A COMPARATIVE EXPERIMENTAL STUDY ON FAST HOLE NEAR DRY EDM OF STAVAX WITH DIFFERENT DIELECTRIC COUPLED WITH SURFACE RESPONSE CURVES

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Abstract: *This paper presents comparative experimental study on machining characteristics of through holes (1000 micron) produced on special alloy steel, Stavax, thick plate with different types of dielectrics. Fast hole rotary Near Dry EDM (NDEDM) machine using tubular hollow brass electrodes are used for machining. Several holes are drilled using identical input parameters based on full factorial design of experiment procedure with four center points. Corresponding values of Material Removal Rate (MRR), Tool Wear Rate (TWR), MRR /TWR ratio & % Electrode Ratio are calculated and compared. The empirical relationship for above responses are developed using Regression Analysis. Surface Response Curves are plotted to compare response of interest. The results revealed that MRR,TWR &MRR/TWR (λ) ratio depends up on appropriate selection of input parameters as well as selection of dielectric.*

Key Words: *Near Dry Electro Discharge Machining (NDEDM), MRR, TWR, Surface Response Curves*

1. INTRODUCTION

Conventional drilling techniques cannot be employed to produce small size holes on difficult to cut materials as high tool wear/breakages and slow machining rates lead to inaccurate hole dimensions and unacceptable surface quality. Electrical Discharge Machining process has recently been used for drilling macro/micro holes of varying sizes on various materials. During EDM process a small gap is maintained between workpiece and tool electrode and machining process takes place due to high voltage sparks causing the removal of small particles away from the workpiece machined.

Fast hole drilling process has became popular due to use of rotary tubular electrode through which pressurized dielectric fluid is continuously flowing in order to provide better flushing effect during process, resulting in an improved Material Removal Rate and reduced Tool Wear Rate. Wang and Yan used rotary EDM concept to make blind holes on Al2O3/6061 Al composite. Mohan et al. studied drilling of holes on Al-SiC metal matrix composite using rotary tubular electrodes made of different materials. Drilling of through and blind holes on plastic mould steel using tungsten carbide electrode was reported in Opoz et al. The characteristics of micro holes produced by EDM on carbide using copper tool electrode were examined by Yan et al. Nakaokua et al investigated the hole drilling on sintered diamond by rotary micro-EDM using tungsten electrode. Diver et al. produced micro-EDM tapered holes on casehardened steel (18CrNi8) using rotary WC electrode.

Various components in aerospace industry such as turbine blades and discs, compressor blades and other engine parts are made up of special alloy. These components have small size holes for cooling as they are working in hostile environment (i.e. high speed and elevated temperatures). Consequently, such holes are required to have good surface finish and excellent dimensional accuracy. Pradhan et al studied the optimization of EDM hole drilling parameters on Ti-6Al-4V using brass electrode. The influence of EDM parameters in deep hole drilling of Inconel 718 using pure electrolytic copper was examined by Kuppan et al.

In this comparative experimental study in fast hole drilling of stavax using EDM process. Two types of dielectrics are used to produce through holes using tubular brass electrode with identical process parameters. MRR, TWR. MRR/TWR ratio & % Electrode Wear Ratio values are determined and compared. Stavax, special alloy steel combines corrosion and wear resistant with excellent polishability, good machinability and stability in hardening. This stavax is the right choice when rust in production is unacceptable and where requirements for good hygiene are high, as within the medical industry, optical industry and for other high quality transparent parts. (Uddeholms AB).

2. EXPERIMENTAL PROCEDURE:

2.1 WORK MATERIAL, ELECTRODE MATERIAL AND DIELECTRICS

The workpiece material is 8 mm thick stavax plate. Chemical composition of stavax and physical properties of same are given in Table No 1 & 2 respectively.

Table 1: Chemical Composition of Stavax

Material	% by Weight
C	0.380%
Cr	13.6%
Mn	0.5%
Si	0.9%
V	0.3%

Electrodes are of electrolytic brass and are hollow cylindrical having outside diameter of 1 mm and inside diameter 0.4 mm, rotating at 48 rpm. Melting point of tool brass and workpiece stavax is 940 ^{0}C and 1336 ^{0}C respectively. Pure water and water- air in mist form are used as dielectrics.

2.2 EXPERIMENTAL SETUP

Table 2: Physical Properties of Stavax

Hardness	200 Brinell 40-50 Rockwell
Tensile strength ultimate	1770 MPa
Tensile Strength Ultimate	1470 MPa
Thermal Conductivity	24 W/m K at 399^{0}C
Specific Heat	0.460 J/g ^{0}C
Good Corrosion Resistance	*Good Wear Resistance*
Good Polishability	*Good Stability During Hardening*

Table 3: Design of Experiments Table for Input Parameters with Coded Values

Parameter Code	Gap Voltage (V_g) Volts	Discharge Current (I) Amp.	Pulse on time (T_{ON}) μ sec.
High (+1)	40	5	32
Medium (0)	30	4	24
Low (-1)	20	3	18

The experiments are preformed on Rapid drilling EDM machine manufactured by Electronica Machine Tools Ltd, capable of holding 0.2 mm electrode. Fig. 1 shows experimental set up, all experiments are planned according to full factorial design of experiments with 4 center points. Input parameters are Gap Voltage (V), Discharge Current(I) and Pulse On Time (Ton) at constant Pulse off Time and constant Servo Stabilizing Voltage. Table No 3 gives coded values of parameters and their respective values of parameters. Experiments are performed by the authors in the area of Near-dry EDM using water as the basic dielectric in one case and water-air in other case (oxygen with 2 MPa pressure) is used.

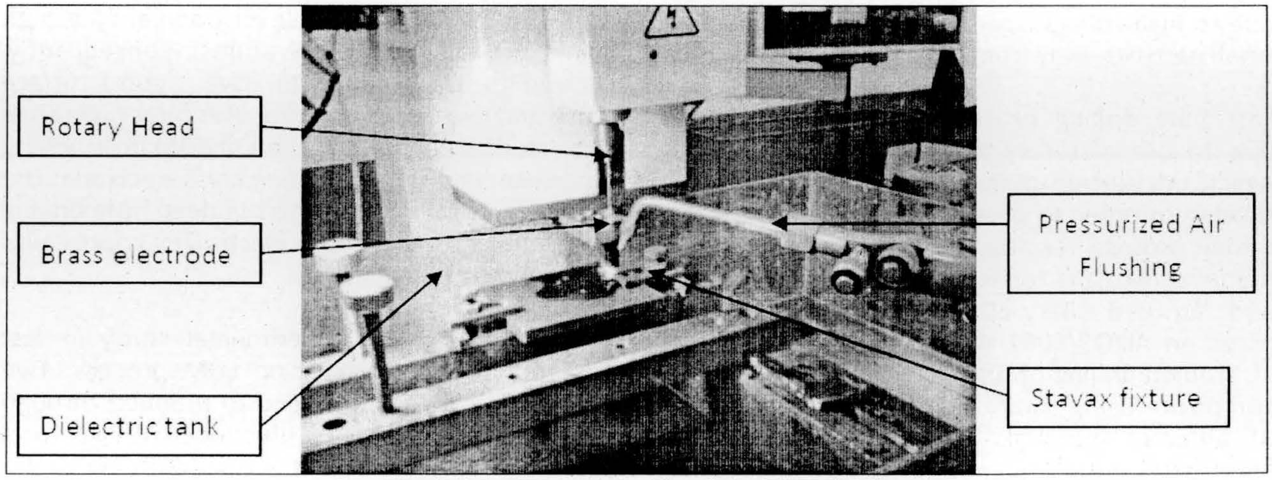

Fig 1. Experimental Set Up of Near Dry EDM

2.3 Measurement Procedure

The drilling time for each hole is recorded by using sensitive stop watch. The test-piece is weighed before and after drilling using a digital precision scale. Material Removal Rate (MRR), Tool Wear Ratio and %Electrode Wear Ratio for each experiment is calculated by following formula:

$$MRR(gm/\sec) = \frac{\textit{Initial}\text{ Weight - Final Weight}}{\textit{Machining}\text{ Time}} \quad \ldots\ldots\ldots\ldots \tag{1}$$

$$TWR\ (\text{gm/sec}) = \frac{\text{Final Reading of Z axis - Inistial reading of Z axis}}{\textit{Machining}\text{ Time}} \times {}^{wt}\!/_{mm} \quad \ldots\ldots\ldots\ldots \tag{2}$$

Electrode Wear (EW) was determined according to depth of drilled hole and the amount of electrode consumption(i.e. the variation in electrode length):

$$\%EWR = \frac{\text{Consumed Electrode Length} \times 100}{\text{Depth of drilled hole}} \quad \ldots\ldots\ldots\ldots \tag{3}$$

2.4 Observations

Table 4: Observations for Water as Dielectric while Machining Stavax with Brass Electrode

Sr no	voltage	current	pulse on time	MRR gm/sec	TWR gm/sec	MRR/TWR (λ)	% EWR
1	1	1	1	0.002333333	0.001786	1.306702	124.0764
2	1	1	-1	0.001923077	0.001644	1.169499	148.535
3	1	-1	1	0.00046875	0.000134	3.500992	49.61783
4	1	-1	-1	0.000469799	0.000164	2.863278	56.6242
5	-1	1	1	0.002708333	0.002405	1.126077	133.6943
6	-1	1	-1	0.002166667	0.002035	1.064701	141.4013
7	-1	-1	1	0.000779221	0.000148	5.251067	52.92994
8	-1	-1	-1	0.000335052	0.00013	2.580389	58.34395
9	0	0	0	0.001454545	0.000773	1.881689	98.47134
10	0	0	0	0.0017	0.000871	1.951331	100.8917
11	0	0	0	0.001595745	0.000823	1.93836	89.61783
12	0	0	0	0.001442308	0.000736	1.960656	88.59873

Table 5: Observations for Water-air as Dielectric While Machining Stavax with Brass Electrode

Sr no	voltage	current	pulse on time	MRR	TWR gm/sec	MRR/TWR (λ)	% EWR
1	1	1	1	0.002143	0.001766286	1.2132	143.1847
2	1	1	-1	0.001667	0.001394556	1.195124	145.3503
3	1	-1	1	0.000528	0.000190563	2.771619	62.67516
4	1	-1	-1	0.000441	0.000193956	2.274623	76.36943
5	-1	1	1	0.003065	0.001917016	1.598587	137.6433
6	-1	1	-1	0.0025	0.001870982	1.336197	121.3376
7	-1	-1	1	0.00041	0.000126641	3.239522	57.19745
8	-1	-1	-1	0.000268	8.79018E-05	3.047232	57.00637
9	0	0	0	0.001176	0.000520882	2.258611	82.03822
10	0	0	0	0.001148	0.000586066	1.958042	82.80255
11	0	0	0	0.001207	0.000598362	2.017	80.38217
12	0	0	0	0.001207	0.00066569	1.813002	89.42675

2.5 Mathematical Formulation

With the observations made for responses with given set of input parameters, developing empirical relationship using Regression Analysis. We consider relation between response (output parameter) and input parameters in exponential form, as given below:

$$Y = K\,P^{a}\,Q^{b}\,R^{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where, Y = Desired Response; P, Q & R input Parameters, a , b & c power of indices; K = Constant

From the above observation table we develop equations for MRR and TWR with water as dielectric and water-air as dielectric. Similar from output tables other equations can be developed for all responses. The generalized equations showing relation between response and input parameters are developed and they are shown below.

$$MRRbw = 0.001274\,\mathrm{V}^{-0.0238} I^{0.332605} T_{on}^{0.068309} \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$TWRbw = 0.0006065\,\mathrm{V}^{-0.02062} I^{0.566357} T_{on}^{0.009758} \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$\lambda bw = 1.9727\,\mathrm{V}^{-0.00319} I^{-0.233} T_{on}^{0.0585} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$\%EWRbw = 88.739\mathrm{V}^{-0.006511} I^{-0.2004} T_{on}^{0.02527} \quad \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$MRRbwa = 0.01075\,\mathrm{V}^{-0.04538} I^{-0.16288} T_{on}^{0.024598} \quad \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

$$TWRbwa = 0.0005254\,\mathrm{V}^{0.04475} I^{0.5415} T_{on}^{0.0330} \quad \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

$$\lambda bwa = 1.955\,\mathrm{V}^{-0.045} I^{-0.162} T_{on}^{0.02} \quad \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

$$\%\mathrm{EWRbwa} = 89.52\,\mathrm{V}^{-0.0327} I^{0.1684} T_{on}^{-0.0452} \quad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

Where, MRRbw-Material Removal Rate with brass as tool and water as dielectric;

TWRbw-Tool Wear Rate with brass as tool and water as dielectric;

λbw-Material Removal Rate/Tool Wear Rate with brass as tool and water as dielectric;

%EWRbw-Tool Wear Rate with brass as tool and water as dielectric;

MRRbwa-Material Removal Rate with brass as tool and water-air as dielectric;

TWRbwa-Tool Wear Rate with brass as tool and water-air as dielectric.

λbwa-Ratio of MRR to TWR with brass as tool and water-air as dielectric;

%EWRbwa-Material Removal Rate with brass as tool and water-air as dielectric;

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Material Removal Rate (MRR)

Fig. 2, Fig. 3 and Fig. 4 shows comparative values of MRR for brass electrode with water (MRR bw) and water-air (MRR ba) mist for highest, lowest and middle energy levels. In all three cases MRR for water-air mixture shows lower values. This may be due to poor flushing of debris. In each case energy level is calculated as product of Voltage, current and pulse on time.

3.2 Tool Wear Rate (TWR)

Fig 5, Fig 6 and Fig 7 shows comparative values of Tool Wear Rates with water and water-air dielectric for highest, lowest and middle energy levels. In all three cases TWR for water as dielectric medium shows higher values, which is desirable.

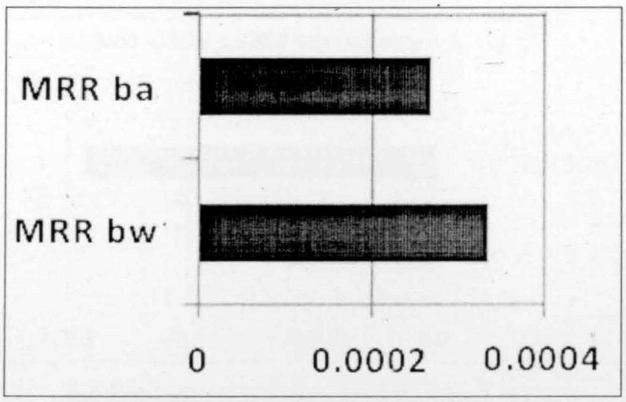

Fig 2. A Input Energy 6400 µWatt High (MRR in gm/sec)

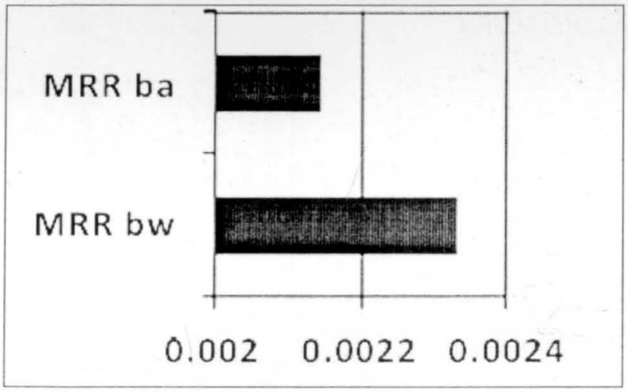

Fig 3. A Input Energy 2880 µ Watt Low (MRR in gm/sec)

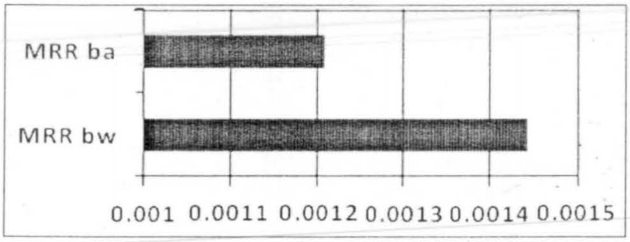

Fig 4. A Input Energy 1080 µWatt Medium

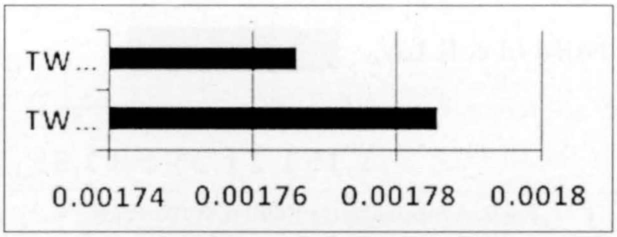

Fig 5. A Input Energy 6400 µWatt High

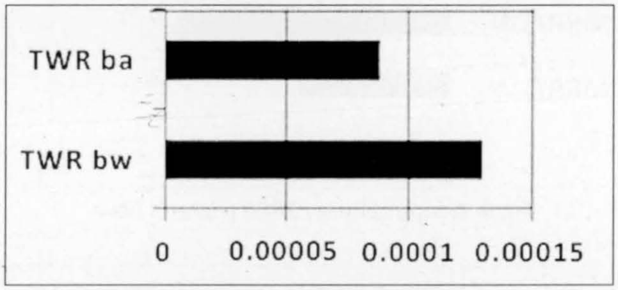

Fig 6. A Input Energy 2880 µWatt Low

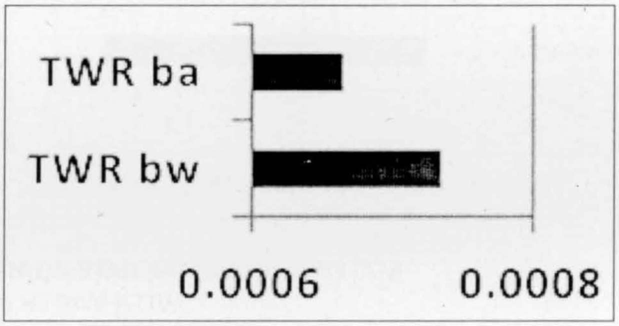

Fig 7. A Input Energy 1080 µWatt Medium

3.3 MRR/TWR (λ)

Fig 8, Fig 9 and Fig 10 shows comparative values of MRR/TWR (λ) values at three different energy levels for brass electrode while machining with water and water- air dielectric medium. At higher and medium energy ratio shows smaller values for water-air dielectric combination. At lower energy level reverse is the case.

3.4 % Electrode Wear Ratio

Fig. 11, Fig. 12 and Fig. 13 shows comparative values of % Electrode wear at highest, lowest and middle input energy levels. For water-air dielectric values are higher at high and middle energy level than water dielectric. At low energy levels water-air dielectric shows low value.

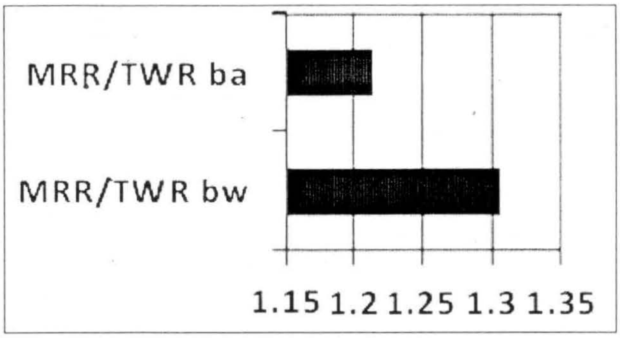

Fig 8. A Input Energy 6400 μ Watts High

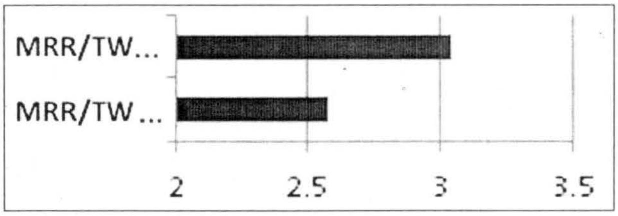

Fig 9. A Input Energy 2880 μ Watts Low

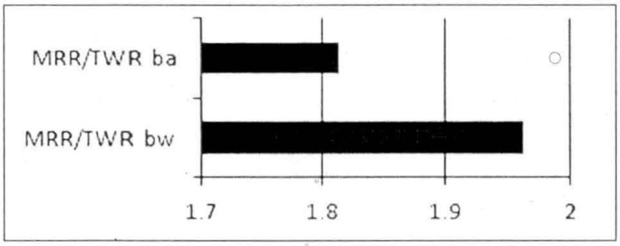

Fig 10. A Input Energy 1080 μ Watts Medium

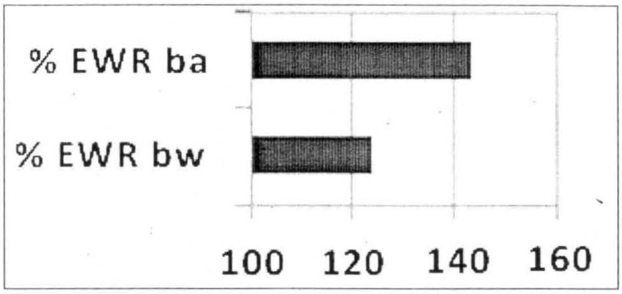

Fig 11. A Input Energy 6400 μ Watts High

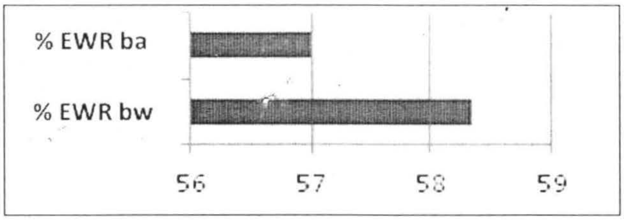

Fig 12. A Input Energy 2880μ Watts Low

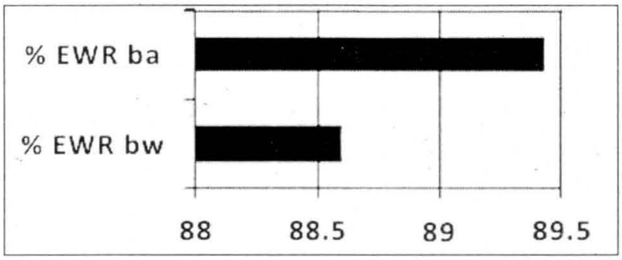

Fig 13. A Input Energy 1080 μ Watts Medium

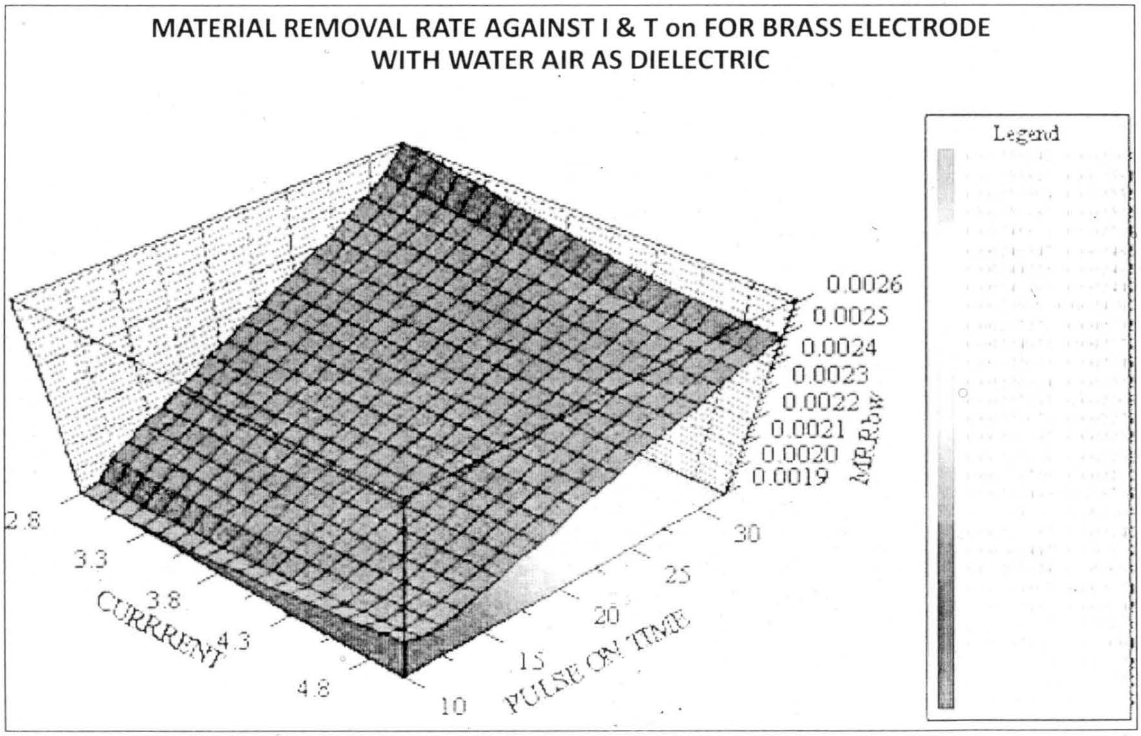

Fig 14. Surface Response Curve for MRR Against Current and Ton with Water as Dielectric

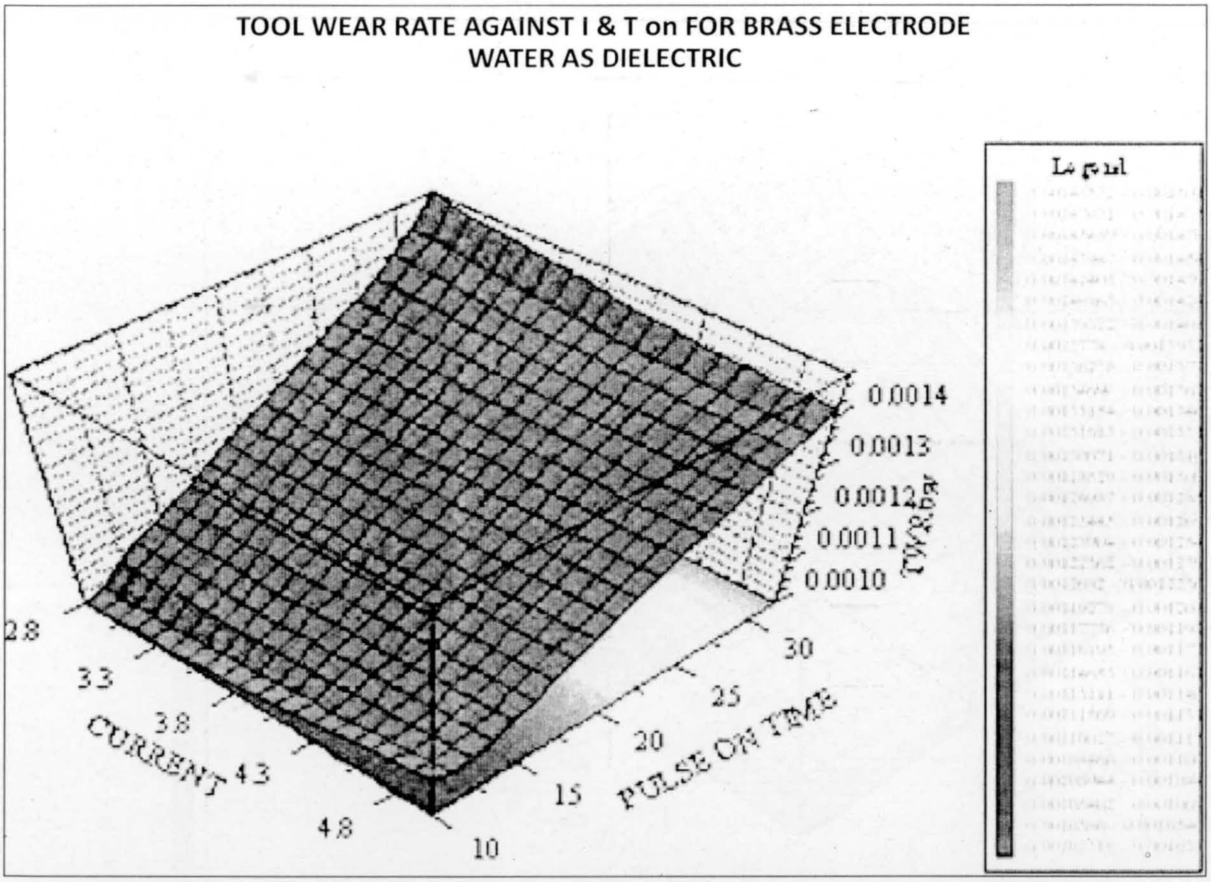

Fig 15. Surface Response Curve for TWR against Current and Ton with water as Dielectric

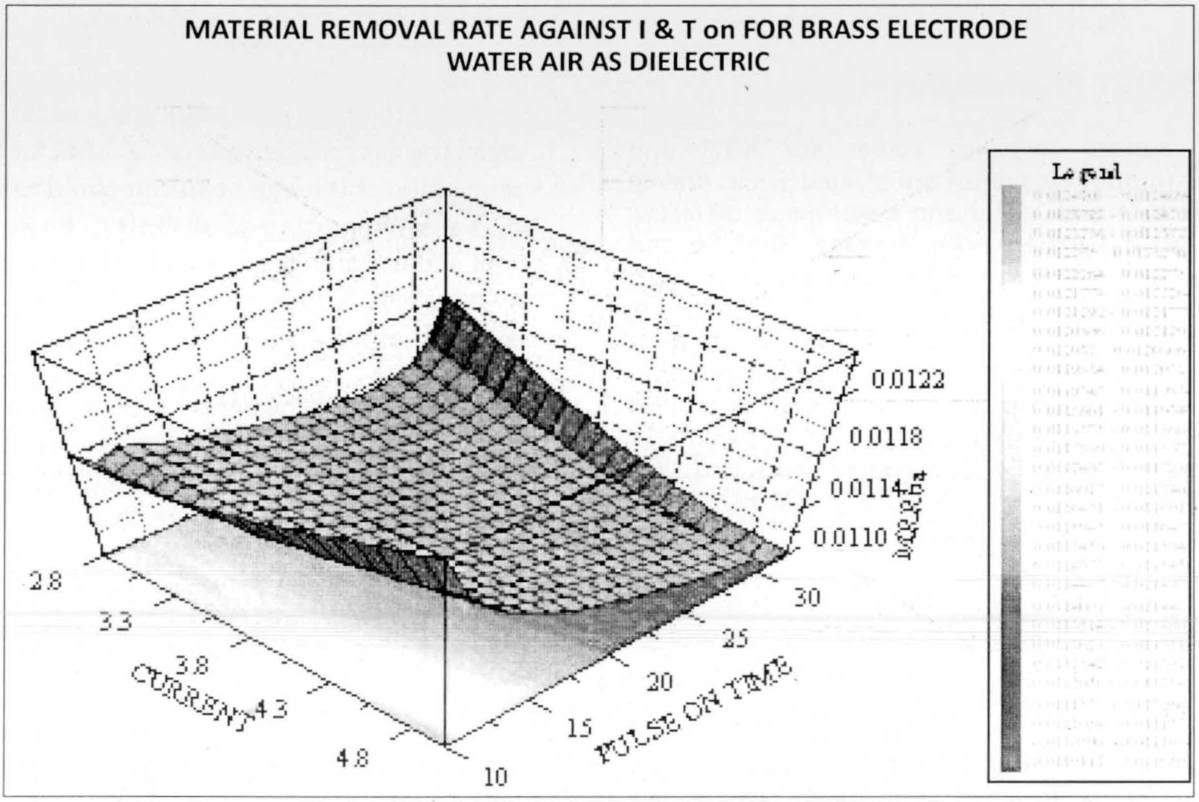

Fig 16. Surface Response Curve for MRR Against Current and Ton with Water-air as Dielectric

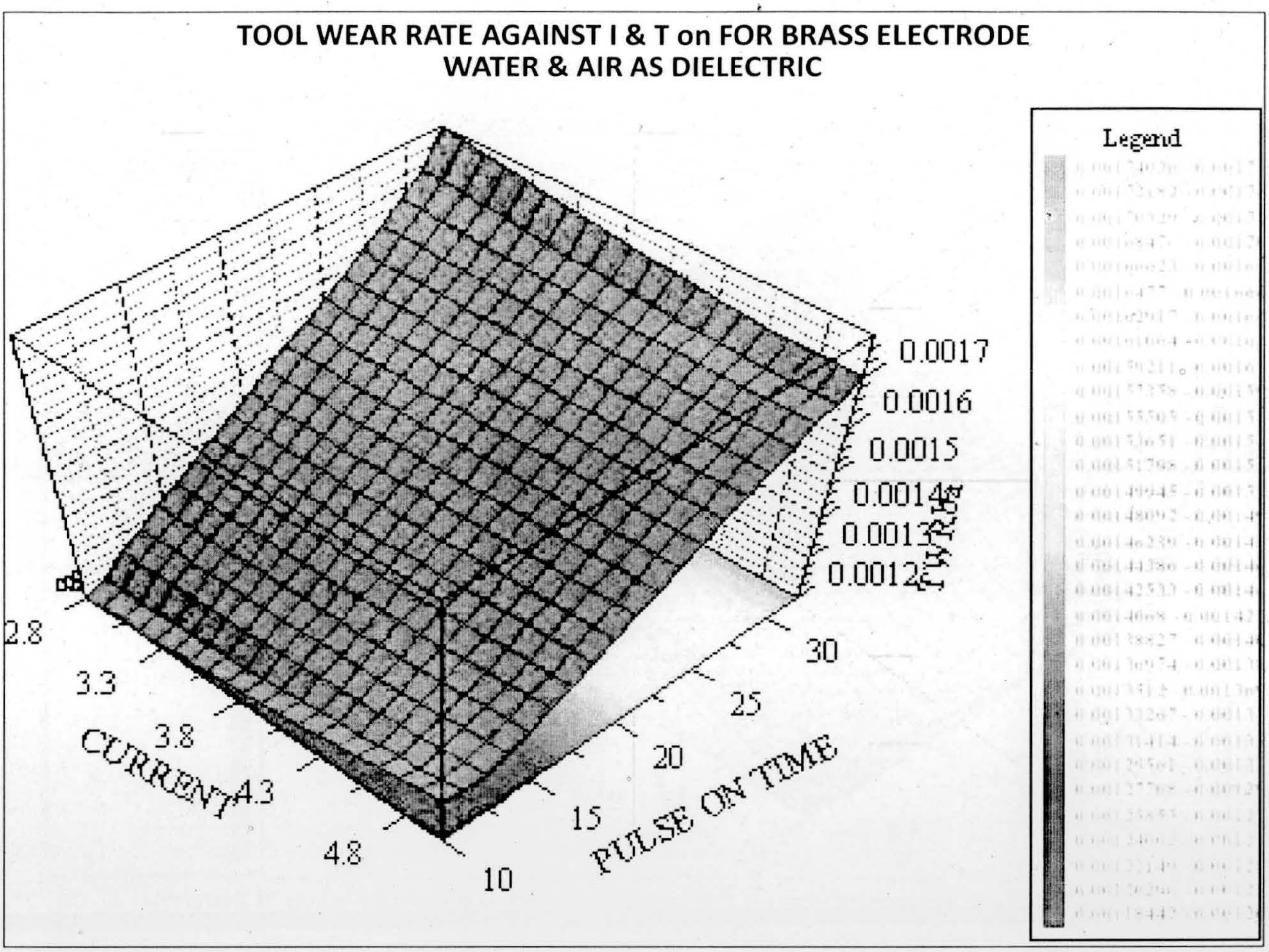

Fig 17. Surface Response Curve for TWR Against Current and Ton with Water-air as Dielectric

3.5 Surface Response Curves

The surface response curves for MRR and TWR (output Response) are plotted while drilling 1mm hole with water and water-air as dielectric for input variables, Gap Voltage, Current and Pulse on Time. By analyzing equations developed by regression analysis the effect of least important factor is deleted by keeping it constant which in this case is Voltage. Relation between input variables and output is plotted in 3-D surface response. Fig. 14, 15, 16 and 17 shows surface response curves for MRR and TWR for both water as well as water-air as dielectric.

4. CONCLUSIONS

Number of through holes have been drilled at identical Near Dry EDM process parameters on stavax testpiece with brass electrode using water and water-air mixture as dielectric. The changes in magnitude of MRR, TWR , λ and % EWR have been compared. With analysis following conclusions have been drawn:

- In general brass electrode with water as dielectric has provided a superior MRR for the production of through holes compared to use of water-air mixture as dielectric. However Tool Wear Ratio for machining with water as dielectric is higher than machining with water-air as dielectric.
- Ratio MRR/TWR is higher at higher and middle input energy levels for water as dielectric. However at low energy input levels this ratio is higher for water-air mixture than water as dielectric.
- % EWR values are higher for water-air dielectric compared to machining with water as dielectric.
- Both processes are environment friendly, avoids accidents and cheaper in process.

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