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Impact of change in machining time, MRR in WEDM modeled by ANN-RSM

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Abstract

A combination of nickel and chromium alloy named as Inconel 800 and zinc coated brass wire is used as a workpiece and wire electrode respectively for this experimental analysis designed by Taguchi orthogonal array L18. The experimental analysis is carried out under the highest, medium and lowest rate of dielectric fluid flushing through both the upper and lower nozzle placed nearer to the metal cutting edge. The flushing through the nozzles is in litters per minutes and the process parameters such as pulse on time, pulse off time, spark gap voltage, peak current were varies during the experimental phase and wire tension, wire feed, water pressure, peak voltage, servo feed were kept constant. For checking the correctness of the input parameters a digital storage oscilloscope (Agilent 3000) is used to find out the pulse on and pulse off time signals and the signals were validated with respect to their actual units by analyzing the time signals. The status of the influence and the search for best possible responses of the machining parameters for minimum machining time and increase in MRR, is determined by using analysis of variance (ANOVA). Finally an analytical model has been designed with the help of artificial neural network (ANN) and Response surface methodology (RSM).

Keywords: *Wire EDM, Inconel 800, Zn coated wire, Machining time, MRR, flushing rate, ANN.*

INTRODUCTION

Wire electrical discharge machining process has higher range of acceptability for its machining accuracy and negligible amount of error for developing a product. The development of mechanical industry and the demands for alloy materials having high hardness, toughness and impact resistance are increasing. The experimental analysis is carried out by varying process parameters such as pulse on time, pulse off time, spark gap voltage, peak current and dielectric fluid flushing rate per minute. According to the flow meter the variation in the flushing rate of dielectric fluid per minute have a range from 0 to 12 liters/minute and due to some frictional losses in pipes the maximum and minimum flushing rates though the upper nozzle can be achieved up to 10 LPM and 2.5 LPM respectively, similarly for the lower nozzle the maximum and minimum flushing rate can be achieved up to 8.5 LPM and 1.5 LPM respectively. Finally for the experimental phase the upper nozzle is set at a flushing rate of 10, 6 and 2.5 LPM and the lower nozzle is set at a rate of 8.5, 5 and 1.5 LPM as highest, medium and lowest rates of flushing respectively. A digital storage oscilloscope Agilent 3000 is used to analyses the correctness in time signals (Ton/Toff) digitally to identify the correctness of the experiments. The design for the experiment is scheduled by Taguchi's orthogonal array L18 to cut the workpiece (Inconel 800) linearly up to 10 mm by means of zinc coated wire. After completing the definite set of experiments at flushing conditions such as highest, medium and lowest flushing rate, a set of output comes as a result in less machining time with respect to increase in material removal rate for same kind of machining operation[1-3].The analysis of variance (ANOVA) defines the most influencing factor on the machining time (M/C time) and material removal rate (MRR) for each and every flushing condition. In the end the predicted value by using Artificial Neural Network (ANN) and Response Surface Methodology (RSM) were compared with the experimental values. The Root mean square errors (RMSE) for machining time are found to be 0.0175620, 0.141375 and 0.0075425 by ANN at three flushing rates respectively and by RSM 0.0094428, 0.0430103 and 0.0085302 at three flushing rates respectively, for material removal rate 0.0193978, 0.0204711 and 0.0214323 by ANN at three flushing rates respectively and by RSM 0.0255217, 0.0280531 and 0.0128587 at three flushing rates respectively. Finally it has been observed that the predicted values with RSM are nearer to experimental values as compared to ANN model[4-6].

LITERATURE SURVEY

Portillo E., et al. [1] developed recurrent neural network model to diagnose degraded cutting regimes in Wire Electrical Discharge Machining process, which helps to detect the degradation of the cutting process which results in breakage of the wire electrode tool, productivity of the process and accuracy required. Trang Y. S. et al. [2] developed a neural network model to determine pulse duration, time, open circuit voltage, peak current, electric capacitance and wire speed servo reference voltage for the estimation of cutting speed and surface. Tomura Shunsuke, et al.[3] clarify the mechanism that how electromagnetic force is applied to the wire electrode in wire electrical discharge machining (wire-EDM) is being generated. Rajyalakshmi and Ramaiah [4] carried out an experimental investigation on the influence of cutting parameters of WEDM during the machining of Inconel825. The response of surface roughness is considered for improving the machining efficiency. Jin et al. (2008) [5] discussed the development of reliable multiobjective optimization based on Gaussian Process Regression (GPR) to optimize the highspeed wirecut electrical discharge machining (WEDMHS) process, considering mean current, ontime and offtime as input features and material remove rate and surface roughness as output responses. Nihat Tosun and Can Cogun [6] In this study, the effect of cutting parameters on wire electrode wear was investigated experimentally in wire electrical discharge machining(WEDM). The experiments were conducted under different settings of pulse duration, open circuit voltage, wire speed and dielectric fluid pressure. Brass wire of 0.25 mm diameter and AISI 4140 steel of 10 mm thickness were used as tool and work piece material. The level of importance of the machining parameters on the WWR was determined by using analysis of variance (ANOVA) method. Jennes and Snoey [7] Believed that the traditional research purpose was not to improve machining efficiency, but to prevent from wire rupture during the machining process. Hence, one possible new WEDM challenge and future work area will be steered towards attaining higher machining efficiency by acquiring a higher CR and MRR with a low wire consumption and frequency of wire breakage. Shandilya et al. [8] used a RSM and artificial neural network based mathematical modelling for average cutting speed of Si Cp/6061 Al metal matrix composite during WEDM. Four WEDM parameters namely servo voltage, pulse-on time, pulse-off time and wire feed rate were chosen as machining process parameters. They developed a back propagation neural network to establish the process model[7,8]. The performance of the developed artificial neural network models was compared with the RSM mathematical models of average cutting speed. Sharma et al [9] investigated the effect of parameters on metal removal rate for WEDM using high strength low alloy as work-piece and brass wire as electrode. They observed that material removal rate and surface roughness increase with increase in pulse on time and peak current. RSM is used to optimize the process parameter for material removal rate and surface roughness. They developed a mathematical model which correlates the independent process parameters with the desired metal removal rate and Surface Roughness. The central composite rotatable design has been used to conduct the experiments. Sarkar et al [10] studied the trim cutting operation in Wire EDM of γ-titanium aluminide. A second order mathematical model was developed for surface roughness, dimensional shift and cutting speed using response surface methodology (RSM). The experimental plan was based on the face centered, central composite design. It was observed that the performance of the developed Pareto optimization algorithm is superior compared to desirability function approach.

EXPERIMENTAL SETUP

Fig 1: *Wire EDM machine*

The experiments were done on wire EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. installed at NTM Lab of Production Engineering Department, N.I.T., Agartala, Tripura, India. In this experimental work Inconel 800 is used as a workpiece and zinc coated brass wire (0.25 mm) is used as a wire electrode material.

SELECTION OF PROCESS PARAMETERS

This paper makes use of Taguchi’s method for designing the experiments. Hence L18 mixed orthogonal array was selected for the present investigation. Parameters and their levels selected for final experimentation has been depicted. The following process parameters and their ranges were selected for the experiments.

Table 1:*Input process parameters*

Factors	Symbol	Units	Ranges
Pulse on time	Ton	µs	105,108,111,114,117,120
Pulse off time	Toff	µs	63,60,57
Peak current	IP	A	230,220,210
Spark gap voltage	SV	V	20,35,50
Wire tension	WT	gram	6
Wire feed	WF	m/min	8
Water Pressure	WP	1 unit (15 kg/cm²)	1
Peak voltage	VP	2 units (110V DC)	2
Servo feed	SF	Unit	1050

VARIATION ON DIELECTRIC FLUID DISCHARGE RATE

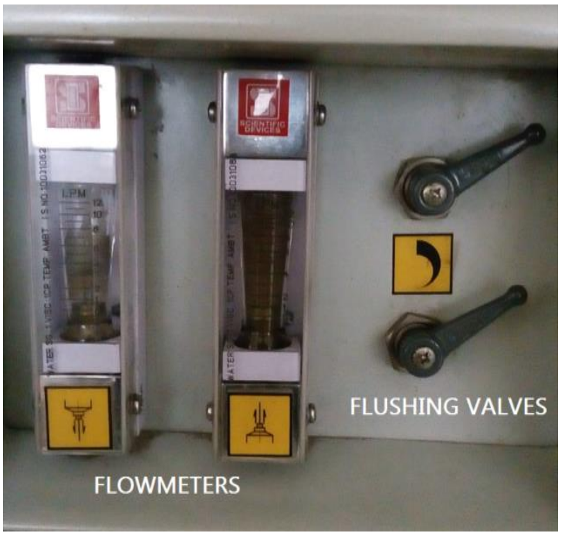


Fig 2: *Flow meter of the machine*

During machining period, the machining area is continuously flushed with dielectric fluid preferably deionised water mixed with resin is passing through the nozzles on both sides of the workpiece. The spark discharge across the work piece and wire electrodes causes an ionization of the water which is used as a dielectric medium[9,10]. The experiments were done under the varying condition of the dielectric fluid discharge rate through the upper and lower nozzle. According to the flow meter the deviation of the dielectric fluid discharge rate having range from 0 to 12 liters/minute (LPM) but the highest rate of dielectric fluid discharge per minute by the upper and lower nozzle can be achieved up to 10 LPM and 8.5 LPM respectively by the rotation of the flushing valves. Similarly the lowest rate of dielectric fluid discharge per minute by the upper and lower nozzle can be achieved up to 2.5 LPM and 1.5 LPM respectively. Now by taking the average value between the highest and lowest rate of discharge the medium rate of dielectric fluid discharge per minute by the upper and lower nozzle is taken as 6 LPM and 5 LPM respectively.

VALIDATION OF TIME CYCLE (PLUSE ON/OFF TIME)

Fig 3:*oscilloscope connection by passive proves to the two (positive/negative) terminals*

To check and identify the actual units of the parameters with respect to their machine units a Agilent 3000 series oscilloscopes is used to analyze the their actual units form the graphical observation of constantly varying signal voltages, usually as a two dimensional plot of one or more signals as a function of time.

The oscilloscope is connected by the passive prove to two (positive/negative) terminals as shown in the figure 2 and the input analogue signal is sampled and then converted into a digital record of the amplitude of the signal at each sample time. The oscilloscope has been set by auto scaling of 5V/div, 10µs/div and 10MSa/s. Now during the cutting condition the oscilloscope starts showing the waveforms on its display screen and by pressing on the STOP/RUN button the waveforms at a particular time has been observed. Finally after measuring the waveform for the cycle we can identify and get the actual units for input data.

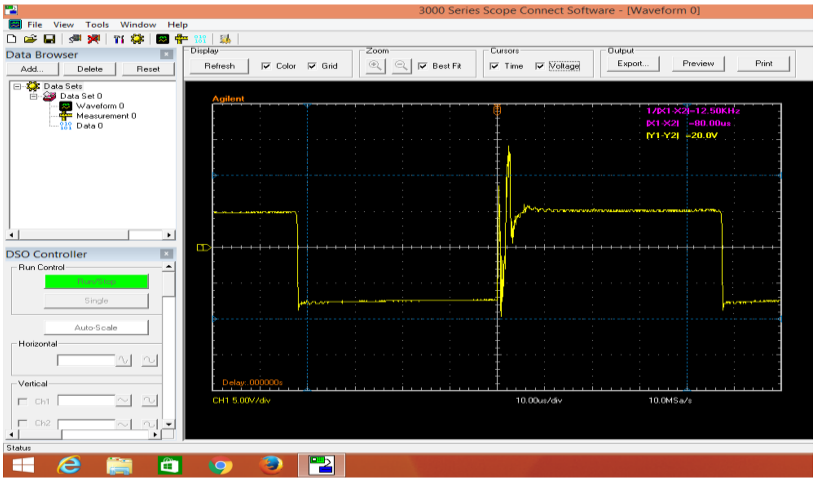


Fig 4: *Observation of pulse ON/OFF time cycle*

Table 2: *Actual units (microseconds) of Ton/Toff and their validation*

Experiment No	Machine Unit		Actual Unit(µs)		Graphical Analysis(µs)	
	Ton	Toff	Ton	Toff	Ton	Toff
1	105	63	5.35	52	5.60	54
2	105	60	5.35	46	5.40	50
3	105	57	5.35	40	5.40	42
4	108	63	5.50	52	5.80	50
5	108	60	5.50	46	6.00	46
6	108	57	5.50	40	6.00	38
7	111	63	5.65	52	6.20	46
8	111	60	5.65	46	6.20	44
9	111	57	5.65	40	6.40	44
10	114	63	5.80	52	6.00	48
11	114	60	5.80	46	5.80	46
12	114	57	5.80	40	5.60	44
13	117	63	5.95	52	6.00	54
14	117	60	5.95	46	6.00	42
15	117	57	5.95	40	5.80	40
16	120	63	6.10	52	5.80	50
17	120	60	6.10	46	6.20	46
18	120	57	6.10	40	6.40	42

The input analogue signal is sampled and then converted into a digital record of the amplitude of the signal at each sample time. The oscilloscope has been set by auto scaling of 5V/div, 10µs/div and 10MSa/s. Now during the cutting condition the oscilloscope starts showing the waveforms on its display screen and by pressing on the STOP/RUN button the waveforms at a particular time has been observed. Finally after analyzing the waveform for the time cycle we can identify and get the actual units of input data. As the increase in input values for the Ton there must be a negligible amount of decrease in Toff values for the same input value of the Toff with respect to increase in Ton values. As per the graph of all the experiments designed by Taguchi orthogonal array of L18 for the Ton/Toff cycle the actual unit comes from the graphical analysis are mostly as same the standard actual units and thus we can say that the experiments have negligible amount of error and their might not be any kind of calibration on the machine power circuit.

METAL CUTTING AS PER THE DESIGN OF EXPERIMENTS UNDER VARIOUS FLUSHING RATES AND KERF WIDTH MEASUREMENTS

***Fig 5:10** mm linear cut on metal piece as CNC programmed (G01)*

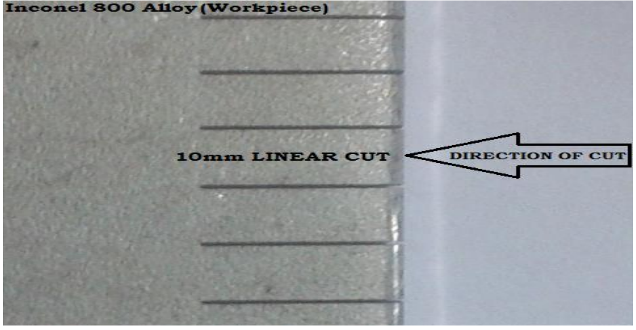
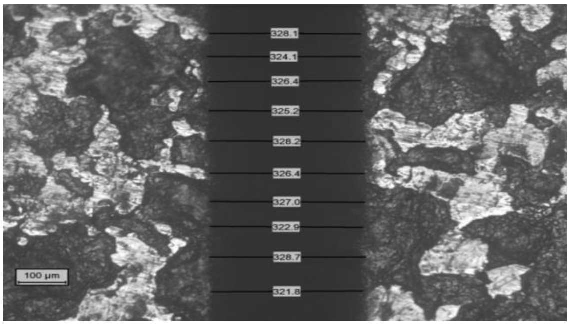


***Fig 6:** Microscopic view of kerf width*



Kerf width is one of the important performance measures in WEDM. It is the measure of the amount of the material that is wasted during machining and determines the dimensional accuracy of the finishing part. The internal corner radiuses to be produced in WEDM operation are also limited by the kerf width. In setting the machining parameters, the main goal is the maximum MRR with the minimum Kerf width. The detailed section of the Kerf width is shown in Fig.6. It is measured in micrometers (µm). For present experiments kerf width has been measured using Optical Microscope, shown in Fig. 12. Optical microscopes are microscopes that typically use visible light and a system of lenses to magnify images of small samples. It aims to improve resolution and sample contrast. Images from an optical microscope can be captured by normal light-sensitive cameras to generate a micrograph. The optical microscope was used to obtain kerf width of the specimen as shown in Fig. 13.The main purpose of present work is to investigate and correlate the relationship between the various input and output parameters.

***Table 3:** Kerf thickness at various flushing rates*

Experiment No	Highest flushing rate	Medium flushing rate	Lowest flushing rate
	K_1	K_2	K_3
1	339.51	332.41	314.46
2	339.39	328.56	307.13
3	342.47	328.66	309.31
4	337.50	329.27	315.23
5	326.86	326.41	315.12
6	331.52	325.24	317.78
7	333.77	319.57	319.54
8	334.28	318.84	320.69
9	331.41	319.93	325.66
10	324.67	320.74	326.20
11	321.83	314.15	324.43
12	320.90	313.15	338.39
13	308.48	309.26	327.29
14	307.98	311.75	328.90
15	309.66	332.80	333.23
16	310.00	339.32	342.15
17	313.84	331.91	336.26
18	315.67	336.56	339.88

MATERIAL REMOVAL RATE

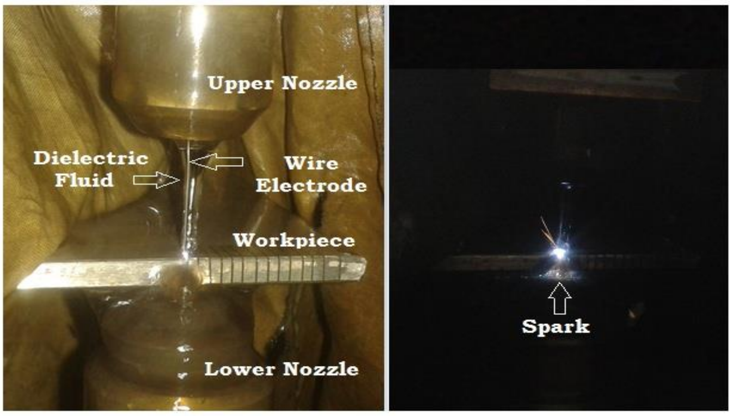


Fig 7: *Material removal due to spark event in wire EDM*

Performance of WEDM is evaluated on the basis of material removal rate (MRR). The mean cutting speed is calculated by; Mean cutting speed (Vc) = length of travel/ machining time.Machining time is obtained from the start to end time of the metal cutting process.The MRR is calculated by utilizing the formula, $MRR = (K \times t \times Vc \times \rho)$ mm^3/min. Here,K is the kerf thickness, t is the thickness of workpiece = 0.4 mm, Vc is cutting speed in mm/min.ρ is the density of workpiece material 7.94 g/cm^3.

Table 4: *Machining time (M/C Time) and material removal rate (MRR) at various flushing rates*

Experiment No	Highest flushing rate		Medium flushing rate		Lowest flushing rate	
	M/C TIME	MRR	M/C TIME	MRR	M/C TIME	MRR
1	7.27	1.48320	6.20	1.70280	7.40	1.34963
2	7.31	1.47456	6.56	1.59071	8.36	1.16680
3	8.45	1.28720	7.45	1.40111	10.22	0.96122
4	6.40	1.67484	5.24	1.99573	6.43	1.55703
5	6.48	1.60202	6.06	1.71069	7.42	1.34882
6	4.19	2.51291	3.57	2.89345	4.52	2.23290
7	3.55	2.98607	3.37	3.01173	4.22	2.40488
8	4.15	2.55825	3.55	2.85250	4.45	2.28879
9	4.35	2.41967	4.14	2.45434	5.02	2.06035
10	4.37	2.35962	4.16	2.44873	5.01	2.06789
11	2.48	4.12150	3.00	3.32580	3.29	3.13188
12	2.58	3.95030	3.08	3.22911	3.31	3.24691
13	3.42	2.86471	3.49	2.81435	4.15	2.50475
14	2.27	4.30901	2.32	4.26775	3.25	3.21411
15	2.35	4.18502	2.40	4.40405	3.07	3.44736
16	2.40	4.10233	2.46	4.38081	3.21	3.38526
17	2.56	3.89358	3.02	3.49055	3.30	3.23625
18	2.05	4.89058	2.01	5.31798	3.26	3.31122

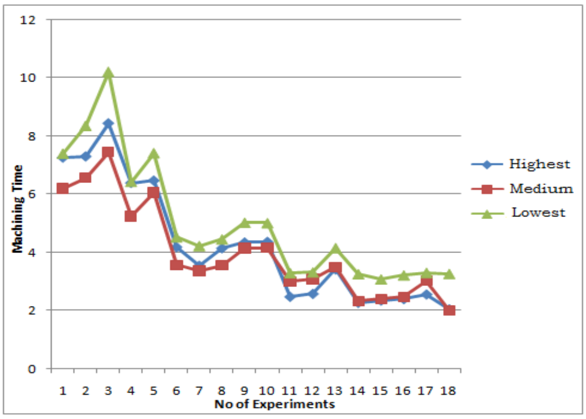


***Fig 8:** Machining time at various flushing rates*

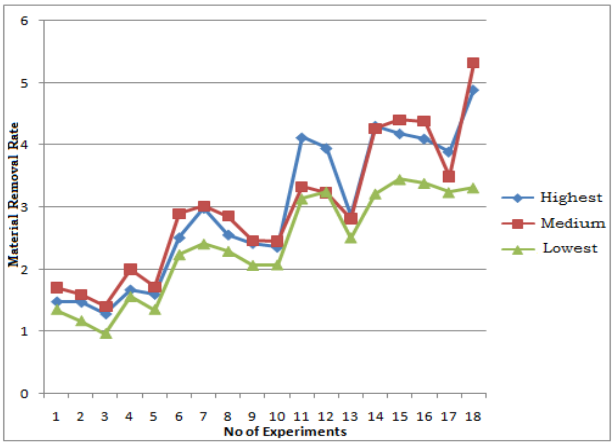


***Fig 9:** Material removal rate at various flushing rates*

RESULTS AND DISCUSSION

6.1 ANALYSIS OF VARIANCE

The terminology of ANOVA is largely from the statistical design of experiments. The experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the results. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially random error. In short, ANOVA is a statistical tool used in several ways to develop and confirm an explanation for the observed data.

ANOVA FOR MACHINING TIME

***Table 5:** F-values/P-values at three successive flushing rates*

Flushing Rates	Highest Flushing		Medium Flushing		Lowest Flushing	
	Linear	Square	Linear	Square	Linear	Square
F Value	564.96	135.49	135.75	34.15	125.38	52.28
P Value	0.000	0.001	0.001	0.010	0.002	0.005

The ANOVA results shows that for the machining time under various flushing rates the Pulse ON time is the top most influencing factor which gives most dependency on the results and the interaction of Pulse ON time with the Pulse ON time provides the reasonable cause on machining time with respect to their F-values and P-values.

6.1.2 ANOVA FOR MATERIAL REMOVAL RATE

***Table 6:**F-values/P-values at three successive flushing rates*

Flushing Rates	Highest Flushing		Medium Flushing		Lowest Flushing	
	Linear	Square	Linear	Square	Linear	Square
F Value	204.41	3.77	97.85	4.17	173.51	11.76
P Value	0.001	0.147	0.002	0.134	0.001	0.042

The ANOVA results shows that for the MRR under various flushing rates the Pulse ON time is the top most influencing factor which gives most dependency on the results and for the highest and lowest flushing rate the interaction of Pulse ON time with the Pulse ON time and for the medium flushing rate the interaction of Pulse OFF time with the Pulse OFF time provides the reasonable cause on machining time with respect to their F-values and P-values.

ARTIFICIAL NEURAL NETWORK (ANN) AND RESPONSE SURFACE METHODELOGY (RSM)

The mathematical models have been developed to predict machining time and material removal rate while machining Inconel 800 at different machining conditions. The machining time and material removal rate have been modeled through the ANN and RSM.

ARTIFICIAL NEURAL NETWORK (ANN)

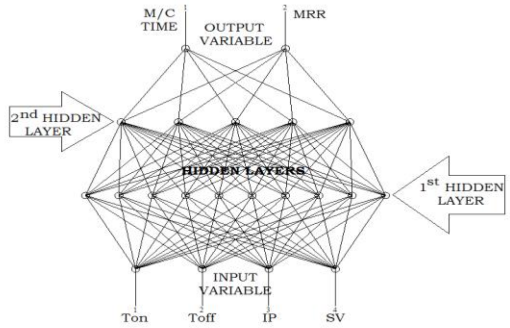


***Fig10:** Artificial Neural Network Model*

Modeling machining time and material removal rate with neural networks is composed of two phases: training and testing of the neural networks with experimental data. Pulse on time, pulse off time duration, peak current and spark gap voltage have been used as the input layer, while machining time and material removal rate was used as the output layer. In the present work, a 4-input, 2-hidden layer (1st hidden layers+2nd hidden) and 2 output neural network as shown Figure 2 has been used.

RESPONSE SURFACE METHODELOGY (RSM)

RSM is useful for the modeling and analysis of experiments in which a response of interest is influenced by several variables and the objective is to optimize that response. The initial requirement of RSM for achieving the accurate and reliable measurements of response variables is design of experiments. For modeling the input output parameters we have developed response surface regression equation as given below.

***Table 7:**Regression equation for machining time at individual flushing rates*

Flushing rates	Regression equation
Highest Flushing rate	441.0-4.761Ton-0.65Toff-1.323IP+0.542SV+ 0.02475Ton*Ton+0.0120Toff*Toff+0.002375IP*IP+ 0.000393SV*SV-0.01605Ton*Toff-0.00009Ton*IP- 0.00470Ton*SV+0.00498Toff*IP+ 0.00189Toff*SV-0.000460IP*SV
Medium Flushing rate	110-3.77Ton+1.88Toff+0.433IP+0.703SV+ 0.01825Ton*Ton-0.0224Toff*Toff-0.00092IP*IP+ 0.000811SV*SV-0.00112Ton*Toff-0.00199Ton*IP- 0.00207Ton*SV+0.00456Toff*IP- 0.00073Toff*SV-0.001973IP*SV
Lowest Flushing rate	439-7.16Ton-0.04Toff-0.33IP+1.150SV+ 0.03134Ton*Ton+0.0046Toff*Toff+0.00005IP*IP+ 0.001128SV*SV-0.0069Ton*Toff+0.00210Ton*IP- 0.00757Ton*SV+0.00180Toff*IP- 0.00062Toff*SV-0.00130IP*SV

Table 8:*Regression equation for material removal rate at individual flushing rates*

Flushing rates	Regression equation
Highest Flushing rate	-150.3+0.868Ton+0.81Toff+0.589IP+0.408SV-0.00438Ton*Ton-0.0170 Toff*Toff-0.00132IP*IP-0.000523SV*SV+0.00751Ton*Toff-0.00058 Ton*IP+ 0.00032Ton*SV+0.00170Toff*IP-0.00342Toff*SV-0.001077IP*SV
Medium Flushing rate	103-0.611Ton-0.85Toff-0.429IP-0.006SV+ 0.00333Ton*Ton+0.0263Toff*Toff+0.00114IP*IP – 0.000633SV*SV-0.00762Ton*Toff+0.00254Ton*IP-0.00230Ton*SV-0.00676Toff*IP+0.00051Toff*SV+ 0.001095IP*SV
Lowest Flushing rate	-80.1+1.185Ton-0.24Toff+0.136IP+0.121SV-0.00630Ton*Ton-0.00895Toff*Toff-0.000373IP*IP-0.000978SV*SV+0.00762Ton*Toff-0.00064Ton*IP+ 0.002241Ton*SV+0.00212Toff*IP –0.00294Toff*SV-0.000678IP*SV

COMPARISON FOR PREDICTED VALUES BY ANN AND RSM TO THE ACTUAL EXPERIMENTAL VALUES

Table 9: *Comparison between machining time values by Experiment with the predicted values by ANN and RSM*

Experiment no	Highest			Medium			Lowest		
	Actual	ANN	RSM	Actual	ANN	RSM	Actual	ANN	RSM
1	0.727	0.713125	0.719	0.62	0.809649	0.646	0.37	0.368405	0.3575
2	0.731	0.76573	0.72	0.656	0.863109	0.708	0.418	0.412267	0.4
3	0.845	0.801769	0.834	0.745	0.948498	0.801	0.511	0.509358	0.5
4	0.64	0.622492	0.639	0.524	0.707879	0.546	0.3215	0.309028	0.312
5	0.648	0.680472	0.649	0.606	0.841526	0.635	0.371	0.389564	0.3735
6	0.419	0.411425	0.417	0.357	0.489158	0.419	0.226	0.23322	0.2235
7	0.355	0.367129	0.354	0.337	0.464599	0.401	0.211	0.210871	0.203
8	0.415	0.423539	0.411	0.355	0.478558	0.404	0.2225	0.228007	0.224
9	0.435	0.434152	0.429	0.414	0.566745	0.45	0.251	0.244967	0.2665
10	0.437	0.439641	0.435	0.416	0.537219	0.43	0.2505	0.248302	0.2595
11	0.248	0.24461	0.245	0.3	0.388272	0.328	0.1645	0.162802	0.1565
12	0.258	0.271654	0.255	0.308	0.371514	0.319	0.1655	0.167021	0.156
13	0.342	0.326391	0.322	0.349	0.444034	0.418	0.2075	0.19723	0.2085
14	0.227	0.214996	0.207	0.232	0.31097	0.232	0.1625	0.161595	0.1565
15	0.235	0.236793	0.215	0.24	0.356193	0.258	0.1535	0.153699	0.156
16	0.24	0.237707	0.244	0.246	0.341889	0.319	0.1605	0.172092	0.161
17	0.256	0.254575	0.257	0.302	0.402446	0.33	0.165	0.171494	0.1605
18	0.205	0.211466	0.204	0.201	0.258356	0.24	0.163	0.154401	0.1625

Table 10: *Comparison between material removal rate values by Experiment with the predicted values by ANN and RSM*

Experiment no	Highest			Medium			lowest		
	Actual	ANN	RSM	Actual	RSM	RSM	Actual	ANN	RSM
1	0.29664	0.284854	0.28271	0.22704	0.198353	0.198353	0.269926	0.268272	0.27081
2	0.294912	0.285273	0.267584	0.212095	0.204643	0.204643	0.23336	0.241436	0.239664
3	0.25744	0.271042	0.23797	0.186815	0.162473	0.162473	0.192244	0.18514	0.1924
4	0.334968	0.356717	0.303298	0.266097	0.250456	0.250456	0.311406	0.318787	0.307512
5	0.320404	0.308826	0.297036	0.228092	0.178989	0.178989	0.269764	0.251601	0.24544
6	0.502582	0.531656	0.483328	0.385793	0.354173	0.354173	0.44658	0.45828	0.437806
7	0.597214	0.583827	0.57201	0.401564	0.382209	0.382209	0.480976	0.475799	0.478846
8	0.51165	0.510721	0.532278	0.380333	0.340328	0.340328	0.457758	0.467204	0.486426
9	0.483934	0.482642	0.478478	0.327245	0.300265	0.300265	0.41207	0.44186	0.426948
10	0.471924	0.453324	0.428428	0.326497	0.319845	0.319845	0.413578	0.415806	0.406978
11	0.8243	0.814646	0.802904	0.44344	0.421397	0.421397	0.626376	0.597443	0.626196
12	0.79006	0.741651	0.746084	0.430548	0.41626	0.41626	0.649382	0.607792	0.63289
13	0.572942	0.598561	0.576138	0.375247	0.341473	0.341473	0.50095	0.519226	0.520204
14	0.861802	0.873579	0.827596	0.569033	0.554209	0.554209	0.642822	0.643689	0.634348
15	0.837004	0.859256	0.819508	0.587207	0.542716	0.542716	0.689472	0.67613	0.674656
16	0.820466	0.833834	0.799974	0.584108	0.552544	0.552544	0.677052	0.656938	0.67162
17	0.778716	0.780203	0.7442	0.465407	0.445333	0.445333	0.64725	0.639639	0.63966
18	0.978116	0.956475	0.97452	0.709064	0.679693	0.679693	0.662244	0.717723	0.67405

ROOT MEAN SQUARE ERROR

RMSE = $\sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mathrm{ti}-\mathrm{oi})^2}$ here, n is the number of pattern in the data set, t_i is the experimental output, o_i is the predicted output

Table 11: *Error for machining time after comparison with actual experimental values*

FLUSHING RATE	HIGHEST		MEDIUM		LOWEST	
RMSE	RSM	ANN	RSM	ANN	RSM	ANN
	0.0094428	0.0175620	0.0430103	0.141375	0.0085302	0.0075425

Table 12: *Error for material removal rate after comparison with actual experimental values*

FLUSHING RATE	HIGHEST		MEDIUM		LOWEST	
	RSM	ANN	RSM	ANN	RSM	ANN
RMSE	0.0255217	0.0193978	0.0280531	0.0204711	0.0128587	0.0214323

Two models were developed for predicting the machining time and material removal rate under highest, medium and lowest flushing rates. The Artificial Neural Network has designed for predicting the machining time and material removal rate and response surface methodology is used for developing mathematical regression equation. The values predicted by ANN and RSM model are compared with experimental values and the root mean square errors have also calculated. It has been observed that the values predicted with both the models are approximately same as the experimental values.

CONCLUSION

In this experimental research work the effect of pulse on time, pulse off time, peak current and spark gap voltage in reducing machining time and improving material removal rate by varying flushing conditions were investigated on Inconel 800 alloy with zinc coated wire. ANOVA reflects the factor Pulse on time (Ton) is the most momentous factor for decreasing the machining time and improving the material removal rate. The mathematical model developed using ANN and RSM confirms the suitability of model in predicting the machining time and material removal rates in WEDM. The proposed ANN and RSM model has successfully predicted the result which matches with the experimental values. Based on experimental results and the present analysis it can be stated that the optimum parameter combination and developed mathematical model is useful for predicting and machining Inconel 800 materials. Thereby, it confirms the usefulness of Inconel 800 alloy and WEDM for manufacturing..

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