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# Experimental Investigation on Surface Roughness, Hardness and MRR of Stainless Steel 316L in EDM with Distilled water as electrolyte using Taguchi Method

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## ABSTRACT

Stainless steel 316 L is combination of chromium-nickel-molybdenum austenitic stainless steel developed to improve the corrosion resistance better than alloy 304.It also provides higher creep, stress-to-rupture ratio and good tensile strength at elevated temperatures. Machining in Distilled water has given better result at higher MRR and low tool wear rate than in kerosene. The machining accuracy was not very good but the surface finish was slight better. This paper deals with the optimization and analysis of the EDM process of SS 316L. The Taguchi method was used to determine the combination of EDM process parameters like current, pulse ON, pulse OFF, Voltage which minimize surface roughness and maximize hardness of the material. The experiments were planned & performed as per L9 orthogonal array (OA) and signal-to-noise (S/N) ratio was applied to determine the proposed performance characteristics.

**Keywords** : SS316L, EDM, taguchi, surface roughness, hardness, MRR

## I. INTRODUCTION

In this sinking EDM process, work piece surface is slightly a mirror image of tool shape occurs. In sinking EDM electrode material is generally copper or graphite. The numerical controls monitor the gaps between the conditions (voltage and current) and synchronously control at different axes and the pulse generator. He also noticed that during machining with distilled water as the dielectric fluid, the machining accuracy was not very good but the surface finish was slight better. Alloy 316L/316 (UNS S31603/ S31600) is a combination of chromium-nickel-molybdenum austenitic stainless steel developed to improve the corrosion resistance with respect to Alloy 304L/304 in moderately corrosive. It is often utilized in process streams such as chlorides or halides. The addition of molybdenum not only improves general corrosion and but also resist chloride pitting resist. It also provides higher creep, stress-to-rupture ratio and good tensile strength at elevated temperatures. Alloy 316L resists atmospheric corrosion, as well as, moderate oxidizing and reducing environments. It also resists corrosion of the alloy in polluted marine atmospheres. The alloy provides excellent resistance to inter granular corrosion at welded condition. Alloy 316/316L has an excellent strength and toughness at cryogenic temperatures and these alloys are non-magnetic in the annealed condition, but can become slightly magnetic when comes to cold working.

**Table 1:** Chemical composition of Cu Electrode

| **Element** | Sn | Fe | Bi | Cu |
|---|---|---|---|---|
| **Wt%** | 0.055 | 0.007 | 0.002 | 99.91 |

**Table 2:** Mechanical properties of pure Cu Electrode

| Properties | Description |
|---|---|
| Specific gravity(g/cm$^3$) | 8.94 |
| Melting range ($^0$C) | 1065-1083 |
| Thermal conductivity (w/mk) | 388 |
| Specific heat(J/kg K) | 385 |
| Thermal expansion coefficient(/$^0$C) | $16.7 \times 10^{-6}$ |
| Electrical resistivity(Ω cm) | $1.7 \times 10^{-6}$ |

## II. EXPERIMENTAL PROCEDURE

In this experiment, Taguchi method was used accordingly to determine the EDM process parameters like current, pulse ON, pulse OFF and Voltage which minimize surface roughness and maximize hardness of the material. The experiments were planned as per L9 orthogonal array (OA) and signal-to-noise (S/N) ratio was applied to determine the proposed performance characteristics.

A. Experimental Flow chart

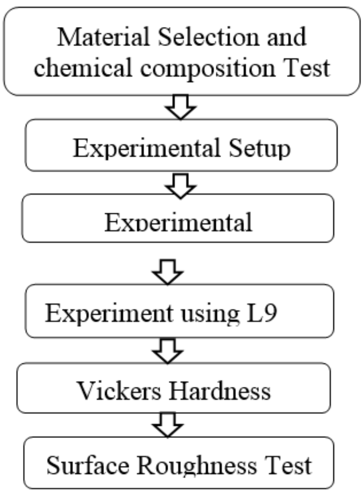


**Table 3:** Physical properties of SS 316L

| Properties | Description |
|---|---|
| Density(g/cm$^3$) | 7.90 |
| Melting range ($^0$C) | 1390-1440 |
| Thermal conductivity (w/mk) | 14.6 |
| Specific heat(J/kg K) | 450 |
| Modulus of elasticity(GPa) | 200 |

**Table 4:** Mechanical properties of SS 316L

| Properties | Description |
|---|---|
| Tensile (MN/m$^2$) | 650 |
| Yeild strength (MN/m$^2$) | 280 |
| Elongation at fracture | 45 |
| Vickers hardness (Hv) | 190 |
| Young's Modulus (GN/m$^2$) | 211 |
| Fatigue limit (GN/m$^2$) | 0.28 |

B. Experimental Setup

The pure Cupper rod of size ϕ 20 × 50 mm was used as an electrode and workpiece is cut 25mm× 24 mm from a sheet of 250mm × 250 mm with 3 mm thickness.

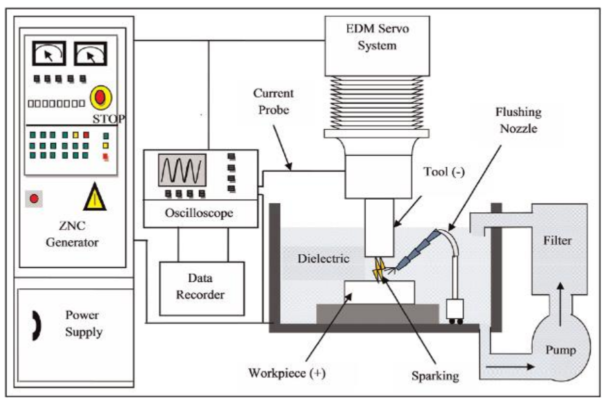


**Figure 1** Schematic Diagram of EDM

It consists of an electrode and the workpiece which are submerged in the dielectric fluids such as distilled water. The electrode and workpiece are connected with a suitable power supply. The power supply generated gives an electrical potential between the two parts. Dielectric breakdown occurs in the fluid when the electrode approaches the workpiece forming a plasma channel and a small spark jumps. These sparks usually strike one at a time.

These sparks happen in huge number randomly at locations between the electrode and the workpiece. As the base metal is eroded, and the spark gap is increased subsequently, the electrode is lowered automatically by the machine so as to continue the machining process uninterrupted. More than an hundred thousand sparks occur per second simultaneously with the actual duty cycle carefully which are controlled by the setup parameters.

**Table 5** EDM Machine Specifications

| Factors | Specifications |
|---|---|
| Workpiece polarity | Positive(P) |
| Current (Amp) | 14,17,20 |
| Pulse ON (sec) | 4,5,6 |
| Pulse OFF (sec) | 4,5,6 |
| Voltage (V) | 40,60,80 |
| Dielectric fluid | Distilled water |
| Workpiece material | SS 316 L |
| Electrode Diameter (mm) | Cu ,20 |

C. Control Factors and Levels

**Table 6** Control Factors and Levels

| Code | Control Factor | Level | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| A | Current, Amp | 14 | 17 | 20 |
| B | Pulse ON, sec | 4 | 5 | 6 |
| C | Pulse OFF, sec | 4 | 5 | 6 |
| D | Voltage, V | 40 | 60 | 80 |

D. Taguchi L9 orthogonal Array

**Table 7** Taguchi L9 orthogonal Array

| Experiment Number | Current ( Amp ) | Pulse ON (Sec) | Pulse OFF (Sec) | Voltage ( V ) |
|---|---|---|---|---|
| 1 | 14 | 4 | 4 | 40 |
| 2 | 14 | 5 | 5 | 60 |
| 3 | 14 | 6 | 6 | 80 |
| 4 | 17 | 4 | 5 | 80 |
| 5 | 17 | 5 | 6 | 40 |
| 6 | 17 | 6 | 4 | 60 |
| 7 | 20 | 4 | 6 | 60 |
| 8 | 20 | 5 | 4 | 80 |
| 9 | 20 | 6 | 5 | 40 |

E. Vickers Hardness and Surface Roughness Tests

The Vickers hardness test method consists of a diamond shaped indenter on the test material, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf.

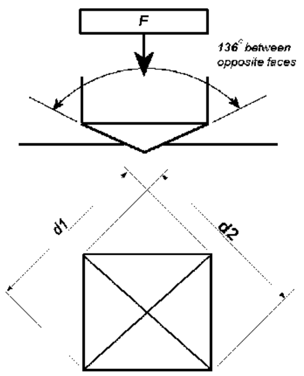


**Figure 2** Indentation Method

The following formulae is used for obtaining the Hardness value in the micro hardness tester

$$y = \frac{2F\sin\frac{136^\circ}{2}}{d^2} \qquad HV = 1.854\,\frac{F}{d^2}$$

Where F = Load (kgf)

d = Mean of the two diagonals,$d_1$ and $d_2$ in mm

HV = Vickers hardness

Surface Roughness is measured by taylor habson machine

**Figure 3** Picture of Taylor Habson Surfonic S-300 Series

## III.RESULTS AND DISCUSSION

### A.Chemical composition of SS 316L

**Table 8** Chemical composition of SS 316L

| | |
|---|---|
| C% | 0.0246 |
| Si% | 0.4350 |
| Mn% | 1.5280 |
| P% | 0.0320 |
| S% | 0.0124 |
| Cr% | 16.5360 |
| Mo% | 2.0340 |
| Ni% | 10.4220 |

### B. Surface Hardness, Surface roughness, and MRR results

**Table 9** Surface Hardness, Surface roughness, and MRR results

| Experiment Number | Surface Hardness (Hv) | Surface Roughness (Ra) | MRR (g/min) |
|---|---|---|---|
| 1 | 326.2 | 9.92 | 0.0134 |
| 2 | 818.2 | 9.87 | 0.002 |
| 3 | 248.5 | 10.3 | 0.0105 |
| 4 | 757.1 | 10.8 | 0.036 |
| 5 | 294.5 | 10.9 | 0.05 |
| 6 | 204.0 | 9.96 | 0.023 |
| 7 | 706.8 | 10.9 | 0.084 |
| 8 | 514.5 | 9.83 | 0.093 |
| 9 | 639.6 | 12 | 0.013 |

### C.ANOM for Surface Hardness

**Table 9** Response Table for SN ratio of surface hardness in EDM

| Level | Current | Pulse ON | Pulse OFF | Voltage |
|---|---|---|---|---|
| 1 | 52.14 | 54.95 | 50.23 | 51.92 |
| 2 | 51.05 | 53.96 | 57.32 | 53.81 |
| 3 | 55.78 | 50.07 | 51.42 | 53.24 |
| Delta | 4.72 | 4.87 | 7.09 | 1.89 |
| Rank | 3 | 2 | 1 | 4 |

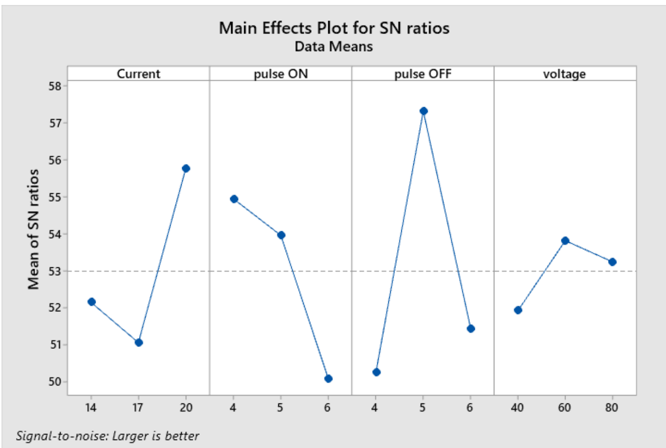


**Figure 4** Main effect plot for SN ratio of surface hardness

**Table 10** Response Table for means of surface hardness

| Level | Current | Pulse ON | Pulse OFF | Voltage |
|---|---|---|---|---|
| 1 | 464.3 | 596.7 | 348.2 | 420.1 |
| 2 | 418.5 | 542.4 | 738.3 | 576.3 |
| 3 | 620.3 | 364.0 | 416.6 | 506.7 |
| Delta | 201.8 | 232.7 | 390.1 | 156.2 |
| Rank | 3 | 2 | 1 | 4 |


**Figure 5** Main effect plot for means of surface hardness

Based on the SN ratio of surface hardness EDM the best combination is determined as A1-B2-C1-D2. As the combination does not match with the experimental combinations taken in taguchi L9 orthogonal array we theoretically find out the optimum surface hardness value using the below equation

Y(opt) = m+(mAopt – m)+ (mBopt – m)+ (mCopt – m)+ (mDopt – m)

The above equation gives the optimum surface hardness value as 1028.468.To further evaluate the values the confirmation test run are been carried with the factors obtained in ANOM analysis. The overall result of ANOM analysis for EDM is given below

**Table 11** Confirmation test for best combination for surface hardness in EDM

| | |
|---|---|
| Best Combination | A3-B1-C2-D2 |
| Y(opt) value in Hv | 1028.468 |
| Confirmation Test Result | 1012.569 |
| Error | 15.899 |

D.ANOM for Surface roughness

**Table 12** Response Table for SN ratio of surface roughness EDM

| Level | Current | Pulse ON | Pulse OFF | Voltage |
|---|---|---|---|---|
| 1 | -20.02 | -20.45 | -19.92 | -20.75 |
| 2 | -20.46 | -20.16 | -20.71 | -20.20 |
| 3 | -20.73 | -20.60 | -20.58 | -20.26 |
| Delta | 0.70 | 0.44 | 0.80 | 0.55 |
| Rank | 2 | 4 | 1 | 3 |


**Figure 6** Main effect plot for SN ratio of surface roughness

**Table 13** Response Table for means of surface roughness in EDM

| Level | Current | Pulse ON | Pulse OFF | Voltage |
|---|---|---|---|---|
| 1 | 10.030 | 10.540 | 9.903 | 10.940 |
| 2 | 10.553 | 10.200 | 10.890 | 10.243 |
| 3 | 10.910 | 10.753 | 10.700 | 10.310 |
| Delta | 0.880 | 0.553 | 0.987 | 0.697 |
| Rank | 2 | 4 | 1 | 3 |

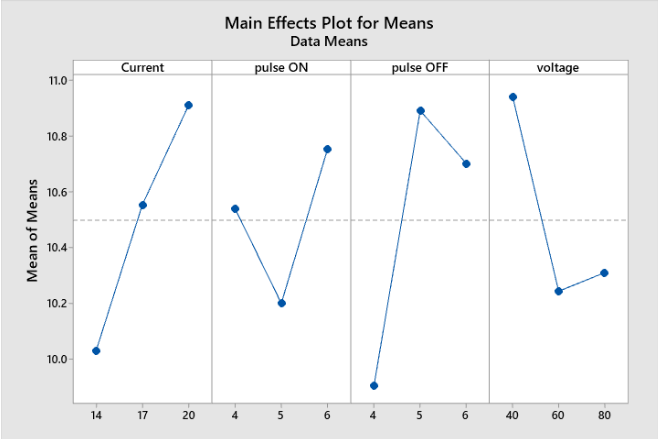


**Figure 7** Main effect plot for means of surface roughness

Based on the SN ratio of surface roughness in EDM the best combination is determined as A1-B2-C1-D2. As the combination does not match with the experimental combinations taken in taguchi L9 orthogonal array we theoretically find out the optimum surface roughness value using the below equation

Y(opt) = m+(mAopt – m)+ (mBopt – m)+ (mCopt – m)+ (mDopt – m)

The above equation gives the optimum surface roughness value as 8.885.To further evaluate the values the confirmation test run are been carried with the factors obtained in ANOM analysis. The overall result of ANOM analysis for EDM is given below

**Table 14** Confirmation test for best combination for surface roughness in EDM

| | |
|---|---|
| Best Combination | A1-B2-C1-D2 |
| Y(opt) value in Ra | 8.885 |
| Confirmation Test Result | 9.524 |
| Error | 0.689 |

E.ANOM for MRR

**Table 15** Response Table for SN ratio of MRR in EDM

| Level | Current | Pulse ON | Pulse OFF | Voltage |
|---|---|---|---|---|
| 1 | -43.67 | -29.28 | -30.28 | -33.73 |
| 2 | -29.22 | -33.54 | -40.19 | -36.09 |
| 3 | -26.62 | -36.69 | -29.04 | -29.69 |
| Delta | 17.05 | 7.41 | 11.15 | 6.39 |
| Rank | 1 | 3 | 2 | 4 |

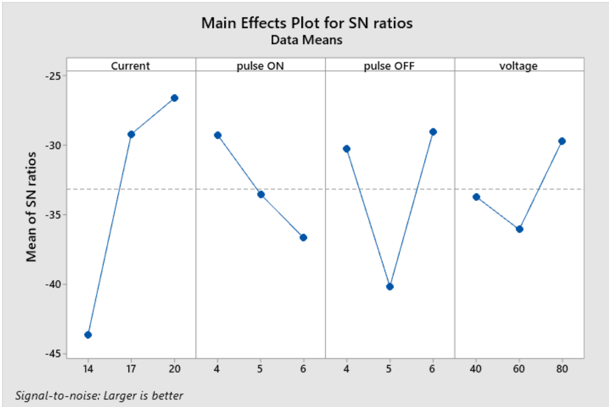


**Figure 8** Main effect plot for SN ratio of MRR

**Table 16** Response Table for means of MRR

| Level | Current | Pulse ON | Pulse OFF | Voltage |
|---|---|---|---|---|
| 1 | 0.008633 | 0.044467 | 0.043133 | 0.025467 |
| 2 | 0.036333 | 0.048333 | 0.017000 | 0.036333 |
| 3 | 0.063333 | 0.015500 | 0.048167 | 0.046500 |
| Delta | 0.054700 | 0.032833 | 0.031167 | 0.021033 |
| Rank | 1 | 2 | 3 | 4 |

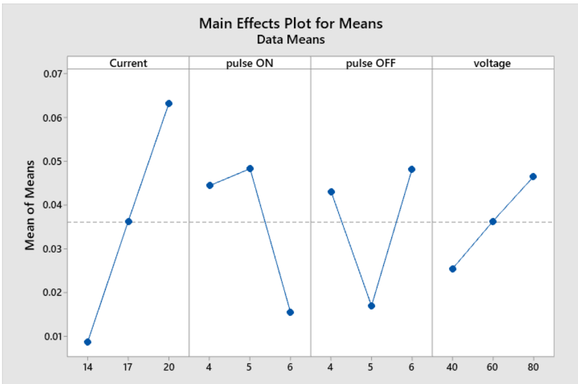


**Figure 9** Main effect plot for means of MRR

Based on the SN ratio of MRR in EDM the best combination is determined as A3-B1-C3-D3.

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