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► **To cite this version:**

M Sangeetha, A Srinivasulu Reddy, G Vijaya Kumar. Optimization of Die-Sinking EDM Process Parameters in Machining OF AMMC-Desirability Approach. *Mechanics, Materials Science & Engineering Journal*, 2017, 7, <10.2412/mmse.7.643.887>. <hal-01508699>

HAL Id: hal-01508699

<https://hal.science/hal-01508699v1>

Submitted on 14 Apr 2017

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Optimization of Die-Sinking EDM Process Parameters in Machining OF AMMC-Desirability Approach

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DOI 10.2412/mmse.7.643.887

Keywords: metal matrix composites, die-sink EDM, MRR, EWR, SR, cost, desirability function analysis.

ABSTRACT. Metal Matrix Composites (MMCs) are one of the recent advanced materials having the properties of light weight, high specific strength and high wear resistance which are essential in Aircraft fittings, gears and shafts, missile parts, regulating valve parts, aerospace and defence applications. In the present work, Orthogonal Array L_{27} Taguchi Experimental design is prepared using Minitab software by considering material parameters: type of the base material (Al5052, Al6082, Al7075), type of reinforcement material (FlyAsh, SiC, Al_2O_3), percentage of the reinforcement (2, 5, 10%) and machining parameters current (I_p), pulse on time (T_{on}), pulse off time (T_{off}), tool lifting time (TL). AMMC samples are fabricated using stir casting process and experiments have been performed on these samples by using electro discharge machining (EDM) as per Taguchi design of experiments and the responses such as Material removal rate (MRR), surface roughness (SR), and Electrode wear rate (EWR) and cost are measured. The experimental response data of electro discharge machining process is analysed and the optimal combinations of influential parameters are determined using Desirability Function Analysis. Based on these optimum parameters combinations conformation test has been carried out and predicted results have been found to be in good agreement with experimental findings.

1. Introduction. Conventional materials have the limitations in achieving good combination of strength, stiffness, toughness and density etc. To overcome these limitations and to meet the ever increasing demand of modern day technology, composites are most promising materials of recent days. Metal matrix composites (MMCs) possess high strength, hardness, toughness, and good thermal resistance properties as compared to unreinforced alloys.

Aluminium MMCs are difficult to machine by traditional machining techniques. Non-traditional machining techniques such as water jet machining, laser machining and wire EDM can be applied but these processes are mainly limited to linear cutting. Laser cutting and abrasive water jet machining had been used for machining of aluminium and MMCs and found suitable for rough cutting applications. Since the cost for using laser machining is generally prohibitive and EDM wire-cut process is not appropriate for a metal matrix composite work piece due to excessive breakage of the electrode wire, sinking EDM becomes an optimal choice for the machining of aluminium MMCs composite owing to its easy control in operation and precise criterion of high complex-shape components.

2. Literature review

T. Senthilvelan [1] used EDM to machine EN8 and D3 steel materials which has wide application in Industry fields. The process parameters that have been selected are peak current, pulse on time, die electric pressure and tool diameter. The outputs responses are material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). The Cast Copper and Sintered Powder Metallurgy Copper (P/M Copper) considered as tool electrodes. Gangadharudu Talla et al. [2] conducted experiments on aluminium/alumina MMC using EDM by adding aluminium powder in kerosene dielectric. Results showed an increase in MRR and decrease in surface roughness compared to those for conventional machining. Mandeep Dhillon, Chandan Deep Singh, Jasvinder Singh [3] studied the optimization of EDM parameters during machining of Aluminium Alloy 7075. Four parameters namely peak current,

pulse on time, duty cycle and flushing pressure are selected as input process parameters. Performance of EDM for Material removal rate (MRR), Surface Roughness (Ra) and Tool wear rate (TWR) is measured using a Copper electrode. Central composite design of Response Surface Methodology is opted for experimentation. Feng Yerui et al. [4] studied the influence of peak current, pulse duration on the surface roughness, material removal rate and material removal mode (MRD) on TiC/Ni metal ceramic processing. C. Velmurugan et al. [5] investigated the effect of parameters like Current(I), Pulse on time(T), Voltage(V) and Flushing pressure(P) on metal removal rate (MRR), tool wear rate(TWR) as well as surface roughness(SR) on the EDM machining of hybrid Al6061 metal matrix composites reinforced with 10% SiC and 4% graphite particles. M. Kathiresan and T. Sornakumar [6] Electrical Discharge Machining (EDM) studies were conducted on the aluminum alloy-silicon carbide composite work piece using a copper electrode. The Material Removal Rate (MRR) and surface roughness of the work piece increases with an increase in the current. The MRR decreases with increase in the percent weight of silicon carbide. The surface finish of the machined work piece improves with percent weight of silicon carbide. Gopalakannan et al. [7] performed experiments by choosing the process parameters such as pulse current, gap voltage, pulse on time and pulse off time. The Taguchi based grey relational analysis was adopted to obtain grey relational grade for EDM process with multiple characteristics namely material removal rate (MRR), Electrode wear rate (EWR) and surface roughness(SR). S. Kannan and K. Ramanathan [8] investigated the effect of current (C), pulse on-time (POT) and flushing pressure (P) on Metal removal Rate (MRR), Tool Wear Rate (TRR) during electrical discharge machining of as sintered Al-TiC MMC (5% reinforcement) was prepared by in-situ technique by synthesis route using stir casting furnace. Analysis of variance (ANOVA) was performed to find the validity of the experimental plan. S. Singh [9] applied the designs of experiments and grey relational analysis (GRA) approach to optimize parameters for electrical discharge machining process of 6061Al/Al₂O₃p/20P aluminium metal matrix composites. The process parameters included pulse current, pulse ON time, duty cycle, gap voltage and tool electrode lift time with three levels each. The material removal rate, tool wear rate and surface roughness were selected as the evaluation criteria, in this study. Ms. Pallavi S. Karande [10] conducted the experiments on EN-31 material with Copper as Electrode material using EDM. Various Process parameters namely Discharge Current (DC), Pulse on Time, Pulse off Time etc. have been considered. The process performance is measured in terms of Response variable like Tool Wear. Abhijeetsinh V. Makwana¹, Kapil S. Banker [11] discussed the performance of die sinking EDM due to the shape configuration of the electrode. The optimization of the parameters of the EDM machining has been carried out by using the Taguchi method for design of experiments (DOE). Md. Ashikur Rahman Khan et al. [12] studied the surface finish characteristics of the machined surface in EDM on Ti-5Al-2.5Sn titanium alloy. The microstructure of the machined surface is investigated for discharge energy and electrode materials. The peak current, pulse-on time, pulse-off time, servo voltage and electrode material (copper, copper-tungsten and graphite) are considered as process variables. Paras Kumar & Ravi Parkash [13] investigated the effect of electric discharge machining(EDM) process parameters current, pulse-on time (Ton), pulse off time (Toff) and electrode material on material removal rate (MRR), electrode wear rate (EWR) and surface roughness(SR) during machining of aluminium boron carbide (Al-B₄C) composite. Kuldeep Ojha et al. [14] Reported research on EDM relating to improvement in MRR along with some insight into mechanism of material removal. F. Klockea, M. Schwadea, A. Klink, D. Veselovac [15] investigated the specific wear behaviour and material removal rate in detail in this paper and linked to the physical characteristics of the graphite material. In total 5 different kinds of graphite were chosen with significantly different physical characteristics concerning their specific electric resistance, thermal conductivity and grain size. The performance of each grade was evaluated in terms of material removal rate and tool wear for roughing. K. M. Patel et al. [16] investigated the EDM machinability on ceramic composite material (Al₂O₃-SiCw-TiC). Experiments were conducted using discharge current, pulse-on time, duty cycle and gap voltage as typical process parameters. The grey relational analysis was adopted to obtain grey relational grade for EDM process with multiple characteristics namely material removal rate and surface roughness. M. M. Pawade and, S. S. Banwait [17] reviewed

that the development of die-sinking EDM within the past decades for the improvement of machining characteristics such as Material Removal Rate, Surface Roughness and Tool wear ratio. Jeevamalar and Ramabalan [18] reviewed about the Electrical Discharge Machining in which electrical energy is directly used to remove or cut the metals. . The metal is removed by electrical spark discharge between tool (Cathode) and workpiece (Anode). Electrical Discharge Machining is used in mould and die making industries, Automobile industries and making of Aerospace components. B. Venkatesh, B. Harish. [19]investigated the processing of Al/SiC by powder metallurgy method to achieve desired properties and also the results of an experimental investigation on the mechanical properties of Al/SiC are determined. A. M. S. Hamouda [20] described the processing and characterization of quartz particulate reinforced aluminium-silicon alloy matrix composite. In this regard, quartz-silicon dioxide particulate reinforced LM6 alloy matrix composites were fabricated by carbon dioxide sand moulding process with different particulate volume fraction. The tensile strength of the composites decreases with the increase in addition of quartz particulate. R. Ramanujamet al [20]investigated the parameter optimization of end milling operation for Inconel 718 super alloy with multi-response criteria based on the Taguchi method and desirability function analysis. .

3. Design of experiments and preparation of aluminium metal matrix composites

In the present work nine AMMC samples are produced using stir casting furnace as per Taguchi L27 experimental design (Table. 2) which is obtained by considering material and die sinking EDM parameters (Table 1). To produce AMMCs, the required amount of base material is poured into the graphite crucible and the temperature is raised up to 900^oC and allow it to maintain the same up to complete melting of base material. After melting of base metal the reinforcement particles (2.5%,5%,10% by wt) are added gradually into the molten metal. Along with the particles, 2% of magnesium is also added to the molten metal as a wetting agent. The effect of magnesium reduces the surface tension of aluminium as well as increases the wetting properties between the aluminium and reinforcement material in molten stage. In this way, mixing and dispersion time also reduce a large extent. It is possible to disperse the particles uniformly in the molten aluminium alloy after 5 minutes of stirring.

Table 1. Influential parameters and their levels.

Sl. no	Influential parameters	Level 1	Level 2	Level 3
Material Parameters				
1	Base material (BM)	Al5052	Al6082	Al7075
2	Type of reinforcement material (RM)	Fly Ash	SiC	Al ₂ O ₃
3	Percentage of reinforcement particle (%RM)	2.5	5	10
Die-sinking EDM Parameters				
4	Current(I)(Amps)	4	8	12
5	Pulse on time (T _{on})(μs)	100	150	200
6	Pulse off time(T _{off})(μs)	25	50	75
7	Tool lifting time(TL)(μs)	5	10	20

Table 2. Taguchi design of experiments.

Exp Run No	AMMC Sample No.	Material parameters			Die sinking EDM parameters			
		BM	RM	%RM	I	T _{on}	T _{off}	TL
1	1	5052	FA	2.5	4	100	25	5
2		5052	FA	2.5	4	150	50	10
3		5052	FA	2.5	4	300	75	20
4	2	5052	SIC	5	8	100	25	5
5		5052	SIC	5	8	150	50	20
6		5052	SIC	5	8	300	75	20
7	3	5052	Al2O3	10	12	100	25	5
8		5052	Al2O3	10	12	150	50	10
9		5052	Al2O3	10	12	300	75	20
10	4	6082	FA	5	12	100	50	5
11		6082	FA	5	12	150	75	10
12		6082	FA	5	12	300	25	20
13	5	6082	SIC	10	4	100	50	20
14		6082	SIC	10	4	150	75	5
15		6082	SIC	10	4	300	25	10
16	6	6082	Al2O3	2.5	8	100	50	20
17		6082	Al2O3	2.5	8	150	75	5
18		6082	Al2O3	2.5	8	300	25	10
19	7	7075	FA	10	8	100	75	10
20		7075	FA	10	8	150	25	20
21		7075	FA	10	8	300	50	5
22	8	7075	SIC	2.5	12	100	75	10
23		7075	SIC	2.5	12	150	25	20
24		7075	SIC	2.5	12	300	50	5
25	9	7075	Al2O3	5	4	100	75	10
26		7075	Al2O3	5	4	150	25	20
27		7075	Al2O3	5	4	300	50	5

4. Experimentation.

The experiments were conducted on compact type Diesinking-EDM machine as per the Taguchi design of experiments and the experimental data is recorded in the Table 3. For these experiments, copper electrode is used and EDM oil is used as dielectric fluid.



Fig. 1. Die sinking EDM Machine.

Table 3. Experimental results.

Expt. no	EWR (mm ³ /min.)	MRR (mm ³ /min.)	SR (μm)	Process cost (Rs.)
1	8. 1164	2. 9991	4. 219	766. 6847
2	7. 3588	1. 7601	4. 9489	1349. 5366
3	1. 1814	5. 0532	4. 9402	475. 2602
4	8. 8303	3. 1306	4. 4478	757. 1636
5	4. 5905	7. 9877	4. 6050	299. 3395
6	3. 9964	18. 366	5. 1280	130. 7047
7	5. 0045	7. 1909	4. 4013	327. 1253
8	2. 2267	25. 4550	6. 4324	94. 5096
9	8. 4285	85. 3710	6. 1329	28. 1085
10	1. 7367	8. 9727	5. 0199	257. 1854
11	8. 6933	27. 9498	8. 4435	85. 9414
12	4. 9565	38. 6139	8. 8298	62. 3554
13	1. 4249	3. 5680	2. 9198	662. 3273
14	4. 5593	12. 042	3. 4696	200. 3140
15	4. 9995	3. 0239	4. 2515	796. 4090
16	2. 8526	3. 3258	3. 8150	701. 9061
17	4. 8051	6. 4011	4. 8840	378. 8423
18	3. 7952	26. 9494	5. 9468	88. 6873
19	5. 4205	2. 4795	3. 2708	933. 7269
20	5. 0638	7. 4035	4. 6040	313. 2328

21	5. 5754	7. 3063	6. 3509	316. 1610
22	3. 7939	13. 3042	4. 0599	175. 9246
23	5. 7060	40. 2047	6. 0704	59. 7810
24	4. 7450	28. 5399	7. 1979	85. 3065
25	5. 5338	1. 8543	4. 1016	1260. 0380
26	3. 5655	4. 0683	4. 2547	580. 5867
27	3. 2487	6. 4621	5. 3993	367. 8497

5. Desirability functional analysis

Step 1: Calculate the individual desirability index (d_i) for the corresponding responses using the formula proposed by the Derringer and Suich. There are three forms of the desirability functions according to the response characteristics.

i. Nominal - the best: The value of \hat{y} is required to achieve a particular target T . When the ‘ y ’ equals to T , the desirability value equals to 1; if the departure of ‘ y ’ exceeds a particular range from the target, the desirability value equals to 0, and such situation represents the worst case.

$$d_i = \begin{cases} \left(\frac{\hat{y}-y_{min}}{T-y_{min}}\right)^s, & y_{min} \leq y \leq T, s \geq 0 \\ \left(\frac{\hat{y}-y_{min}}{T-y_{min}}\right)^t, & T \leq \hat{y} \leq y_{max}, t \geq 0 \\ 0 & \end{cases} \quad (1)$$

ii. Larger-the better: The value of ‘ \hat{y} ’ is expected to be the larger the better. When the ‘ y ’ exceeds a particular criteria value, which can be viewed as the requirement, the desirability value equals to 1; if the ‘ y ’ is less than a particular criteria value, which is unacceptable, the desirability value equals to 0.

$$d_i = \begin{cases} 0 & \hat{y} \leq y_{min} \\ \left(\frac{\hat{y}-y_{min}}{y_{max}-y_{min}}\right)^r, & y_{min} \leq \hat{y} \leq y_{max}, r \geq 0 \\ 1 & \hat{y} \geq y_{min} \end{cases} \quad (2)$$

iii. Smaller-the better: The value of ‘ \hat{y} ’ is expected to be the smaller the better. When the ‘ y ’ is less than a particular criteria value, the desirability value equals to 1; if the ‘ y ’ exceeds a particular criteria value, the desirability value equals to 0. In this study, “smaller the better” and “larger the better” characteristics are applied to determine the individual desirability values for minimize the TWR,SR, Process cost and maximize the MRR.

$$d_i = \begin{cases} 1 & \hat{y} \leq y_{min} \\ \left(\frac{\hat{y}-y_{max}}{y_{min}-y_{max}}\right)^r, & y_{min} \leq \hat{y} \leq y_{max}, r \geq 0 \\ 0 & \hat{y} \geq y_{min} \end{cases} \quad (3)$$

Step 2: Compute the composite desirability (D). The individual desirability index of all the responses can be combined to form a single value called composite desirability (D) by the following Equation.

$$D=(d_i^{w_1} \times d_i^{w_2} \times \dots \times d_i^{w_n})^{1/w} \tag{4}$$

Step 3: Determine the optimal parameter and its level combination. The higher composite desirability value implies better product quality. Therefore, on the basis of the composite desirability (D), the parameter effect and the optimum level for each controllable parameter are estimated.

Step 4: Obtaining optimal combination of influential factors:

After determining the composite desirability the effect of each parameter is separated based on composite desirability values at different levels. The mean values of composite desirability for each level of the influential factors and the effect of influential factors on multi responses in rank wise are summarized in Table 6 Basically, larger the composite desirability(D)means it is close to the product quality. Thus, a higher value of the ‘D’ is desirable. From the Table 6 and fig 1, the optimal combination of influential factors are BM3RM2%RM3I3T_{on}3T_{off}2TL3. This means Base material at level 3 ie; Al7075Reinforcement material at level 2ie; SiC percentage of Reinforcement material at level 3 ie; 10, T_{on}at level 3 ie; 300μs, T_{off} at level 2 ie; 50μs, TLat level 3 ie; 20μs

6. Conformation test

For the obtained optimal combination, confirmation test has been conducted and compared the results (Table 6) with initial set of parameters. These results are satisfactory as the responses for optimal combination shows better performance.

Table 4. Desirability indexes.

SL NO	Individual desirability indexes				Composite desirability (D)
	EWR	MRR	SR	COST	
1	0.0933	0.0148	0.7802	0.4411	0.1477
2	0.1924	0	0.6567	0	0
3	1	0.0394	0.6581	0.6616	0.3619
4	0	0.0164	0.7415	0.4483	0
5	0.5543	0.0745	0.7149	0.7947	0.3913
6	0.632	0.1986	0.6264	0.9224	0.5189
7	0.5002	0.065	0.7493	0.7737	0.3705
8	0.8633	0.2834	0.4057	0.9498	0.5541
9	0.0525	1	0.4563	1	0.3935
10	0.9274	0.0863	0.6447	0.8266	0.4544
11	0.0179	0.3132	0.0654	0.9562	0.1368
12	0.5065	0.4408	0	0.9741	0
13	0.9682	0.0216	1	0.5201	0.323
14	0.5584	0.123	0.907	0.8697	0.4824

15	0.5008	0.0151	0.7747	0.4186	0.2226
16	0.7815	0.0187	0.8485	0.4901	0.2793
17	0.5262	0.0555	0.6676	0.7346	0.346
18	0.6583	0.3013	0.4878	0.9542	0.5512
19	0.4458	0.0086	0.9406	0.3147	0.1836
20	0.4924	0.0675	0.715	0.7842	0.3695
21	0.4255	0.0663	0.4194	0.782	0.3102
22	0.6584	0.1381	0.8071	0.8881	0.5052
23	0.4085	0.4598	0.4669	0.976	0.5409
24	0.5341	0.3203	0.2761	0.9567	0.4611
25	0.431	0.0011	0.8	0.0677	0.0716
26	0.6883	0.0276	0.7741	0.5819	0.3042
27	0.7297	0.0562	0.5805	0.7429	0.3647

Table 5. Response Table for the Composite Desirability.

Level	BM	RM	%RM	I	Ton	Toff	TL
1	0.3042	0.2182	0.3548	0.2531	0.2595	0.2785	0.2910
2	0.3106	0.3828	0.2491	0.3278	0.3472	0.3487	0.2755
3	0.3457	0.3595	0.3566	0.3796	0.3538	0.3333	0.3940
Delta	0.0415	0.1646	0.1075	0.1265	0.0943	0.0702	0.1184
Rank	7	1	4	2	5	6	3

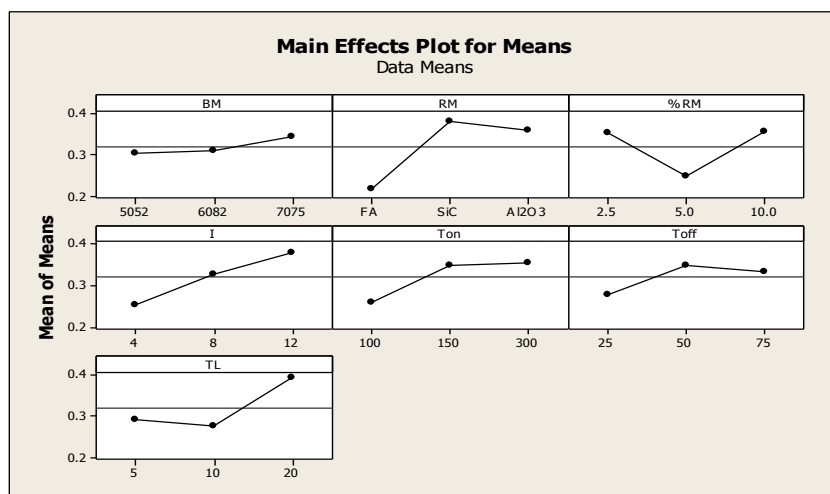


Fig. 4. Response Graph for Composite Desirability.

Table 6. Comparison of responses between AMMC with initial combination and optimal combination.

	Combination of Controllable Parameters	EWR	MRR	SR	COST	Composite desirability
Initial set of	BM2RM2%RM2I2TON2TOFF2TL2	7.9244	26.4326	7.2412	620	0.2683
Optimal combination	BM3 RM2%RM3I3TON3TOFF2TL3	1.3234	45.9327	3.1243	340	0.7864
Improvement in composite desirability						0.5181

Summary. After analysing the data of obtained influential factors combination, it is concluded that Reinforcement material, current and tool lifting time are the most significant parameters which influence the multi responses, % of Reinforcement material and pulse on time are the medium influenced parameters on multi responses and pulse off time, Base metal are influenced lastly the multi responses and the improvement in composite desirability is 0.5181. From the table 6 EWR is reduced from 7.9244 to 1.3234, MRR increased from 26.4326 to 45.9327, surface roughness decreased from 7.2412 to 3.1243 and process cost decreased from 620 to 340.

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