iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** X **Month of publication:** October 2021

DOI: https://doi.org/10.22214/ijraset.2021.38537

Optimization of Process Parameters for Minimum Surface Roughness in Wire Electrical Discharge Machining of AISI 1045 Steel Using Taguchi Method

Rouhan Rafiq[1], Gurlal Singh[2]
[1, 2]Department of Mechanical Engineering, Desh Bhagat University, Mandi Gobindgarh

***Abstract:** One of the important non-traditional machining processes is Wire Electrical Discharge Machining, used for machining difficult to machine materials like composites and inter-metallic materials. WEDM involves complex physical and chemical process including heating and cooling. Accompanying the development of mechanical industry, the demand for alloy materials having high hardness, toughness and impact resistance are increasing. The WEDM satisfy the present demands of the manufacturing industries such as better finish, low tolerance, higher production rate, miniaturization etc. The consistent quality of parts being machined in WEDM is difficult because the process parameters cannot be controlled effectively. The problem of arriving at the optimum levels of the operating parameters has attracted the attention of the researcher and practicing engineers for a very long time.*

The objective of the present study was to experimentally investigate the effects of various Wire Electrical Discharge Machining variables on Surface Roughness and Material Removal Rate of AISI 1045 using ANOVA method. Taguchi's L_{18} Orthogonal Array was used to conduct experiments, which correspond to randomly chosen different combination of process parameters: wire type, pulse on time, pulse off time, peak current, servo voltage, wire feed rate, flushing pressure each to be varied in three different levels. The surface roughness and material removal rate were selected as output responses for the present investigation. The effect of all the input parameters on the output responses have been analyzed using analysis of variance (ANOVA). The effect of variation in input parameters has been studied on the output responses. Plots of S/N ratio have been used to determine the best relationship between the responses and the input parameters. In other words, the optimum set of input parameters for minimum surface roughness and maximum material removal rate were determined. It has been found that wire type, pulse on time are most significant factors for surface roughness and wire type, pulse on time, pulse off time, wire feed rate are most significant factors for material removal rate.

Keywords: Input Parameters, Wire Electric Discharge Machining, ANOVA, Taguchi

I. INTRODUCTION

Electric Discharge Machining is a machining method typically used for hard metals, makes it possible to work with metals for which traditional machining techniques are ineffective. An important point to remember with EDM Machining is that it will only work with materials that are electrically conductive. With good EDM Machining equipment it is possible to cut small odd-shaped angels, detailed cavities in hardened steel as well as exotic metals like titanium, hastaloy, kovar, inconel, and carbide. The EDM process is commonly used in the Tool and Die industry for mold-making, however in recent years EDM has become integral part for making prototype and production parts. This is seen in the aerospace and electronics industries where production quantities remain low. The accuracy, surface finish and time required to complete a job is extremely predictable, making it much easier to quote. WEDM leaves a totally random pattern on the surface as compared to tooling marks left by milling cutters and grinding wheels. The WEDM 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 completely automatic. The spark theory on a Wire EDM is basically the same as that of the vertical EDM process. The basic principle of WEDM is shown below in Fig. 1. With wire EDM, conductive materials are eroded and vaporized with a series of high frequency electrical discharges that are produced between an accurately positioned moving wire electrode and the work piece in the presence of a dielectric.

These high frequency pulses of alternative or direct current, is discharged from the wire to the work piece through an insulated dielectric fluid creating a very small discharge spark gap. Many sparks can be observed at one time, because actual discharges can occur more than one hundred to thousand times per second, with discharge sparks lasting in the range of 1/1000,000 of a second or less. The volume of metal removed during this short period of spark discharge depends on the desired cutting speed and the surface finish required. By raising the current for a given discharge frequency, the cutting speeds will increase, however, the surface finish will become slightly rougher. Keep in mind that there is repeated ON and OFF time of the spark that removes material, not just the flow of electric current.

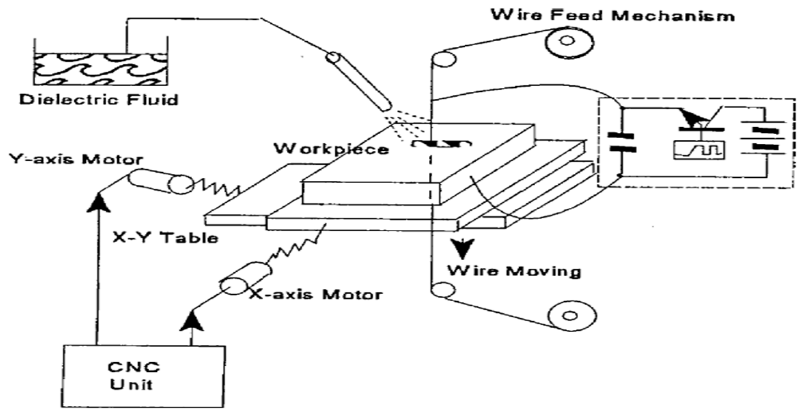

Fig.1. Basic Principle of wire EDM (Saha et al., 2004)

II. LITERATURE SURVEY

Saleh et al. (2) presents the results of an investigation on the capacity of wire electrical discharge machining (WEDM) to produce micro channels in the Nickel-based alloy, Monel 400. The main objective of the current study is to produce micro channels with desired/target geometry and acceptable surface quality. Square cross-sectional micro channels with dimensions of 500 × 500 µm were investigated. Experiments were conducted based on the one-factor-at-a-time approach for the key input WEDM process parameters, namely pulse-on time (TON), pulse-off time (TOFF), average gap voltage (VGAP), wire feed (WF), and dielectric flow rate (FR). Dimensional accuracy, machining speed, surface roughness, surface morphology, micro hardness, and microstructure were analyzed to evaluate the micro channels. The minimum errors of 6% and 3% were observed in the width and depth of the micro channels, respectively. Furthermore, micro channels with enhanced surface integrity could be produced exhibiting smooth surface morphology and shallow recast layer (~0–2.55 µm).Ahmad et al. (3) carried out research on building ANN model to predict metal removal rate (MRR) and surface roughness (Ra) values for machining AISI 1045 steel, identifying the significance of the pulse on-time (T_{ON}), pulse off time (T_{OFF}) and servo feed (S_F) for the MRR and Ra, and selecting optimal machining parameters that give maximum MRR value and that give the minimum Ra value. Taguchi method (Design of Experiments), artificial neural network (ANN), and analysis of variances (ANOVA) used in this research as a methodology to fulfill research objectives. Slatineanu et al. (4) aimed to reveal the aspects that characterize the process, phenomena, performances, and evolution trends specific to the wire electrical discharge machining processes, as they result from scientific works published mainly in the last two decades. Naveed (5) shows that during WEDM cutting, a thin layer extending to a depth of a few micrometers below the surface of the cut, is transformed. This layer is known as the recast layer. Using controlled-depth etching and X-ray diffraction, it is shown that this induces an additional tensile residual stress, parallel to the plane of the cut surface. Patel et al. (6) reviews paper describe the latest research trends in WEDM process in relation between different input process parameter and different output measure like material removal rate, surface roughness, dimensional deviation, kerf width and wire wear ratio. Paper highlights different wire material, wire diameter and optimization methods and discusses their role in WEDM process. Anurag. S (7) reviews the feasibility of wire-EDM as the preferred machining process over traditional broaching process, for gamma titanium aluminides in future jet engine components. Madhavakrishnan et al. (8) review of the recent work has been done. Some properties and parameters that affect the machining performance of WEDM are also discussed. Shah et al. (1) carried out wire electric discharge machining of Inconel-600 material on CONCORD DK7720C WEDM machine. They studied the effect of WEDM process parameters such as peak current, pulse on time, pulse off time and wire feed on material removal rate of Inconel-600. Molybdenum wire of diameter 0.18 mm was used as electrode and de-mineralized water was used as dielectric fluid. They have used workpiece of size 10 mm × 5 mm × 5mm for the experimental operation.

The models for co-relating the inter-relationship of various WEDM machining parameters of Inconel-600 material had been established using response surface methodology. The ANOVA was carried out to study the effect of process parameters on process performance and it was shown that pulse-on time, pulse-off time and peak current were most significant parameters. An optimum parametric combination for the maximum material removal rate was obtained by using signal-to-noise ratio. Harpreet et. al (9) investigated wear behaviour of AISI D3 die steel using cryogenic treated copper and brass electrode in electric discharge machining. The input process parameters as current using four different types of electrodes i.e. Cu, cryogenic treated Cu, Br and cryogenic treated Br. The weight of the work pieces and electrodes was done before machining and after machining on the weighing machine with least count of 1 mg. Kerosene oil was used as dielectric fluid experiments. The electrodes having the size of 16 mm diameter and 55 mm length were prepared out of the rods of Copper and Brass for performing the experiments. After preparing the required size the face of all the electrodes was polished so as to get good surface finish using different emery papers ranges from 220 to 2000 grit size. After that electrodes of Cu and Br were cryogenically treated to improve properties. Work piece size of 25mm×18mm×6mm were prepared by using wire EDM. The prepare sample were heat treated to improve their hardness. After heat treatment the hardness of work piece material was 58HRc. Copper electrode is best electrode for high material removal rate. But cryogenic treated copper electrode has very low tool wear as compared to cooper electrode.

III. OBJECTIVES OF PRESENT INVESTIGATION

A. To find out the effect of different process parameters on surface roughness.
B. Optimization of input process parameters for minimum surface roughness by using ANOVA method.

IV. EXPERIMENTATION

The experiments were carried out on a WEDM machine, model: ELEKTRA SPRINTCUT 734 of Electronica Machine Tools Ltd. This machine comprises of a Machine Tool, a Power Supply Unit and a Dielectric Unit. The machine tool comprises of a main worktable (called X-Y table) on which the work piece is clamped, an auxiliary table (called U-V table) and wire drive mechanism. In this study AISI 1045 steel is selected as the work piece material, which is a medium carbon steel. This material offers a very good balance of strength and good ductility. Due to these properties it is generally used for making shafts and gears. AISI 1045 steel is also used in extrusion dies, plastic mould and swaging dies. The AISI 1045 hot work tool steel specimens of 55 mm length, 25 mm width and 20 mm thickness have been used as work piece material for the present investigation. Surface roughness is output parameters in this present research. In this study the factors which mainly affect the response parameters (surface roughness) with their levels were taken. Some of the factors like number of passes, thickness of work piece, angle of cut were kept constant during the experimental study. The various parameters which were taken for experimental study were type of wire, pulse on time, pulse off time, peak current, servo voltage, wire feed rate, flushing pressure. Three levels of each parameter were taken for the experimental operation. The experiments are conducted after fixing some parameters as given in Table 1. The control factors and their levels taken are shown in Table 2.

Table 1 Fixed Parameters

Parameter	Value
Dielectric media Used	De-ionized Water
Shape of cut	Straight cut 40mm path length
Diameter of wire	0.25mm
Angle of cut	Vertical cut
Thickness / Height of the work piece	15mm

Table 2 Input Factors and Their Levels

S.No.	Paramater	Symbol	Level 1	Level 2	Level 3	Units
1.	Wire Type	-----	Brass	Diffused	Recoated	
2.	Pulse On Time	TON	115	120	125	µs
3.	Pulse Off Time	TOFF	50	54	58	µs
4.	Peak Current	PC	220	230	240	Ampere
5.	Servo Voltage	SV	15	20	25	Volts
6.	Wire Feed Rate	WF	5	6	7	m/min
7.	Flushing Pressure	FP	08	10	12	Kg/cm^2

For this case the L_{18} orthogonal arrays having eighteen experimental runs is found most suitable. The L_{18} orthogonal arrays along with independent variables and their selected levels used for the experiment is shown in Table 3.

Table 3 Experimental Design using L_{18} Orthogonal Array

Exp. No.	WIRE TYPE	TON	TOFF	PC	SV	WF	FP
1.	Brass	117	50	220	15	5	8
2.	Brass	122	54	230	20	6	10
3.	Brass	127	58	240	25	7	12
4.	Diffused	117	50	220	20	6	12
5.	Diffused	122	54	230	30	7	8
6.	Diffused	127	58	240	20	5	10
7.	Recoated	117	50	230	15	7	10
8.	Recoated	122	54	240	20	5	12
9.	Recoated	127	58	220	25	6	8
10.	Brass	117	50	240	25	6	10
11.	Brass	122	54	220	15	7	12
12.	Brass	127	58	230	20	5	8
13.	Diffused	117	50	230	25	5	12
14.	Diffused	122	54	240	15	6	8
15.	Diffused	127	58	220	20	7	12
16.	Recoated	117	50	240	20	7	8
17.	Recoated	122	54	220	25	5	10
18.	Recoated	127	58	230	15	6	12

V. RESULT AND ANALYSIS

After conducting all the 18 experiments with different input factor levels, the results were obtained for surface roughness for the work pieces. These results have been shown in Table 4. The surface roughness and material removal rate for each experiment has been shown against each experimental run.

Table 4 Results for Surface Roughness

1.	Brass	117	50	220	15	5	8	3.41	0.060
2.	Brass	122	54	230	20	6	10	3.24	0.058
3.	Brass	127	58	240	25	7	12	3.05	0.042
4.	Diffused	117	50	220	20	6	12	3.50	0.078
5.	Diffused	122	54	230	30	7	8	3.38	0.078
6.	Diffused	127	58	240	20	5	10	3.25	0.073
7.	Recoated	117	50	230	15	7	10	4.10	0.090
8.	Recoated	122	54	240	20	5	12	3.81	0.094
9.	Recoated	127	58	220	25	6	8	3.60	0.050
10.	Brass	117	50	240	25	6	10	3.65	0.062
11.	Brass	122	54	220	15	7	12	2.28	0.062
12.	Brass	127	58	230	20	5	8	2.53	0.058
13.	Diffused	117	50	230	25	5	12	2.97	0.079
14.	Diffused	122	54	240	15	6	8	3.91	0.073
15.	Diffused	127	58	220	20	7	12	3.04	0.078
16.	Recoated	117	50	240	20	7	8	4.01	0.130
17.	Recoated	122	54	220	25	5	10	3.85	0.140
18.	Recoated	127	58	230	15	6	12	3.70	0.122

Table 5 Result for surface Roughness (Ra)

Exp. No.	WIRE TYPE	TON	TOFF	PC	SV	WF	FP	SR (μm)	S/N Ratio(dB)
1.	Brass	117	50	220	15	5	8	3.41	-10.655
2.	Brass	122	54	230	20	6	10	3.24	-10.210
3.	Brass	127	58	240	25	7	12	3.05	-9.685
4.	Diffused	117	50	220	20	6	12	3.50	-10.881
5.	Diffused	122	54	230	30	7	8	3.38	-10.578
6.	Diffused	127	58	240	20	5	10	3.25	-10.237
7.	Recoated	117	50	230	15	7	10	4.10	-12.555
8.	Recoated	122	54	240	20	5	12	3.81	-11.618
9.	Recoated	127	58	220	25	6	8	3.60	-11.126
10.	Brass	117	50	240	25	6	10	3.65	-11.245
11.	Brass	122	54	220	15	7	12	2.28	-7.158
12.	Brass	127	58	230	20	5	8	2.53	-10.955
13.	Diffused	117	50	230	25	5	12	2.97	-9.455
14.	Diffused	122	54	240	15	6	8	3.91	-11.843
15.	Diffused	127	58	220	20	7	12	3.04	-9.657
16.	Recoated	117	50	240	20	7	8	4.01	-12.062
17.	Recoated	122	54	220	25	5	10	3.85	-11.709
18.	Recoated	127	58	230	15	6	12	3.70	-11.364

The experimental results for surface roughness were analyzed using ANOVA calculations and given in table 6.

Table 6 Analysis of variance for S/N ratio for surface roughness (Ra)

S. No.	Source	Sum of Squares	Degree of Freedom	Mean Square	F-ratio	Status	Percentage Contribution
1.	WIRE TYPE	3.225	2	1.612	1.364	Insignificant	7.70 %
2.	PULSE ON TIME	15.498	2	7.749	6.555	Significant	37.0%
3.	PULSE OFF TIME	0.629	2	0.314	0.265	Insignificant	3.50%
4.	PEAK CURRENT	0.150	2	0.075	0.063	Insignificant	2.43%
5.	SERVO VOLTAGE	5.663	2	2.831	2.395	Insignificant	13.52%
6.	WIRE FEED RATE	1.792	2	0.896	0.758	Insignificant	6.27%
7.	FLUSHING PRESSURE	2.096	2	1.048	0.886	Insignificant	7.00%
	ERROR	9.460	8	1.182			22.58%
	TOTAL	38.513	22				100%

The F-values given in the table suggests the significance of the factors on the desired characteristic. The principle of F test is that larger the F value more is the significance of factor. In these experiments the $F_{0.05,2,8}$ table value, determines significance of a factor at 95% confidence level, if it is greater than 4.46. Since $F_{0.05,2,8}$ = 4.46, effect of pulse-on time shows significance. The error variation is large (contribution = 22.58%), suggesting that some factors would not have been included in the study. However, the rank order based on contribution is same as that obtained earlier through percentage contribution method.

The response table for signal-to-noise ratio for all the variables is given in Table 7. In the last row of Table 7 ranks have been given to various factors. Higher is the rank, higher is the significance. In the Table 7 pulse-on time has the highest rank 1 and this is the most significant factor followed by servo voltage with rank 2. However, the other factors have less effect.

Table 7 Response table for signal-to-noise ratio for surface roughness

Level	Wire Type	TON	TOFF	PC	SV	WF	FP
1	-10.838	-9.629*	-10.695	-10.480	-11.112	-10.226*	-10.844
2	-10.605	-10.358	-10.430	-10.398*	-10.318	-10.838	-10.450
3	-10.016*	-11.472	-10.334*	-10.581	-10.029*	-10.395	-10.165*
DELTA	0.822	1.843	0.361	0.183	1.083	0.612	0.679
RANK	3	1	6	7	2	5	4

*Larger S/N ratios are better to minimize loss function.

A. *Effect of Different Wire Electrodes*

The effect of different wire electrode's materials on surface roughness is shown in Fig. 2. It shows that the value of surface roughness decreases when wire is changed from brass wire to diffused wire to recoated zinc wire. Minimum surface roughness was observed with recoated wire and maximum with brass wire.

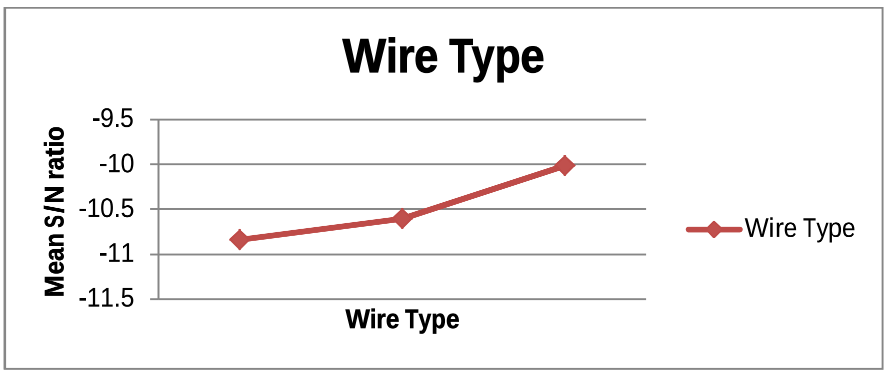

Fig. 2. Effect of Wire Type on Surface Roughness

B. *Effect of Pulse-On Time*

The effect of varying pulse on time on surface roughness is shown in Fig. 3. It shows that the surface roughness increases with increase in value of pulse-on time. It may be due to increase in pulse current produces stronger spark and higher temperatures. This causes more melting of the material and eroding the workpiece and consequent increase in surface roughness.

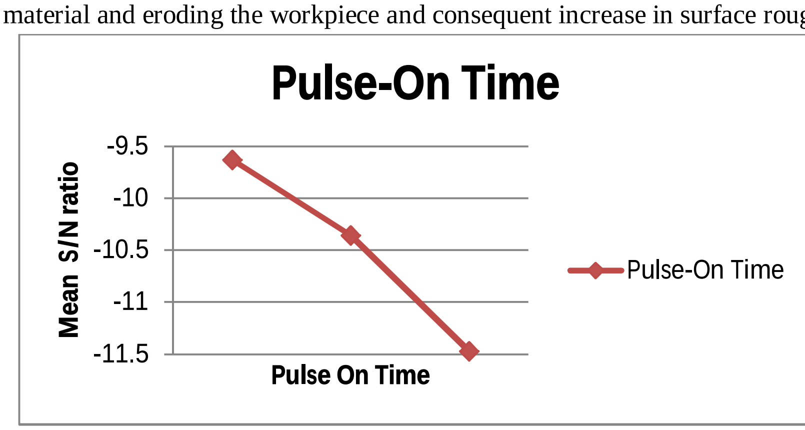

Fig. 3. Effect of Pulse-On Time on Surface Roughness

C. *Effect of Pulse-Off Time*

The effect of varying pulse off time on surface roughness is shown in Fig. 4. It shows that with increased value of pulse off time, the surface roughness decreases. This may be because of higher the value of pulse off time, lesser is the number of discharges in a given time, resulting in non uniform sparking and lesser number of particles disloged near surface of work materials. This causes more hills and valleys rather than uniform rounded surfaces.

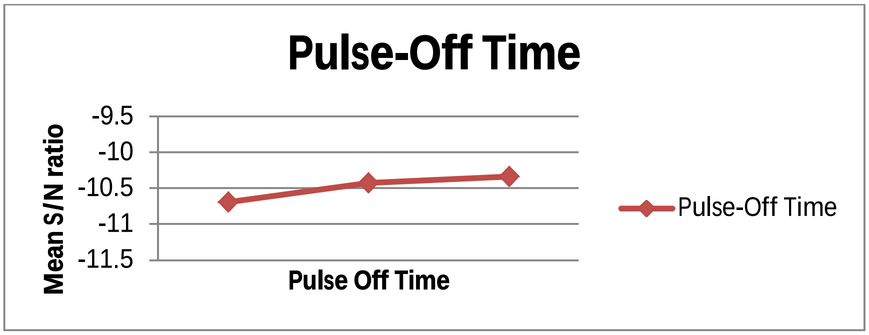

Fig. 4. Effect of Pulse Off Time on Surface Roughness

D. *Effect of Peak Current*

The effect of varying peak current on surface roughness is shown in Fig. 5. It shows that the surface roughness increases with increase in value of peak current. Increase in value of peak current increases the discharge energy. So increasing the discharge energy generally increases surface irregularities due to much more melting and re-solidification of materials. Because of this, large debris is formed which cannot easily pass through a narrow gap, it stays between the wire and workpiece reducing the surface quality. Hence, it is found that surface roughness tends to increase significantly with increase in peak current.

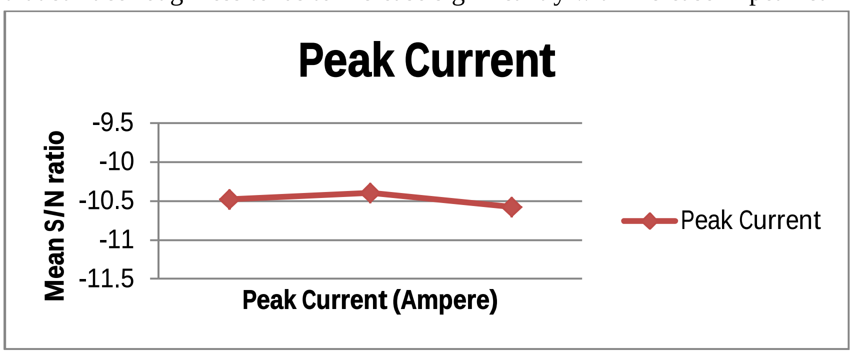

Fig. 5. Effect of Peak Current on Surface Roughness

E. *Effect of Servo Voltage*

The effect of varying servo voltage on surface roughness is shown in Fig. 6. It shows that with increase in value of servo voltage, surface roughness decreases. The reason for this may be that when the value for servo voltage is higher; the gap between the work piece and the electrode becomes wider. Higher value for servo voltage decreases the number of electric sparks, stabilizing electric discharge, although the machining rate is slowed down. When a smaller value is set for servo voltage, the mean gap becomes narrower, which leads to an increase in number of electric sparks. It can speed up the machining rate; however, resulting in poor surface and wire breakage.

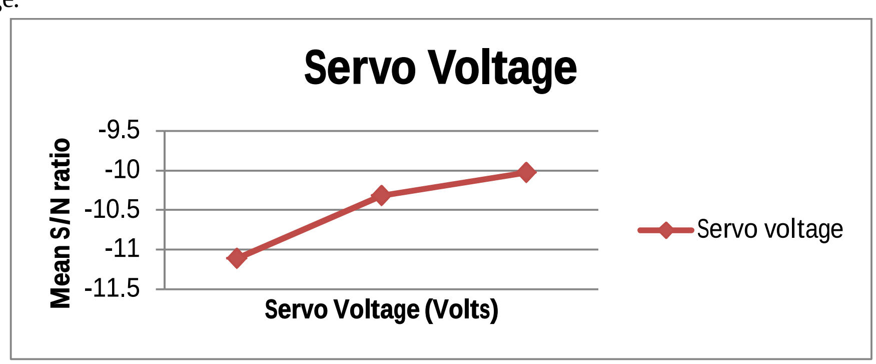

Fig. 6. Effect of Servo Voltage on Surface Roughness

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue X Oct 2021- Available at www.ijraset.com

F. *Effect of Wire Feed Rate*

The effect of varying wire feed rate on surface roughness is shown in Fig. 7. It shows that surface roughness with wire feed has first increases and then decreases. Wire feed did not play a vital role on surface roughness of the workpiece. On the other hand as the wire feed increased the wear ratio decreased drastically. This is because the spark erosion on the travelling wire electrode becomes thin and brittle with increased feeds. When wire feed is at maximum, fresh wire is introduced and the spark generation was also greater.

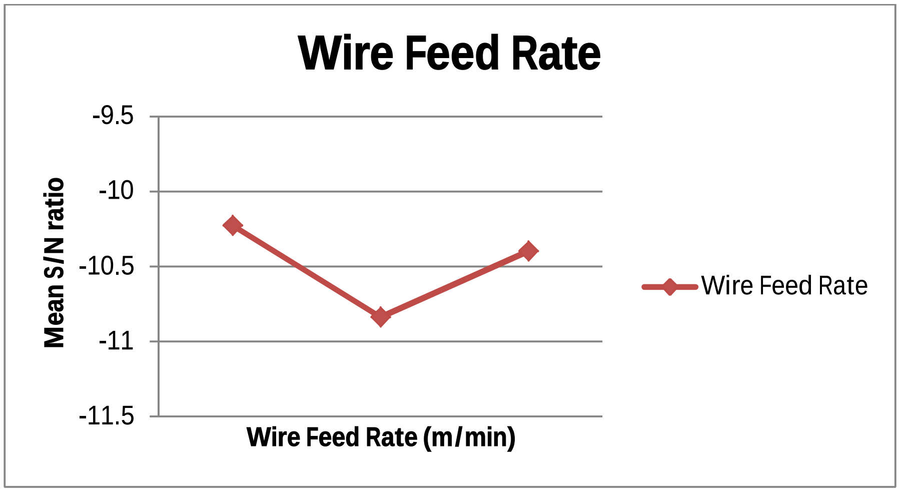

Fig. 7. Effect of Wire Feed Rate on Surface Roughness

G. *Effect of Flushing Pressure*

The effect of varying flushing pressure on surface roughness is shown in Fig. 8. It shows that increase in value of flushing presure decreases the surface roughness. This is may be due to the cooling effect of dielectric flow rate on the workpiece surface. The other reason could be that increased flow on the workpiece may prevent debris adhering to the surface. Sufficient flushing pressure is needed for proper functioning.

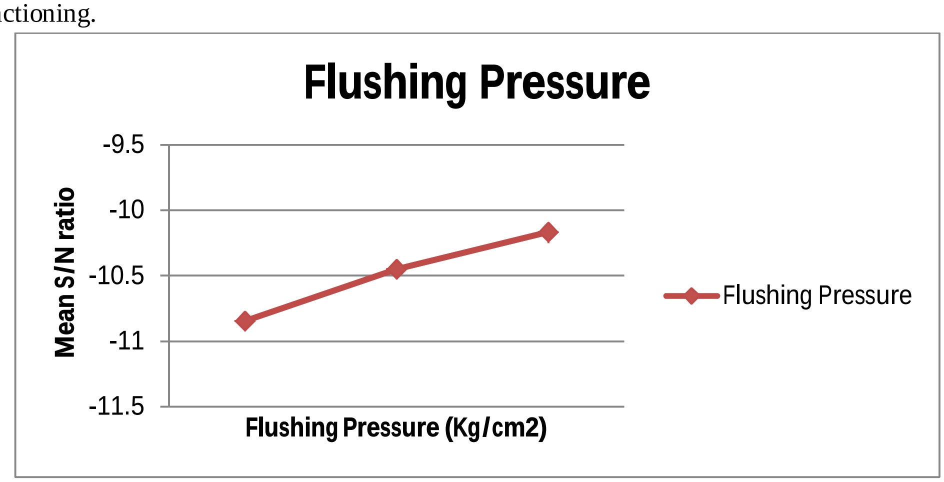

Fig. 8. Effect of Flushing Pressure on Surface Roughness

VI. CONCLUSION

Pulse-on time found to be most significant factors for surface roughness, while less effect has been shown by wire type, peak current, servo voltage, pulse off time, wire feed rate, flushing pressure on surface roughness.

A. The surface roughness was found to be minimum with recoated wire and maximum with plain brass wire.
B. The surface roughness increases with increase in pulse on time and peak current.
C. The surface roughness decreases with increase in pulse off time, servo voltage, flushing pressure.
D. As the wire feed rate increases, the surface roughness first increases and then decreases.

REFERENCES

[1] Saha, S., Panchan, M., Ghosal. A., and Schulz, M.J.(2004), 'Finite element modeling and optimization to prevent wire breakage in electro-discharge machining', Mechanics Research Communications, Vol. 31, pp. 451-463.
[2] Saleh, M., Anwar, S., Tamimi, A., Mohammed, M., and Ahmad, S. (2020), 'Milling Microchannels in Monel 400 Alloy by Wire EDM: An Experimental Analysis', Micromachines, 11,469.
[3] Ahmad, A., Ubaid, A., Abaid, M., and Elias, R. (2020),' Wire EDM process optimization for machining AISI 1045 steel by use of Taguchi method, artificial neural network and analysis of variances', International Journal of Systems Assurance Engineering and Management, 11(1–4).
[4] Slatineanu, L., Dodun, O., and Nagit, G. (2020),' Wire Electrical Discharge Machining—A Review', Machines, 8(4):69.
[5] Naveed, N. (2018),' Experimental study of the effects of wire EDM on the characteristics of ferritic steel, at a micro-scale on the contour cut surface', Metallurgical Research and Technology, 115(4):413.
[6] Patel, J., and Maniya, K. (2018),' A Review on: Wire cut electrical discharge machining process for metal matrix composite', 2nd International Conference on Materials Manufacturing and Design Engineering, 253-258.
[7] Anurag, S. (2018),' Wire-EDM: a potential manufacturing process for gamma titanium aluminides in future aero engines', The International Journal of Advanced Manufacturing Technology, 94(10).
[8] Madhavakrishnan, S., and Suresh, P. (2016),' RECENT DEVELOPMENTS IN WIRE EDM', Journal of Mechanical Engineering and Technology (JMET), Volume 4, Issue 1.
[9] Singh, H., and Garg, R. (2009), 'Effects of process parameters on material removal rate in Wire Electric Discharge Machining', Journal of Achievements in Materials and Manufacturing Engineering, Vol. 32, No. 1, pp. 70-74.