Received: May 6, 2017

International Journal of
Intelligent Engineering & Systems

http://www.inass.org/

Experimental Investigation and Multi Response Optimization of WEDM Process of AA7075 Metal Matrix Composites Using Particle Swarm Optimization

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Abstract: Wire electric discharge machining (WEDM) has turned out to be one of the well-known machining procedures utilized in bringing up elaborate aspects on electrically conductive substances. To improve the performance of WEDM process an attempt was made to improve the material removal rate (MRR) and minimize surface roughness (SR) on AA7075-activated carbon composites. The machined surface integrity associated with MRR and SR have been analysed as a function of processing parameters, such as discharge current, pulse on time, pulse off time and servo speed rate. Analysis of variance (ANOVA) is carried out in the idea of identifying tremendous causes of parameters. Experimental outcome authorize the feasibility of proposed prediction strategy and the developed particle swarm optimization (PSO) algorithm. Experiment result indicates that the MRR and SR are more sensitive to a change in size than a change in volume fraction of reinforcement. AA7075-activated carbon composites have extensive applications in aerospace and marine sectors.

Keywords: MRR, Surface roughness, WEDM, Response surface methodology, ANOVA, Particle swarm optimization.

1. Introduction

Wire electrical discharge machining (WEDM) has developed as a hotspot in assembling venture through the advance of electromechanical procedures and contraptions. Developing for quick, coordinate, andmass assembling of scaled down items from super composites in aviation, auto, biomedical, and spacecraft applications. WEDM is without uncertainty one of the non conventional machining that makes utilization of the warm vitality created because ofthe discrete sparkles happening among the workpiece and work piece. An appropriate dielectric is persistently outfitted to the bury anode gap. WEDM is a variation ofelectrical discharge machining (EDM) system, where, a moving wire (Φ10–100μm) manufactured from thin copper, metal, or tungsten is utilized as terminal. Movement of wire is overseen numerically to procure the difficult three-dimensional shapes on dubious to registering gadget materials like super composites [1, 2].Possessing good range of benefits WEDM over the other machining strategies, it was holed for the most part licensed in aviation and atomic space industry to machine tricky shapes. Aluminum and its amalgams possess numerous engaging properties like high point by point quality, brilliant erosion resistance, and over the top quality to weight proportion. Therefore, they're to a great extent utilized as a part of aviation, atomic, biomedical, marine, and in numerous destructive environment; in any case, they have awful attributes. The machine of scaled down parts in aluminum compounds is completely requested [3, 4]. WEDM is a progressed machining process that could be utilized in machining of aluminum compounds. Because of its stochastic nature and the raised amount of factors included, attaining the ideal execution measures of machining of super combinations keeps on being a risk in the machining. Hence, the machinability of WEDM strategy on aluminum wants to be investigated. Only a couple of specialists had been analysed, on the machining of aluminum making utilization of WEDM. In any case, there is a requirement for the multiple responses optimization of WEDM process.

Fuzzy logic analysis together with Taguchi method has been utilized in optimizing high-pace EDM approach for the machining of SKD11 instrument metal [5]. Majumder et al. [6] offered using fuzzy algorithm to predict removing rate, tool wear ratio, and surface roughness in traditional and ultrasonic vibration supported EDM process. Fuzzy model offered lots of particular and informal decision of EDM input parameters was noticed, and was also identified as capable in forecasting the outcomes with accuracies greater than 90%. Puertas et al., [7] has subsidised a fuzzy-situated multi objective particle swarm optimization (PSO) procedure to the optimization of EDM with parameter of chrome steel. In this learn, RSM technique utilized in experimentation and regression approach to mannequin the association among the responses and input parameters. A fuzzy technique adopted in contributing a fit value for PSO and the feasibility of the method used to be proved by way of experimental comparison. ShajanKuriakose et al [8] modelled roughness of WEDM system by way of the response methodology and a response surface model which has been developed situated on a crucial composite rotatable experimental design. Both the models were associated for goodness of fit and identified that bothmodels affordexact outcome corresponding to the procedure.

Analysis of variance (ANOVA) has been utilized to search out the extent of significance of the parameters associated with machining on kerf and MRR. Mannaand Bhattacharya et al., [9] brought up a more than one regression model for representing the relationship among inputand output variables. Top-rated mixture of parameters was shortlisted for preferred outputs utilising non dominated sorting algorithm (NSGA) for wire EDM approach. CNC wire cut electrical discharge machining parameters on aluminium-reinforced silicon carbide steel matrix composite machining that was optimized by way of Lin Tsao et al., [10] utilizing Gauss elimination dual response process. Rajyalakshmiet al. [11] proposed a manipulate approach centred on Fuzzy common data to complain up the machining accuracy at edge of the WEDM system.Experiments were performed beneath changing reducing circumstances of different parameters. A mathematical model has been developed centred on regression analysis. A strive was performed through optimize the parameters of process [12] of conventional wire EDM parameters of copper substrate for micromachining. Wire electro discharge machining of high strengthmaterial was in place to model using synthetic neural community and Taguchi's L9 orthogonal array with the aid of selvakumar et. al., [13]. They discovered that the brought up ANN mannequin could identify the efficiency traits safely and the outcome of more than a few approach parameters corresponding to pulse on time, wire feed velocity, extend time, and ignition present have been studied. Liao and Haung et al., [14] investigated on experimental parameters and multi-objective optimization of WEDM of 5083 aluminum alloy.

From survey of literatures, it has been found that numerous specialists were included in the advancements of EDM, WEDM. As of late, the looks into in WEDM demonstrated that aluminum composites gives magnificent reactions in machining application [15]. Thus, associated to current review, an endeavour was performed in exploring the process parameters impact on the reactions like MRR and surface roughness. Response surface methodology (RSM) based box behnken configuration has been utilized for directing the examinations. At last, PSO was utilized to predict the ideal procedure parameter for multi execution qualities advancement of WEDM process. Investigational results confirm the feasibility of the approach and the range of machining conditions would be useful to the manufacturing communities. From now, the current methods to develop a mathematical model of machining responses and to carry out an extensive analysis of input process parameters. Response surface methodology (RSM) has been in effect used for this purpose with PSO optimization technique. It is very necessary to establish optimal parametric combination with the intension of obtaining improved machined surface.

2. Experimental procedure

In the WEDM, the analyses were done with the instrument cathode as negative extremity, in the order acquired from response surface technique. Dielectric liquid is provided consistently that contributes not only in cooling purposes.

Fig.1 demonstrates the WEDM setup utilized as a part of Machining focus. The trials have been done in a WEDM elektrasprint cut of electronicmachine tools ltd have been included.

Received: May 6, 2017

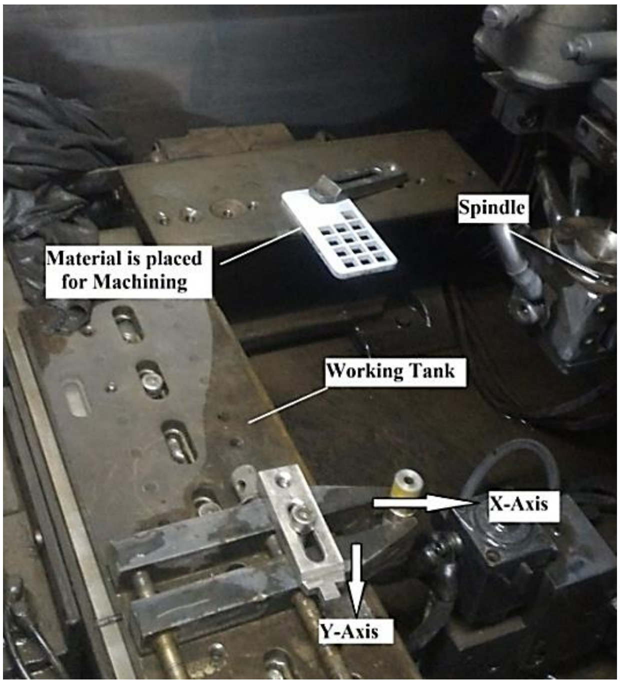


Figure.1 Experimental setup of WEDM machine

In this review, AA7075-PAC metal matrix composite and tungsten have been shortlisted as the workpiece and wire cathode, separately. The difficult outline device is supplanted by moving conductive wire and relative development of wire aides. Figure demonstrates the course of action in WEDM instrument comprising of a principle worktable (X-Y), on which is clasped the work piece; a helper table (U-V) and wire drive system. The voyaging wire is consistently sustained from wire feed spool and gathered on take up spool moving however the work piece and is upheld under pressure between a couple of wire aides situated at the inverse sides of the work piece.

2.1. Machining parameters and their levels

In spite of the fact that, the real parameters and their qualities contrast somewhat from maker to producer of the WEDM machine. The regular information parameters like discharge current, pulse on time, pulse off time and servo speed rate were taken in view of the survey of articles, study, and analysis from past outcomes [16]. From the preparatory investigation, straight model is identified as a noteworthy and a moment arrange model is essential to break down the impact of the procedure parameters on theperformance measures. Thus, going three level test plans for the info parameters are required. The parameters and their corresponding levels preferred for review are appeared in Table 1.

Table.1 Input process parameters and their levels

Parameters	symbol	Level 1	Level 2	Level 3
Discharge Current	I_A	1500	1750	2000
Pulse on Time	T_{on}	5	10	15
Pulse off time	T_{off}	25	50	75
Servo speed	SS	50	100	150

In current review, an attempt for modelling similar type of stochastic process by customary various regression test. A relationship between the process parameters and the yield execution qualities could be provided. At first, straight model was suggested, yet from ANOVA test outcomes it was neglected later. At long last, the investigation is performed to concentrate the primary impacts and their associations to investigate the quadratic impacts of parameters on the exhibitions. The relation can be explained by the second order polynomial model shown below.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i + \sum i \sum j \beta_{ij} X_i X_j + \varepsilon \tag{1}$$

Where z is the reactions (MRR or Ra), β_0 is the capture, β_i speaks to the direct impact of i^{th} component. The examination of difference and F proportion test were carried out to test the sufficiency of the model and additionally noteworthiness of the individual model coefficient. Valuing p esteem is under 0.05 is possible that implies the model is noteworthy at 95 % certainty level. The R^2 esteem is greater near 1 that is attractive. Balanced R^2 is especially valuable when contrasting the models and distinctive number of terms. Analyses were done for exploring the impact of machining process parameters. The surface roughness (Ra) estimation of the opening was measured utilizing surface roughness analyzer (profilometer). Material removal rate (MRR) is figured as the normal material volume expelled over a machining time.

3. Result and discussions

Selected combinations of the used process parameters better to be tested to accomplish the correct execution measures; MRR and surface roughness are as appeared in Table 2.

Received: May 6, 2017

Table.2 Box Behnken Response surface experimental design and results

Exp No	I_A	Ton	Toff	SS	MRR	SR
1	1750	5	50	150	9.54	3.67
2	1750	10	75	50	6.84	4.03
3	1500	10	75	100	8.2	3.99
4	2000	10	50	150	7.44	3.93
5	1750	10	50	100	8.82	3.89
6	1750	10	50	100	8.82	3.89
7	1750	10	25	150	10.8	3.74
8	1500	10	50	150	10.26	3.85
9	1500	15	50	100	8.02	3.83
10	1750	5	75	100	7.56	3.82
11	2000	15	75	100	9.66	3.95
12	2000	5	75	150	9.6	3.61
13	1750	15	75	50	8.14	4.01
14	1750	10	25	100	9.36	3.85
15	1750	15	75	50	7.62	4.15
16	1750	15	50	150	11.1	3.91
17	1750	10	75	100	8.34	3.93
18	2000	10	25	50	8.04	3.88
19	1750	5	50	100	8.04	3.77
20	1750	5	25	100	8.58	3.73
21	1750	15	25	100	11.62	3.86
22	2000	10	50	100	8.94	3.83
23	1500	15	50	100	9.57	4.06
24	1500	10	25	100	9.31	3.9
25	1500	10	50	50	7.33	4.05
26	1750	10	50	100	8.82	3.89
27	2000	10	75	100	8.64	3.87

3.1 Analysis of MRR

The ANOVA for MRR are carried out by the support of design expert software. Table 3 shows the model was produced at 95 % certainty level. The Model F-estimation of 13.57 infers the model is noteworthy. Estimations of Prob > F under 0.0500 show display terms are important. There is a 16.25% shot that an Absence of Fit F-esteem this expansive could happen because of commotion. The Anticipated R^2 of 0.5424 is in sensible concurrence with the Adj R^2 0.6592; i.e. the distinction is under 0.2. A deq Accuracy measures the flag to vibrations proportion. A proportion more significant than 4 is appealing. Outline proportion of 13.225 shows a sufficient flag. Current model is utilized for navigating outlines pace. Particular power change was picked inside the certainty level, which was recommended by programming tool compartment utilizing Box-Cox plot.

Table.3 ANOVA table for MRR

Source	SS	Df	MS	F	prob> F
Model	25.76	4	13.57	21.1	< 0.0001
Current	0.02	1	0.043	8.87	0.8381
Pulse On time	7.08	1	14.91	25.1	0.0008
Pulse off time	3.73	1	7.86	2.27	0.0104
Servo speed	16.52	1	34.83	19.6	< 0.0001
Residual	10.44	22	0.47		
Lack of Fit	9.68	18	0.54	2.82	0.1625
Pure Error	0.76	4	0.19		

The created factual quadratic citation for MRR is:

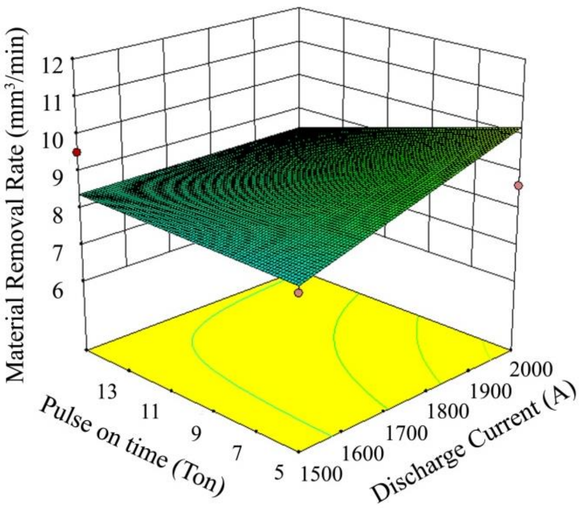
$$MRR(mm^3/\min) = +8.79 + 0.042\times A + 0.81\times A - 0.52\times C + 1.29\times D \quad (2)$$

Fig. 2 (a) demonstrates the 3D surface plot and Fig. 2 (b) demonstrates the contour plot for MRR regarding process parameters. From mentioned diagrams, it is watched that, MRR is highly delicate to pulse on time and discharge current. With increment in on time, expansive vitality being distributed, this produces more grounded flashes bringing about greater material evacuation.

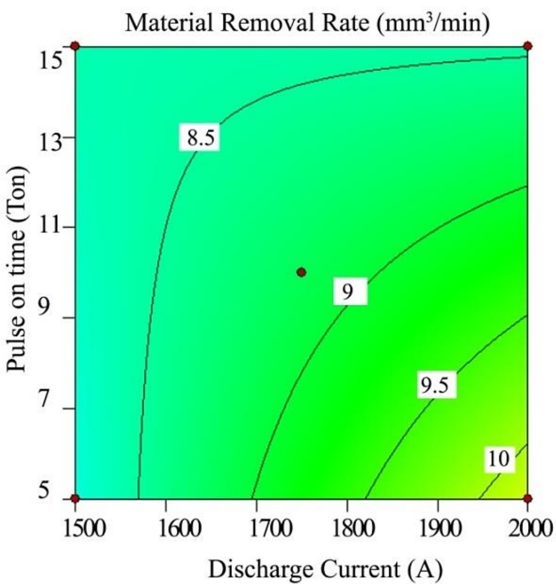
MRR increments up to an ideal level, there after it gives unfaltering; this is expected to the unlashed trash caught between instrument cathode and workpiece that end up in auxiliary sparkles [17]. Besides, legitimate flushing may not be conceivable if the working crevice turns out to be too little, which thusly diminishes the MRR. As the release current builds, the interim between the beats likewise expands which lessens the power force after an ideal level [18]. The plot which is checks the presumption of ordinariness. In this review, it is watched that a large portion of the focuses are bunched around the line, showing that the blunders are roughly typical. Along these lines, the suspicion of ordinariness is legitimate.

3.2 Analysis of SR

Table 4 condenses the ANOVA comes about the impact of process factors and their consequences for



(a)



(b)

Figure.2 Estimated response surface for MRR: (a) surface plot and (b) contour plot

second-arrange quadratic model for surface roughness. Suitability of this model for 95 % certainty level has been noticed.Model F-estimation of 21.15 infers the model is critical. There is just a 0.01% shot that an F-esteem this vast could happen because of vibrations.Estimations of Prob > F under 0.0500 demonstrate display terms are important. For this situation A, B, and D are huge model terms. Values more prominent than 0.1000 demonstrate the model terms are not critical. On the off chance that there are numerous inconsequential model terms, model diminishment may enhance your model. The Lack of Fit F-estimation of 1.11 suggests the Lack of Fit is not noteworthy in respect to the immaculate error.

Table.4 ANOVA table for Surface Roughness

Source	**SS**	**Df**	**MS**	**F value**	**Prob> F**
Model	1.1	4	0.27	21.15	< 0.0001
A-Current	0.12	1	0.12	8.87	0.0069
B-Pulse On time	0.33	1	0.33	25.11	< 0.0001
C-Pulse off time	0.03	1	0.03	2.27	0.146
D-Servo speed rate	0.26	1	0.26	19.66	0.0002
Residual	0.29	22	0.013		
Lack of Fit	0.24	18	0.013	1.11	0.5179
Pure Error	0.048	4	0.012		
Cor Total	1.39	26			

There is a 51.79% shot that Lack of Fit F-esteem this vast could happen because of vibrations. A proportion more prominent than 4 is attractive. Your proportion of 15.732 demonstrates a sufficient flag.This model can be utilized to explore the outline space. For this situation, A^2 is the term remarkable to the model. Created measurable model for SR in coded shape is,

$$SR = +3.67 + 0.10 \times A - 0.17 \times B$$
$$+0.046 \times C + 0.16 \times D \quad (3)$$

The created 3D response surface and contour plot forsurface roughness are appeared in Fig. 3 and Fig.4. It is seen from pulse off time is emphatically impacting the SR. With increment in current huge vitality being dispersed; this disintegrates more material with more grounded flashes. This solid start dissolves the material with high measure of flotsam and jetsam caught between machining zones bringing about undesirable start. In this manner, bring down Ra is acquired. As the servo speed is expanded past the ideal esteem, the substantial vitality is disseminated. The more prominent the release vitality causes themore energy to be led into workpiece.

3.3 Analysis of machined surfaces

Subsequent to WEDM operations, the machine samples have been analysed utilizing filtering microscope instrument. SEM pictures of surfaces appeared for AA7075-PAC metal matrix composite workpiece are appeared in Fig. 5.

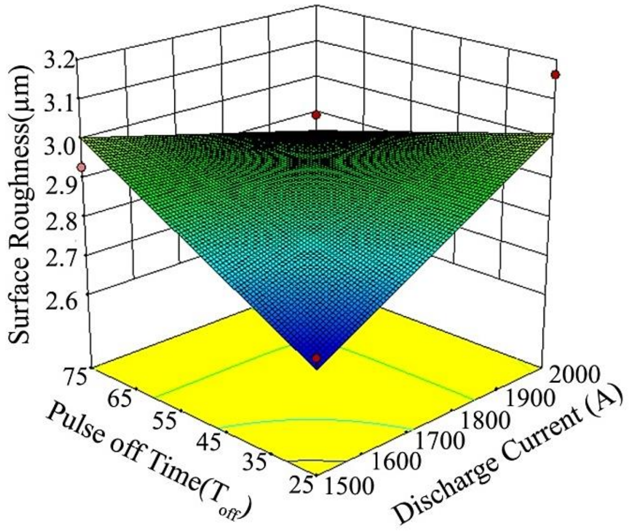


Figure.3 Estimated response Surface plot for SR

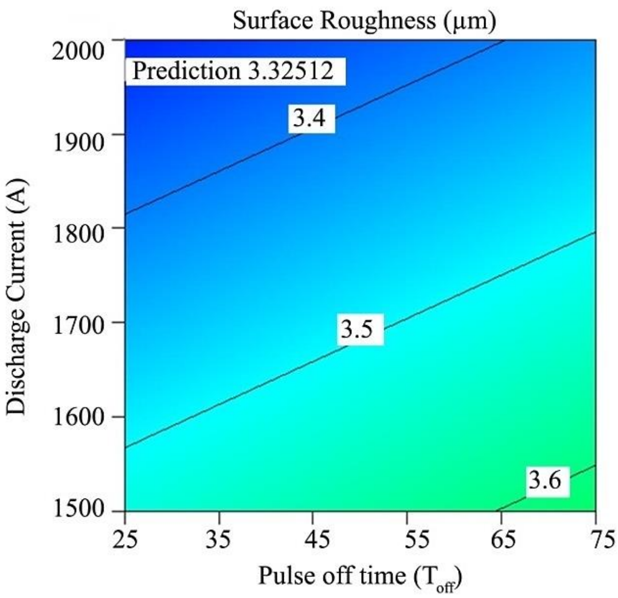


Figure.4 Estimated response Contour plot for SR

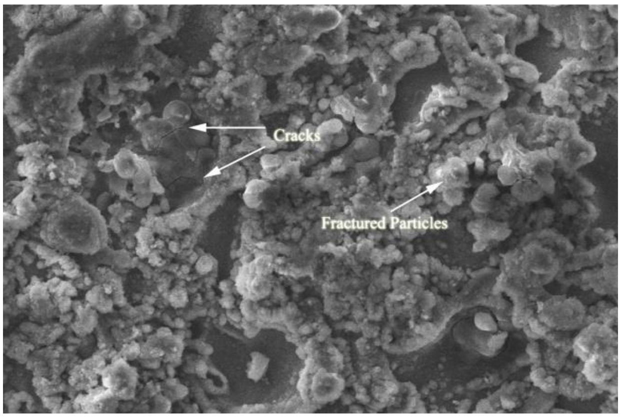


Figure.5 SEM images of WEDM workpiece surface of 30µm, 20.0KV

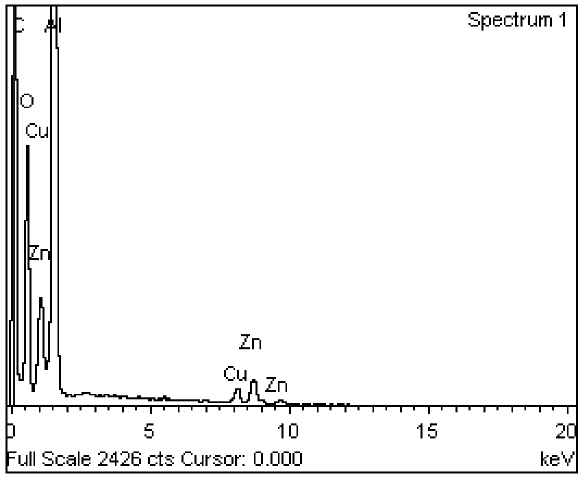


Figure.6 EDS composition analysis of WEDM of AA7075-PAC composite

It demonstrates the ordinary SEM picture acquired the holes are uniform in breadth and dispersed consistently lengthwise the surface which seems to be a result of good machining conditions with info parameters.

3.4 Composition of WEDM surface

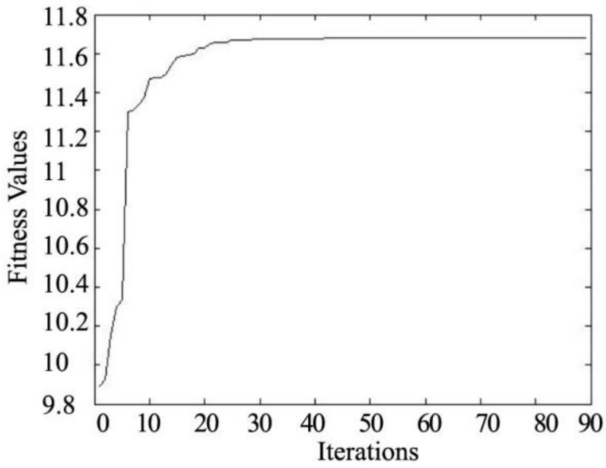
Throughout wire electrical discharge machining, it has been accounted for that materials can be exchanged among the electrodes. The same phenomenon has been accounted for in WEDM [19]. Consequently, in this review, EDS range investigation is utilized to identify the components over the workpiece surface. Over and done with EDS investigation, the residuals of Al, C, Zn, Cu, and so on could be found. The relative proportion of every synthesis appeared in Fig. 6. This confirms that Zinc and carbon are available on the machined surface which is because of the way that tungsten wire softening and solidification terminal happens amid the WEDM operation. Nearness of carbon could be clarified by the decay of dielectric liquid in the plasma channel. With this, it has been concluded that a changed layer is formed over the surface that is machined and a blend of responses happen amid WEDM of AA7075-PAC composites.

4. Particle swarm optimization

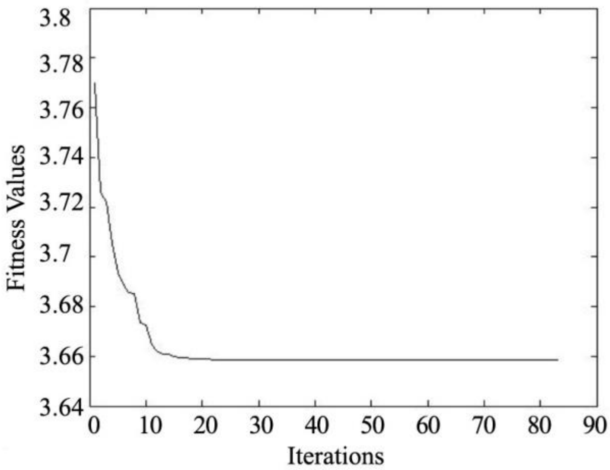
PSO is a worldwide inquiry improvement strategy that arrangements with arbitrary movement of particle swarm [20]. So imparts numerous similitudes to transformative calculation systems, for example, Genetic Algorithms (GA).

The framework is introduced with a populace of irregular arrangements and looks for optima by upgrading eras. In any case, not at all like GA, PSO has no advancement administrators, for example, hybrid and transformation. Contrasted with GA, the upsides of PSO are that PSO is anything but difficult to execute and there are couple of parameters to conform. PSO has been effectively connected in numerous territories: work streamlining, fake neural system preparing, fuzzy framework control, and different ranges where GA can be connected. Ventures for enhancing the WEDM procedure parameters are as per the following:

1. Instatement of a variety of ten particles with irregular positions and speeds. Speed vector has four measurements: Discharge current, pulse on time, and pulse off time and servo speed rate.
2. Assessment of goals (MRR and SR) capacities for every molecule.
3. On the off chance that a superior position is accomplished by a molecule, the P_{best} esteem is supplanted by the present esteem.



(a)



(b)

Figure.7 Convergence curve of PSO algorithm: (a) MRR and (b) SR

4. Assurance of the molecule which has accomplished the bestobjective. (Four information parameters)
5. Calculation of particles new speed.
6. Upgrade molecule's position bymoving toward the objectivefunction.
7. Steps 1 and 2 are rehashed until the cycle number achieves a foreordained emphasis.

In common circumstances, a large portion of the issues are multi objective;there could be various ideal arrangements expanding the MPCI esteem thatis important to decide the ideal procedure parameters.

Fig.7 (a) and Fig. 7(b)demonstrate the joining of PSO for MRR and SR to get an upgraded slant and the best target esteem accomplished amid every cycle. It depicts the proficiency of the calculations to at first investigate via the arrangement space and meet to a close ideal or pre-eminent ideal arrangement towards the end of the calculation. Calculation has been performed for a few circumstances to ensure the repeatability of the outcomes. Table 5demonstrates the enhanced and test comes about. Blunder between the test and anticipated outcomes is sensibly little, i.e., under 5 %. Comes about demonstrated that current technique involved in viable utilization for locating the close ideal execution of WEDM of metal matrix composite.

Subject to

$$1500 \leq IA \leq 2000$$
$$5 \leq Ton \leq 15$$
$$25 \leq Toff \leq 75$$
$$50 \leq SS \leq 150$$

Table.5 PSO Optimization results

Objective	**Process parameters**			
	Discharge Current (IA)	**Pulse on time (μs)**	**Pulse off time (μs)**	**Servo speed (rpm)**
Optimum Values	1566	15	25	100
	MRR (mm^3/min)	SR (μm)	-	-
Experiment	11.8451	3.9412	-	-
Predicted	11.6776	3.8216	-	-
Error %	1.148	1.0346	-	-

5. Conclusions

An optimization technique has been presented for AA7075-PAC metal matrix composite. The present approach includes two phases. Conditions are produced to predict the responses in stage 1. Arrange 2 include the enhancement of multi target machining prepare utilizing the multi objective PSO algorithms. Here, the objective work in the PSO was utilized to change over multi reaction into single reaction. Proposed technique come up with the below mentioned conclusions.

- The execution qualities are seen to have most extreme MRR and least surface roughness when the procedure parameters are discharge current (1566 Amps), pulse on time (5µs), pulse off time (25µs), and servo speed rate (50rpm).
- After discovering ideal process parameters, approval tests were led, which affirm the superb reproducibility of trial conclusions.
- PSO calculation could be a mean and effective technique for expectation and optimization of WEDM of AA7075-PAC metal matrix composite as per the process parameters.

Therefore a favourable multi objective optimizationtool for WEDMoperations for metal matrix composites has been proposed in this paper.Further research might challenge to consider the other performance criteria, such as Wire wear ratio, form accuracy and surface flatness as output parameters. This PSO technique can be tried for the other non-conventional machining processes for effective operation of machine equipment.

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