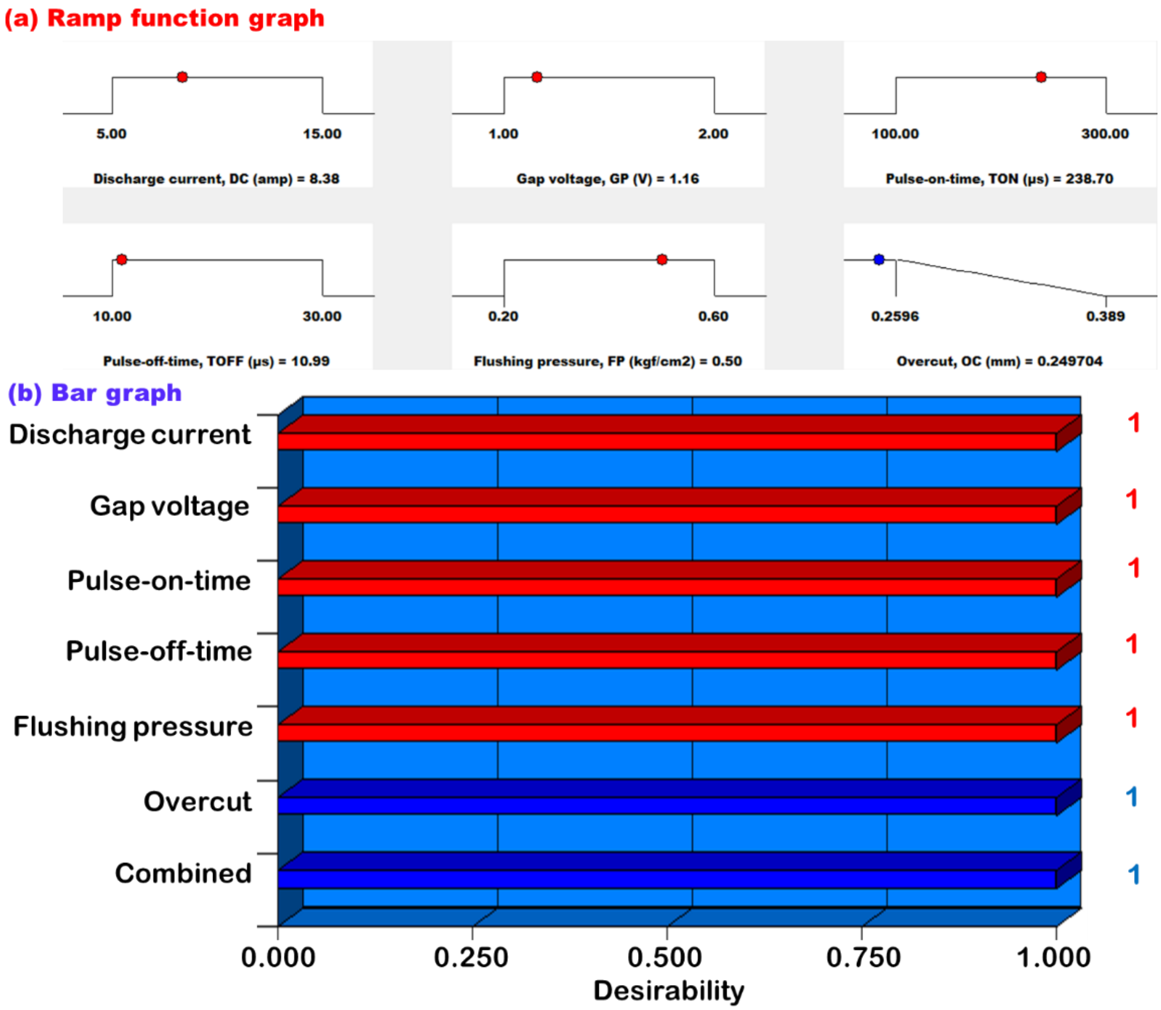

Fig. 6. Optimization results using desirability function analysis

5. Conclusion

Effect plot reported that, the dimensional deviation of hole (in particular overcut) developed from EDMing is due to increase of discharge current and pulse duration. Using desirability function analysis of RSM, the optimum cutting solution was preferred at 1.16 V, pulse-off-time of 11μs, discharge current of 8.38 Amp and flushing pressure of 0.5 kgf/cm^2. The predicted hole overcut was found as 0.2497 mm. The research outcomes along with proposed predictive design optimization will offer useful practicable information for difficult-to-machine Al-SiC MMC.

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