OPTIMIZATION IN WIRE-CUT EDM OF ALUMINIUM HYBRID METAL MATRIX COMPOSITE USING TAGUCHI COUPLED DENG'S SIMILARITY BASED APPROACH

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The objective of this paper is to analyze the effects of wire-cut EDM process parameters on the material removal rate (MRR) and surface roughness (Ra) using analysis of variance and Taguchi's coupled Deng's similarity based approach. The wire-cut EDM experiments were conducted on aluminium hybrid metal matrix composite under varying pulse on time, pulse off time, sensitivity, wire type and dielectric flushing pressure. The wire-cut EDM parameters setting were determined using Taguchi's methodology. The order of importance of the wire-cut EDM process parameters on the output responses of aluminium hybrid metal matrix composite is determined using analysis of variance. This result signifies the most influential process parameters on single responses solely. Therefore, to study the multi objective problem the Taguchi's coupled Deng's similarity based approach was used and results showed the optimized process parameters for obtaining best output responses corresponding to material removal rate and surface roughness. From the results of present work, it is concluded that Taguchi's coupled Deng's similarity based approach can be efficiently used as multi objective optimization approach.

Keywords: wire-cut EDM, aluminium based hybrid MMC, stir casting, ANOVA, Taguchi coupled Deng's approach.

1. Introduction

Wire cut electrical discharge machining (wire-cut EDM) is a specialized electro-thermal machining process [2, 11, 9 and 14] which has the ability to accurately machine the difficult to cut materials, irregulars and intricate shapes on electrically conductive parts. This machining technique allowed success in the machining of newer materials especially in aerospace, automobiles, nuclear and medical industries [13]. To process the advanced ceramics, wire-cut EDM process is evolved as one of the most promising techniques [25]. This processing method has been gaining vital interest because of its combination of electrodynamic, electromagnetic, hydraulics and thermaldynamic actions, exhibits a complex and stochastic nature [22]. Today's manufacturing world, wire-cut EDM method is

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also being employed to machine a wide variety of miniature and micro-parts in metals, alloys, sintered materials, cemented carbides, ceramics and silicon. In this method, a thin electrically conductive electrode wire is a continuously moving (made of brass, copper, tungsten or coated brass wire of diameter 0.05-0.3mm) to generate series of discrete electrical sparks between workpiece and electrode tool for erodes material from the workpiece through vaporization mechanism [15]. The cutting force throughout wire-cut EDM is low therefore this aspect makes a wire-cut EDM as a vital method to manufacture precise, intricate, and miniature features on mechanical parts [21]. A good surface quality of precise workpiece is obtained by providing low discharge parameters with high dielectric flushing rate and necessary repetitive finish cuts along with rough cutting [8, 7].

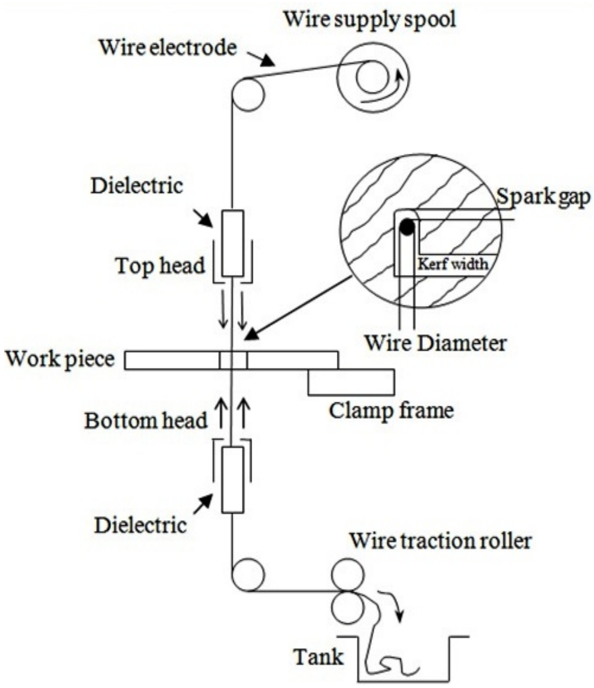


Fig. 1. Detail diagram of the wire-cut EDM method and its responses

As shown in Fig. 1, the electrode wire is moving on the spool, feeds through the workpiece, and is held on a second spool or receiver tank. The gap between the electrode wire and the work piece is flooded with a dielectric fluid (deionized water), that flushes away the eroded particles from machining space and cools the material [3]. So as to boost the dimensional accuracies of wire-cut EDM materials, the used wire collected at the receiver tank can need to be discarded and may not be reused again [4]. On the other hand, there’s no mechanical contact between the electrode wire and the workpiece, and thus, it eliminates the mechanical stress throughout wire-cut EDM operation. In order to achieve the specified two-dimensional and three-dimensional complicated shapes on electrical conductive parts, the electrode wire movement is controlled numerically [23].

Many researchers have investigated the consequences of varied wire-cut EDM process parameters on different materials. For example, Liao et al., [26] reported that to regulate and predict the machining characteristics of various materials, even when they are machined under the same wire-cut EDM conditions, are very tough. Due to a higher pulse-on time settings leads to thicker recast layer on the machined surface and conjointly a lower pulse-on time and higher pulse-off time results in low deposition of the wire on the machined surface [1]. During cutting of hard materials with wire-cut EDM, the cutting rate, surface integrity, material removal rate, kerf width and gap current are the most significant performance measures of a material and they rely on influential machining parameters such as spark gap voltage, discharge current, pulse on time and off time, wire speed, wire tension, type of dielectric fluid and flushing conditions [16, 17]. In this process, the wire will be discarded in most of the cases to reinforce the working accuracy because once the wire passes through the workpiece; it is scrap and not reusable. So that wire wear rate isn't necessary parameter to assume as an output response [12].

1.1 Hybrid metal matrix composites and their applications

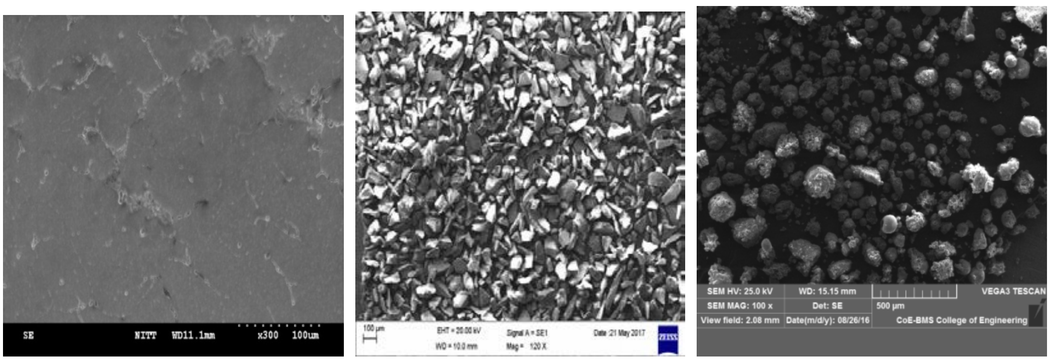
Hybrid metal matrix composites (HMMCs) are the new class of composite materials which constitutes two or more chemically non-reactive reinforcing materials, for enhancing the material properties. Hybrid MMCs are emerging as important materials to satisfy the demands in the modern industrial world with their properties of lightweight, high strength, good wear resistance, and a low thermal expansion coefficient [19]. The incorporation of hard ceramic reinforcements makes machining of HMMCs using conventional machining route more difficult. In view of the difficulties such as tool wear and poor surface finish, encountered during machining of HMMCs with traditional methods, nonconventional machining process such as wire-cut EDM is widely used to perform the precision machining of HMMCs.

So far only a few literatures are reported on wire-cut EDM characteristics of hybrid MMCs and there is no readily available information for selection of correct wire-cut EDM parameters to machine such a new of class of composites [21]. Therefore, the selection of optimum wire-cut EDM parameter combinations for getting higher accuracy may be a difficult task [24]. So as to answer the challenges in the selection of optimum wire-cut EDM parameters, an attempt has been established through Taguchi's coupled Deng's approach in the present investigation.

2. Experimentation

2.1 work material

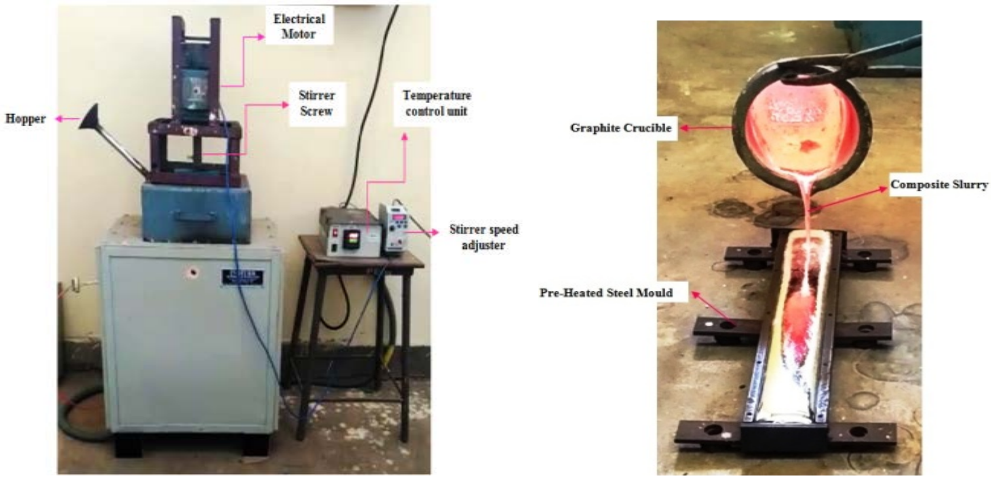
The Hybrid MMC employed in present investigation consist wrought aluminium alloy (AA 6082), as the matrix material with flyash (range of 53-106 μm) and alumina (53 μm) particles, as a reinforcement material, shown in Fig. 2. The flyash particles and alumina particles were preheated at 250°C for two hours prior to introduction into the melt. At the same time, the matrix alloy was liquified, around 700°C using stir casting furnace, as shown in Fig. 3. This HMMC is prepared with optimum process conditions, to make uniform dispersions of hybrid reinforcements in matrix alloy. The preheated particles such as half ceramic particulate reinforcement and remaining half flyash reinforcement along with 2% magnesium were added to the melt after an effective degassing with hexachloroethane tablet. In the mean time, the prepared special die for the workpiece of size 190×45×10 mm was also preheated to 600°C. The melt was mechanically stirred using a zirconium coated stainless-steel stirrer at a speed of 600 rpm for 10 minutes. After thorough stirring, the slurry was poured into the preheated die. The prepared composites were allowed to cool in the die at room temperature. Finally, the rectangular block size of cast aluminium based hybrid MMC AA6082/3%Al_2O_3/3%FA was fabricated.



(a) AA 6082 (b) Alumina (Al_2O_3) (c) Flyash (FA)

Fig. 2. SEM photographs of matrix and reinforcement materials

The presences of Al_2O_3 and flyash particles in the composite materials have been identified using scanning electron microscope images, shown in Fig. 4 (a). These pictures show discrete localized agglomeration of Al_2O_3 and flyash particles. In order to study the material removal rate (MRR) and surface roughness (R_a) of hybrid MMC under wire-cut EDM process, the Taguchi's (L_{18}) orthogonal array was used to organize the wire EDM process parameters and the levels at which they vary.



(a) Stir Casting Furnace (b) Mould with composite slurry

Fig. 3. Fabrication of hybrid MMC by using stir casting furnace

Table 1

Process parameters of wire-cut EDM

Process parameters	Symbol	Levels			Units
		1	2	3	
Wire type (WT_y)	A	Brass	Zinc coated brass	--	
Pulse on time (T_{on})	B	100	102	104	µs
Pulse off time (T_{off})	C	46	48	50	µs
Sensitivity (S)	D	1	3	5	microns
Flushing pressure (Fp)	E	75	85	95	kg/cm^2

2.2 Machining of hybrid MMC

Machining of hybrid MMC is performed on 4-axis smart cut CNC wire-cut EDM machine, shown in Fig. 4 (b). Different settings of wire-cut EDM parameters such as pulse on time and off time, sensitivity, flushing pressure and wire type were used in the experiments and their levels are shown in Table 1. These parameter settings at different levels are selected as per the trial experiment conducted to avoid the wire breakage during machining of hybrid MMC and also following parameters such as peak current (3A), wire feed (30 mm/min.) and wire tension (30g) were kept constant throughout the experiments.

In this experiment, two types of electrode wires with 0.25 mm diameter were used as one of wire-cut EDM process parameter to determine the best-suited wire electrode to machine the hybrid MMCs. Demineralised water is used as a dielectric medium with varying pressure to flush out the debris from the machined area and to cool the material.

In wire-cut EDM, machining rate is a term, used to express the material removal rate in which an electrode wire removes unwanted material from the workpiece to generate the desired shape. The Material Removal Rate (MRR) is the rate at which the cross-section area of material removed per unit of time. It is determined using Eq. (1) (Ramesh et al., 2013 [18]) which involves the following parameters such as spark gap, the diameter of a wire, the thickness of the workpiece, the distance covered by the tool and time required for machining the one complete profile.

$$MRR = (2SG + D) \times t \times L/T, \text{ mm}^3\text{/min} \quad (1)$$

Here, *SG* is the spark gap in millimetres, *t* is the thickness of workpiece in millimetres (10 mm), *T* is the time taken to cut one profile in minutes, *D* is the diameter of the wire in millimetres and *L* is the distance covered by the tool to cut one profile in millimetres.

Here, the spark gap is defined as the average of the distance between kerf width and wire diameter, which decides the accuracy of a machined part in wire-cut EDM. As well as kerf width is the measure of the amount of the material that is wasted during machining for finishing part. The detailed section of the spark gap and kerf width is shown in Fig. 1.

The kerf width and spark gap of the composite are directly affected by reinforcement material and that will cause to fluctuate the material removal rate and surface generation. Due to the heat resistance of reinforced particles in composite material delays the rate of material removal, so the wire electrode stays longer in touch with intense heat and effects on the kerf width and surface formation.

However, the surface roughness (Ra) is the measure of irregularities occurred on the machined surface during wire-cut EDM and it is determined by measuring the peripheral of machined surface with MAHR surface roughness tester (Fig. 4 (c)) and also the photograph of machined composite is shown in Fig. 4 (d). The performance measures such as MRR and Ra is shown in Table 2.

Table 2

Experimental design and responses

Exp. No.	A	B	C	D	E	MRR (mm^3/min.)	R_a (μm)
1	1	1	1	1	1	6.52	2.03
2	1	1	2	2	2	8.61	1.86
3	1	1	3	3	3	8.27	3.67
4	1	2	1	1	2	4.56	3.1
5	1	2	2	2	3	4.82	2.77
6	1	2	3	3	1	3.57	3.14
7	1	3	1	2	1	2.89	4.46
8	1	3	2	3	2	5.31	2.35
9	1	3	3	1	3	3.02	2.56
10	**2**	**1**	**1**	**3**	**3**	**11.34**	**2.32**
11	2	1	2	1	1	7.29	2.2
12	2	1	3	2	2	2.17	3.14
13	2	2	1	2	3	1.67	4.46
14	2	2	2	3	1	4.44	1.61
15	2	2	3	1	2	6.11	3.67
16	2	3	1	3	2	5.61	4.87
17	2	3	2	1	3	3.75	2.37
18	2	3	3	2	1	3.96	2.52

3. Analysis and discussion

In this work the analysis of variance (ANOVA) was used, to determine the statistical significance and percent contribution of wire-cut EDM process parameters on MRR and R_a responses.

3.1 Effects of process parameters on MRR

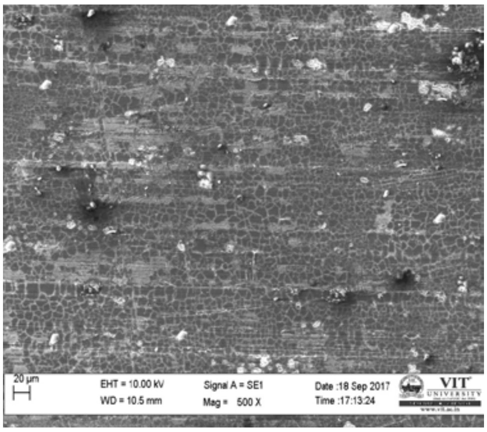
This test is carried out for a significance level of 0.05 to find out the relative importance of individual parameters using the statistical software 'Minitab 15'. The effects of wire-cut EDM process parameters on MRR were tabulated in Table 3. In ANOVA result tables, the last column indicates the percent contribution of each process parameter that shows the degree of influence on output responses to varying. From Table 3, it is found that the pulse on time and sensitivity parameters have the greatest influence to vary the MRR response. Hence pulse on time is the most influential process parameter (39.62%) for MRR followed by sensitivity (16.49%), pulse off time (4.14%), flushing pressure

(1.67%) and wire type (0.079%). The process parameters such as wire type and flushing pressure show the lower percent contribution among all parameters thus flushing pressure and wire type have the least influence on MRR.

Table 3

ANOVA results for MRR

Process parameters	DF	Seq SS	Adj MS	F	Contribution %
A	1	0.084	0.084	0.02	0.079
B	2	41.614	20.807	4.2	39.622
C	2	4.638	2.319	0.47	4.416
D	2	17.329	8.664	1.75	16.499
E	2	1.754	0.877	0.18	1.670
Error	8	39.605	4.951		
Total	17	105.025			



(a) SEM image of HMMC

(b) wire-cut EDM machine

(c) MAHR surface roughness tester

(d) machined HMMC samples

Fig. 4. Photographs of SEM micrograph, EDM machine and machined hybrid MMC

3.2 Effects of process parameters on R_a

The effects of process parameters on R_a are tabulated in Table 4. Through this percent contribution, the process parameter effects would be analyzed.

Table 4

ANOVA results for Ra response

Process parameters	DF	Seq SS	Adj MS	F	Contribution %
A	1	0.0827	0.0827	0.11	0.542
B	2	1.5496	0.7748	1	10.172
C	2	5.6905	2.8453	3.68	37.355
D	2	0.9134	0.4567	0.59	5.996
E	2	0.8157	0.4078	0.53	5.354
Error	8	6.1814	0.7727		
Total	17	15.2334			

From Table 4, it is found that pulse off time shows higher percent contribution among all parameters in R_a response. Hence pulse off time is found as most influential process parameter on R_a response (37.35%), followed by the pulse on time (10.17%), sensitivity (5.99%), flushing pressure (5.35%) and wire type (0.54%). From the ANOVA results, it is observed that the flushing pressure and wire type process parameters have the least significance to vary the both MRR and R_a responses respectively. Based on the ANOVA analysis, it is found that both the responses are highly influenced with pulse duration for obtaining the optimal wire-cut EDM responses of aluminium hybrid metal matrix composites.

3.3 Multi-Attribute Decision Making Optimization Methodology

As a part of the current investigation, an attempt has been established to find the optimum machining parameters settings for the objective of maximum MRR and minimum surface roughness. In this case, Deng's similarity-based approach was used to search optimum machining parameters for multi-performance responses.

This methodology is introduced by Deng in 2007 [5] with a concept of an alternative gradient to represent the conflict of alternatives in multi-criteria decision-making problems. This methodology is also used to rank the services for reliability estimation of service-oriented design systems and to eradicate the uncertainty drawback in ranking the alternatives based on their distances between the positive and the negative ideal solutions (PIS and NIS) in some situation.

However, this method is just like the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodology to rank the alternatives based on their distances between PIS and NIS whereas Deng's similarity method measures the angle between PIS and NIS to calculate the degree of conflict

between them. The detailed algorithm of the Deng's similarity-based method was explained by [20, 10 and 6] as in the following steps to solve multi-objective problems.
Step 1: Constructing the decision matrix (X) with 'm' attributes and 'n' alternatives as Eq. 2.

$$X = \begin{bmatrix} a_{11} & a_{12} & \ldots\ldots & a_{1m} \\ a_{21} & a_{22} & \ldots\ldots & a_{2m} \\ \vdots & \vdots & \vdots\,\vdots & \vdots \\ a_{n1} & a_{n2} & \ldots\ldots & a_{nm} \end{bmatrix} \tag{2}$$

Where a_{ij} are the value shows that the performance measure of alternative A_i with respect to the criterion C_j.
The formulated decision matrix of wire EDM responses with 'm' attributes and 'n' alternatives are enumerated in Table 5.
Step 2: Determining the weighting factors for the chosen criterion
A weighting factor as W = (w_1, w_2, …, w_m) can be allocated to represent the relative significance of each criterion with respect to the overall objective of the problem.
In the present investigation, equal weights were allocated to the criterion, which means each criterion is allocated by 0.5 values as a weighting factor.
Step 3: Normalizing the decision matrix (X) using Euclidean normalization
The decision matrix is to be normalized to make a suitable comparison between each criterion over another by using Eq. 3 and is tabulated in Table 5.

$$X'_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{n} a_{ij}^2}} \tag{3}$$

Step 4: Determining the performance matrix
The performance matrix (Y) can be obtained by considering the allocated weights as Eq. 4.

$$Y = W \times X'_{ij} \tag{4}$$

Step 5: Determining the ideal solutions
The positive and negative ideal solutions are consists of the best and worst criteria values from possible 'n' alternatives. Before determining the ideal solutions, it ought to be considered whether the criteria values are the higher-the-best or lower-the-best. Therefore, these ideal solutions can be achieved by using Eqs. (5) and (6).

$$A^{+} = \left(\begin{matrix} max \\ i \end{matrix} y_{ij} : j \in J, \begin{matrix} min \\ i \end{matrix} y_{ij} : j \in J' | i = 1, 2, \ldots\ldots, \ldots n\right)$$
$$= (y_1^{+}, y_2^{+}, y_3^{+}, \ldots\ldots, \ldots, y_m^{+}) \quad (5)$$

$$A^{-} = \left(\begin{matrix} min \\ i \end{matrix} y_{ij} : j \in J, \begin{matrix} max \\ i \end{matrix} y_{ij} : j \in J' | i = 1, 2, \ldots\ldots, \ldots . n\right)$$
$$= (y_1^{-}, y_2^{-}, y_3^{-}, \ldots\ldots, \ldots, y_m^{-}) \quad (6)$$

Where, J is the set of positive criteria, and J' is the set of negative criteria.
In the present investigation the positive ideal solution (PIS) and negative ideal solution (NIS) was observed from table 5 as follows:
A^{+}= (0.23, 0.061); A^{-}= (0.034, 0.185)
Step 6: Determining the degree of conflict index between the alternatives and the ideal solutions
The degree of conflict between alternatives and both the ideal solutions can be determined by using Eqs. (7) and (8) respectively. The angle between vectors is represented by 'θ_{ij}' as shown in Fig. 5.

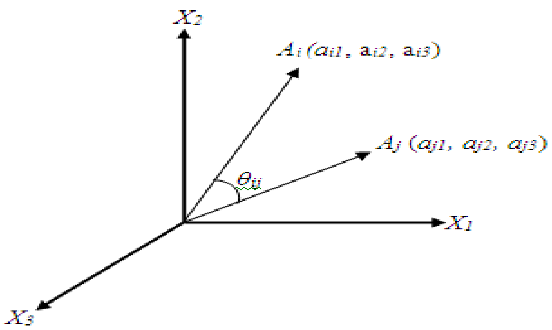


Fig. 5. The degree of conflict between alternatives and ideal solutions

$$\cos\theta_{i+} = \frac{\sum_{j=1}^{m} y_{ij} y_j^{+}}{\sqrt{\sum_{j=1}^{m} y_{ij}^2 \sum_{j=1}^{m} y_j^{+2}}} \quad (7)$$

$$\cos\theta_{i-} = \frac{\sum_{j=1}^{m} y_{ij} y_j^{-}}{\sqrt{\sum_{j=1}^{m} y_{ij}^2 \sum_{j=1}^{m} y_j^{-2}}} \quad (8)$$

Where $\cos\theta_{i+}$ and $\cos\theta_{i-}$ are the degree of conflicts between the alternatives and positive ideal solution and negative ideal solution respectively and these values are tabulated in Table 5.

As a consequence, the degree of similarity between each alternative and both the ideal solutions can be determined based on the degree of the conflicts as Eqs. (9) and (10). The degree of similarity is denoted as S_{i+}, which quantifies the relative similarity between the alternatives and positive ideal solutions, and the degree of similarity 'S_{i-}' quantifies the relative similarity between the alternatives negative ideal solutions.

$$S_i^+ = \frac{\sqrt{\sum_{j=1}^{m} y_{ij}^2} * \cos\theta_{i+}}{\sqrt{\sum_{j=1}^{m} y_j^{+2}}} \tag{9}$$

$$S_i^- = \frac{\sqrt{\sum_{j=1}^{m} y_{ij}^2} * \cos\theta_{i-}}{\sqrt{\sum_{j=1}^{m} y_j^{-2}}} \tag{10}$$

Where, S_{i+} and S_{i-} are the degree of similarity between the ideal solutions.

Step 7: Determining the overall performance index

This index is also be called as overall similarity index which calculated for each alternative based on the concept of the degree of similarity as Eq. (11). This performance index is denoted as 'P_i', the larger the value of P_i, the higher the ranking of the alternative.

$$P_i = \frac{S_i^+}{S_i^+ + S_i^-} \tag{11}$$

Final Step in this algorithm is to rank the alternatives based on their overall performance index in the descending order of the 'P_i' index value. Table 6 shows the degree of similarity index and overall performance index values.

In the present study, the multi-objective problem is revived into a single objective problem using Deng's similarity based optimization method. In such a way that the single objective optimization result such as overall performance index is analyzed using Taguchi method to study the comparative results of obtained optimum parameter settings through Deng's and Taguchi's coupled Deng's similarity-based approach for attaining the more accurate multi-performance measures in wire-cut EDM of hybrid MMC.

From the Table 6, it is observed that the optimum parameter settings through Deng's approach are 10^{th} experimental run ($A_2B_1C_1D_3E_3$), had the higher overall performance value and as a result, this alternative is ranked one for satisfying the performance measure objectives such as minimum surface roughness and maximum MRR simultaneously among the eighteen experiments.

Table 5

The values of $\cos\theta^{+}$ and $\cos\theta^{-}$ along with decision matrix

		'm' attributes							
		Wire-cut EDM responses		Normalized matrix		Performance matrix		Conflict Index	
								$\cos\theta^{+}$	$\cos\theta^{-}$
	Exp. Run	MRR	R_a	MRR	Ra	MRR	Ra		
'n' alternatives	1	6.52	2.03	0.26	0.15	0.13	0.07	0.96	0.64
	2	8.61	1.86	0.35	0.14	0.17	0.07	0.99	0.53
	3	8.27	3.67	0.33	0.27	0.16	0.13	0.908	0.76
	4	4.56	3.1	0.18	0.23	0.09	0.11	0.79	0.88
	5	4.82	2.77	0.19	0.21	0.09	0.10	0.84	0.84
	6	3.57	3.14	0.14	0.23	0.07	0.11	0.72	0.93
	7	2.89	4.46	0.11	0.34	0.05	0.17	0.55	0.98
	8	5.31	2.35	0.21	0.17	0.10	0.08	0.90	0.76
	9	3.02	2.56	0.12	0.19	0.06	0.09	0.73	0.92
	10	11.34	2.32	0.46	0.17	0.23	0.08	0.99	0.51
	11	7.29	2.2	0.29	0.16	0.14	0.08	0.96	0.63
	12	2.17	3.14	0.08	0.23	0.04	0.11	0.57	0.98
	13	1.67	4.46	0.06	0.34	0.03	0.17	0.44	0.99
	14	4.44	1.61	0.18	0.12	0.09	0.06	0.94	0.70
	15	6.11	3.67	0.25	0.27	0.12	0.13	0.83	0.85
	16	5.61	4.87	0.22	0.37	0.11	0.18	0.72	0.93
	17	3.75	2.37	0.15	0.18	0.07	0.09	0.82	0.86
	18	3.96	2.52	0.16	0.19	0.08	0.09	0.81	0.868

Table 6

The values of the degree of similarity ($S_i^{\pm}$) and overall performances index (P_i)

Exp. Run	S_i^{+}	S_i^{-}	P_i	Ranking
1	0.61	0.53	0.538	4
2	0.78	0.538	0.59	2
3	0.83	0.89	0.4822	7
4	0.501	0.705	0.41	12
5	0.509	0.64	0.44	8
6	0.42	0.69	0.377	15
7	0.418	0.94	0.307	17
8	0.53	0.57	0.4826	6
9	0.35	0.56	0.38	13
10	1.02	0.68	0.61	1
11	0.69	0.58	0.54	3
12	0.306	0.66	0.31	16
13	0.318	0.91	0.25	18
14	0.43	0.40	0.514	5
15	0.65	0.84	0.43	9
16	0.659	1.07	0.379	14
17	0.40	0.54	0.426	10
18	0.42	0.57	0.42	11

In Taguchi analysis, the higher-the-better characteristics were chosen for overall performance index, because the target of the current work is to higher the multiple performance characteristics. The level of machining parameters with higher means shows the optimum level of parameter settings. From the Fig. 6, it is observed that the optimum parameter settings were $A_1B_1C_2D_3E_1$.

Table 7

Response table for means of the overall performance index

Level	A	B	C	D	E
1	0.4452	0.5117	0.4157	0.454	0.4493
2	0.431	0.4035	0.4988	0.3862	0.4336
3	---	0.3991	0.3999	0.4741	0.4314
Delta	0.0142	0.1126	0.0989	0.088	0.018
Rank	5	1	2	3	4

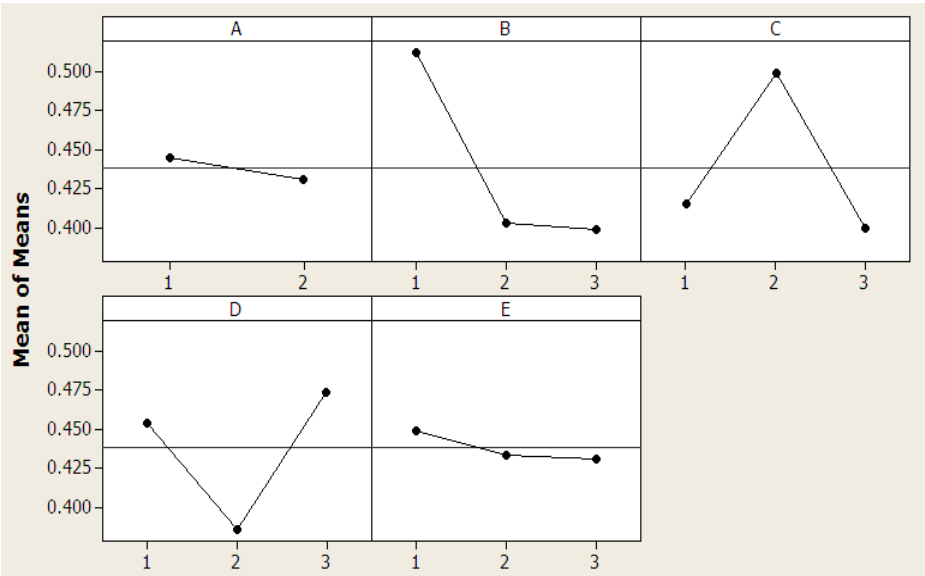


Fig. 6. Main effects plot for means of the overall performance index

Along with that the most significantly influential parameter was also determined through the mean response table, as in Table 7. From this table, it is observed that the pulse on time (B) is ranked one. As consequently, the pulse on time is the highly influential parameter for getting the maximum MRR and minimum surface roughness followed by pulse off time (C), sensitivity (D), flushing pressure (E) and wire type (A).

4. Validation check

The final step of the optimization process is to validate the optimum process parameters settings through confirmation tests for wire-cut EDM of aluminium hybrid metal matrix composite with respect to the chosen initial parameter setting. In this validation method, optimum parameter levels (10th experimental run) evaluated with Deng's similarity-based approach is chosen as the initial parameter settings. Later on, the confirmation experiments were performed with the use of optimum parameter settings obtained through the Taguchi coupled Deng's similarity-based approach for predicting and validating the wire-cut EDM responses with initial parameter settings. The predicted responses using the optimum parameter settings can be estimated as:

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{k}(\acute{\gamma}_i - \gamma_m) \quad (12)$$

Where γ_m is the total mean value of overall performance index (P_i), $\acute{\gamma}_i$ is the mean of overall performance index (p_i) at the optimum level and k is the number of main process parameters that significantly affect the multi-performance characteristics.

Table 8

Comparison of results through confirmation tests

	Initial parameters settings	Optimal parameters settings	
		Prediction	Experimental
Levels	$A_2B_1C_1D_3E_3$	$A_1B_1C_2D_3E_1$	$A_1B_1C_2D_3E_1$
MRR	11.34	9.0882	11.58
R_a	2.32	4.313	3.99

The comparison results between wire-cut EDM responses using optimum parameters settings are shown in Table 8. From this result, it is found that the utilization of the optimum parameters setting combination improves the multi performances characteristics. Especially the optimum parameters settings obtained through Taguchi analysis improves the performance measures and confirmed the validity of the Taguchi integrated Deng's similarity-based approach. From the results in Table 8, it is observed that the MRR and surface roughness is improved when compared to initial values obtained through initial parameter settings.

5. Conclusions

In this paper, an application of Taguchi coupled Deng's similarity-based approach and ANOVA analysis is employed to investigate the effects of process parameters on material removal rate and surface roughness in wire-cut EDM of AHMMC. The following conclusions might be drawn based on the results of the current investigation:

1. From the current investigation, it can be concluded that aluminium hybrid metal matrix composite is fairly machinable by using wire-cut EDM method.
2. From the ANOVA analysis, it can be concluded that pulse on time is the highly influential factor for MRR response and also the percent contribution of this factor specifies the small variation of this factor leads to greatly varying in MRR response.
3. According to R_a response, the pulse off time parameter shows high contribution percent hence it can be concluded that pulse off time parameter is the most influential factor.
4. One more thing needs to be recognized that the flushing pressure and wire type parameters are insignificant on both the responses.
5. According to Deng's similarity based optimization method the best MRR and R_a was obtained at the higher level of wire type, lower levels of the pulse on time and pulse off time and higher levels of sensitivity and flushing pressure.
6. For improving the wire-cut EDM accuracy, Deng's similarity approach was coupled with the Taguchi technique to analyze the obtained overall performance index from Deng's similarity approach. From the results, it is concluded that lower level of wire type and pulse on time, medium level of pulse off time, the higher level of sensitivity and lower level of flushing pressure was obtained for best multi-performance responses.
7. From the confirmation results, it can also be concluded that Taguchi coupled Deng's similarity-based approach gives better MRR and R_a responses in wire-cut EDM of aluminium hybrid metal matrix composite. Therefore, it is strongly recommended and inferred that Taguchi coupled Deng's similarity approach can be efficiently optimized multi-performance objective problems.

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