Optimization of Parameters for Nitronic-60 on Wire-Cut Electrical Discharge Machining using Zinc-Coated Wire

V. Srinivasa Reddy\textsuperscript{1*}, V. Gopinath\textsuperscript{1*}, M. Haritha\textsuperscript{1*} P Marimuthu\textsuperscript{12*}, K. Chandrasekaran\textsuperscript{3} and N S Kalyan Chakravarthy\textsuperscript{4*}

\textsuperscript{1}Department of Mechanical Engineering,\textsuperscript{3} Department of Mechanical Engineering, MAM School of Engineering, Tiruchirappalli, India\textsuperscript{4} Department of Data Science and Business Systems\textsuperscript{*}QIS College of Engineering and Technology, Vengamukkapalem, Ongole, Prakasam District, Andhra Pradesh-523 272, India\textsuperscript{2} Email: pmarimuthu69@gmail.com (Corresponding author)

Abstract. The objectives of this work are to research the effective parameters of pulse ON time, pulse OFF time, voltage & wire feed whereas machined on Nitronic-60 exploitation wire-cut discharge machining exploitation zinc-coated wire. During this work, metal removal rate, surface roughness, and kerfwidth are taken as output parameters. The experimental results planned an optimum combination of parameters that provide the utmost material removal rate, minimum surface roughness, and kerf dimension. Finally, confirmation experiments were disbursed to spot the effectiveness of the planned technique. Multivariate analysis and ANOVA are performed exploitation Response Surface Linear Model.

1. Introduction

Machining eliminates certain components of work piece items to alter them to finished components. Machining are classified into ancient machining and Non-traditional machining. Ancient Machining, conjointly referred to as typical machining needs the tougher tool than the work piece. This tool ought to be pierced within the workpiece to a definite depth. Besides, a motion between tool and workpiece is to blame for creating or producing the desired form. The nonappearance of any of those parts in machining method like the absence of tool and workpiece contact or relative motion makes the method a non-traditional one.
2. Literature survey
Vinod Kumar et al (2015) have planned a mathematical model and experimented by taking six WEDM method parameters. They have used D2 alloy steel employing Zn coated Copper wire conductor. Output such as MRR, Surface Roughness, and Kerf were used for further analysis. Soundrarajan et al (2015) have mentioned and investigated the analysis of various parameters using RSM. ANOVA is employed to search out the share contribution of serious method parameters. WEDM was used for machining A413 alloy which are making tools.

Pujari Srinivasa et al (2016) experimented the work on Ti6AL4V alloy for analysing the result of voltage, material pressure, and pulse on time and pulse off-time. It is concluded that pulse on-time and pulse off time are important parameters that affect the spark gap of WEDM. Antar et al (2011) studied the various factors that affect the WEDM of Inconel-600 using RSM method. They have used four input method parameters of WEDM to review the method performance. Brajaesh lodhi and Sanjay Agarwal (2014) investigated the results of the responses by varying WEDM method parameters on the machining AISI 304 chrome steel and got the optimized results from the analysis.

Panchal Yogesh Ratilal et al (2018) used L18 OA for conduction of experiments for solving single response problem. H-21 die alloy steel was taken as work piece material and Zn coated brass wire was taken as tool material. Herbert et al (2012) have conducted experiments on Nickel based super alloy for the evaluation of surface integrity in hole making process. A detailed review was given by Chennakeseva Reddy Alavala and Naresh Baki (2016) in the area of application of CNC EDT for Aerospace application. RSM is the powerful tool that can be used for optimization of WEDM process (Gopalakannan et al 2012) and (Balasubramanian and Senthilvelan 2014). Sharanya Nair and Nehal Joshi (2014) reviewed the various works carried out on composite materials using WEDM. Kamal Jangara (2012) conducted the experiments in WEDM for studying unmachined area in intricate machining after roughcut.

Several machining parameters optimization were carried out by the previous researchers on different materials using WEDM and RSM was used for the development of mathematical models. But there is a lacking in WEDM study of Nitronic 60 material which is used for making stack liners, ducts, dampers, scrubbers etc. So in this work experiments were conducted on Nitronic 60 material in WEDM and RSM method is used for developing mathematical model for the important responses such as machining time and surface roughness and kerfwidth.

3. Experimental details
Experiments were conducted on corrosion materials of Nitronic 60 using a wire electrical discharge machine (WEDM). Zinc wires is used as tool. Table 1 shows the composition of Nitronic 60 and Table 2 shows its properties.

| MATERIALS | COMPOSITION (%) |
|-----------|-----------------|
| Ni        | 8-9             |
| Cr        | 16-18           |
| N         | 0.08-0.18       |
| Mn        | 7-9 Max.        |
| C         | 0.1 Max.        |
| Si        | 3.5-4.5 Max.    |
Table 2 Properties of Nitronic 60

| Property                        | Value                          |
|---------------------------------|--------------------------------|
| Density @ 72° F                 | 7700-7700 lb/in. ³             |
| Melting Temperature             | 1450° F to 1510° F             |
| Specific heat                   | 460-460 Btu/lb. ° F           |
| Electrical Resistivity @ 75° F  | 0.55-0.55 µΩ.m                |

Zinc anodes are sensibly protected and can be concentrated also. They yield unexpected voltages in comparison to the copper cells. In a specific, magnesium or copper cells can create voltage as extensive as 1.6v in lemon cells. This voltage is bigger than zinc or copper cells. It is similar to that of standard family unit 1.5v which helps control gadgets. Zinc is a somewhat blue-white, radiant metal. It is weak at normal temperatures yet pliable at 373-545k. It is a reasonable transmitter of power and consumes noticeable all around at high red warmth with an assessment of white billows of oxides. The metal is utilized in various amalgams with different metals. Metal, nickel, silver, business bronze, and aluminium are probably the most significant amalgams. Enormous amounts of zinc are utilized to deliver bite the dust projecting, which are utilized widely via auto, electrical, and equipment businesses. So Zinc terminals are utilized for wire electrical release machining of Nitronic 60. The test results have appeared in Table 3. Reaction Surface Methodology is utilized for additional examination.

4. Result and discussions

The primary objectives of this work is to analyze various input parameters in WEDM for machining Nitronic 60. Ton, Toff, Voltage and Wire feed were taken as input parameters and Machining time, Surface roughness and Kerfwidth were taken as responses. RSM was used for further analysis. Table 4 and Figure 1 shows the regression analysis for machining time.

Table 3 Experimental Results

| Ton  | Toff | Voltage | Wire feed | Machining time | Surface roughness | Kerfwidth |
|------|------|---------|-----------|----------------|-------------------|-----------|
| 4    | 2    | 40      | 2         | 477.38         | 2.18              | 0.247     |
| 4    | 4    | 45      | 4         | 557.07         | 2.03              | 0.291     |
| 4    | 6    | 50      | 6         | 671.96         | 1.8               | 0.289     |
| 4    | 8    | 55      | 8         | 796.43         | 1.64              | 0.294     |
| 6    | 2    | 50      | 4         | 465.75         | 1.69              | 0.297     |
| 6    | 4    | 55      | 6         | 562.08         | 1.85              | 0.32      |
| 6    | 6    | 40      | 8         | 500.24         | 2.03              | 0.289     |
| 6    | 8    | 45      | 2         | 556.47         | 1.99              | 0.29      |
| 8    | 2    | 55      | 6         | 463.32         | 1.86              | 0.292     |
| 8    | 4    | 50      | 8         | 472.12         | 1.83              | 0.293     |
| 8    | 6    | 45      | 2         | 488.27         | 1.84              | 0.355     |
| 8    | 8    | 40      | 4         | 208.37         | 2.17              | 0.344     |
| 10   | 2    | 45      | 8         | 445.53         | 2                 | 0.332     |
| 10   | 4    | 40      | 6         | 459.38         | 2.26              | 0.357     |
| 10   | 6    | 55      | 4         | 568.47         | 1.69              | 0.368     |
| 10   | 8    | 50      | 2         | 559.75         | 1.79              | 0.367     |
Table 4 Regression analysis for machining time

| Response | 1 | Machining time |
|----------|---|----------------|
| ANOVA    |   |                |
|          | Sum of | Mean | F | p-value |
| Source   | Squares | Df | Square | Value | Prob > F |
| Model    | 214396.9 | 10 | 21439.6889 | 9.550327755 | 0.0112 |
| A-T on   | 31950 | 1 | 31949.99962 | 14.23215465 | 0.001 |
| B-T off  | 1717.577 | 1 | 1717.576805 | 0.765096057 | 0.4218 |
| C-       | 13780.75 | 1 | 13780.74551 | 6.138644874 | 0.056 |
| D-       | 5278.945 | 1 | 5278.944858 | 2.351510502 | 0.1857 |
| AB       | 8746.831 | 1 | 8746.830521 | 3.896283136 | 0.1054 |
| AC       | 526.5104 | 1 | 526.5103892 | 0.234534503 | 0.6486 |
| AD       | 2803.898 | 1 | 2803.898386 | 1.248998934 | 0.3145 |
| BC       | 62741.26 | 1 | 62741.26249 | 27.94814904 | 0.0032 |
| BD       | 2241.242 | 1 | 2241.24209 | 0.998363206 | 0.3636 |
| CD       | 4562.817 | 1 | 4562.816535 | 2.032510528 | 0.2133 |
| Residual | 11224.58 | 5 | 2244.916557 |                |          |
| Cor Total| 225621.5 | 15 |                |          |          |
| Std. Dev. | 47.38055 |   |                |          |          |
| R-       | 0.950250379 |   |                |          |          |
| Mean     | 515.7869 |   |                |          |          |
| Adj R- | 0.850751136 |   |                |          |          |
| C.V. %   | 9.186071 |   |                |          |          |
| Pred R- | 0.21641521 |   |                |          |          |
| Adeq Precision | 14.18041228 |   |                |          |          |

Figure 1 Machining time

From Table 4 and figure 1, the Pred R-Squared" is 0.2164 and Adj R-Squared is 0.8508 "Adeq Precision" measures the signal-to-noise ratio. A ratio greater than 4 is desirable. A ratio of
14.180 indicates satisfactory signal. The model developed for machining time from this study is given below

\[
\text{Machining time} = +685.03319 + 22.19034 \times T_{on} - 192.37313 \times T_{off} - 13.26234 \times \text{Voltage} + 196.16216 \times \text{Wirefeed} - 9.66693 \times T_{on} \times T_{off} + 0.76868 \times T_{on} \times \text{Voltage} - 8.40988 \times T_{on} \times \text{Wirefeed} + 5.90026 \times T_{off} \times \text{Voltage} - 4.90879 \times T_{off} \times \text{Wirefeed} - 2.58316 \times \text{Voltage} \times \text{Wirefeed}
\]

From Table 5 and Figure 2, it is observed that Model F-value is 9.30 that implies the model is significant. There is only a 0.15% chance that a "Model F-value" this large could occur due to noise.

The "Pred R-Squared" of 0.5652 is reasonable with the "Adj R-Squared" of 0.6889. A ratio of 8.519 indicates satisfactory signal. The model for surface roughness is shown below

\[
\text{Surface roughness} = +3.25645 + 5.12500E-003 \times T_{on} - 0.012348 \times T_{off} - 0.027961 \times \text{Voltage} + 2.63587E-003 \times \text{Wirefeed}
\]

| Response | 2 | Surface roughness |
|----------|---|-------------------|
| **ANOVA** | | |
| Source | Sum of Squares | Df | Mean Square | F | p-value |
| Model | 0.400905109 | 4 | 0.100226277 | 9.304597 | 0.0015 |
| A-T on | 0.00210125 | 1 | 0.00210125 | 0.195071 | 0.6673 |
| B-T off | 0.011689275 | 1 | 0.011689275 | 1.085184 | 0.3199 |
| C-Voltage | 0.3746174 | 1 | 0.3746174 | 34.77794 | 0.0001 |
| D-Wirefeed | 0.000511359 | 1 | 0.000511359 | 0.047472 | 0.8315 |
| Residual | 0.118488641 | 11 | 0.010771695 | | |
| Cor Total | 0.51939375 | 15 | | | |
| Std. Dev. | 0.103786775 | | R-Squared | 0.771871 | |
| Mean | 1.915625 | | Adj R-Squared | 0.688915 | |
| C.V. % | 5.417906688 | | Pred R-Squared | 0.565183 | |
| PRESS | 0.225841212 | | Adeq Precision | 8.519386 | |
**Figure 2 Surface roughness**

![Surface Roughness](image)

**Table 6 Regression analysis for Kerfwidth**

| Response   | 3 | Kerfwidth |
|------------|---|------------|
| **ANOVA**  |   |            |
| Source     | Sum of Squares | Df | Mean Square | F Value | p-value |
| Model      | 0.014964       | 4  | 0.003741    | 10.26591 | 0.001   |
| A-T on     | 0.012425       | 1  | 0.012425    | 34.09576 | 0.0001  |
| B-T off    | 0.001851       | 1  | 0.001851    | 5.078177 | 0.0456  |
| C-Voltage  | 0.000164       | 1  | 0.000164    | 0.449651 | 0.5163  |
| D-Wirefeed | 0.000225       | 1  | 0.000225    | 0.616601 | 0.4489  |
| Residual   | 0.004009       | 11 | 0.000364    |          |         |
| Cor Total  | 0.018973       | 15 |           |          |         |
| **Std. Dev.** | 0.01909 | R-Squared | 0.78872 |
| **Mean**   | 0.314063       | Adj R-Squared | 0.711891 |
| **C.V. %** | 6.078325       | Pred R-Squared | 0.586968 |
| **PRESS**  | 0.007836       | Adeq Precision | 10.31731 |
Table 6 and Figure 3 shows the Regression analysis for Kerfwidth. From Table 6 and Figure 3, it is observed that The Model F-value is 10.27 that implies the model is significant. are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The Pred R-Squared" of 0.5870 is in reasonable with the Adj R-Squared" of 0.7119. The ratio of 10.317 indicates an adequate signal. The developed model for Kerfwidth is shown below.

\[
\text{Kerfwidth} = +0.18322 + 0.012463 \times T_{\text{on}} + 4.91304E-003 \times T_{\text{off}} + 5.84783E-004 \times \text{Voltage} - 1.74728E-003 \times \text{Wire feed}
\]

5. Conclusion

This experimental work uncovers the accompanying ends on the WEDM procedure on Nitronic 60 workpiece material. The main principle objective was to build up the experimental model utilizing RSM. The reaction surface philosophy is probably the best method to recognize the impacts of machining boundaries on the WEDM cycle. The voltage and heartbeat off time significantly affect machining time. The more elevated level of current produces lower machining time. The reaction surface models were created dependent on the plan of the analysis with current, voltage, and beat on schedule, and heartbeat off time as info, and machining time and surface harshness were the reactions. The reaction surface model has a more modest deviation from test information and affirms that the created model can be utilized to foresee the machining time and surface unpleasantness esteem adequately.

References

[1] Vinod Kumar, Vikas Kumar, and Kamal Kumar Jangra (2015), “An Experimental Analysis and Optimization Of Machining Rate And Surface Characteristics In Wedm Of Monel-400 Using RSM And Desirability Approach”, Journal of Industrial Engineering International, Vol. 11, pp. 297-307.
[2] R. Soundrarajan, A. Ramesh, N. Mohanraj and N. Parthasarathi (2016), “An investigation of material removal rate and surface roughness of squeeze cast a413 alloy a WEDM by multi-response optimization using RSM”, Journal Of Alloy And Compounds, Vol. 685, pp. 533-545.

[3] Pujari Srinivasa Rao, Koona Ramji, and Beela Satyanarayan (2016), “Effect Of Wire EDM Conditions On Generation Of Residual Stresses In Machining Of Aluminium 2014 T6 Alloy” Alexandria Engineering Journal, Vol. 55 issues 2, pp. 1077-1084.

[4] M. T. Antar, S. L. Soo, D. K. Aspinwall, D. Jones and R. Perez (2011), “Productivity And Workpiece Surface Integrity When WEDM Aerospace Alloys Using Coated Wires”, Procedia Engineering, Vol. 19, pp. 3-8.

[5] Brajaesh lodhi and Sanjay Agarwal (2014), “Modeling Of Wire Electrical Discharge Machining Of AISI D3 Steel Using Response Surface Methodology” 5th International & 26th All India Manufacturing Technology, Design, and Research Conference (AIMTDR 2014), IIT Guwahati, Assam, India

[6] Panchal Yogesh Ratilal, Nilesh K.Patel and Kapil S.Banker (2018), “Review Of Research Work In Wire Cut Electrical Discharge Machining On Metal Matrix Composite Materials” Procedia Manufacturing, Vol. 20, pp. 253-258.

[7] C. R. J. Herbert, J. Kwong, D. A. Axinte, M. C. Hardy and P.J. Witters (2012), “Evaluation Of The Evaluation Of Work Piece Surface Integrity In Hole Making Operations For A Nickel-Based Superalloy” Journal Of Materials Processing Technology, Vol. 212, Issue 8, pp.1723-1730.

[8] Chennakesava Reddy Alavala and Naresh Baki (2016), “Application of CNC Electrical Discharge Turning for Aerospace Materials – A Review”, International Journal of science and research, Vol.5, issue 11, pp.1647-1653

[9] T. Gopalakannan, S. Senthilvelan and S. Ranganathan (2012), “Modeling and Optimization of EDM Process Parameters on Machining of Al 7075-B4C MMC Using RSM”, Procedia Engineering, Vol. 38, pp. 685-690.

[10] P.Balasubramanian and T.Senthilvelan (2014), “Optimization of Machining Parameters in EDM Process Using Cast and Sintered Copper Electrodes”, Procedia Materials Science, Vol. 6, pp. 1292-1302.

[11] Sharanya Nair and Nehal Joshi (2014), “A review on wire electrical discharge machining (WEDM) of composite materials”, International Journal of Engineering Trends and Technology Vol. 17, Number 9, Pp. 415-420.

[12] Kamal Jangra (2012), “Study of the unmachined area in intricate machining after rough cut in WEDM”, International Journal of Industrial Engineering Computations, 3 Issue 5 pp. 887-892.