Optimization of process parameters for Surface Roughness and Material Removal Rate of H13 die tool steel for wire EDM using Taguchi Technique

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Abstract. In this paper, Study on Material expulsion rate and Surface Roughness of H13 die tool using Wire cut EDM process is focused. H 13 chromium hot work steel is far and wide used in hot and freezing work tooling purpose. Due to its excellent amalgamation of high robustness and fatigue resistance H13 is used more than any supplementary tool steel in tooling applications. The H-13 hot die-hard substance dimension 103.70 mm x 13.95 mm has been utilized as a work section substance in favor of the current research, wire electrode of brass having standard diameter 0.25 mm is used as electrode. Four Parameters (Ton, Toff, WF and voltage) are chose to consider its impact on cutting rate and surface harshness. Taguchi Plan of technique is used in the experimentation & analyze by Minitab 15 programming. Observations brings voltage is the most noteworthy boundaries on SR where Ton and Toff are less critical and also observed that MRR amplify with enhance in Ton and WF and diminish on escalating of Vg and Toff.

Keywords: WEDM, H-13 Die tool steel, MRR, Surface roughness, Taguchi technique.

1. Introduction
The development within the production sector have created new span to different company such as aerospace automobile and many other industrial that require accuracy in their respective product. There are many more new machines have been introduced to change old method in machining process. Machine capacity also improves because now a day almost all firm need accuracy and reduce in the machining time. Now a day non-conventional machining is used by many production firms. Unconventional method is work with the high force, without any tool wear and it is also the environment friendly process as compared to conventional methods of machining. Metal chips are not deal in this action and on basis of electrode only water is used. (Wire-EDM), water jet cutting, die sink, laser cutting are unconventional methods which are used in many firms.

Now a days in automotive industry like die making, aerospace etc. materials having lofty robustness, high rigidity and high contact resistance are in greater demand. But most of the traditional machining methods make it difficult to machine such materials. Thus, for machining such materials nontraditional machining methods are applied which includes electrochemical machining, ultrasonic machining, electro discharge machining, electro chemical grinding, laser beam machining etc.

2. Literature survey
T.A. Duc et.al [1] proposed an investigation because of procedure boundaries on the machining time in WEDM of 9CrSi instrument steel. Likewise, by experiment the impacts of the info boundary including
the cutting voltage, TON, TOFF, Vg, WF and the CR on the machining time were assessed.

S. Dhiman et.al [2] studies the impacts of different control variables for S7 steel on CNC-wire cut EDM. This paper realized the impact on cutting pace of S7 steel by various procedure boundaries like TON, TOFF, Vg, IP, line feed, line pressure. OFAT strategy is utilized in this. There is an increment in cutting rate with increment in ton and peak current. Cutting rate is turn down with increment of heartbeat span and servo gap voltage.

Jaganathan [3] this paper explored the impacts of various info boundaries on MRR and surface harshness and finally by utilizing Taguchi streamlining method the outcome is gotten.

J.J. Singh et.al [4] represents the Impacts of Procedure Boundaries on MRR and SR in WEDM of P20 Apparatus Steel by Taguchi strategy. From this outcome most transcendent elements for the greatest material evacuation rate which is 22.21 mm3/min and ton is 125 μs, anyway rest three variables (voltage 20V, beat off time 40μs and wire feed 7mm/min) has less effect as contrast with the prevalent components. The most prevalent elements for Least surface harshness which is 0.89μm heartbeat on time 115μs and voltage 60V. In any case, rest three variables beat off time 60 μs and wire feed 7mm/min has less effect as contrast with the dominating elements.

C.Cogun et.al [5] paper examines the impact on kerf width and MRR by adjusting machining boundaries on Taguchi test plan technique. To discover critical boundaries ANOVA technique is utilized and by S/N proportion ideal machining boundary blend was gotten. The goal is to discover least kerf with greatest MRR. Based on the ANOVA profoundly powerful boundary on kerf and MRR is open circuit voltage and heartbeat term, while less compelling components are wire pace and dielectric flushing stress.

Chang et.al [6] paper introduced for deciding the ideal boundaries setting of WEDM process the utilization of gray relation and S/N proportion examination. The outcomes indicated that by the table feed rate and TON the MRR and surface harshness are prejudiced.

Surinder Kumar and Parveen Kumar [7] analyzed outcomes utilizing S/N ratio, reaction table &response graphs with assistance Minitab-16 programming. Process parameters were set and O.A L16 was chosen for analysis to get results for material expulsion rate. It has been discovered that the most extreme MRR of 25.892 mm3/min is accomplished in trial 13 at TON (120μs), TOFF (25 μs), wire feed (11 kgf) and voltage (40 volts).

A. Alias et.al [8] studies the Kuriachen Basil Flash hole advancement of WEDM process on Ti6Al4V. In this investigation the impact of voltage, dielectric process, Ton and Toff on sparkle fissure of Ti6Al4V composite is examined. The cooperation of dielectric weight and association of Ton & Toff are the most influencing boundaries for flash hole.

A. Kumar [9] The exploratory arrangement depends on Six boundaries for example TON, TOFF, peak current, Vg, WF and wire strain has been modified to inspect their brunt on SR. In this work, it was explanation that the facade ruggedness was disappearance since 2.48 μm to 2.62 μm during WEDM of unadulterated titanium.

B. Bhattacharyya et.al [10] paper presents a survey of gamma-titanium aluminized alloy on WEDM. A broad exploration study has been done to get the ideal surface completion and dimensional exactness with a plan to choose the ideal critical circumstance with a suitable cable counteract setting. Puri et.al [11] utilized Taguchi system including thirteen organize feature with 3 stage in favor of a symmetrical cluster L27 to discover the fundamental boundaries that influence the diverse machining models, for example, normal cutting velocity, surface harshness esteems and the geometrical incorrectness caused because of wire slack.

R. Garg et.al [12] researches the bang of procedure boundaries on MRR of WEDM. It discovered that with increment in Pulse on time and peak current there is straightforwardly increments in MRR while Vg and TOFF diminishes.

3. Methodology
3.1. Experimental design strategy
Taguchi has given the concept of orthogonal array (OA) for lying out of experiments. In this research work by the help of this orthogonal array we will able to get the optimum result with the use of minimum
number of experiments. It basically works on the number of factors and number of levels. It’s basic formula for getting DOE is to level to the power factor so if we not use this technique then we have to do full factorial method which is very complicated and time consumption.

Taguchi shows diverse routes to bring out the entire appraisal. First the usual approach, where in the end result of a solitary run or the frequent of rhythmic runs are processed through principal effect and ANOVA evaluation (Raw statistics analysis). The 2nd method which Taguchi robustly propose for more than one runs is to use S/N for the same steps in the analysis. The S/N ratio is the important function which we use in this research work generally there are three methods for getting S/N ratio we will use it according to our goal of experiment:

   a) Larger is better
   b) Nominal is better
   c) Smaller is better

**Material removal rate**
MRR is measured during the experimental work on WEDM.

\[ \text{MRR} = \text{Diameter of wire} \times \text{Diameter of work piece} \times \text{Feed rate of machine} \]

by this method we get the values of MRR. Figure 1 shows surface roughness tester.

![Surface roughness tester](image)

**Figure 1.** Mitutoyo Surftest SJ-210 - Apparatus for Testing Surface Roughness.

### 4. Process parameters and levels

In this work, four process parameters are selected to study its effects on cutting rate and surface roughness. The ranges of the parameters are shown in the table and selected process parameters and their four factors with four levels are shown in table below:

| Parameters                  | 1    | 2    | 3    | 4    |
|-----------------------------|------|------|------|------|
| Pulse ON Time (μs)          | 105  | 110  | 115  | 120  |
| Pulse OFF Time (μs)         | 25   | 35   | 40   | 45   |
| Wire Feed (mm/min)          | 5    | 7    | 9    | 11   |
| Servo Voltage (V)           | 35   | 40   | 45   | 50   |

| Parameters                  | 1    | 2    | 3    | 4    |
|-----------------------------|------|------|------|------|
5. Experimentation
The research was approved on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Step Tool which is shown in figure 2. To study the effects on Material expulsion rate and surface roughness by setting different inputs process variables of pulse ON time, pulse OFF time, wire feed and voltage. In this work wire electrode of brass having standard diameter 0.25 mm is used as electrode. The H-13 hot die hard substance dimension 103.70 mm x 13.95 mm has been utilize as a work section substance in favor of the current research. Workpiece diameter and length were 13.95mm and 103.70mm respectively. The weight of the workpiece was 494 gm. Figure 3 & figure 4 shows workpiece diameter and length respectively before wire cut electric discharge machining. Figure 5 shows H13 workpiece after machining.

Figure 2. WEDM Machine.
Figure 3. Work Piece Diameter.

Figure 4. Work Piece Length.

Figure 5. 16 Work Piece after machining.
### Table 3. Experimental Results of Surface Roughness and MRR.

| Serial No. | Pulse ON Time (μs) | Pulse OFF Time (μs) | Wire Feed (mm/min) | Servo Voltage (V) | Surface Roughness (μm) | MRR (mm³/min) |
|------------|--------------------|---------------------|---------------------|-------------------|------------------------|---------------|
| 1          | 105                | 25                  | 5                   | 35                | 1.985                  | 2.929         |
| 2          | 105                | 35                  | 7                   | 40                | 2.362                  | 2.301         |
| 3          | 105                | 40                  | 9                   | 45                | 2.650                  | 2.057         |
| 4          | 105                | 45                  | 11                  | 50                | 2.895                  | 1.395         |
| 5          | 110                | 25                  | 7                   | 45                | 3.601                  | 4.289         |
| 6          | 110                | 35                  | 5                   | 50                | 4.057                  | 3.836         |
| 7          | 110                | 40                  | 11                  | 35                | 1.850                  | 3.696         |
| 8          | 110                | 45                  | 9                   | 40                | 3.257                  | 3.243         |
| 9          | 115                | 25                  | 9                   | 50                | 4.518                  | 5.301         |
| 10         | 115                | 35                  | 11                  | 45                | 1.897                  | 5.091         |
| 11         | 115                | 40                  | 5                   | 40                | 3.166                  | 4.219         |
| 12         | 115                | 45                  | 7                   | 35                | 2.495                  | 3.627         |
| 13         | 120                | 25                  | 11                  | 40                | 2.154                  | 8.997         |
| 14         | 120                | 35                  | 9                   | 35                | 1.750                  | 7.951         |
| 15         | 120                | 40                  | 7                   | 50                | 2.013                  | 6.172         |
| 16         | 120                | 45                  | 5                   | 45                | 2.957                  | 4.840         |

6. Results and Discussion

#### 6.1. Taguchi analysis for Surface Roughness

Smallest the Better formula

\[(S/N)_{SB} = -10 \log (MSDSB)\]

Where \[MSDSB = \frac{1}{n} \sum (i=1)^n (R_a)^2\]

\[Ra = \text{Response of Surface Roughness}\]

\[N = \text{Number of experiments}\]

Experimental factors along with their levels

| Factors | Parameters         | Levels                     |
|---------|--------------------|----------------------------|
| A       | Pulse ON Time(μs)  | 105,110,115,120            |
| B       | Pulse OFF Time(μs) | 25,35,40,45                |
| C       | Wire Feed (mm/min) | 5,7,9,11                  |
| D       | Servo Voltage(v)   | 35,40,45,50                |

#### 6.1.1. Results and discussion for Surface Roughness of S/N and Mean

| Levels | S/N ratio of Surface Roughness on T<sub>on</sub> | S/N ratio of Surface Roughness on T<sub>off</sub> | S/N ratio of Surface Roughness on Wire Feed | S/N ratio of Surface Roughness on Servo Voltage |
|--------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------|-----------------------------------------------|
| 1      | -7.780                                        | -9.212                                        | -9.409                                    | -6.025                                        |
| 2      | -9.962                                        | -7.513                                        | -8.153                                    | -8.599                                        |
| 3      | -10.002                                       | -7.417                                        | -9.170                                    | -8.655                                        |
| 4      | -7.134                                        | -9.234                                        | -6.701                                    | -10.143                                       |
| Delta  | 2.868                                         | 1.760                                         | 2.708                                     | 4.118                                         |
| Rank   | 2                                              | 4                                             | 3                                         | 1                                             |
Table 6. Response table for Mean.

| Levels | Mean of Surface Roughness on T_on | Mean of Surface Roughness on T_off | Mean of Surface Roughness on Wire Feed | Mean of Surface Roughness on Servo Voltage |
|--------|----------------------------------|-----------------------------------|---------------------------------------|------------------------------------------|
| 1      | 2.473                            | 3.064                             | 3.049                                 | 2.020                                    |
| 2      | 3.191                            | 2.517                             | 2.618                                 | 2.735                                    |
| 3      | 3.019                            | 2.420                             | 3.044                                 | 2.784                                    |
| 4      | 2.226                            | 2.909                             | 2.199                                 | 3.371                                    |
| Delta  | 0.965                            | 0.645                             | 0.850                                 | 1.351                                    |
| Rank   | 2                                | 4                                 | 3                                     | 1                                        |

6.1.2. Main effect plots for surface roughness

![Figure 6. Main effects plot for S/N ratio.](image)

![Figure 7. Main effect plot for mean.](image)
Table 7. Orthogonal Array sheet.

| Serial No. | Pulse Time (μs) | Pulse OFF Time (μs) | Wire Feed (mm/min) | Servo Voltage (v) | Surface Roughness (µm) | MRR (mm³/min) | S/N Ratio (dB) |
|------------|----------------|---------------------|-------------------|------------------|------------------------|----------------|----------------|
| 1          | 105            | 25                  | 5                 | 35               | 1.985                  | 2.929          | -5.9552        |
| 2          | 105            | 35                  | 7                 | 40               | 2.362                  | 2.301          | -7.4656        |
| 3          | 105            | 40                  | 9                 | 45               | 2.650                  | 2.057          | -8.4649        |
| 4          | 105            | 45                  | 11                | 50               | 2.895                  | 1.395          | -9.2330        |
| 5          | 110            | 25                  | 7                 | 45               | 3.601                  | 4.289          | -               |
| 6          | 110            | 35                  | 5                 | 50               | 4.057                  | 3.836          | 11.1285        |
| 7          | 110            | 40                  | 11                | 35               | 1.85                   | 3.696          | -5.3434        |
| 8          | 110            | 45                  | 9                 | 40               | 3.257                  | 3.243          | 10.2564        |
| 9          | 115            | 25                  | 9                 | 50               | 4.518                  | 5.301          | -              |
| 10         | 115            | 35                  | 11                | 45               | 1.897                  | 5.091          | -5.5613        |
| 11         | 115            | 40                  | 5                 | 40               | 3.166                  | 4.219          | 13.0989        |
| 12         | 115            | 45                  | 7                 | 35               | 2.495                  | 3.627          | -7.9414        |
| 13         | 120            | 25                  | 11                | 40               | 2.154                  | 8.997          | -6.6649        |
| 14         | 120            | 35                  | 9                 | 35               | 1.750                  | 7.951          | -4.8608        |
| 15         | 120            | 40                  | 7                 | 50               | 2.013                  | 6.172          | -6.0769        |
| 16         | 120            | 45                  | 5                 | 45               | 2.987                  | 4.840          | -9.5047        |

From the above research on SR to get optimum assessment while using smaller is better signal to noise ratio. The worth of surface roughness amplify with a raise in WF, Ton and diminish with enhance in voltage and Toff. So, optimum value of surface coarseness is 1.420 µm.

Table 8. Optimum parameter for Surface Roughness.

| Pulse Time(μs) | Pulse OFF Time(μs) | Wire Feed (mm/min) | Servo Voltage (v) | Surface Roughness (µm) |
|----------------|--------------------|--------------------|-------------------|------------------------|
| 110            | 45                 | 5                  | 50                | 1.420                  |

6.2. Taguchi analysis for Material Removal Rate
MRR affect the parameters viz. $T_{on}$, $T_{off}$, WF, Vg. Optimum constraint are accomplished for MRR with the help out of “Minitab 15 software”. S/N Ratio table and mean table are detecting. Larger the Better

$$(S/N)_{LB}= -10\log (MSDLB)$$

Where $MSDLB= 1/n \sum_{i=1}^{n} (S/N^2)/(MRR^2)$

$MRR=$ Response of Material Removal Rate

n = Number of experiments
6.2.1. Results and Discussion for MRR of S/N and Mean Table:

Table 9. Response table for Signal to Noise Ratios Larger is better.

| Levels | S/N ratio of MRR on T_{on} | S/N ratio of MRR on T_{off} | S/N ratio of MRR on Wire Feed | S/N ratio of MRR on Servo Voltage |
|--------|-----------------------------|-----------------------------|-----------------------------|---------------------------------|
| 1      | 5.786                       | 13.888                      | 11.803                      | 12.472                          |
| 2      | 11.121                      | 12.765                      | 11.721                      | 12.261                          |
| 3      | 12.879                      | 11.483                      | 12.245                      | 11.686                          |
| 4      | 16.193                      | 9.500                       | 11.866                      | 11.216                          |
| Delta  | 10.407                      | 4.388                       | 0.524                       | 1.256                           |
| Rank   | 1                           | 2                           | 4                           | 3                               |

Table 10. Response table for Mean.

| Levels | Mean MRR Of Surface Roughness on T_{on} | Mean MRR Of Surface Roughness on T_{off} | Mean MRR Of Surface Roughness on Wire Feed | Mean MRR Of Surface Roughness on Servo Voltage |
|--------|-----------------------------------------|------------------------------------------|-------------------------------------------|-----------------------------------------------|
| 1      | 2.171                                   | 5.379                                    | 3.956                                     | 4.551                                         |
| 2      | 3.766                                   | 4.795                                    | 4.097                                     | 4.690                                         |
| 3      | 4.559                                   | 4.036                                    | 4.638                                     | 4.069                                         |
| 4      | 6.990                                   | 3.276                                    | 4.795                                     | 4.176                                         |
| Delta  | 4.819                                   | 2.103                                    | 0.839                                     | 0.621                                         |
| Rank   | 1                                       | 2                                       | 3                                        | 4                                             |

6.2.2. Main effect plots for MR:

Figure 8. Main effects plot for S/N ratio.
From this it is conclude that best MRR is getting by above MRR research is 9.235mm³/min and as well as amplify Ton, and wire feed as MRR increases. But MRR decline with enhancement in Toff and Vg.

Table 11. Experimental values for MRR on S/N RATIO.

| Sr No. | Pulse ON Time (μs) | Pulse OFF Time (μs) | Wire Feed (mm/min) | Servo Voltage (v) | MRR (mm³/min) | S/N Ratio(dB) |
|--------|--------------------|---------------------|--------------------|-------------------|---------------|---------------|
| 1      | 105                | 25                  | 5                  | 35                | 2.929         | 9.3344        |
| 2      | 105                | 35                  | 7                  | 40                | 2.301         | 7.2383        |
| 3      | 105                | 40                  | 9                  | 45                | 2.057         | 6.2747        |
| 4      | 105                | 45                  | 11                 | 50                | 1.395         | 2.8915        |
| 5      | 110                | 25                  | 7                  | 45                | 4.289         | 12.6471       |
| 6      | 110                | 35                  | 5                  | 50                | 3.836         | 11.6776       |
| 7      | 110                | 40                  | 11                 | 35                | 3.696         | 11.3546       |
| 8      | 110                | 45                  | 9                  | 40                | 3.243         | 10.2189       |
| 9      | 115                | 25                  | 9                  | 50                | 5.091         | 14.4872       |
| 10     | 115                | 35                  | 11                 | 45                | 5.431         | 14.1361       |
| 11     | 115                | 40                  | 5                  | 40                | 4.219         | 12.5042       |
| 12     | 115                | 45                  | 7                  | 35                | 3.627         | 11.1910       |
| 13     | 120                | 25                  | 11                 | 40                | 8.997         | 19.0820       |
| 14     | 120                | 35                  | 9                  | 35                | 7.951         | 18.0084       |
| 15     | 120                | 40                  | 7                  | 50                | 6.172         | 15.8085       |
| 16     | 120                | 45                  | 5                  | 45                | 4.840         | 13.6969       |

Table 12. Optimum parameter for MRR.

| Pulse ON Time (μs) | Pulse OFF Time (μs) | Wire Feed (mm/min) | Servo Voltage (v) | MRR (mm³/min) |
|-------------------|--------------------|--------------------|-------------------|---------------|
| 120               | 25                 | 9                  | 35                | 9.235         |
7. Conclusion
Investigational analysis on WEDM of H13 die tool steel is executed with a view to link the development consideration with recital measure of SR. The procedure has been effectively displayed utilizing Taguchi plan of technique and investigation is done utilizing Minitab programming. At long last, an endeavor has been made to evaluate the ideal machining conditions to create the most ideal reaction inside the trial imperatives. The present study develops a model for four factors Ton, Toff, WF, V and four levels on H13 tool steel.

It is discovered that all the boundaries and their associations have critical brunt on SR. It is presumed that voltage is the most noteworthy boundaries on SR where Ton and Toff are less critical.

It is bringing into notice that MRR amplify with enhance in Ton and WF and diminish on escalating of Vg and Toff.

The most favorable constraints for SR are as follows: Ton =110 μs, Toff =45 μs, Voltage = 50 volts and WF =5 mm/min.

The finest considerations for MRR are as follow: Ton= 120 μs, Toff =25 μs, Voltage = 35 volts and WF =9 mm/min.

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