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SELECTION OF BEST MATERIAL AND OPTIMIZATION OF PROCESS PARAMETERS IN ELECTRICAL DISCHARGE MACHINING

M Hari Prasad
P. Venkataramaiah

Abstract

The present work has been done in three stages. In the first stage AA 6101- B4C /Se/CNT hybrid aluminium metal matrix composite(HAMMCs) samples are prepared with different combinations of reinforcement materials with fixed weight ratio and tested its properties viz. hardness, corrosion resistance, wear resistance, tensile strength, flexural strength, impact strength and electrical conductivity. The best material which possesses all these good properties is selected among the developed composites by analysing the data of the characteristics using AHP-GRA, in the view of reduction of experimental cost and time. In the second stage, Set-I experiments are conducted on selected composite according to Taguchi experimental design (OA9) for different parameter combinations. Further machining outputs are studied by analysing them through GRA-Taguchi method and optimal processes parameters are selected. Confirmation tests are used to validate these results and the order of influence of process parameters on machining outputs is determined through analysis of variance. In third stage, Set-II experiments are conducted on selected composite. Again machining outputs are analysed and optimal processes parameters are selected. This parameter selection methodology will be useful to increase the rate of production and the quality of items produced with the WEDM process

Keywords: HAMMCs, AA6101, stir casting, Analytical Hierarchy process, Grey relational analysis, Analysis of variance

1. INTRODUCTION

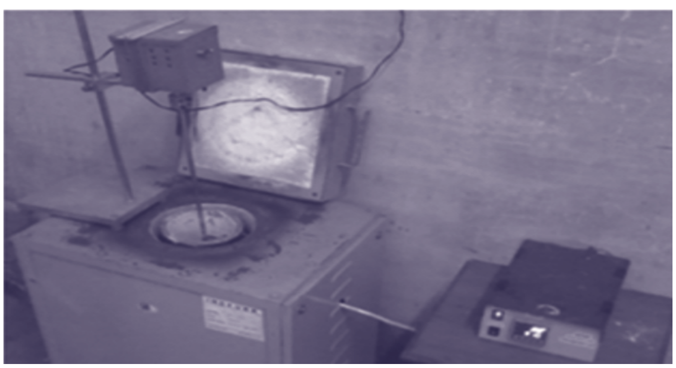
Aluminum Metal Matrix Composites (AMMCs) are presently receiving greater attention from the automotive and aerospace industries because of their attractive characteristics. Rapid improvements in industries such as automobiles, aerospace and the military requires new generation of materials with improved properties. Hybrid Aluminum metal matrix composites (HAMMCs) are a good-looking composite materials that have two or more reinforcement materials to meets requirements [1]. Reinforcements (B4C, CNT, SiC,Al_2O_3, TiB_2 etc) are the materials, which are added to boost the desired qualities. Type of reinforcement materials, its size, combination, distribution in matrix material, percentage in matrix material play a key role on properties of HAMMCs[2-6]. Stir casting is one of the promising manufacturing process for preparing HAMMCs due to its cost-effectiveness, where mechanical stirring combined a dispersed phase of reinforcing materials with a molten base material [7-8]. It is challenging to machine HAMMCs because of abrasive nature and high hardness of reinforcement materials. WEDM is the best unconventional machining method for cutting any electrically conductive material, regardless of its hardness. An electrical spark is used as a cutting tool in the WEDM process to cut (erode) the work piece and make it to the required shape. WEDM is particularly useful for many applications due to the high degree of accuracy in work piece dimensions and the precise surface finish. [9-10]. The main machining outputs in WEDM are surface roughness, material removal rate, kerf and tool wear. Dielectric fluid (Electrolyte), dielectric pressure, wire feed, wire tension, electrode material, pulse on time, peak current, pulse off time, discharge capacitance, average working voltage are the main parameters which effect performance measures [11-13].It is very important to select best material and optimal process parameters in electrical discharge machining to attain required machining outputs with enhanced properties of HAMMCs by using optimization methods[13].

Amresh Kumar et al., [14] studied to determine the best machining inputs for WEDM of graphite, Fe_2O_3, and SiC samples using five input parameters and three machining outputs such as MRR, surface roughness, and spark gap by using Analytical hierarchy processes(AHP) and genetic algorithms(GA). Rajyalakshmi G. and P.Venkata Ramaiah [15] used Fuzzy-Grey relational analysis to optimise process parameters for optimum machining outputs of WEDM on Inconel-825 super alloy. Taguchi mixed orthogonal array L36 is used to design the experiments. Vijayabhaskar S and Rajmohan T[16] used a four-factor D-optimal design according to the response surface methodology to investigate machining parameters and weight percentage of nano-SiC in WEDM of magnesium metal matrix nano composites. A. Perumal el al [17] used Taguchi L27 design method for conduct WEDM experiments on Ti-6Al-2Sn-4Zr-2Mo alloy to study the influence of input values such as wire tension, pulse on duration, and wire feed on metal removal rate (MRR) and surface roughness (SR). Analysis of variance (ANOVA) and the grey relational analysis approach is used in optimising the process parameters. Kumba Anand and P Venkataramaiah [18] create an Al 6061/2% SiCp/3 µm particulate MMC and optimise its WEDM input parameters by using AHP-TOPSIS approach, also the particle distribution was assessed by SEM. Kumba Anand& P Venkataramaiah [19] investigated the best material by using AHP process by taking into account five criteria such as tensile strength, specific mass, cost, hardness and melting point. M. Madduleti & P. Venkataramaiah [20] conducted turning as per Taguchi experimental design (L16) on a composite created by reinforcing MWCNT of 2% weight with Al alloy at various inputs and the machining outputs recorded. Based on orthogonal experimental results, Oxley's model is utilised to determine dynamic parameters such as temperature, strain, tool chip interfacial friction and strain rate. Kirankumar and P.Venkataramaiah [21] investigated the surface integrity of Inconel 718 during hot machining and optimised the process using grey relational analysis (GRA). Further, conducted ANOVA to study the most influential factor.

After going through literature, to the best of the authors' knowledge there is no published work on the characteristics and optimization of process parameters of AA6101-B_4C/Se/CNT in three stages, in view of simplification of problem.

2. STAGE-I: FABRICATION AND SELECTION OF BEST MATERIAL

2.1 Fabrication of HAMMCs: The melting of Aluminium matrix material was carried out in a stir casting furnace over a range of 750ºC. Using a graphite stirrer, the melt was mechanically stirred and in this period the pre-heated (350 ºC) reinforcements particles of CNT /Se/B4C and wetting agent of 0.2% of magnesium (to lower the surface tension of the aluminium and improve the wetting property between the matrix and the reinforcement material) were gradually added into the molten metal. The stirring operation is done for 10 minutes. The molten metal is then transferred to a metal die, which is then left for while to solidify. K-type thermocouple is used measure the changes in temperature of molten metal.



(a)

(b)

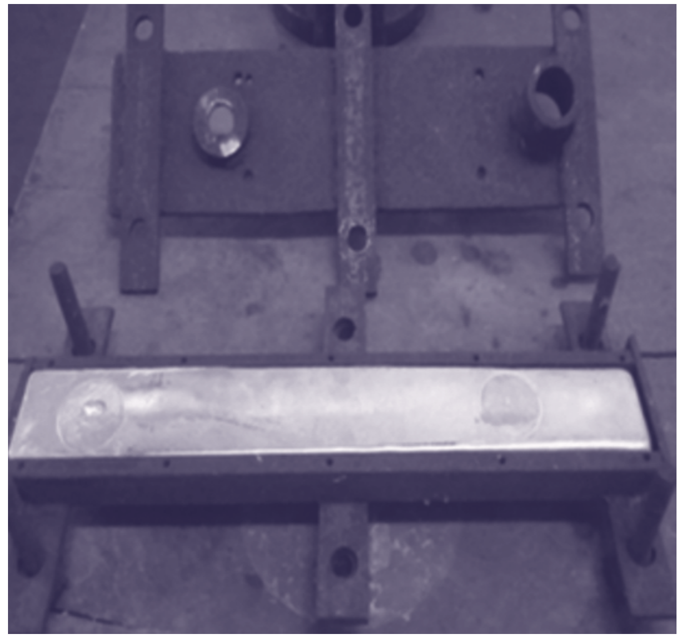


Figure 2.1: Setup for fabrication of HAMMCs (a) stir casting furnace (b) HAMMC sample along with metal die.

Using the above procedure, different composite samples (Table 2.1) are prepared with different reinforcements B4C/Se/CNT and fixed weight ratio of 0.8%, 0.8%, 0.2 % respectively.

Table 2.1 Composition of Composite Samples

Samples	Composition
M1	AA6101-100%
M2	AA6101-98.4% + 0.8% B4C +0.8%Se
M3	AA6101-99.00% + 0.8% Se + 0.2% CNT
M4	AA6101-99.00% + 0.2% CNT +0.8% B4C
M5	AA6101-98.2%+0.8% B4C +0.8% Se +0.2% CNT

2.2 Properties of developed composites: The developed samples are tested for different properties such as impact strength, tensile strength, flexural strength, hardness, corrosion, electrical conductivity, wear resistance and results are recorded(Table 2.2).

Table 2.2 Tests Data of Composites

Sample No	Tensile Strength (TS) (Mpa)	Hardness (H) (HBW)	Impact Strength (IS) (Joules)	Flexural Strength (FS) (Mpa)	Electrical Conductivity (EC) (S/m)	Wear Loss (WL) (g)	Corrosion Loss (CL) (g)
1	97.4	71.66	14	215.21	56.25	0.1961	0.0162
2	103.7	77.33	37.2	321.42	81.81	0.1163	0.0193
3	127.82	79	27.7	283.32	60	0.1064	0.0064
4	140.6	77	32	287.12	90	0.1281	0.0261
5	154.62	82.33	34	314.36	81.81	0.1123	0.0125

2.3 selection of best composite by using AHP-GRA method: The data of properties of composites obtained by tests is given in Table 2.2 and the best composite is selected by analysing test data using AHP-GRA method as in the following by considering the required weightages for the characteristics. In AHP-GRA method, firstly weightages of different properties are determined through AHP. Later best material, which possesses best properties is identified by GRA adopting the weightages of properties obtained from AHP by following steps.

Step-1: Identifying the relative importance of several factors in relation to the goal is done by preparing pair wise comparison matrix. In this step, comparison matrices are developed and performed pair wise comparisons, as shown in Table 2.3.

$$X_{ij} = \begin{bmatrix} 1 & a_{12} & a_{13} \\ a_{21} & 1 & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix} \quad (1)$$

i = 1, 2, 3,…….., m; j = 1, 2, 3, …….., n

Table 2.3 Comparison Matrix

	EC	TS	IS	FS	H	WL	CL
EC	1	1	3	3	2	3	2
TS	1	1	2	2	4	2	2
IS	0.333	0.5	1	2	3	2	2
FS	0.333	0.5	0.5	1	3	3	2
H	0.5	0.25	0.333	0.333	1	2	2
WL	0.333	0.5	0.5	0.333	0.5	1	2
CL	0.5	0.333	0.5	0.5	0.5	0.5	1
sum(v)	4	4.083	7.833	9.166	14	13.5	13

Table 2.4 Normalized Comparison Matrix

	EC	TS	IS	FS	H	WL	CL	weights
EC	0.25	0.244	0.382	0.327	0.142	0.222	0.153	0.246
TS	0.25	0.244	0.255	0.218	0.285	0.148	0.153	0.222
IS	0.083	0.122	0.127	0.218	0.214	0.148	0.153	0.152
FS	0.083	0.122	0.063	0.109	0.214	0.222	0.153	0.138
H	0.125	0.061	0.042	0.036	0.071	0.148	0.153	0.091
WL	0.083	0.122	0.063	0.036	0.035	0.074	0.153	0.081
CL	0.125	0.081	0.063	0.054	0.035	0.037	0.076	0.067

Scaling of properties is done and thereby weightages are calculated based on the requirement to use in specific application as in Table 2.3

In this work, the order of priority is given as EC, TS, IS, FS, H, WL, CL respectively using the following scale values.

1 – Equal importance, 3 – Moderate importance, 5-Strong importance,

7 – Very strong importance, 9 – Extreme importance

2,4,6,8 – Intermediate values, 1/3,1/5,1/7- Values for inverse comparison.

Step-2: In this step, normalized comparison matrix is prepared (Table 2.4) and criteria weights are calculated based on the average of the all row elements for each row separately

Step-3: In this step consistency ratio values are calculated as follows (Table 2.6)

SW= sum of all elements in the row
Ratio= SW/criteria
λmax =average of Ratio
Consistency Index (CI) = (λmax-n)/(n-1) ,
n= number of criteria in pairwise comparison matrix
Consistency Ratio = CI/RI
RI = random index taken from Table 2.5

Table 2.5 Random Index Values

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 2.6 Consistency Ratio Values

	EC	TS	IS	FS	H	WL	CL	SW	RATIO
EC	0.246	0.222	0.457	0.415	0.182	0.244	0.135	1.903	7.729
TS	0.246	0.222	0.305	0.276	0.364	0.162	0.135	1.713	7.709
IS	0.082	0.111	0.152	0.276	0.273	0.162	0.135	1.194	7.831
FS	0.082	0.111	0.076	0.138	0.273	0.244	0.135	1.061	7.666
H	0.123	0.055	0.050	0.046	0.091	0.162	0.182	0.712	7.806
WL	0.082	0.111	0.076	0.046	0.045	0.081	0.135	0.578	7.106
CL	0.123	0.074	0.076	0.069	0.045	0.040	0.067	0.496	7.326

Table 2.7 Consistency Values

λ	7.59677
CI	0.099462
CR	0.07535

The pair wise comparison matrix is acceptable as the CR value is less than 10%.

Step-4: In this step the test data values are normalized as follows and represented in

Table 2.8.The comparability sequences (k) can be calculated as follows for "Lower is better"

$$x^*_i(k) = \frac{\max x^o_i(k) - x^o_i(k)}{\max x^o_i(k) - \min x^o_i(k)} \quad (2)$$

The comparability sequences (k) can be calculated as follows for "Larger is better"

$$x^*_i(k) = \frac{x^o_i(k) - \min x^o_i(k)}{\max x^o_i(k) - \min x^o_i(k)} \quad (3)$$

For i=1, 2, 3…...9, k =1, 2, 3,4. Where 'k' is number of responses and 'i' is no of experimental trails

Table 2.8 Normalisation of test data

Sample No	TS	H	IS	FS	EC	WL	CL
1	0	0	0	0	0	0	0.502
2	0.110	0.531	1	1	0.757	0.889	0.345
3	0.531	0.687	0.590	0.641	0.111	1	1
4	0.754	0.500	0.775	0.677	1	0.758	0
5	1	1	0.862	0.933	0.757	0.934	0.690

Step-5: In this step deviation sequence is find out as follows and represented in Table 2.9 Deviation sequence (Δij) = Xoi-Xij,

Where, Xoi-max of column of each property, Xij - values of column corresponding to i and j

Table 2.9 Deviation Sequence Values

Sample No	TS	H	IS	FS	E C	WL	CL
1	1	1	1	1	1	1	0.497
2	0.889	0.468	0	0	0.242	0.110	0.654
3	0.468	0.312	0.409	0.358	0.888	0	0
4	0.245	0.499	0.224	0.322	0	0.241	1
5	0	0	0.137	0.066	0.242	0.065	0.309

Step-6: Grey relation co-efficient and grey relation grade (GRG) are calculated and represented in Table 2.10.

The Grey relation Coefficient (k) for the kth response in the ith experiment can be expressed as (Eq.4)

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \quad (4)$$

Grey relational grade is calculated by using the Eq.5.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} w_k \, \xi_i(k) \quad (5)$$

Table 2.10 Grey relation coefficient and Grey relation grade (GRG) values

Sample No	Grey relational coefficient values							GRG
	TS	H	IS	FS	EC	WL	CL	
1	0.333	0.333	0.333	0.333	0.333	0.333	0.501	0.357
2	0.359	0.516	1	1	0.673	0.819	0.432	0.685
3	0.516	0.615	0.549	0.582	0.360	1	1	0.660
4	0.671	0.500	0.690	0.607	1	0.673	0.333	0.639
5	1	1	0.783	0.882	0.673	0.883	0.617	0.834

Step7: In this step Grey relational coefficient values are multiplied with weights (Table 2.11) and make average of coefficients to calculate weighted GRG. The composite sample which has highest weighted average is selected, which possess required properties to meet the application.

Table 2.11 Weighted GRG values

Sample No	TS (Mpa)	H (HBW)	IS (Joules)	FS (Mpa)	EC (S/m)	WL (g)	CL (g)	Weighted GRG
1	0.0733	0.0301	0.0503	0.0456	0.0812	0.0406	0.0223	0.04911
2	0.0800	0.0474	0.1525	0.1384	0.1657	0.0349	0.0556	0.09640
3	0.1155	0.0565	0.0884	0.0761	0.0886	0.0813	0.0678	0.08209
4	0.1489	0.0456	0.0930	0.0955	0.2462	0.0268	0.0457	0.10028
5	0.2223	0.0912	0.1342	0.1079	0.1657	0.0504	0.0596	0.11880

From the AHP-GRA method, the sample M5 (AA6101-98.2%+0.8%B_4C+0.8% Se+0.2%CNT) has the optimum properties compared to remaining composite samples. Hence it is taken for EDM to study its machining characteristics.

3. STAGE-II: SELECTION OF SET-I OPTIMAL PROCESS PARAMETERS IN EDM OF COMPOSITE

3.1 Set-I EDM Experiments: In this work, Set-I EDM experiments are conducted on selected composite M5: AA6104-B4C/Se/CNT as per experimental design Taguchi OA9 for different parameter combinations such as electrolyte type [Distilled water (DW), Ethylene glycol (EG)], wire feed and wire tension. The process parameters along with their levels are given in Table 3.1. The machining outputs such as material removal rate (MRR), surface roughness (SR), kerf width (KW) and tool wear(TW) are recorded for each experiment run (Table 3.2) by keeping remaining parameters constant. The machined composite is shown in Figure 3.1.

Table.3.1 Process Parameters along with their Levels

Sl. No.	Process parameters	Symbol	Level 1	Level 2	Level 3
1	Electrolyte	X	water	DW	DW+EG
2	Wire feed (m/min)	Y	35	37	40
3	Wire tension (gms)	Z	8	9	10

Figure 3.1Work Piece after Machining

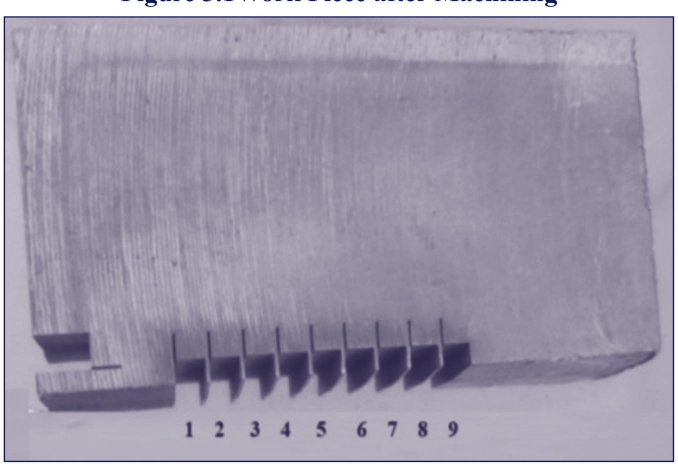


Table 3.2 Orthogonal array (OA9) along with Machining outputs for Set-I experiment

Exp. No.	X	Y	Z	SR (μm)	MRR (mm3/ min)	KW (mm)	TW (mm)
01	1	1	1	4.134	3.713	0.673	0.024
02	1	1	2	5.531	3.873	0.691	0.035
03	1	1	3	3.622	4.401	0.618	0.044
04	2	2	1	6.212	3.523	0.716	0.031
05	2	2	2	4.433	4.112	0.714	0.043
06	2	2	3	2.745	5.858	0.612	0.052
07	3	3	2	6.812	4.724	0.557	0.053
08	3	3	3	4.761	5.830	0.725	0.042
09	3	3	1	3.476	5.442	0.667	0.038

3.2 Analysis of set-1 experimental data using GRA-Taguchi method: An analysis is conducted on first set of EDM experimental data of machining outputs and the optimum values of parameters are identified using GRA-Taguchi S/N ratio analysis by following method as in section 2.3(step-4 to step-7) and the Grey relational grade and rank presented in Table 3.3. Additionally, used analysis of variance (ANOVA) to determine the most influence parameters on machining outputs in a particular order.

Table 3.3 The Grey Relational Grade and Rank

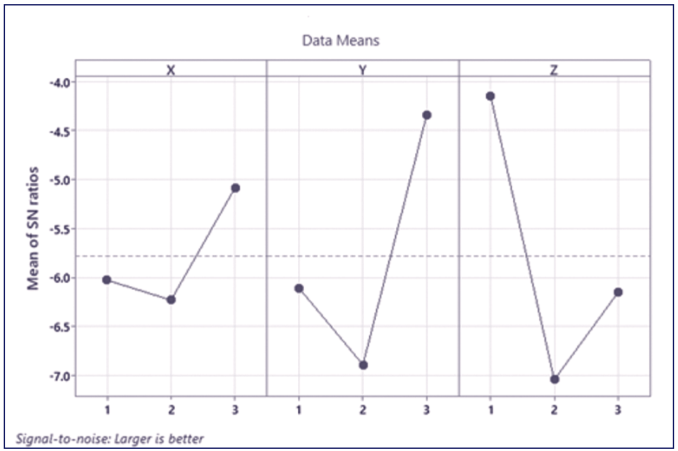
Exp. No.	SR	MRR	KW	TW	Sum	Grey relation grade (GRG)	Rank
1	0.594	0.352	0.42	1	4.035	0.591	2
2	0.421	0.370	0.385	0.430	2.846	0.402	8
3	0.698	0.444	0.579	0.375	2.844	0.524	6
4	0.369	0.333	0.345	0.460	2.720	0.377	9
5	0.546	0.400	0.348	0.381	2.490	0.419	7
6	1	1	0.604	0.337	3.355	0.735	1
7	0.333	0.507	1	0.333	1.817	0.543	5
8	0.502	0.976	0.333	0.386	2.061	0.549	4
9	0.735	0.737	0.432	0.410	2.439	0.579	3

3.2.1 Selection of optimal combination of influential parameters: Further S/N ratio analysis is done on Grey grade values of Table 3.3 and its output responses for signal to noise ratio (Table 3.4) and main effects plots for signal to noise ratios (Figure 3.2) are presented. The optimal values of influential parameters are identified (Figure 3.2) which are corresponding to higher S/N ratio, the optimal influential parameters setting is X3Y3Z1.

Table 3.4 Response Table for S/N Ratios

Level	Electrolyte	Wire feed	Wire tension
1	-6.025	-6.106	-4.141
2	-6.228	-6.887	-7.040
3	-5.079	-4.338	-6.150
Delta	1.149	2.549	2.899
Rank	3	2	1

Figure 3.2 Main effects Plots for S/N ratios



3.2.2 Confirmation test Results: The confirmation test is conducted for optimal parameter values (X3Y3Z1) obtained from Grey-Taguchi (Electrolyte: Distilled water + Ethylene glycol, wire feed: 40m/min, wire tension:8gms) and responses are recorded(Table 3.5).The confirmation test results are better compared experimental results(Table 3.3).Hence selected optimal parameter setting is best one and the confirmation test result is satisfactory.

Table 3.5 Confirmation Test Results

Optimal parameters setting	Surface roughness **(µm)**	Material removal rate (mm^3/min)	Kerf width (mm)	Tool wear (mm)	GRG
X3Y3Z1	2.897	5.952	0.625	0.023	0.7546

3.2.3 Analysis of Variance: The order of influential parameters affecting the machining outputs is determined by performing ANOVA on GRG values using mini tab software and the results are given Table 3.6. From ANOVA results, it is found that wire tension has more influence on combined machining outputs and same is known from Table 3.4. The order of influential parameters is Wire tension, Wire feed and Electrolyte, it means Wire tension has more influence on responses and followed others respectively.

Table 3.6 Results of ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution %
X	2	0.01484	0.00242	0.54	0.647	13.41
Y	2	0.038449	0.019224	4.33	0.188	34.73
Z	2	0.048526	0.024263	5.46	0.155	43.84
Error	2	0.008885	0.004443			8.03
Total	8	0.1107				

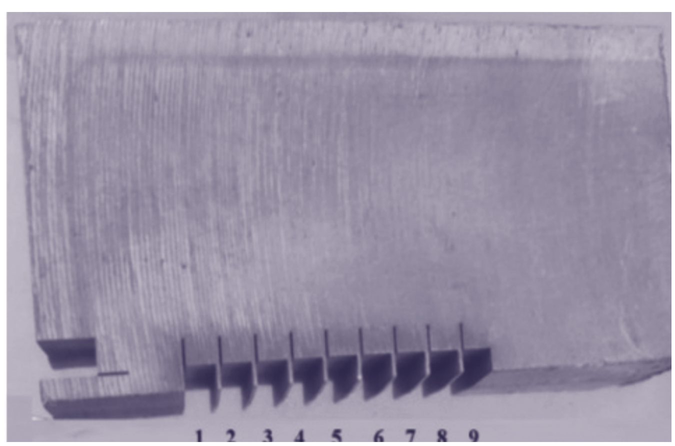
4. STAGE-III: SELECTION OF SET-II OPTIMAL PROCESS PARAMETERS IN EDM OF COMPOSITE

4.1 Set-2 EDM Experiments: For second set, conducted EDM experiments on the same composite based on experimental design OA18, which is prepared by considering different process parameters viz Electrode material, Pulse on time (Ton), Pulse off time (Toff) and peak current (Ip) with different levels as mentioned in Table 4.1 by fixing the optimum values of electrolyte type, wire tension, and wire feed as constants, which are taken from first experimental data set. The experimental data of machining outputs are measured for each experimental run (Table 4.2). The machined composites are shown in Figure 4.1.

Table 4.1 Process parameters with their levels

Sl. No.	Process parameters	Symbol	Level 1	Level 2	Level 3
1	electrode material	A	Zn coated Brass	brass	--
2	Ton (µs)	B	100	105	110
3	Toff (µs)	C	36	42	48
4	Ip (amp)	D	2	3	4

Figure 4.1 Work pieces after machining



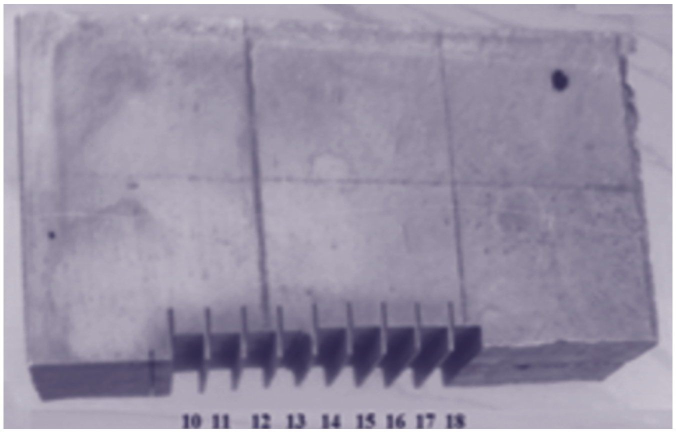


Table 4.2 OA18 orthogonal array along with machining responses.

Exp no.	WEDM parameters				Experimental results			
	elec-trode	Ton (µs)	Toff (µs)	Ip (amp)	SR (µm)	MRR (mm3/ min)	KW (mm)	TW (mm)
1	1	1	1	1	2.935	4.308	0.54	0.018
2	1	1	1	2	2.827	5.363	0.632	0.021
3	1	1	1	3	2.714	5.369	0.615	0.023
4	1	2	2	1	2.468	5.753	0.62	0.022
5	1	2	2	2	2.842	6.145	0.72	0.020
6	1	2	2	3	2.279	5.191	0.7	0.021
7	1	3	3	2	2.657	6.132	0.62	0.025
8	1	3	3	3	2.245	6.676	0.63	0.029
9	1	3	3	1	2.054	8.420	0.75	0.024
10	2	1	1	3	3.347	4.713	0.53	0.039
11	2	1	1	1	3.215	5.873	0.56	0.032
12	2	1	1	2	3.747	5.401	0.53	0.034
13	2	2	2	2	3.015	5.523	0.52	0.029
14	2	2	2	3	3.907	5.112	0.55	0.027
15	2	2	2	1	3.418	5.858	0.56	0.036
16	2	3	3	3	3.817	4.724	0.5	0.038
17	2	3	3	1	3.121	6.830	0.61	0.034
18	2	3	3	2	3.762	5.442	0.58	0.039

4.2 Analysis of set-2 experimental data: The analysis is conducted on machining outputs taken from second set of EDM experimental data(Table 4.2), the optimum values of process parameters were identified using GRA-Taguchi S/N ratio analysis using the procedure given in section 2.3(step-4 to step-7) and GRG values, rank are represented in Table 4.3. The order of the process parameters that have the greatest influence on machining outputs is also determined using ANOVA.

Table 4.3 Grey relation grade values and rank for machining outputs

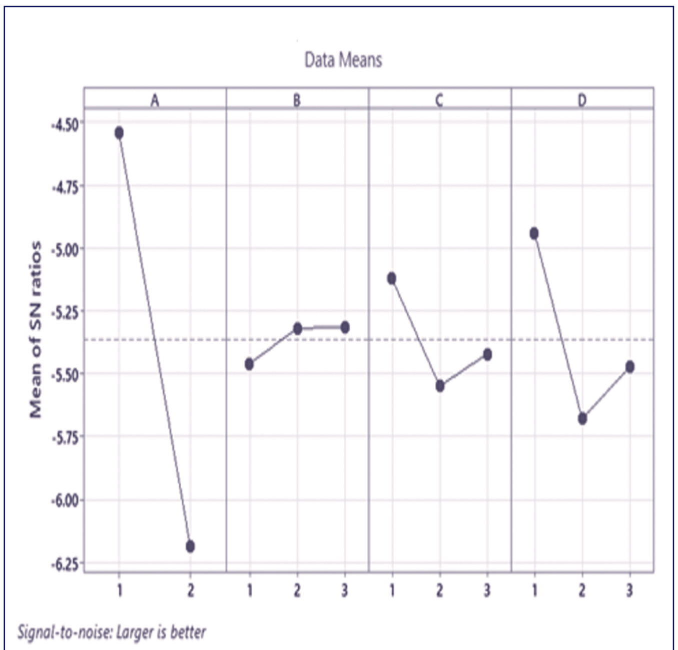
Exp. no	Grey relational Coefficient				Grey relational Grade	Rank
	SR (**µm**)	MRR mm3/) (min	KW (mm)	TW (mm)		
1	0.512586	0.333333	0.757576	1	0.650874	2
2	0.54516	0.402112	0.486381	0.777778	0.552858	8
3	0.58399	0.402585	0.520833	0.677419	0.546207	10
4	0.69116	0.435317	0.510204	0.724138	0.590205	3
5	0.540391	0.474717	0.362319	0.84	0.554357	7
6	0.804603	0.389026	0.384615	0.777778	0.589005	4
7	0.605754	0.473297	0.510204	0.6	0.547314	9
8	0.829083	0.541053	0.490196	0.488372	0.587176	5
9	1	1	0.333333	0.636364	0.742424	1
10	0.417436	0.356759	0.806452	0.333333	0.478495	16
11	0.443832	0.446665	0.675676	0.428571	0.498686	12
12	0.353693	0.405123	0.806452	0.396226	0.490374	14
13	0.490861	0.415102	0.862069	0.488372	0.564101	6
14	0.333333	0.383296	0.714286	0.538462	0.492344	13
15	0.404497	0.445214	0.675676	0.368421	0.473452	17
16	0.344488	0.357441	1	0.344262	0.511548	11
17	0.46476	0.563906	0.531915	0.396226	0.489202	15
18	0.35168	0.408423	0.609756	0.333333	0.425798	18

4.2.1 Selection of optimal combination of influential parameters: Further S/N ratio analysis is done on Grey grade values (Table 4.5) and response values for signal to noise ratio (Table4.4) and main plots for SN ratios (Figure 4.2) are presented. The optimal values of influential parameters are identified from this analysis (Figure 4.2) which are corresponding to higher S/N ratio. The optimal influential parameters setting is A1B3C1D1 i.e., Electrode wire type: Zn coated brass electrode, Ton:110, Toff: 36 , Ip:02 amp.

Table 4.4 Responses for S/N Ratios

Level	Electrode (A)	Ton (B)	Toff (C)	Peak current(D)
1	-4.542	-5.461	-5.124	-4.941
2	-6.190	-5.321	-5.551	-5.681
3		-5.316	-5.423	-5.476
Delta	1.647	0.145	0.427	0.740
Rank	1	4	3	2

Figure 4.2 Main plots for SN ratios of data means (GRG)



4.2.2 ANOVA of grey grade values: The order of influential parameters affecting the machining outputs is determined by performing ANOVA on GRG values using mini tab software and the results are given Table 4.5. From ANOVA results, it is known that Electrode has more influence on combined machining outputs and same is known from Table 4.4. The order of influential parameters is electrode, peak current, Pulse off time and pulse on time.

Table 4.5 Results of ANOVA

Source	DF	AdjSS	Adj MS	F-Value	P-Value	Contri-% bution
Elec-trode	2	0.007514	0.003757	3.8	0.199	33.52
Pulse on	2	0.00238	0.00119	2.5	0.308	10.62
Pulse off	2	0.0048716	0.0024358	15.31	0.003	21.74
Peak current	2	0.00617	0.003085	1.39	0.294	27.52
Error	2	0.00148	0.00074			6.60
Total	10	0.0224156				100

4.2.3 Confirmation Test Results: The confirmation test is conducted for optimal parameter values (A1B3C1D1) obtained from Grey-Taguchi (Electrode: Zn coated brass, Ton: 110 µs, Toff: 36 µs, Ip:2 amps) and responses are recorded (Table 4.6). The confirmation test results are better compared experimental results (Table 4.3). Hence selected optimal parameter setting is best one and the confirmation test result is satisfactory.

Table 4.6 Confirmation test results

Optimization method	Optimal param-eter setting	Machining outputs				GRG
		SR (µm)	MRR mm3/) (min	KW (mm)	TW (mm)	
GRA-Taguchi	A1B-3C1D1	2.724	8.596	0.522	0.024	0.766

5. CONCLUSIONS

In this work, AA6101- B4C/Se/CNT composites are prepared and tested for its properties. The WEDM is done on the best selected composite by varying the influential parameters such as electrolyte, wire tension, wire feed, electrode type, peak current pulse on time and pulse off time. The effects of process parameters on machining outputs MRR, SR, Kerf Width and tool wear are studied and optimal process parameters are selected. From the results the following statements are concluded.

i. The stir casting method has been effectively used to fabricate various HAMMCs with varied wt% of reinforcements.

ii. Higher tensile strength, hardness, wear resistance are observed in composite M5 (AA6101-98.20% + 0.8% B4C + 0.8% Se +0.2% CNT) due to the formation strong bond among B4C,CNT and Al-Se compound.

iii. The highest impact strength of 37.2 J and flexural strength 321.42Mpa is observed for composite M2(AA 6101-98.4% + 0.8% B4C +0.8%Se),it is understood that the inclusion of B4C acts as impact modifier and increases the toughness of the aluminum matrix .

iv. The addition of CNT, which has superior electrical conductivity increases the electrical conductivity of composite M4(AA6101-99.10% + 0.2%CNT+ 0.8% B4C) compared to other composites, which is essential property for WEDM.

v. Corrosion resistance of the AA6101-99.00% + 0.8% Se + 0.2% CNT composite (M3) was much higher compared to remaining composites due to selenium increases corrosion resistance, which is a critical feature in marine applications and vehicle radiators.

vi. Among the developed composites, the best material (M5) which possesses all these good properties is selected by analyzing the data of the characteristics using AHP-GRA.

vii. AHP-GRA and GRA-Taguchi methods are successfully applied in this study to select the best composite and to establish the optimal process parameters setting for obtaining the improved performance of EDM process.

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AUTHORS

M Hari Prasad, Lecturer in Mechanical Engineering, Department of Technical Education (AP) India
Email : hariprasad.vision@gmail.com / Mob : 9618118131

P. Venkataramaiah, Professor, Department of Mechanical Engineering, Sri Venkateswara University College of Engineering, Tirupati – 517 502, (AP) India