Fabrication of Al-SiC Metal Matrix Composite and Parametric Optimization on Electro Discharge Machine

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***Abstract*: In the present study or Experiment, pure aluminum alloy powder is mixed with 12% Silicon Carbide on weight basis to produce the MMC (metal matrix composite) material. The main objective of this paper and study is to investigate the effect of process parameters such as pulse on time(Ton), flushing pressure (Fp) and peak current (Ip) on tool wear rate (TWR), metal removing rate (MRR) and surface roughness (SR) during electrical discharge machining (EDM) of Al-SiC12% MMC .The experiment is done by Central composite design (CCD) method under different combination of process parameters .In this Experiment or paper RSM (Response surface methodology) is used to develop the mathematical model and to correlate the process parameters with the response. Also ANOVA (Analysis of Variance) technique is used to check the significance of the model and confirmation test is done to compare the predicted data with the Experimental data to identify the effectiveness of the given method. From the main effective plot or graph it is found that peak current is the most significant process parameter among the other parameter. Further the morphology study of the composite material is carried out by the FESEM (Field emission Scanning electron microscope) of the surface after machining to make a relation with the model.**

***Keywords*: Aluminum metal matrix composite (MMC), ANOVA, FESEM, RSM.**

I. INTRODUCTION

In present day's, researcher all over the world are focusing mainly variety of innovative and advanced composite materials which are quickly replacing to conventional materials for different applications like aerospace, automotive, sports, defense, Electrical appliance and other industries. According to..

Hung et al. (1994) [1] Aluminum alloys materials are light in weight in compare to other monolithic material when aluminum alloys is reinforced with Silicon Carbide to form an aluminium metal matrix composite (MMC).

Renjie e al. (2012) [2] carried out in our study and expressed their view that Al-SiC composite is one of the advance type of metal matrix composite material that have a superior mechanical and physical properties in compare to other conventional material.

Kohli et al.(2012) [3] carried out in our study and have applied fuzzy logic analysis to compare the experimental results with the result output by the fuzzy model during the die sinking EDM process. Copper used as electrode and Medium Carbon Steel (AISI 1040) as work-piece or specimen to evaluate the MRR (material removal rate).

Hocheng et al. (1997) [4] carried out in our study, the effect of machining parameters like electrical current, pulse on time in Electro Discharge Machining of Al-SiC (aluminum silicon carbide) composite material and compared the crater size produced by a single spark. According to researcher, the crater size of the Al-SiC (aluminum silicon carbide) composite is larger than common steel and the MRR (material removal rate) is proportional to the pulse on time and applied current.

Muller et al. (2001) [5] done our experiment and investigated the machining of A356-SiC-35P and AA2618-SiC-20P composite material in machining by both LASER and EDM process. They stated that MRR (material removing rate) decreases with increase in % of SiC, more ever LASER machining induced higher thermal damage to the surface in compare to Electro Discharge Machining.

Patel et al. (2009) [6] carried in our study about machining characteristics like material removal and surface integrity mechanism of Al2O3–SiCw–TiC ceramic composite and its found that surface roughness increases with the pulse on time and Discharge current as well as it provides the information on the mechanisms of formation of recast layer.

Dhar et al. (2007) [7] carried out a experiment, in which pulse duration, pulse current and gap voltage are selected as a process parameters that affect the MRR (metal removal rate), TWR (tool wear rate) ,radial over cut and surface roughness of Al–4Cu–6Si alloy with 10 wt.% SiC (silicon carbide) composites. Researcher observed that MRR (material removal rate), TWR (tool wear rate) and radial over cut increase significantly in a nonlinear way with current. They Also a mathematical model is established to study the optimal conditions suitable for the selected model.

Karthikeyan et al. (1999) [8] done a experiment and mathematical model for the response parameters like tool wear rate, metal removing rate and surface roughness using the process parameters such as pulse duration, current and the percent volume fraction of Silicon Carbide followed by three level full factorial design & analyzed by ANOVA. They concluded that MRR (material removal rate) decreases with increase in the % volume of SiC (silicon carbide), while the surface roughness and TWR (tool wear rate) is increase with the increase in percentage volume of Silicon Carbide.

Gopalakanan et al. (2013) [9] carried out a study on the hybrid MMC (metal matrix composite) using Taguchi based grey relation analysis and make a correlation between machining process parameters like as pulse off time, gap voltage, current and pulse on time with MRR (material removal rate), electrode wear ratio, surface roughness and according to them pulse current and pulse on time are the most signifing process parameters.

Shandilya et al. (2012) [10] carried out a study on Response surface methodology and ANOVA process or technique to optimize the parameters of Al6061-SiC MMC (metal matrix composite) during Wire cut EDM and study out the microstructure of the machining surface through scanning electron microscopic.

Hu. et al. (2013) [11] carried out a study and Compared the effect of Powder mixed EDM and conventional EDM on the Al-SiC composite MMC and found that the roughness decreases about 31.5% during powder-mixed EDM. Based on the above consideration, it is found that limited work is carried out with pure Aluminium alloy-SiC on EDM. The objective of this Research paper is to study the effects of pulse on time, peak current and flushing pressure on the MRR (metal removal rate), surface roughness and TWR (tool wear rate) using a Response surface methodology technique.

2. EXPERIMENTAL DETAILS

2.1 Specimen Preparation

The specimen or work piece materials are fabricated by the using of commercial pure Al with purity 98 percent and SiC (silicon carbide) having the average particle grain size is 0.0228 mm. The composite materials are prepared or fabricated on the basis of 12% weight fraction of SiC (silicon carbide) and remaining weight as Al (aluminium) alloy by using Stir casting process. In this process the molten Al (aluminium) and SiC (silicon carbide) are aggregated at 400 rpm to get uniformly distributed of the silicon carbide in aluminium to obtain the specimen material.

2.2 Experimental Setup and Procedure

The EDM (Electrical Discharge machining) as shown in Figure 1 with a model of MIC-432CS CNC manufactured by ECOWIN EDM. The specimen or work pieces are prepared 40 mm in diameter with 10 mm thickness and the electrolyte copper electrode are used for tool with average diameter 25.4 mm for each experiment. The dielectric medium used is commercial Electro Discharge Machining oil with side impulse jet flushing system are adopted to flush away the eroded material from both specimen and tool near the sparking zone. The experiments are conducted basis on the central composite design method and each specimen or workpiece is machined up to depth 2 mm. The machining time of work piece is recorded in the timer of Electro Discharge Machine. The Tool wear rate, Material removal rate are measured by using weight difference between the specimen or work piece and tool by using electronic METLERPM200 digital type of weight measurement machine. Surface roughness is measured by the “MITUTOYO” at surface roughness tester.

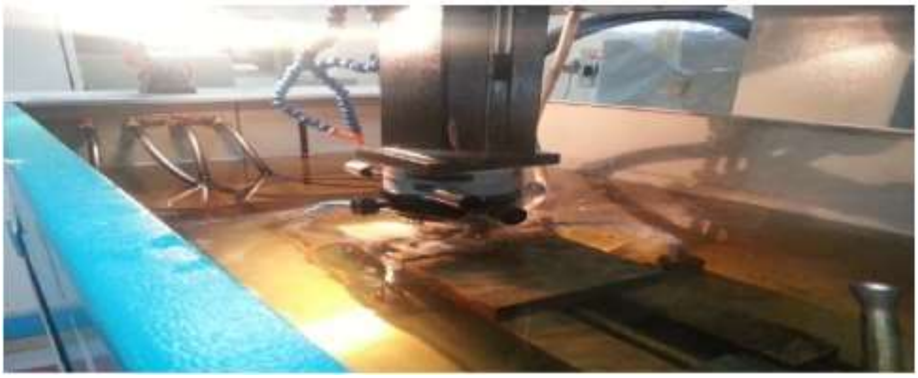

Figure1: Experimental set up of EDM

2.3 Response Variables Evaluation

The machining process parameter are evaluated to study the effect of TWR, MRR and SR on Al 12%SiC MMC (metal matrix composite) with the following numerical formula.

Material removal rate (MRR):- Material removal rate is defined as ratio of the differences in weight of the work piece or specimen before and after machining to machining time. Mathematically it is expressed as

$$MRR = \frac{\mathrm{Wb-Wa}}{\mathrm{t}}\,\mathrm{mg/min} \qquad (1)$$

where

W_b = Weight of work piece before machining (mg)

W_a = Weight of work piece after machining (mg)

t = Machining time in (min)

Tool wear rate (TWR):- Tool wear rate is a ratio of the differences in weight of tool before and after machining to machining time. Mathematically TWR is expressed as

$$TWR = \frac{\mathrm{Tb-Ta}}{\mathrm{t}}\,\mathrm{mg/min} \qquad (2)$$

where

T_b= Weight of work piece before machining (mg)

T_a = Weight of work piece after machining (mg)

t = Machining time (min)

Surface roughness (SR):-The Ra values are taken at three different position of the work piece and the average of three measurements is recorded.

2.4 Design of Experiment

The experiments are conducted based on the effect of three process parameters like peak current (Ip) in Ampere (A), Pulse on time (Ton) in Microsecond (µS), Flushing pressure (Fp) in Kg/cm2 proposed by CCD (Central composite design) method to run around 20 experiments. The process parameter variables with their actual values on different levels are shown in the Table 1.

Table 1: Process parameters and their levels

Symbols	Levels		
	-1	0	1
Ip	10	20	30
Ton	150	200	250
Fp	0.3	0.5	0.7

3. RESULTS AND DISCUSSION

3.1 Analysis Of Variance (ANOVA)

The output or results are further analyzed with (ANOVA) Analysis of variance and the F-ratio test is done to check the adequacy of the model .The results of the Analysis of variance (ANOVA) for TWR, MRR and Ra are shown in Tables 2, 3 and 4 respectively. From the Analysis of variance (ANOVA) table it is again analyzed that significance level of _=0.05, i.e. for the confidence level of 95 percent .It has been acceptable that P value lesser than 0.05 is shows that the performance of the process parameter statistically significant and higher than 0.05 less significant to the model. Also it is found that the R2 value for the TWR, MRR and Ra are 0.96, 0.98 and 0.98 respectively that significant the R2 value is closed to 1 which is desirable. The predicted R2 is in reasonable agreement with the adjusted R2.

3.2. Second Order Mathematical Model

The mathematical relation of the response parameters are defined in terms of process parameter. In this case the model is quadratic form in nature involving quadratic and linear interactions of process variables. The mathematical model equation or relation are commonly represented by a function (Ø) i.e. R=Ø (Ton, Ip, Fp)

where,

R = define as the response.

Ton = pulse on time

Ip = peak current

Fp = dielectric flushing pressure

The mathematical model equation of TWR, MRR and Ra are given in equations 3, 4 and 5 respectively.

Table 2: Analysis of Variance for MRR

Source	DF	Seq SS	Adj MS	F	p
T_{on}	1	3130	8	0.00	0.969
Ip	1	2518	4302	90.25	0.000
Fp	1	4498	5280	1.11	0.317
T_{on}*T_{on}	1	5947	7927	1.66	0.226
Ip*Ip	1	1710	1718	3.60	0.087
Fp*Fp	1	93	93	0.02	0.892
T_{on}*Ip	1	2265	2265	47.51	0.000
T_{on}*Fp	1	1102	1102	23.11	0.001
Ip*Fp	1	1500	1500	31.47	0.000
Residual Error	10	4768	4768		
Lack-of-Fit	5	4634	4634	34.76	0.001
Pure Error	5	1333	1333		
Total	19	3434	3434		

R-Sq = 98.61%, R-Sq (adj) = 97.36%

Table 3: Analysis of Variance for TWR

Source	DF	Seq SS	Adj MS	F	p
T_{on}	1	68.771	38.2	19.78	0.001
Ip	1	298.63	17.5	9.09	0.013
Fp	1	91.17	123.7	64.1	0.000
T_{on}*T_{on}	1	0.01	0.8	0.4	0.539
Ip*Ip	1	23.833	27.1	14.07	0.004
Fp*Fp	1	12.805	12.8	6.64	0.028

T_{on}*Ip	1	10.91	10.9	5.66	0.039
T_{on}*Fp	1	91.257	91.3	47.3	0.000
Ip*Fp	1	10.41	10.4	5.4	0.043
Residual Error	10	19.293	1.9		
Lack-of-Fit	5	19.212	3.8	235.6	0.000
Pure Error	5	0.082	0.0		
Total	19	627.09			

R-Sq = 96.92%, R-Sq (adj) = 94.15%

$$MRR= -1129.41 + 0.13Ton + 130.67\ Ip - 754.57\ Fp + 0.01\ Ton^2 + 0.35\ Ip^2 + 63.72\ Fp^2 - 0.34Ton*Ip + 11.74Ton*Fp - 68.47\ Ip*Fp$$

$$TWR= 75.419 - 0.298Ton - 0.834\ Ip - 115.484\ Fp + 0.000\ Ton^2 + 0.014\ Ip^2 + 23.603\ Fp^2 + 0.002Ton*Ip + 0.338Ton*Fp - 0.570\ Ip*Fp$$

$$Ra= 37.4303 - 0.1844Ton - 0.5459\ Ip - 45.368\ Fp + 0.0002\ Ton^2 + 0.0086\ Ip^2 + 18.7153\ Fp^2 - 0.0027Ton*Ip + 0.1604Ton*Fp - 0.2240\ Ip*Fp$$

Table 4: Analysis of Variance for Ra

Source	DF	Seq SS	Adj MS	F	p
T_{on}	1	62.719	14.628	17.26	0.002
Ip	1	281.31	7.5091	8.86	0.014
Fp	1	53.518	19.086	22.53	0.001
T_{on}*T_{on}	1	2.766	4.8112	5.68	0.038
Ip*Ip	1	8.927	10.577	12.48	0.005
Fp*Fp	1	8.051	8.0507	9.50	0.012
T_{on}*Ip	1	14.835	14.834	17.51	0.002
T_{on}*Fp	1	20.576	20.576	24.29	0.001
Ip*Fp	1	1.606	1.6056	1.90	0.199
Residual Error	10	8.473	0.8473		
Lack-of-Fit	5	7.966	1.593	15.7	0.00
Pure Error	5	0.506	0.101		
Total	19	462.7			

R-Sq = 98.17%, R-Sq (adj) = 96.52%

3.3 Interpretation of Plots

The important or main effects plot is most useful when many factors are considered for optimization of the model. The plot or graphs show the variation of individual response with the 3 parameters, i.e. Pulse on time, peak current and Flushing pressure separately

As shown in Figure 2, it is found that with the increase in all the machining parameters the material removal rate is gradually increases. The MRR increases with peak current because at the time of machining, a high amount of discharge current flows in between the specimen or work piece and tool. These spark discharges develop impulsive force in the spark gap so that the melting and evaporation occurs and the entire surface is eroded.

Also further analyzed that when pulse on time increases, the spark discharges for a long time as a result the MRR gradually increases and increase in flushing pressures the wear debris are eliminated quickly in the sparking gaps for which the ionization of dielectric fluid is continuously replaced in every spark discharge, hence the MRR is increases

In Figure 3, it is shown that the tool wear rate increases with peak current but decreases with other parameters like pulse on time and flushing pressure.

According to **Velusamy et al. (2011) [12]** it is found that when peak current is increases the material is lost on both work piece and tool because the sparking occurs near about 20,000 to 30, 0000 times per second on the machined surface. Therefore with increase of peak current, the spark discharge is also increases which enhanced the TWR. But there is a variation of attribute due to longer spark generation time. The peak current heats the interface surface continuously so that the wear debris are burnt to form the carbon particles and deposited on the tool surface which helps to reduce the tool wear rate. Further higher the flushing pressure, the cooling rate of the tool is increased for which the tool wear rate is reduced.

Furthermore as shown in Figure 4, it is found that the surface roughness Ra increases with all the process parameters. The increase in current, the MRR becomes faster which indicates that Ra increases with the increase of current. However pulse on time is directly proportional to the MRR. Therefore increase in pulse on time the roughness increases. It is also observed that when flushing pressure increases the spark arcing decreases so that MRR increases. Hence rise in flushing pressure, the roughness increases.

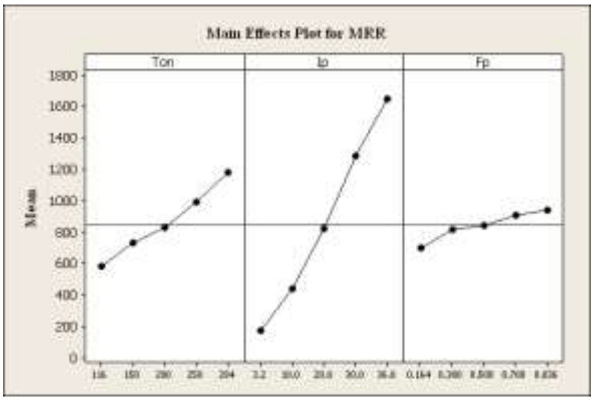

Figure 2: Main effect plot of MRR

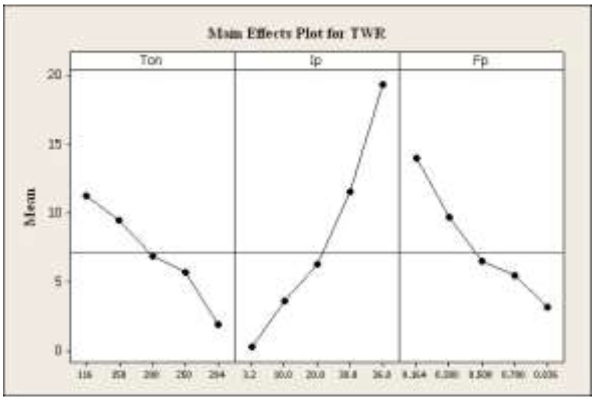

Figure 3: Main effect plot of TWR

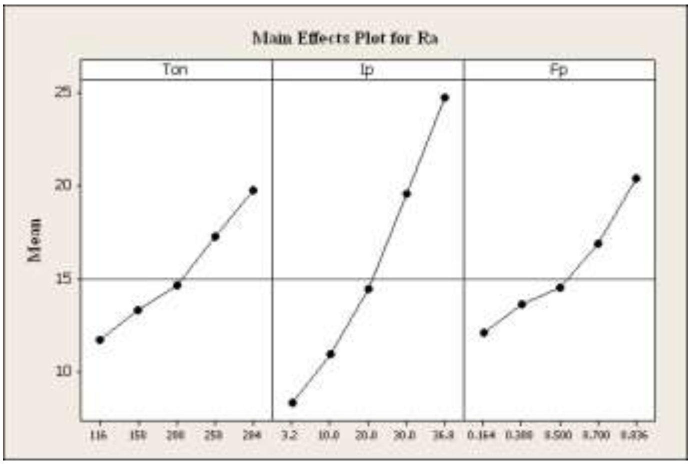

Figure 4: Main effect plot of Ra

4. MICRO STRUCTURAL STUDIES

In Figure 5, it is shows the micro surface textures of the erode surfaces during EDM, process there are a large number of voids, micro holes, gas bubbles and micro crackers appearing on the surface. According to **Velusamy *et al.* (2011) [11]** the morphological defects are due to high tensile stress developed on the imperfect joining of molten droplets during machining. Due to this a lot of stress gradient exceeds the ultimate tensile strength of the composite material. But **Muller *et al.* (2001) [5]** explain that during the machining process, there is extremely high energy discharge in the area between work piece and the tool to form a plasma phase. In this phase temperature rises highly so that a molten metal stage is developed on the machining surface .When this machining surface is contacts, with the air and flushing of dielectric result to form the recast layer on the surface. According to **Velmurugan *et al.* (2011) [13]** flushing pressure plays an important role for this type of morphological defects which depends upon the rate of solidifications on the molten surface. When the flushing pressure increase more cracks are over the machined surface lowering the pressure cracks will be less.

Moreover it has been found that when the current is minimum the spark discharge strikes less on the surface but in the case of maximum it strikes the surface more intensely as a result the diameter and depth of the craters in machining surface increases and the surface become more roughness.

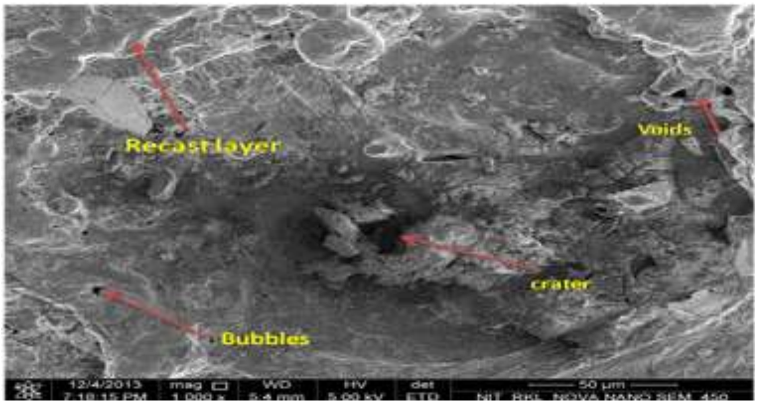

Figure 5: FESEM of Machined Surface

5. CONFIRMATION TEST

The experiments are further analyzed by conducting with a new set of process parameters within the range of previously selective process variables .The predicted result is found by using the mathematical equation 3 to 5 and compared with the experimental observation value. It is found that the error of MRR, TWR and Ra within a range of -.1.12 to 3.01 %, 1.5 to2.5 % and 2.21 to 5.41 % as shown in the Table 5, 6 and7 respectively. From this confirmation test it found that the average accuracy of the model is near about 95%. The confirmation test results are calculated using the following formula i.e.

$$\%Error = \frac{(\text{Experimental result} - \text{Predicted result})}{\text{Predicted result}} \times 100$$

Table 5: Confirmation test for MRR

Test	Ton	Ip	Fp	MRR Pred	MRR Exp	Error (%)
1	160	16	0.4	478.820	493.250	3.01
2	190	24	0.6	966.159	955.340	-1.12
3	240	28	0.8	1283.627	1302.12	1.44

Table 6: Confirmation test for TWR

Test	Ton	Ip	Fp	TWR Pred	TWR Exp	Error (%)
1	160	16	0.4	5.96	6.110	2.517
2	190	24	0.6	1.91	1.950	2.094
3	240	28	0.8	5.345	5.429	1.572

Table 7: Confirmation test for Ra

Test	Ton	Ip	Fp	Ra Pred	Ra Exp	Error (%)
1	160	16	0.4	9.971	10.512	5.4
2	190	24	0.6	14.806	15.134	2.2
3	240	28	0.8	25.793	24.876	-3.5

6. CONCLUSION

It is conclude that through this analysis Al-SiC 12% composite to be machined using EDM with selecting optimum levels of process parameter that is peak current (Ip), pulse on time (Ton), and flushing pressure (Fp).The parameter peak current is the most significant parameter and it increases linearly with the MRR, TWR and Ra .The pulse on time and flushing pressure increase with MRR and Ra but decrease with TWR. The developed mathematical model is used to predict the optimal condition suitable for the selected process.

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