International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October2016

Analytical Investigation of Material Removal Rate During Wedm and The Effect of Process Parameters On It

Swapna Poosarla
M.tech, Mechanical Engineering
Avanthi Institute of Engineering & Technology

Sheik.Hidayatulla Shariff
Mtech, IIT Madras
Associate Professor,
Department OF Mechanical Engineering
Avanthi Institute of Engineering & Technology

ABSTRACT
For any machining process and, particularly, in process related to Wire Electrical Discharge Machining (WEDM) the right selection of machining conditions is one of the most important aspects to be taken into consideration. WEDM is capable of machining of geometrically complex shapes or material components having higher hardness, that are precise and very difficult-to-machine such as composites, super alloys heat treated tool steels, ceramics, heat resistant steels, carbides etc. This investigation discusses the effects of machining parameters like pulse on time, pulse off time and voltage on the material removal rate of wire electric discharge machining. For this investigation, stainless steel (SS 304) has been used as a work piece and a brass wire and a diffused wire having 0.25 mm diameter is used as tool electrodes. The design of experiment is based on Taguchi Design approach L9 orthogonal array. The results show that, the pulse on time and servo voltage has the highest influence on material removal rate (MRR). As the pulse on time increases, the material removal rate increases. It is also concludes that, with the increase of pulse off time and servo voltage, the material removal rate decreases.

Keywords: material removal rate (MRR), servo voltage, Wire Electrical Discharge Machining (WEDM).

INTRODUCTION:
Wire-Cut EDM is a unique adoption of the non-conventional machining process, which uses an electrode to initialize the sparking process. Wire-Cut EDM utilizes a continuously travelling thin wire electrode made up of copper, brass or tungsten of diameter varies from 0.05 to 0.30 mm, which is capable of achieving very small corner radii. The thin wire electrode is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the Wire-Cut EDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. Wire-Cut EDM is used primarily for cut shapes through a selected part or assembly.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October2016

With a Wire-Cut EDM machine, if a cutout needs to be created, an initial hole must first be drilled in the material, and then the wire can be fed through the hole to complete the machining. In a Wire-Cut EDM, the wire electrode is held vertically by two wire guides located separately above and below the work piece with the wire traveling longitudinally during machining. The work piece is usually mounted on an x-y table.

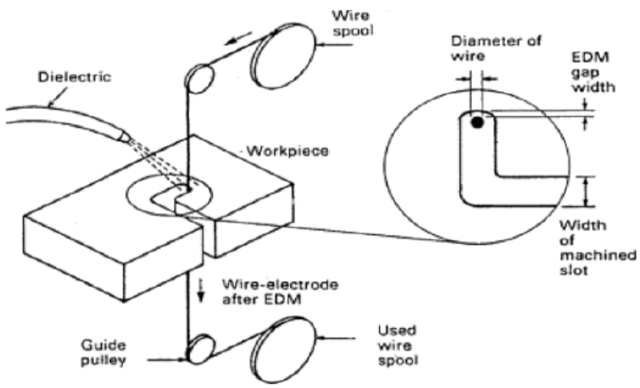


Fig. 1 Setup of Wire-Cut EDM

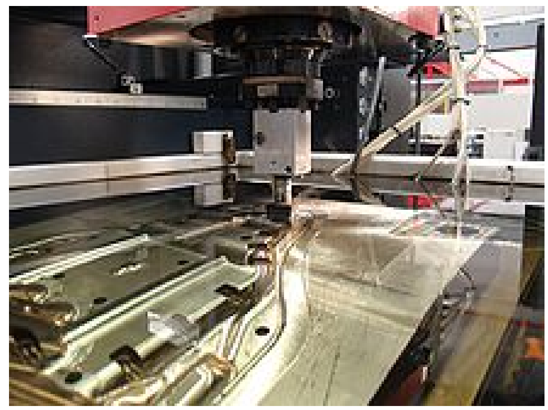


Figure 2: Wire-Cut EDM machine tool

The Wire-Cut EDM machine tool comprises of a main worktable (X-Y) on which the work piece is clamped; an auxiliary table (U-V) and wire drive mechanism. The main table moves along X and Y-axis and it is driven by the D.C servo motors. The travelling wire is continuously fed from wire feed spool and collected on take up spool which moves though the work piece and is supported under tension between a pair of wire guides located at the opposite sides of the work piece. The lower wire guide is stationary whereas the upper wire guide, supported by the U-V table, can be displaced transversely along U and V-axis with respect to lower wire guide. The upper wire guide can also be positioned vertically along Z-axis by moving the quill. A series of electrical pulses generated by the pulse generator unit is applied between the work piece and the travelling wire electrode, to cause the electro erosion of the work piece material. As the process proceeds, the X-Y controller displaces the worktable carrying the work piece transversely along a predetermined path programmed in the controller. Therefore, in order to prevent the ionization of water, an ion exchange resin is used in the dielectric distribution system to maintain the conductivity of water.

Wire electrical discharge machining (WEDM) of hot-pressed boron carbide is considered in this work. Hot-pressed boron carbide possesses superior hardness, high Young's modulus and low density. Due to the excellent properties, it is a promising material as personnel body armour. This material is used to fabricatea variety of armourpanels to provide ballistic protection against different threats. This material cannot be processed by conventional metal cutting techniques like turning and milling due to its high hardness and strength levels. Wire electrical discharge machining a type of unconventional machining process, is employed to accomplish the objective.

WEDM plays significant role in cutting the electrically conductive materials to produce intricate profiles and complex shapes. The material removal takes place due to melting and evaporation of workpiece because of the heat produced by discharges. The wire traverse is regulated by numerically controlled system to accomplish the desired accuracy of components.

The most significant performance measures of WEDM are material removal rate (MRR) and surface roughness (Ra) of workpiece. Spark gap voltage, discharge current, pulse on-time, pulse off-time and dielectric flushing conditions are the machining parameters that influence the performance measures. Tosun et al. investigated the effect of WEDM machining parameters on performance characteristics, i.e MRR, kerf width and Ra. An optimum combination of process parameters was derived for large MRR and small Ra by using analysis of variance (ANOVA). Poros et al. made an attempt to develop a model to correlate the thermal properties of material and the efficiency of machining. Buckingham pi theorem was employed to establish the relationship between the variables used in the study. Tzeng et al. studied the influences of cutting speed, depth of cut and feed rate on surface roughness using the Taguchi technique and grey relational analysis. In this study, an orthogonal array was applied to plan the experiments for optimizing the cutting operations with multiple response measures. Chiang et al. carried out grey relational analysis to optimize the wire-EDM process with multiresponse characteristics such as MRR and Ra.

The optimum process parameters were selected from the response graph obtained by grey relational grade. Kumar et al. employed a grey relational methodology to optimize the input parameters of EDM, i.e., duty factor, pulse on-time and peak current to maximize MRR. The optimum process parameters were validated by confirmation experiments. Wang et al. explored the possibility of removing a recast layer using etching by means of EDM. An L9 orthogonal array was selected to design the experiments for attaining the optimum process parameters. Somasekhar et al. presented the modelling and optimization of micro-EDM using back propagation and genetic algorithms. The neural network model has been established and simulated using MATLAB. Lin et al. attempted to improve the multiple response characteristics using Taguchi technique with grey relational analysis by optimizing the process parameters of EDM. Patel et al. developed a surface roughness prediction model for electric discharge machining of Al_2O_3/SiC/TiC ceramic composite. This model optimized the machining variables to obtain high surface quality. Lin et al. studied the effects of EDM parameters on material removal rate, electrode wear rate and surface roughness for ceramics (Al_2O_3+ 30% VolTiC). Machining parameters have been optimized for each performance measure by using Taguchi method.

The purpose of the present study is to examine the effects of machining parameters on material removal rate (MRR) and surface roughness (Ra) of hot-pressed boron carbide. The material removal rate (MRR) can be considered as the degree of production whereas surface roughness (Ra) represents the measure of surface quality. Based on the literature survey, several pilot experiments have been performed to select the process parameters influencing on performance characteristics. The chosen machining variables are pulse on-time, pulse off-time, peak current and spark voltage. The Taguchi technique is a dominant experimental planning tool that uses an efficient and orderly approach for obtaining the optimum process variables. An appropriate design of experiments (DOE) is selected to perform more precise and accurate experiments. In the present research, an L16 Taguchi standard orthogonal array was selected for the design of experiments. Confirmation experiments were then conducted based on the Taguchi analysis. The surfaces of machined samples were examined using scanning electron microscopy (SEM). The influences of machining parameters on mechanism of MRR and Ra were described.

ELECTRICAL DISCHARGE MACHINING (EDM):

Electrical discharge machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Material is removed from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the "tool" or "electrode", while the other is called the workpiece-electrode, or "workpiece". The process depends upon the tool and workpiece not making actual contact.

When the voltage between the two electrodes is increased, the intensity of the electric field in the volume between the electrodes becomes greater than the strength of the dielectric (at least in some point(s)), which breaks, allowing current to flow between the two electrodes. This phenomenon is the same as the breakdown of a capacitor (condenser) (see also breakdown voltage). As a result, material is removed from both electrodes. Once the current stops (or is stopped, depending on the type of generator), new liquid dielectric is usually conveyed into the inter-electrode volume, enabling the solid particles (debris) to be carried away and the insulating properties of the dielectric to be restored. Adding new liquid dielectric in the inter-electrode volume is commonly referred to as "flushing". Also, after a current flow, the difference of potential between the electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur.

Wire-cut EDM

The wire-cut type of machine arose in the 1960s for the purpose of making tools (dies) from hardened steel. The tool electrode in wire EDM is simply a wire. To avoid the erosion of material from the wire causing it to break, the wire is wound between two spools so that the active part of the wire is constantly changing. The earliest numerical controlled (NC) machines were conversions of punched-tape vertical milling machines. The first commercially available NC machine built as a wire-cut EDM machine was manufactured in the USSR in 1967. Machines that could optically follow lines on a master drawing were developed by David H. Dulebohn's group in the 1960s at Andrew Engineering Company for milling and grinding machines. Master drawings were later produced by computer numerical controlled (CNC) plotters for greater accuracy. A wire-cut EDM machine using the CNC drawing plotter and optical line follower techniques was produced in 1974. Dulebohn later used the same plotter CNC program to directly control the EDM machine, and the first CNC EDM machine was produced in 1976.

RELATED WORK:

Cyriac et. al. (2015), optimized the Wire-Cut EDM parameters of EN 24 steel by using Taguchi method. The process parameters selected for this experiment were pulse on time, pulse off time, current and speed. In this experiment the effect of above mentioned process parameters was observed on surface roughness. The design of experiment was based on Taguchi L16 orthogonal array. Analysis of variance (ANOVA) was used by the authors to find out the most significant parameter that affects the surface roughness. Further, the regression analysis was carried out to generate a mathematical model of surface roughness. From results, authors observed that current has major influence on surface roughness followed by pulse on time, pulse off time and cutting speed.

Singh et. al. (2015), investigated the Wire-Cut EDM to optimize the dimensional deviation of EN8 steel by using Taguchi design approach. Wire feed, servo voltage and pulse off time were the input parameters selected for this experiment. Dimensional deviation was the output parameter. Taguchi method was used to optimize the parameters and L18 orthogonal array was used for the statistical analysis. Authors observed that, among the three parameters servo voltage has the greatest effect on dimensional deviation and was followed by pulse off time and wire feed. Authors observed that, as the servo voltage and wire feed rate increases the dimensional deviation was decreases. And when the pulse off time increases, the dimensional deviation initially increases and further it decreases.

Sivaraman et. al. (2015), studied the effect of control parameters on material removal rate and surface finish during wire electric discharge machining. Titanium was used as a work piece material for this experiment. Pulse on time, pulse off time, wire feed rate, wire tension, gap voltage, dielectric pressure and table feed were the control parameters and material removal rate and surface finish were the performance parameters. The design of experiment was based on Taguchi L18 orthogonal array. Further, analysis of variance (ANOVA) was used to find out the significance of each input parameter on the performance parameters i.e. material removal rate and surface finish. Authors observed that, pulse off time was the major influencing factor for MRR followed by pulse on time, wire feed, gap voltage, wire tension, table feed and dielectric pressure. Authors also concluded that, gap voltage was the most influencing factor for surface roughness followed by pulse on time, pulse off time, wire feed rate, dielectric pressure, wire tension and gap voltage.

METHODOLOGY:

Work Piece Material

The Wire Electric Discharge Machining is used to machine hard materials like steel, carbides and composites. The work piece material should be electrically conductive for an Electrical discharge machining process. Stainless Steel (SS 304) is used as a work piece material in this experiment. The chemical composition of stainless steel (SS304) is shown in table 1.

Table 1 Chemical Composition of SS 304

Elements	Wt %
Cr	18.1
Ni	8.02
Mn	1.211
Si	0.3677
C	0.0458
P	0.01349
S	0.00898

Process Parameters and Design of Experiment

The experimental layout for the machining parameters is based on the Taguchi design approach L9 orthogonal array. This array consists of three control parameters viz. pulse on time, pulse off time and voltage and their three levels. In Taguchi method, mostly all of the observed values are calculated based on 'higher the better' and 'smaller the better'. Thus in this experiment, the observed values of MRR is set to maximum. In Taguchi method, S/N ratio is the measure of quality characteristics. S/N ratio is determined for material removal rate larger the better criterion by using equation (1). Next, the optimizations of the observed values are determined by analysis of variance (ANOVA) which is based on the Taguchi design approach.

$$SN_i = -10log\frac{1}{N_i}\sum_{u=1}^{N_i}\frac{1}{y^2}$$

Process Parameters	Pulse on Time	Pulse off Time	Servo Voltage
Symbol	Ton	Toff	SV
Unit	µs	µs	Volt
Range	Min	100	0 0
Max	131	63	99
Levels	Level 1	115	45 15
Level 2	120	50	25
Level 3	125	55	35

Table 2 Process Parameters and their Levels

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October2016

Column	C1	C2	C3	Response Data (MRR)	S/N Ratio
Run	Ton		Toff	SV	
1	115	45	15	-	-
2	115	50	25	-	-

Table 3: L9 Orthogonal Array in Terms of Actual Parameters

Conduct of Experiment

Experimentally, a brass wire and a diffused wire are used as electrode. Stainless steel (SS 304) is used as a work piece material. The experiment is performed on Sprintcut Electronica Wire-Cut EDM machine. De-ionized water is used as a dielectric fluid with external pressure flushing. The process parameters used for experiment are pulse on time (Ton), pulse off time (Toff) and servo voltage (SV). The machining performance is evaluated in term of material removal rate (MRR). In this experiment peak current, flushing pressure, wire feed and wire tension are kept constant 230 Amp, 0.2kgf/cm2, 8 m/min and 9 units respectively. The layout of design of experiment is based on Taguchi L9 orthogonal array.

Run	Pulse on Time (μs)	Pulse off Time (μs)	Servo Voltage (V)	MRR (mm3/min)		S/N Ratio	
Using Brass wire		Using Diffused Wire		Using Brass wire		Using Diffused Wire	
1	115	45	15	7.63	7.85	17.650	17.897
2	115	50	25	5.75	5.96	15.193	15.505
3	115	55	35	4.37	4.57	12.809	13.198
4	120	45	25	9.47	9.61	19.527	19.655
5	120	50	35	7.39	7.60	17.373	17.616
6	120	55	15	8.35	8.56	18.434	18.649
7	125	45	35	10.97	11.18	20.804	20.968
8	125	50	15	9.75	9.96	19.780	19.965
9	125	55	25	8.96	9.17	19.046	19.247

Table 4: Observation Table

The experiments were performed using a CNC ULTRACUT WEDM (maker: Electronica Machine Tools Ltd). The wire cut electric discharge machine consists of a machine tool, a CNC pulse generator and a dielectric fluid supply unit. The tool consists of a main worktable, an auxiliary table and a wire drive mechanism. CuZn37 brass wire with 0.25 mm in diameter was employed in the present trials. Wire travels through the workpiece from upper and lower wire guides. In wire-cut EDM process the spark is generated between continuous travelling wire and workpiece. Hot-pressed boron carbide blocks (100 mm × 100 mm × 5 mm thickness) were used.

The strength of the material is 410 GPa, its hardness is 31 GPa, and the Young's modulus is 460 GPa. Machining performance was evaluated by MRR and SR. The MRR was determined by equation (1)

MRR (mm^3/min) = $V_c \times b \times h$
where V_c is the cutting rate; b is width of the cut; and h is the depth of the job (mm).

The surface roughness, usually expressed as R_a value in microns, was obtained by Taylor Hobson Surtronic 25 roughness checker.

Taguchi method: planning of experiments

To study the effects of machining parameters on the performance characteristics (MRR and R_a) under the optimal machining parameters, a specifically designed experimental procedure is required. Based on the preliminary investigations, the input parameters chosen were pulse on-time (TON), peak current (IP) and spark voltage (SV). The working range of input parameters and the levels.

Table 5: Input process parameters and their levels.

Parameters	**Level 1**	**Level 2**	**Level 3**	**Level 4**
TON/µs	0.65	0.7	0.75	0.8
IP/A	12	14	16	18
SV/V	10	15	20	25

In this study, the Taguchi method, a powerful tool for parameter design of performance characteristics, was used to optimize the machining parameters for maximum metal removal rate, maximum gap current and minimum surface roughness in WEDM. Two major tools used in this method are (i) S/N (signal/noise) ratio to measure the quality and (ii) orthogonal array to accommodate many factors affecting simultaneously to evaluate the machining performances. According to Taguchi quality design concept, an L16 orthogonal array table with 16 rows was chosen for the experiments. The experimental observations are further transformed into a signal-to-noise (S/N) ratio by using ANOVA.

Table 6: Experimental design using L16 orthogonal array.

Expt. No	**TON**	**IP**	**SV**	**MRR/(mm^3·min^{-1})**	**R_a/µm**
1	0.65	12	10	0.182	1.76
2	0.65	14	15	0.269	1.94
3	0.65	16	20	0.316	2.61
4	0.65	18	25	0.435	2.85
5	0.70	12	15	0.279	1.98
6	0.70	14	10	0.315	2.12

7	0.70	16	25	0.427	2.81
8	0.70	18	20	0.528	2.93
9	0.75	12	20	0.296	2.09
10	0.75	14	25	0.328	2.34
11	0.75	16	10	0.493	3.09
12	0.75	18	15	0.542	3.57
13	0.80	12	25	0.475	3.34
14	0.80	14	20	0.538	3.61
15	0.80	16	15	0.557	3.68
16	0.80	18	10	0.576	3.76

The analysis of variance (ANOVA) of S/N data is carried out to identify the significant variables and quantify their effects on the response characteristics. In the present study, all designs, plots and analysis were carried out using Minitab statistical software. There are several S/N ratios available depending on the type of characteristics. The characteristic of which higher value represents better machining performance, such as MRR, is called 'higher is better, HB'. Inversely, the characteristic of which lower value represents better machining performance, such as surface roughness, is called 'lower is better, LB". Therefore, "HB" for the MRR and "LB'' for the Ra were selected for obtaining the optimum machining performance characteristics. The confirmation test is an essential step for validating the conclusions drawn from DOE with experimental results. The response characteristics of significant variables.

Table 7: (a). Analysis of variance for MRR.

Source	DF	Seq SS	Adj MS	F	P
TON	3	59.62	19.884	13.63	0.004
IP	3	57.98	19.328	13.25	0.005
SV	3	3.644	1.215	0.83	0.523
Residual error	6	8.754	1.459		
Total	15	130.033			

Table 7: (b). Analysis of Variance for Surface roughness.

Source	DF	Seq SS	Adj MS	F	P
TON	3	38.463	12.82	17.05	0.002
IP	3	29.26	9.753	12.97	0.005
SV	3	1.465	0.488	0.65	0.612
Residual error	6	4.513	0.752		
Total	15	73.701			

ARTIFICIAL NEURAL NETWORK MODEL

Since the objective is to evolve a model that relates selected inputs with outputs, so, the back-propagation network (BPN) constitutes an excellent tool due to its universal approximation capabilities. The BPN is a multiple-layer network with an input layer, output layer, and some hidden layers between the input and output layers. Before practical application, the network has to be trained so that the free parameters or connection weights are determined, and the mapping between inputs and outputs is accomplished. The training method is called back-propagation, a supervised learning technique, which generally involves two phases through different layers of the network; a forward phase and a backward phase. In the forward phase, input vectors are presented and propagated forward to compute the output for each neuron. These two phases are iterated untilthe weight factors stabilize their values and the mean square error is at a minimum or an acceptably small value. The advantage of Back propagation network is that it provides a computationally efficient method for changing the weights in a feed forward network, with differentiable activation function units, to learn a training set of input-output examples. Modeling of the EDM process using Neural Network is composed of two stages: training and testing of the network with experimental machining data. The training data consists of values for discharge current (Ip), pulse on time (Ton) and diameter of the tool (Dt), and the corresponding MRR and TWR. In all, 20 such data sets were used, of which, 18 data sets were selected for training purpose and remaining 2 data sets were used for testing the predictive accuracy of the network model.

RESULTS:

From the observation table, it is clears that the diffused wire gives more material removal rate as compared to brass wire. The response tables of S/N ratio for MRR using brass wire and diffused wire respectively. The delta values and ranks for pulse on time, pulse off time and servo voltage are 4.66, 2.56, 1.63 and 1, 2 and 3 respectively, as shown in response table 4.2 for S/N ratio (MRR) using brass wire. Similarly from table 4.3 i.e. the response table for S/N ratio (MRR) using diffused wire, the delta values and ranks for input parameters viz. pulse on time, pulse off time and servo voltage are 4.53, 2.48 and 1.58 and 1, 2 and 3 respectively. The rank shows the relative importance of each input factor to the response. The ranks and delta values indicates that the pulse on time (Ton) has the highest impact on the material removal rate (MRR) followed by the pulse off time and servo voltage.

Table 8: Response Table for S/N Ratio using Brass Wire

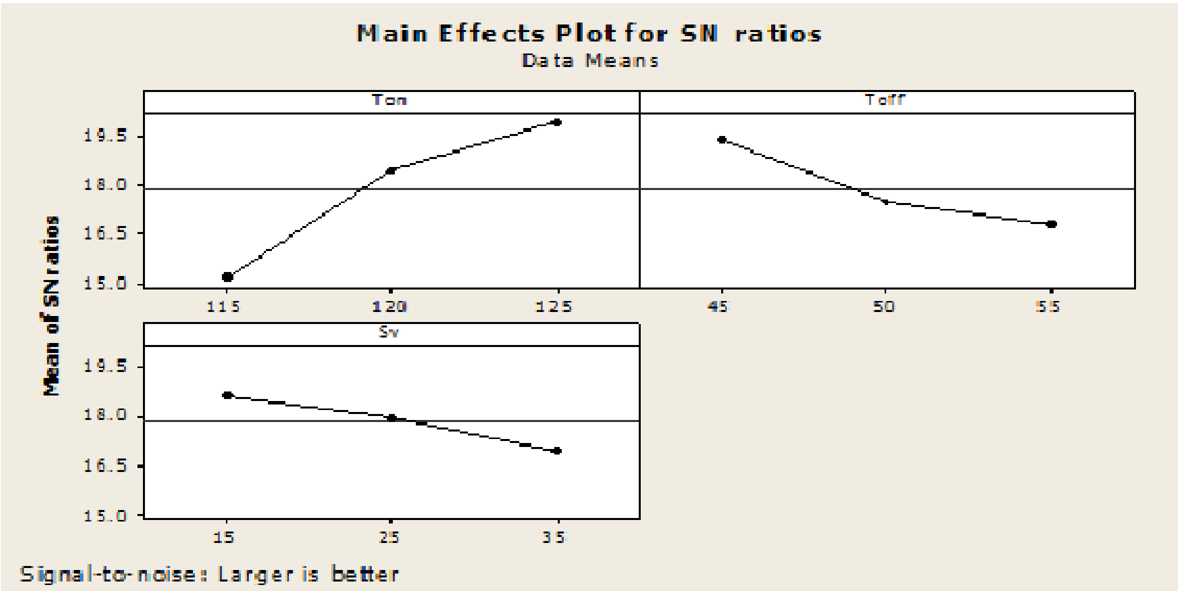
Level	Ton	Toff	SV
1	15.22	19.33	18.62
2	18.44	17.45	17.92
Delta	4.66	2.56	1.63
Rank	1	2	3

International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October2016

During the process of Wire-Cut EDM, the effect of various input parameter like pulse on time, pulse off time and servo voltage has significant effect on MRR as shown in main effect plot for S/N ratio of MRR. These graphs clearly show that as the pulse on time increases, the material removal rate also increases. On the other hand, as the pulse off time increases, the material removal rate decreases.

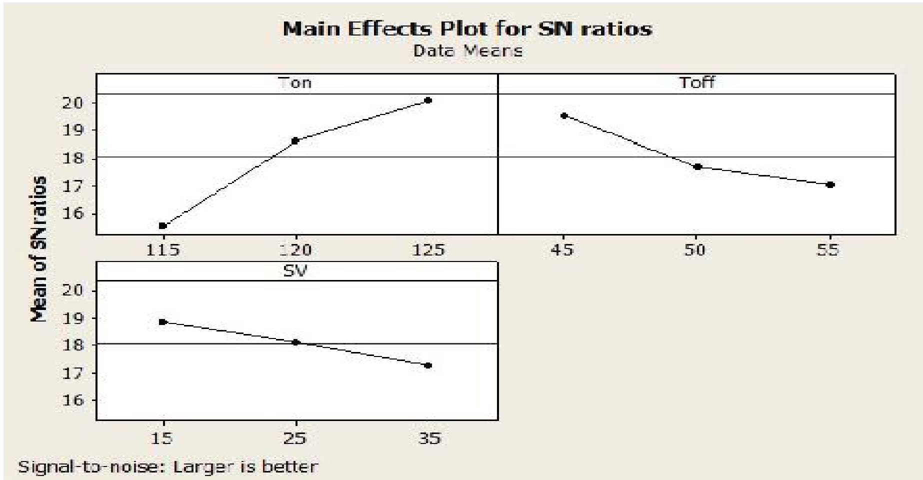
Table 9 Response Table for S/N Ratio Using Diffused Wire

Level	Ton	Toff	SV
1	15.53	19.51	18.84
2	18.64	17.70	18.14
3	20.06	17.03	17.26
Delta	4.53	2.48	1.58
Rank	1	2	3



Graph 1: Main Effects plot for S/N Ratio using Brass Wire

This is because the discharge energy increases with the increase in pulse on time and peak current leading to a higher material removal rate. And as the pulse off time decreases, the number of discharges within a given period becomes more which leads to a higher material removal rate. With increase in spark gap set voltage the average discharge gap gets widened resulting into a lower material removal rate.



Graph 2: Main Effects plot for S/N Ratio using Diffused Wire

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Ton	2	34.1690	34.1690	17.0845	33.06	0.029	68.65
Toff	2	10.5728	10.5728	5.2864	10.23	0.089	21.24
Sv	2	3.9911	3.9911	1.9956	3.86	0.206	8.01
Error	2	1.0335	1.0335	0.5167			
Total	8	49.7664					

Table 10: Analysis of Variance for S/N Ratio using Brass Wire

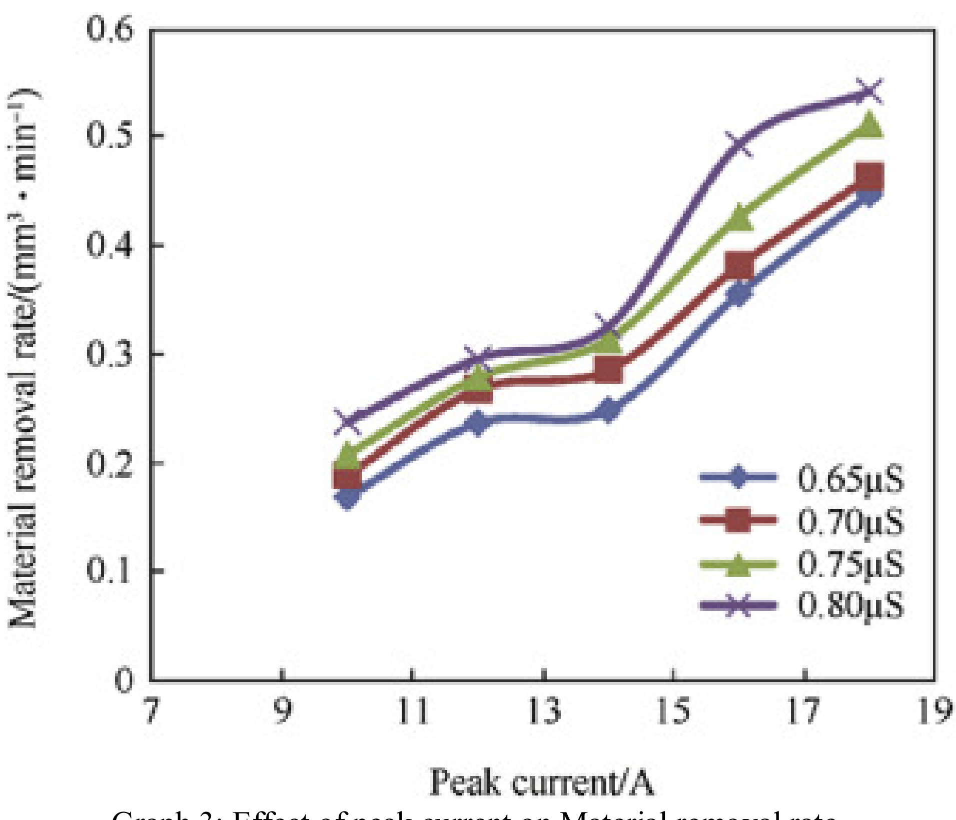
In an analysis of variance table, the P value indicates the most significant parameter. The factor whose P value is less than 0.05 will be most effective parameter. The analysis of variance tables for S/N ratio for both the wires shows that the servo voltage is not important for influencing MRR and the value of pulse on time and pulse off time is most affected the MRR.

From these tables it is clearly definite that pulse on time is the most effective parameter for material removal rate followed by pulse off time and last one is the servo voltage.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Ton	2	32.1611	32.1611	16.0805	31.39	0.031	68.75
Toff	2	9.8483	19.8483	4.9242	9.61	0.094	21.05
Sv	2	3.7416	3.7416	1.8708	3.45	0.215	7.99
Error	2	1.0245	1.0245	0.5123			
Total	8	46.7755					

Table 11: Analysis of Variance for S/N Ratio using Diffused Wire

The effect of peak current on MRR for various values of TON of 0.65 µs, 0.7 µs, 0.75 µs and 0.8 µs. It can be seen from Fig. 2 that the MRR value tends to increase with the higher TON and peak current levels. MRR is directly proportional to the power supplied during TON. It is observed that the TON and peak current have strong effects on MRR. It is suggested to apply TON of 0.8µs and peak current of 18 A, respectively, for achieving maximum MRR. At low input power, a small amount of thermal energy is produced, and a significant portion of thermal energy is absorbed by the surroundings. This keeps available energy less. But the rise in input power generates an intense discharge, which impacts the surface of the workpiece and causes more molten material to be driven out of the crater. Flushing pressure (FP) has a significant influence on MRR. Higher MRR can be achieved by supplying dielectric fluid at low velocity in the spark gap. This enhances an improvement in efficiency and thus increases MRR. Higher FP hinders the creation of ionized bridges across the gap, which would reduce spark energy and diminish MRR.

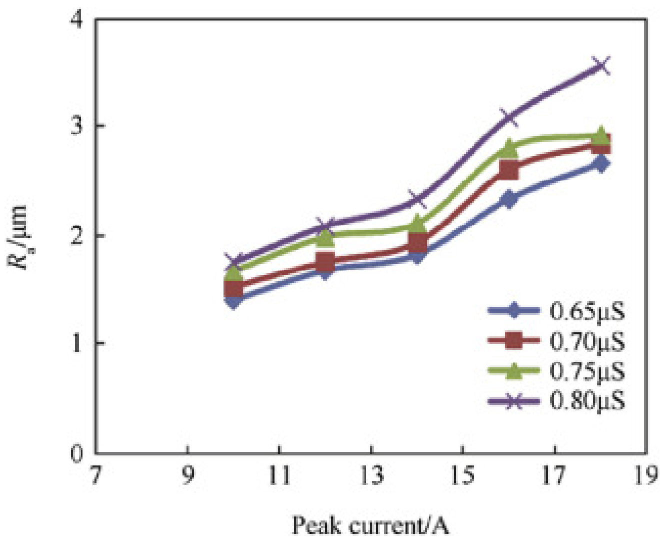


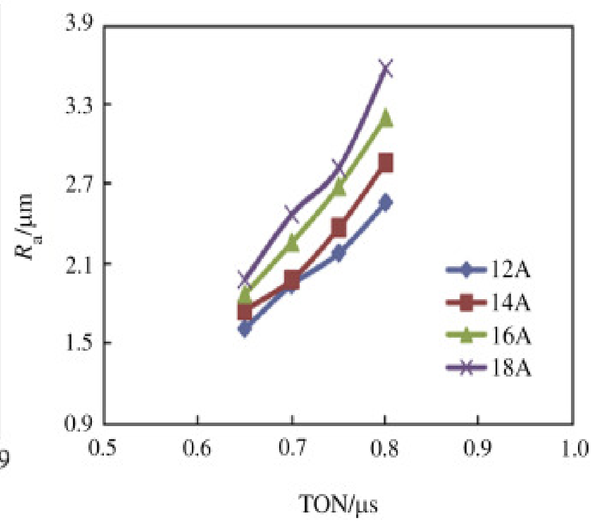
Graph 3: Effect of peak current on Material removal rate.

Increase in TON from 0.65 to 0.8 µs resulted in the formation of larger craters on the machined surface. This is reason for the increase in Ra with input power and TON. It is recommended to use TON of 0.65µs and IP of 12 A, respectively, for obtaining minimum Ra. The thermal power generates the high temperatures and causes the melting and vaporization of the material. The demonstrate Ra in function of the parameters of TON and peak current. The data indicates that Ra decreases by decreasing TON and peak current values. The influence of

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October2016

spark voltage on response characteristics is shown in Fig. 5, for TON of 0.85 µs, TON of 32 µsec and peak current of 16 A. The influence of spark voltage on surface roughness (Ra) is illustrated in Fig. 6. The plot exhibits a trend of increase from 1.26 to 2.35 µm. MRR is found to increase with spark voltage up to certain range and then it decreases at higher spark voltage due to widening of discharge gap. The depicts the effect of spark voltage on Ra. The Ra enhances with the raise in TON. With longer period of spark duration, the number of discharges increases, resulting in the wider craters. Hence, the surface finish will be rougher. When spark gap voltage is increased, the discharge gap gets widened, resulting in better surface accuracy due to stable machining. The influence of wire tension is not very significant.





Graph 4: Effect of peak current on surface roughness. Graph 5: Effect of pulse on time on surface roughness

The surfaces of machined samples were examined using scanning electron microscope (SEM). It is observed from SEM micrographs that the machined surfaces contain spherical modules, craters, pochmarks and microcracks. The TON (0.8 µs) and peak current (18 A) were observed as the most significant parameters affecting the surface properties. The increase in TON resulted in the formation of craters on the surface. These craters were developed due to a succession of sparks. Small portion of the melted material generated by the electric discharge was removed by the dielectric fluid.

The generation of spherical particles was noticed and it was attributed to the surface tension of molten material. Macro-ridges were also observed on the surface due to the protrusion of molten material. The demonstrates that fewer numbers of craters were formed at peak current (12 A) and TON (0.65 µs). Due to low peak current and TON, the machined surface is bombarded with fewer energy sparks. The crack formation is mainly attributed to the fast heating and cooling of the machined surface by dielectric fluid. The uneven heating and cooling caused the development of stresses, which leads to crack formation.

ANALYSIS OF VARIANCE (ANOVA) TERMS AND NOTATIONS

In the analysis of variance many quantities such as degrees of freedom, sums of squares, mean squares, etc., are computed and organized in a standard tabular format.

C.F. = Correction factor	n = Number of trials
r = Number of repetition	e = Error
P = Percent contribution	F = Variance ratio
T = Total of results	f = Degree of freedom
S = Sum of squares	fe= Degree of freedom of error
SS'= Pure sum of squares	fT = Total degree of freedom
V= Mean squares (variance)	

Degree of freedom: It is a measure of the amount of information that can be uniquely determined from a given set of data. DOF for data concerning a factor equals one less than the number of levels. Degree of freedom measures how much independents information is available to calculate each sum of square.
DF (Degree of freedom) total = n-1, where n is the number of observations.
DF (Degree of freedom) for factor = k-1, where k is the number of factor levels.
Total number of trials: The total number of trials is the sum of trials at each level.
Sequential Sum of Squares (Seq SS): The sequential Sum of squares for each term in the model measures the amount of variation in the response.
Adjusted Sum of Squares (Adj SS): The Adjusted sum of squares for term in the model measure the amount of additional variation in the response.
Adjusted Mean Square (Adj MS): The Adjusted Mean Square for a term is simply the Adjusted Sum of Squares divided by the Degree of Freedom.
Variance Ratio: Variance ratio is the ratio of variance due to effect of a factor and variance due to the error term. This ratio is used to measure the significance of the factor under investigation with respect to the variance of all the factors included in the error term. The F value obtained in the analysis is compared with a value from standard F- tables for a given level of significance. When the computed F value is less than the value determined from the F tables at the selected level of significance, the factor does not contribute to the sum of squares within the confidence level. First the formula finding for the Pure Sum of Square (SS') is given below:
SS'= Seq SS – DF * (Adj MS Error)
And the Percentage Contribution formula is given below:
Percentage contribution = (SS'/ Total Seq. SS) * 100%

PERCENTAGE CONTRIBUTION OF INPUT PARAMETERS TO OUTPUTS MRR, KERF WIDTH, AND SURFACE ROUGHNESS

ANOVA analysis carried out in Minitab 16 software and the results are shown here. If there is the p-value known as probability value is less than 0.05 (alpha value). It shows that all the parameters are significant. Statistically, F-test provides a decision at some confidence level as to whether these estimates are significantly different. Larger F-value indicates that the variation of the process parameter makes a big change on the performance characteristics.

ANOVA for MRR (Half Hard Brass Wire (0.25mm))

In this research work, ANOVA Table for MRR Half Hard Brass wire (0.25mm) is shown

Table 11: Table for MRR Half Hard Brass

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
WF (m/min)	1	36.780	36.780	36.780	19.54	0.002	4.93
Ton (µs)	2	514.252	514.252	257.126	136.62	0.000	**72.12**
Toff (µs)	2	106.255	106.255	53.128	28.23	0.000	**14.48**
Ip (Amp)	2	16.506	16.506	8.253	4.39	0.052	1.80
Sv (Volt)	2	18.993	18.993	9.497	5.05	0.038	2.15
Error	8	15.056	15.056	1.882			4.52
Total	17	707.842					**100**

Calculation of SS' and Percentage Contribution of MRR for Half Hard Brass wire.

1) Pure Sum of Square (SS') -

= For WF SS':

= 36.780 – (1*1.882)

= 36.780 – 1.882

= 34.898

For Ton SS':

= 514.252 – (2*1.882)

= 514.252 – 3.764

= 510.488

For Toff SS':

= 106.255 – (2*1.882)

= 106.255 – 3.764

= 102.491

For Ip SS':

= 16.506 – (2*1.882)

= 16.506 – 3.764

= 12.742

For SV SS':

= 18.993 – (2*1.882)

= 18.993 – 3.764

= 15.229

2) Percentage Contribution -

For WF Percentage Contribution:

= 34.898/707.842* 100%
= 4.93 %
For Ton Percentage Contribution:
= 510.488/707.842* 100%
= 72.12 %
For Toff Percentage Contribution:
= 102.491/707.842* 100%
= 14.48 %
For Ip Percentage Contribution:
= 12.742/707.842* 100%
= 1.80 %
For SV Percentage Contribution:
= 15.229/707.842* 100%
= 2.15 %

Above analysis shows the percentage contribution of individual process input parameters of WEDM on Pure Titanium for Material removal rate for Half Hard Brass Wire. The percentage contribution of Wire feed rate is 4.93%, Pulse on time is 72.12%, Pulse off time is 14.48%, Peak current is 1.80%, Servo voltage is 2.15%, and error is 4.52%. This error is due to machine vibration.

ANOVA for Kerf Width (Half Hard Brass wire (0.25mm))

In this research work, ANOVA Table for Kerf Width for Half Hard Brass wire (0.25mm) is shown

Table; 12: Table for Kerf Width for Half Hard Brass wire (0.25mm)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
WF (m/min)	1	0.0138889	0.0138889	0.0138889	35.74	0.000	**39.60**
Ton (µs)	2	0.0032444	0.0032444	0.0016222	4.17	0.057	**7.23**
Toff (µs)	2	0.0087155	0.0087155	0.0043578	11.21	0.005	**23.29**
Ip (Amp)	2	0.0032068	0.0032068	0.0016034	4.13	0.059	**7.13**
Sv (Volt)	2	0.0019261	0.0019261	0.0009631	2.48	0.145	**3.37**
Error	8	0.0031089	0.0031089	0.0003886			**19.38**
Total	17	0.0340906					**100**

Calculation of SS' and Percentage Contribution of Kerf Width for Half Hard Brass wire.

1) Pure Sum of Square (SS') -

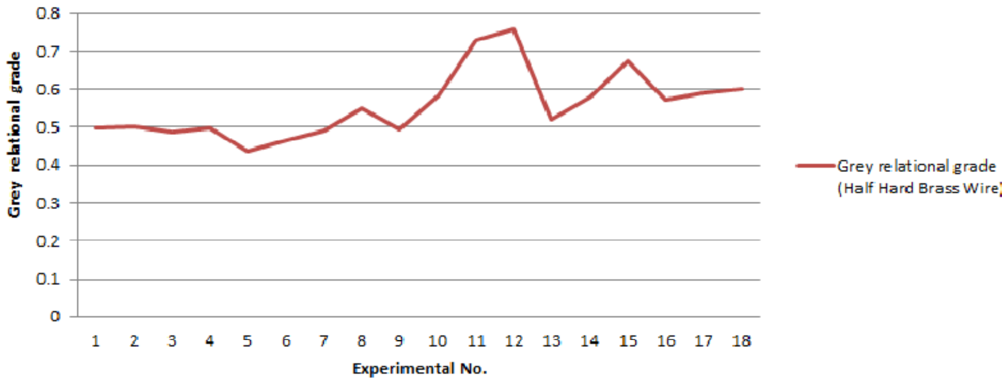
For WF SS':
0.0138889 – (1*0.0003886)
0.0138889 – 0.0003886
0.013500
For Ton SS':
0.0032444 – (2*0.0003886)
0.0032444 – 0.0007772
0.002467
For Toff SS':
0.0087155 – (2*0.0003886)
0.0087155 – 0.0007772
0.007938
For Ip SS':
0.0032068 – (2*0.0003886)
0.0032068 – 0.0007772
0.0024296
For SV SS':
0.0019261 – (2*0.0003886)
0.0019261 – 0.0007772
0.0011489

Analysis of experimental results

Optimal parameter combination on the Pure Titanium work-piece for material removal rate, kerf width and surface roughness with different combinations of WEDM parameter of 18 experimental runs and used Half Hard Brass wire (0.25 mm) and Zn-Coated Brass Wire (0.25 mm).

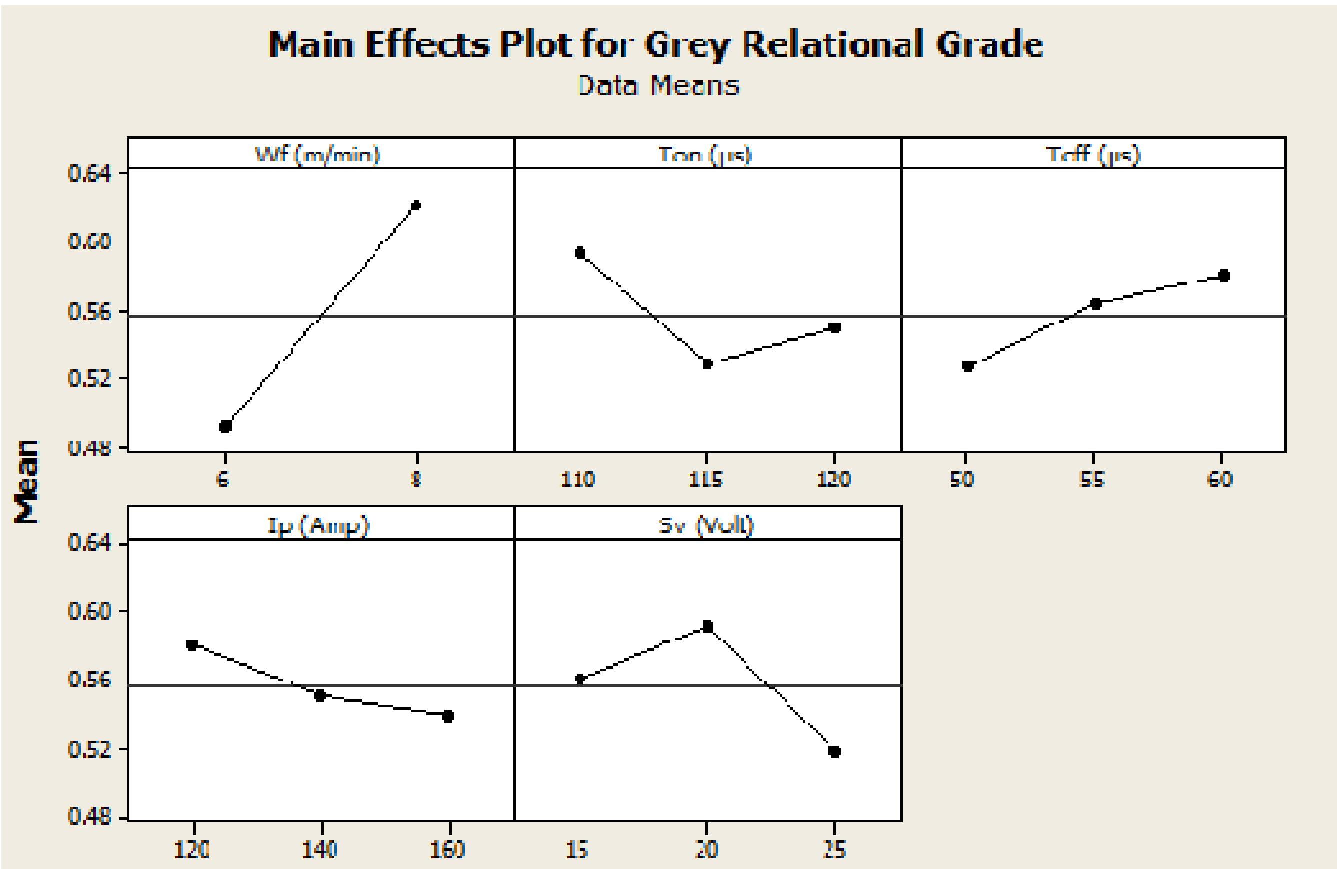
Graph of Grey relational grades for Half Hard Brass Wire (0.25 mm)

According to performed experimental design, it is clearly observed from and the Grey relational grade graph which shows the change in the response when the factors go from one level to other that the WEDM parameters setting of experiment no. 12 has highest grey relation grade for Half Hard Brass wire. Thus, the twelve experiments gives the best multi- performance characteristics of the WEDM process among the 18 experiments.



Graph 6: Graph of Grey relational grades for Half Hard Brass Wire

Main effect plot for grey relational grade (Half Hard Brass Wire (0.25 mm)):

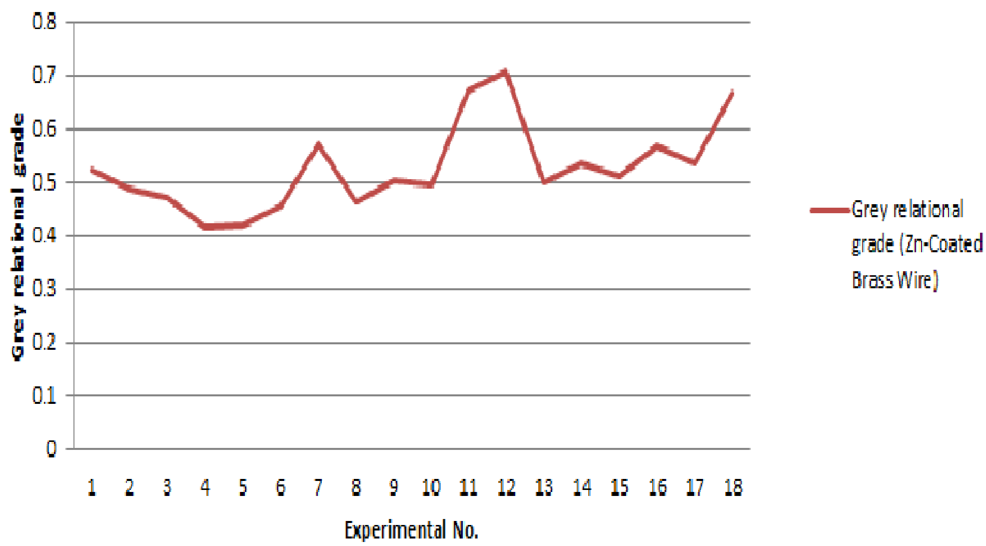


Graph 7: Graph of grey relational grade v/s Inputs Parameters

The effect wire feed on grey relational grade. From this graph we conclude that at 8 m/min wire feed, grey relational grade is higher compare to 6 m/min. So, 8 m/min is optimum parameter level from two level of wire feed rate. the effect Pulse on time (Ton), on grey relational grade. From this graph we conclude that at 110 µs, grey relational grade is higher compare to 115 µs and 120 µs Pulse on time. So, 110 µs is optimum parameter level from three level of Pulse on time. The effect Pulse off time (Toff), on grey relational grade. From this graph we conclude that at 60 µs, grey relational grade is higher compare to 50 µs and 55 µs Pulse on time. So, 60 µs is optimum parameter level from three level of Pulse off time. The effect Peak current (Ip), on grey relational grade. From this graph we conclude that at 120 Amp, grey relational grade is higher compare to 140 Amp and 160 Amp Peak current. So, 120 Amp is optimum parameter level from three level of peak current. The effect Servo voltage (Sv), on grey relational grade. From this graph we conclude that at 20 V, grey relational grade is higher compare to 15 µs and 25 µs Servo voltage. So, 20 V is optimum parameter level from three level of Servo voltage.

Graph of Grey relational grades for Zn-Coated Brass Wire (0.25 mm)

Graph of Grey relational grades for Zn-Coated Brass Wire shown.

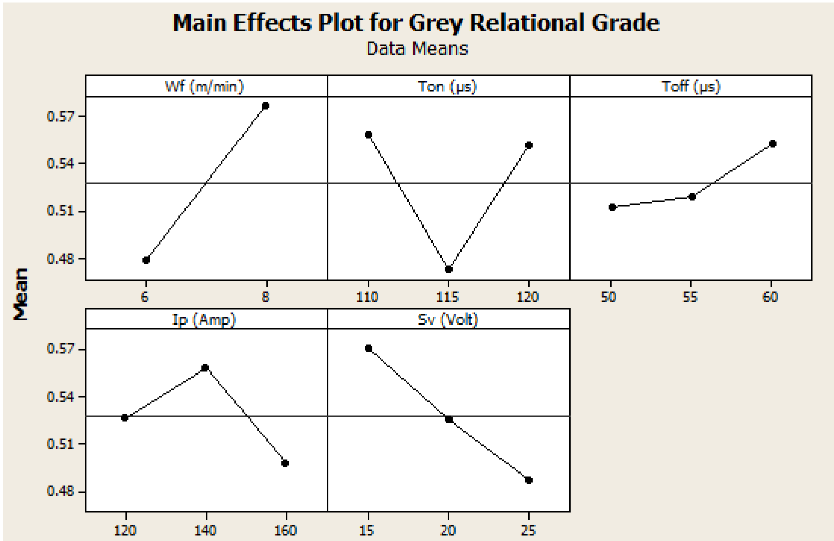


Graph 8: Graph of Grey relational grades for Zn-Coated Brass Wire

According to performed experimental design, it is clearly observed from the Grey relational grade graph which shows the change in the response when the factors go from one level to other that the WEDM parameters setting of experiment no. 12 has highest grey relation grade for Zn-Coated Brass wire. Thus, the twelve experiment gives the best multi- performance characteristics of the WEDM process among the 18 experiments.

Main effect plot for grey relational grade (Zn-Coated Brass Wire (0.25 mm))

The Main effect plot for grey relational grade for various input parameters for Zn-Coated Brass wire.

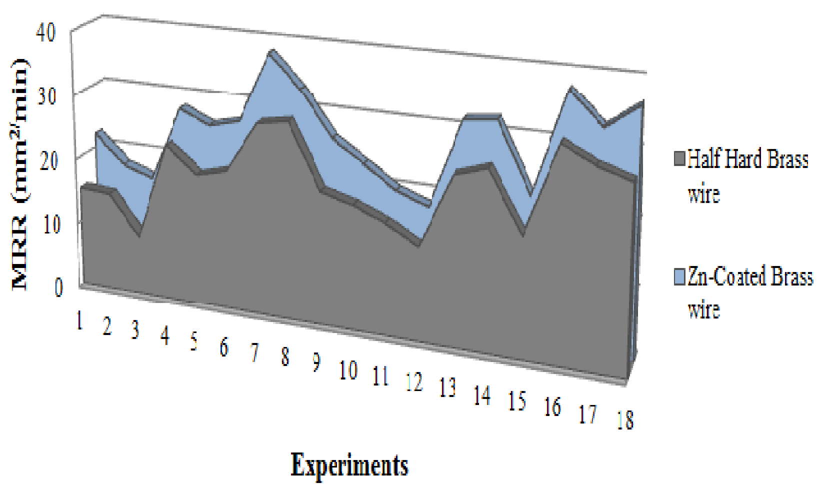


Graph 9: Graph of grey relational grade v/s Inputs Parameters

The effect wire feed on grey relational grade. From this graph we conclude that at 8 m/min wire feed, grey relational grade is higher compare to 6 m/min. So, 8 m/min is optimum parameter level from two level of wire feed rate. The effect Pulse on time (Ton), on grey relational grade. From this graph we conclude that at 110 µs, grey relational grade is higher compare to 115 µs and 120 µs Pulse on time. So, 110 µs is optimum parameter level from three level of Pulse on time.

Material Removal Rate (MRR)

The MRR of Pure Titanium with Half Hard Brass wires under the same operational parameters for the Zinc-Coated Brass Wire.



Graph 10: MRR of Titanium for Both Wires

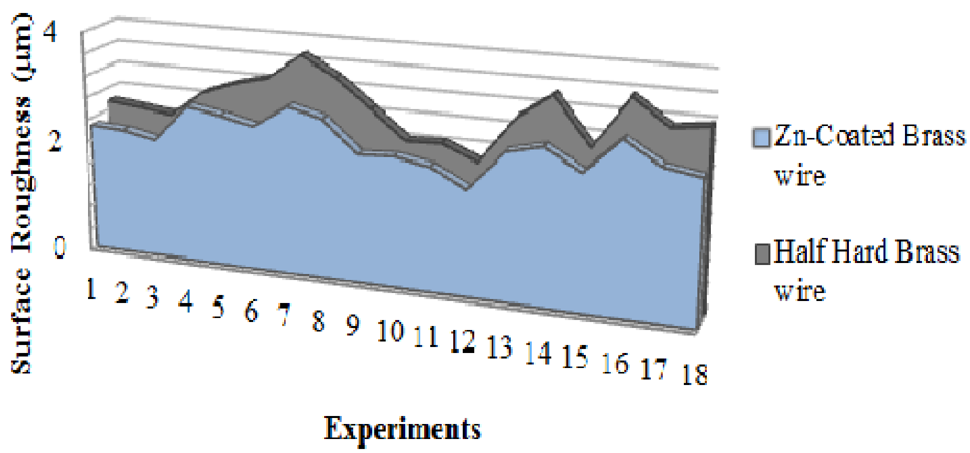
The MRR values for Pure Titanium machined with Zn-Coated Brass wire are higher than Pure Titanium machined with Half Hard Brass wire. The higher MRR is desirable. Good sparking properties of zinc layer on brass core result in improving cutting speed. In fact, the addition of zinc to brass wire leads to reduction in the wire melting point. The low melting temperature of wire improves the spark formation and decrease dielectric ionization time. Thus, the cutting rate increases and gets higher the MRR.

Kerf Width

The kerf width of Pure Titanium with Half Hard Brass wires under the same operational parameters for the Zinc-Coated Brass Wire. The kerf width values for Pure Titanium machined with Zn-Coated Brass wire are higher than Pure Titanium machined with Half Hard Brass wire. The smaller kerf width is desirable. Good sparking properties of zinc layer on brass core result in improving sparking efficiency. The low melting temperature of wire improves the spark formation and decrease dielectric ionization time. Thus, the increasing erosion of material takes place. Hence, kerf width is higher in Zn-coated Brass wire.

Surface Roughness

The Zinc-Coated Brass wire can produce smoother surface in comparison to Half Hard Brass wire.



Graph 11: Surface Roughness of Titanium for Both Wires

The surface roughness values for Pure Titanium machined with Zn-Coated Brass wire are less than Pure Titanium machined with Half Hard Brass wire. The small surface toughness is desirable. The existence of zinc in coated brass wire provides higher tensile strength for 105 wire. The wire with high tensile strength is a good heat resistance in high temperature and maintains straight under vibration and tension. Also, the uniform zinc layer on coated wire provides good discharge characteristics. A finer discharge can be created with good discharge characteristics and higher tensile strength. As a result, the quality of work piece surface will improve.

CONCLUSIONS

It is observed that diffused wire gives more material removal rate (MRR) as compared to the brass wire. After analyzing S/N graphs and mean plots for optimal conditions for Material Removal Rate, it is

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October2016

observed that the MRR increases with the increase in pulse on time, and decreases with increase in pulse off time and servo voltage. The significance of machining variables of WEDM on MRR and Ra of hot-pressed boron carbide has been studied. The effects of machining variables on the mechanism of MRR and surface roughness have been assessed by using scanning electron microscope. This experiment was conducted to develop a better process model using feed-forward back-propagation neural network after investigating the influencing process parameters on MRR and TWR, while machining Ti-6Al-4V using Copper Tungsten electrode with negative polarity, on EDM. The significance of the process parameters was determined using ANOVA. Discharge Current is the most significant parameter in influencing both MRR and TWR, followed by pulse on time and diameter of the tool. Feed forward-back propagation neural network of ANN for process modeling was developed to evaluate the EDM performance characteristics. The proposed NN models were verified with the two experimental data sets meant for testing. The result shows that the developed NN models can predict the MRR and TWR with reasonable accuracy.

REFERENCES:

1. Cyriac S., Prof. Sharos H. (2015), Optimization of wire-cut EDM Parameters of EN 24 Steel Using Taguchi's Method. International Journal of Engineering Research and Technology, PP. 633-636.
2. Singh P., Chaudhary A. K., Singh T., Rana A.K. (2015), Experimental Investigation of Wire-Cut EDM to Optimize Dimensional Deviation of EN 8 Steel Through Taguchi's Technique. International Research Journal of Engineering and Technology, PP. 1753-1757,
3. Sivaraman B., Eswaramoorthy C., Shanmugham E.P. (2015), Optimal Control Parameters of Machining in CNC Wire Cut EDM. International Journal of Applied Science and Engineering Research, PP. 102-121,
4. Nagaraja R., Chandrasekaran K., Shenbhgaraj S. (2015), Optimization of Parameter for Metal Matrix Composite in Wire-Cut EDM. International Journal of Engineering Science and Research Technology, PP. 570-574
5. Ramesh S., Natarajan N., Krishnaraj V. (2014), Experimental Investigation of Al6061/SiCp/B4Cp hybrid MMCs in Wire Electric Discharge Machine. Indian Journal of Engineering and Materials Science, PP. 409-417
6. Saini P.K., Verma M. (2014), Experimental Investigation of Wire-EDM Process Parameters on MRR of Ti-6al-4v Alloy. International Journal of Innovative Technology and Exploring Engineering, PP. 677-692
7. Saini P.K., Singh G., Singh T., Study the Effect of Process Variables on Cutting Velocity During wire-cut EDM of Al/ZrO2-MMC. International Journal of Engineering Science Invention Research & Development, PP. 564-573.
8. Mathew B., Benkim B.A., Babu J. (2014), Multi Process Parameter optimization of WIRE-CUT EDM on SS 304 Using Utility Approach.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 03 Issue 14
October2016

International Conference on Advances in Manufacturing and Materials Engineering, PP. 1863-1872

9. Lodhi B.K., Agarwal S. (2014), Optimization of machining parameters in WIRE-CUT EDM of AISI D3 Steel using Taguchi Technique CIRP International Conference on High Performance Cutting, PP. 194-199
10. Hemalatha K., Venkatachalapathy V.S.K., Alagumurthy N. (2014), Surface Integrity analysis in Wire-Cut Electric Discharge Machining of Al 6063/Al2O3 Metal Matrix Composite through Response Surface Methodology. International Journal of Scientific & Engineering Research, PP. 104-110
11. Garg S.K., Manna A., Jain A. (2013), Multi-Objective Optimization of Machining Characteristics during Wire Electrical Discharge Machining of Al/ZrO2 Particulate Reinforced Metal Matrix Composite. Journal of Engineering Research, PP. 145-160
12. N. Tosun, C. Cogun, G. Tosun, A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method, J Mater Process Technol, 152 (2004), pp. 316–322