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A Comparative Study to Maximize MRR in Electro Discharge Machining Process by Variation of Control Parameters Using Taguchi Analysis

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ABSTRACT
Electro Discharge Machining (EDM) is a non-traditional machining process, based on thermo electric energy between the work piece and electrode. In this process, the material removal is occurred electro thermally by a series of successive discrete discharges between electrode and the work piece. Electro Discharge Machine which has the ability to machine hard, difficult to machine material and parts with internal complex shape by using precisely controlled sparks that occurs between electrode and work piece in the presence of dielectric fluid. This spark removes material from both work piece and electrode. Material Removal Rate (MRR) is of crucial importance in this process. In this research experiment has been done along with Copper and Graphite tool material as well as Mild Steel and Aluminium material has been used as work piece. Three major Parameters named as Electrode Speed **(V),** Current **(I),** and Depth of Cut **(h)** are considered to determine the MRR. In this experiment three levels of each parameter has been taken by using Taguchi L_9 orthogonal array to find out the best combination of electrode and work piece at the optimal setting of control parameters for maximum Material Removal Rate.
.**Keywords**: Current, Depth of Cut, Electrode Speed, MRR, Taguchi Analysis.

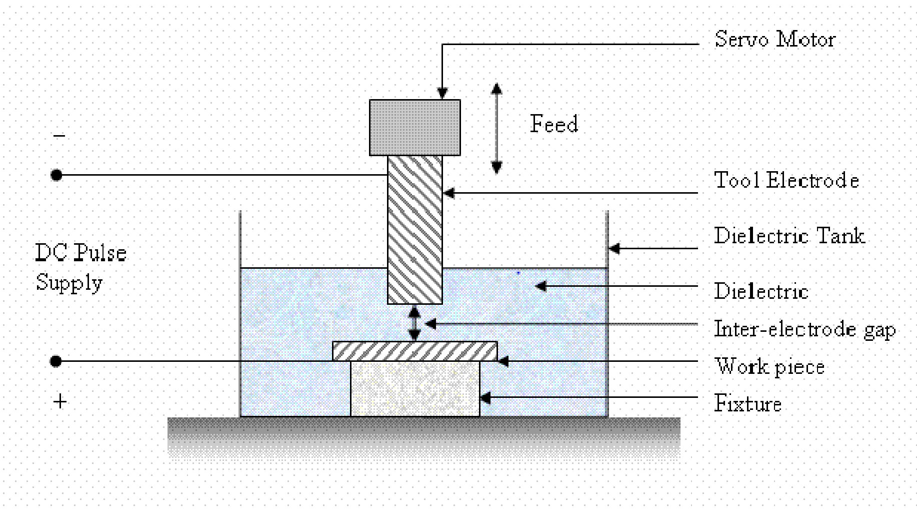
I. INTRODUCTION

There has been rapid growth in the development of harder and difficult to machine metals and alloys during last two decades. Machining process that involves chip formation have number of inherent limitations which limit their application in industry. Large amount of energy are expended to produce unwanted chips which must be removed and discarded. Electro Discharge Machining Process is now become the most important accepted technologies in manufacturing industries since may many complex 3D shapes can be machined using simple shaped tool electrode. EDM is an important non-traditional manufacturing method. The basis of Electro Discharge Machining (EDM) was first traced far back in 1770's by English scientist Joseph Priesty who discovered the erosive effect of electrical discharges of sparks. The EDM technique was developed by two Russian scientists B.R Lazarenko and N.I Lazarenko in the year 1943. Electrical-discharge machining (EDM) is an unconventional, non-contact machining process where metal removal is based on thermo-electric principles. In this process, the material removal mechanism uses the electrical energy and turns it into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed in an insulating dielectric fluid . Its unique feature of using thermal energy is to machine electrically conductive parts regardless of their hardness; its distinctive advantage is in the manufacture of mould, die, automotive, aerospace and other applications. Moreover, EDM does not make direct contact between the electrode and the work piece, eliminating mechanical stresses, chatter and vibration problems during machining. Hence, the tool material is generally softer than the work piece material. A dielectric fluid is required to maintain the sparking gap between the electrode and work piece. This dielectric fluid is normally a fluid. Dielectric fluid is used in EDM machine provides important functions in this process. These are : (i) Controlling the sparking gap spacing (ii) Cooling the heated material to form the chip and (iii) Removing chips from the sparking area. EDM process is basically of two types : (i) Die sinking EDM (ii). Wire cut EDM. We have been performed this experiment by using Die-Sinking type Electro Discharge Machine.

Material Removal Rate (MRR) is an important performance measure in EDM process. MRR is mainly dependent on the different input machining parameters, electrode and work piece. It is found already many works has been done on optimization of MRR but very little work has been done on optimization of MRR for different material and different electrode in EDM. In this work study on EDM relating to analyze the variation of Material Removal Rate with control parameters and predict the Maximum Material Rate (MRR) at optimal setting of control parameters by using Taguchi L_9 orthogonal Array. Electrode Speed (**V**), Current (**I**) and Depth of Cut (**h**) are the basic variable and three levels of each parameter are taken in this experimental study.

II. EXPERIMENTAL SET-UP

We have done this experimental research work at MSME tool room, Kolkata with different Work piece and different electrode. The whole experiments have been done by Electro Discharge Machine, model AGITRON COMPACT-1 (Die-Sinking type) and positive polarity for electrode is used to conduct the experiments. The materials that are normally used as electrodes in this EDM are copper, graphite, tungsten and brass. Copper and Graphite are selected as tool/electrode in this experiment. Electrodes are prepared with the diameter of 8 mm. Mild Steel and Aluminium are selected as work piece. One piece Mild Steel and one piece Aluminium is prepared with dimension of (101*62*9.7) mm^3 and (110*65.3*15) mm^3 respectively for this experimental work . These two electrodes copper and graphite is expected to give better MRR and it is major commercially available EDM electrodes. The work piece material are used for this work are mild Steel and Aluminum which is having a wide applications in industrial field like manufacturing, cryogenic, space application etc. RUSTLICK E.D.M. 20 oil (specific gravity = 0.763, freezing point = 94^0C) is used as Dielectric Fluid in this experiment.



Component of EDM

III. PARAMETERS AND RANGE SELECTION

In this study L_9 orthogonal array has been used which is attributed to its suitability for three level problems. On the basis of Taguchi method three factors with three levels of each are selected and L_9 array has been made for calculating MRR. We have been selected the following suitable level values of various factors.

Parameters	Symbol	Level		
		Low	Medium	High
Electrode Speed (mm/min)	V	500	600	700
Current (Amp)	I	4	6	8.5
Depth of Cut (mm)	h	2	3	4

Taguchi L_9 Orthogonal Array

Exp. No	Control Factors		
	A	B	C
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

IV. OBSERVATION TABLE

Work Piece- Aluminium
Electrode- Copper

Table - 1

Exp. No	Impulse	Spark Gap (mm)	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Machining Time (min)	MRR (mm^3/min)
1	1060	0.20	500	4	2	7.167	14.730
2	1070	0.26	500	6	3	5.033	31.924
3	1080	0.31	500	8.5	4	4.50	48.186
4	1060	0.20	600	4	3	8.167	19.390
5	1070	0.26	600	6	4	6.10	35.120
6	1080	0.31	600	8.5	2	1.75	61.953
7	1060	0.20	700	4	4	10.233	20.633
8	1070	0.26	700	6	2	2.133	50.219
9	1080	0.31	700	8.5	3	2.367	68.706

Work Piece - Aluminium
Electrode- Graphite

Table - 2

Exp. No	Impulse	Spark Gap (mm)	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Machining Time (min)	MRR (mm^3/min)
1	1060	0.20	500	4	2	7.50	14.076
2	1070	0.26	500	6	3	6.317	25.435
3	1080	0.31	500	8.5	4	4.467	38.950
4	1060	0.20	600	4	3	9.0	17.500
5	1070	0.26	600	6	4	7.317	29.279
6	1080	0.31	600	8.5	2	2.233	48.553
7	1060	0.20	700	4	4	10.333	20.433
8	1070	0.26	700	6	2	2.567	41.728
9	1080	0.31	700	8.5	3	2.75	59.137

Work Piece - Mild Steel
Electrode - Copper

Table - 3

Exp. No	Impulse	Spark Gap (mm)	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Machining Time (min)	MRR (mm^3/min)
1	1060	0.20	500	4	2	13.75	7.678
2	1070	0.26	500	6	3	13.167	12.203
3	1080	0.31	500	8.5	4	9.5	22.825
4	1060	0.20	600	4	3	18.75	8.445
5	1070	0.26	600	6	4	15.533	13.792
6	1080	0.31	600	8.5	2	3.95	27.447
7	1060	0.20	700	4	4	23.667	9.315
8	1070	0.26	700	6	2	6.0	17.853
9	1080	0.31	700	8.5	3	4.417	36.818

Work Piece - Mild Steel
Electrode - Graphite

Table - 4

Exp. No	Impulse	Spark Gap (mm)	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Machining Time (min)	MRR (mm^3/min)
1	1060	0.20	500	4	2	26.667	3.959
2	1070	0.26	500	6	3	31.20	5.150
3	1080	0.31	500	8.5	4	30.0	7.228
4	1060	0.20	600	4	3	38.333	4.130
5	1070	0.26	600	6	4	38.933	5.503
6	1080	0.31	600	8.5	2	14.0	7.749
7	1060	0.20	700	4	4	48.333	4.368
8	1070	0.26	700	6	2	17.367	6.168
9	1080	0.31	700	8.5	3	19.0	8.560

V. CALCULATION OF MRR

Material Removal Rate (MRR) refers to the amount of material removed from work piece per unit time. Material removal rate is calculated by measuring the cross section area of cut multiplying with the depth of cut then it is divided by machining time.

Material Removal Rate (MRR) = $\frac{Volume}{Time} = \frac{\pi/4 * D^2 * h}{Time}$ mm^3/min

[Where D = Diameter of Electrode, h = Depth of Cut]

VI. REGRESSION ANALYSIS

Regression analysis is the relationship between various variables. By regression analysis one can construct a relationship between response variable and predictor variable. It demonstrates what will be the changes in response variable because of the changes in predictor variable. Simple regression equation is

y=a+ b x

In this problem more than one predictor variable is involved and hence simple regression analysis cannot be used. We have to take the help of multiple regression analysis. There are two types of multiple regression analysis- (i) Simple multiple regression analysis (regression equation of first order) (ii) Polynomial multiple regression analysis (regression equation of second order or more)

Simple multiple regression analysis is represented by the equation of first order regression

$Y= \beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\ldots\ldots\ldots\ldots+\varepsilon$

Where β is constant terms & X is the variables & ε is the experimental error.

Polynomial multiple regression analysis equation is

$Y = \beta_0+ \beta_1X_1+\beta_2X_2+\beta_3X_3+ \beta_{11}X^2_{11}+ \beta_{22}X^2_{22}+ \beta_{33}X^2_{33}+ \beta_{12}X_1X_2+ \beta_{13}X_2X_3+ \beta_{23}X_1X_3$

The above equation is second order polynomial equation for 3 variables. Where β are constant, X_1 , X_2 , X_3 are the linear terms, X_{12} X_{13} X_{23} are the interaction terms between the factors, and lastly X_{11} X_{22} X_{33} are the square terms.

Here, MRR is Response variable,

Electrode Speed (V), Current (I), Depth of Cut (h) are the predictor variables.

Polynomial regression equation becomes after replacing real problem variables

$MRR = \beta_0 + \beta_1(V) + \beta_2(I) + \beta_3(h) + \beta_{11}(V)*(V) + \beta_{22}(I)*(I) + \beta_{33}(h)*(h) + \beta_{12}(V)*(I) + \beta_{23}(I)*(h) + \beta_{13}(V)*(h)$ …………..(1)

To solve this equation following matrix method is used

MRR= [β][X]………………..(2)

[β]=[MRR] [X^{-1}] where [β] is the coefficient matrix, MRR is the response variable matrix; [X^{-1}] is the inverse of predictor variable matrix……………….(3)

In this problem there are 3 independent variables and each variable has 3 levels and hence from the Taguchi Orthogonal Array (OA) table L9 OA is best selected.

Experiments have been carried out using Taguchi's L_9 Orthogonal array experimental design which consist of 9 combination of Electrode Speed, Current, and Depth of Cut. It considers three process parameters to be varied three discrete levels. The experimental design has been shown in above table. Replacing the value of three variables in the polynomial regression equation….(1) we get the following equations according to the Taguchi L_9 table.

MRR= β_0+500 β_1+4 β_2+2 β_3+250000 β_4+16 β_5+4 β_6+2000 β_7+8 β_8+1000β_9
MRR = β_0+500 β_1+6 β_2+3 β_3+250000 β_4+36 β_5+9 β_6+3000 β_7+18 β_8+1500 β_9
MRR = β_0+500 β_1+8.5 β_2+4 β_3+250000 β_4+72.25 β_5+16 β_6+4250 β_7+34β_8+2000 β_9
MRR = β_0+600 β_1+4 β_2+3 β_3+360000 β_4+16 β_5+9 β_6+2400 β_7+12 β_8+1800 β_9
MRR = β_0+600 β_1+6 β_2+4 β_3+360000 β_4+36β_5+16 β_6+3600 β_7+24 β_8+2400 β_9
MRR= β_0+600 β_1+8. 5 β_2+2 β_3+ 360000β_4+72.25 β_5+4 β_6+5100 β_7+17 β_8+1200 β_9
MRR= β_0+700 β_1+4β_2+4 β_3+490000β_4+16 β_5+16 β_6+2800 β_7+16 β_8+2800 β_9
MRR= β_0+700 β1+6 β_2+2 β_3+ 490000β_4+36 β_5+4 β_6+4200β_7+12 β_8+1400 β_9
MRR = β_0+700 β_1+8. 5 β_2+3 β_3+490000 β_4+72.25 β_5+9 β_6+5950 β_7+25.5 β_8+2100 β_9

VII. RESULTS AND DISCUSSIONS

Value of Coefficients for the Predicted Equation

β_0 = -2.514, β_1 = -0.1562, β_2 = 0.1808, β_3 = 28.4601, β_4 = 0.0002, β_5 = 0.0172, β_6 = 0.9305, β_7 = 0.0197, β_8 = -1.3485, β_9 = -0.0457

Predicted Equation from Regression Analysis for Maximum MRR

MRR = -2.514 - 0.1562**(V)** + 0.1808**(I)** + 28.4601**(h)** + 0.0002**(V)*****(V)** + 0.0172**(I)*****(I)** + 0.9305**(h)*****(h)** + 0.0197**(V)*****(I)** - 1.3485**(I)*****(h)** - 0.0457**(V)*****(h)**

Results Showing the Experimental and Predicted Value of MRR

Work Piece - Aluminium
Electrode- Copper

Table - 5

Exp. No	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Experimental MRR (mm^3/min)	Predicted MRR (mm^3/min)
1	500	4	2	14.730	13.939
2	500	6	3	31.924	31.122
3	500	8.5	4	48.186	47.370
4	600	4	3	19.390	19.357
5	600	6	4	35.120	35.074
6	600	8.5	2	61.953	61.893
7	700	4	4	20.633	21.497
8	700	6	2	50.219	51.070
9	700	8.5	3	68.706	69.539

Work Piece - Aluminium
Electrode- Graphite

Table - 6

Exp. No	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Experimental MRR (mm^3/min)	Predicted MRR (mm^3/min)
1	500	4	2	14.076	12.425
2	500	6	3	25.435	23.806
3	500	8.5	4	38.950	37.348
4	600	4	3	17.500	17.380
5	600	6	4	29.279	29.185
6	600	8.5	2	48.553	48.488
7	700	4	4	20.433	22.122
8	700	6	2	41.728	43.443
9	700	8.5	3	59.137	60.890

Work Piece - Mild Steel
Electrode- Copper

Table - 7

Exp. No	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Experimental MRR (mm^3/min)	Predicted MRR (mm^3/min)
1	500	4	2	7.678	9.694
2	500	6	3	12.203	14.179
3	500	8.5	4	22.825	24.757
4	600	4	3	8.445	8.578
5	600	6	4	13.792	13.882
6	600	8.5	2	27.447	27.562
7	700	4	4	9.315	7.221
8	700	6	2	17.853	15.799
9	700	8.5	3	36.818	34.702

Work Piece - Mild Steel
Electrode- Graphite

Table - 8

Exp. No	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Experimental MRR (mm^3/min)	Predicted MRR (mm^3/min)
1	500	4	2	3.959	3.123
2	500	6	3	5.150	4.317
3	500	8.5	4	7.228	6.398
4	600	4	3	4.130	4.084
5	600	6	4	5.503	5.460
6	600	8.5	2	7.749	7.697
7	700	4	4	4.368	5.255
8	700	6	2	6.168	7.044
9	700	8.5	3	8.560	9.440

Graphical Representation

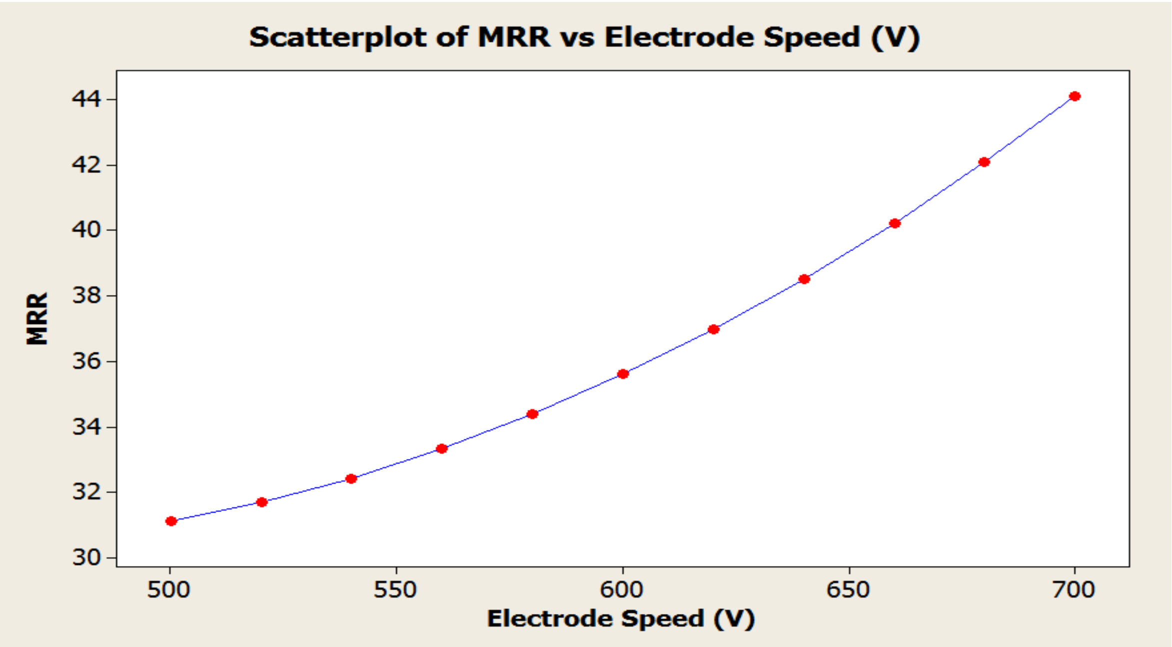


Figure: 1 Variation of MRR with Electrode Speed

This figure:1 shows that the Material Removal Rate (MRR) increases with electrode speed increases. In the higher electrode speed the increment of MRR is more than the lower electrode speed.

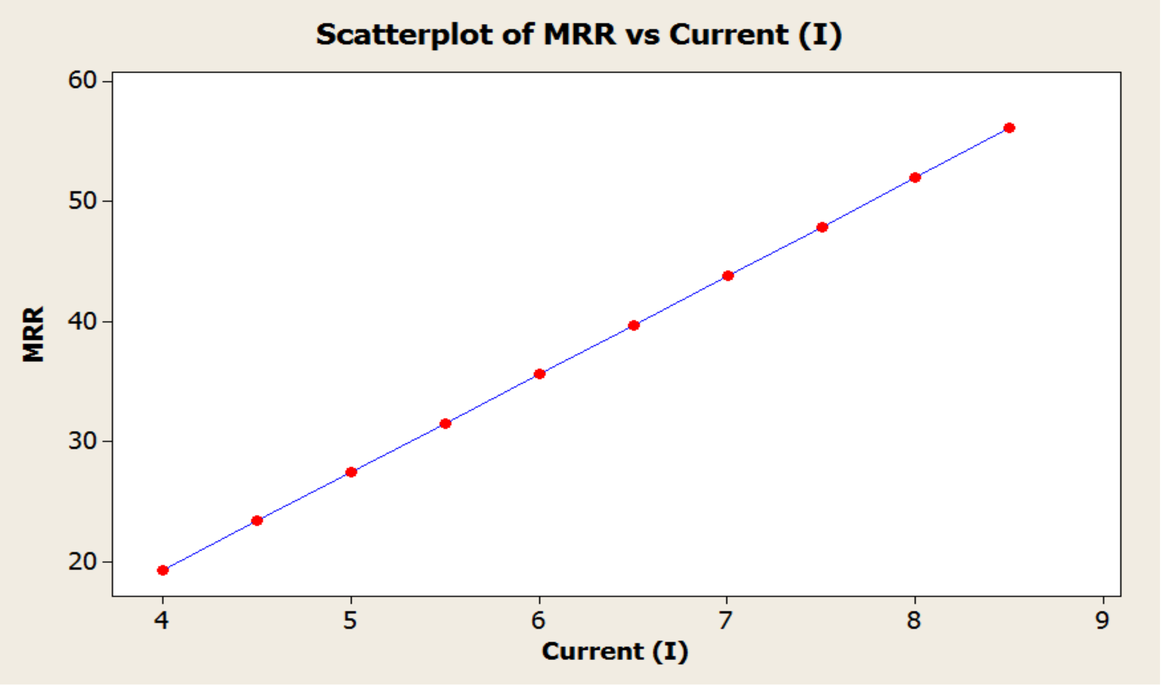


Figure: 2 Variation of MRR with Current

Figure:2 It shows that Material Removal Rate increases with Current increases linearly.

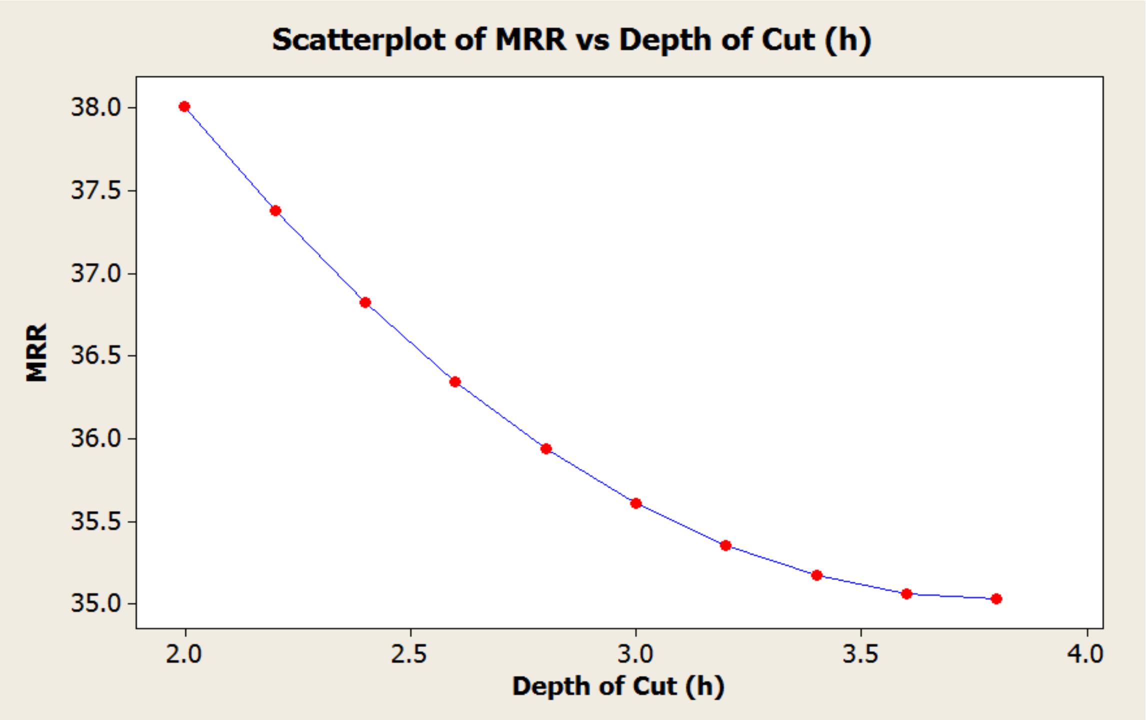


Figure: 3 Variation of MRR with Depth of cut

Figure:3 shows that Material Removal Rate (MRR) decreases with Depth of Cut increases. In lower depth of cut the decrement of MRR is more than higher depth of cut.

VIII. CONCLUSION

(1) In this work we have used different work piece and electrode with different combination as like (i) Aluminium with Copper (ii) Aluminium with Graphite (iii) Mild steel with Copper and (iv) Mild Steel with Graphite by varying three parameter Electrode Speed, Current, and Depth of Cut to find out the best combination of Work piece and Electrode for maximum MRR. Finally it can be concluded that the best combination for maximum MRR is Work piece Aluminium and Electrode Copper. The optimal value of control parameters for maximum MRR are 700 mm/min Electrode Speed, 8.5 amp Current and 3 mm Depth of Cut.

(2) In this experimental work we also concluded the variation of MRR with each control parameter are as follows:
  (a) From fig:1. It is concluded that the increase in Electrode Speed leads to increase in Material Removal Rate nonlinearly.
  (b) From fig:2. It is concluded that the increase in Current leads to increase in Material Removal Rate linearly.
  (c) And from fig:3. It is concluded that increase in Depth of Cut leads to decrease in the Material Removal Rate nonlinearly.

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