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Experimental Investigations on Machining Characteristics of AA5754 – TiB_2 Composites by Wire EDM

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Abstract - *A Non-traditional process like Wire Electro-Discharge Machining (WEDM) is found to show a promise for machining Metal Matrix Composites (MMC's). In this present work, the effect of WEDM machining process parameters like pulse on time, pulse off time, servo voltage, wire feed and wire tension on surface roughness and material removal rate while machining the newly developed AA5754 – 5TiB2 composite. Experimentation was performed on the L27 orthogonal array of Taguchi under various parameter combinations. ANOVA was used to evaluate the design parameters that affected the response significantly. Using S / N ratio study, the effect of these parameters on the responses was evaluated. The experimental results indicated an optimal combination of parameters that would give maximum material removal rate to the minimum surface roughness. Experiments for confirmation were conducted to determine the effectiveness of the proposed method.*

Key Words: MMC's, Taguchi, ANOVA, WEDM;

1. INTRODUCTION

Aluminium matrix composites refer to the most attractive alternatives for the manufacturing of light weight, high performance aluminium centric material systems due to their low density and high specific strength. Properties of aluminium matrix composites can be tailored to the demands of different industrial applications by suitable combinations of matrix, reinforcement and processing route. Aluminium matrix composites are produced by powder metallurgy, stir casting, metal infiltration, spraying and in-situ processing techniques [1]. Stir casting is a liquid state method of composite materials fabrication, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirring. Simplicity, flexibility and applicability to large quantities of output are its advantages. It is also desirable as it enables the use of a traditional metal processing route in general and thus minimizes the product's final cost. The most economical of all possible routes for metal matrix composite processing is this liquid metallurgy technique.

Greater hardness and reinforcement make machining difficult using traditional techniques that have hindered the development of MMCs. Because of the abrasive nature of reinforcing particles, the use of traditional machinery to machine hard composite materials causes serious tool wear, shortening the life of the tool. Although it is possible to apply advanced non-traditional machining techniques such as water jet machining and laser beam machining, the machine equipment is costly and the workpiece height is limited. WEDM is therefore the best choice for the manufacture of composite materials because it is easy to control and machine complex shapes. [2]. Fig. 1 shows a schematic diagram of WEDM process.

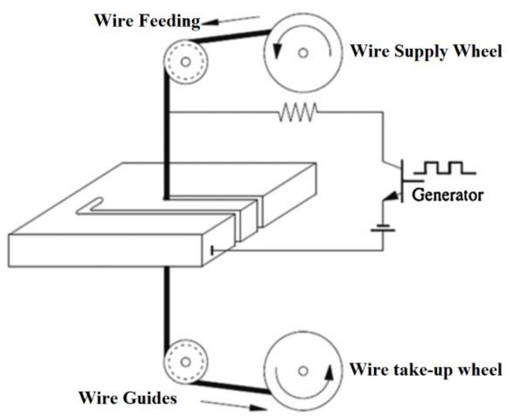

Fig.1. Schematic diagram of wire EDM process

WEDM is an important and promising non-conventional machining process. When precision is of major factor, it is widely used in the machining of materials. WEDM is an ideal tool for making such tools because it is capable of cutting any conductive material regardless of hardness. With the use of WEDM technology, where more intricate tool geometries can be created with high quality, the productivity of manufacturing micro tools can be increased. Material is eroded by series of discrete sparks between the work piece and a tool electrode (small wire) immersed in a liquid dielectric medium (deionized water). These electrical discharges melt and vaporize diminutive quantities of work material, which the dielectric then ejects and flushes away. Since there is no physical contact between the work piece and the electrode, WEDM can process conductive material irrespective of their hardness and durability. It consumes a continuously moving wire electrode made of thin brass, copper or coated wire with a diameter of 0.05–0.3 mm that is capable of achieving very small corner radii and machine reliability, complexity and irregularity with high precision and fine surface finish [3-4]. Selecting a suitable cutting parameter is an important task in the WEDM, since incorrect choice contributes to breakage of the wire and short circuiting, thereby reducing the rate of output. Since, the kerf width and surface finish are the major out-put responses in the WEDM, many researchers have investigated them [5].

Fard et al. have considered Pulse on time, pulse off time, discharge current, gap voltage, wire feed frequency and wire voltage for the WEDM Al – SiC Metal Matrix Composite Machining Study and stated that pulse-on time and discharge current are the most important factors affecting cutting speed and surface roughness. [6]. C. Velmurugan et al. reported that The metal removal frequency of the composite increases with increased current, time pulse, and dielectric fluid flushing pressure as it decreases with increased voltage. The tool wear frequency of the formed composite increases with higher current and voltage and decreases with higher pulse on time and dielectric fluid flushing pressure [7].

A.Muniappan et al. investigated the effect and optimization of machining parameters on kerf width and surface roughness of Al 60661 hybrid composite in WEDM operations. Taguchi based Grey relational analysis was used to optimize the performance characteristics while machining [8]. Rao, investigated the optimization of wire EDM and claims that the quality of a wire EDM surface is strongly influenced by its parameter settings and the material to be machined [9]. Bobbili investigated a multi response optimization technique for wire EDM operations on ballistic grade aluminium alloy for armour applications. Four machining variables were used for the experiment: pulse-on time, pulse-off time, peak current and spark voltage, which proved to be significant to the Grey relational grade [10].

Mangesh R. Phate, Shraddha B. Toney investigated the surface roughness and the material removal rate in the WEDM of AlSiCp MMC. The Material removal rate and the surface roughness increases with the increase in the pulse on time and the thermal conductivity. Material removal rate and the surface roughness decreases with the increase in the composition of SiC. Out of all the process parameters, the pulse on time was found to be most influencing parameter followed by the current and wire feed rate [11].

N G Patil et al, investigated the effect of combination of electrical as well as mechanical parameters on the performance of WEDM of metal matrix composite (Al/SiCp) was studied by using Taguchi experiments. Taguchi methods and grey relational analysis was used to optimize multiple performance characteristic of wire electro discharge machining of Al/SiCp composites. It is shown that kerf width and cutting speed are improved together. Wire breakage was found to pose a limitation on the material removal rates that could be achieved while machining these composites. However, wire breakages could be reduced by employing higher flushing pressures, higher pulse off-times and suitable value of servo reference voltage [12-13].

From the literatures it is observed that very few studies have been carried out to investigate the influence of reinforcement particles affecting the machinability of WEDM process. However no work is reported on Al-Mg-TiB2 in situ composite, this was the seed to carry out this novel work. Hence the Al-Mg Alloy with 5 wt% of TiB2 is selected to perform the experiments through WEDM process. The parameter which significantly affects the WEDM process was found out using ANOVA. The percentage contribution of parameters was determined by S/N ratio. Optimum parameters level was obtained for different input parameters and finally confirmation experiment was conducted to obtain the best results. The most important performance measures in WEDM are material removal rate (MRR) and surface roughness (Ra).

2. MATERIAL & METHODS

2.1 Casting of the in-situ composite

The concentrated Al-Mg-5wt% TiB2 insitu composite were produced by the mixed salt route method. Al-Mg master alloy and the salts K2TiF6 and KBF4 in calculated proportions were melted together, where the reaction temperature was maintained at 800oC for 60min while the melt was stirred intermittently after every 10min. The exact details of this procedure are given elsewhere [14].

2.2 Machining Parameters and Response

Five input process parameters in WEDM, namely, Pulse on Time (TON), Pulse off Time (TOFF), servo voltage (SV), Wire Feed (WF) and Wire Tension (WT) were chosen to study their effects on Material Removal Rate (MRR) and Surface Roughness (Ra) while machining the in-situ composite. The ranges of these process parameters were selected on the basis of the pilot experiments. The levels of various parameters and their designations are presented in Table 1.

2.3 Experimental design using Taguchi method

Taguchi technique is an efficient tool for the design of a high-quality manufacturing system. It is a method based on OA experiments, which provide much reduced variance for the experiment with optimum setting of process control parameters. The five control parameters, that is, Pulse on Time (TON), Pulse off Time (TOFF), servo voltage (SV), Wire Feed (WF) and Wire Tension (WT) at three levels were selected in this study. The experiments were done according to Table 1. This table only represents particular level of the various factors of the process at which the experiments would be conducted. Column 1 presents serial order of experiments. Columns A–E indicates various levels of the parameters according to OA. The Minitab 18 software was used to analyze the results.

Table 1: Process parameters and their levels

Symbol	Process Parameters	Units	Level 1	Level 2	Level 3
T_{ON}	Pulse On Time (A)	µ sec	115	120	125
T_{OFF}	Pulse Off Time (B)	µ sec	53	58	63
SV	Servo Voltage (C)	volts	20	25	30
WF	Wire Feed (D)	m/min	2	3	4
WT	Wire Tension (E)	Kg-f	3	5	7

2.4 Experimental Set-up for WEDM Process:

Experiments were conducted on Electronica Sprint cut (Electra-Elplus 40A Dlx) CNC wire electrical discharge machine to study the Surface Roughness and Material Removal Rate affected by the machining parameters at different levels. Between the work piece and the wire electrode, the sparks are produced. The dielectric fluid is continuously fed with the required pressure into the machining region. A series of discrete sparks occurring in the region to be machined by electro-thermal process removes the material. Small gap between the work and the wire material was maintained during the machining process. The machined particles have been flushed away by the dielectric fluid's study flow.

The wire is supported at the top and bottom sections of the work piece by a pin guide. Due to the electrical discharge between the wire and the work part, the wire is subject to complex oscillations. It is therefore necessary to keep the wire against the work piece in its intended location. Once used for cutting at a set level of process parameters, the wire is not reused. In the next experiment a fresh wire length is used for each cut. The work specimen size used in this study is 150 x 150 x 15 mm square plate. 10 x 10 x 15 mm size square work was cut from the specimen. In this study, a 0.25 mm diameter zinc-coated brass electrode wire was used. Deionized water was used at room temperature as a dielectric fluid. The specimens were cleaned with acetone after processing. SR (Ra) was measured in micrometer using Mitutoyo SJ-301 Surface roughness tester. On each machined surface, SR was measured at three places spread over the entire machined area.

Results of the experiments are studied by using the analysis of variance (ANOVA) and signal-to-noise (S/N ratio) analysis. The analyses of S/N ratio and ANOVA were carried out to study the relative influence of the machining parameters on the material removal rate and surface roughness of the machined in-situ composite. S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio characteristics can be classified into three categories, 'larger-is-better, smaller-is-better', and 'nominal-the-best'. The S/N ratio can be calculated as a logarithmic transformation of the function as shown in Eq. (2) and Eq. (3). For material removal rate (MRR), 'larger-is-better and for surface roughness (Ra), smaller-is-better were selected for obtaining optimum machining performance characteristics.

$$\text{S/N ratio for MRR} = -10\log_{10}\frac{1}{n}\Sigma\left[\frac{1}{y^2}\right]$$

$$\text{S/N ratio for Ra} = -10\log_{10}\frac{1}{n}\Sigma y^2$$

Where,

n = number of observations

y = observed data (MRR or Ra)

The objectives are to maximize material removal rate (MRR) and to minimize surface roughness (Ra). Based on S/N ratio and ANOVA analysis, the optimal setting of the machining parameters for machined surface roughness and material removal rate were obtained and verified. Taguchi based L27 orthogonal array is selected.

3. Results and discussion

The analyses of the experimental data were carried out using MINITAB 18 software, which is especially used for DOE applications (Table 2). The experimental observations were transformed into S/N ratios for measuring the quality characteristics. The calculated S/N ratios of MRR and Ra for Al-Mg-5wt% TiB2 in-situ composite are shown in table 3.

Table 2: Experimental Design Layout

Exp. No	TON	TOFF	SV	WF	WT
1	115	53	20	2	3
2	115	53	20	2	5
3	115	53	20	2	7
4	115	58	25	3	3
5	115	58	25	3	5
6	115	58	25	3	7
7	115	63	30	4	3
8	115	63	30	4	5
9	115	63	30	4	7
10	120	53	25	4	3
11	120	53	25	4	5

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12	120	53	25	4	7
13	120	58	30	2	3
14	120	58	30	2	5
15	120	58	30	2	7
16	120	63	20	3	3
17	120	63	20	3	5
18	120	63	20	3	7
19	125	53	30	3	3
20	125	53	30	3	5
21	125	53	30	3	7
22	125	58	20	4	3
23	125	58	20	4	5
24	125	58	20	4	7
25	125	63	25	2	3
26	125	63	25	2	5
27	125	63	25	2	7

Table 3: Experimental Design Result

Exp. No	Ra	S/N Ratio	MRR	S/N Ratio
1	3.5	-10.88	8.4	18.49
2	3.4	-10.63	8.85	18.94
3	3.34	-10.47	8.55	18.64
4	3.38	-10.58	8.025	18.09
5	3.275	-10.30	8.1	18.17
6	3.295	-10.36	8.325	18.41
7	3.48	-10.83	6.7	16.52
8	3.358	-10.52	6.975	16.87
9	3.43	-10.71	7.115	17.04
10	3.531	-10.96	8.575	18.66
11	3.41	-10.66	8.925	19.01
12	3.38	-10.58	9.0	19.08
13	3.53	-10.96	8.15	18.22
14	3.523	-10.94	8.25	18.33
15	3.51	-10.91	8.425	18.51
16	3.46	-10.78	7.05	16.96
17	3.38	-10.58	7.275	17.24
18	3.295	-10.36	7.14	17.07
19	3.847	-11.70	8.725	18.82
20	3.718	-11.41	8.95	19.04
21	3.68	-11.32	9.3	19.37
22	3.781	-11.55	8.35	18.43
23	3.731	-11.44	8.425	18.51
24	3.63	-11.20	8.775	18.86
25	3.69	-11.34	7.2	17.15
26	3.72	-11.41	7.325	17.30
27	3.68	-11.32	7.175	17.12

3.1 Effect of Process Parameters on Surface Roughness

Analysis of Variance (ANOVA) was carried to analyse the influence of process parameters on the response parameters. The coefficient of determination (R2) indicates the percentage of total variation in the measure of the degree of fit. When R2 approaches to unity, the better the response model fits the actual data. The statistical analysis shows that the model is fairly good agreement with experimental data. The value of probability > F confirms the models are significant and its value must be under 0.05.

Table 4. ANOVA Results for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Cont
Ton	2	3.42219	3.422	1.711	164.23	0.00	80.03
Toff	2	0.03196	0.031	0.01598	1.53	0.246	0.75
SV	2	0.19574	0.195	0.097	9.39	0.002	4.58
WF	2	0.1279	0.127	0.063	6.14	0.011	2.99
WT	2	0.33171	0.33	0.165	15.92	0.00	7.76
Residual Error	16	0.1667	0.16	0.010			
Total	26	4.27619					

Table 4 presents the ANOVA results for the surface roughness. The coefficient of determination (R2) value 96.16% and R2 (pred) is 89.07%. The process parameters such as Pulse on time, Pulse off time, Servo Voltage Gap, Wire Feed and Wire Tension showing significant influence on Ra as their P-value is less than 0.05. It the Pulse on Time is observed as the most significant factor affecting Surface Roughness (Ra), its F-value is 164.23 and contribution is 80.03% for this model. Wire Tension, Servo Voltage Gap and Wire Feed and are showing moderate influence and their contributions are 7.76%, 4.58% and 2.99% respectively on Ra. However, Pulse off time does not show any statistical significance on Ra as their F-values are 1.53. Similarly, the optimum parameter setting for minimum surface roughness during machining operation is presented through the response Table for S/N Ratio and are presented in Table 5 and main effects plot for means as shown in Fig 1.

Table 5: Response Table for Means for Surface Roughness

Level	Ton	Toff	SV	WF	WT
1	-10.59	-10.96	-10.88	-10.98	-11.06
2	-10.75	-10.91	-10.83	-10.82	-10.88
3	-11.41	-10.87	-11.03	-10.94	-10.8
Delta	0.82	0.08	0.2	0.16	0.26
Rank	1	5	3	4	2

3.2 Effect of Process Parameters on Material Removal Rate

ANOVA results for the material removal rate are tabulated in Table 6. The coefficient of determination (R2) value 98.12% and R2 (pred) is 94.63%. The process parameters such as Pulse on time, Pulse off time, Servo Voltage Gap, Wire Feed and Wire Tension showing significant influence on Dimensional Deviation as their P-value is less than 0.05.

Table 6: ANOVA Results for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Cont
Ton	2	0.655	0.655	0.328	17.23	0.00	3.6
Toff	2	16.754	16.754	8.377	440.6	0.00	92.07
SV	2	0.010	0.010	0.005	0.27	0.765	0.06
WF	2	0.013	0.013	0.007	0.34	0.714	0.07
WT	2	0.459	0.459	0.230	12.08	0.001	2.52
Residual Error	16	0.304	0.304	0.019			
Total	26	18.196					

It can be observed from the S/N ratio table 7 that the Pulse off time is the most important factor affecting Material Removal Rate (MRR) as its F-value is 440.6 with contribution of 92.07%. Pulse on Time has showing moderate influence and their contributions are 3.60%, and Wire Tension shows minor significance on this model. However, the servo voltage gap and wire feed has does not show any statistical significance on MRR as their F-values are 0.34 and 0.27 respectively

Table 7: Response Table for Means for MRR

Level	Ton	Toff	SV	WF	WT
1	17.91	18.89	18.13	18.08	17.93
2	18.12	18.39	18.11	18.13	18.16
3	18.29	17.03	18.08	18.11	18.23
Delta	0.38	1.86	0.05	0.05	0.31
Rank	2	1	5	4	3

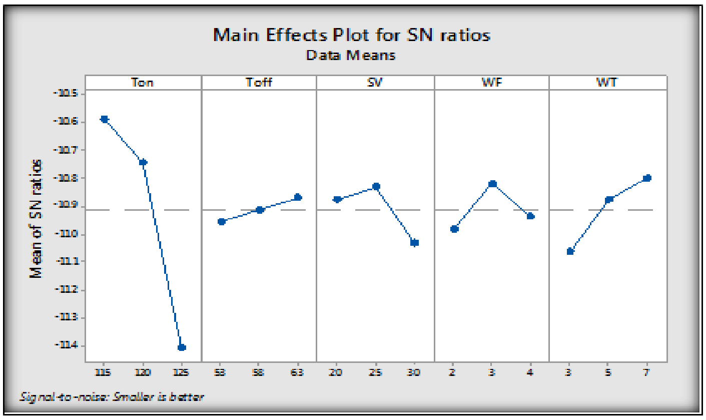

Fig. 1 Main Effects Plot for S/N Ratio of SR (Ra)

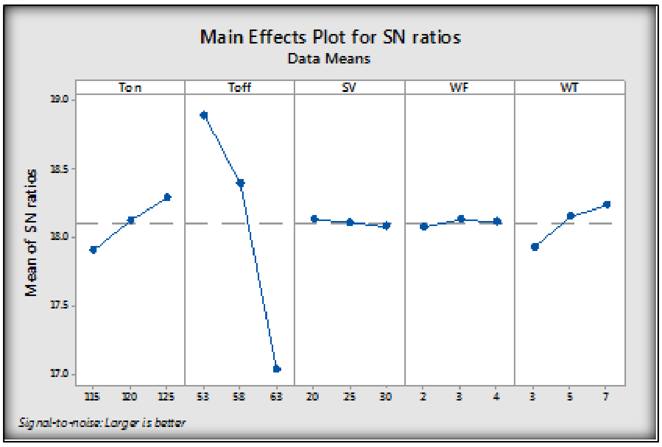

Fig. 2 Main Effects Plot for S/N Ratio of MRR

3.3 CONFORMATION TESTS

The last step is the approval of the results. The confirmation tests are conducted at the optimal parameters which are identified from the main effect plot and compared with predicted value and the results tabulated in Table 8.

Table 8: Conformation Test

Response Parameters	Levels	Experimental Values	Predicted Values
Surface Roughness	TON3,TOFF1,SV3,WF1,WT1	-11.407	-11.544
Material Removal Rate	TON3,TOFF1,SV1,WF2,WT3	19.169	19.077

4. Conclusions:

The effect of combination of electrical as well as mechanical parameters on the performance of WEDM of MMC (AA5754 – 5% TiB2) was studied by using Taguchi experiments. It was found that WEDM could be used to machine ceramic reinforced MMCs.

- Influence of process parameters on AA 5754 – 5 TiB2 composite was investigated.
- The optimum process parameters observed to be the third level of Pulse on time (TON3), the first level of Pulse off time (TOFF1), third level of Servo Voltage Gap (SV3), first level of Wire Feed (WF1) and first level of Wire Tension (WT1), are given as minimum value of surface roughness (Ra) during machining of AA5754-5TiB2 using WEDM.
- The Pulse on Time is observed as the most significant factor affecting Surface Roughness (Ra), its F-value is 164.23 and contribution is 80.03% for this model.
- It is also observed that third level of Pulse on time (TON3), the first level of Pulse off time (TOFF1), first

level of Servo Voltage Gap (SV1), second level of Wire Feed (WF2) and third level of Wire Tension (WT3) are gives the minimum value of Material removal rate during machining of AA5754-5TiB2 using WEDM.

- It can be observed that the Pulse off time is the most important factor affecting Material Removal Rate (MRR) as its F-value is 440.6 with contribution of 92.07%.

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