# Experimental Investigation Of AISI d3 Steel With Four Input Parameters Using Wire EDM By ANOVA Techniques

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## ABSTRACT

*An experimental study has conducted, in this work to determine statistical models for optimization of process parameters in wire EDM. Wire electrical discharge machining (WEDM) technology has extensively used in the field of medical, mould making, Die making, aerospace and automobile industries. AISI D3 Steel(contains 1.5-1.8% carbon) is the hard material so that cutting by other machining is very difficult. But this cutting process make easy with wire EDM. D3 steel is widely used in making the press dies for cutting and forming operation therefore surface finishing of it is very important. The paper is focusing on to find out the combination of process parameters for optimum surface roughness, material removal rate (MRR), Kerf width and wire wear ratio in wire electro discharge machining (EDM) of AISID3 Steel. The best combination of machining parameter viz. machine feed, voltage, pulse on time and pulse off time. The paper highlights the importance of process parameters and different machining conditions on MRR, surface roughness (Ra), kerf width and surface topography. In this work, machine feed, voltage, pulse on time and pulse off are input parameters and surface roughness ,MRR, kerf width and wire wear ratio as output parameters. The optimal values of these parameters have defined with the aim of achieving the better surface roughness and higher MRR and better WWR.*

*The experiment work had conducted with three input parameters pulse on time, pulse off time, machine feed and voltage, and also its different levels. Full factorial technique had been used for accurate results. ANOVA had been used for the analysis and defined optimum value of input parameters for getting best output on D3 steel.*

**Keyword : -** *WEDM , AISI D3 STEEL, PULSE ON – OFF TIME, VOLTAGE,MRR,SR,WWR,ANOVA*

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### 1.1 INTRODUCTION TO WIRE EDM

Wire EDM was introduced in the late 1960s', has revolutionized the tool and die, mould , and metalworking industries. It is probably the most exciting and diversified machine tool developed for this industry in the last fifty years, and has numerous advantages to offer.

It can machine anything that is electrically conductive regardless of the hardness, from relatively common materials such as tool steel, aluminium, copper, and graphite, to exotic space-age alloys including has inconel, titanium, carbide, polycrystalline diamond compacts and conductive ceramics. The wire does not touch the work piece , so there is no physical pressure imparted on the work piece compared to grinding wheels and milling cutters. The amount of clamping pressure required to hold small, thin and fragile parts is minimal, preventing damage or distortion to the work piece.

The accuracy, surface finish and time required to complete a job is extremely predictable, making it much easier to quote, EDM leaves a totally random pattern on the surface as compared to tooling marks left by milling cutters and grinding wheels. The EDM process leaves no residual burrs on the work piece, which reduces or eliminates the need for subsequent finishing operations.

Wire EDM also gives designers more latitude in designing dies, and management more control of manufacturing, since the machining is completed automatically. Parts that have complex geometry and tolerances don't require you to rely on different skill levels or multiple equipment. Long jobs are cut overnight, or over the weekend, while

shorter jobs are scheduled during the day. Most work pieces come off the machine as a finished part ,without the need for secondary operations. It's a one-step process.
The wire electric discharge machining shortly known as WEDM, is a variation of basically the EDM process and is commonly known as wire cutting. In this process a thin metallic wire is fed into the work piece, which is submerged in a tank of dielectric fluid such as such as de-ionized water. This process can also cut plates as thick as 300 mili meters. Therefore, this is considered to be very useful process. It is also used in making punches, tools and dies from hard metals that are difficult to machine with other metals. The wire, which is constantly fed from a spool is held between the upper and lower diamond guides.

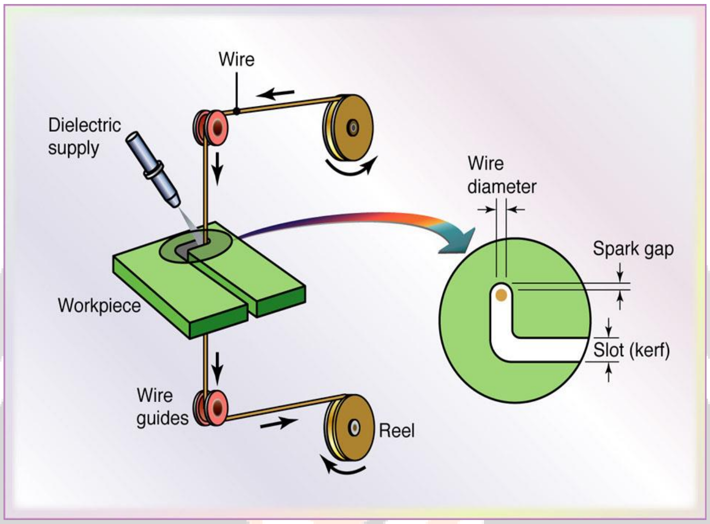


Fig 1.1 wire EDM process

This motions of this work table and hence the work piece can be controlled or programmed through CNC machining device. The WEDM process requires lesser cutting forces in material removal. It is generally used when lower residual stresses in the work piece are desired. If the energy or power for pulse is relatively low, as in the finishing operations, then very little changes in the mechanical properties of the material are expected, due to these low residual stresses. The materials which are not stress relieved earlier can get distorted in the WEDM process.

## 1.2 MECHANISM OF MATERIAL REMOVAL IN WEDM PROCESS

The mechanism of metal removal in wire electrical discharge machining mainly involves the removal of material due to melting and vaporization caused by the electric spark discharge generated by a pulsating direct current power supply between the electrodes. In WEDM, negative electrode is a continuously moving wire and the positive electrode is the work piece. The sparks will generate between two closely spaced electrodes under the influence of dielectric liquid. Water is used as dielectric in WEDM, because of its low viscosity and rapid cooling rate. No conclusive theory has been established for the complex machining process. However, empirical evidence suggests that the applied voltage creates an ionized channel between the nearest points of the work piece and the wire electrodes in the initial stage. In the next stage the actual discharge takes place with heavy flow of current and the resistance of the ionized channel gradually decreases. The high intensity of current continues to further ionize the channel and a powerful magnetic filed is generated. This magnetic field compresses the ionized channel and results in localized heating. Even with sparks of very short duration, the temperature of electrodes can locally rise to very high value which is more than the melting point of the work material due to transformation of the kinetic energy of electrons into heat. The high energy density erodes a part of material from both the wire and work piece by locally melting and vaporizing and thus it is the dominant thermal erosion process.

**Step by step wire cut EDM process:**
**Stage 1:** Power supply generates volts and amps.

- De-ionized water surrounds the wire electrode as the power supply generates volts and amps to produce the spark.

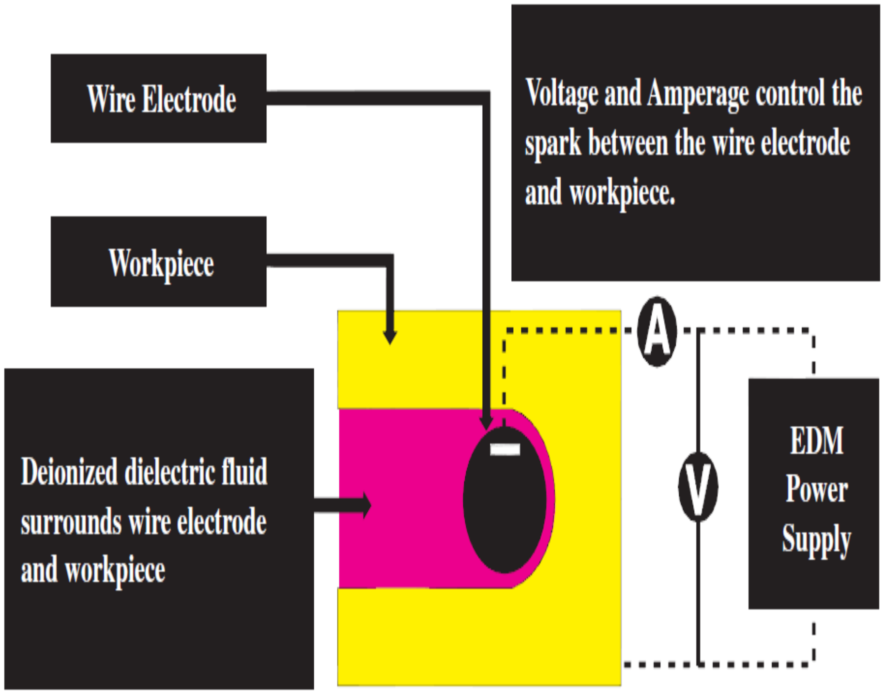


Fig.1.2 WEDM process stage – 1

***Stage 2:*** During on time controlled spark erodes material.

- Spark precisely melt and vaporize the material.

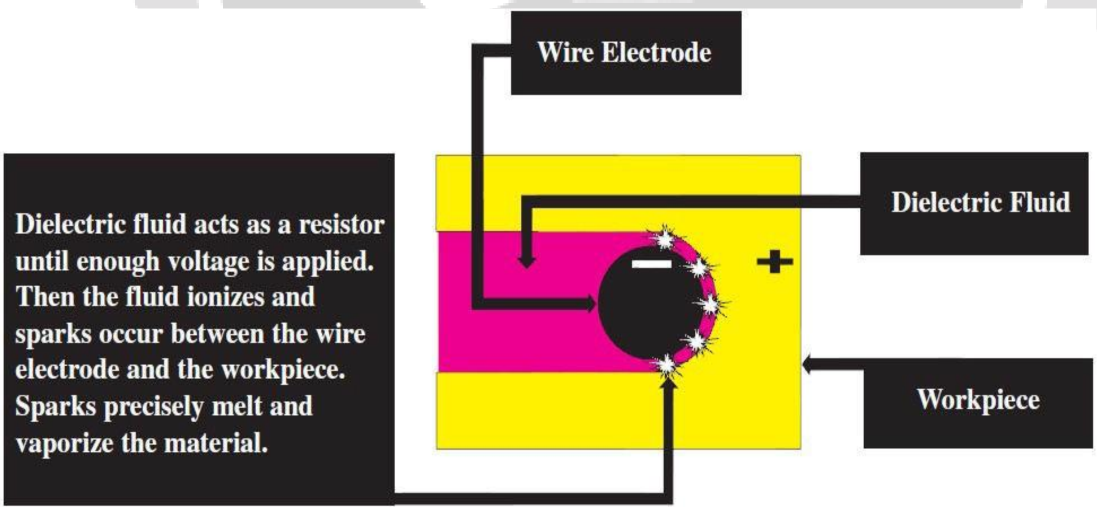


*Fig.1.3 WEDM process stage – 2*

***Stage 3:*** Off time allows fluid to remove erod particles.

- During the off cycle, the pressurized dielectric fluid immediately cools the material and flushes the erod particles.

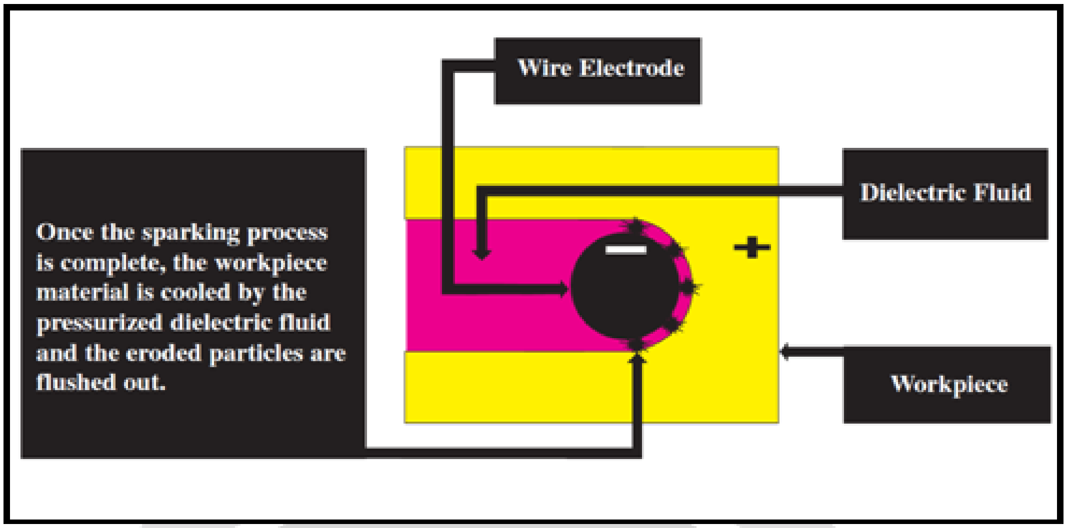


Fig.1.4 WEDM process stage – 3

**Step 4:** The erod particles are removed and separated by a filter system.

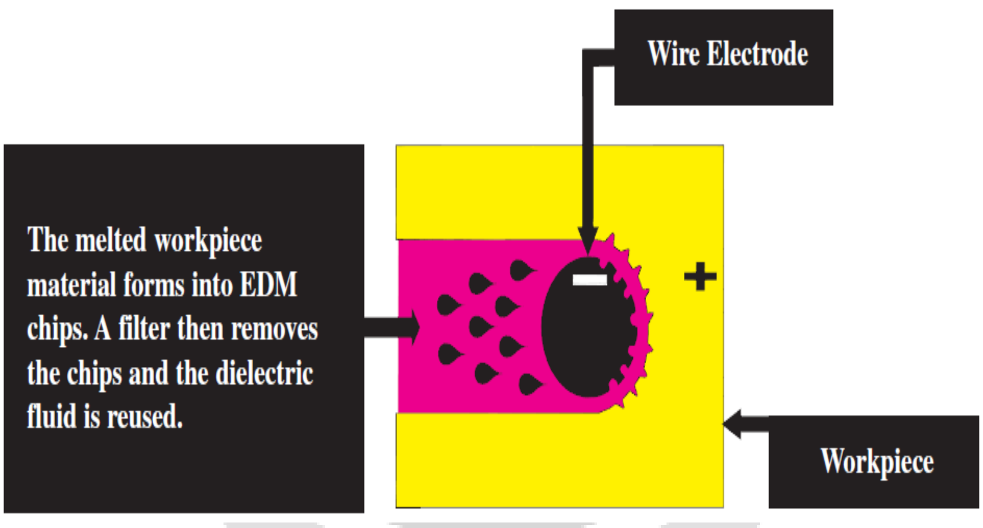


Fig.1.5 WEDM process stage – 4

## LITERATURE REVIEW:

**Aniza Alias et al.(2012).**In this research he worked on machine feed rate in WEDM of titaniumti-6al-4v with constant current (6a) using brass wire. Objective of the paper is to uncover the influence of three different machine rates which are 2 mm/min, 4 mm/min and 6 mm/min with constant current (6A). The effects of different process parameters on the kerf width, material removal rate, surface roughness and surface topography are also discussed. The best combination of machining parameter viz. machine feed rate (4 mm/min), wire speed (8 m/min), wire tension (1.4kg) and voltage (60V) were identified.

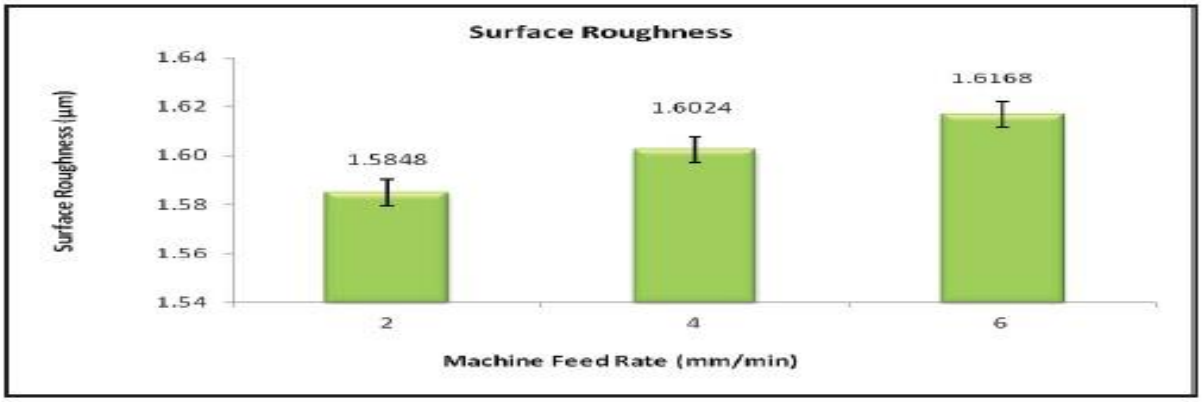


*Fig. 2.1 Result on surface roughness at different machine feed rate*

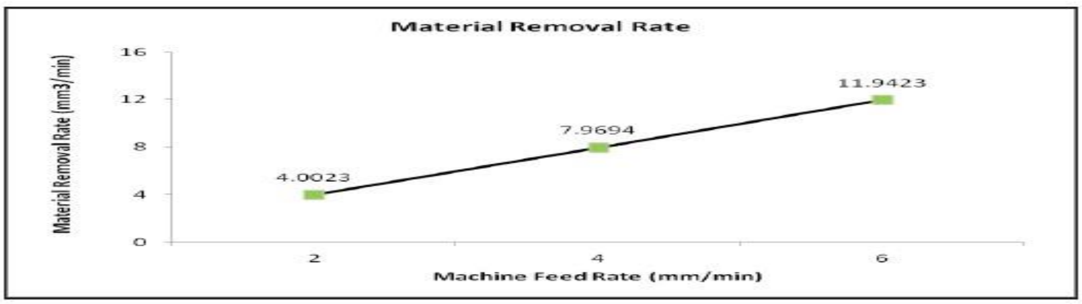


*Fig. 2.2 Result on material removal rate at different machine feed rate*

In this paper the main goal is to find the best combination of machining parameters as known the cost and quality of WEDM which depends heavily on the process parameters. Machine feed rate have been proven to play an important role in this experimental work. Since the low kerf and the high MRR are equally important goals in WEDM, equal machine feed rate are recommended.

**P. Sivaprakasam, P. Hariharan, S. Gowri et al.[13]** investigate the influence of three different input parameters such as voltage, capacitance and feed rate of wire electrical discharge machining (WEDM) performances of material removal rate (MRR), Kerf width (KW) and surface roughness (SR) using response surface methodology. The experiments are carried out on titanium alloy (Ti-6Al-4V). The machining characteristics are significantly influenced by the electrical and non-electrical parameters in WEDM process. Analysis of variance (ANOVA) was performed to find out the significant influence of each factor. The model developed can use a genetic algorithm (GA) to determine the optimal machining conditions. The optimal machining performance of material removal rate, Kerf width and surface roughness are 0.01802 mm3/min, 101.5 mm and 0.789 mm, respectively, using this optimal machining conditions viz. voltage 100 V and feed rate 15 mm/s.

**Amitesh Goswami, Jatinder Kumar et al.[14]**uses Taguchi method for wire electrical discharge machining (WEDM) of Nimonic-80A alloy. The machining characteristics that are being investigated are material removal rate (MRR) and surface roughness (SR). The study makes use of experimentation planned and executed as per Taguchi methodology. The Investigation indicated that material removal rate and surface roughness increases with increase in pulse-on time and decreases with increase in pulse-off time. Significant interactions have been found between pulse-on time and pulse-off time, pulse-on time and peak current , pulse-off time and peak current for material removal rate; and pulse-on time and peak current for surface roughness.

**G. Selvakumar, G. Sornalatha, S. Sarkar, S. Mitra et al.[15]** aims at the selection of the most optimal machining parameter combination for wire electrical discharge machining (WEDM) of 5083 aluminum alloy. Based on the Taguchi experimental design method, a series of experiments were performed by considering pulse-on time, pulse-off time, peak current and wire tension as input parameters. The surface roughness and cutting speed were

considered responses. The influence of the input parameters on the responses was determined. The optimal machining parameters setting for the maximum cutting speed and minimum surface roughness were found using Taguchi methodology.
An experimental investigation on wire electrical discharge machining of 5083 Al alloy was presented. ANOVA test was performed to determine the level of significance of the parameters on the cutting speed and surface roughness. ANOVA revealed that the CS was independent on wire tension and Ra was independent on pulse-off time and wire tension.

**Hsien-Ching Chen et al.(2010).** This study analyzed variation of cutting velocity and work piece surface finish depending WEDM process parameters during manufacture of pure tungsten profiles. He used integration of two method of back propagation neural network (BPNN) and simulated annealing algorithm (SAA).The specimens are prepared under different WEDM process conditions based on a Taguchi orthogonal array table. The results of 18 experimental runs were utilized to train the BPNN predicting the cutting velocity, roughness average (Ra), and roughness maximum (Rt) properties at various WEDM process conditions and then the SAA approaches was applied to search for an optimal setting.
In addition, the analysis of variance (ANOVA) was implemented to identify significant factors for the WEDM process.

The BPNN could be utilized successfully to predict cutting velocity (CV), roughness average (Ra) and roughness maximum (Rt) properties for WEDM process during manufacture of pure tungsten profiles after being properly trained. At the same time, the BPNN prediction models yield smaller MSE after training, namely, the BPNN was gave reasonable prediction in the experimental runs based on the BPNN approach.

**M.durairaj and D sudharshan .**In this paper analysis of process parameters in wire EDM with stainless steel using single objective Taguchi method . The machining characteristics that are being investigated are material removal rate (MRR) and surface roughness (SR) along with surface topography of the machined surface for ss304. The Investigation indicated based on Taguchi optimization of machining that input parameters combination to get the minimum surface roughness are 40Vgap voltage ,2mm/min wire feed , similarly optimized condition to get the minimum kerf width are 50 v. material removal rate and surface roughness increases with increase in pulse-on time and decreases with increase in pulse-off time.

**S.R NITHIN ARVIND , S.SOWMYA IEEE(ICAESM-2012.** In This Paper , Optimization of metal removal rate and surface roughness on Wire EDM using Taguchi Method. This Paper deals with finding five optimal control parameters input voltage, current , speed , pulse on-off time to maximize metal removal rate and minimize surface roughness on wire edm. Wire edm is an electro thermal production process in which a thin single stand metal wire in conjuction with de-ionised water (used to electricity) allows the wire to cut through metal by the use of heat from electrical sparks. For the purpose to get the best solution to maximize MRR and reduced SR ,here they optimize parameters using taguchi method.

**T.TAMIZHARASAN , N.SENTHIL KUMAR IEEE(ICAESM-2012)**. In This Paper deals with the experimental investigation of effects of geometrical parameters of cuttings tool insert and analysis of output responses such as surface roughness and MRR during machining AISI 1045 steel. The analysis is essential ,since the wear ,occurring at the cutting edge of the insert favour the surface roughness at the machine surface. taguchi's designed of experiments (DOE) is used to design the experimental array, based on which experiments were conducted .For 3 parameters and 3 level of each parameters ,L9 orthogonal array is selected. To evaluate the output quality characteristics taguchi method single to noise ratio is used, based on which the optimum condition are determined.
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An interaction effect of one input parameters over another parameters studies to understand their influences on output performance characteristics . analysis of variance (ANOVA) is also performed to study the contribution of individual parameters on the output quality characteristics .

*Fig Shapes of cutting inserts used in turning*

## Work piece Material

*Fig AISID3 die steel work piece plate*

## Chemical composition:

**Table : Composition of WPS Die Steel Material**

| ***Elements*** | ***Weight Limits %*** | ***Actual Weight %*** |
|---|---|---|
| *C* | *1.5-1.8* | *1.5* |
| *Ch* | *10-12* | *12* |
| *V* | *1.00-2.15* | *1.00* |
| *Mo* | *1.00-2.00* | *1.00* |

**Table : Mechanical Properties of AISId3 Tool Steel**

| ***Properties*** | |
|---|---|
| *Density* | *7.70 x 103 kg/m3* |
| *Thermal conductivity* | *40.9-55.2 x10-3cal/cmsoc* |
| *Elastic Modulus* | *173-193Gpa* |
| *Hardness* | *62+-20 RC* |

**Applications:**

- Aerospace,
- Automobile,
- Shipbuilding,
- Valves,
- Pump shafts,
- Heat exchangers
- Moulds and Different types of dies

**Wire material**

Base material: CuZn37%,CuZn35%,CuZn40%

**Property of copper soft wire**

- Copper wire had high electrical conductivity, it would make the ideal EDM wire. Unfortunately, Copper wire has both low tensile strength and low flushability.
- Prevent brass powder sticking
- Reduce wire breakage
- Excellence straightness
- Wire dia.=0.10-0.30mm
- Tensile strength=440-540 N/mm2
- Elongation=20%


Fig wire roll

**Selection of Input and Output Parameters**

There are different input parameters which affect on the output parameters such as pulse on time, pulse off time, wire speed, wire tension, gap voltage, peak current, machine feed, dielectric flow rate etc. There are different output parameters such as material removal rate , surface roughness, kerf width, wire wear ratio, duty cycle depends on input parameters .This experiment include three input parameters pulse on time ,pulse off time and machine feed from the above inputs affect on output parameters such as MRR, surface roughness of AISI D3 steel.

**DESIGN OF EXPERIMENT**

**Objective**

DOE, is used by industry today. Regardless of whether the experimental work takes place in the laboratory, the pilot plant, or the full-scale production plant, design of experiments is useful for three primary experimental objectives, screening, optimization and robustness testing.

Experimental design and optimization are tools that are used to systematically examine different types of problems that arise within. e.g. research, development and production. It is obvious that if experiments are performed randomly the result obtained will also be random. Therefore, it is a necessity to plan the experiments in such a way that the interesting information will be obtained.

Areas where DOE is used in industrial research, development and production:

• Optimization of manufacturing processes
• Optimization of analytical instruments
• Screening and identification of important factors
• Robustness testing of methods
• Robustness testing of products
• Formulation experiments

**4.2What is DOE?**

DOE involves making a set of experiments representative with regards to a given question. The way to do this is, of course, problem dependent, and in reality the shape and complexity of a statistical experimental design may vary considerably. A common approach in DOE is to define an interesting standard reference experiment and then perform new. These new experiments are laid out in a symmetrical fashion around the standard reference experiment. Hence, the standard reference experiment is usually called the centre-point.

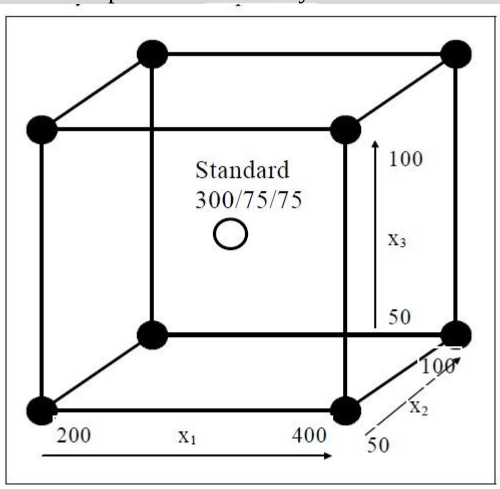



Fig : A symmetrical distribution of experimental points around a center-point experiment.

In the given illustration, the standard operating condition was used as the center-point. It prescribed that the first factor (x1) should be set at the value 300, the second factor (x2) at 75, and the third factor (x3) at 75.

**ANOVA**

Once the mathematical model has been selected, it is important to determine its significance by means of a variance analysis (ANOVA). If the standard deviations present a lower value than the mean values, it is possible to assume that the mathematical model is significant. If this does not happen, the experimental data should be evaluated in order to not presume that the effect is not significant.

- Standard deviation of the estimated parameters and model
- Statistical significance of the estimated parameters
- Regression coefficient
- Value of the objective function
- Significance of the regression (ANOVA)
- Analysis of the residuals.

It is considered a good fit to the experimental data when:

-The standard deviation of the parameter presents a lower value than the correspondent effect, indicating that the standard deviation of the proposed mathematical model is low

-The parameters of a model need to be significant, otherwise they will not contribute to the model.

**DESIGN OF EXPERIMENTAL READING**

Table 4.2Experimental Readings

| Run | *Factor1* | *Factor 2* | *Factor 3* | *Factor4* | *Response1* | *Response 2* | *Response3* | *Response4* |
|---|---|---|---|---|---|---|---|---|
| | *A: Ton* | *B: Toff* | *C:Machine feed* | *D:voltage* | *MRR* | *SR (micro)* | *Kerf width* | *WWR* |
| | *µs* | *µs* | *Mm/min* | *v* | *mgm/min* | *Avg* | *µm* | *Avg* |
| 1 | 108 | 45 | 0.4 | 105 | 74 | 2.778 | 123 | 0.0093 |
| 2 | 108 | 50 | 0.6 | 105 | 74 | 2.787 | 122 | 0.1093 |
| 3 | 108 | 45 | 0.4 | 130 | 83 | 2.810 | 115 | 0.0755 |
| 4 | 108 | 45 | 0.6 | 55 | 101 | 2.960 | 125 | 0.0787 |
| 5 | 108 | 45 | 0.8 | 55 | 102 | 2.963 | 121 | 0.0797 |
| 6 | 108 | 50 | 0.4 | 55 | 78 | 2.793 | 121 | 0.0757 |
| 7 | 108 | 45 | 1.0 | 55 | 104 | 2.964 | 128 | 0.1098 |
| 8 | 108 | 60 | 0.8 | 105 | 85 | 2.812 | 97 | 0.0813 |
| 9 | 108 | 45 | 0.4 | 55 | 98 | 2.786 | 120 | 0.0567 |
| 10 | 108 | 50 | 0.4 | 80 | 76 | 2.811 | 121 | 0.0755 |
| 11 | 108 | 55 | 0.4 | 55 | 90 | 2.855 | 115 | 0.1020 |
| 12 | 108 | 60 | 0.4 | 55 | 85 | 2.821 | 99 | 0.0833 |
| 13 | 108 | 55 | 0.8 | 130 | 90 | 2.857 | 128 | 0.0753 |
| 14 | 108 | 55 | 0.6 | 105 | 104 | 2.967 | 155 | 0.1053 |
| 15 | 108 | 50 | 1.0 | 105 | 123 | 2.934 | 101 | 0.0810 |
| 16 | 108 | 60 | 1.0 | 80 | 119 | 2.899 | 99 | 0.0800 |
| 17 | 112 | 45 | 0.8 | 105 | 65 | 2.684 | 122 | 0.0833 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 18 | 112 | 50 | 1.0 | 105 | 81 | 2.798 | 98 | 0.0803 |
| 19 | 112 | 55 | 0.6 | 80 | 66 | 2.684 | 95 | 0.0700 |
| 20 | 112 | 55 | 0.8 | 55 | 69 | 2.699 | 145 | 0.0907 |
| 21 | 112 | 55 | 1.0 | 130 | 73 | 2.704 | 153 | 0.0743 |
| 22 | 112 | 60 | 0.4 | 55 | 68 | 2.688 | 98 | 0.0884 |
| 23 | 112 | 60 | 0.4 | 55 | 64 | 2.681 | 118 | 0.1027 |
| 24 | 112 | 50 | 0.6 | 80 | 80 | 2.775 | 98 | 0.0908 |
| 25 | 112 | 45 | 0.6 | 80 | 67 | 2.711 | 115 | 0.0832 |
| 26 | 112 | 55 | 0.6 | 80 | 73 | 2.278 | 151 | 0.0800 |
| 27 | 112 | 60 | 0.6 | 80 | 61 | 2.688 | 120 | 0.1020 |
| 28 | 112 | 50 | 0.4 | 80 | 80 | 2.799 | 100 | 0.0980 |
| 29 | 112 | 50 | 0.6 | 80 | 78 | 2.698 | 97 | 0.0977 |
| 30 | 112 | 45 | 0.4 | 55 | 66 | 2.781 | 90 | 0.0811 |
| 31 | 112 | 45 | 0.8 | 130 | 68 | 2.713 | 123 | 0.0899 |
| 32 | 112 | 55 | 1.0 | 80 | 71 | 2.699 | 145 | 0.0798 |
| 33 | 116 | 55 | 0.6 | 105 | 88 | 2.834 | 123 | 0.0933 |
| 34 | 116 | 55 | 0.4 | 55 | 86 | 2.790 | 121 | 0.0888 |
| 35 | 116 | 45 | 0.8 | 105 | 93 | 2.943 | 98 | 0.0955 |
| 36 | 116 | 55 | 0.6 | 80 | 90 | 2.840 | 123 | 0.0989 |
| 37 | 116 | 45 | 1.0 | 105 | 92 | 2.895 | 147 | 0.0910 |
| 38 | 116 | 60 | 1.0 | 105 | 89 | 2.858 | 120 | 0.0880 |
| 39 | 116 | 55 | 1.0 | 130 | 101 | 2.803 | 115 | 0.086 |
| 40 | 116 | 45 | 0.4 | 55 | 85 | 2.900 | 115 | 0.0611 |
| 41 | 116 | 45 | 0.6 | 80 | 88 | 2.940 | 125 | 0.0867 |
| 42 | 116 | 60 | 0.6 | 80 | 82 | 2.803 | 109 | 0.0790 |
| 43 | 116 | 50 | 0.4 | 105 | 97 | 2.955 | 129 | 0.0917 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 44 | 116 | 45 | 1.0 | 130 | 95 | 2.909 | 148 | 0.1001 |
| 45 | 116 | 50 | 0.4 | 55 | 80 | 2.687 | 129 | 0.0983 |
| 46 | 116 | 60 | 1.0 | 130 | 105 | 2.968 | 122 | 0.0645 |
| 47 | 116 | 50 | 0.4 | 80 | 77 | 2.545 | 125 | 0.0892 |
| 48 | 116 | 45 | 0.4 | 80 | 91 | 2.937 | 124 | 0.0680 |
| 49 | 120 | 45 | 0.6 | 105 | 95 | 2.954 | 151 | 0.0670 |
| 50 | 120 | 60 | 0.8 | 55 | 99 | 2.965 | 111 | 0.1043 |
| 51 | 120 | 55 | 1.0 | 130 | 110 | 3.012 | 128 | 0.0649 |
| 52 | 120 | 45 | 0.8 | 80 | 107 | 2.989 | 113 | 0.1160 |
| 53 | 120 | 60 | 1.0 | 80 | 103 | 2.978 | 109 | 0.0793 |
| 54 | 120 | 50 | 0.6 | 55 | 118 | 3.078 | 134 | 0.1448 |
| 55 | 120 | 50 | 0.4 | 130 | 120 | 2.895 | 135 | 0.0507 |
| 56 | 120 | 60 | 1.0 | 130 | 115 | 2.988 | 117 | 0.0882 |
| 57 | 120 | 60 | 0.4 | 55 | 85 | 2.709 | 103 | 0.0940 |
| 58 | 120 | 60 | 0.6 | 80 | 97 | 2.888 | 101 | 0.0760 |
| 59 | 120 | 60 | 0.8 | 105 | 120 | 2.987 | 118 | 0.1201 |
| 60 | 120 | 55 | 0.8 | 105 | 92 | 2.874 | 124 | 0.0985 |
| 61 | 120 | 55 | 0.6 | 80 | 76 | 2.654 | 105 | 0.0878 |
| 62 | 120 | 55 | 0.8 | 130 | 108 | 2.998 | 123 | 0.0644 |
| 63 | 120 | 50 | 0.6 | 80 | 121 | 3.008 | 135 | 0.1440 |
| 64 | 120 | 50 | 1.0 | 130 | 130 | 3.090 | 138 | 0.1448 |

**ANALYSIS OF VARIANCE FOR MRR**

Response 1:MRR

ANOVA for selected factorial model

| *Source* | *Sum of Squares* | *df* | *Mean Square* | *F Value* | *p-value Prob > F* | |
|---|---|---|---|---|---|---|
| *Model* | *7652* | *18* | *425.1235* | *402.7485* | *< 0.0001* | *significant* |
| *A-Ton* | *6460* | *2* | *3230.111* | *3060.105* | *< 0.0001* | |
| *B-Toff* | *881.6* | *2* | *440.7778* | *417.5789* | *< 0.0001* | |
| *C-M/C FEED* | *162.7* | *2* | *81.33333* | *77.05263* | *< 0.0001* | |
| *D-voltage* | *2.286* | *1* | *2.286* | *23.80* | *<0.0001* | |
| *AB* | *146.9* | *4* | *36.72222* | *34.78947* | *< 0.0001* | |
| *AC* | *0.444* | *4* | *0.111111* | *0.105263* | *0.9774* | |
| *CD* | *0.444* | *4* | *0.111111* | *0.105263* | *0.9774* | |
| *Residual* | *8.444* | *27* | *1.055556* | | | |
| *Cor Total* | *7663* | *64* | | | | |

*Table .Analysis of variance table*

**GRAPHS FOR MRR**

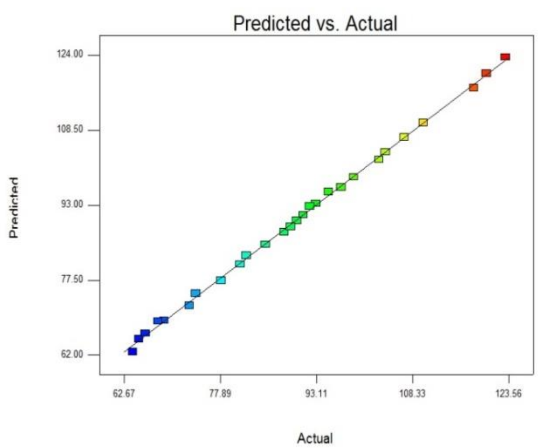



*Fig . predicted VS Actual plot*

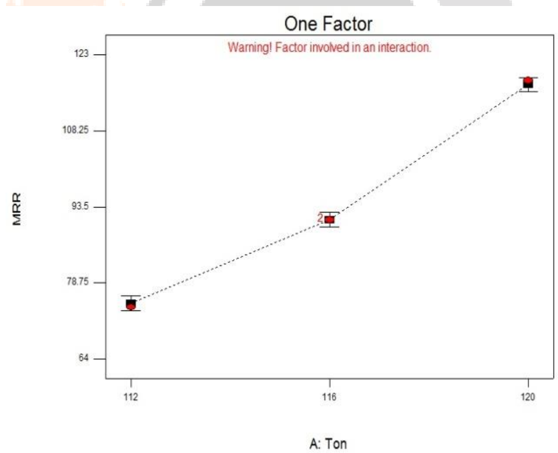
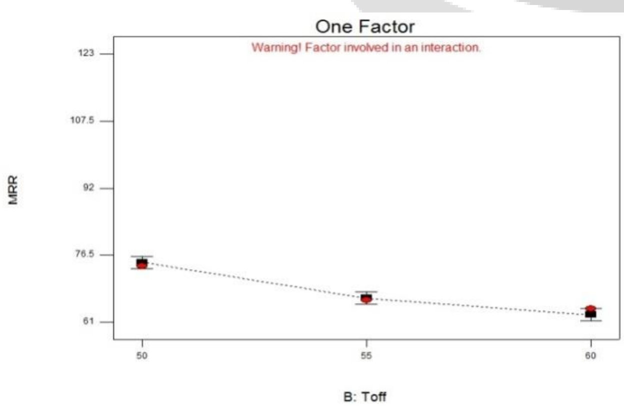



*Fig Ton VS MRR plot*



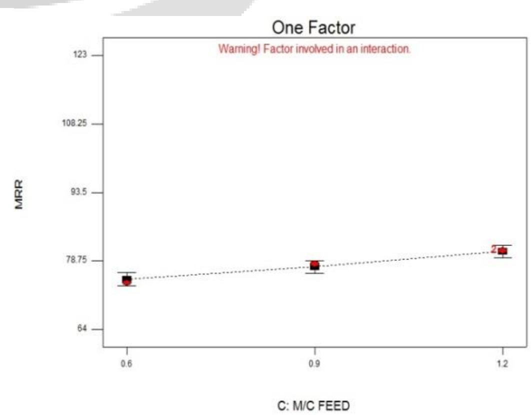
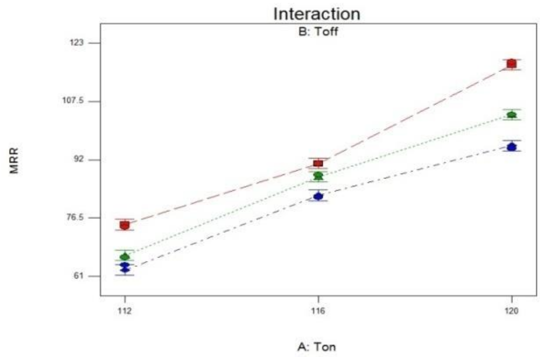



*Fig .Toff VS MRR plot*

*Fig Machine Feed VS MRR*



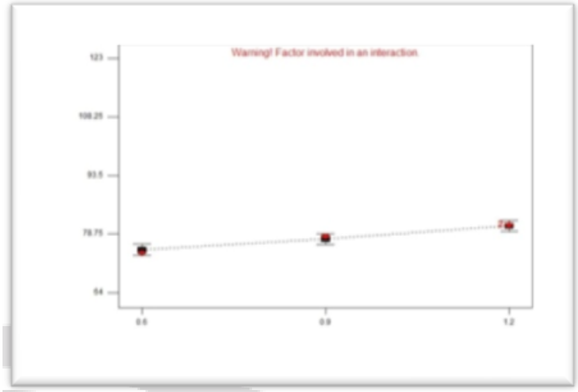



*Fig. Ton & Toff VS MRR plot*

*Fig . voltage vs MRR plot*

**ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS:**

*Table Analysis of variance table*

| Source | Sum of Squares | Df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 0.346279 | 18 | 0.019238 | 15.89458 | 0.0002 | Significant |
| A-Ton | 0.286844 | 2 | 0.143422 | 118.4978 | < 0.0001 | |
| B-Toff | 0.028251 | 2 | 0.014125 | 11.67071 | 0.0042 | |
| C-M/C FEED | 0.001903 | 2 | 0.000951 | 0.786101 | 0.4879 | |
| D-voltage | 0.004504 | 2 | 0.002252 | 120.34 | 0.0000 | |
| AB | 0.016876 | 4 | 0.004219 | 3.485725 | 0.0626 | |
| AC | 0.005273 | 4 | 0.001318 | 1.08914 | 0.4235 | |
| BC | 0.007134 | 4 | 0.001783 | 1.473469 | 0.2964 | |
| Residual | 0.009683 | 26 | 0.00121 | | | |
| Cor Total | 0.360466 | 64 | | | | |

The Model F-value of 15.89 implies the model is significant. There is only a 0.02% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

| | | | |
|---|---|---|---|
| Std. Dev. | 0.03479 | R-Squared | 0.972799 |
| Mean | 2.858667 | Adj R-Squared | 0.911595 |
| C.V. % | 1.216996 | Pred R-Squared | 0.690159 |
| PRESS | 0.110292 | Adeq Precision | 12.35068 |

**GRAPHS FOR SURFACE ROUGHNESS**

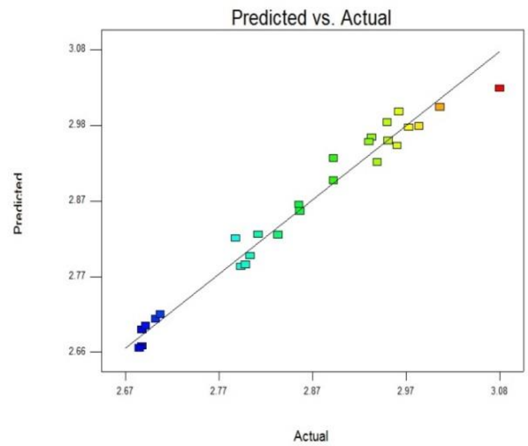



*Fig .Predicted VS Actual plot*

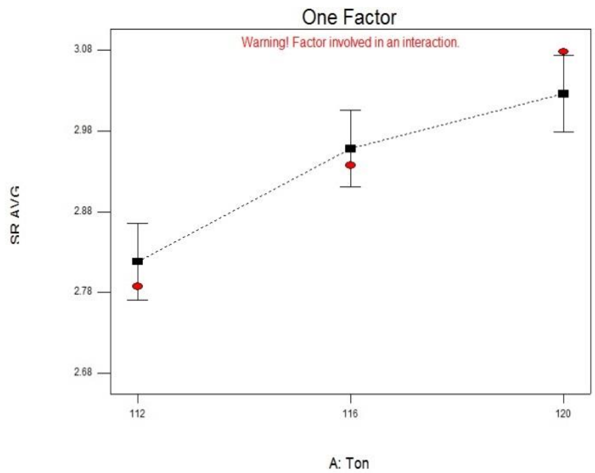



*Fig .Ton VS SR plot*

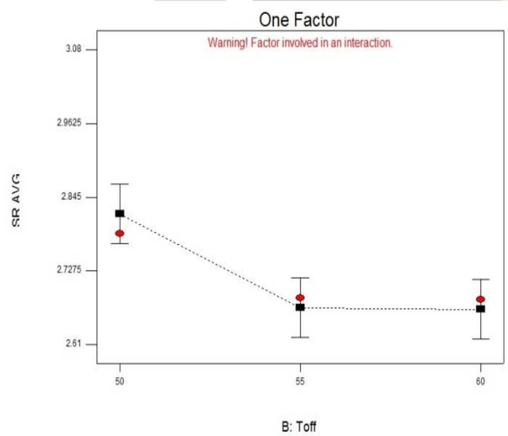



*Fig .Toff VS SR plot*

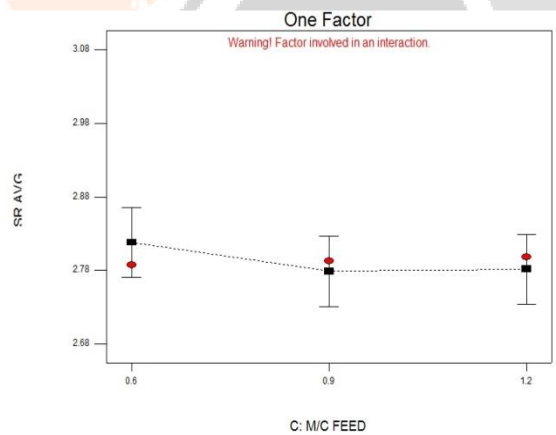
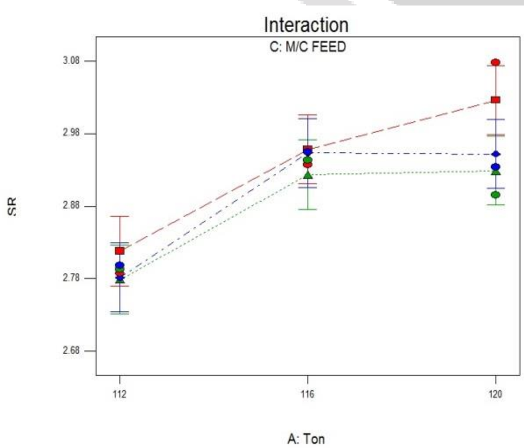
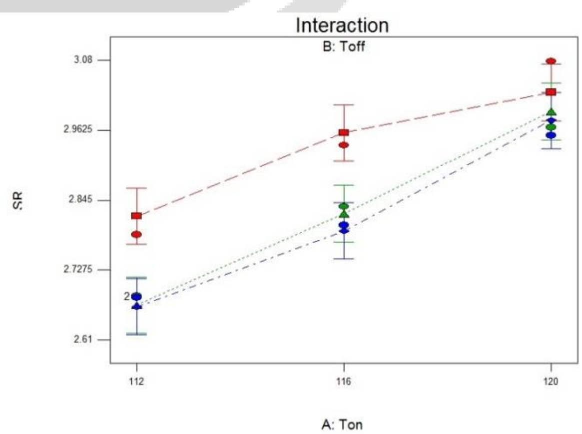



*Fig .MC feed VS SR plot*



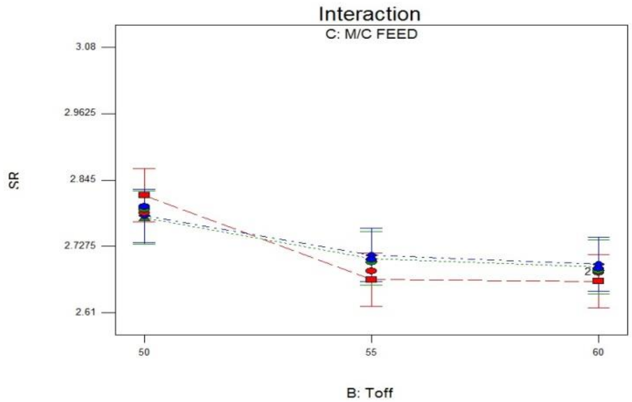



*Fig.Ton , Toff , voltage/Mc feed vs SR*

**ANALYSIS OF VARIANCE FOR KERF WIDTH**

ANOVA for selected factorial model

| Source | Sum of Squares | Df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| A-Ton | 0.3277 | 3 | 0.1092 | 52.1234 | <0.0001 | Significant |
| B-Toff | 0.082 | 3 | 0.0275 | 13.1064 | | |
| C-M/C FEED | 3.08 | 1 | 3.08 | 0.22 | 0.6422 | |
| D-voltage | 747.59 | 1 | 747.59 | 53.86 | <0.0001 | Significant |
| AB | 146.9 | 4 | 36.72222 | 34.78947 | | |
| AC | 0.444 | 4 | 0.111111 | 0.105263 | 0.9774 | |
| CD | 0.444 | 4 | 0.111111 | 0.105263 | 0.9774 | |
| Residual | 8.444 | 44 | 1.055556 | | | |
| Cor. Total | 907.31 | 64 | | | | |

Kerf width = +58.55654+0.31572A+310.69223B+19.9533C+0.00477D-0.5833CD

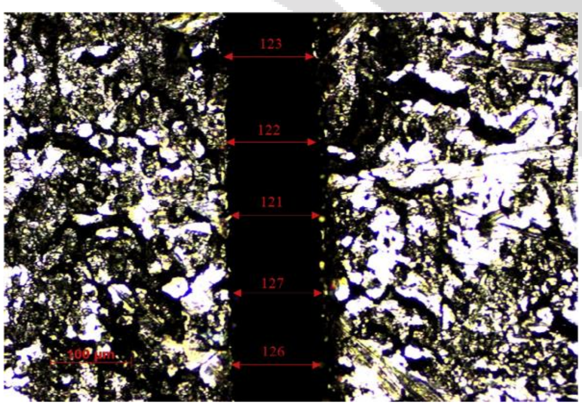



Fig. Kerf width optical measurements in microscope

**ANALYSIS OF VARIANCE FOR WWR**

Table 4.6 Analysis of variance table

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| A-Ton | 0.01773 | 2 | 0.01740 | 9.41 | < 0.0001 | significant |
| B-Toff | 0.00249 | 2 | 0.00249 | 0.79 | 0.446 | |
| C-M/C FEED | 0.001903 | 2 | 0.000951 | 0.786101 | 0.4879 | |
| D-voltage | 0.004504 | 2 | 0.004500 | 120.34 | 0.0000 | |
| AB | 0.017540 | 4 | 0.004219 | 3.485725 | 0.0626 | |
| AC | 0.005032 | 4 | 0.001318 | 1.08914 | 0.4235 | |
| BC | 0.0071200 | 4 | 0.001783 | 1.473469 | 0.2964 | |
| Residual | 0.009600 | 40 | 0.032661 | | | |
| Cor Total | 0.065919 | 64 | | | | |

The predicted optimum value of WWR is calculated as

$\mu WWR = (\mu Ton1 + \mu Toff3 + \mu WF3 + \mu V1) - 4\mu$

$\mu WWR = 0.093$ variance of error = 0.0000301

Normal Probability Plot of WWR

**OPTIMIZATION:**

| Number | Ton | Toff | M/C FEED | voltage | MRR | SR AVG | Kerf | WWR | Desirability | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 116 | 55 | 0.6 | 105 | 87.44444 | 2.822556 | 123 | 0.093 | 0.686591 | Selected |
| 2 | 108 | 55 | 0.6 | 130 | 89.77778 | 2.865 | 128 | 0.075 | 0.657419 | |
| 3 | 116 | 55 | 0.6 | 105 | 88.55556 | 2.856 | 123 | 0.093 | 0.65506 | |
| 4 | 108 | 60 | 0.8 | 105 | 84.88889 | 2.823556 | 125 | 0.051 | 0.646821 | |
| 5 | 116 | 60 | 0.6 | 80 | 82.55556 | 2.793444 | 135 | 0.079 | 0.644689 | |
| 6 | 116 | 45 | 1.0 | 105 | 92.77778 | 2.898444 | 147 | 0.091 | 0.637761 | |
| 7 | 116 | 45 | 0.8 | 105 | 93.33333 | 2.923444 | 112 | 0.095 | 0.597383 | |
| 8 | 116 | 50 | 0.4 | 105 | 96.66667 | 2.953556 | 129 | 0.091 | 0.552922 | |
| 9 | 116 | 45 | 0.4 | 80 | 91 | 2.958 | 124 | 0.068 | 0.505013 | |

## Conclusion

By performing and analyzing the experiment we can conclude that the input parameter such as Ton ,T off , machine feed, voltage are effect on material AISI D3 Steel differently with output parameters(MRR ,kerf width , SR and WWR).

- With increasing Ton time ,MRR ,SR and WWR are increase.
- With increasing T off time ,MRR and SR are decrease .
- With increasing voltage ,machine feed ,MRR and SR are increase.
- For getting maximum MRR and kerf width and better surface roughness and WWR the input values are Ton=116µs,Toff=55 µs,machine feed=0.6 and voltage=105v.
- In this experiment the maximum MRR is 123 mgm/min and Average surface roughness and kerf width is 2.681 micron and 128.

## FUTURE SCOPE

- Better MRR and SR can be found with different levels of inputs.
- Different results may be found on aisi d3 steel with using different wire as an electrode.
- Instead of pulse on time ,pulse off time , machine feed and voltage ,we can take another inputs to get good results for AISI D3 STEEL.
- This experiment had performed on eco cut WEDM. The results should be different with Print cut WEDM and Ultra cut WEDM.

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