Prediction of Wire-EDM Machining Parameters for Optimum of Surface Finish and MRR in an Aluminum Alloy 7075-T6

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Abstract

Wire-cut EDM is a process that works by continuously feeding a wire electrode under tension on a vertical axis. A discharge voltage is applied through the wire, crosses via a dielectric liquid, and strikes the grounded work-piece. The work-piece is moved in an X-Y plane to trace a cut pattern through the material. The process is applicable to cut complex and elaborate shapes of workings in all conductive, hard and thicker materials. An appropriate modeling can advance the machining presentation and the product exactness. Surface Response Methodology (RSM) coupled with grey relation analysis method has been proposed to predict the performance characteristics namely the surface roughness and material removal rate of WEDM on the alloy AL7075-T6 work-piece material. Selected input parameters such as pulse on time, pulse off time, wire feed, wire tension and dielectric pressure. ANOVA is applied to determine significance of the input parameters for optimizing the process.

Keywords

Wire-cut EDM, RSM, grey relation analysis, ANOVA, WEDM

1. Introduction

Wire EDM is used for the direct, single-stage processing of hard materials from basic billet form to a finished state. Its single-stage nature reduces costs and improves toolmaking precision for a range of industries, including: extruder, punch, and die tooling, aerospace, medical equipment, automotive, and electronics.

This benefit arises from the process' ability to directly work with pre-hardened tool steels. The hardening process can introduce serious internal stresses and distortion/inaccuracy in machined parts. The ability to cut pre-hardened materials removes this issue almost entirely. The wire used in an EDM machine comes in various grades and purposes. Among the choices are: copper, brass, tungsten, molybdenum, coated (zinc-coated and diffusion-annealed), and steel-core wires. The wire acts as the EDM device's cutting tool. Each type of wire affects the machining process in different ways.

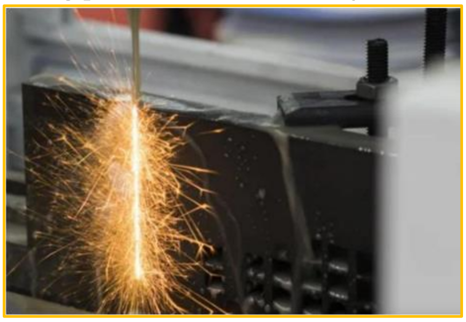

Fig.1.1: Wire-cut EDM Process

Machining a part using the process involves submerging the workpiece into a dielectric fluid, securing it with a machinist vise, and running the wire through it to produce sparks as it passes an electric current.

In other words, the wire carries one side of the charge, and the workpiece, which must be a conductive material, carries the other side of the charge. When the two get close, a hot electric charge jumps the gap and melts tiny pieces of the metal away.

The electric spark is the cutting tool to cut the material in the desired shape. Additionally, the wire EDM process involves deionized water to control the process and flush away tiny particles removed.

Selecting the appropriate machining parameter for high quality product is very difficult. Much research is not found in the field of WEDM to find the optimum parameter; In the present research, GRA is used to find the response variables of WEDM.

2.Literature Review

S.Suresh et. al., the study on impact of WEDM parameters on Ra and MRR in metal matrix nanocomposites of Al7075/nano-SiC. The experiments were conducted by means of L9 orthogonal array and out comes were analysed using response graph's[1]., Sener Karabulut et. al., WEDM behaviours of Al 7075-T6 were investigated and influence of input parameters were evaluated with the output response surface roughness. L27 OA implemented for design and ANOVA were used to evaluate input parameters on Ra [2]., D.Vijay Praveen et. al., focussing on influence of wire-cut EDM process parameters on MRR and Ra of Ni-P-coated and un-coated alumina-reinforced composite materials. Taguchi's L18 OA was adopted to conduct experiments. The effect of machining performance was analysed using ANOVA to identify the significance of the result [3]., Daniel M. Madyira, reports on influence of WEDM on the fracture toughness of aluminum 7075-T6511. The fracture toughness was found to be significantly dependent on the effect of the WEDM on the material [5], Vaibhavkumar Patel & et. al., the paper reviews the various works in field of WEDM and magnifies on effect to machining parameters on MRR, kerf width and surface roughness [7], Ashutosh Kumar Singh & et. al., the paper work deals with the machining of Al 7075 with brass electrode using EDM process. L27 set of runs are performed with four input like peak current, voltage gap, pulse on time and flushing pressure and MRR is estimated. The results shows that MRR is essentially impacted by peak current, voltage gap and pulse on time. Whereas the effect flushing pressure on MRR is insignificant [9], K. Raju & et. al., Al7075 metal matrix with silicon nitride was machined to study the significant process parameters. Taguchi L9 OA was selected with three factors current, pulse on time and wire feed and influencing factors are identified using ANOVA for better MRR and good surface finish [11], Veeresh Murthy & et. al., machining of Al7075-T651 during WEDM with brass as wire electrode to study the operational behaviour on MRR and Ra. Taguchi technique was used to optimize the process parameters and ANOVA method is used to analyse the effect of each parameter on the response MRR and Ra [13].

3. Material and Working method

Taguchi orthogonal array of technique was utilised to design experiments with various input parameters varied during the process are Pulse on time (Ton), Pulse off time (Toff), Wire feed (WF), Wire tension (WT) and dielectric pressure (P). The effect of these input parameters is studied on Surface roughness (Ra) and Material Removal Rate (MRR). The main objectives of present study are

- To estimate percentage contribution of input parameters on the output responses Ra and MRR.
- To Predict the input parameters at optimum levels of Ra and MRR.
- To optimize the responses Ra and MRR by setting predict values to input parameters.

Taguchi method

L12 orthogonal Array of matrix (5factor, 2level array) was used for design and conduct experiments shown in Table 3.1 and 3,2.

S.no.	**Independent Variables**	**Notation**	**Units**	**Levels**	
				1	**2**
1	Pulse on-time	T_{on}	µs	2	7
2	Pulse off-time	T_{off}	µs	4	8
3	Wire feed	WF	Mm/min	3	6
4	Wire tension	WT	N	2	9
5	Dielectric pressure	P	Kg/cm^2	3	5

Table 3.1: Selected factors and their levels for machining of AL7075-T6

Ex.	A	B	C	D	E	T on	T off	W F	W T		P
1	1	1	1	1	1	2	4	3	2		3
2	1	1	1	1	1	2	4	3	2		3
3	1	1	2	2	2	2	4	6	9		5
4	1	2	1	2	2	2	8	3	9		5
5	1	2	2	1	2	2	8	6	2		5
6	1	2	2	2	1	2	8	6	9		3
7	2	1	2	2	1	7	4	6	9		3
8	2	1	2	1	2	7	4	6	2		5
9	2	1	1	2	2	7	4	3	9		5
10	2	2	2	1	1	7	8	6	2		3
11	2	2	1	2	1	7	8	3	9		3
12	2	2	1	1	2	7	8	3	2		5

Table 3.2: Assigning selected factors to Orthogonal Array of matrix

Selection of Material

Work-piece material used for experimentation is Aluminium alloy AL7075-T6. The dimensions of sample is 135x40x10mm.

Experimental setup

Excetek EX400 Series Submerged Type CNC wire-cut EDM was used for conduct experiments. The WEDM machine tool has the following specifications:

- X/Y travel : 400x300mm
- Z travel : 220mm
- U/V travel : 80x80mm
- Wire dia. : 0.15 to 0.3mm
- Taper angle up to +/-22deg./80mm

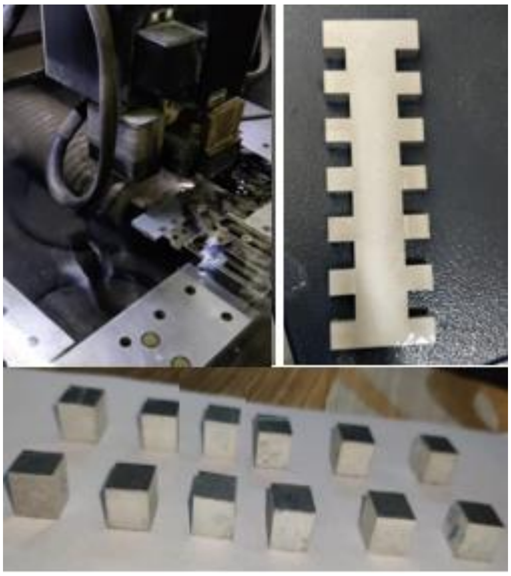

Fig.3.1: Wire-EDM Machining operation and work-piece

A 0.25mm dia. Milscut brass wire by MANAN Associates was used as cutting electrode and Ra is measured using Mitotoyo SJ-210 Surface Profilometer.

Fig.3.2: Ra measurement setup

4. Data Analysis

The objective of Response Surface Methods (RSM) is optimization, finding the best set of factor levels to achieve some goal. It is useful for analysing problems in which several independent variables influence a response, and the goal is to optimize this response. The application of RSM is in various fields and industries, primarily agricultural, pharmaceutical, and electronic fields. However, the main objective of RSM is to optimize the response.

In many experimental conditions, the independent variables x_1, x_2,x_3…x_k in RSM, and the assumption is that response is a function of a set of independent variables. While the function can be represented in some regions of the polynomial model.

$y = f(x_i)$

$y = f(x_1, x_2, x_3 \ldots x_k)$

y is the response or dependent variable and k independent variable.

If the factors are known, directly estimate the effects and also the interactions. Otherwise, use a screening method to calculate the unknown factors.

Estimate the interaction effect using the 1st order model

$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$

ε-Error

$\beta_0, \beta_1, \beta_2$ are the constants

If the curvature exists, then use RSM. Use 2nd order model to approximate the response variable.

$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \varepsilon$

Finally, plot the graph and identify the stationary point. Maximum, minimum response or saddle point, which is the sudden drastic change between minimum to the maximum from the values $X_1, X_2, X_3\ldots$

Ex.	**Ton**	**Toff**	**WF**	**WT**	**P**	**Ra (μm)**	**MRR (mm³/min)**
1	2	4	3	2	3	2.979	15750
2	2	4	3	2	3	3.13	10900
3	2	4	6	9	5	3.179	9240
4	2	8	3	9	5	3.047	91650
5	2	8	6	2	5	2.897	82950
6	2	8	6	9	3	1.595	13530
7	7	4	6	9	3	3.296	15600
8	7	4	6	2	5	3.343	18600
9	7	4	3	9	5	3.05	14400
10	7	8	6	2	3	2.958	12780
11	7	8	3	9	3	3.626	10350
12	7	8	3	2	5	3.032	12760

Table 4.1: Result data in tabular form

A. Regression analysis

The experimental results were used to develop a mathematical model, for expressing the relation between process parameters and responses. The coefficients of mathematical models are computed using method of multiple regressions.

Ra(μm) = 2.19 + 0.0917 Ton(μs) + 0.0647 Toff(μs) - 0.045 Wf(mm/min) - 0.0130 WT(N) + 0.081 P(kg/cm2)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.92956	0.18591	0.65	0.673
Linear	5	0.92956	0.18591	0.65	0.673
Ton(μs)	1	0.54096	0.54096	1.89	0.218
Toff(μs)	1	0.17205	0.17205	0.60	0.467
Wf(mm/min)	1	0.03699	0.03699	0.13	0.731
WT(N)	1	0.02503	0.02503	0.09	0.777
P(kg/cm2)	1	0.07776	0.07776	0.27	0.620
Error	6	1.71331	0.28555		
Lack-of-Fit	5	1.70191	0.34038	29.86	0.138
Pure Error	1	0.01140	0.01140		
Total	11	2.64287			

Table 4.2: ANOVA for Surface Roughness (Ra)

MRR(mm3/min) = 59030 - 3659 Ton(μs) - 7054 Toff(μs) - 4977 Wf(mm/min) + 27 WT(N) + 12550 P(kg/cm2)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	5580815372	1116163074	1.84	0.239
Linear	5	5580815372	1116163074	1.84	0.239
Ton(μs)	1	860466134	860466134	1.42	0.278
Toff(μs)	1	2047401334	2047401334	3.38	0.116
Wf(mm/min)	1	445909339	445909339	0.74	0.424
WT(N)	1	104533	104533	0.00	0.990
P(kg/cm2)	1	1890030000	1890030000	3.12	0.128
Error	6	3635672394	605945399		
Lack-of-Fit	5	3623911144	724782229	61.62	0.096
Pure Error	1	11761250	11761250		
Total	11	9216487767			

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Table 4.3: ANOVA for Material Removal Rate (MRR)

B. Main effect plots

main effects plots are drawn showing the effect of various input parameters on Ra and MRR.

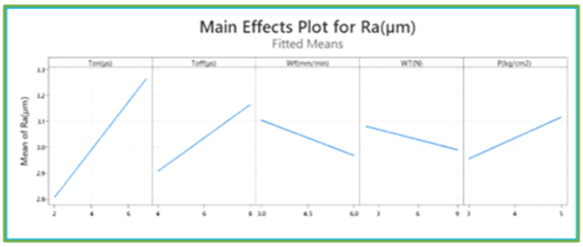

Fig.4.1: Main Effects Plot for Ra.

Ra is minimum at lower levels of Ton, Toff, Flushing pressure and higher levels of wire feed, wire tension.

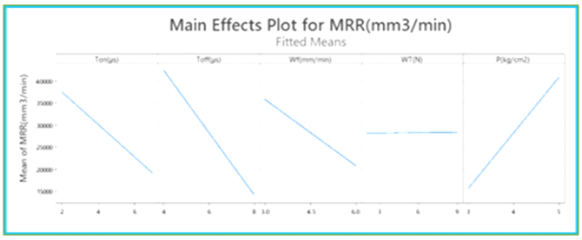

Fig.4.2: Main Effects Plot for MRR

MRR is maximum at lower levels of Ton, Toff, wire feed and higher levels of flushing pressure.

C. Surface plots

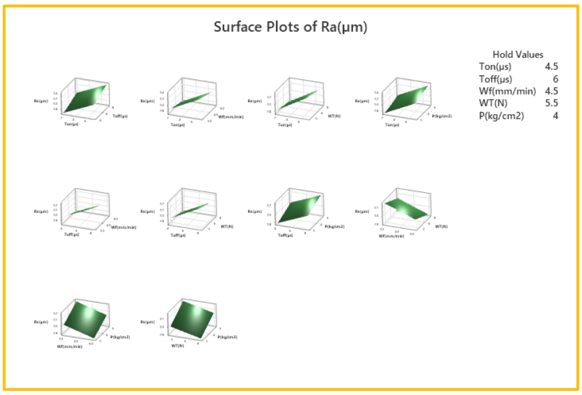

Fig.4.3: Surface Pots of Ra

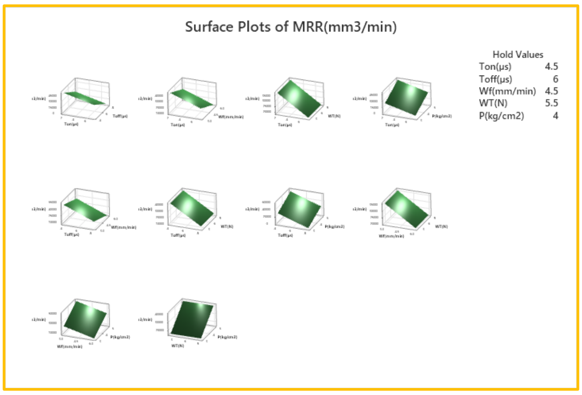

Fig.4.4: Surface Plots of MRR

D. Optimization using desirability approach

Optimization of Ra

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Ra(µm)	Minimum		1.593	3.626	1	1

Solution

Solution	Ton	Toff	Wf	WT	P	Ra Fit	Composite Desirability
1	2	4	6	9	3	2.48067	0.563371

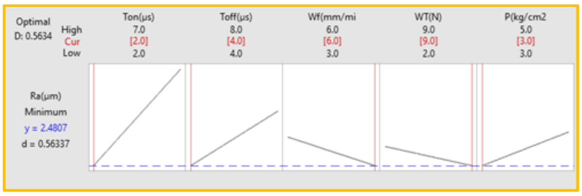

Fig.4.5: Optimization of Ra

Optimization of MRR

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
MRR(mm3/min)	Maximum	9240	91650		1	1

Solution

Solution	Ton	Toff	Wf	WT	P	MRR Fit	Composite Desirability
1	2	4	3	9	5	71554.4	0.756151

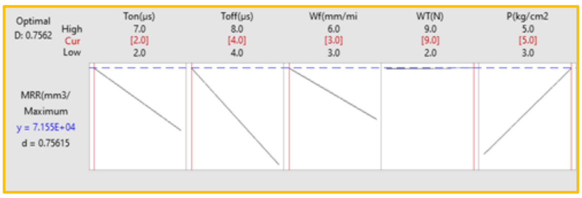

Fig.4.6: Optimization of MRR

The above graph shows optimization plots for Ra and MRR. The ultimate objective for our work was to minimize the surface roughness and to maximize the MRR. Predict values of the variables are obtained by desirability approach in order to get the optimum value Ra and MRR.

5. Conclusions

In this study an attempt was made to minimize the Ra and maximize the MRR in wire EDM of Al 7075-T6 alloy with Ton, Toff, Wire feed, Wire tension and Flushing pressure as input parameters. Taguchi OA and RSM approach was employed for designing as well as for finding out the optimal solutions.

- Effect Percentage contribution of input parameters on Ra is of 20.47% Ton, 6.51% Toff, 1.39% wire feed, 0.95% wire tension and 3.16% flushing pressure.
- Effect Percentage contribution of input parameters on MRR is of 9.34% Ton, 22.22% Toff, 4.8% wire feed, 0.0% wire tension and 20.51% flushing pressure.
- The predict values of input parameters for minimum of Ra are Ton=2.0, Toff=4.0, Wire feed=6.0, wire tension=9.0 and flushing pressure=3.0
- The predict values of input parameters for maximum of MRR are Ton=2.0, Toff=4.0, Wire feed=3.0, wire tension=9.0 and flushing pressure=5.0
- Ra is optimized with the combination of lower levels of Ton, Toff, flushing pressure and higher levels of Wire feed and wire tension.
- MRR is optimized with the combination of lower levels of Ton, Toff, Wire feed and higher levels of wire tension and flushing pressure.

References

[1] S.Suresh & D.Sudhakara., "Investigation on Wire Electric Discharge Machining and Mechanical Behaviour of Al 7075/Nano-SiC Composites", JIE, Series D 100, 217-227, 3rd September 2019.

[2] Sener karabulut et. al., "Study on the Wire Electrical Discharge Machining of AA 7075 Al Alloy", 2018 9th International Conference on Mechanical and Aerospace Engineering (ICMAE.2018.8467605).

[3] D.Vijai Praveen et. al., "Assessment of Optimal Parameters of Wire EDM on Ni-Coated Al_2O_{3p}/AA7075 MMcs Using PCA Coupled GRA", AJSE, 7953-7966, 13th April 2021.

[4] Manpreet Singh et.al., "Recent Developments in Wire EDM: A Review", IJRMET, ISSN: 2249-5770, Vol. 3, Issue 2, Mar-2013.

[5] Daniel M. Madyira, "Effect of Wire EDM on Microstructure and Fracture Toughness of 7075-T6511 Aluminum Alloy:, July 2015, Conference Proceedings of the World Congress on Engineering at London, Volume II.

[6] Kumaravel Subramaniam et.al. "Optimization of Wire-cut EDM Process Parameters of Al/SiO_2 Composites Using Taguchi Method", SAE Technical Paper 2020-28-0426, 2020.

[7] Vaibhavkumar Patel and Prof. Ankit Darji, "A Review of Experimental Investigation of Wire EDM for Aluminum 7075-T6", Indial Journal of Research, ISSN:2250-1991, Volume 5, Issue 12, December 2016.

[8] Nagarajan Lenin et.al., "Optimization of Process Parameters for WEDM of Al-LM25/Fly Ash/B4C Hybrid Composites Using Evolutionary Algorithms: A Comparative Study", Metals 2021, 11, 1105.

[9] Ashutosh Kumar Singh & et. al., "Machining of aluminum 7075 alloy using EDM process: An ANN validation", materialstoday: Proceedings, Volume 26, Part 2, 2020, Pages 2839-2844.

[10] Mohammad Taha et.al., "Optimization of Process Parameters on EN 34 Steel for WEDM Operations", NCETER, 2021, Vol. 09, Issue 11.

[11] K. Raju & et. al., "Parametric Optimization of Wire Electrical Discharge Machining in AA 7075 Metal Matrix Composite", Advances in Materials Science and Engineering, Research Article, Volume 2022, ID 4438419.

[12] Mangesh R. Phate et.al., "Analysis of Machining Parameters in WEDM of Al/SiCp20 MMC Using Taguchi-Based Grey-Fuzzy Approach", Vol. 2019, ID 1483169.

[13] Veeresh Murthy & et. al., “Optimization of Wire EDM Machining Parameters for Optimum Material Removal Rate and Surface Finish in an Aliminum 7075-T651 Alloy”, IJERT, ISSN:2278-0181, Volume 7, Issue 09, 2019.