International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P) Volume-8, Issue-2, February 2018

Optimization of EDM process parameters for Al-SiC reinforced metal matrix composite

Hany A. Shehata, Samy J. Ebeid, A. M. Kohail

Abstract— **In the present study, stir casting method (SCM) was used to produce metal matrix composites (MMC). Aluminum (Al) 6061 and silicon carbide particles (F500≈15µm) were selected as matrix and reinforcement materials respectively. Matrix, Al-5%SiC and Al-10%SiC were subjected to Electric discharge machining (EDM) to analyses the effect of input parameters namely peak current (Ip), pulse-on-time (Ton), duty cycle (DT) and gap voltage (Vg). Optical microscope was used to determine the SiC particles distribution in the Al matrix of the composites (as-cast). A digital balance was used to determine the material removal rate (MRR) and Tool wear (TWR) for the matrix and composites. Surface roughness measurement tester used to determine the surface roughness (Ra) for the matrix and composites.**

Index Terms— **Electric discharge machining, composite materials, optimization, reinforced metal matrix composites.**

I. INTRODUCTION

Recently, aluminum based MMCs have been successfully applied in the military, automotive and aerospace industries due to their light weight, high strength, stiffness and resistance to high temperature. [1]. Al MMCs are difficult to machine as they contain hard and brittle reinforcements. High tool wear and high tool cost have been reported during conventional machining of these composites. [2].

Hence EDM is an optimal choice for machining such materials. EDM is a thermo-electrical process in which material removal occurs by a series of successive discharges between the tool and the workpiece separated by a dielectric medium. In this experiment, electric discharge machining is done on the workpiece materials Al6061, Al-5%SiC and AL-10%SiC respectively by copper tool electrode.

II. EXPERIMENTAL SETUP

The EDM machine used for the experiment is EMCO of model ENGEMAQ EDM 200 NC, EDM (Die sinking type EDM) as shown in Fig.1 with servo-head and positive polarity for electrode. Commercial grade EDM oil was used as dielectric fluid (specific gravity= 0.763, freezing point= 94°C). Conventional copper (Bronze) was selected as the tool electrode to machine the workpieces Al 6061, AL-5%SiC and AL-10%SiC metal matrix composite. The workpiece materials were prepared by stir casting method.[3]. Portable stylus type profile meter was used to measure the surface roughness of the specimen after machining. Machine specifications of EDM are presented in Table 1.

Fig. 1. EDM machine used for the experiment

Table 1: Machine specifications of EDM

Parameters	Input Current (Ip) (A)	Pulse on Time (Ton) (µsec)	Duty Cycle (DC) (%)	Gap Voltage (Vg) (V)	Flushing Pressure (p) (kg/cm^2)
Range	0-80	1-999	1-99%	0-300	0-1.5

III. ELECTRODE AND WORKPIECE MATERIAL

Conventional copper tool of 20mm diameter and 60 mm length was taken as the tool electrode. The properties of tool electrode are shown in Table 2 [4].

The workpiece material chosen for the experiment were Aluminum 6061 and aluminum silicon carbide metal matrix composite (AlSiC MMC) with aluminum as the base metal with 5% and 10% SiC as reinforcement. The AlSiC MMC was fabricated by stir-casting process in which initially the aluminum and silicon carbide powder were preheated for 3 to 4 hours at 450°C and 900°C respectively [5] and then the powders were mixed mechanically below their melting points. This AlSiC mixture was then poured into the graphite crucible and put in to the electric furnace at 760°C temperature. [6]. After heating, the slurry was taken into the steel rectangular mould and allowed it to solidify within thirty seconds. Finally the samples were prepared as per the requirement shown in Fig. 2, Fig. 3 and Fig. 4 [7].

Hany A. Shehata, Design and production Engineering Department, Modern Academy for Engineering and Technology/Faculty of Engineering, Cairo, Egypt, +201229258964.

Samy J. Ebeid, Design and production Engineering Department, Ain Shams University/Faculty of Engineering, Cairo, Egypt, +201223720125.

A.M.Kohail, Mechanical engineering & manufacturing technology Department, Modern Academy for Engineering and Technology /Faculty of Engineering, Cairo, Egypt, +201000183337.

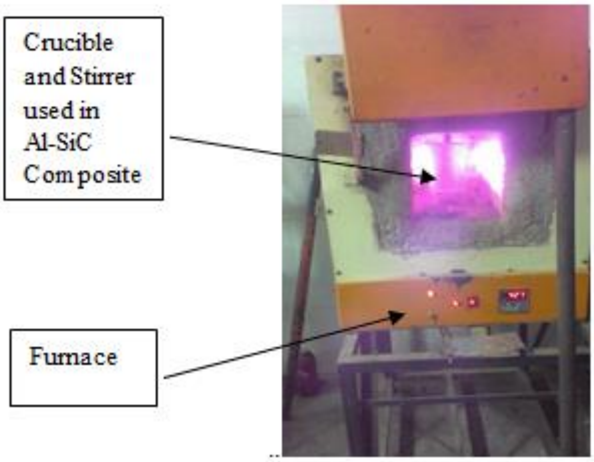

Fig. 2 - Stir casting apparatus

Fig. 3 - AlSiC workpiece prepared by stir casting method

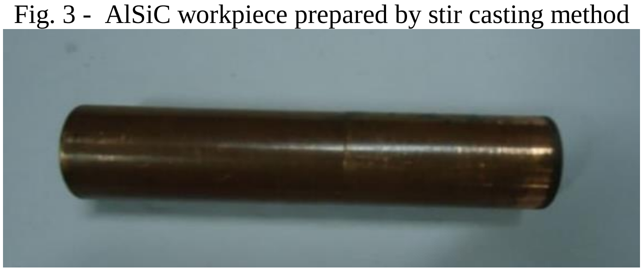

Fig. 4 - Copper tool electrode

Table 2: Properties of tool electrode

PROPERTY	Copper tool
Chemical composition	Cu
Density (gm/cm^3)	8.96
Thermal conductivity (W/mK)	364.86
Melting point (^{0}C)	1085
Specific heat (J/kgK)	0.386

IV. Design of Experiments

The Taguchi technique was used to determine the design of experiments. This method uses Orthogonal Arrays (OAs) which provide less number of experimental runs. In this work, three level and four factors are chosen and the total number of experiments to be conducted is 27. So L27 OA was chosen to conduct the experiments. Input factors and their levels are given in table 3

Table 3: Input factors and their levels

Factors ,Symbol (units)	Levels		
	Level 1	Level 2	Level 3
Input Current “Ip” (A)	2	4	8
Pulse on time “Ton” (µs)	15	30	45
Duty Cycle “DT”	50	65	85
Spark Gap “Sg” (mm)	0.25	0.35	0.45

Pressure of oil (P_{oil}) = 1 Kg/cm^2

The average number of tests carried out in association with the machining process parameter and the output are given in Table 4 for AL 6061, Al-5%SiC and Al-10%SiC.

Table 4: Process variables and their corresponding responses

AL 6061									
No.	Ip (A)	Ton (µs)	DT (%)	Gap (mm)	MRR(g/min)	Ra(µm)	Rmax(µm)	Vv%	Voltage(V)
1	2	15	50	0.25	0.052	2.603	18.34	9.615384615	60
2	2	15	50	0.25	0.055666667	2.494	15.84	8.383233533	60
3	2	15	50	0.25	0.085333333	2.474	20.13	5.859375	60
4	2	30	65	0.35	0.044	2.519	22.6	5.303030303	65
5	2	30	65	0.35	0.037666667	1.588	11.85	4.424778761	50
6	2	30	65	0.35	0.014	1.552	13.07	7.142857143	50
7	2	45	85	0.45	0.015	1.648	15.84	8.888888889	65
8	2	45	85	0.45	0.044	1.627	12.46	3.03030303	65
9	2	45	85	0.45	0.018666667	1.62	11.47	3.571428571	65
10	4	15	65	0.45	0.148333333	3.283	24.07	9.662921348	75
11	4	15	65	0.45	0.113333333	3.16	21.79	9.705882353	75
12	4	15	65	0.45	0.114333333	3.203	27	15.16034985	75
13	4	30	85	0.25	0.145333333	2.962	21.47	2.752293578	60
14	4	30	85	0.25	0.124666667	2.809	20.87	3.20855615	60
15	4	30	85	0.25	0.125333333	2.635	22.65	2.925531915	60
16	4	45	50	0.35	0.165333333	4.24	35.11	4.233870968	90
17	4	45	50	0.35	0.161	5.683	38.31	0.414078675	90
18	4	45	50	0.35	0.17	4.846	35.74	7.450980392	90
19	8	15	85	0.35	0.244666667	3.632	26.68	7.084468665	65
20	8	15	85	0.35	0.240666667	3.534	25.05	6.509695291	65
21	8	15	85	0.35	0.243	4.075	26.28	5.349794239	65
22	8	30	50	0.45	0.299	5.03	38.72	12.37458194	100
23	8	30	50	0.45	0.355760483	5.687	36.27	12.09899175	100
24	8	30	50	0.45	0.306666667	5.797	50.36	12.5	100
25	8	45	65	0.25	0.315	5.674	34.08	4.973544974	85
26	8	45	65	0.25	0.293666667	5.378	38.27	4.880817253	85
27	8	45	65	0.25	0.317	5.3	38.58	4.311251314	85

AL+5%SiC									
No.	Ip (A)	Ton (μs)	DT (%)	Gap (mm)	MRR(g/min)	Ra(μm)	Rmax(μm)	Vv%	Voltage(V)
1	2	15	50	0.25	0.006333333	3.755	30.1	0.6	50
2	2	15	50	0.25	0.058666667	3.747	33.13	0.568181818	50
3	2	15	50	0.25	0.058666667	4.477	53.24	11.36363636	50
4	2	30	65	0.35	0.071333333	4.787	37.43	11.21495327	60
5	2	30	65	0.35	0.027333333	4.192	37.59	2.43902439	50
6	2	30	65	0.35	0.011333333	4.282	35.95	0	60
7	2	45	85	0.45	0.031666667	2.13	16.84	4.210526316	70
8	2	45	85	0.45	0.015	1.963	17.81	4.444444444	70
9	2	45	85	0.45	0.032666667	2.276	23.42	1.020408163	70
10	4	15	65	0.45	0.133666667	3.98	25.92	11.4713217	80
11	4	15	65	0.45	0.127666667	3.793	28.42	11.48825065	80
12	4	15	65	0.45	0.126333333	3.695	24.12	12.40105541	80
13	4	30	85	0.25	0.036333333	4.872	39.31	0.917431193	55
14	4	30	85	0.25	0.119666667	4.82	48.04	2.78551532	60
15	4	30	85	0.25	0.119	4.935	34.27	3.641456583	60
16	4	45	50	0.35	0.133333333	7.729	48.24	5.5	80
17	4	45	50	0.35	0.153	7.009	55.75	3.48583878	80
18	4	45	50	0.35	0.148	5.853	38.86	6.306306306	80
19	8	15	85	0.35	0.233333333	4.702	32	5.142857143	70
20	8	15	85	0.35	0.231666667	4.101	34.08	4.316546763	70
21	8	15	85	0.35	0.225666667	4.918	32.27	6.203840473	70
22	8	30	50	0.45	0.302333333	6.431	37.84	12.12789416	90
23	8	30	50	0.45	0.31	6.115	41.79	13.65591398	90
24	8	30	50	0.45	0.315666667	5.57	38.79	10.98204857	90
25	8	45	65	0.25	0.318666667	6.266	36.88	4.916317992	90
26	8	45	65	0.25	0.324	5.941	47.2	5.555555556	90
27	8	45	65	0.25	0.321	4.294	42.15	5.088265836	90

AL+10%SiC									
No.	Ip (A)	Ton (μs)	DT (%)	Gap (mm)	MRR(g/min)	Ra(μm)	Rmax(μm)	Vv%	Voltage(V)
1	2	15	50	0.25	0.022333333	3.354	24.39	2.985074627	60
2	2	15	50	0.25	0.069	3.486	27.31	14.00966184	60
3	2	15	50	0.25	0.054333333	6.44	47.31	9.81595092	60
4	2	30	65	0.35	0.084	6.11	63.68	8.73015873	60
5	2	30	65	0.35	0.086333333	5.943	42.68	0.386100386	60
6	2	30	65	0.35	0.075	6.181	68.04	4.444444444	60
7	2	45	85	0.45	0.025666667	4.051	39.56	12.98701299	75
8	2	45	85	0.45	0.041666667	4.41	37.2	6.4	75
9	2	45	85	0.45	0.033	5.152	51.04	5.050505051	75
10	4	15	65	0.45	0.083333333	6.138	59.11	18.4	80
11	4	15	65	0.45	0.082333333	3.641	33.22	12.95546559	80
12	4	15	65	0.45	0.056666667	7.297	62.75	10	80
13	4	30	85	0.25	0.087	4.656	36.79	11.11111111	60
14	4	30	85	0.25	0.129666667	4.349	38.38	1.542416452	60
15	4	30	85	0.25	0.136333333	4.636	32.27	8.068459658	60
16	4	45	50	0.35	0.149666667	5.27	36.24	6.458797327	120
17	4	45	50	0.35	0.168666667	5.324	32.4	3.95256917	120
18	4	45	50	0.35	0.146666667	5.763	37.31	0.681818182	120
19	8	15	85	0.35	0.238	3.723	26.87	8.683473389	70
20	8	15	85	0.35	0.214666667	3.633	27.71	6.366459627	70
21	8	15	85	0.35	0.217333333	4.229	30.92	2.607361963	70
22	8	30	50	0.45	0.11	4.362	36.58	7.878787879	80
23	8	30	50	0.45	0.223666667	4.831	31.68	11.32637854	80
24	8	30	50	0.45	0.328333333	6.136	48	10.35532995	80
25	8	45	65	0.25	0.254333333	5.23	32.34	5.897771953	80
26	8	45	65	0.25	0.344333333	6.1	51.31	5.421103582	80
27	8	45	65	0.25	0.337666667	7.076	47.93	3.356367226	80

V. Preparation of Specimens

The close up view of plate blank used for cutting the specimens is mounted on the EDM machine is shown in Fig. 5 and the machined work piece is in Fig. 6.

VI. Surface Roughness (SR)

The portable surface roughness tester TR200 with tip radius of 5µm has been utilized to measure surface texture which is shown in Fig. 7.

VII. Material Removal Rate (MRR)

For EDM, cutting rate is a desirable characteristic and it should be as high as possible to give least machine cycle time leading to increased productivity. In the present study MRR in g/min is calculated by the formula given below

$$MRR(g/min)=\frac{(\text{intial weight}-\text{final weight})}{(\text{Machining time})} \quad \ldots\ldots\ldots\ldots\ldots..(1)$$

VIII. Tool Wear (TWR)

$$TWR(g/min)=\frac{(\text{intial weight}-\text{final weight})}{(\text{Machining time})} \quad \ldots\ldots\ldots..(2)$$

$$Vv\% = \frac{TWR}{MRR}\ \% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Fig. 5 Plate material blank mounted on EDM machine.

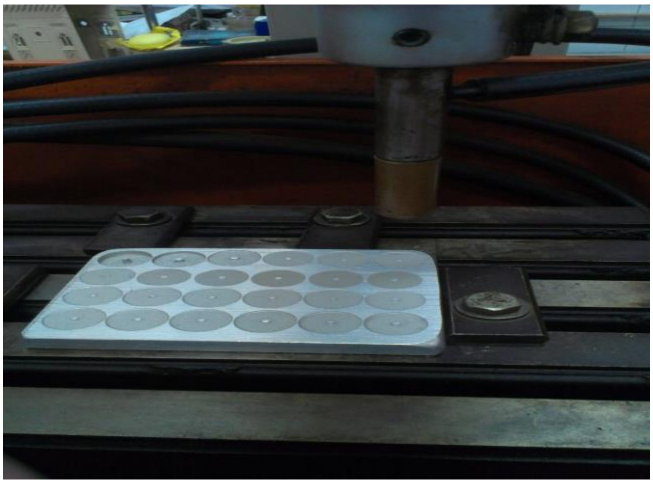

Fig. 6 The machined work piece specimens.

Fig.7 Set up for surface roughness measurement tester.

IX. Results & Discussion

The MRR found in the experiment by varying the input parameters such as input current, pulse on time, duty cycle and gap voltage. The variation of MRR with Input Current and it was observed that with increase in Input Current, MRR increases. Because of the increase in current the spark energy increases which melts and evaporates the material from the workpiece. the variation of MRR with Pulse on Time and it was observed that with increase in Pulse on Time, MRR decreases. the variation of MRR with Gap Voltage and it was observed that at first MRR increases with increase in Gap Voltage and after reaching certain value it starts decreasing. Increase in voltage increases current which removes material from the workpiece. So, the optimal input parameters to achieve larger MRR shown in Fig.8, Fig.11 and Fig.14 for Al 6061, Al+5%SiC and Al+10%SiC respectively.

For Al 6061 the optimal parameters are Ip = 8A, Ton = 15µs, DT = 50% and Gap = 0.25mm.

For Al+5%SiC the optimal parameters are Ip = 8A, Ton = 45µs, DT = 65% and Gap = 0.45mm.

For Al+10%SiC the optimal parameters are Ip = 8A, Ton = 45µs, DT = 65% and Gap = 0.35mm.

The Surface Roughness found in the experiment by varying the input parameters such as input current, pulse on time, duty cycle and gap voltage. the variation of Input Current with Surface Roughness and it was observed that higher MRR of the electrode at high values of currents is accompanied by larger and deeper craters, resulting in a greater surface roughness. Thus, with the increase in Input Current, Surface Roughness increases. the variation of Pulse on Time with Surface Roughness and it was observed that Surface Roughness decreases with increase in Pulse on Time. At low discharge currents, spark energy is low; leading to formation of small craters on the ED machined surface and thereby improving surface finish. Hence smaller craters are formed resulting in good surface finish. the variation of Gap Voltage with Surface Roughness and it was observed that with increase in Gap Voltage, Surface Roughness remains constant up to certain level then it rises suddenly. The optimal input

parameters to achieve smaller Ra shown in Fig.9, Fig.12 and Fig.15 for Al 6061, Al+5%SiC and Al+10%SiC respectively.
For Al 6061 the optimal parameters are Ip = 8A, Ton = 45µs, DT = 50% and Gap = 0.25mm.
For Al+5%SiC the optimal parameters are Ip = 8A, Ton = 30µs, DT = 50% and Gap = 0.35mm.
For Al+10%SiC the optimal parameters are Ip = 4A, Ton = 45µs, DT = 65% and Gap = 0.45mm.

Electrode wear is mainly due to high-density electron impingement, thermal effect, mechanical vibrations generated by metal particles from the work material and imperfections in the microstructure of electrode material. The TWR found in the experiment by varying the input parameters such as input current, pulse on time, duty cycle and gap voltage. the variation of Input Current with TWR and it was observed that with increase in Input Current, TWR decreases up to certain value and then it increases. the variation of Pulse on Time with TWR and it was observed that initially TWR decreases with increase in Pulse on Time up to certain value then it increases. the variation of Gap Voltage with TWR and it was observed that initially with increase in Gap voltage there is a very minute decrease in TWR up to a certain extent and then there is a sudden rise in TWR. The optimal input parameters to achieve smaller TWR shown in figure Fig.10, Fig.13 and Fig.16 for Al 6061, Al+5%SiC and Al+10%SiC respectively.
For Al 6061 the optimal parameters are Ip = 8A, Ton = 15µs, DT = 50% and Gap = 0.45mm.
For Al+5%SiC the optimal parameters are Ip = 2A, Ton = 15µs, DT = 50% and Gap = 0.25mm.
For Al+10%SiC the optimal parameters are Ip = 2A, Ton = 15µs, DT = 85% and Gap = 0.45mm.

A. Optimal input and output parameters for Al 6061

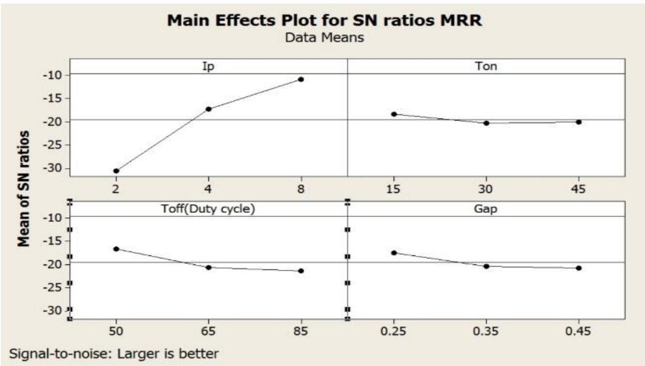

Fig. 8 – Optimal input parameters to achieve larger MRR for Al 6061

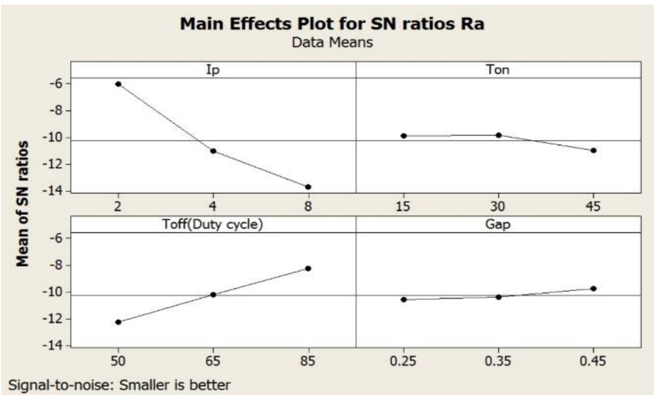

Fig. 9 - Optimal input parameters to achieve smaller Ra for Al 6061

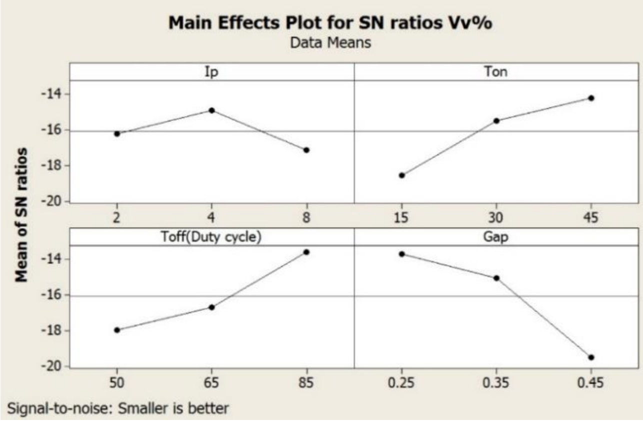

Fig. 10 - Optimal input parameters to achieve smaller Vv% for Al 6061

B. Optimal input and output parameters for Al+5%SiC

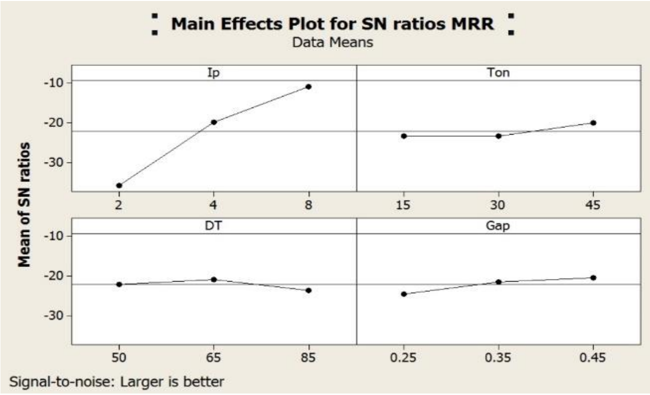

Fig. 11 - Optimal input parameters to achieve larger MRR for Al-5%SiC

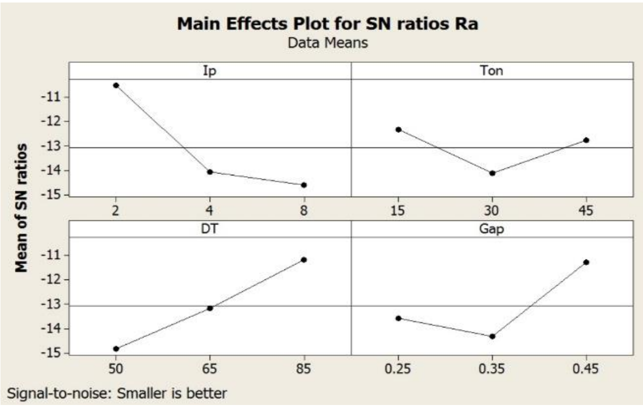

Fig. 12 Optimal input parameters to achieve smaller Ra for Al-5%SiC

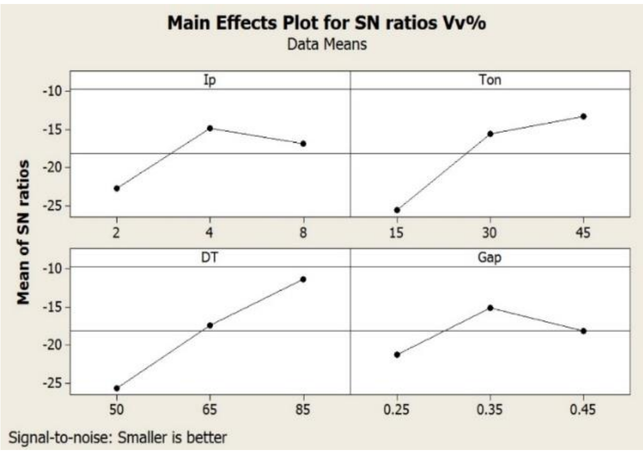

Fig. 13 Optimal input parameters to achieve smaller Vv% for Al-5%SiC

C. Optimal input and output parameters for Al+10%SiC

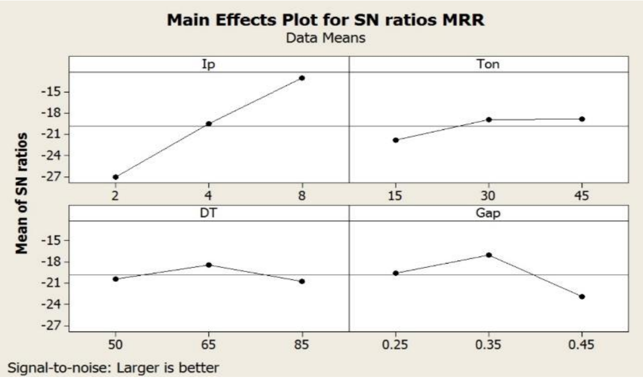

Fig. 14 - Optimal input parameters to achieve larger MRR for Al-10%SiC

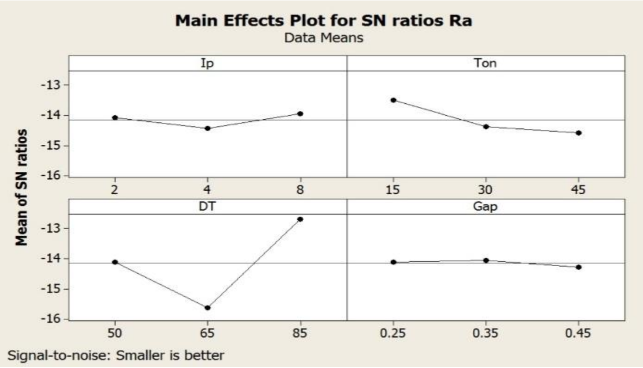

Fig. 15 Optimal input parameters to achieve smaller Ra for Al-10%SiC

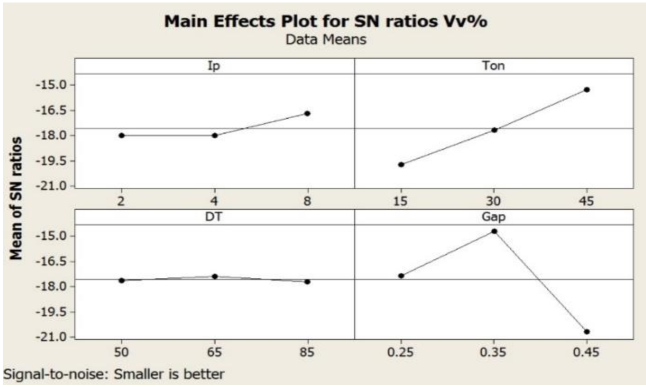

Fig. 16 Optimal input parameters to achieve smaller Vv% for Al-10%SiC

X. Conclusion

After conducting the experiments on Al 6061 and AlSiC-Metal Matrix Composite, the important conclusions are as follows:

- The maximum values of MRR obtained, were 0.3557g/min, 0.324g/min and 0.3443g/min in case of matrix, Al-5%SiC and Al-10%SiC respectively.
- The minimum values of TWR obtained, were 0.4140%, 0% and 0.3861% in case of matrix, Al-5%SiC and Al-10%SiC respectively.
- The minimum values of Ra obtained, were 1.552µm, 1.963µm and 3.354µm in case of matrix, Al-5%SiC and Al-10%SiC respectively.
- The feasibility of machining AlSiC-MMC (5% and 10% SiC Reinforcement) was evaluated.
- Maximum MRR was obtained for high Input Current, low Pulse On Time, high Duty Cycle and intermediate Gap Voltage.
- For minimum TWR, MRR was found closer to its minimum value.
- For the optimum set of input parameters, MRR was found closer to the maximum value and TWR found closer to the minimum value.

References

[1] N. Mohd Abbas, D.G. Solomon, Md. Faud Bahari, A review on current research trends in electric discharge machining, Int. J. Mach. Tool Manuf. 47 (2006) 1214–1228.

[2] L. Cronjäger, Machining of fibre and particle-reinforced aluminium, Ann. CIRP 41 (1) (1992) 63–66.

[3] Sushant Dhar, Rajsh Purohit, Nishant Saini, Akhil Sharma, G. Hemanth Kumar, Mathematical modelling of ED machining of cast Al-4Cu-6Si alloy- 10% SiCp composites, Journals of Materials Processing Technology 194 (2007) 24-29

[4] B Mohan, A Rajadurai, K. G. Satyanarayana, Effect of SiC and rotation of electrode on Electric Discharge Machining of Al-SiC composite, Journal of Materials Processing Technology 124 (2002) 297-304

[5] S. Gopalakannan, T Senthilvelam, Application of response surface method on machining of AlSiC nano-composites, Al-SiC nano-composites with Cu electrode by adopting face centred central composite design of RSM, Measurement 46 (2013) 2705-2715

[6] F.Q. Hu, F.Y. Cao, B.Y. Song, P.J. Hou, Y. Zhang, K. Chen, J.Q. Wei, Surface properties of SiCp/Al composite by powder-mixed EDM, Procedia CIRP 6 (2013) 101 – 106

[7] Debaprasanna Puhan, Siba Sankar Mahapatra, Jambeswar Sahu, Layatitdev Das," A hybrid approach for multi-response optimization of nonconventional machining on AlSiCp MMC", Measurement 46 (2013) 3581–3592

Hany A. Shehata, B.Sc. is a teaching assistant at the "Design and Production Engineering" Department of Modern Academy For Engineering and Technology in Cairo – Egypt. His current research interests are in the areas of Non-Traditional machining, Composite materials, Machine Design and Stress analysis.

Samy J. Ebeid, Ph.D is an Emeritus professor at the "Design and Production Engineering" Department of Ain Shams University in Cairo – Egypt. The main research interests lie in the fields of recent manufacturing processes (ECM – EDM - LASER – RP ….etc), Machine Design and Stress Analysis. Samy J. Ebeid has above 50 local and international publications covering the mentioned fields. Samy J. Ebeid is also a referee for international journals in addition was a member of the Egyptian Scientific committee for the promotion of professors and a member of the Egyptian national committee for welding technology.

A.M.Kohail, Ph.D is a professor in mechanical engineering & manufacturing technology in Modern Academy for engineering and technology in Maadi, Cairo – Egypt. The main research interests lie in the fields of non-traditional manufacturing processes Engineering metrology. A.M.Kohail has above 30 local and international publications covering the mentioned fields. A.M.Kohail is also a referee for the international scientific conferences of MTC and other Egyptian Scientific Conferences.