Analysis of the influence of EDM parameters on surface Quality, MRR, EWR and Micro Hardness of AISI O2 (1.2842)

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Abstract:

The adequate selection of manufacturing conditions is one of important aspects to take into consideration in the die sinking.elecltrical discharge machining (EDM) of cold working tool steels, as these conditions are the ones that are to determine such important characteristics as surface roughness, electrode wear (EW) and material removal rate ,among others .In this work, a study was carried out on the influence of factors of intensity like peak current(I), pulse ON time (Ton) and duty cycle (n) over the listed technological characteristics. The cold work tool steel used in this study was O2 (OHNS) of BOHLER mostly used in press tools .Accordingly Mathematical models will be obtained using the technique of design of experiments. ***The Objective of this work is to investigate the effect of current(I),Pulse On Time(Ton),Duty Factor(n) on Material Removal Rate(MRR), Electrode Wear Rate(EWR), Micro Hardness & Surface Roughness during EDM .***

Keywords: EDM, MRR, EWR, Surface Roughness, Microhardness, DOE, Taguchi L-9 Design.

1. Introduction

Electrical discharge machining (EDM) is a non-traditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharges (created by electric pulse generators at short intervals) between a tool, called electrode, and the part being machined in the presence of a dielectric fluid [1]. At the present time, EDM is a widespread technique used in industry for high-precision machining of all types of conductive materials such as: metals, metallic Alloys, graphite, or even some ceramic materials, of whatsoever hardness In this work, a study focused on the die-sinking EDM of Oil Hardened Non Shrinkage Steel ,AISI-O2 material such as oil hardened non shrinkage tool steel (OHNS), whose field of applications is in constant growth, was carried out. Consequently, an analysis on the influence of intensity, pulse time and duty cycle over technological variables such as: surface roughness, electrode wear (EWR) and material removal rate and Micro hardness was performed. This was done using the technique of design of experiments (DOE) and techniques such as Taguchi Technique L-9 Design analysis. The combined use of these techniques has allowed us to create both first and second-order models, which make it possible to explain the variability associated with each of the technological variables studied in this work.

2. Experimental

In this section, there will be a brief description of the equipment used to carry out the EDM experiments, along with the ohns material used and its dimensions. Also, the design factors used in this work will be outlined

2.1. Equipment used in the experiments

The equipment used in order to carry out the EDM of (Ohns) was a die-sinking EDM machine of type SMART-ZNC. Fig. 1 shows a photograph of this Equipment. The machine used is of Electronica model-Smart-ZNC, Pulse generator Type MOSFET, with maximum Working Current of 50A. Max MRR of 350 mm^3/min (Cu-St), with best surface finish of 0.29 u Ra. The EDM machine we have used with a magnetic v-block in order to hold the parts in place. In Fig. 2, a photograph illustrating the whole fixture system employed in the experiments is shown. In addition, in the same figure, the type of flushing used for the EDM experiments in order to assure an adequate removal of the debris from the work gap is shown. In this case, due to its simplicity and the shallow machining carried out in these experiments, jet flushing was selected. The pressure used for the dielectric fluid was .1kg/cm^2.

2.2. Material used in the experiments

Accordingly, the ohns steel is an important tool and die material mainly because of its high strength, high hardness & high wear resistance. EDM is a non conventional process that removes material by thermal erosion such as melting and vaporization of material. To understand the machining characteristics of OHNS steel by EDM are studied in this experiment. OHNS also has equivalent names like AISI O2, DIN 1.2842.

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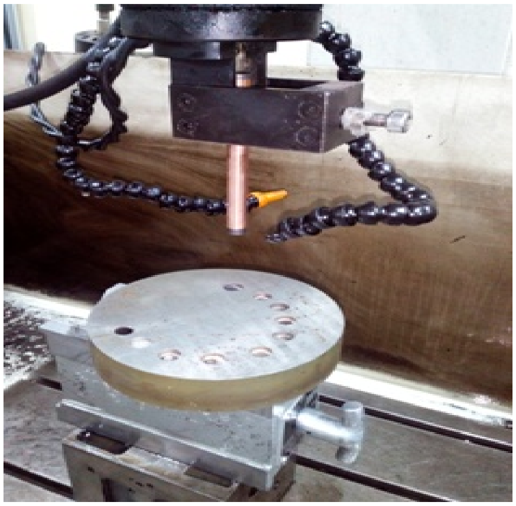
Table:1 Chemical Composition of OHNS Tool Steel

C	Si	Mn	Cr	Mo	V
0.90	0.25	2.00	0.35	-	0.13

Fig.1. Work piece and electrode.



Cold work tool steels with high dimensional stability at heat treatment, very high resistance to cracking, high mach inability, medium toughness & resistance to wear. Physical properties at ambient temperature Modulus of Elasticity (10 3 N/mm^2): 210, Density (g/cm^3): 7.85, Thermal Conductivity (W/Mk): 30.0, Electrical Resistivity (ohm mm^2/min): 0.35, Specific heat capacity (J/gO K) : 0.46.

At present, although approximately mostly used as cold work tool steel in press tools such as punches, Dies ,thrust plates, punch holder, stripper, punch back alternative applications is quickly growing. Among these alternative applications, could be highlighted: Punch, Die, measuring tools, machine knives for wood, paper and metal industry, cold cutting shear blades, cutting tools. The samples of OHNS were taken as vacuum heat treated and ground the following dimensions: Dia 120x30 mm. Moreover, the electrodes used were made of electrolytic copper given that, according to the bibliographic sources consulted, it is the most highly recommended material for the EDM process of OHNS. As per ISO Cu-ETP It is Excellent on
cold as well as hot working tool steels. It has a Tensile Strength of 250-300 Mpa, Elongation of 25-40%, hardness of 80-110 HV.

Furthermore, the electrode material selection depends upon type of finish desired, amount of electrode wear. Copper has distinct advantage over graphite because it performs better in discharge dressing the copper electrodes were selected in a round Dia of 11 mm x120 mm.

2.3. Design factors and response technological variables analyzed

There are a large number of design factors to be considered In the EDM process, but in this work we have only considered the level of the Peak Current (*I*), pulse ON time (*Ton*) and duty cycle (n) [1,6]. The surface roughness parameter selected as Response variable, defined in accordance with UNE-EN-ISO 4287: 1999, DIN 4768 was the arithmetic average roughness Value of the roughness profile, that is to say, the *R*a parameter. When carrying out the roughness measurements over the edm surface of ohns material, a phase corrected 2CR filter for the rugosimeter, along with a length of measurement or evaluation of 6.4mm (8mm × 0.8 mm), were selected. The values of the surface roughness parameter for each experiment were obtained from the arithmetic mean for the values of measurements taken following parallel directions and in an equidistant distribution over the total area subjected to the EDM process.

In addition to surface roughness, other very important response variables which are of interest when studying EDM processes, are material removal rate MRR in (grams/min) and electrode EWR in (grams/min) and Micro Hardness (HV).

MRR = Diff. in weight of work piece before & after machining ***/*** minute

EWR = Diff. in weight of work piece before & after machining ***/*** minute

Although other ways of measuring MRR and EWR do exist in this work the material removal rate and electrode wear values have been calculated by the weight difference of the work piece and electrode before and after undergoing the EDM process.

3. Design of the experiments

The design which was finally chosen was a Taguchi Method with three controllable Factors as Peak Current (Ip), Pulse on Time (Ton), and Duty Cycle (n). For the case of the response variables which a total of 9 experiments, the previous the graphs presented here were done using Mini-Tab-17. Table 1 presents the relationship between the design factors and their corresponding selected variation levels, taking into account that the study wanted to focus on the finishing Machining stages, owing to the influence which a good Surface quality, in the case of OHNS, has over properties Such as fatigue strength and wear. Consequently, the intensity. Levels chosen for the case of the intensity factor were 3 Factors and levels selected for the experiments

(10 A), (30A) and 50 A). On the other hand, levels of 100,150 and 200_s as well as levels of 4, 6 and 8 were selected for pulse time and duty cycle, respectively. The reason for using levels of Intensity instead of intensities is due to the requirements of the programming of the EDM equipment.

Table 2 shows the design matrix resulting from the type of Experiment, as well as the observations for the case of the three response variables which are considered, where the intensity values 3, 4 and 5 are equivalent to 10 A, 30 A and 50 A, respectively.

Table:2 Working Range for process parameters and their levels

Factors	Levels		
	-1	0	+1
Ip	10	30	*50*
Ton	100	150	200
n	4	6	8

Scheme of Investigation:

In order to explore the Desirable Performance Measures and minimize undesirable Performance Measures, The Investigation is done with Following Sequence.

3.1 Selection of OA

In this study three process parameters are considered each parameter having three levels the degree of freedom are 2 and total degrees of freedom is 3x2=6.the selected OA must be greater than 6 hence L9,
(3^4) OA is considered for present study .There is no interaction between selected process parametres

Table-3: Experimental layout using an L9 (34) OA

Sr.No	A (Peak Current)	B(Pulse On Time)	C (Duty Cycle)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The Experiments were carried out using above table of combinations for obtaining Taguchi Design of Experiment in which Three Input Factors with three Levels are used as Peak Current (A), Pulse on Time (Ton), Duty Cycle (n).Four Output Responses were Obtained Namely Material Removal Rate (MRR), Electrode Wear Rate (EWR), Surface Roughness (u), and Micro Hardness on the EDM Surface was Measured.

3.2 Parameters Selection:

A Practical Manual was considered before deciding the Range of Parameters as well as Machine Manual for selection of Parameters for EDM ing of OHNS O2 (1.2842) was taken into consideration as well Machine users were considered before selection of Factors and Their Levels, The Recording of Readings Obtained is shown in Table.no.4

3.3 Conduct the Experiments as per selected OA L9.

The Workpiece selected having dia 110mm and 30 mm thick Experiments were conducted as per layout shown in Table.no.4.prior to machining the workpieces and electrode were cleaned and polished .The workpiece was clamped on magnetic v- block as shown in fig.1 and immersed in Electrol EDM oil. The positive Polarity was used during the Experiments.

3.4 Record the Response Variables.

(i.e., MRR, EWR, SR, Micro Hardness)
MRR and EWR were calculated as per above formulae and surface roughness as well as micro hardness readings were directly obtained on respective instruments which is given in tabulated form in table.no.4

Table 4: Response Measure of EDM

Sr, no	*Ip amp*	*Ton (_s)*	n	*R*a (_m)	EWR mm3/min	MRR mm3/min	Micro Hardness(hv)
1	10	100	4	0.14	2.31	1.030	655
2	30	150	4	0.53	8.67	28.91	730
3	50	200	4	0.86	29.86	76.33	860
4	30	100	6	0.49	25.44	39.75	740
5	50	150	6	0.78	31.80	79.51	830
6	10	200	6	0.18	8.942	18.17	710
7	50	100	8	0.64	22.90	63.61	805
8	10	150	8	0.16	7.96	15.14	667
9	30	200	8	0.56	23.40	57.81	776

4. Analysis of Experiments:

As Responses of given inputs were obtained further step was to Study the Results of Experiment and Validation. For the Analysis Purpose as per plan of DOE we have used Minitab-17 for evaluation purpose in which the first step was to find the Main Effects Plot and obtain the Main Effects caused by the input Variables on the output Responses First case chosen was of Response Variable Surface Roughness (u) Ra Value.

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4.1 Analysis of surface roughness

Fig-4: SN RATIO SURFACE ROUGHNESS

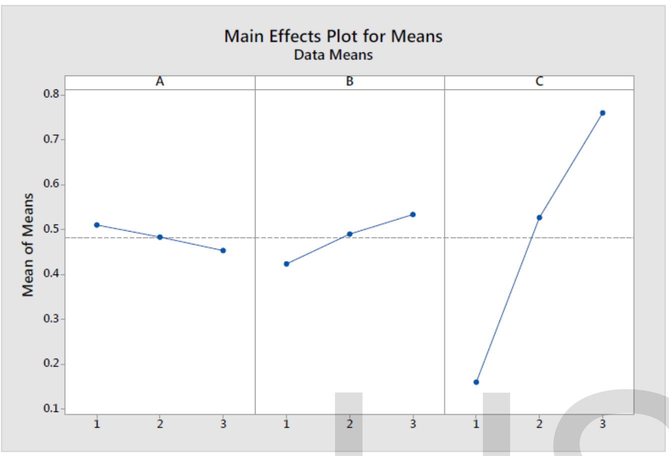


Table-8: ANOVA SURFACE ROUGHNESS

symbol	edm parameter	dof	sum of squares	mean of squares	f value	Contribution (%)	p value
A	peak current	2	0.0048	0.0024	0.03	0.84	0.975
B	pulse on time	2	0.0184	0.0092	0.10	3.19	0.907
C	duty factor	2	0.5488	0.2744	58.67	95.14	0.000
error		2	0.0049			0.83	
total		8	0.5770			100	

The Analysis was carried out for Taguchi L-9 Method in which first of all means effect was calculated graphs obtained .signal to noise ratio was found using Minitab-17 .S\N Ratio Predicted was calculated to obtain optimized condition for surface roughness (A2 B1 C3) Confidence level of 93.51% was obtained which is acceptable. This condition experiment has been done at fourth number. in which the surface roughness value obtained is 0.49 u Ra. Using the condition of Lower is better. Where, the values of the considered variables have been specified according to their original units

4.2 Analysis of MRR

Fig -2: S/N RATIO MRR

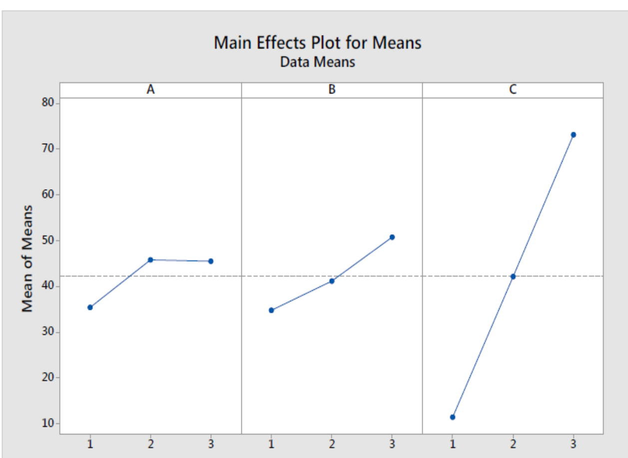


Table -6: ANOVA MRR FINAL

Symbol	EDM Parameter	DOF	Sum of Squares	Mean of Squares	F Value	Contribution (%)	P Value
A	Peak Current	2	173.22	86.60	0.55	15.43	0.605
B	Pulse on time	2	160.6	80.32	0.50	14.31	0.629
C	Duty Factor	2	712.2	356.12	5.21	63.46	0.049
ERROR		2	76.18			6.8	
TOTAL		8	1122.2			100	

The Analysis was carried out for Taguchi L-9 Method in which first of all means effect was calculated & graphs obtained .signal to noise ratio was found using Minitab-16 .S\N Ratio Predicted was calculated to obtain optimized condition for MRR (Material Removal Rate) (A2 B3 C3) Confidence level of 97.26 % was obtained which is acceptable. This condition experiment has been done at fourth number.in which the MRR (Material Removal Rate) value obtained is 0.4545 mm3/min. using the condition of Higher is better.

4.3 Analysis of Electrode Wear

Fig- 3 : SN RATIO OF EWR

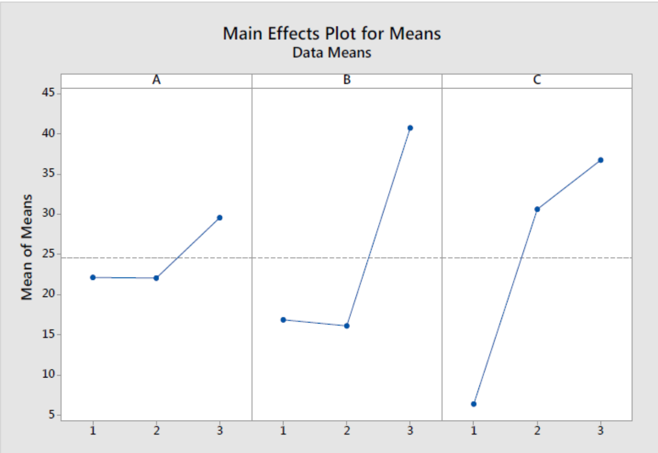


Table-7 Anova for Electrode Wear

symbol	EDM Parameter	DOF	Sum of Squares	Mean of Squares	F Value	Contribution (%)	P Value
A	Peak Current	2	86.79	43.110	0.75	19.97	0.513
B	Pulse on time	2	30.94	15.47	0.23	7.12	0.801
C	Duty Factor	2	316.9	158.46	8.08	63.89	0.020
ERROR		2	39.2			9.02	
TOTAL		8	434.70			100	

The Analysis was carried out for Taguchi L-9 Method in which first of all means effect was calculated & graphs obtained .signal to noise ratio was found using Minitab-16 .S\N Ratio Predicted was calculated to obtain optimized condition for EWR (Electrode Wear Rate) (A3 B2 C1) Confidence level of 85 % was obtained which is acceptable. This condition experiment is not included .in which the EWR (Electrode Wear Rate) value obtained is mm3/min. Using the condition of Lower is better.

4.4 Analysis of Micro Hardness

Fig.no.5 S/N RATIO MICROHARDNESS

Table.no-9 ANOVA MICRO HARDNESS

symbol	EDM Parameter	DOF	Sum of Squares	Mean of Squares	F Value	Contribution (%)	P Value
A	Peak Current	2	251	125	0.02	0.62	0.981
B	Pulse on time	2	4023	2011	0.33	10.02	0.729
C	Duty Factor	2	35796	17898	24.63	89.14	0.001
ERROR		2	86			0.22	
TOTAL		8	40156			100	

The Analysis was carried out for Taguchi L-9 Method in which first of all means effect was calculated & graphs obtained .signal to noise ratio was found using Minitab-16 .S\N Ratio Predicted was calculated to obtain optimized condition for Micro Hardness (A3 B2 C1) Confidence level of 85 % was obtained which is acceptable. This condition experiment is not included .in which the Micro Hardness value obtained is 805 hv. Using the condition of Lower is better.

Table.no-10 Response Variables and Their S/N Ratios

Sr, no	MRR Mm3/min	*S/N Ratio (dB)*	*Ra (_m)*	*S/N Ratio (dB)*	EWR Mm3/min	*S/N Ratio (dB)*	Micro Hardness(hv)	*S/N Ratio (dB)*
1	1.030	0.2567	0.14	16.98	2.31	-7.272	655	-56.32
2	28.91	29.22	0.53	5.41	8.67	-18.76	730	-57.26
3	76.33	37.65	0.86	1.50	29.86	-29.50	860	-58.69
4	39.75	31.98	0.49	6.38	25.44	-28.11	740	-57.38
5	79.51	38.00	0.78	2.065	31.80	-30.04	830	-58.38
6	18.17	25.18	0.18	14.79	8.942	-19.02	710	-57.02
7	63.61	36.07	0.64	3.77	22.90	-27.19	805	-58.11
8	15.14	23.60	0.16	16.10	7.96	-18.01	667	-56.48
9	57.81	35.24	0.56	4.94	23.40	-27.38	776	-57.79

4.5. Find Optimum condition for Response Variables and identify the significant factors.

Taguchi Method the effects of machining parameters on Response Variables are evaluated under optimal condition. It is used to determine appropriate combination of machining parameters to maximize MRR and minimize EWR, SR, Micro Hardness. The experimental results of MRR, EWR, SR, Micro Hardness were further transformed into signal to noise ratio (S/N) ratio. Higher value of MRR represents "higher the better". The lower value represents better machining performance such as EWR, SR, Micro Hardness is "lower the better". Taguchi method uses S/N ratio to measure quality characteristic deviating from the desired value the S/N ratio η is defined as η = -10 log (MSD)
Where MSD is the mean square deviation for the output characteristic.

To obtain optimal EDM performance, higher - the - better quality characteristic for material removal rate must be taken. The MSD for higher – the – better characteristic can be expressed as

$MSD= 1/m\Sigma 1/MRR^2$

Where m is number of tests and MRR is value of MRR and test
On the other hand lower- the – better quality characteristics for EWR, SR, Micro Hardness should be taken for obtaining optimal EDM performance

$MSD= 1/m\Sigma 1/EWR^2$

Where EWR^2 is value of EWR for i^{th} test

$MSD= 1/m\Sigma 1/SR^2$

Where SR^2 is value of SR for i^{th} test

$MSD= 1/m\Sigma 1/MH^2$
Where MH^2 is value of MH for th test

The average experimental results of MRR, EWR, SR, Micro Hardness and their corresponding S/N ratios using above equations are presented in Table no. 5. After calculating S/N ratio the effect of each machining parameter at different levels is separated. The mean S/N ratio for each machining parameter at each level was calculated by averaging the S/N ratios for the experiments at the same level for that particular parameter. Table-6 shows ANOVA S/N response table for MRR and Fig-2 shows the S/N response graph of MRR.
For Response variable like EWR, SR, MH greater S/N ratios were considered as they result in smaller variance of output with the targeted value. The Experimental Results of EWR and the S/N ratio response graph for EWR are shown in Fig.no-3 and Table.no.7 ANOVA
Respectively Fig-4 shows S/N ratio Response graph for Surface Roughness and Table-8 shows ANOVA for the same.
Similarly Fig-5 shows S/N ratio Response graph for Micro Haedness and Table-9 is ANOVA for MH(HV)
The optimization of process parameters using Taguchi method permits evaluation of the effects of individual parameters independent of the other parameters. The analysis of variance (ANOVA) is used to determine which design parameters significantly affect the performance measures. In ANOVA, first total sum of square deviations, SS_t from total mean S/N ratio η_m can be calculated as

$SS_t = \Sigma (\eta_i - \eta_m)^2$

Where n is the number of experiments in orthogonal array and η_i is mean S/N ratio for i^{th} experiment.

ANOVA was applied to find out the significance of main factors and the F test was used to determine the significant effect of process parameters on the responses (MRR, EWR, SR, MH). The EDM process parameters has significant response when F ratio is large. Table-6 to 10 shows the results of ANOVA (MRR, EWR, SR, MH).

4.6 Confirmation test

Optimum level of design parameters were used for prediction and confirmation of response variables improvement. The estimated S/N ratio,

$\hat{\eta} = \eta_m + \Sigma (\eta_i - \eta_m)$

where, η_m is total mean S/N ratio, $\hat{\eta}$ is the mean S/N ratio at optimum level.

For the validation of the optimum results experiments were conducted as per the optimum conditions and machining performance measures were evaluated and the results are presented in Table- . It is observed that, experimental values are closure to the optimum values.

5. Discussion

Based on S/N ratio and ANOVA analysis of the result ,conclusions are drawn fig-2,table-6 factors at level A2(Peak Current,30A),B3(Pulse on time,200µ) C3(Duty Cycle,8) gives Maximum MRR.The contribution order of machining parameters for MRR is Peak Current, Pulse on time, duty cycle. Heat energy supplied to remove work piece material is controlled by Peak Current. Hence the contribution and significance of peak current is largest. The Pulse on time controls the duration of time for which current is allowed to flow per cycle. Thus it is second factor as far as contribution and significance is concerned. Duty cycle is ratio of pulse on time and pulse off time it has highest significant effect for MRR.

For EWR refer fig-3, Table-7 Recommended factors are A2(Peak Current,30A),B3(Pulse on time,200µ) C3(Duty Cycle,8) gives Minimum EWR.The contribution order of machining parameters for EWR is Peak Current, Pulse on time, duty cycle contribution of factors A and B is very less to minimize EWR.Peak Current has largest significance and contribution of towards EWR.The electrode is exposed to less heat than the work piece when it has positive polarity. When pulse is on electrode wear is less and when pulse is off electrode wear is null.

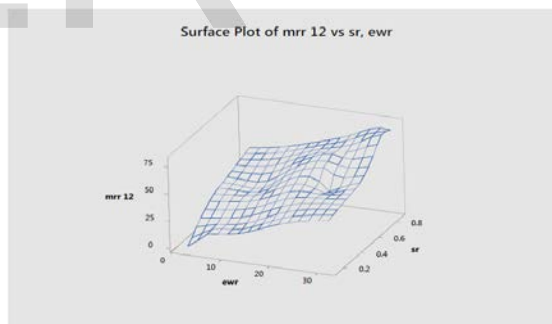
Surface Roughness refer fig-4, Table-8 it shows that there is least effect of factor A(Peak Current,30A),B1(Pulse on time,150µs),C3(Duty cycle,8) has greater impact on minimizing electrode wear. Time duration of heat energy available for material removal depends upon pulse on time .this energy is shared by large no of results in improved surface finish.

Micro Hardness depends upon various factors due to high temperature and duration of contact creates distortion on surface we have measured the MH on top EDM surface the optimum condition is A3 (Peak current, 50A), B2 (PULSE ON TIME,150µs),C1(Duty cycle,4) it is dependent on duty cycle. Which controls the ON/OFF of Pulse Current.

Table.-11 : Optimum Values for machining EDM Response measures and Validation

Performance Measure	Optimum Condition	Optimum Value	Experimental Values
MRR (mm3/min)	A2B3C3	55.86 mm3/min	57.81 mm3/min
EWR (mm3/min}	A2B3C3	21.49 mm3/min	23.40 mm3/min
SR	A2B1C3	0.51 µ Ra	0.49 µRa
Micro Hardness	A3B2C1	805 hv	801 hv

Fig-6: 3D-Graph of three Responses MRR, EWR and SR



6. Conclusions

In this present work, modeling procedures of some of the most important parameters within the process of die-sinking. EDM of conductive OHNS material were carried out. due to its growing range of applications not only in the field of cutting tools but also in some other non-machining ones. With this work, it has been confirmed that the technique of design of Taguchi robust design technique can be successfully applied to modeling the functions which depend on various variables. This has been carried out in an efficient way, as a great number of experiments have not been necessary.

In order to carry out this study, some technological variables such as: surface roughness (evaluated by means of the *R*a parameter), the volumetric electrode wear (EWR) and material removal rate (MRR) as well as Micro Hardness (MH) were selected. These technological variables were studied in relation to design factors such as: the level of intensity supplied by the EDM machine generator peak current (*Ip*), pulse on time (T*on*) and duty cycle (*η*). In all the response variables used in this work. In the case of the *R*a parameter the most influential factors was intensity, followed by the duty cycle factor while the pulse on time factor was not significant at the considered level. As duty cycle is the ratio of pulse on time and pulse off time so the influence of duty cycle is shown more than the pulse on time factor. When either intensity or pulse time were increased, the roughness value also increased. Furthermore, a significant interaction effect was observed between the intensity and pulse time factors. Therefore, in order to obtain a good surface finish in the case of ohns, low values should be used for both intensity and pulse time. Another way of obtaining low roughness values, although higher than in the previous cases, is to combine the use of high values of intensity and low values of pulse time, within the considered work interval.

In the case of electrode wear, it was also seen that the intensity factor was the most influential, followed by its own pure quadratic effect and the interaction effect of intensity and pulse time. In order to be able to obtain low values of electrode wear, values of the intensity factor close to its central value or slightly higher should be used along with low values for pulse time, within the considered work interval.

In the case of material removal rate, it was observed that the most influential factor was once again intensity, followed by the duty cycle factor, the pulse time factor and the interaction effect of the first two. The value of material removal rate increased, as would logically be expected, when intensity and duty cycle were increased, whilst an increase in pulse time brought about a decrease in MRR. Therefore, in order to obtain high values of material removal rate for the case of OHNS tool steel, within the work interval considered in this study, one should use, above all, high values for intensity and duty cycle. Furthermore, although to a lesser extent, low values of the pulse time factor should also be used.

Finally, for the case of Micro Hardness it is observed that the influential factors are pulse on time and duty cycle. The value of Micro Hardness increase when pulse on time and duty cycle were increased.

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