A COMPARATIVE EXPLORATION ON NUMERICAL AND EXPERIMENTAL MODELLING AND OPTIMIZATION OF MATERIAL REMOVAL RATE IN WIRE CUT EDM FOR EN-19 STEEL ALLOY

[1]Devara Venkata Krishna, [2]Preethi S, [3]Prasanna Srinivas R

[1,2,3] Assistant Professor, Department of Mechanical Engineering
Sri Venkateswara College of Engineering & Technology, R.V.S Nagar, Chittoor
[1]E-mail: venky364@gmail.com

Abstract: *At present scenario the demand for compact, integrated and small size products by a non-traditional process is increased because it gives high accuracy. Machining performance specifications of concern include minimum feature size, tolerance, surface finish, and material removal rate (MRR) and applications of advanced, which is very difficult to machine the materials. Wire cut EDM is an important manufacturing process that meets these demands and it has been widely used in production, aerospace/aircraft, medical, and virtually in all areas of conductive material machining. In the present research work, EN-19 steel alloy is used as work material. Experimentation on WEDM is conducted for modelling the material removal rate. The experimental results are used for determining the more dominant parameter on material removal rate (MRR) using optimization techniques. A numerical analysis is carried out using experimental conditions. In this, a model of work is analyzed and theoretical material removal rate is estimated using finite element analysis (FEA). A comparative study is made between the numerical and experimental results.*

Keywords: *Material Removal Rate (MRR), Wire Cut EDM (WEDM), Factorial Design, Voltage, Current.*

1. INTRODUCTION

WEDM is a thermo- electrical process in which material is removed by a series of sparks between work piece and wire electrode (tool). The part and wire are immersed in a dielectric (electrically non-conducting) fluid, usually deionised water, which also acts as a coolant and flushes the debris away. The material which is to be cut must be electrically conductive. CNC wire cut EDM machine puts impulse voltage between electrode wire and work piece through impulse source, controlled by servo system, to get a certain gap, and realize impulse discharging in the working liquid between electrode wire and work piece. Numerous tiny holes appear due to erosion of impulse discharging, and therefore get the needed shape of work piece. Electrode wire is connected to cathode of impulse power source, and work piece is connected to anode of impulse power source. When work piece is approaching electrode wire, in the insulating liquid and when a gap between them reaches to a certain value, insulating liquid will be broken through; very shortly, discharging channel forms, and electrical discharging happens. And release huge high temperature instantaneously, up to more than 10000 degree centigrade, the eroded work piece is cooled down swiftly in working liquid and flushed away. Manna and Bhattacharyya [1], carried out an experimental investigation to determine the parameters setting during the machining of aluminium-reinforced silicon carbide metal matrix composite (Al/Sic-MMC). Mathematical models relating to the machining performance such as MRR and Ra are established using the Gauss elimination method for the effective machining of Al/Sic-MMC. Y.S Liao et al. [2] investigated that WEDM machines have endorsed the pulse generating circuit using low power for high power and ignition for machining. Rathod V.T et al, [3] has used the finite element analysis for modeling MRR for AISI 304 using ANSYS software and effect of various process parameters on MRR has investigated. For optimization of process

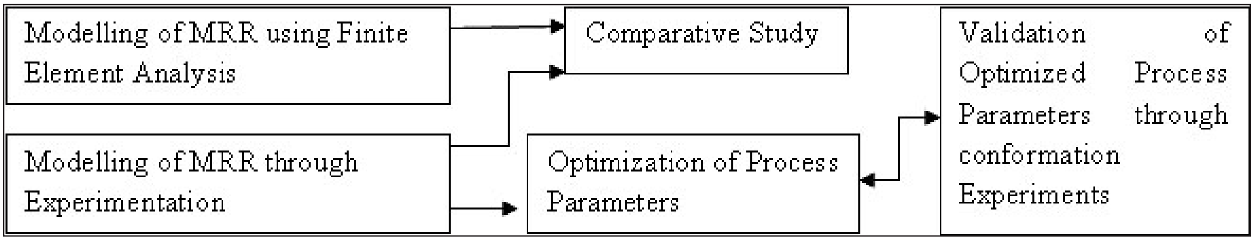


Fig 1. Methodology

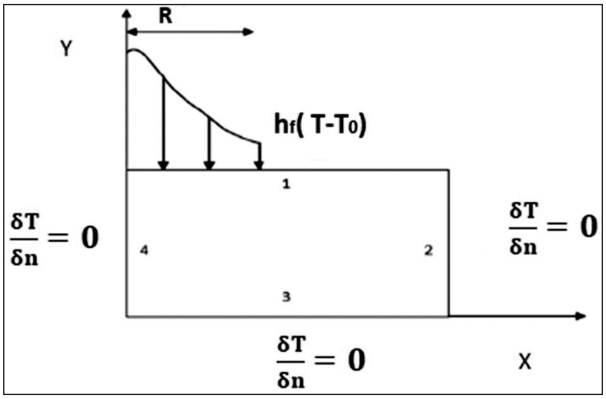


Fig 2. FEA Model for EDM Process

parameters, the research papers considered as reference papers listed in references from 4 to 11. From the literature, several researchers applied the Taguchi method and used it to optimize the performance parameters in WEDM process. In the Present work EN-19 steel alloy is considered for calculating the output parameters like surface roughness, material removal rate using factorial design with 5 levels and a comparative study is been made on output response between the experimental and finite element results.

2. METHODOLOGY

The objective of the project is, to model and optimize the material removal rate for EN-19 Steel alloy followed by numerical and experimentation. The proposed methodology is shown in the figure.1. EN19 Steel Alloy is used as Work piece Material at present work and the copper material is used as tool with a diameter of 0.25mm.

3. FINITE ELEMENT ANALYSIS

The finite element analysis through the ANSYS software is used for obtaining the material removal rate based on the experimental conditions. The work piece domain is considered to be axi-symmetric about z axis. The maximum heat input will be at centre top of the work piece. On the top surface, the heat transferred to the work piece is shown by Gaussian heat flux distribution. Heat flux is applied on centre top up to spark radius R, beyond R convection takes place due to dielectric fluids. As other positions are far from the spark location no heat transfer conditions have been assumed for them. For outer layer, as it is axis of symmetry the heat transfer is zero.

In mathematical terms, the applied boundary conditions are given as follows:

$\frac{K\delta T}{\delta Z} = Q(r)$, when R<r for center top /position;

Where, $Q(r) = \frac{4.45\ PVI}{\Pi R^2} e^{-4.5\left(\frac{r^2}{R^2}\right)}$, Gaussian distribution for heat flux (4).

$\frac{K\delta T}{\delta Z} = h_f(T - T_0)$, when R = > r for centre top position;

$\frac{\delta T}{\delta n} = 0$, at the outer layers. Where, h is heat transfer coefficient of dielectric fluid; Q(r) is heat flux due to the spark; T_0 is the initial temperature.

The typical boundary conditions used for modelling EDM process in FEA is shown in the figure. 2. The solid and Meshed model of a component of EN-19 steel alloy in ANSYS is shown in figure 3. The component is analysed in ANSYS software at various phases and Heat Distribution after the post processor phase is shown in figure 4.

4. MRR ESTIMATION FROM THE FEA

MRR per single spark = volume of the hemisphere

$= \frac{2}{3}\pi r^3$

Where, r = radius of the carter generated

From Finite element analysis for the given input parameters (given below), the radius of the carter (Fig. 5) is found to be 0.652 mm

5. EXPERIMENTATION

The cylindrical rod of the EN 19 steel alloy is cut into the small size using the hack saw. The rod is cut into the small cylindrical shape according

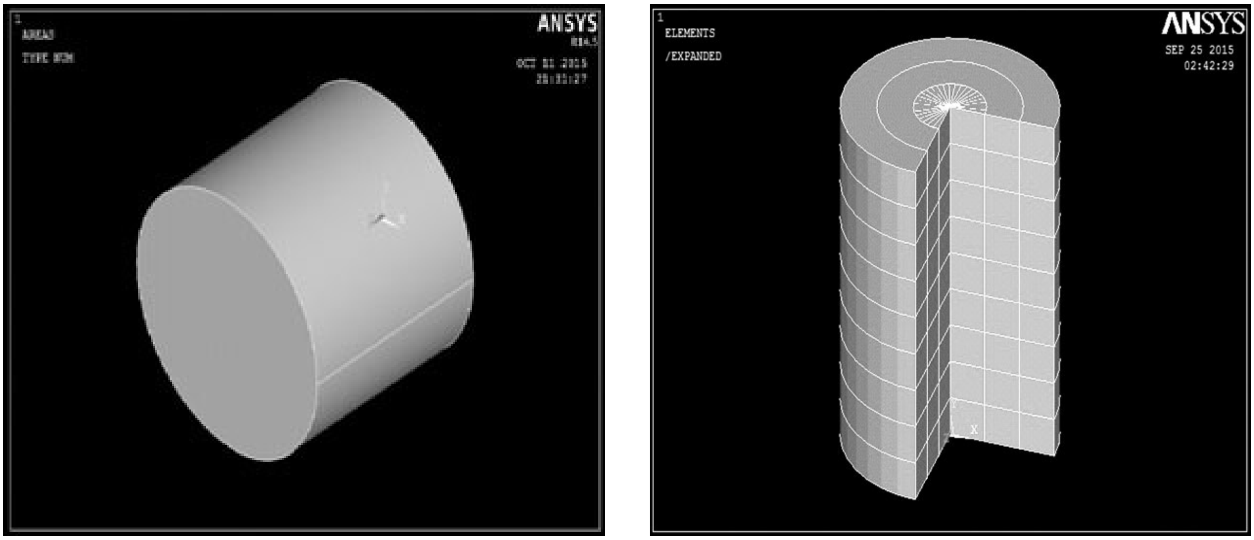


Fig 3: Solid and Meshed Model in ANSYS

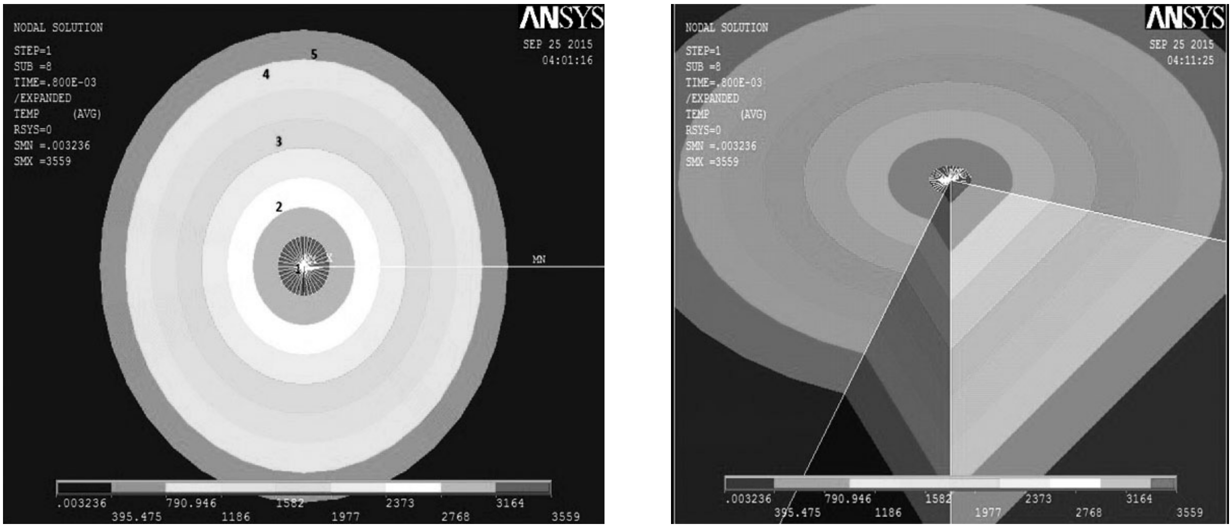


Fig 4. Heat Distribution after the Post Processor Phase & Sectional view of the Work Piece

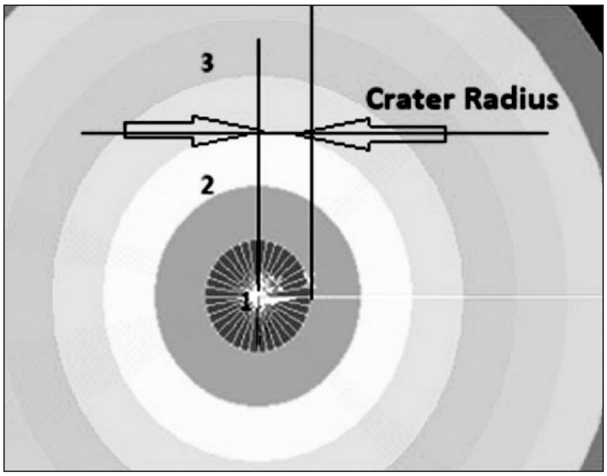


Fig 5. Crater Radius from FEA Results

Table 1: Specification of Dielectric Fluid Used

Appearance	Colourless
Density at 15 0C (g/cm3)	0.7884
Total Acid No. (mgKOH/g)	0.01
Viscosity, cSt at 40 0C	2.874
Flash Point (PM), oC	92
Distillation Range, oC	206

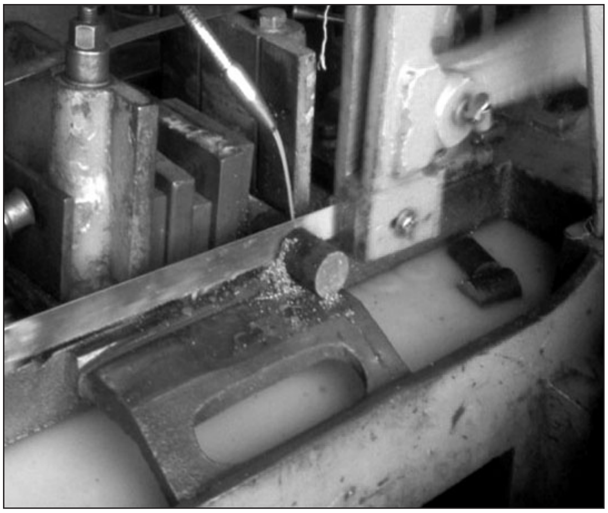


Fig 6. Cutting of EN19 Steel Alloy

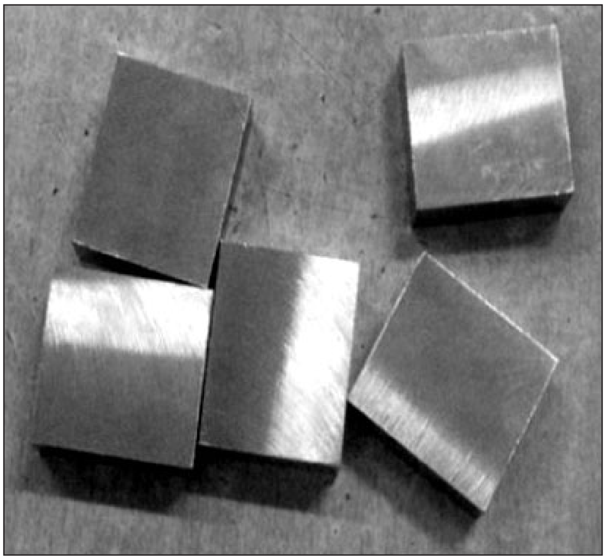


Fig 7. EN19 Steel Alloy Material in Square Shape

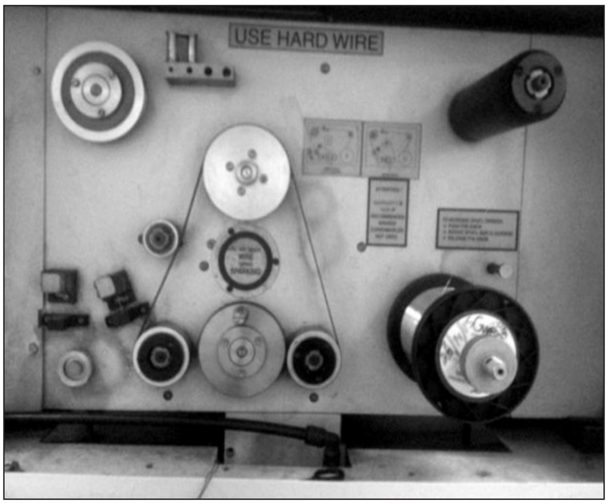


Fig 8. Dial Gauge for the Alignment

Fig 9. Wire Feed Mechanism

to the required height. The cutting of the EN 19 rod can be seen in the fig 6. The cylindrical work piece should be converted into the rectangular shape so using the slotter machine the cylindrical work piece is converted into the rectangle of the required dimension and it is shown in the fig 7. The dielectric fluid is selected for present work is DAPHNE CUT HL 25-S (Dielectric Fluid). The typical Specifications of dielectric fluid are listed in table 1.

5.1 Tool (Copper Wire)

Generally in the wire cut EDM, copper, tungsten, carbide, etc material is preferred to be selected as the tool. The tool used in Wire cut EDM should be electrically conductive. The wire is continuously fed across the work material so that the cutting of the work material takes place by the vaporization.

5.2 Wire Feed Mechanism

The roll of the copper wire is placed at one place with the help of the some rotating mechanism the wire is feed towards the work material. The wire of the diameter 0.25 mm is used for this purpose and the wire feed rate is maintained 3mm\s. The fig.8 shows the wire feeding for the machining. The wire feed, dielectric fluid pressure is set constant for all the experiments. The required input parameters which affect the MRR and the time required for cutting slot of 5×20×15 mm diameter is noted. The procedure is repeated by changing the parameters which affect the MRR for the five pieces of the sample work pieces. The initial and final weight (after cutting) of the work piece is found to be as 150 gm and 139 gm respectively with

Table 2: Experimental and Predicted MRR

S. No	T_{on} (ms)	T_{off} (ms)	IP (A)	VP (V)	Time (min)	Wire Feed (mm/s)	MRR (mm^3/ min)	Experimental MRR (mm^3/s)	Estimated MRR(mm^3/s)	Error
1	105	63	12	1	39	3	34.9	0.58	0.5449928	0.035
2	107	60	12	1	33	3	41.4	0.69	0.7249928	0.0349
3	109	57	11	1	24	3	57.3	0.96	0.9949928	0.034
4	111	54	11	1	19	3	72.7	1.21	1.1749928	0.035
5	113	51	11	1	15	3	92.4	1.54	1.5399928	7.2E-6

Table 3: Typical Different Combination from Factorial Design

T_{on}	T_{off}	I	Voltage	MRR (mm^3/s)	S/N Ratio	T_{on}	T_{off}	I	Voltage	MRR (mm^3/s)	S/N Ratio
3	2	3	1	1.03	0.29	3	5	1	2	1.36	2.66
3	3	1	2	1.14	1.17	5	1	2	2	0.93	-0.63
4	2	2	1	0.94	-0.51	4	4	3	2	1.34	2.56
3	2	1	2	1.04	0.32	2	3	2	1	1.05	0.42
3	3	3	1	1.14	1.14	3	4	2	2	1.25	1.95
2	5	2	1	1.26	2.04	5	1	2	1	0.84	-1.56
3	3	1	1	1.05	0.42	1	3	1	1	1.05	0.42

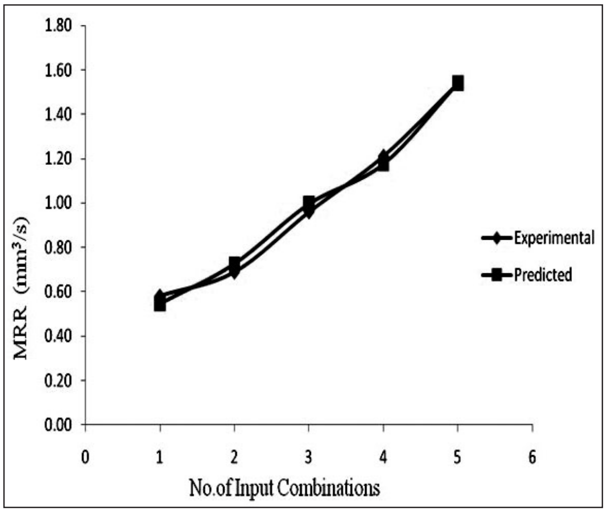


Fig 10. Comparison Between Exp. and Predicted MRR

weight of the scrap 11 gm for particular condition.

The experimental data from the wire cut EDM are listed below in the table 2. From these data listed during the experiment helps for finding the experimental MRR. The equation below is used for the estimation of the experimental MRR.

$$\text{MRR} = \frac{(\text{w}\backslash\text{p weight removed in gram}*1000)}{\left[\text{Density in}\frac{\text{gm}}{\text{cc}}\right]*[\text{Machining Time}]} - 1$$

The statistical equation (Equation.I) is generated from the MATLAB for predicting the MRR at various input conditions and comparison between the predicted and exp.MRR is shown in figure.10. The comparison of predicted and experimental is shown in the Table.2 and it is inferred that the variation in the estimated and experimental is considerably small and is shown in figure 10.

$\text{MRR} = (36.1224\ T_{on}) + (-35.9184\ T_{off}) + (-0.09\ I) + (0.095V)$ -- I

Where, MRR = material removal rate in mm^3/s;

T_{on} = pulse on time in sec;

T_{off} = pulse off time in sec;

I = current in amp;

V = voltage in volts

6. FACTORIAL DESIGN

A factorial design is type of designed experiment that lets you study of the effects that several factors can have on a response. When conducting an experiment, varying the levels of all factors at the same time instead of one at a time lets study the interactions between the factors. For the prepration of the different combination,

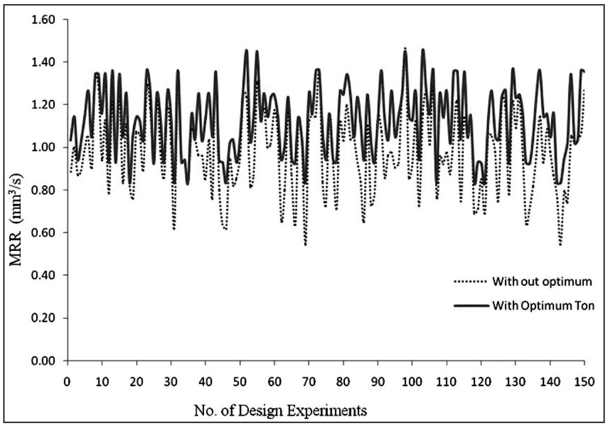


Fig 11. MRR With and Without the Optimized T_{on}

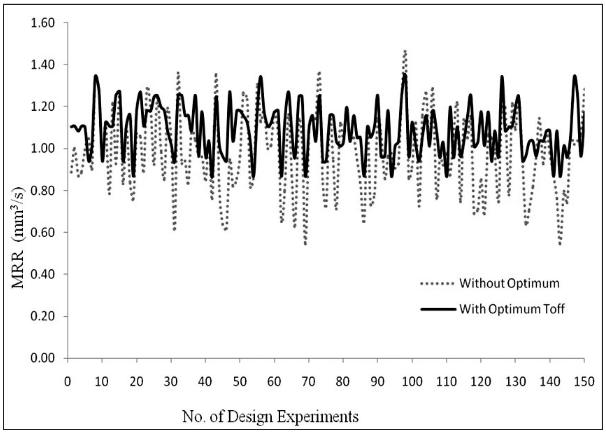


Fig 12. MRR With and Without Optimized T_{off}

the following conditions are used. Number of conditions = 4 (Pulse on time, pulse of time, current, voltage). The typical different combinations obtained from the full factorial design is shown in Table 3.

Number of levels

Pulse on time = 5; Pulse off time = 5; Current =3;Voltage= 2

From the Fig 11, it is inferred that the average MRR for optimum Ton is more compared to the without optimized Ton. MRR variation for optimized and without optimized MRR. The maximum MRR is found to be 1.54 mm3\s for the optimized pulse on time. From the figure 12, it is inferred that the average MRR for optimum Ton is more compared to the without optimized Ton. MRR variation for optimized and without optimized MRR. The maximum MRR is found to be 1.58 mm^3/s for the optimized pulse on time. From the Fig.13, it is inferred that the average material removal rate is more for the optimum current than the without optimized current. The optimized current is shown with dotted red colour and dark blue colour represent with optimized current. The Fig.14

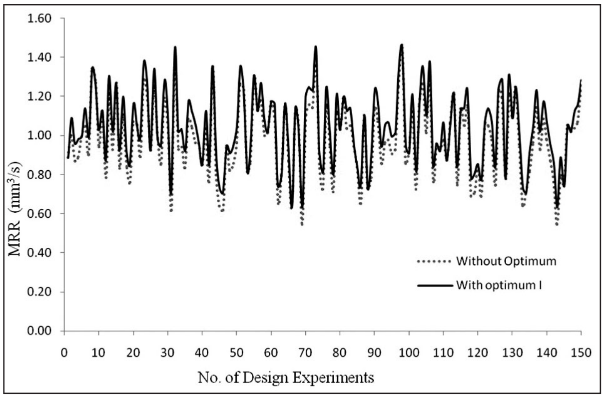


Fig 13. MRR With and Without Optimization of Current

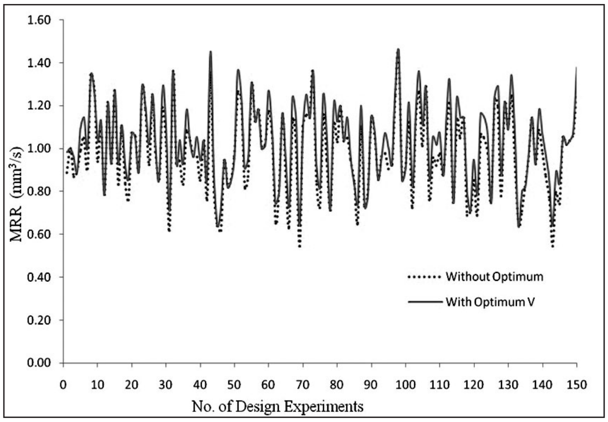


Fig 14. MRR With and Without Optimized Voltage

shows the MRR variation for optimized and without optimized voltage. The red dotted curve indicates the MRR without optimization and the green curve shows the MRR with the optimization. The voltage does not affect much in the MRR.

7. CONFIRMATION TEST FOR OPTIMUM PULSE ON TIME

From the combinations of factorial design, it is found that 0.113 sec is optimum pulse on time. In test I, the experiment has conducted by making the pulse on time as constant and other process parameters are varying. The experimental and predicted MRR followed by the amount of deviation (error) for same conditions are listed in Table 4. From the Table 4, it is inferred that the predicted MRR is not that much deviation from the experimental MRR. The mean experimental and predicted MRR are found to be 1.12 mm^3/s and 1.138 mm^3/s respectively. The mean error between the experimental and predicted MRR is found to be -0.018 mm^3\s. The conformation test for remaining conditions has conducted as same and results are found to be acceptable.

Table 4: Confirmation Test for Optimum Pulse on Time

S. No	T_{on}	T_{off}	I (amp)	Voltage	Water Pressure	Wire feed	Wire tension	MRR (mm^3/s)		Error
								Experimental	Predicted	
1	0.113	0.063	12	1	3	3	10	0.78	0.83	-0.05
2	0.113	0.06	12	1	3	3	10	0.92	0.94	-0.02
3	0.113	0.057	11	1	3	3	10	1.04	1.14	-0.1
4	0.113	0.054	11	1	3	3	10	1.32	1.25	0.07
5	0.113	0.051	10	2	3	3	10	1.54	1.53	0.01
							AVG	1.12	1.138	-0.018

Table 5: Percentage Improvement in MRR

Process Parameters (Optimum)	**% of improvement in MRR**
T_{on}	12.30
T_{off}	17.43
Current	9.270
Voltage	6.635

8. RESULTS AND DISCUSSIONS

Machining process is analyses through the finite element analysis and MRR is found to be 0.5804 mm3/s at particular condition. Experimentation is conducted on CNC wire cut EDM for machining EN-19 steel alloy and MRR is estimated based upon weight of the component before and after machining. Statistical MRR equation is developed for above process parameters using MATLAB software. Factorial design is used for finding the different combinations of input parameters for given conditions. Statistical equation is used for finding the MRR for different combination and an optimum input parameter set is determined based on Maximum MRR S/N ratio. Optimization process is continued for different combinations in which one of the parameter consists optimum constant values and remaining all are varying. Conformation experiment is conducted for validating the DOE results. From the optimization and experimental results, it is found that the following process parameters more influence on MRR. The improvement with respect to the process parameter is shown in Table 5.

9. CONCLUSION AND FUTURE SCOPE

From the discussion of results, it is found that the spark off time (T_{off}) and Spark on time (Ton) is influencing more on the MRR and MRR in improved by 17% and 12% respectively compared to without usage of optimum values of T_{off} and Ton. In this research work, only major four process parameters are taken into consideration for modelling MRR. It can be extended for optimizing the MRR by selecting minor process parameters such as wire feed, wire tension etc. It can be extended in terms of application to the advanced materials and dielectric fluids.

Acknowledgement

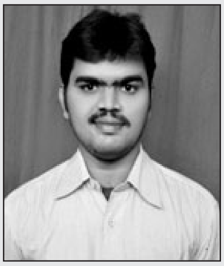
The authors wish to thank CITD (Central Institute of Tool Design)-MSME Tool Room, Hyderabad for benevolent permission to utilize the experimental setup of Wire Cut- EDM. The authors would like to express their sincere thanks to Sri Ravuri Srinivas garu, Vice Chancellor, RVS Institutions-SVCET Chittoor, for providing the necessary facilities and support to carry out the research work.

REFERENCES

1. A. Manna · B. Bhattacharyya, Taguchi and Gauss elimination method: A dual response approach for parametric optimization of CNC wire cut EDM of PRAlSiCMMC, Int J Adv Manuf Technol, 2006, 28: 67–75.
2. Y.S. Liao, Y.P. Yu, Study of specific discharge energy in WEDM and its application International Journal of Machine Tools and Manufacture, 44, 2004, 1373.
3. Mr. Rathod VT, Mr. Sayyad LK. in ijariie, Modeling Of Electro Discharge Machining in

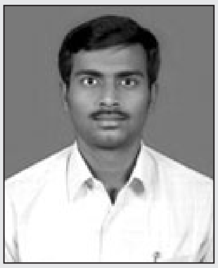
Aisi304 tMaterial, vol. 2, no. 6, June 2013, 1-9.

4. U K Vishwakarma , A Dvivedi and P. Kumar, FEA Modeling of Material Removal Rate in Electrical Discharge Machining of Al6063/SiC Composites", vol. 6, 2012-03-24 , 2012 , 1-5.
5. Ali MOARREFZADEH, Study of workpiece thermal profile in Electrical Discharge Machining (EDM) process, no. 2, vol. 7 , April 2012 , 4-9.
6. W. König, Machining of new materials, Annals CIRP, vol. 39 (2), 1990, 673–681.
7. P Narender Singh, Electric discharge machining of Al–10%SiCP as-cast metal matrix composites, 'Journal of Materials Processing Technology', vol. 155–156, 2004, 1653–1657.
8. D. Kanagarajan, R. Karthikeyan, K. Palanikumar and J. Paulo Davim, Optimization of electrical discharge machining characteristics of WC/Co composites using non-dominated sorting genetic algorithm (NSGA-II), 'International Journal of Advance Manufacturing Technology', vol. 36, 2008, 1124– 1132, DOI 10.1007/s00170-006-0921-8.
9. D. D. Dibitono and P. T. Eubank, Theoretical model of the electrical discharge machining process I. A Simple Cathode erosion model, Journal of Applied Physics, vol. 66, 1989, 4095-4103.
10. M. R. Patel, B. A. Maria, P. T. Eubank and D.D. Dibitonto, Theoretical models of the electrical discharge machining process. II. The anode erosion model, 'Journal of Applied Physics', vol. 66/9, 1989, 4104.
11. S. K. Sahu, Saipad Sahu, A comparative study on material removal rate by experimental method and finite element modelling in electrical discharge machining, vol. 4, no. 5, September - October, 2013, 173-181 ◘



Devara Venkata Krishna is presently working as Assistant Professor, Department of Mechanical Engineering, Sri Venkateswara College of Engineering & Technology (Autonomous), Chittoor, Andhra Pradesh. He graduated in Mechanical Engineering from Jawaharlal Nehru Technological University College of Engineering Anantapur, Pulivendula. He received his post graduation in M.E Computer Integrated Manufacturing from PSG College of Technology, Coimbatore. He has 4 years of teaching experience. He has published 5 international papers. His area of interest is Metal cutting and machining, CNC machine tools, Thermo mechanical deformation of Machine Tool parts, and Additive Manufacturing.

S Preethi is presently working as Assistant Professor, Department of Mechanical Engineering, Sri Venkateswara College of Engineering & Technology (Autonomous), Chittoor, Andhra Pradesh. She graduated in Mechanical Engineering from Sri Venkateswara College of Engineering & Technology, Chittoor. She obtained her post graduation (M.Tech) in Machine Design from Dr. MGR research and educational University, Chennai. She has 4 years of teaching experience. Her area of interest is Design for manufacturing, Optimization Techniques and Total quality management.



R Prasanna Srinivas is presently working as Assistant Professor, Department of Mechanical Engineering, Sri Venkateswara College of Engineering & Technology (Autonomous), Chittoor, Andhra Pradesh. He graduated in Mechanical Engineering from Sri Venkateswara College of Engineering & Technology, Chittoor. He received his post graduation in M.E CAD from Adhiyamaan college of Engineering, Hosur. He has 5 years of teaching experience. His area of interest is Computer Aided design, composites manufacturing, and CNC machine tools.