Modelling and Optimizing Process Parameters of AISI D2 Tool Steel for WEDM automation

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Abstract. The AISI D2 tool steel are the material that for machining of heat treated AISI D2 tool steel, a highly developed method must be employed. Due to exceptional thermo-mechanical properties and superior wear resistance AISI D2 tool steel are finding widespread applications in a lot of manufacturing industries. WEDM is one of the highly developed and sophisticated methods for making of intricate shapes and convoluted details as required for dies and punches. For efficient machining, the need of optimization and appropriate choices of process parameters such as Material Removal Rate and Surface Roughness is utmost goal.

Keywords: Wire Electro Discharge Machining (WEDM); Micro-machining; Residual Stresses; AISI D2 tool steel Feed Rate.

1. Introduction
Wire electric discharge machining (WEDM) technique can machine everything that is electrically conductive in spite of the hardness where electric discharge occurs between an electrode wire which is constantly feed to the machining zone and a work piece detached by a flow of dielectric fluid ShajanKuriakose et al. resulting into the cutting of work piece in a required formation. The thin wire actually feed through the work piece constantly by microprocessors that enable part of intricate shapes to be machined with extremely high precision Vamsi Krishna et al.

![Figure 1. WEDM Machining Process](image-url)
Figure 2. WEDM Machine

WEDM makes use of electrical energy between the two terminals and changes it to heat energy at a temperature in the range of 8000 °C -12,000 °C to melt the workpiece through heat energy of an arc along with removal of machining dust. The remains resulting from the melting and or vapourization of surface of workpiece as well as the EDM wire electrode is enclosed in gaseous covering. This plasma ultimately quenched by the dielectric fluid to from solid debris and consequently leaves no residual burrs on the workpiece. Due to the excellent precision the process reduces or completely eliminates the need for following finishing operations. Also, the WEDM wire actually doesn’t touch the workpiece and has to make a number of machining passes alongside the contour to be machined to attain the necessary dimensional precision and surface finish. Thus, no stresses generated due to physical pressure on the workpiece as compared to machining through grinding wheels or milling cutters etc. WEDM also eliminates the requirement for sophisticated preshaped electrodes as are generally essential in EDM for roughing and finishing operations Klocke et al.

Figure 3. WEDM Machine Programming
Now a day’s WEDM processes are generally conducted on the work pieces completely submerged in a tank filled with dielectric fluid. The submerged technique of WEDM has an advantage of thermal stability and effective flushing particularly in the case where work piece has changeable dimensions. To enhance the exactness of the finishing operations, the possibility of conducting dry WEDM in gas atmosphere without using dielectric fluid tested by Kunieda and Furudate. The dielectric fluid within the sparking zone of WEDM can have deionised water as an alternative to hydrocarbon oil. Although it is inappropriate for conventional EDM due to quick electrode wear however, the low viscosity and high cooling rate of deionised water makes it a candidate for WEDM.

![Figure 4. Work piece](image)

The WEDM material removal rate and surface integrity etc can get affected by various process parameters such as

- polarity
- gap voltage
- discharge current
- Feed control mechanism
- pulse duration and frequency
- wire electrode (type, diameter and feed of wire)
- work piece material (structure, conductivity, thickness)
- dielectric liquid (type, impurities, flow rate, temperature)

For enhancing the value of goods manufactured particularly in the improvement of designs for studying the deviations and choices of process parameters with separation of control and noise factors a statistical way has been suggested by Taguchi. The nullification of the effect of noise factors are to be taken care by proper selection of control factors. To carry out the set of experiments, Orthogonal Arrays (OA) are used that can give the absolute information of all the factors affecting performance parameters along with analysis of data and prediction of the quality of components to be produced. Genetic algorithms also have been used to evaluate the maximum or minimum of a function.

| S. No | Properties                  | Units   | Value     |
|-------|-----------------------------|---------|-----------|
| 1     | Hardness                    | HRC     | 64        |
| 2     | Density                     | g/cm³   | 7.7       |
| 3     | Melting Point               | K       | 1694      |
| 4     | Thermal Conductivity        | W/m K   | 20        |
| 5     | Modulus of Elasticity       | GPa     | 190-210   |
| 6     | Compressive yield strength  | MPa     | 1650-2200 |
2. Experimental Setup

2.1. Machine Specification and Setup

| Specification                  | Details                                      |
|--------------------------------|----------------------------------------------|
| Machine Name                  | ELECTRA SUPERCUT 734                        |
| Cutting Tool Material         | Zinc Coated Brass Wire                       |
| Diameter of Wire              | 0.25mm                                       |
| Wire Feed Rate                | 3mm/min                                      |
| Work piece material           | D2 tool steel                                |
| Work piece dimension          | 160mmx80mmx8mm                               |
| Number of holes               | 9                                            |
| Hole dimension                | 10mmx10mmx8mm                                |

A program was developed by using Auto CAD and following are process parameters of wire EDM process and need to be understood:

i. **Pulse on time** ($T_{ON}$-$\mu$s): The voltage applied across the electrodes. $T_{ON}$ setting is directly related to the pulse on period.

ii. **Pulse off time** ($T_{OFF}$-$\mu$s): No voltage is applied for the gap during this period. $T_{OFF}$ setting is also directly related to the pulse off period.

iii. **Peak current** (I-$\text{Ampere}$): Peak current is the maximum value either positive or negative that a waveform attains.

iv. **Servo feed rate** (mm/min): It is the relative velocity at which cutter is advanced along the work piece.

| Experiment Number | Peak current (I-$\text{Ampere}$) | Servo feed rate (mm/min) | Pulse on time ($T_{ON}$-$\mu$s) | Pulse off time ($T_{OFF}$-$\mu$s) |
|-------------------|----------------------------------|--------------------------|----------------------------------|-----------------------------------|
| 1                 | 120                              | 1015                     | 18                               | 56                                |
| 2                 | 120                              | 1018                     | 22                               | 50                                |
| 3                 | 120                              | 1020                     | 25                               | 45                                |
| 4                 | 150                              | 1015                     | 22                               | 45                                |
| 5                 | 150                              | 1018                     | 25                               | 56                                |
| 6                 | 150                              | 1020                     | 18                               | 50                                |
| 7                 | 180                              | 1015                     | 25                               | 50                                |
| 8                 | 180                              | 1018                     | 18                               | 45                                |
| 9                 | 180                              | 1020                     | 22                               | 56                                |

| Process Parameter       | Level 1 | Level 2 | Level 3 |
|-------------------------|---------|---------|---------|
| Peak current(I-$\text{Ampere}$) | 120     | 150     | 180     |
| Servo feed rate(mm/min) | 1015    | 1018    | 1020    |
| Pulse on time($T_{ON}$-$\mu$s) | 18      | 22      | 25      |
| Pulse off time($T_{OFF}$-$\mu$s) | 56      | 50      | 45      |
2.2. Measurement of Surface Roughness

Surface finish or surface texture comprises of the small local deviations of a surface from the perfectly flat plane. Following are the number of useful techniques for measuring surface roughness.

i. Observation or Touch method

ii. Stylus based equipment method

iii. Interferometry method

![Figure 5. Surface Roughness Testing Machine](image)

Stylus equipment method was used for study, as it can track minute changes in surface height along with large changes in surface height with the help of a skid.

2.3. Measurement of Material Removal Rate (MRR)

Ratio of the volume of material removed to the machining time is the Material removal rate (MRR) and is given by:

\[
MRR \ (mm^3/\min) = \text{Cutting speed} \times \text{Width of cut} \times \text{Height of work piece}
\]

Application/Software Packages

1. Minitab is simple and effective software for statistical data input, its manipulation for identification of trends as well as patterns and then extrapolation of answers to the problem.

2. Matlab is numerical computing software that allows manipulation of matrix, mathematical data and function plots, algorithm implementation and many other creations of interfaces written in languages such as C, C++, Java, FORTRAN, and Python etc.

| Experiment Number | Peak current (I_p) (Ampere) | Servo feed rate (mm/min) | Pulse on time (T_on - μs) | Pulse off time (T_off - μs) | Material Removal Rate (MATERIAL REMOVAL RATE) | Surface Roughness (SURFACE ROUGHNESS) |
|-------------------|-----------------------------|--------------------------|---------------------------|----------------------------|---------------------------------------------|----------------------------------------|
| 1                 | 120                         | 1015                     | 18                        | 56                         | 5.68                                        | 1.70                                   |
| 2                 | 120                         | 1018                     | 22                        | 50                         | 6.38                                        | 2.45                                   |
| 3                 | 120                         | 1020                     | 25                        | 45                         | 6.54                                        | 2.20                                   |
| 4                 | 150                         | 1015                     | 22                        | 45                         | 7.80                                        | 1.64                                   |
3. Results and Discussion
Experiments were performed by using MINITAB and MATLAB software and it is shown in tabulated form.

3.1. Effects of process parameters on Surface Roughness

|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 5 | 150 | 1018 | 25 | 56 | 8.27 | 1.62 |
| 6 | 150 | 1020 | 18 | 50 | 6.94 | 2.10 |
| 7 | 180 | 1015 | 25 | 50 | 7.82 | 1.52 |
| 8 | 180 | 1018 | 18 | 45 | 7.34 | 1.85 |
| 9 | 180 | 1020 | 22 | 56 | 8.66 | 2.15 |

**Figure 6.** Graph of Process Parameters for Surface Roughness

3.2. Graph of Peak Current for Surface Roughness

**Figure 7.** Graph of Peak Current for Surface Roughness
3.3. Graph of Servo Feed Rate for Surface Roughness

![Graph of Servo Feed Rate for Surface Roughness](image1)

**Figure 8.** Graph of Servo Feed Rate for Surface Roughness

3.4. GRAPH OF T\text{ON} FOR SURFACE ROUGHNESS

![Graph of T\text{ON} for Surface Roughness](image2)

**Figure 9.** Graph of T\text{ON} for Surface Roughness
3.5. GRAPH OF $T_{OFF}$ FOR SURFACE ROUGHNESS

![Graph of $T_{OFF}$ for Surface Roughness](image)

**Figure 10.** Graph of $T_{OFF}$ for Surface Roughness

| S. No | Process Parameters | Correlation Coefficient |
|-------|--------------------|--------------------------|
| 1     | Peak current (I_p-Ampere) | -0.373                  |
| 2     | Servo feed rate(mm/min)    | 0.725                    |
| 3     | Pulse on time($T_{ON}$-μs) | -0.107                  |
| 4     | Pulse off time ($T_{OFF}$-μs) | -0.112                 |

3.6. PROCESS PARAMETERS GRAPH FOR MATERIAL REMOVAL RATE

![Graph of Process Parameters for MATERIAL REMOVAL RATE](image)

**Figure 11.** Graph of Process Parameters for MATERIAL REMOVAL RATE
3.7. **GRAPH OF PEAK CURRENT FOR MATERIAL REMOVAL RATE**

![Graph of Normal Probability Plot, Residuals Versus Fits, Histogram, and Residuals Versus Order for MRR.](image)

**Figure 12.** Graph of Peak Current for MATERIAL REMOVAL RATE

3.8. **GRAPH OF SF FOR MATERIAL REMOVAL RATE**

![Graph of Normal Probability Plot, Residuals Versus Fits, Histogram, and Residuals Versus Order for MRR.](image)

**Figure 13.** Graph Of SF For MATERIAL REMOVAL RATE
3.9. GRAPH OF T\text{ON} FOR MATERIAL REMOVAL RATE

![Figure 14. Graph of T\text{on} for MATERIAL REMOVAL RATE](image)

3.10. GRAPH OF T\text{OFF} FOR MATERIAL REMOVAL RATE

![Figure 15. GRAPH OF TOFF FOR MATERIAL REMOVAL RATE](image)

Table 6. Correlation coefficient values for Material Removal Rate

| S. No | Process Parameters | Correlation Coefficient |
|-------|--------------------|-------------------------|
| 1     | Peak current (I\text{p-Ampere}) | 0.779                   |
| 2     | Servo feed rate(mm/min) | 0.130                   |
| 3     | Pulse on time(T\text{ON}-\mu s) | 0.419                   |
| 4     | Pulse off time (T\text{OFF}-\mu s) | 0.148                   |
4. Conclusion

- **For Material Removal Rate (MATERIAL REMOVAL RATE)**
  - Peak current ($I_P$) > Pulse on time ($T_{ON}$) > Pulse off time ($T_{OFF}$) > Servo feed rate

- **For Surface Roughness (SURFACE ROUGHNESS)**
  - Servo feed rate > Pulse off time ($T_{OFF}$) > Pulse on time ($T_{ON}$) > Peak current ($I_P$)

- Knowledge of optimized process parameters opens the way for automation. This process can now be automated for D2 Tool Steel.

- The procedure can be useful for automating various hard and difficult to machine materials.

- It is very effective, useful and potent technique and has ample amount of scope in future.

5. References

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