International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-10 Issue-1, October 2020

Multi- Response Optimization of Wire EDM Process Parameter on Aluminium Alloy (5086)

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Abstract*:*In the present work, the effect of process parameters on material removal rate during the machining of aluminium alloy (5086) with WEDM is studied. The four control parameter were selected i.e pulse on time (T_{ON}), pulse off time (T_{OFF}), peak current (I_P), and spark gap voltage (S_V) to investigate their effects on material removal rate (MRR). Each control parameter had three levels. Total 27 experiments were done with a zinc coated brass wire of diameter 0.25 mm. Taguchi L9 orthogonal array technique was used for the experiment. ANOVA was used to find out the significance of control parameters and their contribution on MRR. It was found that maximum material removal rate was 41.52 mm^3/min which was due to high pulse on time and low pulse off time.

***Keywords*: MRR, Process parameters, Taguchi technique, WEDM.**

I. INTRODUCTION

In today's world wire electric discharge machine (WEDM) has become an important unconventional machining process. It is being used in space technology, aircrafts, nuclear, armament and other production and engineering operations. Traditional machining is recognized with the direct contact of tool and work piece. In traditional machining, the tool material should be 30% harder than the work piece material to ensure cutting. Non-traditional machining is done with no direct contact of tool and work piece. As there is no direct contact between work piece and tool, therefore, frictional losses are absent in these processes. These processes also provide better surface finish and compatible with new alloys having greater toughness, strength, hardness and impact resistance. The complex, intricate designs and geometry of work pieces can be machined with non-traditional machining techniques such as Electrical Discharge Machining (EDM), Chemical Machining (CM), Water Jet Machining (WJM) and Electrochemical Machining (ECM) etc. Kumar et al. (2019) conducted an experiment on WEDM process with Inconel 718 by using response surface methodology (RSM) based NSGA-II. Pulse-on time (T_{ON}) and discharge current were found to be the most influential parameters for machining responses. It was found that the T_{ON} and discharge current significantly affects the MRR. It was also found that the corner deviation was almost independent of sparking factors and mostly affected by wire tension [1]. Magabe et al. (2019) Investigated wire-EDM for Ni55.8Ti shape memory alloy and concluded that higher values of S_V, T_{ON}, and W_F resulted in higher MRR [2]. Pramanik et al. (2018) studied the cutting parameters affecting material removal rate of Al 6061 t6 alloy. It was observed that the MRR is significantly affected by the T_{ON}, T_{OFF}, W_F and S_V [3]. Joshi and Chapgaon (2017) selected CNC Wire cut EDM Machine Electronica - Maxicut 734 for experiments with AISI M42 HSS material as work material and brass wire of 0.25mm diameter as wire electrode. Taguchi L18 orthogonal array with GRA were applied for experimentation and optimization. They concluded that the most prominent factors for MRR are T_{ON} followed by T_{OFF} [4]. Takale and Chougule (2017) used Electronica WEDM to investigate the significant effects of process parameters on MRR. They used T149.4Ni50.6 shape memory alloy as work material and zinc coated brass wire as wire electrode for experimentation. They used Taguchi, L18 orthogonal array with ANOVA for the investigation. They concluded that T_{ON} was most significant factor for MRR followed by T_{OFF} [5]. Goswami and Kumar (2017) performed experiments for trim cut operations on Electronica Sprintcut (Electra- Elplus 40A DLX) CNC wire electrical discharge machine with Nimonic 80A alloy as work piece and brass wire electrode of dia. 0.25 mm (soft) to determine the effects of process parameters on performance parameters. They choose GRA for analysis and optimization. They found that during trim cut machining T_{ON} was most important parameter for MRR [6]. Garg et al. (2016) described the comparison between diffused and brass wire by using input parameters such as T_{ON}, T_{OFF} and S_V. For experimentation, they used Stainless steel grade-SS304 as a workpiece and two wires were taken one was brass and another was diffused brass wire with 0.25mm diameter each on electronica sprintcut WEDM. They used taguchi L9 orthogonal array for the experimentation, and ANOVA for analysis the results. After analysis of experimental results found that the MRR of diffused brass wire was more as compare to brass wire. MRR increased with increase of T_{ON}, and MRR decreased with increase of T_{OFF} and S_V [7]. Kumar et al. (2015) studied the effect of process parameter like as T_{ON}, T_{OFF}, peak current (I_P), and S_V on MRR. For experimentation, they used Monal K-500 as a workpiece on Ultima-IF Wire-cut-EDM. By using Taguchi technique,

Revised Manuscript Received on September 26, 2020.
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L27 orthogonal array was selected for the experiment. The Gray relational analysis (GRA) technique was used for optimization and analysis the experimental results and it was found that T_{ON}, T_{OFF}, I_P, and S_V were most significant parameters for MRR. The optimum value of process parameters was found such as T_{ON} -123µs, T_{OFF} -50µs, I_P -13A, S_V -30V [8].

Aggarwal et al. (2015) described the effect of process parameters such as T_{ON}, T_{OFF}, I_P, S_V, wire feed (W_F) and wire tension (W_T) on MRR. For experimental work, they used zinc coated brass wire 0.25 mm diameter and Inconel 718 as a workpiece material on Electra sprintcut CNC WEDM. Response surface methodology (RSM) technique was chosen for experiments design, and ANOVA for analysis the experimental results and after analyzing the results, it was found that T_{ON} was the highly affected parameter on MRR [9]. Sivaraman et al. (2015) performed experiments with titanium material as a work piece using Taguchi method was used to find out the effect of process parameters like as dielectric pressure, T_{ON}, T_{OFF}, and W_T on MRR. ANOVA design approach was used for the optimization and analysis of the experimental results. They observed that Taguchi was the most suitable technique for optimization in WEDM [10]. Kubade et al. (2015) investigated the effect on MRR by using process parameters like as T_{ON}, T_{OFF}, and W_F. For experimentation, they used Titanium Diboride (TiB2) as a workpiece. L27 orthogonal array was used for the experimentation and AVOVA for optimization. It was found that the T_{ON} and T_{OFF} were the highly effected parameters on MRR. For maximum MRR, optimum setting of parameters as like T_{ON}-118 µs, T_{OFF}-48 µs and WF-8 mm/min [11].

This experimental work is focuses over the process parameters optimization of machining Aluminum alloy (5086) by using wire EDM and their effect on MRR. Taguchi L9 orthogonal array technique is used for experimental design and analysis of variance (ANOVA) is used to find out the optimum process parameters as well as the most significant parameters on MRR.

II. DESIGN OF EXPERIMENT

The experiments were performed by using Wire EDM CNC machine (Electronica sprintcut WEDM) manufactured by Electronica India Limited, Pune. It uses zinc coated soft brass wire having diameter 0.25 mm as a tool electrode and distilled water as a dielectric fluid for experimentation. In the present research work the material used for experimentation is Aluminium alloy (5086). The chemical composition, physical properties of the workpiece material (Aluminium alloy 5086) are shown in the Table 1 and Table 2.

Table- I: Chemical Composition of Aluminium alloy (5086)

Element	Al	Mg	Cu	Mn	Fe	Si	Zn	Ti	Cr	Pb
Wt. (%)	94.55	4.02	0.056	0.49	0.42	0.28	0.086	0.003	0.09	0.002

Table- II: Physical properties of Aluminium alloy (5086)

Property	Density	Thermal conductivity	Electrical conductivity	Melting point
Aluminium	2.675 g/cm^3	127 W/mK	3.4×10^7 S/m	588°C

III. EXPERIMENTAL PROCEDURE

The dimensions of the workpiece used for the experiment on the WEDM was 250 mm x 25 mm x 20 mm. A total of 27 experiments have been conducted. The experiment were carried out to prepare of 27 rectangular punches of size 20mm x 10mm as shown in figure 1. Taguchi L9 orthogonal array technique is used for the experiment. The four control parameters, i.e., T_{ON}, T_{OFF}, I_P, and S_V were chosen for MRR during the machining of Aluminium alloy (5086). The experiments were performed as suggested by Taguchi technique. The whole arrangement of sequence of experiments including their inherited process parameters with different levels. In performing experiments, total 27 experiments were performed with three level of each control parameter. The control parameters and their levels are shown in the table 3. After experimentation MRR was calculated by mathematical formulation:

$$MRR= V_C \times M_t \times W_d \quad (1)$$

Table- III: Control parameters and their levels

S. No.	Process parameter	Level 1	Level 2	Level 3
1	T_{ON}	116	120	124
2	T_{OFF}	54	58	62
3	I_P	210	220	230
4	S_V	16	18	20

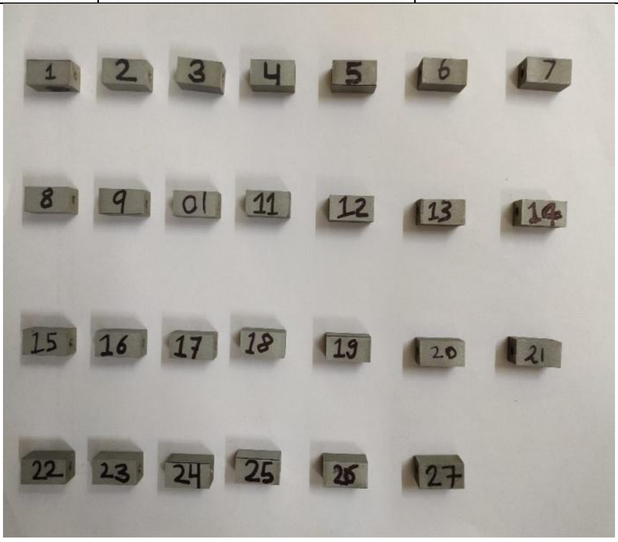

Figure 1 Photograph of machined parts

IV. RESULT AND DISCUSSION

Taguchi method is used for designing and conducting various experiments. MRR is influenced by individual process parameter. Table 4 shows the experimental values of various parameters and analyzed data associated with them i.e. S/N ratio and Means.

Retrieval Number: 100.1/ijeat.A17921010120
DOI:10.35940/ijeat.A1792.1010120
Journal Website: www.ijeat.org

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The parametric effect of process parameters is shown by plotting S/N ratio and Mean value. Also the response characteristics are examined by plotting response curve.

The values of process parameters are determined through ANOVA table and response curve. Analysis of experimental results is done by using MINITAB with Taguchi through S/N ratio and Mean values.

A. S/N ratio for MRR

$$\text{S/N ratio} = -10 \log_{10} (\text{sum } (1/y^2) / N) \quad (2)$$

Table- IV: Analytical result of MRR

Ex. No.	T_{ON}	T_{OFF}	I_p	S_V	MRR	S/N ratio	Mean
1	116	54	210	16	24.666	27.842	24.666
2	116	58	220	18	19.943	25.996	19.943
3	116	62	230	20	16.417	24.306	16.417
4	120	54	220	20	31.211	29.886	31.211
5	120	58	230	16	27.707	28.852	27.707
6	120	62	210	18	23.522	27.43	23.522
7	124	54	230	18	41.538	32.369	41.538
8	124	58	210	20	33.634	30.536	33.634
9	124	62	220	16	31.013	29.831	31.013

Table- V: Response table of S/N ratio for MRR (Larger is better)

Level	T_{ON}	T_{OFF}	I_p	S_V
1	26.05	30.03	28.6	28.84
2	28.72	28.46	28.57	28.6
3	30.91	27.19	28.51	28.24
Delta	4.86	2.84	0.09	0.6
Rank	1	2	4	3

Table- VI: Response table of Means for MRR (Larger is better)

Level	T_{ON}	T_{OFF}	I_p	S_V
1	20.34	32.47	27.27	27.80
2	27.48	27.09	27.39	28.33
3	35.39	23.65	28.55	27.09
Delta	15.05	8.82	1.28	1.25
Rank	1	2	3	4

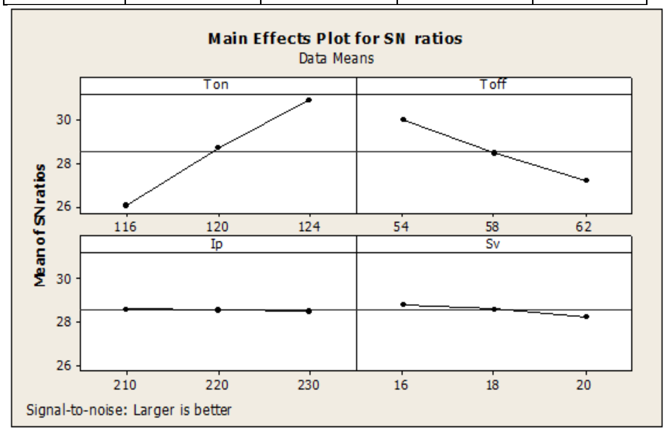

Figure 2 Effect on process parameters on MRR (S/N ratio)

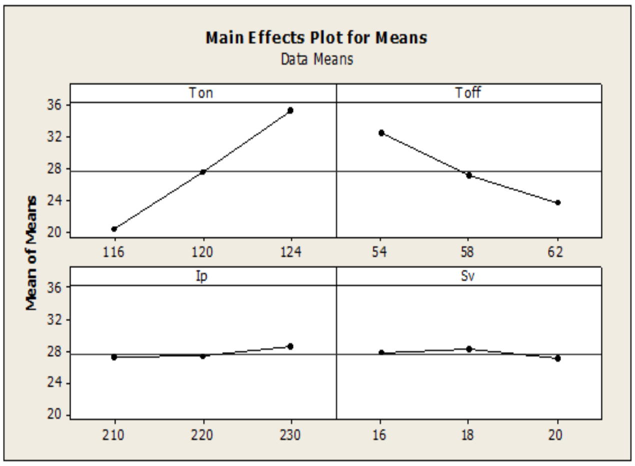

Figure 3 Effect on process parameters on MRR (Means)

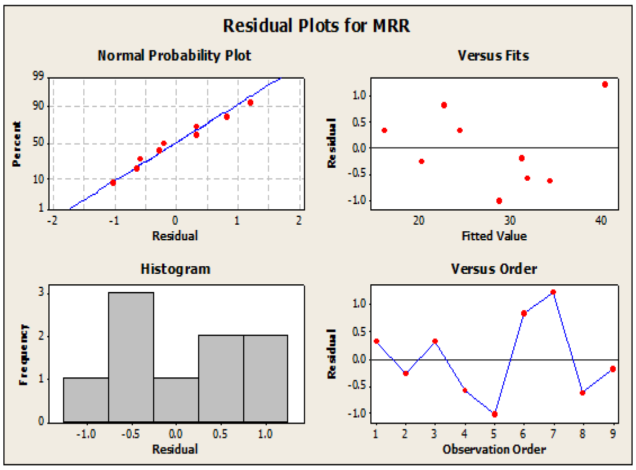

Figure 4 Residual plots for MRR

B. Effects of process parameters on MRR

The value of MRR is found to be increased by increasing the level of T_{ON} and I_P. It is also found that the MRR decreased with increase in T_{OFF} .MRR is first increased and then decreased with increase of S_V (from figure 3). The higher order, non-random variation in relationship non-normality, and non-constant variation have been evaluated in residual plots as shown in Figure 4. Residual plots shows that in case of normal probability plot, residual trace an approximate straight line in the plot between residual and fitted value, residual is found to be constant around zero. The significance of different process parameters is determined through the values of delta and Rank (shown in table 6). T_{ON} and T_{OFF} were found to be the most significant factor w.r.t. to the value of rank and delta on MRR. The higher order, non-random variation in relationship non-normality, and non-constant variation have been evaluated in residual plots as shown in Figure 4. Residual plots shows that in case of normal probability plot, residual trace an approximate straight line in the plot between residual and fitted value, residual is found to be constant around zero.

C. Regression analysis for MRR

Regression equation is established between process parameters and responses. For the calculation of predicted value of MRR the following equation was used.

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$MRR = -145 + 1.88T_{ON} - 1.10T_{OFF} + 0.0640I_P - 0.177S_V$ (3)

The predicted values is obtained using regression equation are tabulated along with experimental results (experimental values) to differentiate the experimental and predicted values of MRR, Table 7 shows the experimental and predicted values of MRR.The comparison of predicted value and the experimental values in the form of response curve is shown in figure 5 and from the response curve it is observed that the experimental values are very close to the predicted values.

Table- VII: Experimental and predicted values of MRR

Ex. No.	1	2	3	4	5	6	7	8	9
Predicted	24.288	20.174	16.06	31.74	28.688	22.654	40.254	34.22	31.168
Experimental	24.666	19.943	16.417	31.211	27.707	23.522	41.538	33.634	31.013

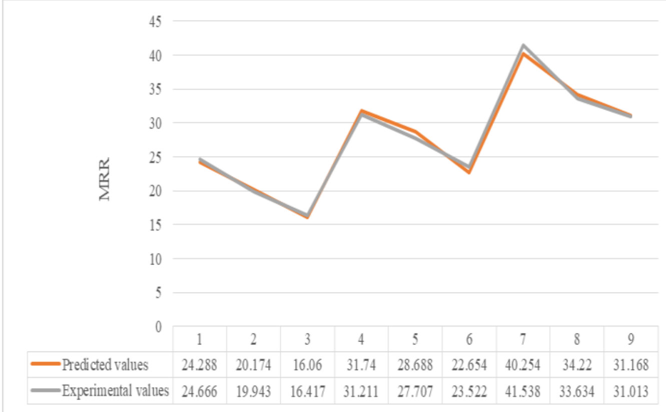

Figure 5 Comparison between predicted and experimental values

D. TWO WAY ANOVA RESULTS

To analyze the effect of parameter Two-way ANOVA method was used. The value of F is calculated in two-way ANOVA. The T_{ON} has maximum value of F according to rank/delta (shown in table 10), therefore T_{ON} has more effect on MRR of Aluminium alloy (5086) during machining on WEDM as followed by T_{OFF}. According to table 8, 9 and 10, T_{ON} and T_{OFF} has maximum and I_P, S_V has minimum effect on MRR.

Table- VIII: Two way ANOVA for MRR V/s T_{ON} and I_P

Source	DF	SS	MS	F	P
T_{ON}	2	340.191	170.096	5.63	0.069
I_P	2	3.009	1.504	0.05	0.952
Error	4	120.93	30.233		
Total	8	464.13			

Table- IX: Two way ANOVA for MRR V/s T_{ON} and S_V

Source	DF	SS	MS	F	P
T_{ON}	2	340.191	170.096	5.60	0.069
S_V	2	2.347	1.173	0.04	0.962
Error	4	121.592	30.398		
Total	8	464.130			

Table- X: Two way ANOVA for T_{ON} and T_{OFF}

Source	DF	SS	MS	F	P
T_{ON}	2	340.191	170.096	127.04	0
T_{OFF}	2	118.583	59.292	44.28	0.002
Error	4	5.356	1.339		
Total	8	464.13			

The tabulated data represents the percentage contribution of different factors in machining operation. The analysis is done through ANOVA by using mean values of MRR

Table- XI: ANOVA table of S/N data showing percentage contribution

Factor	SS	DF	Variance	F Ratio	% Contribution
T_{ON}	35.60402007	2	17.80201	1.00216E+15	73.65957956
T_{OFF}	12.1737952	2	6.0868976	3.42662E+14	25.18582548
I_P	0.013579845	2	0.0067899	3.82239E+11	0.02809474
S_V	0.544504011	2	0.272252	1.53264E+13	1.126500221
Error	3.55271	2	1.776E-14		7.35005E-14
Total	48.33589912	10			

E. SELECTION OF OPTIMUM LEVEL OF PARAMETERS FOR MRR

Optimum process parameters have been selected by using response table 6. ANOVA is used to investigate the optimum process parameters for MRR. Average of every response characteristics is shown in table 5 and 6, for every level of every factor. Delta statics is included in the table on the basis of rank for comparison of the relative effects and magnitude. Delta and rank is assigned by MINTAB. The highest value of Delta, Rank should be 1, for second highest value of Delta; Rank should be 2 and so on. These ranks indicate the relative significance of each factor to the response (MRR). According to rank and delta values, MRR has most influenced by T_{ON}, T_{OFF}, S_V and I_P. As MRR is characterized by the "larger is better" type quality characteristics, it can be seen from figure 3, that the first level of T_{OFF} and second level of S_V and third level of T_{ON} and I_P should be taken to achieve the maximum value of MRR. The optimum value of MRR is found at the optimum process parameters that are $T_{OFF}1$, $T_{ON}3$, I_P3, and S_V2. The optimum value of MRR in mathematical term, determined as:

$MRR_{opt} = \{(T_{on}3 + T_{off}1 + I_P3 + S_V2) - 3(\mu)\}$

Retrieval Number: 100.1/ijeat.A17921010120
DOI:10.35940/ijeat.A1792.1010120
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= {(35.39 + 32.47 + 28.55 + 28.33) - 3(27.739)}
= {(124.74) – (83.217)}
MRR_{opt} **= 41.523 mm³/min**
Where,
μ = overall mean of MRR = (ΣMRR MEAN1)/9 = 27.739
The 95 % confidence intervals of confirmation experiments (CICE) are calculated as:

$$CI_{CE} = \sqrt{\left[f\alpha(1, fe)\left\{\frac{1}{\eta eff} + \frac{1}{r}\right\} Ve\right]}$$

$$CI_{CE} = \sqrt{\left[7.71\left\{\frac{1}{1.8} + \frac{1}{1}\right\} 1.08\right]}$$

CI_{CE} = 3.6
Where, *f* is found from the ANNOVA table
η_{eff} =9/(1 + total DOF)
=9 / (1+4) = 1.8
Where, N = Total number of experiments = 9
Ve = Error of Adj MS = 1.08
r = Sample size for confirmation experiment =1
fe = Error DOF = 4
F0.05 (1, 4) = 7.71 (value from F table)
So, the confidence interval is **37.923≤ μ_{MRR} ≤ 45.123.**
The 95% confidence interval (CICE) for MRR is
37.923≤ μ_{MRR} ≤ 45.123mm³/min.

Table- XII: Optimum values of MRR at optimum levels of parameters with CICE

Performance parameters	**Optimum level of process parameters**	**Optimum value**	**CICE**
MRR (mm³/min)	$T_{ON}3$, $T_{OFF}1$, I_P3, S_V2	41.523 mm³/min	37.923≤ μ_{MRR} ≤ 45.123

V. CONCLUSION

The following conclusions can be made from the present study:

- The value of MRR is found to be increased by increasing the level of T_{ON} and I_P. It is also found that the MRR decreased with increase in T_{OFF} .MRR is first increased and then decreased with increase in S_V.
- T_{ON} and T_{OFF} are the most significant process parameter while I_P and S_V are less significant for MRR. It is found that Ton has maximum contribution (73.65%) followed by T_{OFF} (35.18%), Sv (1.12%) and I_P (0.03%) in WEDM operation.
- The optimum setting of process parameter for maximum MRR is T_{ON} -124 µs, T_{OFF} -54 µs, I_P -230 A and S_V -18 V, during machining of aluminum alloy (5086) on WEDM.
- The optimum value of MRR is 41.52mm³/min at optimum setting of process parameter. The 95 % confidence interval (CICE) for MRR is 37.923≤ μ_{MRR} ≤ 45.123mm³/min.

NOMENCLATURE

T_{ON}	Spark on time (µs)
T_{OFF}	Spark off time (µs)
S_V	Servo voltage (V)
W_f	Wire feed rate(mm/min)
I_P	Input current (A)
V_C	Cutting speed (mm/min)
M_t	Thickness of the workpiece (mm)
W_d	Diameter of the wire
n	Total number of experiments
y	Mean value
CS	Cutting speed (mm/min)
MRR	Material removal rate (mm/min)
WEDM	Wire electrical discharge machining
SS	Sum of squares of the factors
MS	Mean of squares of the factors
DF	Degree of freedom

REFERENCES

1. A. Kumar, K. Vivekananda, and K. Abhishek. (2019). Experimental investigation and optimization of process parameter for Inconel 718 using wire electrical discharge machining (WEDM). Journal of Advanced Manufacturing Systems.doi:10.1142/s0219686719500185.
2. R. Magabe, N. Sharma,K. Gupta, and J. P. Davim. (2019). Modeling and optimization of Wire-EDM parameters for machining of Ni55.8Ti shape memory alloy using hybrid approach of Taguchi and NSGA-II. The International Journal of Advanced Manufacturing Technology. doi:10.1007/s00170-019-03287-z.
3. D. Pramanik, A. S. Kuar, and D. Bose. (2018). Effects of wire EDM machining variables on material removal rate and surface roughness of Al 6061 alloy. Renewable Energy and its Innovative Technologies. Doi:10.1007/978-981-13-2116-0_19.
4. G. R. Joshi and A. N. Chapgaon. (2017). Multi-response optimization of AISI M42 HSS material in wire-cut EDM using grey relational analysis. International Journal of Advanced Research in Engineering and Applied Sciences. 6(8), 1 – 14.
5. A. M. Takale,N. K. Chougule,R. L. Patil, and A. S. Awate. (2017). Analysis and optimization of wire electro discharge machining parameters of TiNi shape memory alloy using Taguchi technique. International Conference on Advances in Thermal Systems, Materials and Design Engineering, 2017.
6. A. Goswami and J. Kumar. (2017). Trim cut machining and surface integrity analysis of Nimonic 80A alloy using wire cut EDM. Engineering Science and Technology: An International Journal. 20(1), 175–186.
7. S. Garg,S. Kumar and G. Chawla. (2016) Experimental investigation of effect of process parameters on material removal rate during WEDM. International Journal of Current Engineering and Technology, 6(1) 40-45.
8. A. Kumar,V. Gulati and A. Goswami. (2015). Optimization of process parameter in WEDM for Monel K-500 using Taguchi method and grey relational analysis. International Journal of Research in Aeronautical and Mechanical Engineering. 3(4), 53-68.
9. V. Aggarwal, R. K. Garg and S. S. Khangura. (2015). Parametric modeling and optimization for wire electrical discharge machining of Inconel 718 using response surface. International Journal of Advanced Manufacturing Technology. 79(1-4), 31–47.
10. B. Sivaraman,C. Eswaramoorthy and E. Shanmugham. (2015). Optimal control parameters of machining in CNC Wire-Cut EDM for Titanium. International Journal of Applied Sciences and Engineering Researches. 4(1), 102-121.
11. P. Kubade, S. Jamadade, R. Bhedasgaonkar, R. Attar, N. Solapure, U. Vanarse and S. Patil. (2015). Parametric study and optimization of WEDM parameters for Titanium diboride TiB2. International Journal of Engineering and Technology. 2(4) 1657-1661.

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Retrieval Number: 100.1/ijeat.A17921010120
DOI:10.35940/ijeat.A1792.1010120
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