Asian Journal of Applied Science and Technology (AJAST)
(Open Access Quarterly International Journal) Volume 1, Issue 9, Pages 314-325, 2017

Analysis of Kerf Width and Cutting Speed Characteristics of Aluminium/Tungsten Carbide Composites using TOPSIS Method

M.Subramanian[1], V.Ganeshan[2], A.Prabhu[3] and P.Mohanraj[4]

[1,2,3,4]*Assistant Professor, Department of Mechanical Engineering, Adithya Institute of Technology, Coimbatore, Tamilnadu, India.*

Article Received: 05 August 2017 *Article Accepted: 30 September 2017* *Article Published: 19 November 2017*

ABSTRACT

In this work to optimize the WEDM process parameters while machining Al (6082)/ Tungsten Carbide/Graphite composite. Peak current, pulse on time, pulse off time, wire feed rate and WC percentage were used as process variables to study the Kerf width and cutting speed of composites. TOPSIS technique was used to study the effect of process parameters on response variables. . The optimum parameter set for the current study is Peak current- 25 Amps, Pulse on Time- 20 sec, Pulse off Time- 2.54 sec, Feed rate - 49.83 mm/min and % Tungsten carbide -2% for maximizing the MRR cutting speed and minimizing the kerf width.

Keywords: Composites, Aluminium, WEDM, Kerf width and TOPSIS Technique.

1. INTRODUCTION

Metal matrix composites (MMCs), an important class of materials with excellent mechanical and tribological properties have the potential to replace number of conventional materials used in automotive, aerospace, defense and engineering components [1]. The coefficient of friction, wear resistance, ultimate tensile strength and hardness of aluminium composites were superior compared to that of the base alloy [2]. The machining efficiency of composites was highly influenced by unstable machining while cutting an irregular shaped work piece [3]. The process parameters like wire offset, pulse on time, pulse off time, wire feed, peak current, servo voltage and wire material are the major factors influencing the material removal rate and surface roughness in finish cut Wire Electrical Discharge Machining (WEDM) operation [4]. The extent of thermal damage due to the discharge energy across the work surface underneath the machined surface describes the micro hardness of the work piece. A single trim cut at low discharge energy and appropriate wire offset value, was better compared to that of a multi cut [5]. The material removal rate and surface roughness of the aluminum composites increases with an increase in the current and decreases with increase in the percent weight of reinforcement, while the surface finish of the composites increases with percent weight of reinforcement [6]. The tension in wire has small effect on the cutting speed and heat affected zone having greater influence on the surface roughness [7]

The machining parameters namely the cutting radius, discharge on time, discharge off time, arc on time, arc off time, servo voltage, wire feed and water flow are the factors influencing the optimum performance characteristics of WEDM [8]. Higher current, wire speed, pulse on time and pulse off time increases the material erosion causing dimensional deviation in the machined composites [9]. Higher the current, more will be the energy per spark leading to the formation of crater with higher depth and surface roughness [10]. The surface finish of the machined composite material is affected by the presence of re solidified layer of aluminium in the composites [11]. A warping phenomenon is observed while machining thin sheets owing to thermal residual stress during WEDM of insulating ceramics [12]. Optimization algorithms like genetic algorithm, particle swarm optimization, sheep flock algorithm, ant colony optimization, artificial bee colony, biogeography -based optimization, Pareto optimization algorithm etc can be used for multi-objective optimization of WEDM processes [13-15].

Aluminium alloy (Al 6082) a medium strength alloy with excellent corrosion resistance, wettability, machinability characteristics are used in high stress applications like trusses, bridges, cranes, transport etc. Limited study is available on machining of Al (6082) composites and Tungsten Carbide/Graphite as reinforcement materials. Kerf width is defined as the width of material that is removed by the WEDM cutting process. In this study, the effects of the machining parameters and their level of significance on cutting speed and kerf width are evaluated using ANOVA and RSM technique.

Pulse on time, pulse off time, current, wire feed, reinforcement percentages are the machining parameters considered in the study. Scanning Electron Microscope (SEM) was employed to investigate the effect of process parameters on the microstructure of WEDM considered in the study. Scanning Electron microscope (SEM) was employed to investigate the effect of process parameters on the microstructure of WEDM.

2. MATERIALS AND METHODS

Aluminum alloy (Table 1) is reinforced with tungsten carbide in weight percentages of 2,4,6,8 and 10% and graphite (5%) by liquid metallurgy technique. Aluminium alloy 6082 in the form of ingots was melted in the Electric Resistance Furnace at 800ºC. The reinforcement particles (Tungsten carbide and graphite) were preheated for one hour at 790ºC to remove the moisture content. The stirrer was lowered vertically into the crucible and the speed of the stirrer was gradually raised up to 500rpm. The preheated reinforcement particles were then added into the melt. Stirring was continued for 5-7 minutes for proper mixing of reinforcement in the matrix. To increase the wettability of the particles one weight percent of magnesium was added with the melt. The melt was then poured in the mould for a size of 100mm × 100mm × 10mm. The specimens were the cut into 10 mm square for conducting experiments.

Table 1: Composition of Aluminum 6082 Alloy

Weight%	Al	Si	Fe	Cu	Mn	Cr	Mg	Zn	Ti	Others
6082	Bal	1.12	0.19	0.02	0.87	0.15	0.92	0.17	0.086	0.075

3. TOPSIS METHODOLOGY

The relationship between various process parameters and their responses are determined using Topsis . In order to study the effect of cutting speed and kerf width on WEDM process parameters of 6082 Al/WC/Gr composites a second order polynomial response representing Peak current, Pulse on time, Pulse off time, Wire feed rate and % WC (Table 2) can be expressed as Y=f (I, O,T, F,W), where Y is the response or yield.

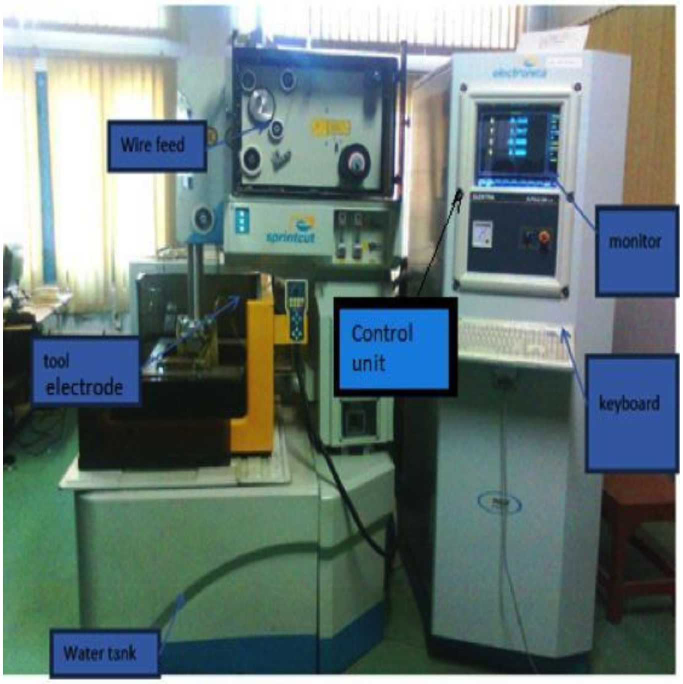

Figure 1: Experimental setup of WEDM

Table 2: Process Variables and their Levels

Parameters	**Symbol**	**UNITS**	**-2**	**-1**	**0**	**1**	**2**
Peak current	I	A	25	50	75	100	125
Pulse on time	O	S	4	8	12	16	20
Pulse off time	T	S	2	4	6	8	10
Wire feed rate	F	mm/min	10	20	30	40	50
% WC	W	%	2	4	6	8	10

The process variables and their levels are selected according to the half central composite design using RSM technique with output response variables are surface roughness and kerf width.

2.1 TOPSIS Method

TOPSIS was first presented by Yoon (1980) and Hwang and Yoon (1981), for solving Multiple Criteria Decision Making (MCDM) problems based on the concept that the chosen alternative should have the shortest Euclidian distance from the Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS). For instance, PIS maximizes the benefit and minimizes the cost, whereas the NIS maximizes the cost and minimizes the benefit. It assumes that each criterion require to be maximized or minimized. TOPSIS is a simple and useful technique for ranking a number of possible alternatives according to closeness to the ideal solution. The TOPSIS procedure is based on an intuitive and simple idea, which is that the optimal ideal solution, having the maximum benefit, is obtained by selecting the best alternative which is far from the most unsuitable alternative, having minimal benefits [3]. The ideal solution should have a rank of ‗1‘ (one), while the worst alternative should have a rank approaching ‗0‘ (zero). As ideal WEDM process are not probable and each alternative would have some intermediate ranking between the ideal solution extremes. Regardless of absolute accuracy of rankings, comparison of number of different process parameters under the same set of selection criteria allows accurate weighting of relative parameter suitability and hence optimal parameters selection. Mathematically the application of the TOPSIS method involves the following steps.

Step 1: Establish the decision matrix

The first step of the TOPSIS method involves the construction of a Decision Matrix (DM).

Table -3 Decision Matrix (DM)

s.no	current	on time	off time	wire	%
1	50	8	4	20	8
2	50	8	4	40	4
3	50	4	8	40	8
4	75	12	6	10	6
5	100	16	8	20	4
6	75	12	2	30	6
7	75	12	6	30	2
8	125	12	6	30	6
9	75	12	6	30	6
10	75	12	6	30	6
11	75	12	6	50	6
12	50	16	8	40	4
13	25	12	6	30	6
14	75	12	10	30	6
15	100	8	8	20	8
16	75	20	6	30	6
17	100	8	4	40	8
18	100	16	4	20	8
19	50	16	8	20	8
20	100	16	8	40	8
21	75	12	6	30	6
22	75	12	6	30	6
23	75	12	6	30	6
24	100	16	4	40	4
25	50	16	4	40	8
26	75	12	6	30	10
27	50	16	4	40	8
28	75	12	6	30	6
29	100	8	4	20	4
30	100	8	8	40	4
31	50	8	8	20	4
32	75	4	6	30	6

Step 2: Calculate a normalized decision matrix

The normalized values denote the Normalized Decision Matrix (NDM) which represents the relative performance of the generated design alternatives.

$$\text{NDM} = R_{ij} = X_{ij} \ / \ \sqrt{\sum_{i=1}^{m} X_{ij}^2} \quad \text{-------------------- (1)}$$

Table- 4 Normalized Decision Matrix (NDM)

s.no	current	on time	off time	wire	%
1	0.123047	0.082531261	0.045160997	0.096691724	0.056674908
2	0.123047	0.082531261	0.045160997	0.193383448	0.028337454
3	0.123047	0.041265631	0.090321993	0.193383448	0.056674908
4	0.18457	0.123796892	0.067741495	0.048345862	0.042506181
5	0.246094	0.165062523	0.090321993	0.096691724	0.028337454
6	0.18457	0.123796892	0.022580498	0.145037586	0.042506181
7	0.18457	0.123796892	0.067741495	0.145037586	0.014168727
8	0.307617	0.123796892	0.067741495	0.145037586	0.042506181
9	0.18457	0.123796892	0.067741495	0.145037586	0.042506181
10	0.18457	0.123796892	0.067741495	0.145037586	0.042506181
11	0.18457	0.123796892	0.067741495	0.24172931	0.042506181
12	0.123047	0.165062523	0.090321993	0.193383448	0.028337454
13	0.061523	0.123796892	0.067741495	0.145037586	0.042506181
14	0.18457	0.123796892	0.112902492	0.145037586	0.042506181
15	0.246094	0.082531261	0.090321993	0.096691724	0.056674908
16	0.18457	0.206328154	0.067741495	0.145037586	0.042506181
17	0.246094	0.082531261	0.045160997	0.193383448	0.056674908
18	0.246094	0.165062523	0.045160997	0.096691724	0.056674908
19	0.123047	0.165062523	0.090321993	0.096691724	0.056674908
20	0.246094	0.165062523	0.090321993	0.193383448	0.056674908
21	0.18457	0.123796892	0.067741495	0.145037586	0.042506181
22	0.18457	0.123796892	0.067741495	0.145037586	0.042506181
23	0.18457	0.123796892	0.067741495	0.145037586	0.042506181
24	0.246094	0.165062523	0.045160997	0.193383448	0.028337454
25	0.123047	0.165062523	0.045160997	0.193383448	0.056674908
26	0.18457	0.123796892	0.067741495	0.145037586	0.070843635
27	0.123047	0.165062523	0.045160997	0.193383448	0.056674908
28	0.18457	0.123796892	0.067741495	0.145037586	0.042506181
29	0.246094	0.082531261	0.045160997	0.096691724	0.028337454
30	0.246094	0.082531261	0.090321993	0.193383448	0.028337454
31	0.123047	0.082531261	0.090321993	0.096691724	0.028337454
32	0.18457	0.041265631	0.067741495	0.145037586	0.042506181

Step 3: Determine the weighted decision matrix

Not all of the selection criteria may be of equal importance and hence weighting were introduced from AHP (Analytical Hierarchy Process) technique to quantify the relative importance of the different selection criteria. The weighting decision matrix is simply constructed by multiply each element of each column of the normalized decision matrix by the random weights.

$$V = V_{ij} = W_j \times R_{ij} \quad \text{------------------------------------ (2)}$$

Table 5 weighted Normalized decision matrix

s.no	current	on time	off time	wire	%
1	0.061523	0.033012505	0.013548299	0.019338345	0.005667491
2	0.061523	0.033012505	0.013548299	0.03867669	0.002833745
3	0.061523	0.016506252	0.027096598	0.03867669	0.005667491
4	0.092285	0.049518757	0.020322448	0.009669172	0.004250618
5	0.123047	0.066025009	0.027096598	0.019338345	0.002833745
6	0.092285	0.049518757	0.006774149	0.029007517	0.004250618
7	0.092285	0.049518757	0.020322448	0.029007517	0.001416873
8	0.153808	0.049518757	0.020322448	0.029007517	0.004250618
9	0.092285	0.049518757	0.020322448	0.029007517	0.004250618
10	0.092285	0.049518757	0.020322448	0.029007517	0.004250618
11	0.092285	0.049518757	0.020322448	0.048345862	0.004250618
12	0.061523	0.066025009	0.027096598	0.03867669	0.002833745
13	0.030762	0.049518757	0.020322448	0.029007517	0.004250618
14	0.092285	0.049518757	0.033870747	0.029007517	0.004250618
15	0.123047	0.033012505	0.027096598	0.019338345	0.005667491
16	0.092285	0.082531261	0.020322448	0.029007517	0.004250618
17	0.123047	0.033012505	0.013548299	0.03867669	0.005667491
18	0.123047	0.066025009	0.013548299	0.019338345	0.005667491
19	0.061523	0.066025009	0.027096598	0.019338345	0.005667491
20	0.123047	0.066025009	0.027096598	0.03867669	0.005667491
21	0.092285	0.049518757	0.020322448	0.029007517	0.004250618
22	0.092285	0.049518757	0.020322448	0.029007517	0.004250618
23	0.092285	0.049518757	0.020322448	0.029007517	0.004250618
24	0.123047	0.066025009	0.013548299	0.03867669	0.002833745
25	0.061523	0.066025009	0.013548299	0.03867669	0.005667491
26	0.092285	0.049518757	0.020322448	0.029007517	0.007084363
27	0.061523	0.066025009	0.013548299	0.03867669	0.005667491
28	0.092285	0.049518757	0.020322448	0.029007517	0.004250618
29	0.123047	0.033012505	0.013548299	0.019338345	0.002833745
30	0.123047	0.033012505	0.027096598	0.03867669	0.002833745
31	0.061523	0.033012505	0.027096598	0.019338345	0.002833745
32	0.092285	0.016506252	0.020322448	0.029007517	0.004250618

Step 4: Identify the Positive and Negative Ideal Solution

The positive ideal (A+) and the negative ideal (A-) solutions are defined according to the weighted decision matrix via equations (4)and (5) below

PIS = A+ = { V1+,V2+…, Vn+}, where: Vj+={(maxi (Vij) if j ϵ J);(mini Vij if j ϵ J') } ------ (3)

NIS = A- ={ V1,V2…,Vn}, where: Vj={(mini (Vij) if j ϵ J);(maxi Vij if j ϵ J') } ------------ (4)

Step 5: Calculate the separation distance of each competitive alternative from the ideal and non- ideal solution.

Table 6 Ideal and non- ideal solution

s.no	current	on time	off time	wire	%	∑ (vi-vij)^2	Si*
1	0.008368	0.0299	0.057817021	0.005877009	0.0000182	0.1020	0.3194
2	0.008368	0.0299	0.057817021	0.003285962	0.0000021	0.0994	0.3153
3	0.008368	0.0359	0.051485154	0.003285962	0.0000182	0.0991	0.3147
4	0.003686	0.0245	0.054605198	0.007453012	0.0000081	0.0902	0.3004
5	0.000897	0.0196	0.051485154	0.005877009	0.0000021	0.0779	0.2790
6	0.003686	0.0245	0.061120621	0.004487993	0.0000081	0.0938	0.3063
7	0.003686	0.0245	0.054605198	0.004487993	0.0000000	0.0873	0.2954
8	0.0000	0.0245	0.054605198	0.004487993	0.0000081	0.0836	0.2891
9	0.003686	0.0245	0.054605198	0.004487993	0.0000081	0.0873	0.2954
10	0.003686	0.0245	0.054605198	0.004487993	0.0000081	0.0873	0.2954
11	0.003686	0.0245	0.054605198	0.002270917	0.0000081	0.0851	0.2916
12	0.008368	0.0196	0.051485154	0.003285962	0.0000021	0.0827	0.2876
13	0.014942	0.0245	0.054605198	0.004487993	0.0000081	0.0985	0.3139
14	0.003686	0.0245	0.048456888	0.004487993	0.0000081	0.0811	0.2848
15	0.000897	0.0299	0.051485154	0.005877009	0.0000182	0.0882	0.2970
16	0.003686	0.0152	0.054605198	0.004487993	0.0000081	0.0780	0.2793
17	0.000897	0.0299	0.057817021	0.003285962	0.0000182	0.0919	0.3032
18	0.000897	0.0196	0.057817021	0.005877009	0.0000182	0.0842	0.2902
19	0.008368	0.0196	0.051485154	0.005877009	0.0000182	0.0853	0.2921
20	0.000897	0.0196	0.051485154	0.003285962	0.0000182	0.0753	0.2744
21	0.003686	0.0245	0.054605198	0.004487993	0.0000081	0.0873	0.2954
22	0.003686	0.0245	0.054605198	0.004487993	0.0000081	0.0873	0.2954
23	0.003686	0.0245	0.054605198	0.004487993	0.0000081	0.0873	0.2954
24	0.000897	0.0196	0.057817021	0.003285962	0.0000021	0.0816	0.2856
25	0.008368	0.0196	0.057817021	0.003285962	0.0000182	0.0891	0.2985
26	0.003686	0.0245	0.054605198	0.004487993	0.0000323	0.0873	0.2955
27	0.008368	0.0196	0.057817021	0.003285962	0.0000182	0.0891	0.2985
28	0.003686	0.0245	0.054605198	0.004487993	0.0000081	0.0873	0.2954
29	0.000897	0.0299	0.057817021	0.005877009	0.0000021	0.0945	0.3074
30	0.000897	0.0299	0.051485154	0.003285962	0.0000021	0.0856	0.2926
31	0.008368	0.0299	0.051485154	0.005877009	0.0000021	0.0957	0.3093
32	0.003686	0.0359	0.054605198	0.004487993	0.0000081	0.0987	0.3142

S+ = √(∑_(j=1)^n▒() V_j^+- Vij)2   i = 1,...., m --------- (5)

S+ = √(∑_(j=1)^n▒() V_j^-- Vij)2   i = 1,...., m --------- (6)

Where, i = criterion index, j = alternative index.

Step 6: Measure the relative closeness of each location to the ideal solution.

For each competitive alternative the relative closeness of the potential location with respect to the ideal solution is computed.

Ci= Si- / (Si+ +Si -), 0 ≤ Ci ≤ 1 --------- (7)

Table 7 Calculation of Relative Closeness to the Ideal Solution

s.no	current	on time	off time	wire	%	∑ (vi-vij)^2	Si-
1	0.0035	0.0002	0.0000	0.0000	0.0069	0.0106	0.1030
2	0.0035	0.0002	0.0000	0.0006	0.0073	0.0116	0.1079
3	0.0035	0.0004	0.0002	0.0006	0.0069	0.0116	0.1075
4	0.0082	0.0001	0.0001	0.0000	0.0071	0.0154	0.1241
5	0.0147	0.0000	0.0002	0.0000	0.0073	0.0222	0.1491
6	0.0082	0.0001	0.0000	0.0002	0.0071	0.0156	0.1247
7	0.0082	0.0001	0.0001	0.0002	0.0076	0.0161	0.1267
8	0.0230	0.0001	0.0001	0.0002	0.0071	0.0305	0.1745
9	0.0082	0.0001	0.0001	0.0002	0.0071	0.0156	0.1248
10	0.0082	0.0001	0.0001	0.0002	0.0071	0.0156	0.1248
11	0.0082	0.0001	0.0001	0.0011	0.0071	0.0165	0.1284
12	0.0035	0.0000	0.0002	0.0006	0.0073	0.0117	0.1080
13	0.0008	0.0001	0.0001	0.0002	0.0071	0.0082	0.0908
14	0.0082	0.0001	0.0004	0.0002	0.0071	0.0160	0.1263
15	0.0147	0.0002	0.0002	0.0000	0.0069	0.0219	0.1481
16	0.0082	0.0000	0.0001	0.0002	0.0071	0.0155	0.1245
17	0.0147	0.0002	0.0000	0.0006	0.0069	0.0223	0.1492
18	0.0147	0.0000	0.0000	0.0000	0.0069	0.0215	0.1468
19	0.0035	0.0000	0.0002	0.0000	0.0069	0.0106	0.1031
20	0.0147	0.0000	0.0002	0.0006	0.0069	0.0223	0.1493
21	0.0082	0.0001	0.0001	0.0002	0.0071	0.0156	0.1248
22	0.0082	0.0001	0.0001	0.0002	0.0071	0.0156	0.1248
23	0.0082	0.0001	0.0001	0.0002	0.0071	0.0156	0.1248
24	0.0147	0.0000	0.0000	0.0006	0.0073	0.0226	0.1502
25	0.0035	0.0000	0.0000	0.0006	0.0069	0.0110	0.1048
26	0.0082	0.0001	0.0001	0.0002	0.0066	0.0151	0.1229
27	0.0035	0.0000	0.0000	0.0006	0.0069	0.0110	0.1048
28	0.0082	0.0001	0.0001	0.0002	0.0071	0.0156	0.1248

Step 7: Rank the preference order

According to the value of Ci* the higher the value of the relative closeness, the higher the ranking order and hence the better the performance of the alternative. Ranking of the preference in descending order thus allows relatively better performances to be compared.

Table 8 Rank the preference order

s.no	Si-	**Si***	si*+si-	Ci*	
1	0.1030	0.3194	0.42	0.2439	
2	0.1079	0.3150	0.42	0.2551	Worse
3	0.1075	0.3221	0.43	0.2502	
4	0.1241	0.3003	0.42	0.2924	
5	0.1491	0.2872	0.44	0.3417	
6	0.1247	0.2954	0.42	0.2969	
7	0.1267	0.2927	0.42	0.3021	
8	**0.1745**	**0.2945**	**0.47**	**0.3721**	Best
9	0.1248	0.2954	0.42	0.2970	
10	0.1248	0.2954	0.42	0.2970	
11	0.1284	0.2889	0.42	0.3077	
12	0.1080	0.2930	0.40	0.2692	
13	0.0908	0.3088	0.40	0.2272	
14	0.1263	0.2901	0.42	0.3033	
15	0.1481	0.3022	0.45	0.3289	
16	0.1245	0.2763	0.40	0.3106	
17	0.1492	0.2978	0.45	0.3338	
18	0.1468	0.2818	0.43	0.3425	
19	0.1031	0.2973	0.40	0.2575	
20	0.1493	0.2828	0.43	0.3455	
21	0.1248	0.2927	0.42	0.2989	
22	0.1248	0.2927	0.42	0.2989	
23	0.1248	0.2981	0.42	0.2951	
24	0.1502	0.2828	0.43	0.3469	
25	0.1048	0.2930	0.40	0.2634	
26	0.1229	0.3008	0.42	0.2900	
27	0.1048	0.2957	0.40	0.2616	
28	0.1248	0.2981	0.42	0.2951	
29	0.1490	0.3021	0.45	0.3303	

After determining the significant coefficients for cutting speed and kerf width is given in TOPSIS technique was used to check the adequacy of the developed model. Responses for cutting speed and kerf width best parameter in this study are shown in Table 8.

4. CONCLUSION

The effect of the input parameters on the cutting speed and kerf width of aluminium composites reinforced with tungsten carbide was investigated. TOPSIS method is applied to achieve final ranking preferences in descending order, thus allowing relative performance s to be compared.

A mathematical model was developed to obtain the response variables of aluminium composite material incorporating the effects of process variables. The adequacy of the proposed model was tested using TOPSIS Technique.

The optimum parameter set for the current study is peak current -125 Amps, Pulse on time -12 Sec ,Pulse –off Time – 6 Sec, Fedd rate -30 mm/min and percentage WC – 6% for maximizing the MRR. Cutting speed and minimizing the kerf width.

REFERENCES

[1] Ravikumar K, Mohanasundaram KM, Arumaikkannu G, Subramanian R. Analysis of parameters influencing wear and frictional behavior of aluminum-fly ash composites. Tribol T.2012; 55: 723-729.

[2] Ravikumar K, Mohanasundaram KM, Arumaikkannu G, Subramanian R. Effect of particle size on mechanical properties and tribological behaviour of aluminium/fly ash composites. Sci Eng Compos Mater. 2012; 19: 247-253.

[3] Liao YS, Yan MT, Chang CC. A neural network approach for the on-line estimation of workpiece height in WEDM. J Mater Process Technol. 2002; 121: 252-258. http://dx.doi.org/10.1016/S0924-0136 (01) 01252-3.

[4] Chalisgaonkar R, Kumar J. Multi-response optimization and modeling of trim cut WEDM operation of commercially pure titanium (CPTi) considering multiple user's preferences. Eng Sci Technol. 2015; 18: 125-134.

[5] Kumar V, Kumar V, Jangra KK. An experimental analysis and optimization of machining rate and surface characteristics in WEDM of Monel-400 using RSM and desirability approach. J Ind Eng Int. 2015; 11: 297-307.

[6] Kathiresan M, Sornakumar T. EDM studies on aluminum alloy-silicon carbide composites developed by vortex tech-nique and pressure die casting. J Miner Mater Charact Eng. 2010; 9(1): 79-88.

[7] Ibrahem M, Liew HL, Ahmed ADS, Hamdi M. EDM performance at different machining parameters - ANFIS modeling. IFAC-Papers On Line 2015; 48(12): 105-110.

[8] Chiang KT, Chang FP. Optimization of the WEDM process of particle-reinforced material with multiple performance characteristics using grey relational analysis. J Mater Process Technol. 2006; 180: 96-101. http://dx.doi.org/10.1016/j.jmatprotec.2006.05.008.

[9] Shivade AS, Shinde VD. Multi-objective optimization in WEDM of D3 tool steel using integrated approach of Taguchi method & Grey relational analysis. J Ind Eng Int. 2014; 10:149-162.

[10] http://dx.doi.org/10.1007/s40092-014-0081-7.

[11] Rajaneesh NM, Sadashivappa K. Effect of machining para-meters on MRR and surface roughness in machining of ZA43/ SiCp composite by WEDM. Int J App Sci Eng. 2013; 11(3): 317-330.

[12] Ramesh S, Natarajan N, Krishnaraj V. Experimental Investigation of Al6061/SiCp/B4C hybrid MMCs in wire electrical discharge machine. Indian J Eng Mater Sci. 2014; 21: 409-417.

[13] Tani T, Fukuzawa Y, Mohri N, Saito N, Okada M. Machining phenomena in WEDM of insulating ceramics. J Mater Process Technol. 2004; 149: 124-128.

[14] Singh V, Pradhan SK. Optimization of WEDM parameters using Taguchi technique and response surface methodology in machining of AISI D2 steel. Procedia Eng. 2014; 97: 1597-1608. http://dx.doi.org/10.1016/j.proeng.2014.12.310.

[15] Sarkar S, Mitra S, Bhattacharyya B. Parametric analysis and optimization of wire electrical discharge machining of titanium aluminide alloy. J Mater Process Technol. 2005; 159: 286-294. http://dx.doi.org/10.1016/j.jmatprotec.2004.10.009.

[16] Mukherjee R, Chakraborty S, Samanta S. Selection of wire electrical discharge machining process parameters using non-traditional optimization algorithms. Appl Soft Comput. 2012; 12: 2506-2516. http://dx.doi.org/10.1016/j.asoc.2012.03.053.

[17] Goswami A, Kumar J. Investigation of surface integrity, material removal rate and wire wear ratio for WEDM of Nimonic 80A alloy using GRA and Taguchi method. Eng Sci Technol. 2014; 17(4): 173-184. http://dx.doi.org/10.1016/j.jestch.2014.05.002.

[18] Peroczyk J. Selected problems of electrical discharge machining (EDM) of metal composite materials applied in manufacturing of mechanical vehicles. J KONES Power Train Transport. 2011; 18(1): 429-442.

[19] Ramakrishnan R, Karunamoorthy L. Modeling and multi-response optimization of Inconel 718 on machining of CNC WEDM process. J Mater Process Technol. 2008; 207: 343-349.

[20] Okada A, Uno Y, Onoda S, Habib S. Computational fluid dynamics analysis of working fluid flow and debris movement in wire EDMed kerf. CIRP Annals-Manufact Technol. 2009; 58: 209-212.

[21] Xuyang SC, Dongbo W, Zhenlong W, Guanxin C, Yuan L. Analysis of kerf width in micro-WEDM. Int J Mach Tools Manuf. 2009; 49: 788-792.

[22] Derringer G, Suich R. Simultaneous optimization of several response variables. J Qual Technol. 1980; 12(4): 214-219.

[23] Ravikumar K, Sreebalaji VS. Desirability based multi objective optimization of abrasive wear and frictional behaviour of Aluminium (Al/3.25Cu/8.5Si)/ fly ash composites. Tribol Mater Surf Interfaces. Ahead of print, 2015. 1751584X15Y.0000000012.