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Optimization of machining process of EN-36C using electric discharge machining process

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ABSTRACT

EDM or electric discharge machining is achieved when a discharge take place between two points of the anode and cathode, the intense heat is generated near the zone melts and evaporates the materials in the sparking zone. For improving the effectiveness of the process, the workpiece and the tool are submerged in a dielectric fluid (hydrocarbon or mineral oils). The proposed research is workout on machining of EN36C STEEL and there parameters such as tool dia, peak current, pulse on time, and pulse off time. It is observed that consider parameter namely tool diameter and pulse off time have significant effect on performance parameters and it was also justified by ANOVA analysis. For the validation of result confirmation test has been carried out and the associated error in the context of SR is only 1.14%, MRR 5.85%.

Keywords— *ANOVA, EDM, EN36C STEEL, MRR*

1. INTRODUCTION

EDM or electric discharge machining is achieved when a discharge takes place between two points of the anode and cathode, the intense heat is generated near the zone melts and evaporates the materials in the sparking zone. For improving the effectiveness of the process, the work piece and the tool are submerged in a dielectric fluid (hydrocarbon or mineral oils). It is found that if the materials of electrodes are the same and when it is connected to the positive terminal, it erodes fastly. Due to this reason, the work piece is generally made the anode. Also, some gap is kept in between tool and work piece surfaces which are called a spark gap. In this process this spark occurs continuously at the spot where tool and work piece surfaces come closest, however, the spot changes after each spark in the form of material removal after each continuous spark, the spark travels all over the surface. This causes uniform material removal over the surface; hence work piece conforms to the tool surface.

For hard metals which are unable to machining using conventional methods, EDM proves beneficial means it is easily machine able with the EDM process. It is commonly used for complex type contours or cavities cutting that are difficult to create with conventional machining methods. However the EDM process has limitation too, i.e. it can only work with conductive materials. Some common materials which are machined by this method are nickel-based alloys (aerospace materials), very hard tool steels, High-speed steels, conductive composites, conductive ceramics, etc.

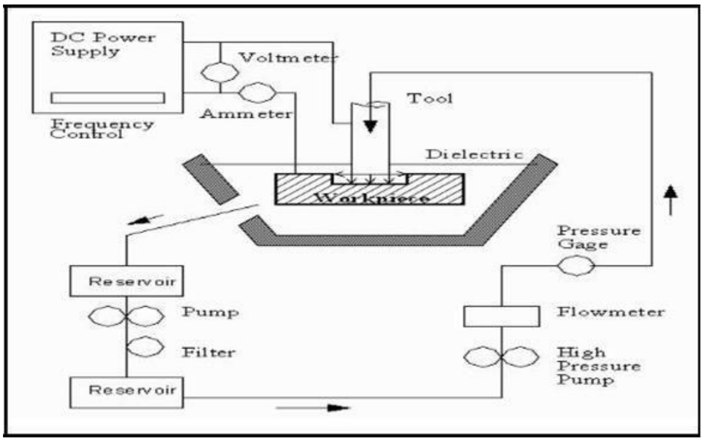

Fig. 1: Electro-Discharge Machine Setup

We can say that EDM is usually an electro-thermal non-traditional type material removal process which is extensively used to produce complicated cuts for aerospace and automotive industry, nozzles, machining of ceramics and composites and surgical components. The basic working principle of the EDM process is centered on thermoelectric energy. This energy is produced between a work piece and an electrode which is submerged in a dielectric fluid with the passageway of electric current. However, for producing a discharge, the ionization of dielectric is required. Suitable voltage is applied and intensity of dielectric field between them builds up. The electrons break loose from the surface of the cathode and are impelled towards the anode under field forces. While moving, the electrons collide with the neutral molecules of dielectric and causes ionization. When this happens, there is an avalanche of electrons flowing towards the anode, resulting in a discharge of energy which is seen as a spark. The discharge leads to the generation of extremely high temperature causing fusion of the metal and the dielectric fluid at the point of discharge. The metal in the form of liquid drops is dispersed into space surrounding the electrodes by the explosive pressure of gaseous product in the discharge. The continuous flushing of the dielectric is necessary for efficient removal of debris. The material removal takes place due to localized heating and the vaporization of material during machining when the distance between the tool electrode and the work piece electrode is maintained as an electrostatic field of sufficient strength is established, causing cold emission of electrons from tool electrode. These liberated electrons accelerate towards the anode. After gaining sufficient velocity, the electrons collide with the molecules of dielectric fluid breaking them into electrons and positive ions. The electrons so produced also accelerate and may ultimately dislodge to other electrons from the dielectric fluid molecules.

2. MATERIALS AND METHOD

2.1 Taguchi method

Taguchi has developed a methodology for the application of designed experiments, including a practitioner's handbook. This methodology has taken the design of experiments from the exclusive world of statistician and brought it more fully into the world of manufacturing [24]. His contributions have also made the practitioner work simpler by advocating the use of fewer experimental designs and providing a clear understanding of the various nature and the economic consequences of quality engineering in the world of manufacturing.

The brief procedure of the Taguchi method is as under.

(a) Identify the objective function.
(b) Select the factors to be evaluated.
(c) Identification of uncontrollable factors and test conditions.
(d) Selection of levels of controllable and uncontrollable factors.
(e) Calculate the total degree of freedom.
(f) Select the appropriate orthogonal array.
(g) Assignment of factors to the column.
(h) Execution of experiments according to the trial conditions in the array.
(i) Analyze the result.
(j) Confirmation results

Tables for Taguchi design of experiment are shown below

Table 1: Process parameters and their levels

S. No.	Parameters	Units	Level 1	Level 2	Level 3
1	Current	A	5	6	7
2	Pulse-off-time	Micro Sec.	15	30	45
3	Pulse-on-time	Micro Sec.	250	500	750
4	Diameter	Mm	10	12	14

Table 2: Experimentation L9 orthogonal array

S. No.	Diameter	Current	Pulse-on-time	Pulse-off-time
1	10	5	250	15
2	10	6	500	30
3	10	7	750	45
4	12	5	500	45
5	12	6	750	15
6	12	7	250	30
7	14	5	750	30
8	14	6	250	45
9	14	7	500	15

2.2 Role of ANOVA

Taguchi replaces the full factorial experiment with a lean, less expensive, faster, partial factorial experiment. Taguchi's design for the partial factorial is based on specially developed OA's. Since the partial experiment is only a sample of the full experiment, the analysis of the partial experiment must include an analysis of the confidence that can be placed in the results. Fortunately, there is a standard statistical technique called Analysis of Variance (ANOVA) which is routinely used to provide a measure of confidence. The technique does not directly analyze the data, but rather determine the variability (variance) of the data. Confidence is measured from the variance. The analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted. This is the second benefit of the methodology.

2.3 Analysis of variance (ANOVA)
In 1930 Sir Ronald Fisher developed this method to evaluate the results associated with agricultural experiments. However many people's think that ANOVA is a complex method, but in reality, it has mathematical beauty accompanying it. We can say that it is a statistical method or a decision-making tool to find out the differences in average performance associated with groups of items tested. However, the decision is rather than using pure judgment, takes variation into account.

3. EXPERIMENTATION
40ASEB EDM was used for machining the samples. The machine is shown in the figure below. EDM comes in 'non-traditional' or 'non-conventional' type group of machining methods. Preferably, it can be as seen as a series of breakdown and restoration of the liquid dielectric in-between the electrodes. EDM uses spark erosion method to remove the material of the work piece.

Table 3: Technical specifications of EDM

S. No.	Specification	Value
1	Model	40ASEB
2	Dielectric Fluid	EDM Oil
3	Electrode	Copper (Cu)
4	Pulse-on-time	05-900
5	Pulse-of-time	01-60
6	Spark Time	01-09
7	Voltage	0-300V

Fig. 2: EDM

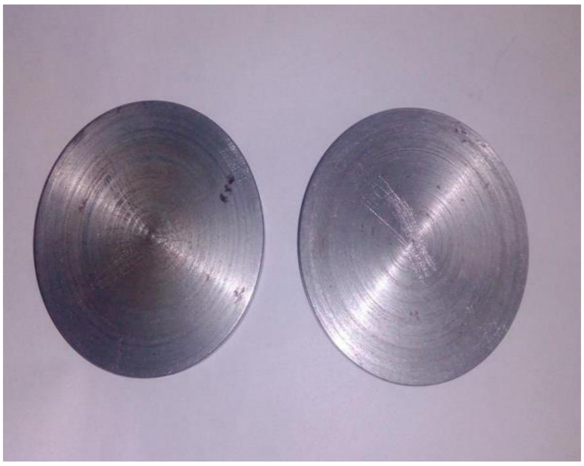

Fig. 3: EN36c Sample

3.1 Tool material
The tool material used for this work is 100% Copper (Cu). The tool was prepared of dimensions as 2 inches length and 10 mm, 12 mm and 14 mm diameter.

Fig. 4: Electrode (Cu)

3.2 Material removal rate
The rate of material removal from the work piece is known as the material removal rate. Some material is melted and then evaporated according to process parameters of an electrical discharge machine during machining. The material removal rate is calculated by dividing the work piece weight loss (in grams) to the product of the density of the work piece (gm/cc) and the

machining time. Higher the material removal rate higher is productivity. Hence it is most desirable to increase the material removal rate. The formula for material removal rate is as shown under

$$MRR = \frac{(Work\ piece\ weight\ loss\ (gm))\ X\ 1000}{Density\ (gm/cc)\ X\ Machining\ Time}$$

3.3 Tool wear rate

The rate of tool wear from the tool used to machine the work piece is known as the tool wear rate. Some material is melted and then evaporated according to process parameters of an electrical discharge machine during machining. The tool wear rate is calculated by dividing the tool weight loss (in grams) to the product of the density of the tool material (gm/cc) and the machining time. It is most desirable to decrease the tool wear rate. The formula for tool wear rate is as shown under.

$$\text{TWR} = \frac{\text{(Tool weight loss (gm)) X 1000}}{Density\ (gm/cc) X\ Machining\ Time}$$

3.4 SEM test

Scanning Electron Microscopy (SEM) provides high-resolution images of the sample by restoring a focused electron beam across the surface and detecting secondary or backscattered electron signal. An Energy Dispersive X-Ray Analyzer (EDX or EDA) is also used to provide element identification and quantitative compositional information.

- Rapid, high resolution with identification of elements present.
- Characterization of particulates and defect.
- Examination of grain structure and segregation effects.
- Characterization of material structure

Fig. 5: Systematic diagram of SEM (IIT Kanpur)

3.5 Surface roughness test

For measuring surface roughness, profilometer is used. Critical dimensions as a step, curvature flatness are computed from the surface topography. Non-scanning technology measures the surface topography within signal camera acquisition, XYZ scanning is no longer needed. As a consequence is dynamic changes to topography are measured in real time. Nowadays profile meter is not only measuring static topography but also dynamic topography such system are described as time-resolved profilometer.

4. RESULT AND DISCUSSION

4.1 Calculation for MRR

$$MRR = \frac{(Work\ piece\ weight\ loss\ (gm))\ X\ 1000}{Density\ (gm/cc)\ X\ Machining\ Time}$$

Table 4: L9 orthogonal array

Exp. No.	Diameter	Current	Ton	Toff	MRR
1	10	5	250	15	0.04398
2	10	6	500	30	0.04495
3	10	7	750	45	0.03841
4	12	5	500	45	0.04798
5	12	6	750	15	0.05513
6	12	7	250	30	0.3453
7	14	5	750	30	0.0637
8	14	6	250	45	0.0343
9	14	7	500	15	0.127

4.2 Calculation of S/N ratio of MRR

$$S/N_{LB} = -10 \log (\Sigma (1/y_i^2))$$

Table 5: Calculation of S/N ratio for MRR

S. No.	MRR	S/N
1	0.04398	-27.1349
2	0.04495	-26.9454
3	0.03841	-28.3111
4	0.04798	-26.3788
5	0.05513	-25.1722
6	0.3453	-9.2361
7	0.0637	-23.9141
8	0.0343	-29.2941
9	0.127	-17.9239

4.3 Calculation of mean S/N ratio for MRR

Mean S/N ratio is calculated by using the following formula

$$n_{fi} = (n_{f1}+n_{f2}+n_{f3})/3$$

Table 6: Response table for S/N larger is better

Level	Tool Dia.	Ip	Ton	Toff
1	-27.46	-25.81	-28.89	-23.41
2	-25.26	-27.14	-23.75	-20.03
3	-23.71	-18.49	-25.80	-27.99
Delta	7.20	8.65	3.91	7.96
Rank	3	1	4	2

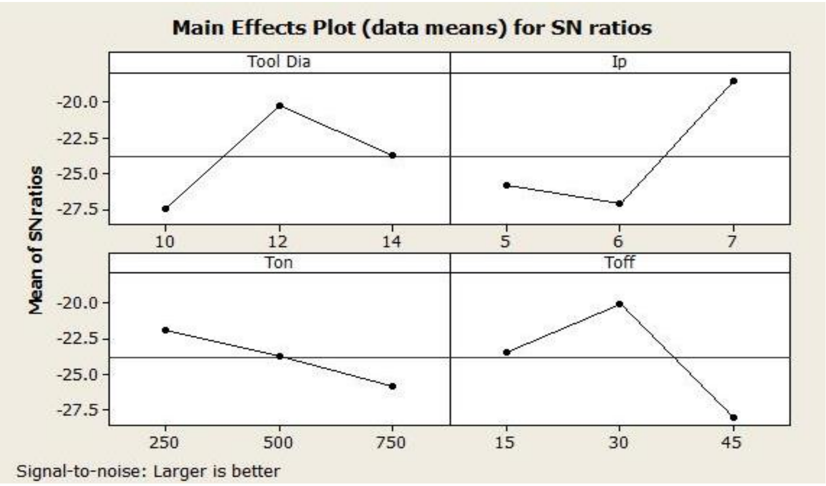

Fig. 6: Main effects plot (data means) for SN ratios

4.4 Analysis of variance for MRR

Table 7: Analysis of variance for residual

Source	Df	SS	Ms	F	P
Regression	4	0.03627	0.00907	0.83	0.571
Residual Error	4	0.04385	0.01096	-	-
Total	8	0.08012	-	-	-

Table 8: Analysis of variance for MRR

S. No.	Factor	DOF (f)	Sum of Sqrs (S)	Variance	F-Ratio	Pure Sum(s')	Percent P (%)
1	**Tool Dia**	2	284.834	142.417	-	284.834	24.374
2	**Ip**	2	402.578	201.289	-	402.578	34.449
3	**Ton**	2	169.899	84.949	-	169.899	14.538
4	**Toff**	2	311.284	155.642	-	311.284	26.637
5	**Other Error**	0					
	Total	**8**	**1168.579**				**100.00%**

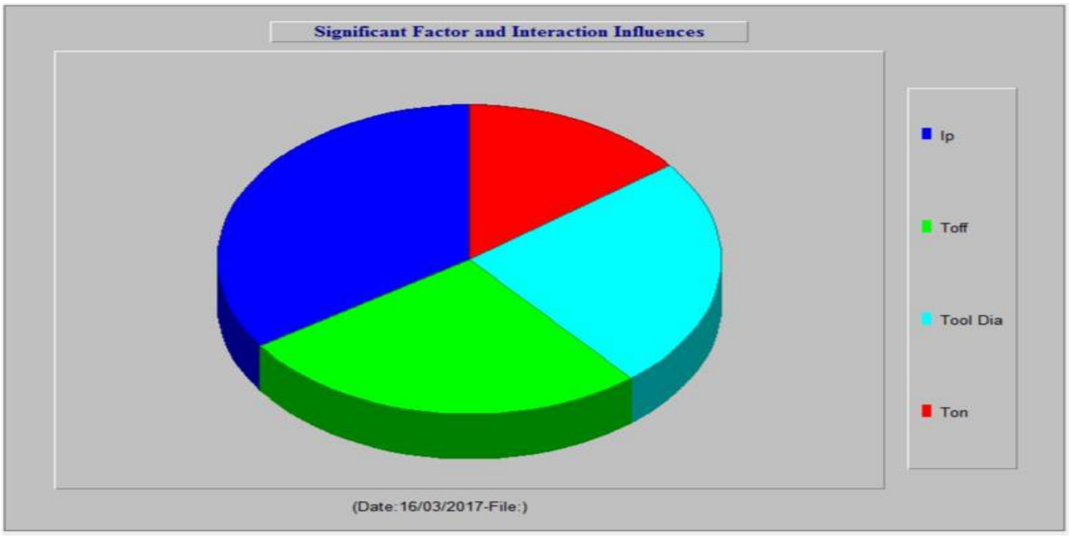

Fig. 7: Significant factor and interaction influences

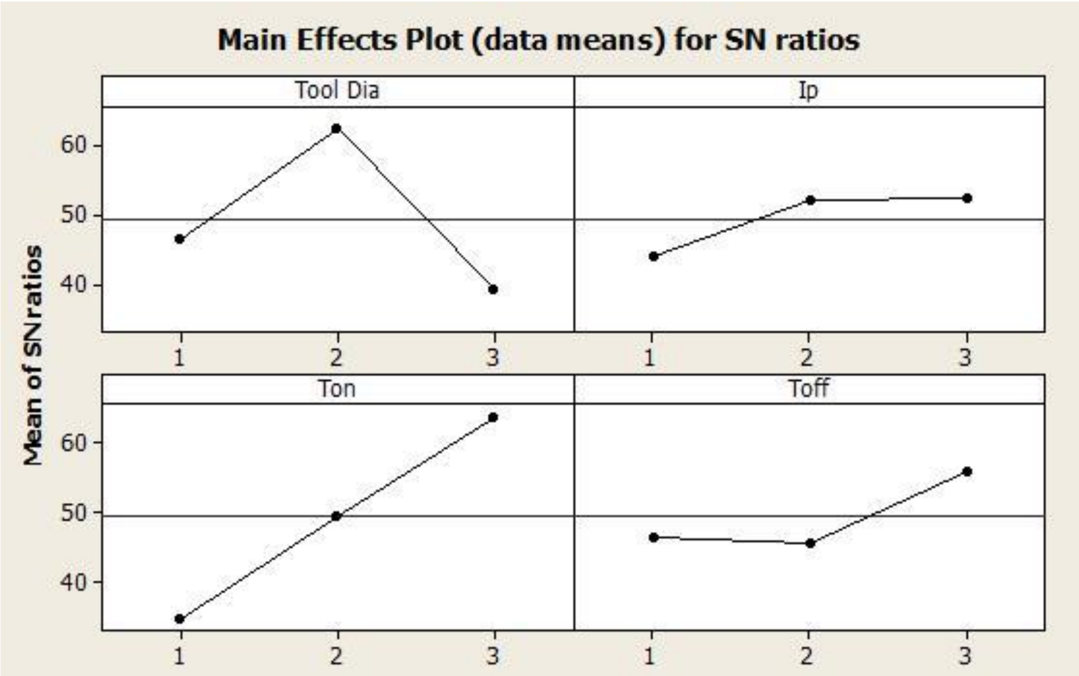

Fig. 8: Main effects plot (data means) for SN ratios

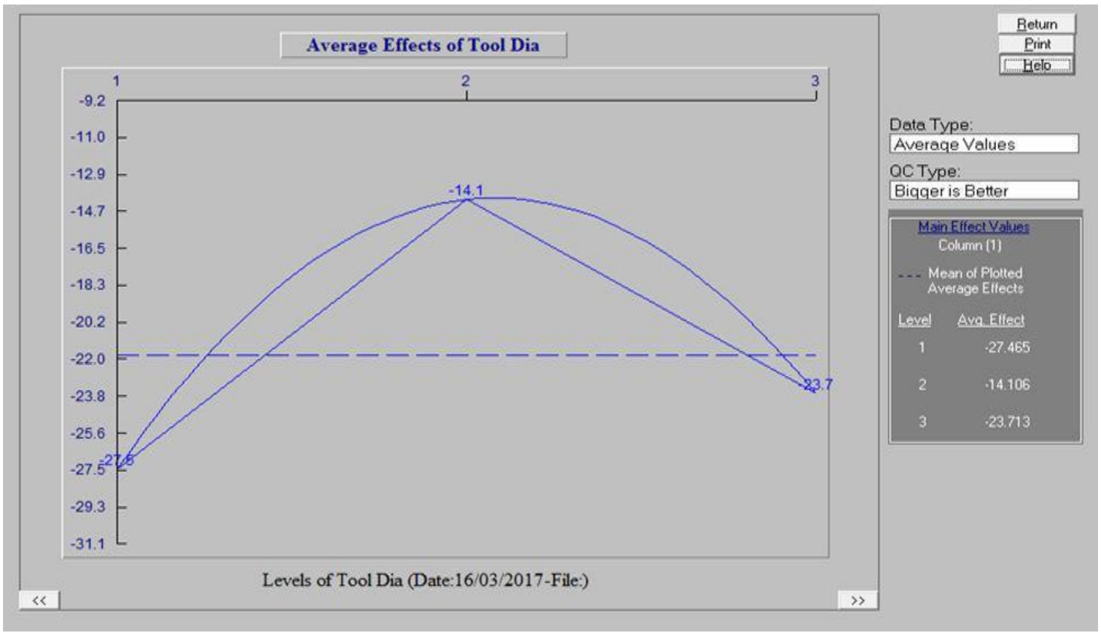

Fig. 9: Average effects of tool dia

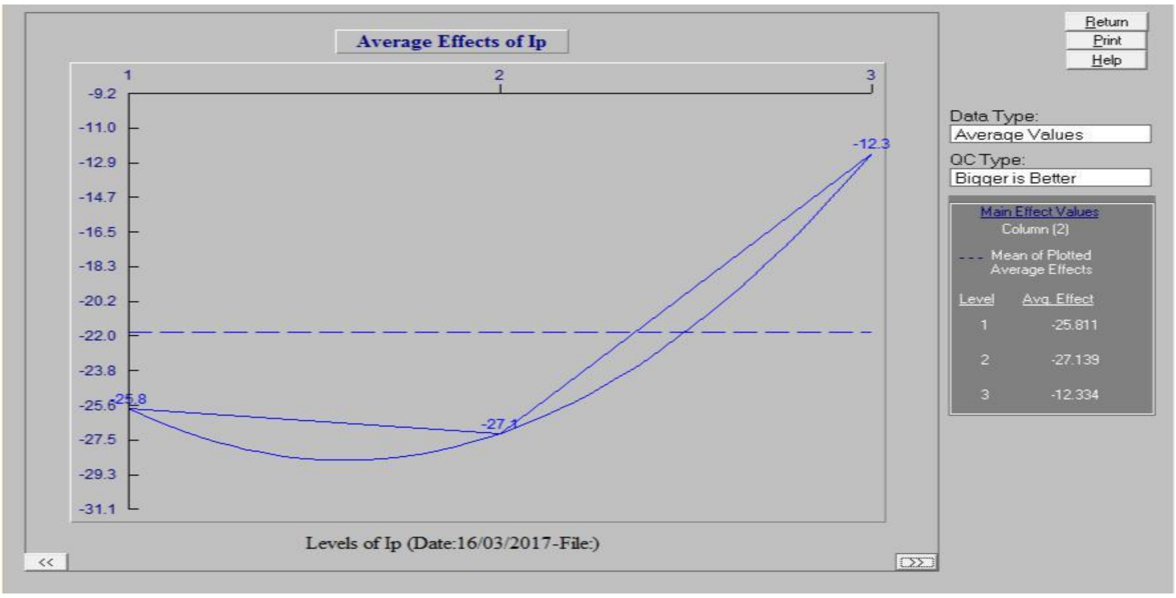

Fig. 10: Average Effects of Ip

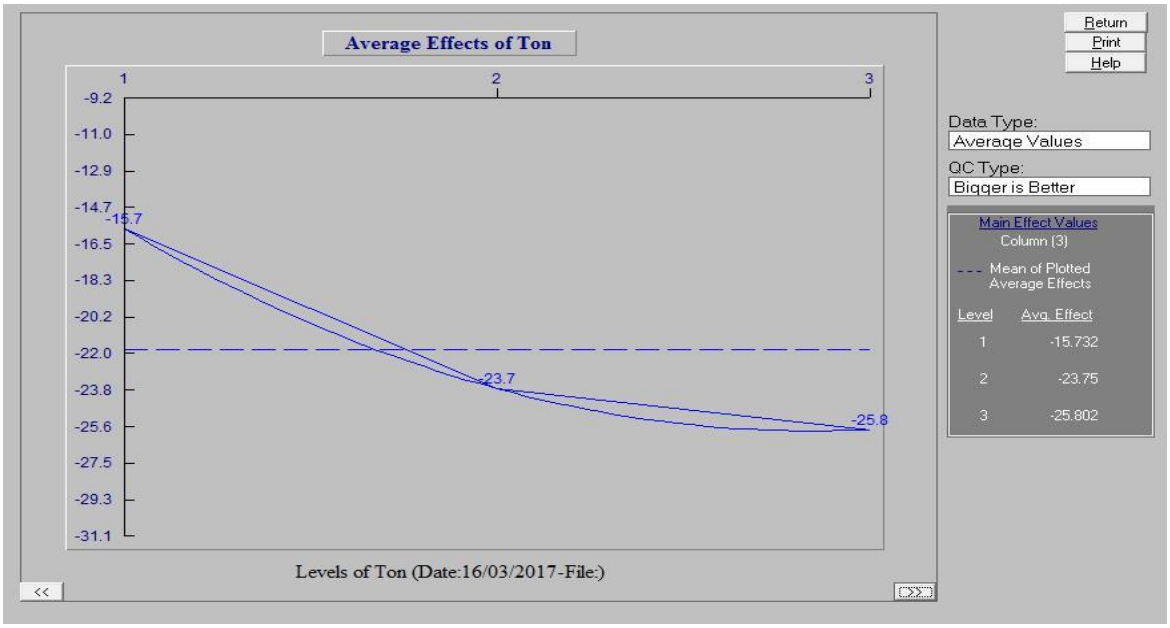

Fig. 11: Average Effects of Ton

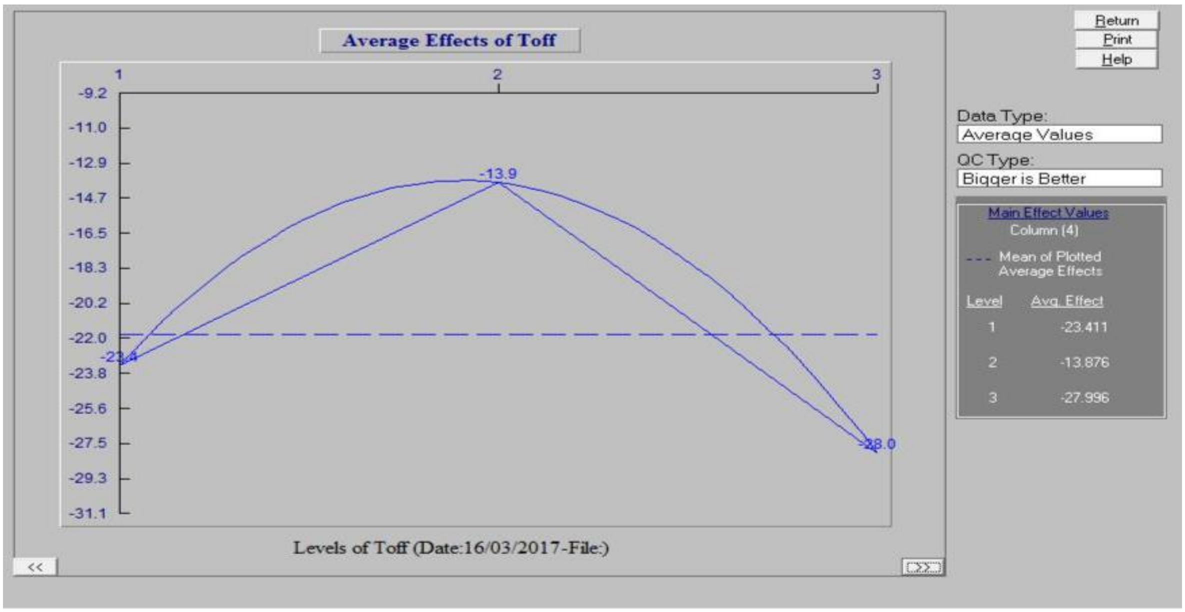

Fig. 12: Average effects of Toff

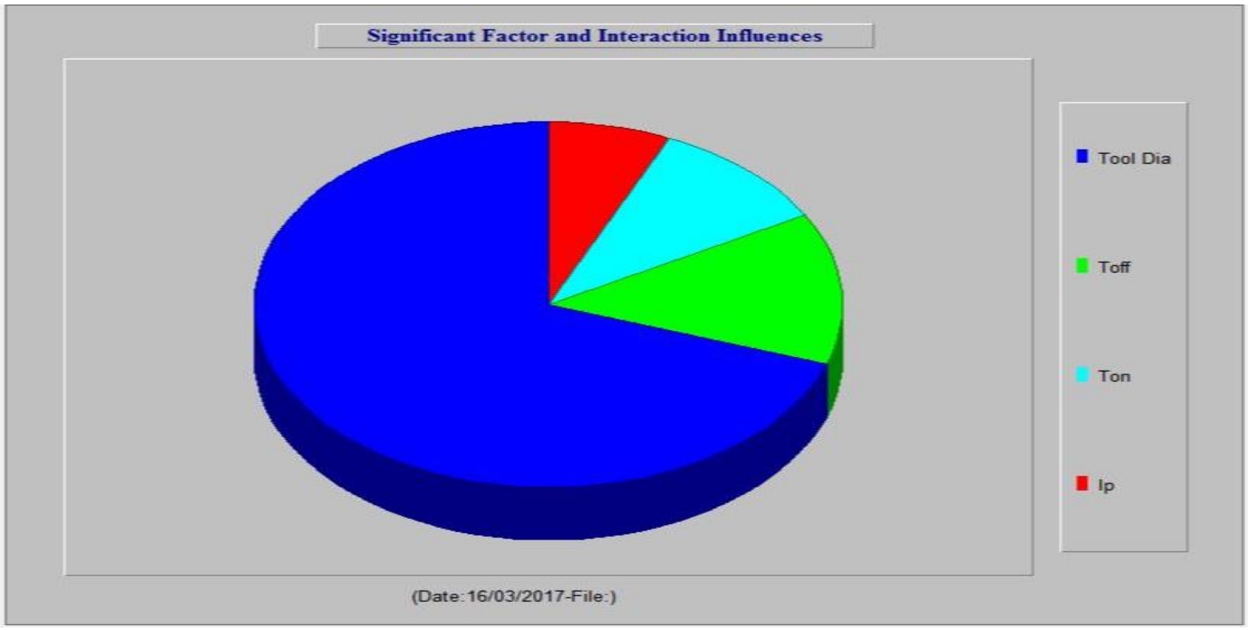

Fig. 13: Significant factor and interaction influences

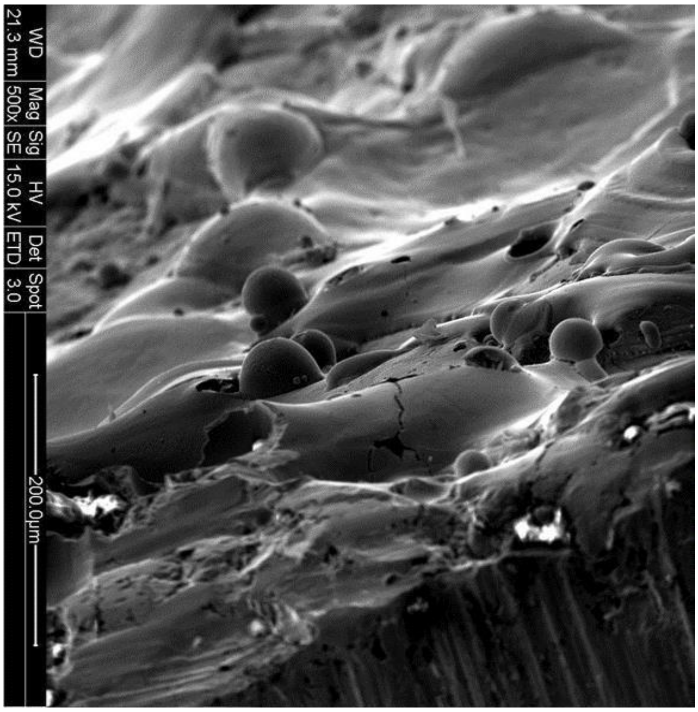

Fig. 14: SEM Test

5. CONCLUSION

It was observed that the Taguchi's parameter is a simple, systematic, reliable and more efficient tool for optimation of the machining parameters. The effect of various parameters such as tool dia, peak current, pulse on time, and pulse off time on the machining of EN36C STEEL has been a workout. It is observed that consider parameter namely tool diameter and pulse off time have a significant effect on performance parameters and it was also justified by ANOVA analysis. For the validation of result confirmation test has been carried out and the associated error in the context of SR is only 1.14%, MRR 5.85%. In today's manufacturing scenario optimum parameters and its value are very essential for automation and implementation of a computer integrated manufacturing system which in turns enhanced productivity and better utilization of various resources.

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