Analysis on Effect of Process Parameter on Performance Measurement in WEDM for Aluminum-6351

Viahvas G. Patel[1], Vaibhav Javale[2]

[1] Research scholar, Mechanical Engg. Dept., Aadishwar College of Technology-Gandhinagar, Gujarat, India

[2] Asst. Prof. Vaibhav Javale, Mechanical Engg. Dept., Aadishwar College of Technology-Gandhinagar, Gujarat, India

ABSTRACT

Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Wire EDM machines are used to cut conductive metals of any hardness or that are difficult or impossible to cut with traditional methods. The machines also specialize in cutting complex shapes that would be difficult to be produced using conventional cutting methods. Wire Electro-Discharge Machining (EDM) is a metal-working process whereby material is removed from a conductive work piece by electrical erosion. Wire EDM is used for machining of sheet metal dies, extrusion dies, prototype parts, small to medium batch size production of cams, rotors, turbine blades, tools, gears etc. This Research work focuses on finding out the optimum parameters in WEDM for machining Aluminum alloy 6351 tool. Input process parameters that are taken into consideration are pulse on time, pulse off time, servo voltage. The effect of input parameters on performance parameters such as material removal rate and surface roughness are experimentally noted and optimization of parameters. Also the use two different wire materials has to be done to find out the best wire material.

Keyword: - *Wire electrical discharge machining (WEDM), Material removal rate (MRR0, Surface roughness*

1. INTRODUCTION

Machining removes certain parts of the work pieces to change them to final parts. Machining nowadays has been classified in two types: (1) Traditional Machining; (2) Non-traditional Machining. Traditional Machining, also known conventional machining requires the presence of a tool that is harder than the work piece to be machined. This tool should be penetrated in the work piece to a certain depth. Moreover, a relative motion between the tool and work piece is responsible for forming or generating the required shape. The absence of any of these elements in any machining process such as the absence of tool-work piece contact or relative motion, makes the process a nontraditional or non-conventional one [1].

Non-conventional machining processes are well established in modern manufacturing industries as they are capable of machining hard materials. Nonconventional machining processes are classified according to the machining action
which helps in material removal from the work piece. The material removal mechanism, machining system components, process variables, technological characteristics, and industrial applications are different for all these processes [1].

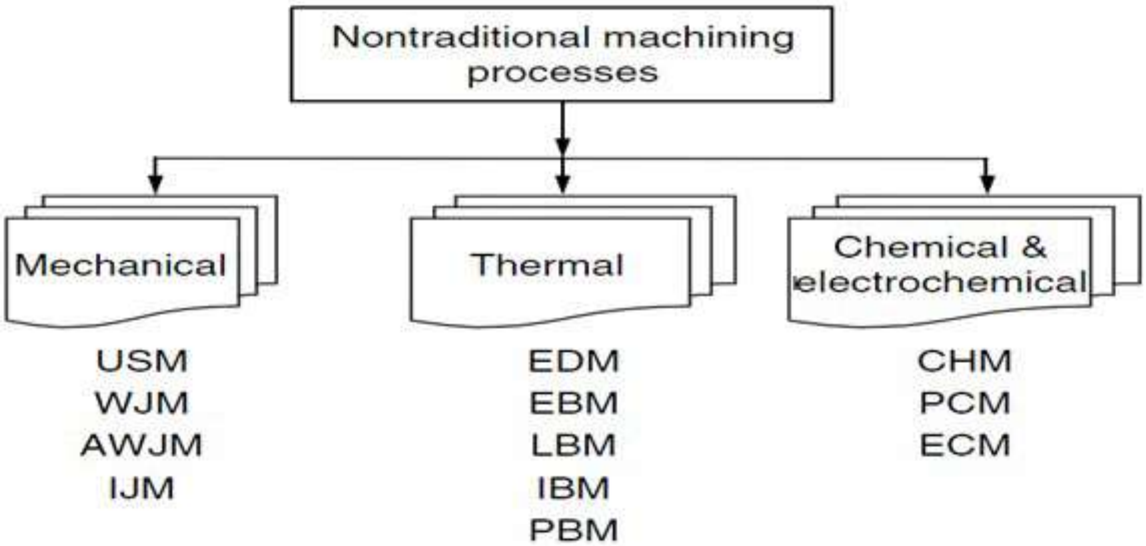

Fig. 1.1 Classification of Non-Traditional processes [1]

1.2 Historical background

The phenomenon of erosion of metals by electric spark was first noticed by Joseph Priestily in 1878 but this was not used for machining of metals until 1930s. Controlled machining of metals by electric sparks was first done by Lazarenko in Russia in 1944 [2].

One of the most widely used Non-Conventional Machining process in industry is Electrical Discharge Machining (EDM). Electric Discharge Machining is a nontraditional concept which is based on the principle of removing material by means of repeated electrical discharges between the tool termed as electrode and the work piece in the presence of a dielectric fluid [3]. Electrical Discharge Machining (EDM) uses thermal energy to achieve a high-precision metal removal process from a fine, accurately controlled electrical discharge. The electrode is moved towards the work piece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric [1]. Short duration discharges are generated in a liquid dielectric gap, which separates tool and work piece. The material is removed with the erosive effect of the electrical discharges from tool and work piece. EDM does not make direct contact between the electrode and the work piece thus it can eliminate mechanical stresses, chatter and vibration problems during machining [3, 4].

EDM is commonly used for machining very hard and tough materials such as tool steels and carbides and for finishing parts for aerospace, automotive industry and surgical components. It is also used to produce complex shapes and small diameter holes, which are difficult or impossible to machine using conventional methods. Since EDM uses an electric discharge to cut the material, its use is limited to conductive materials [1, 3-5].

1.2 Wire Electric Discharge Machining (WEDM)

WEDM is considered as a unique adoption of the conventional EDM process which comprises of a main worktable, wire drive mechanism, a CNC controller, working fluid tank and attachments. The work piece is placed on the fixture table and fixed securely by clamps and bolts. The table moves along X and Y-axis and it is driven by the DC servo motors. Wire electrode usually made of thin copper, brass, molybdenum or tungsten of diameter 0.05-0.30 mm, which transforms electrical energy to thermal energy, is used for cutting materials. The wire is stored and wound on a wire drum which can rotate at1500rpm. The wire is continuously fed from wire drum 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. During the WEDM 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. Also the work piece and the wire electrode (tool) are separated by a thin film of dielectric fluid that is continuously fed to the machining zone to flush away the eroded particles. The movement of table iscontrolled numerically to achieve the desired three-dimensional shape and accuracy of the work piece [8].

1.2.1 WEDM Process

WEDM is a process which erodes and removes material by using the channel of plasma generated by electric sparks between two conductive materials (i.e. electrode and the work piece), this channel of plasma converted into thermal energy at a temperature range of 8000 to 12000º C at a pulsating direct current supply of 20000 to 30000 Hz. The electrode and work piece are separated by a small gap being immersed in dielectric fluid, an electric spark is produced in between this small gap and the work piece material is eroded, as the pulsating current is turned off, the plasma breaks down which leads to sudden reduction in the temperature and the eroded material is flushed away with the help of dielectric fluid in the form of microscopic debris. With each electric spark discharge a small crater is formed on both the work piece and the electrode which is a prime decider in the final surface quality [3, 9]. The taper can ranging from 15º for a 100 mm thick to30º for a 400 mm thick work piece can be obtained on the cut surface material [10]. A WEDM schematic is shown in Fig. 1.2.

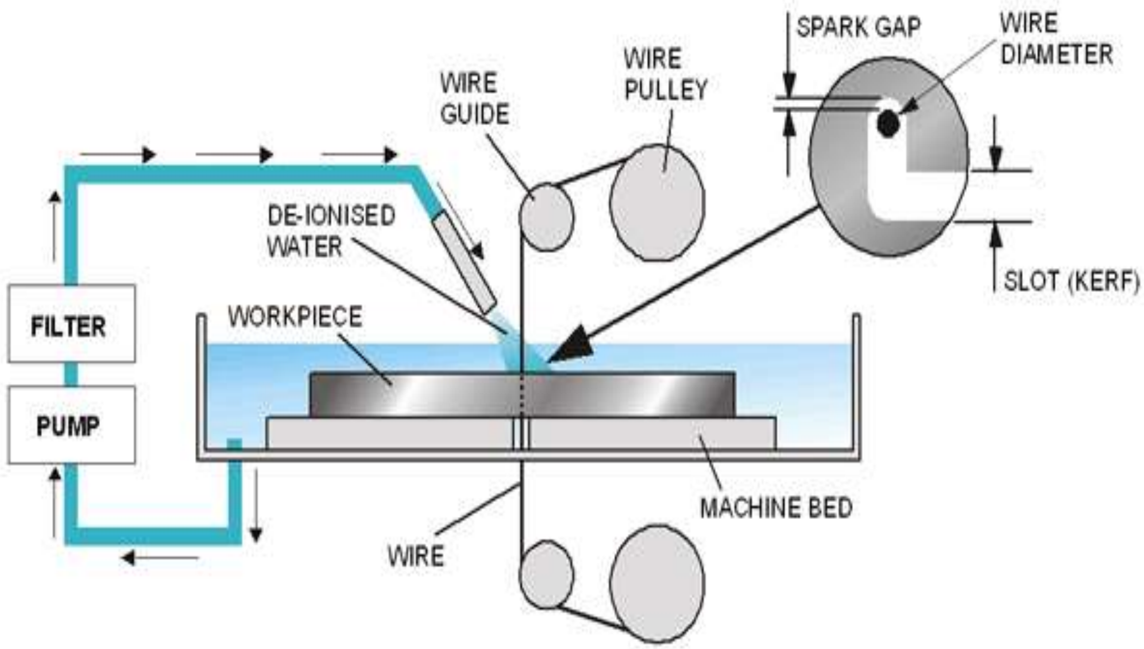

Fig.1.2 Schematic Diagram of WEDM process [10]

Deionized water is used as the dielectric as it is the purest form of water and it acts as an insulator. Normal tap water contains minerals which may be too conductive for Wire EDM, in order to control the water conductivity; water is deionized by passing it through a resin tank which eliminates the conductive elements of water. This deionized water is circulated with the h e l p of a pump. As the machining operation is performed, conductivity of water rises and it is again re-circulated through the resin tank [6]. The purpose of deionised water is to stabilise the spark erosion path and to act as the dielectric medium which is forced into the cutting gap to flush out the eroded metal. There is virtually no cutting force on the part of the machine because the wire electrode and work piece never make contact [3].

WEDM process is usually used in conjunction with CNC and will only work when a part is to be cut completely through. The melting temperature of the parts to be machined is an important parameter for this process rather than strength or hardness. The surface quality and material removal rate (MRR) of the machined surface by wire EDM will depend on different machining parameters such as applied peak current, and wire materials. WEDM process is commonly conducted on submerged condition in a tank fully filled with dielectric fluid; nevertheless it also can be conducted in dry condition. This method is used due to temperature stabilization and efficient flushing in cases where the work piece has varying thickness (10).

2. LITERATURE REVIEW

U. A. Dabade, S. S. Karidkar et al.[1] have analyse the machining conditions for Material Removal Rate (MRR), Surface Roughness (SR), kerf width on WEDM for Inconel 718 using DOE such as Taguchi methodology. The experimental analysis is carried out using Minitab 16 software and it was observed that pulse-on-time is the most influential factor for all the response variables such as MRR, SR, Kerf width. Along with this, peak current was observed to be next significant parameter for kerf width whereas for MRR and SR servo voltage was observed to be the next significant parameter.

A. Dey, V.R.Reddy Bandi, K.M.Pandey et al.[2] had worked on experimental investigations of the effect of machining parameters (pulse-on time, pulse-off time, wire speed) on the performance measure like cutting speed (CS), kerf width(KW) and surface roughness(SR) on wire electrical discharge machining (WEDM) for AA6061. Response surface methodology is employed to analyse the effects of significant machining parameters on the performance characteristics. The main significant factors that affect the Cutting speed is pulse on time. The CS increases with an increase in pulse on time. The pulse on time have statistical significance on both KW and SR. pulse off time and wire speed on SR are not that much significant. The SR decreases with an increase in pulse on time (Ton) whereas with increase in wire speed it increases slightly.

Sreenivasa Rao M, Venkaiah N et al.[3] an attempt has been made to investigate the effect of WEDM process parameters such as pulse on time, pulse off time, peak current and servo voltage in machining of Nimonic-263 alloy. Response Surface Methodology (RSM) has been used for experimental plan. The significance of process parameters are estimated by ANOVA analysis. It was found from the ANOVA results that, pulse on time, peak current and interaction effect of pulse on time and peak current are more influencing parameter. Whereas for SR it was found that pulse on time, peak current, servo voltage.

Prajapati and Patel et al.[4] evaluates the effect of pulse On-Off time, voltage, wire feed and wire tension on MRR, SR, kerf in Wire EDM. The experiments were carried out on wire-cut EDM machine (ELEKTRA SUPERCUT 734) using AISI A2 tool steel as work piece in form of square bar. Based on control factors and their levels L27 orthogonal array was selected. Analysis of data optimization and performance is done by Response Surface Methodology (RSM).

Ravindranadh Bobbili, V. Madhu, A.K. Gogia et al.[5] use a Taguchi method coupled with Grey relational analysis is planned for wire-EDM operations on ballistic grade Aluminum alloy. Experiments have been performed with four machining variables: pulse-on time, pulse-off time, peak current and spark voltage. Experimentation has been planned as per Taguchi technique. Three performance characteristics namely material removal rate (MRR), surface roughness (SR) have been chosen for this study. Results showed that pulse-on time, peak current and spark voltage were significant variables to Grey relational grade. The confirmation tests have also been performed to validate the results obtained by Grey relational analysis and found that great improvement with 6% error is achieved.

Aniza Alias, Bulan Abdullah, Norliana Mohd Abbas et al.[6] evaluates the influence of three different machine rates which are 2 mm/min, 4 mm/min and 6 mm/min with constant current (6A) with WEDM of Titanium Ti-6Al-4V. The effects of different process parameters on the kerf width, material removal rate and surface roughness 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. The paper highlights the importance of process parameters and different machining conditions on kerf width, MRR, surface roughness (Ra) and surface topography. The machine feed rate increases, the kerf width decreases. By increasing machine feed rate, the MRR will increases simultaneously. Smoother surface can be obtained with low setting of machine feed rate. 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.

Amrish Raj. D , Senthilvelan.T et al.[7] optimize the cutting conditions of Wire-EDM for better surface roughness and material removal rate for Titanium alloy. The cutting parameters taken for study in this work includes pulse-on time, pulse off time and wire feed rate. The measured response includes surface roughness and material removal rate. Box-Benkhen approach has been used as the experimental strategy. The results shows that pulse on time and pulse off time are the important parameters that influences the surface roughness whereas the pulse off time has major influence on material removal rate (MRR).

V. Chengal Reddy, N. Deepthi, N.Jayakrishna et.al[8] investigate the effect of various process parameters such as pulse on time, pulse off time, wire tension, current for Aluminum HE30. The experimentation has been completed with the help of Taguchi grey relational analysis. Grey relational analysis is used to optimize the process parameters on Material removal rate, surface finish and kerf width. Grey Relational Analysis (GRA), for finding the optimal parameters affecting MRR, Surface Roughness and Kerf Width are found to be Pulse on time = 112µs, Pulse off time=61µs, Current=11Amp, Wire tension=780gm. Higher MRR value of 0.153mm^3/min, lower Surface Roughness value of 2.861µm and lower Kerf Width value of 0.257mm.

G.Ugrasen, H.V.Ravindra, G.V.Naveen Prakash, Y.N.Theertha Prasad et al.[9] study on the optimization of process parameters in the wire EDM. HCHCr was selected as a work material. This work material was machined using different process parameters based on Taguchi method. Parameters such as pulse-on, pulse-off, current and bed speed was varied. The response variables measured for the analysis are surface roughness, material removal rate. ANOVA has been carried out to know the magnitude of factor affects. Further the verification experiment has been carried out to confirm the performance of optimum parameters. It was found that, each control factors are affecting the response variables to different extent. Comparing the ANOVA table for the HCHCr material, for the surface roughness and MRR it is concluded that, the control factor pulse on time is having more effect on it. The verification experiment was conducted using the optimized process parameters and the performance characteristics Surface roughness and MRR. The values were improved from 2.105µm to 2.055µm for surface roughness, 11.899 mm3/min to 12.23132mm3/min for MRR. After the confirmation experiment, it was concluded that, the optimized parameters have shown good results, so these parameters can be used to achieve good surface finish, higher MRR.

Aniza Alias, Bulan Abdullah, Norliana Mohd Abbas et al.[10] aims to investigate the influence of feed rate on the performance of WEDM on Titanium Ti-Al-4V. Brass wire was employed as the electrode for the investigation. The results on kerf width and material removal rate are graphically tabulated. 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. The selection of parameters depends on the requirements based on a better surface roughness or a maximum material removal rate. Hence an appropriate combination of variables can be selected accordingly. Furthermore, this combination can contributes to increase production rates perceptibly by reducing machining time. The outcome of this study will help in improving the quality of Titanium Ti-6Al-4V products as well as minimizing the machining cost to realize the economic potential to the fullest.

3 DESIGN OF EXPERIMENT

DOE is a technique of defining and investigating all possible combinations in an experiment involving multiple factors and to identify the best combination. In this, different factors and their levels are identified. Design of experiments is also useful to combine the factors at appropriate levels each within the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results. The design of experiment is used to develop a layout of the different conditions to be studied. And experiment design must satisfy two objectives: first, the number of trials musty be determined; second, the conditions for each trial must be specified.

Three factors are chosen the design becomes a 3 level 3 factor full factorial design. The version 17 of the MINITAB software was used to develop the experimental plan for L27 Orthogonal Array. In this experiment other parameters are fixed,

Table.1 Input parameter with Levels value

Sr. No.	Machining process parameter	Level 1	Level 2	Level 3
1	Pulse On Time (µs)	110	115	120
2	Pulse Off Time (µs)	40	45	50
3	Servo Voltage (V)	15	20	25

4. EXPERIMENT SETUP

The machine used for experiments is Exotec CNC WEDM EX40

4.1 Work-piece material

Aluminum alloys are used in many applications in which the combination of high strength and low weight is attractive in air frame in which the low weight can be significant value. Al 6351 is known for its light weight and good corrosion resistance to air, water, oils and many chemicals. Thermal and electrical conductivity is four times greater than steels. It has higher strength amongst the 6000 series alloys. Alloy 6351 is known as a structural alloy, in plate form. This alloy is most commonly used for machining. Though relatively a new alloy the higher strength of 6351 has replaced 6061 alloy in many applications. The AA 6351 aluminum alloy is used in manufacturing due to its strength, bearing capacity, ease of workability and weldability. The advantages of Al 6351 have several important performance characteristics that make them very attractive for aircraft structures, namely light unit weight, only one third that of steel, strength comparable to typical other aluminum alloys, excellent corrosion resistance, with negligible corrosion even in the presence of rain and other drastic conditions, high toughness and resistance to low-ductility fracture even at very low temperatures.

Table 2 Chemical composition of work-piece material

Material	Al	Si	C	Zn	Mn	Cr
Aluminum-6351	97.48 %	0.890 %	0.047 %	0.006 %	0.750 %	0.020 %

Electrode to be used are plain brass wire and zinc coated brass wire with 0.25 mm diameter.

5. EXPERIMENT RESULTS

The effect of process parameters on the machining parameter for both plain brass wire and zinc coated brass wire is recorded in the table. Total 27 experiments done on the WEDM machine based on the full factorial method and summarized in the following table.

For plain brass wire

Table 3 Experiment Results by plain brass wire

Run Order	Actual values			MRR (mm^3/min)	SR (μm)
	Pulse on Time (μs)	Pulse off Time (μs)	Servo Voltage (Volts)		
1	110	40	15	6.6280	2.8596
2	110	40	20	6.4560	2.8100
3	110	40	25	6.0040	2.7604
4	110	45	15	6.2711	2.8666
5	110	45	20	6.1327	2.8170
6	110	45	25	5.5864	2.7674
7	110	50	15	5.7008	2.8736
8	110	50	20	5.4268	2.8241

9	110	50	25	4.8580	2.7745
10	115	40	15	8.6321	3.2305
11	115	40	20	7.7280	3.1809
12	115	40	25	7.4069	3.1313
13	115	45	15	7.1790	3.2376
14	115	45	20	6.8049	3.1880
15	115	45	25	6.5826	3.1384
16	115	50	15	6.1978	3.2446
17	115	50	20	6.0070	3.1950
18	115	50	25	5.4174	3.4154
19	120	40	15	9.1064	3.5509
20	120	40	20	8.3994	3.5013
21	120	40	25	8.3164	3.4517
22	120	45	15	8.4531	3.6085
23	120	45	20	7.9994	3.5589
24	120	45	25	7.8065	3.5093
25	120	50	15	7.7001	3.6155
26	120	50	20	7.3051	3.5659
27	120	50	25	7.1081	3.5163

For zinc coated brass wire

Table 4 Experiment Results by zinc coated brass wire

Run Order	**Actual values**			**MRR (mm^3/min)**	**SR (µm)**
	Pulse on Time (µs)	**Pulse off Time (µs)**	**Servo Voltage (Volts)**		
1	110	40	15	10.8048	2.4964
2	110	40	20	10.4696	2.4528
3	110	40	25	9.6064	2.4291
4	110	45	15	10.0338	2.5202

5	110	45	20	9.7523	2.4789
6	110	45	25	8.7382	2.4353
7	110	50	15	8.8512	2.5388
8	110	50	20	8.6828	2.4852
9	110	50	25	7.3728	2.4416
10	115	40	15	13.8113	2.8428
11	115	40	20	12.3648	2.7992
12	115	40	25	11.8510	2.7755
13	115	45	15	11.5864	2.8491
14	115	45	20	11.1878	2.8054
15	115	45	25	10.5321	2.7818
16	115	50	15	9.9564	2.8552
17	115	50	20	9.7112	2.8116
18	115	50	25	8.6678	3.0052
19	120	40	15	14.5702	3.1248
20	120	40	20	13.4390	3.0811
21	120	40	25	13.3062	3.0375
22	120	45	15	13.5249	3.1755
23	120	45	20	12.7904	3.1318
24	120	45	25	12.4904	3.0882
25	120	50	15	12.3201	3.1816
26	120	50	20	11.6881	3.1380
27	120	50	25	11.273	3.0943

6. RESULT AND DISCUSSION

After performing the experiment for all 27 runs and measuring the output parameters like material removal rate, surface roughness for wire cut EDM of aluminum 6351, whatever results generated are discussed in this chapter.

6.1 Main effect plots for input parameter v/s output parameter for plain brass wire

Fig. 6.1 the first graph shows the effect of pulse on time on material removal rate. From Fig. 6.1, it is clearly shown that with increase in pulse on time, material removal rate increases. When pulse on time increases from 110 to 115 µs, material removal rate increases from 5.8960 to 6.8840mm^3/min. When pulse on time again increases from 115 to 120 µs then material removal rate further increases from 6.8840 to 7.8.0216 mm^3/min.

In fig. 6.1 the second graph indicated the effect of pulse off time on material removal rate. From Fig. 6.1, it is clearly shown that with increase in pulse off time, material removal rate decreases. When pulse off time increases from 40 to 45 µs, material removal rate decreases from 7.6308 to 6.9795mm^3/min. When pulse off time again increases from 45 to 50 µs then material removal rate further decreases from 6.9795 to 6.1912mm^3/min.

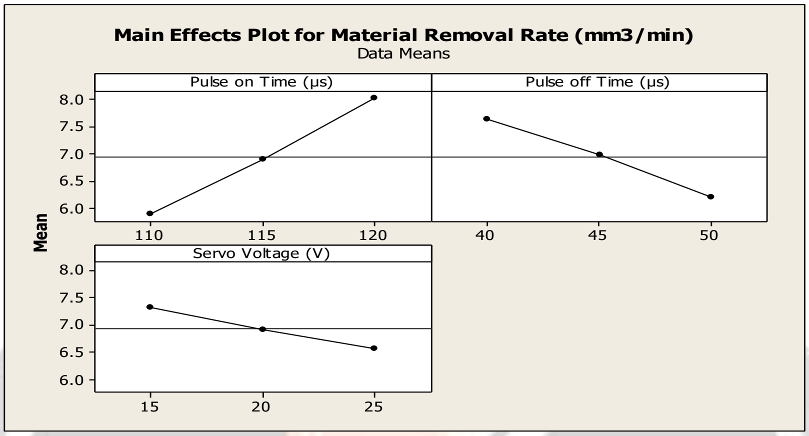

Figure 6.1 Graph of input parameter v/s material removal rate for plain brass wire

The third graph of Fig 6.1 shows the effect of servo voltage on material removal rate. It is shown that with increase in servo voltage, material removal rate gradually decreases. When servo voltage increases from 15 to 20 volts, material removal rate decreases from 7.3207 to 6.9177mm^3/min. When servo voltage again increases from 20 to 25 volts then material removal rate further decreases from 6.9177 to 6.5651mm^3/min.

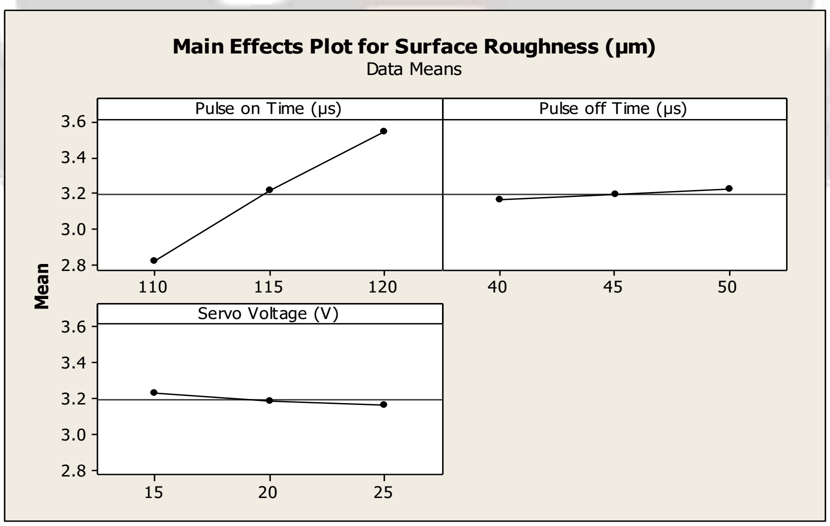

Figure 8.2 Graph of input parameter v/s surface roughness for plain brass wire

Fig. 6.2 the first graph shows the effect of pulse on time on surface roughness .From Fig.6.2, it is clearly shown that with increase in pulse on time, surface roughness suddenly increases. When pulse on time increases from 110 to 115 µs, surface roughness increases from 2.8192 to 3.2180 µm. When pulse on time again increases from 115 to 120 µs then surface roughness increases from 3.2180 to 3.5420 µm.

In fig. 6.2 the second graph indicated the effect of pulse off time on surface roughness. From fig.6.2, it is clearly shown that with increase in pulse off time, surface roughness increases. When pulse off time increases from

40 to 45 µs, surface roughness increases from 3.1641 to 3.1901 µm. When pulse off time again increases from 45 to 50 µs then surface roughness further increases from 3.1901 to 3.2250 µm.

The third graph of Fig 6.2 shows the effect of servo voltage on surface roughness. It is shown that with increase in servo voltage, surface roughness gradually decreases. When servo voltage increases from 15 to 20 volts, surface roughness decreases from 3.2341 to 3.1823 µm. When servo voltage again increases from 20 to 25 volts then surface roughness further decreases from 3.1823 to 3.1637 µm.

6.2 Main effect plots for input parameter v/s output parameter for zinc coated brass wire

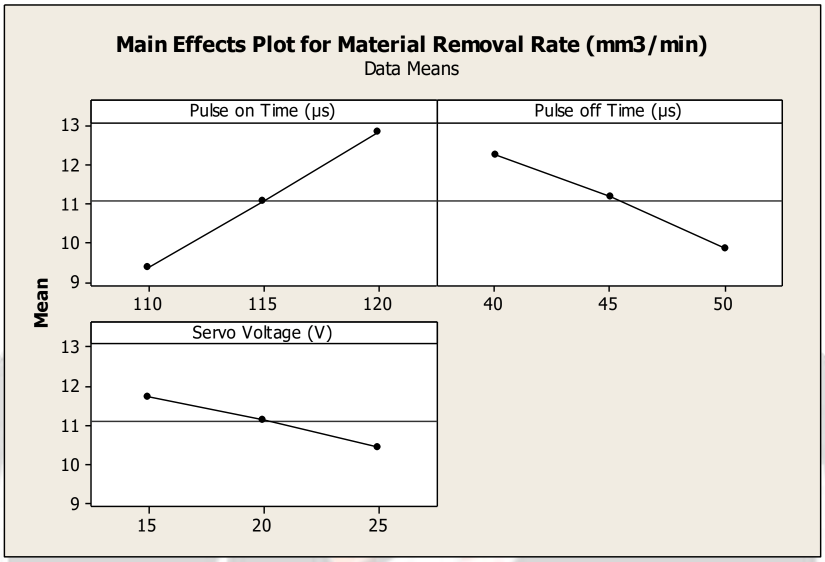

Figure 6.3 Graph of input parameter v/s material removal rate for zinc coated brass wire

Fig. 6.3 the first graph shows the effect of pulse on time on material removal rate. From Fig. 6.3, it is clearly shown that with increase in pulse on time, material removal rate increases. When pulse on time increases from 110 to 115 µs, material removal rate increases from 9.3679 to 11.0743mm^3/min. When pulse on time again increases from 115 to 120 µs then material removal rate further increases from 11.0743 to 12.8225mm^3/min.

In fig. 6.3 the second graph indicated the effect of pulse off time on material removal rate. From Fig. 6.3, it is clearly shown that with increase in pulse off time, material removal rate decreases. When pulse off time increases from 40 to 45 µs, material removal rate decreases from 12.2470 to 11.1818mm^3/min. When pulse off time again increases from 45 to 50 µs then material removal rate further decreases from 11.1818 to 9.8359mm^3/min.

The third graph of Fig 6.3 shows the effect of servo voltage on material removal rate. It is shown that with increase in servo voltage, material removal rate gradually decreases. When servo voltage increases from 15 to 20 volts, material removal rate decreases from 11.7177 to 11.1207mm^3/min. When servo voltage again increases from 20 to 25 volts then material removal rate further decreases from 11.1207 to 10.4264mm^3/min.

Fig. 6.4 the first graph shows the effect of pulse on time on surface roughness .From Fig.6.4, it is clearly shown that with increase in pulse on time, surface roughness suddenly increases. When pulse on time increases from 110 to 115 µs, surface roughness increases from 2.4754 to 2.8362 µm. When pulse on time again increases from 115 to 120 µs then surface roughness increases from 2.8362 to 3.1170 µm.

In fig. 6.4 the second graph indicated the effect of pulse off time on surface roughness. From fig.6.4, it is clearly shown that with increase in pulse off time, surface roughness increases. When pulse off time increases from 40 to 45 µs, surface roughness increases from 2.7821 to 2.8073 µm. When pulse off time again increases from 45 to 50 µs then surface roughness further increases from 2.8073 to 2.8390 µm.

The third graph of Fig 6.4 shows the effect of servo voltage on surface roughness. It is shown that with increase in servo voltage, surface roughness gradually decreases. When servo voltage increases from 15 to 20 volts, surface roughness decreases from 2.8427 to 2.7982 µm. When servo voltage again increases from 20 to 25 volts then surface roughness further decreases from 2.7982 to 2.7875 µm.

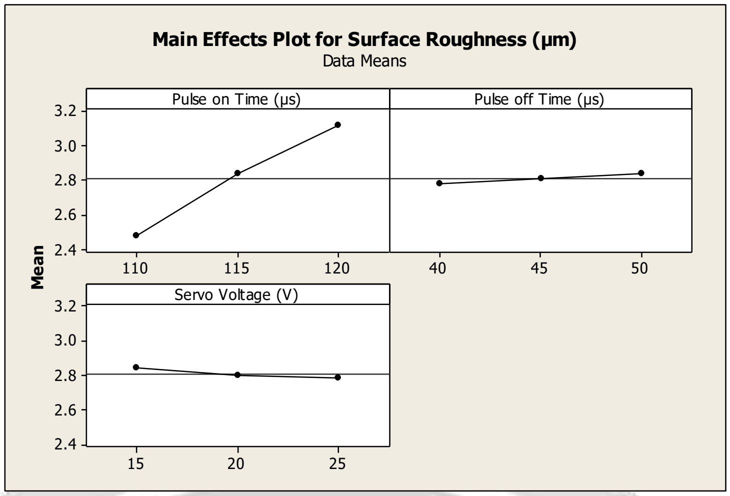

Figure 6.4 Graph of input parameter v/s surface roughness for zinc coated brass wire

7. CONCLUSION AND FUTURE SCOPE

In the presented work, experiments are carried out for material removal rate, surface roughness with variables as pulse on time, pulse off time, servo voltage with two different wire material. There are 27 experimental readings taken for all variables to conduct the parametric study.

Finally it can be concluded that:

- The ANOVA analysis is conducted to know the percentage contribution of the input parameters on output parameters for plain brass wire. ANOVA analysis results that the percentage contribution of pulse on time is 60.68%, pulse off time is 27.86%, servo voltage is 7.63% for material removal rate, which shows that the influence of servo voltage is very less compare to other parameters. The percentage contribution of Pulse on time is 91.93%, Pulse off time is 4.17%, Servo voltage is 1.66% for surface roughness, which shows that the influence of servo voltage is very less compare to other parameters.
- The ANOVA analysis is conducted to know the percentage contribution of the input parameters on output parameters for zinc coated brass wire. ANOVA analysis results that the percentage contribution of pulse on time is 59.55%, pulse off time is 29.14%, servo voltage is 8.33% for material removal rate, which shows that the influence of servo voltage is very less compare to other parameters. The percentage contribution of Pulse on time is 91.81%, Pulse off time is 4.46%, Servo voltage is 1.82% for surface roughness, which shows that the influence of servo voltage is very less compare to other parameters.
- Grey relational analysis is done to find out optimal parameter levels. After grey relational analysis, it is found that optimal parameter levels are pulse on time at level 1 (110 µs), pulse off time at level 1 (40 µs), servo voltage at level 1 (15volts) for both plain brass wire and zinc coated brass wire.
- Zinc coated brass wire gives higher material removal rate, less surface roughness compare to plain brass wire.
- Pulse on time is most significant factor for material removal rate and surface roughness compare to other parameters.
- Increase of Pulse on time generates more spark energy as the length of time that electricity supply increases. MRR and SR all response increasing with pulse on time. Pulse on time found most significant parameter in all response. Surface roughness also increases with increase of pulse on time because the increases of pulse on time produce crater with broader and deeper characteristic.
- Pulse off time has opposite effect to pulse on time.MRR decrease with increase of pulse off time, while surface roughness reduces. During off time removed material flushed away. More the off time better the flushing.
- The MRR increases with increase in servo voltage. This is due to increase in servo voltage result in higher discharge energy per spark because of large ionization of dielectric between working gap; hence the MRR increases.

FUTURE SCOPE

- The mathematical model can be developed with different work piece and electrode materials for EDM and WEDM processes.
- Responses like roundness, circularity, machining cost etc are to be considered in further research.
- The results can be analyzed using other optimization techniques such as neural network, fuzzy logic, genetic algorithm, particle swarm optimization etc., and their effectiveness can be compared.

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