Optimization of Machining Parameters for AISI 316L And 317L Austenitic Stainless Steels using Eco-Cut Wire-EDM Technique

M.V.N. Srujan Manohar, Y. Seetha Rama Rao, Ch. Sree Ram

Abstract-Austenitic stainless steel is one of the most suitable engineering material based on their superior resistance to corrosion and compatibility at high temperatures and high vacuum. However, the machinability of austenitic stainless steel is not very promising owing to lower thermal conductivity, higher degree of ductility and work hardenability. For meeting these challenges, unconventional machining procedures were evolved and can make any impenetrable design/profile on any work substance by acceptable controlling of various machining procedures. The main importance of this paper is to show the impact of machining parameters on Eco-cut Wire Electric Discharge Machining (WEDM) for disparate austenitic stainless steels (AISI 316L & 317L). Initially both the metals are machined on WEDM. Machining parameters like pulse on time($P_{on}$), pulse off time($P_{off}$), voltage(V) and wire tension(WT) are observed for both 316L and 317L stainless steel materials. A Box-Behnken Design (BBD) of response surface methodology (RSM) has been used for experimental work. The reaction of procedure is estimated by ANOVA analysis and response optimizer is used for optimum level checking. A series of trial runs were carried out on both the machined specimens for identifying better material removal rate(MRR), cutting speed(CS) and surface roughness(Ra).

Keywords - Cutting Speed(CS), Material Removal Rate(MRR), Surface Roughness(Ra), pulse on time($P_{on}$), pulse off time($P_{off}$), voltage(V), wire tension(WT), Response Surface Methodology(RSM) and ANOVA.

I. INTRODUCTION

Modern advances in aerospace and nuclear engineering industries is partly reflects to the use of impenetrable-to-machine materials like alloys, nimonics, carbides, stainless steel etc. Many of these substances found various applications in the industrial fields by exploiting their elevated strength-to-weight relationship, hardness and heat-resisting qualities. Conventional machining processes instead of present technological improvement it is impenetrable to machine these substances from the perspective of low-cost production. Un-conventional machining procedures are necessary to control these hard substances. Electrical discharge machining(EDM) is the most favored non-traditional material removal procedures and enhances basic principles of machining in manufacturing industries like aerospace, automotive, nuclear, medical and die-mould production.

II. FUNDAMENTAL WORKING OF WEDM PROCEDURE

WEDM is a procedure of material removal of electrical conductive materials by thermo-electric source of energy. The material removal is by commanded erosion between a series/run of repetitive flash/twinkles in between electrodes, i.e. work piece and tool. In WEDM, the erosion apparatus has been explained as liquefying and/or evaporation of surface material by heat fabricated in the plasma channel. A flash is fabricated in between wire electrode and work piece through deionized water and erodes work piece to fabricate complex 2D and 3D object profiles.

III. MATERIAL AND EXPERIMENTAL WORK

Austenitic stainless steels (AISI 316L & 317L) are pre-owned in this work [4],[5] and the specifications of Wire EDM Machine is shown in Table I and levels of input limitations is shown in Table II.
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The dimensions of the work piece for the work is taken as, Plates of 100x150x5mm thick respectively, and these plates were machined by Wire EDM shown in Fig. 1.

MRR = (0.345) (10) / 449 = 0.038 mm²/min

MITUTOYO SURFTEST SJ 201P surface roughness tester is pre-owned to measure the surface roughness value (Ra).

Table-III: Experimental Plan & Responses of 316L

Table-IV: Experimental Plan and Responses of 317L

IV. EXPERIMENTAL DESIGN AND ANALYSIS

WEDM of eco-cut has been pre-owned to machine Austenitic Stainless Steels AISI 316L and 317L with P₁₀, P₁₄₆, V and WT as input limitations. Varying the above limitations a cut of 10mm length are fabricated on the work piece of two disparate materials. The aim of the present work is to optimize the WEDM procedure parameters for better performance [6],[7]. In this work the showing measures are material removal rate (MRR), surface roughness (Ra) and cutting speed (CS).

The level of input limitations is fixed based on the trial runs displayed in the work table, response surface methodology-Box Behnken Design method has been used for experimentation (Table III and Table IV). The measured and calculated responses are given in the work table after conducting the experiments. ANOVA [8],[9],[10] has been used to know the significant parameter and their contribution.

The trial run defines as in the following steps:
1. Selecting the machining limitations and levels of these limitations.
2. Conducting the trial runs at all feasible level of the combinations.

MRR was calculated using the following equation,

MRR calculation: MRR = [WLT]/Tₘ

T – THICKNESS OF WORK PIECE (mm),
L – LENGTH OF CUT (mm),
W – WIDTH OF CUT OR WIDTH (mm),
Tₘ – MACHINING TIME (min)
V. RESULTS AND DISCUSSION

ANOVA has been applied on the exploratory outcomes for MRR, CS, Ra for both steels 316L and 317L are given Table V, Table VI, Table VII, Table VIII, Table IX and Table X respectively. By using surface optimizer, optimum level has been observed and measured as shown from Fig. 2 to Fig. 7.

Table-V: Outcomes of ANOVA for MRR 316L

| Source | SS  | MS  | F-Value | P-Value | % Contribution |
|--------|-----|-----|---------|---------|----------------|
| Model  | 1   | 44  | 24      | 10      | 0.065          | 3.12           | 2.16 |
| A      | 1   | 46  | 24      | 10      | 0.068          | 3.31           | 2.18 |
| B      | 1   | 45  | 20      | 10      | 0.047          | 2.84           | 2.17 |
| C      | 1   | 45  | 20      | 10      | 0.039          | 2.44           | 1.63 |
| A*B    | 1   | 45  | 24      | 10      | 0.057          | 3.89           | 1.95 |
| A*C    | 1   | 44  | 22      | 9       | 0.062          | 3.15           | 2.19 |
| B*C    | 1   | 46  | 22      | 9       | 0.069          | 3.25           | 2.3  |

...and so on...

Fig. 2. Surface plot of MRR 316L vs. A and B

MRR for 316L = -72.25 + 1.0589 A + 0.4286 B + 0.1345 C + 0.2084 D - 0.004416 A^2 - 0.004388 B^2 + 0.000005 C^2 - 0.001933 D^2 - 0.000286 A*B - 0.001544 A*C - 0.000750 A*D + 0.0007648 B*C - 0.002178 B*D + 0.000596 C*D

Table-VI: Outcomes of ANOVA for CS 316L

| Source | SS  | MS  | F-Value | P-Value | % Contribution |
|--------|-----|-----|---------|---------|----------------|
| Model  | 14  | 0.0093 | 0.00066 | 443.53 | 0.00099 | 99.785 |
| A      | 1   | 0.000499 | 0.000499 | 3330.45 | 0.00056 | 54.655 |
| B      | 1   | 0.00005 | 0.0005 | 1004.32 | 0.00065 | 16.129 |
| C      | 1   | 0.00019 | 0.00019 | 127.72 | 0.00105 | 2.0430 |
| D      | 1   | 0.00000 | 0.00000 | 1.39 | 0.00010 | 0.254 |
| A^2    | 1   | 0.00004 | 0.00004 | 694.20 | 0.00065 | 11.182 |
| B^2    | 1   | 0.00003 | 0.00003 | 685.15 | 0.00065 | 11.075 |
| C^2    | 1   | 0.00000 | 0.00000 | 0.02 | 0.00001 | 0.000 |
| D^2    | 1   | 0.00002 | 0.00002 | 132.94 | 0.00065 | 2.1505 |
| A*B    | 1   | 0.00000 | 0.00000 | 2.18 | 0.00010 | 0.16 |
| A*C    | 1   | 0.000038 | 0.000038 | 254.45 | 0.00065 | 4.0860 |
| A*D    | 1   | 0.00002 | 0.00002 | 15.01 | 0.00065 | 0.2150 |
| B*C    | 1   | 0.000019 | 0.000019 | 62.38 | 0.00065 | 0.9677 |
| D*B    | 1   | 0.000019 | 0.000019 | 126.62 | 0.00065 | 2.0430 |
| C*D    | 1   | 0.000006 | 0.000006 | 37.96 | 0.00065 | 0.6451 |
| Error  | 12  | 0.000002 | 0.000002 | 0.2150 | 0.00065 | 0.000 |
| Total  | 26  |        |         |        |      | 100 |

Fig. 3. Surface plot of CS 316L vs. A and B

CS for 316L = 500 + 1.11 A - 21.26 B - 7.73 C +2.32 D - 0.0112 A*A + 0.2208 B*B + 0.0392 C*C + 0.1998 D*D + 0.0145 A*B + 0.0663 A*C + 0.0790 A*D -0.0375 B*C + 0.0475 B*D + 0.0213 C*D

Table-VII: Outcomes of ANOVA for Ra 316L

| Source | SS  | MS  | F-Value | P-Value | % Contribution |
|--------|-----|-----|---------|---------|----------------|
| Model  | 14  | 0.3181 | 0.0227 | 16.09 | 0.0000 | 94.94017 |

...and so on...
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| Source | DF | SS | MS | F-Value | P-Value | % Contribution |
|--------|----|----|----|---------|---------|----------------|
| Model  | 14 | 4.42615 | 0.31615 | 58.64 | 0.000 | 98.55929 |
| A      | 1  | 3.55 | 0.0569 | 3.55069 | 658.57 | 0.000 | 79.06499 |
| B      | 1  | 0.04 | 0.843 | 0.04843 | 8.98 | 0.011 | 1.078415 |
| C      | 1  | 0.07 | 1.468987 | 0.00121 | 0.22 | 0.644 | 0.026944 |
| D      | 1  | 0.00 | 3.50 | 0.00350 | 0.65 | 0.436 | 0.077936 |
| A^2    | 1  | 0.17 | 5.87 | 0.17587 | 32.62 | 0.000 | 3.916185 |
| B^2    | 1  | 0.19 | 5.77 | 0.19577 | 36.31 | 0.000 | 4.359308 |
| C^2    | 1  | 0.44 | 986 | 0.44986 | 83.44 | 0.000 | 10.01726 |
| D^2    | 1  | 0.34 | 797 | 0.34797 | 64.54 | 0.000 | 7.748422 |
| A*B    | 1  | 0.06 | 597 | 0.06597 | 12.24 | 0.004 | 1.468987 |
| A*C    | 1  | 0.19 | 890 | 0.18890 | 20.20 | 0.001 | 2.424931 |
| A*D    | 1  | 0.00 | 422 | 0.00422 | 0.78 | 0.393 | 0.093969 |
| B*C    | 1  | 0.00 | 563 | 0.000563 | 1.04 | 0.327 | 0.125366 |
| D*B    | 1  | 0.00 | 560 | 0.00360 | 0.67 | 0.430 | 0.080163 |
| C*D    | 1  | 0.00 | 599 | 0.00599 | 1.11 | 0.313 | 0.133382 |

Table-VIII: Outcomes of ANOVA for MRR 317L

Fig. 4. Surface plot of Ra 316L vs. A and B

Ra for 316L = 730 - 11.03 A - 2.11 B - 1.99 C - 7.42 D + 0.0410 A^2 - 0.0210 B^2 - 0.00261 C^2 - 0.0384 D^2 + 0.0271 A*B - 0.00500 A*C + 0.0683 A*D + 0.04865 B*C - 0.0150 B*D + 0.05375 C*D

Table-IX: Outcomes of ANOVA for CS 317L

Fig. 5. Surface plot of MRR 317L vs. A and B

MRR for 317L = -7.11 + 1.709 A - 0.883 B - 0.4149 C - 0.239 D - 0.00744 A^2 A + 0.01274 B^2 B + 0.001969 C^2 C + 0.00663 D^2 D - 0.00228 A*B + 0.003162 A*C + 0.00078 A*D - 0.000500 B*C + 0.00075 B*D - 0.000662 C*D

Model 14 4.42 615 0.31615 58.64 0.000 98.55929
A 1 3.55 0.069 3.55069 658.57 0.000 79.06499
B 1 0.04 0.843 0.04843 8.98 0.011 1.078415
C 1 0.07 1.468987 0.00121 0.22 0.644 0.026944
D 1 0.00 3.50 0.00350 0.65 0.436 0.077936
A^2 1 0.17 5.87 0.17587 32.62 0.000 3.916185
B^2 1 0.19 5.77 0.19577 36.31 0.000 4.359308
C^2 1 0.44 986 0.44986 83.44 0.000 10.01726
D^2 1 0.34 797 0.34797 64.54 0.000 7.748422
A*B 1 0.06 597 0.06597 12.24 0.004 1.468987
A*C 1 0.19 890 0.18890 20.20 0.001 2.424931
A*D 1 0.00 422 0.00422 0.78 0.393 0.093969
B*C 1 0.00 563 0.000563 1.04 0.327 0.125366
D*B 1 0.00 560 0.00360 0.67 0.430 0.080163
C*D 1 0.00 599 0.00599 1.11 0.313 0.133382
ACE methodology is considered as input squares of 0.0300 B*D + 0.1284 A*B + 0.0825 A*C + 0.0325 A*D + 0.0188 B*C + 0.0025 B*D - 0.0193 C*D

Fig. 6. Surface plot of CS 317L vs. A and B
CS for 317L = 3629 - 48.41 A - 32.40 B - 13.17 C - 9.72 D + 0.1816 A*A + 0.1916 B*B + 0.07261 C*C + 0.2554 D*D + 0.1284 A*B + 0.0825 A*C + 0.0325 A*D + 0.0188 B*C + 0.0025 B*D - 0.0193 C*D

Table-X: Outcomes of ANOVA for Ra 317L

| Source | DF | SS     | MS     | F-Value | P-Value | % Contribution |
|--------|----|--------|--------|---------|---------|----------------|
| Model  | 14 | 0.6602 | 0.04715| 8.98    | 0.00    | 91.2873        |
| A      | 1  | 0.0587 | 0.05870| 11.1    | 0.00    | 13.17268       |
| B      | 1  | 0.0013 | 0.00138| 0.26    | 0.61    | 32.40694       |
| C      | 1  | 0.1371 | 0.13717| 26.1    | 0.00    | 9.72058        |
| D      | 1  | 0.0048 | 0.00484| 0.92    | 0.35    | 6.37024        |
| A²     | 1  | 0.0777 | 0.07774| 14.8    | 0.00    | 10.74943       |
| B²     | 1  | 0.1544 | 0.15443| 29.4    | 0.00    | 23.85407       |
| C²     | 1  | 0.0338 | 0.03381| 6.44    | 0.02    | 6.18024        |
| D²     | 1  | 0.0289 | 0.02899| 5.52    | 0.03    | 7.20398        |
| A*B    | 1  | 0.0142 | 0.01429| 2.72    | 0.12    | 1.97619        |
| A*C    | 1  | 0.0462 | 0.04622| 8.80    | 0.01    | 6.391554       |
| A*D    | 1  | 0.0081 | 0.00810| 1.54    | 0.23    | 1.19991        |
| B*C    | 1  | 0.0005 | 0.00055| 0.11    | 0.75    | 0.00057        |
| D*B    | 1  | 0.0000 | 0.00002| 0.00    | 0.94    | 0.0003457      |
| C*D    | 1  | 0.0012 | 0.00126| 0.24    | 0.63    | 0.174221       |
| Error  | 12 | 0.0630 | 0.0525 | 8.71    | 0.28    | 100            |
| Total  | 26 |        |        |         |         | 100            |

Ra for 317L = -693 + 23.03 A - 22.19 B - 7.18 C - 6.27 D - 0.1207 A*A + 0.1702 B*B+ 0.01991 C*C + 0.0737 D*D + 0.0598 A*B + 0.0537 A*C + 0.0450 A*D+ 0.0059 B*C - 0.0025 B*D - 0.0089 C*D

VI. CONCLUSIONS

Response surface methodology (RSM) process has been used in the present work to optimize the WEDM performance measures [material removal rate-MRR, cutting speed-CS and surface roughness-Ra]. Pulse on time(P_on), Pulse off time(P_off), Voltage(V) and Wire tension(WT) have been considered as input limitations. The reaction of procedure limitations have been identified by registering ANOVA analysis for MRR, CS and Ra.

For MRR, it is seen from ANOVA outcomes that,
1. For 316L, P_on, P_off, V, squares of P_on, P_off WT, interaction of P_on & V, P_off & V, P_off & WT, V & WT are more influencing than other model terms.
2. For 317L, squares of P_on, P_off, interaction of V & WT are more influencing than other model terms.

For CS it was develop from ANOVA outcomes that,
1. For 316L, squares of P_off are more influencing than other model terms.
2. For 317L, squares of P_off interaction of V & WT are more influencing than other model terms.

For Ra it was develop from ANOVA outcomes that,
1. For 316L, V, interaction of P_off & V, V & WT are more influencing than other model terms.
2. For 317L, V & squares of P_off are more influencing than other model terms.

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