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Investigation on Machining Characteristics of Al 6061 Hybrid Metal Matrix Composite Using Electrical Discharge Machining

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Abstract: It is necessary to develop a new modern manufacturing process and machining techniques to ensure the high surface finish and metal removal rate of the composite. The most of the problem is raised in machining of composite due to the high hardness and stiffness. The research work is mainly concentrate on the effect of Electrical Discharge Machining (EDM) parameters on the predominant machining criteria. The aluminium based metal matrix composite reinforced with silicon carbide, aluminium oxide and E- glass fiber are fabricated by stir casting technique. The Al based metal matrix composite reinforced with 5 % wt of Al_2O_3, 3% wt of SiC and 2% wt of E-glass short fiber are used as work material, the copper material is used as an electrode. The input parameters are selected in EDM like current, pulse on time and pulse off time to measure the metal removal rate (MRR), tool wear rate and surface roughness. The optimal conditions of input parameters are found by using Box-Benhken design of experiments of response surface methodology (RSM).

Key words: EDM · E- glass fiber · MMC · MRR · RSM and Surface Roughness

INTRODUCTION

Composite materials are gradually becoming important material for their scope and applications in manufacturing industries due to their high fatigue strength, thermal shock resistance, high strength to weight ratio and high hardness. Engineering composite has got wide industrial applications in many engineering industries. Hence, it is essential for developing an efficient machining method for processing advanced materials at good manner. However the improved properties of the aluminium based MMCs have new challenges to the new manufacturing engineers as often haunted by the needs of machining those materials economically, efficiently and also attempting to specify the precision and accuracy. It has been arisen for developing efficient, accurate as well as cost effective machining methods for processing the aluminium based MMCs.

Literature Survey: S. Sureshkumar, M. Uthayakumar, S. Thirumalai Kumaran, P. Parameswaran and E. Mohandas [1] have investigated the effect of parameters of hybrid Al 6351 metal matrix composites reinforcement with 5% wt of SiC and 10% wt of boron carbide. In this experimental work is to optimize the EDM parameters of the Aluminium alloy (Al 6351) matrix reinforced with 5% wt of silicon carbide (SiC) and 10% wt of boron carbide (B_4C) particles fabricated through the stir casting route. The result shows that the pulse current contributes more (83.94%) to affecting the combined output responses. C. Velmurugan, R. Subramanian, S. Thirugnanam, B. Ananadavel [2] have investigated the effect of parameters of hybrid Al 6061 metal matrix composites reinforced with 10 % wt of SiC and 4% wt of graphite particles.The metal removal rate of the composite increases with increase in current, pulse on time and flushing pressure of the dielectric fluid while it decreases with increase in voltage. S.Gopalakannan, T.Senthilvelan and S.Rananathan [3] have investigated the modelling and optimization of EDM process parameters on machining of Al 7075-B_4C MMCs using RSM.The material removal rate first increases with an increase in pulse on time and then decrease with further increase in pulse on time. A.B. Puri and B. Bhattacharyya [4] were carried out the mathematical modelling of white layer depth to correlate the dominant input parameters of the WEDM process, comprising of a rough cut followed by a trim cut. The individual influences of all process parameters on white layer depth have been analyzed based on the developed mathematical model.

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Material Details: In this work Al 6061 alloy was taken as matrix material because of it has good mechanical properties and also it exhibits good weldability. Al_2O_3, SiC and E-glass fiber are taken as the reinforcement material. When adding Al_2O_3 into the matrix material may be enriching hardness and melting point of the composite material. Due to an addition of SiC the strength and hardness may be increased with low density. The tensile strength, chemical resistance and corrosion resistance is increased in the composite material because of the addition of E-glass fiber.

Fabrication of Composite Material: Aluminium 6061 alloy serves as the matrix and aluminium oxide, silicon carbide and E-glass fiber are used as the reinforcement materials. The percentage of composite is fixed as 90% wt of Al 6061, 5% wt of Al_2O_3, 3% wt of SiC and 2% wt of E-glass short fibers. Stir Casting is the simplest and better method for liquid state fabrication, so that Stir casting technique has been adopted for composite fabrication. The stir casting furnace is mounted on the floor and the temperature of the furnace precisely measured and controlled to achieve sound quality composite. Two thermocouples and one PID controller are used for knowing the molten metal temperature during melting. Initially, graphite crucible furnace is heated up to 320°C for reducing moisture content in the electric crucible furnace. The measured quantity of Al 6061 alloy is melted in a graphite crucible in an induction type electric furnace of a stir casting setup. The temperature of the melt was around 950°C. After melting and degassing of the alloy of nitrogen, a simple mechanical four blade alumina coated stirrer was introduced into the melt and stirring was started. The blades of the stirrer are coated to avoid migration of the ferrous ions from the stirrer into the molten metal. The stirrer is rotated at a speed of 800 rpm for ten minutes. The depth of the immersion of the stirrer was maintained about two - thirds the depth of molten metal. The pre -heated 5% wt of Al_2O_3 is added to the molten metal after melting the stirrer is rotated and then 3%wt of SiC is added and repeat the same process itself then finally 2% wt of E-glass short fiber is added and allow them to complete melting and then the stirrer is used to mix these reinforcements into the base metal of Al 6061 alloy. To achieve good bonding between the matrix and particulates, one weight percent of a magnesium alloy is added. After complete melting the pouring temperature is maintained around 720°C then molten metal poured into the prepared mould die. The experimental setup is shown in Figure 1 and mould die in Figure 2.

Fig. 1: Stir casting apparatus

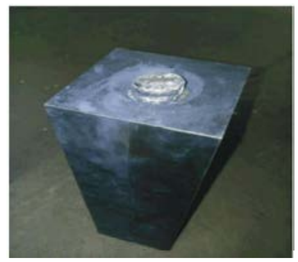

Fig. 2: Moulding Die

Specimen Preparation: The fabricated composite materials are cleaned, separated and then it is machined in conventional lathe then to prepare specimens for EDM machining as shown in Figure 3.

Fig. 3: Prepared specimen

Design of Experiments

Response Surface Methodology: Table 1shows the input parameters are using in Box- Benhken design. RSM is to use a sequence of designed experiments to obtain an optimal response. Response surface methodology uses statistical models to be aware that even the best statistical model is an approximation to reality.

Box- Benhken Design: Box's design reduced the costs of experimentation so that a quadratic model could be fit, which led to a (long-sought) ascent direction. The Parameters for machining are selected based on the literature study and also regarding the machine settings. Table 1 and 2 shows the Box-Benhken design used to set the input parameter for the machining and the ranges of input parameters in EDM.

Table 1: Input parameter using Box- Benhken design

STD	Run	Current	Pulse on Time (µs)	Pulse off Time (µs)
3	1	5	50	8
8	2	15	40	9
13	3	10	40	8
2	4	15	30	8
6	5	15	40	7
1	6	5	30	8
16	7	10	40	8
14	8	10	40	8
15	9	10	40	8
5	10	5	40	7
11	11	10	30	9
17	12	10	40	8
10	13	10	50	7
9	14	10	30	7
4	15	15	50	8
7	16	5	40	9
12	17	10	50	9

Table 2: Shows the range of input parameters in EDM

	Levels		
Input parameters	-1	0	+1
Current(A)	5	10	15
Pulse on time (µs)	30	40	50
Pulse off time (µs)	7	8	9

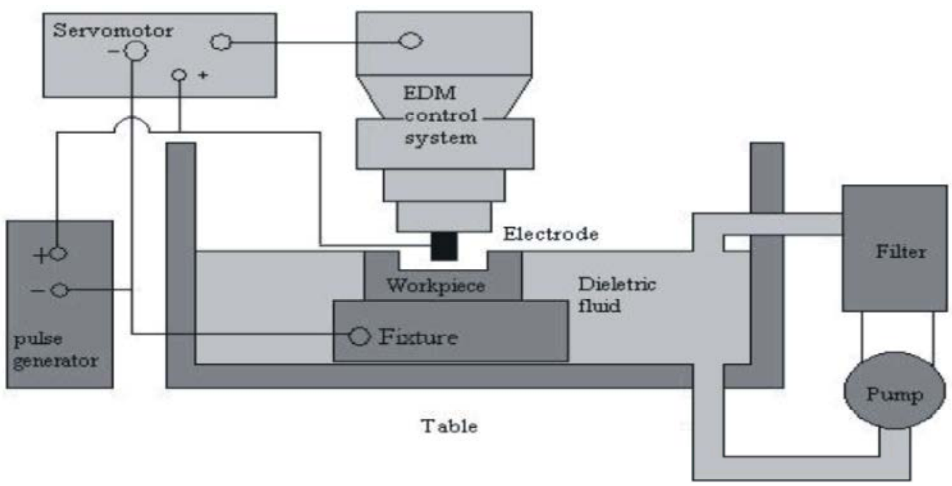

Fig. 4: Schematic diagram of EDM

Fig. 5: Machined specimen through EDM

Fig. 6: Shows Mitutoyo Talysurf tester

Electrical Discharge Machining (EDM): Electrical discharge machine (spark erosion machining) used for the manufacturing of a multitude of ever changing geometries very often produced as unit jobs. Figure 4 shows the Schematic diagram of EDM. The EDM process involves finite discrete periodic sparks between the tool electrode and conductive work piece separated by a thin film of liquid dielectric that causes the removal of work material. The Figure 4 and 5 shows the schematic diagram of EDM and the machined specimen through EDM.

Surface Roughness: The surface roughness of the machined composite is evaluated using a Mitutoyo Talysurf tester shown in figure 8 with a diamond stylus tip and a sampling length of 10 mm. The centre line average value of surface roughness (Ra in micron) for each experiment was obtained directly from the tally profile software integrated with the machine. Figure 6 represents the surface roughness tester.

RESULT AND DISCUSSION

The experiments were developed based on the Box-Benhken design of experiments of response surface methodology (RSM), with the aim of relating the influence of current, pulse on time and pulse off time. These design parameters are distinct and intrinsic features of the process that influence and determine the composite performance. Table 3 shows the experimental values for after machining of the specimen.

Anova Results: ANOVA is used to investigate the influence of the considered EDM input parameters which significantly affects the performance measures. By performing analysis variance, it can be decided which independent factor dominates over the other and the percentage contribution of that particular independent value. Table 5.2 shows the ANOVA results for MRR. For machining Al 6061 metal matrix composite reinforced

Table 3: Experimental values

Std	Run	BLOCK	CURRENT	PULSE ON TIME (μs)	PULSE OFF TIME (μs)	MRR	SR
3	1	Block 1	5	50	8	0.0274	6.876
8	2	Block 1	15	40	9	0.0775	13.65
13	3	Block 1	10	40	8	0.0568	10.561
2	4	Block 1	15	30	8	0.0747	12.43
6	5	Block 1	15	40	7	0.0764	12.764
1	6	Block 1	5	30	8	0.0194	5.768
16	7	Block 1	10	40	8	0.056	10.552
14	8	Block 1	10	40	8	0.0558	10.55
15	9	Block 1	10	40	8	0.0554	10.548
5	10	Block 1	5	40	7	0.0226	6.534
11	11	Block 1	10	30	9	0.0496	9.54
17	12	Block 1	10	40	8	0.0552	10.545
10	13	Block 1	10	50	7	0.0623	10.98
9	14	Block 1	10	30	7	0.042	7.021
4	15	Block 1	15	50	8	0.081	13.986
7	16	Block 1	5	40	9	0.0256	6.845
12	17	Block 1	10	50	9	0.0698	11.853

Table 4: ANOVA Results for MRR

Source	Sum of Squares	Df	Mean Square	F value	p-value Prob> F	
Model	0.006178	3	0.002059	119.2403	< 0.0001	Significant
A-current	0.005757	1	0.005757	333.3177	< 0.0001	
B-pulse on	0.000375	1	0.000375	21.73502	0.0004	
C-pulse off	$4.61\text{x}10^{-5}$	1	$4.61\ \text{x}10^{-5}$	2.668095	0.1264	
Residual	0.000225	13	$1.73\ \text{x}10^{-5}$			
Lack of Fit	0.000223	9	$2.48\ \text{x}10^{-5}$	63.851	0.0006	significant
Pure Error	$1.55\text{x}10^{-6}$	4	$3.88\ \text{x}10^{-7}$			
Cor Total	0.006403	16				

with 5% wt of Al_2O_3, 3% SiC and 2% E-glass fiber by using copper electrode, the current have the maximum effect on metal removal rate. The pulse on time and pulse off time contributes moderate significance only on metal removal rate. Table 4 represents the ANOVA results for MRR.

Mathematical Model for MRR and SR:

- Material removal rate (MRR) =-0.076440+0.01071* current +7.16000E-004 * pulse on+3.57000E-003 * pulse off-8.50000E-006 * current * pulse on - 9.50000E-005 * current * pulse off-2.50000E-006 * pulse on * pulse off-2.12300E-004 * current ^{2}+9.25000E-007 * pulse on^2 -7.50000E-006* pulseoff^2

Surface Roughness:

- SR =-40.26245+0.62515 * current +0.77288 * pulse on+6.08772 * pulse off+2.24000E-003 * current * pulse on+0.028750 * current * pulse off-0.041150* pulse on * pulse off-0.013729 * current ^{2}-4.42975E-003* pulse on^2-0.25972* pulse off^2.

The below graph (Figure 7) indicates that when increasing pulse off time and pulse on time the material removal rate is also increased.

The below graph (Figure 8) indicates that when increasing pulse on time and current the material removal rate also increases. But comparing to the current, pulse on time has less influence on the metal removal rate.

The below graph (Figure 9) shows that the increase in pulse off time and current increases the material removal rate. But comparing to the current, pulse off time has less influence on the metal removal rate.

The above graph (Figure 10) shows that the increase in pulse off time and pulse on time increases the surface Roughness.

The below graph (Figure 11) shows that the increase in pulse on time and current increases the surface Roughness. But comparing to the current, pulse on time has less influence on the surface roughness.

The above graph (Figure 12) shows that the increase in pulse off time and current increases the surface Roughness. But comparing to the current, pulse off time has less influence on the surface roughness.

Using response surface methodology (RSM) the optimum input parameters are obtained for the machining of Al 6061 metal matrix composite reinforced with 5% wt of Al_2O_3, 3% wt of SiC and 2% wt of E-glass fiber as shown in Table 5.

Confirmatory Test: The confirmatory test was carried out for the above optimum input parameters such as current, pulse on time and pulse off time. The output values, MRR and SR are shown Table 6.

The confirmatory test the output values are nearly equal to the output values obtained through the RSM.

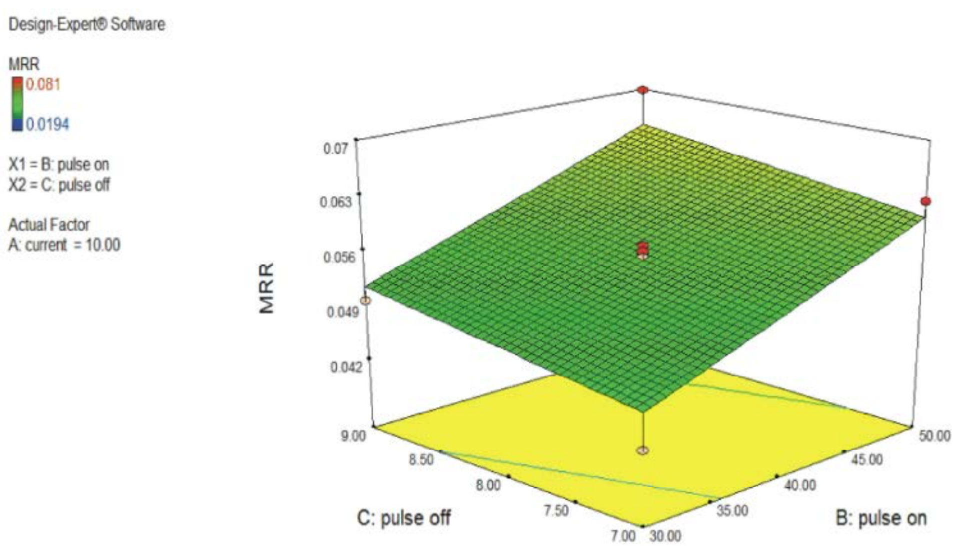

Fig. 7: Effect of pulse off time and pulse on time on MRR

Table 5: Optimum parameters

Current (A)	Pulse on time (µs)	Pulse off time (µs)	MRR (g/min)	SR(µm)
12.40	30	7	0.0588453	9.16645

Table 6: Confirmatory test

Current (A)	Pulse on time (µs)	Pulse off time (µs)	MRR (g/min)	SR(µm)
12.40	30	7	0.0594	9.156

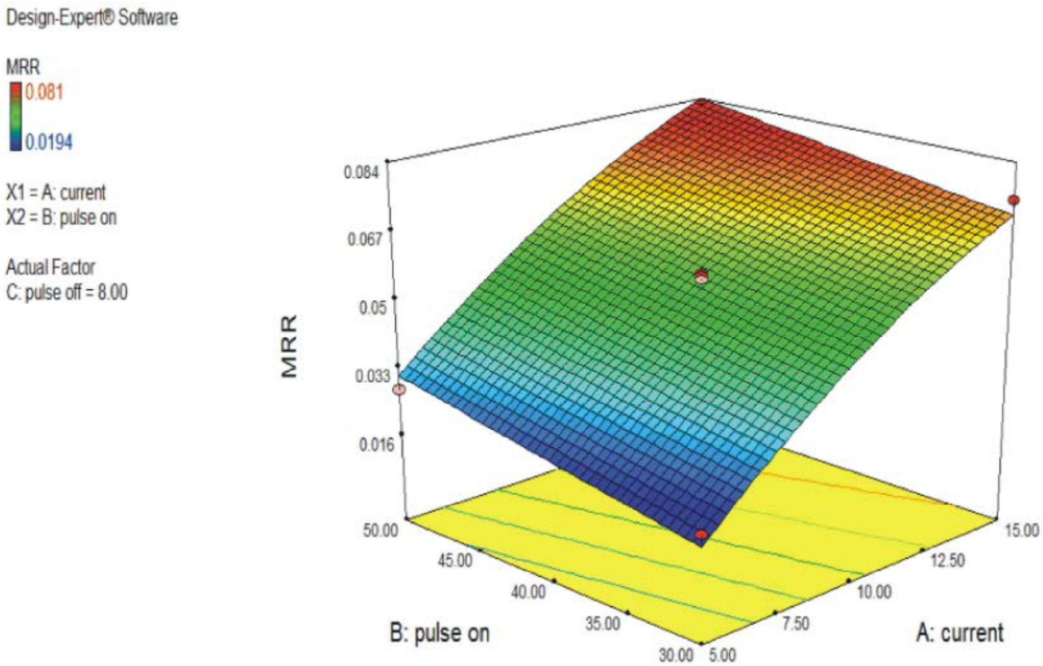

Fig. 8 Effect of pulse on time and current on MRR

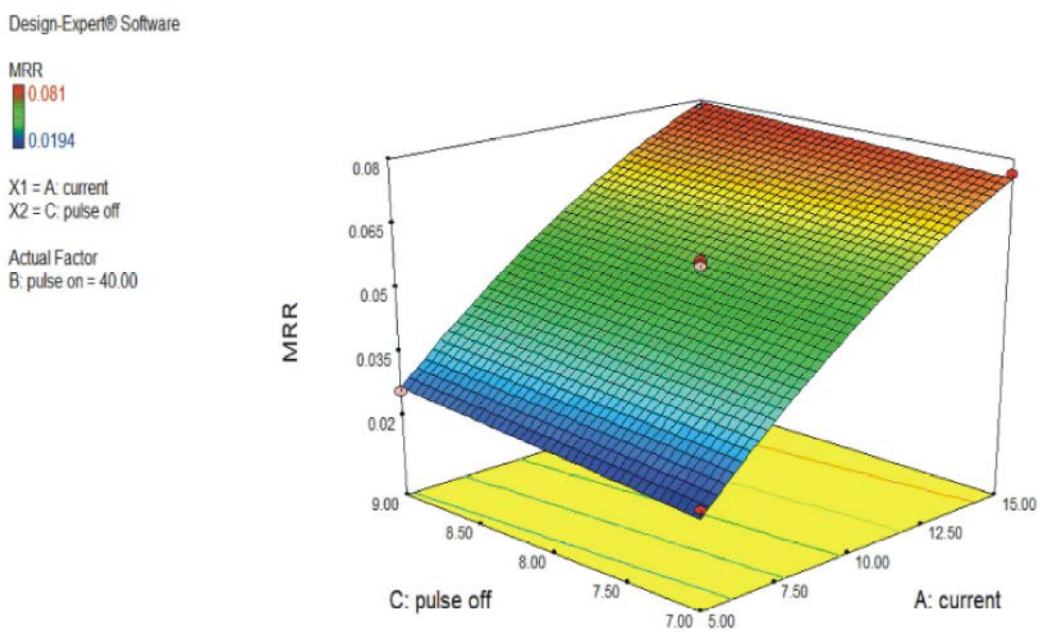

Fig. 9: Effect of pulse off time and current on MRR

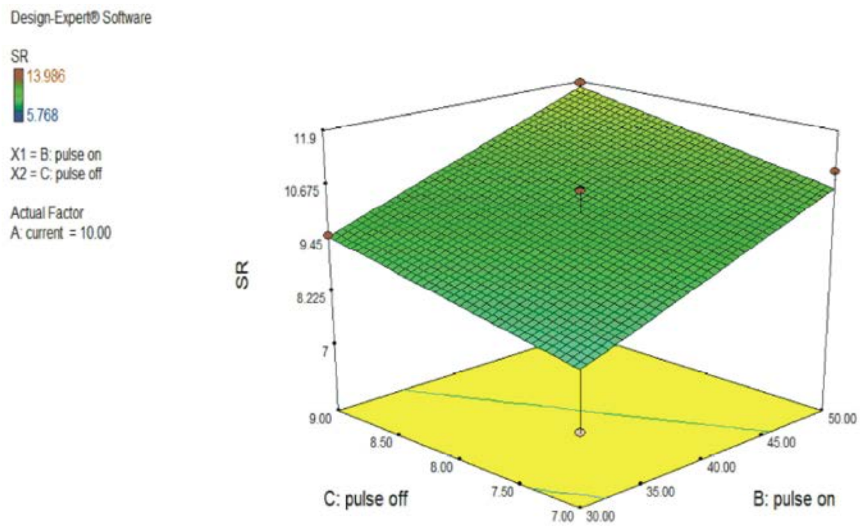

Fig. 10: Effect of pulse off time and pulse on time on SR

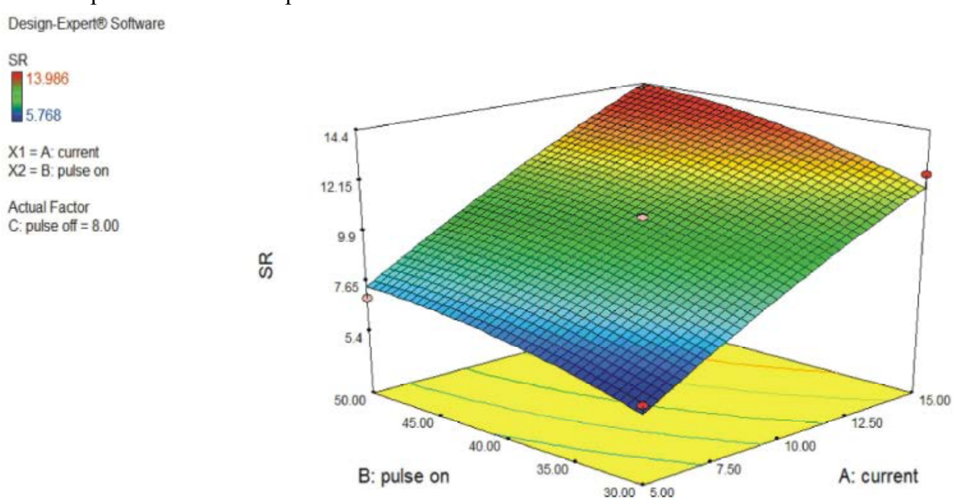

Fig. 11: Effect of pulse on time and current on SR

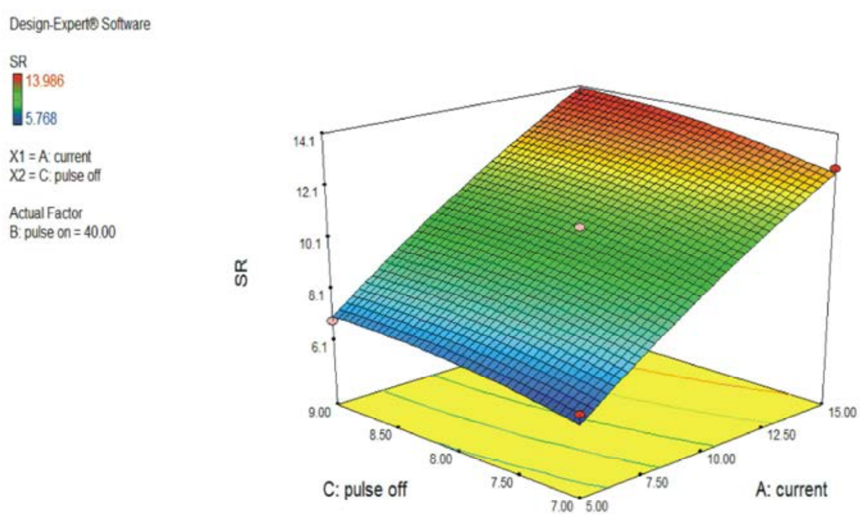

Fig. 12: Effect of pulse off time and current on SR

CONCLUSION

The aluminium based metal matrix composite was fabricated successfully through stir casting technique then the following conclusions are derived from the Electrical Discharge Machining of Al 6061 metal matrix composite reinforced with 5%wt of Al_2O_3, 3% wt of SiC and 2%wt of E-glass fiber are as follows. Both the metal removal rate and surface roughness strongly depends on the current and pulse on time for the machining. The pulse off time has less effect on it. The optimum parameter of combination setting is current 12.40 Amps, pulse on time 30µs and pulse off time 7µs for maximizing the metal removal rate and minimizing the surface roughness.

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