Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management
Bali, Indonesia, January 7 – 9, 2014

Modeling and Optimization of WEDM Parameters for Surface Finish Using Design of Experiments

I. K. Chopde
Visvesvaraya National Institute of Technology
India

ChandrashekharGogte
Marathwada Institute of Technology
Aurangabad, India

DhobeMilind
P.E.S. College of Engineering
Aurangabad, India

Abstract

Non conventional machining processes like electro discharge machining (EDM) and wire electro discharge machining (WEDM) plays important role in precision manufacturing. In wire EDM it is very difficult to choose correct combination of machining parameters and material for various responses like surface roughness, MRR etc. Cryogenic treatment is generally used as secondary treatment to enhance the hardness and wear properties of tool steels. Obtaining better surface finish in cryo treated tool steels by conventional machining is a difficult task. In this paper effect of WEDM parameters on surface finish of cryo treated AISI D2 tool steel are investigated. Taguchi standard orthogonal array was chosen for designing and conducting the experiments. The surface roughness was considered as response for improving surface quality. The Analysis of variance (ANOVA) was done to determine the optimum machining parameter combination for better surface roughness. The regression analysis method was used to formulate the mathematical model. Based on optimized parameter combination experiments were conducted to confirm the effectiveness of the proposed model. The experimental result shows that the model suggested by the Taguchi's method is suitable for improving the surface quality by reducing the surface roughness.

Keywords
Tool steel, Cryo treatment, Taguchi method, WEDM, ANOVA, surface roughness.

1. Introduction

Non-conventional machining processes like Electro discharge machining (EDM) and wire electro discharge machining (WEDM) plays important role in precision manufacturing industries like automobile, aerospace and sheet metal industries. Especially for the manufacturing of punch, dies, jigs and fixtures. Traditional machining processes are easy to implement and execute over non conventional processes, however it is very difficult to machine complicated and complex shapes and hard materials like tool steels. Most of the times the machine tool tables provided by manufacturer do not meet the machining requirements of particular material (Mannaand Bhattacharya 2006). Therefore, in many cases wire electro discharge machining plays an important role in machining complicated and intricate shapes in hard tool steels.But it needs special attention in improving the machining quality and efficiency. Hence for improving the machining efficiency and surface quality necessary attention should be given to develop some methodology and model to predict optimum combinations of machining parameters accurately. In wire EDM it is very difficult to choose correct combinations of machining parameters and materials for various responses like surface roughness (Pujari 2011), MRR(Khan 2008) , white layer (Puri and Bhattacharyya 2005), heat affected zone (Lee 2008), etc. Taguchi's robust Design of Experiments has been used in number of applications to obtain the optimum parameter combinations for desired responses (Esme 2009, Mahapatraand Patnaik 2007, Pujari et al.2011).

Many researchers (Khan 2008, Lee 2008, Das 2009, Pujari et al.2011) have tried to investigate and improve the surface qualityof different materials namely H13, AISI D1, D2, STD 11, aluminum alloy, alloy steels etc. It is noted that the rigidity and higher hardness are significant properties affecting the surface roughness and wear. Therefore high hardness and rigidity material will produce finer surface and low rigidity material like Aluminum alloys produce high surface roughness (Lee2008, Daset al. 2009).

Khan (2008) investigated the Material removal rate during EDM of aluminum and mild steel using copper and brass electrodes. Aluminum has shown highest material removal rate due to high thermal conductivity and low melting point when compared to steel having high melting point and low thermal conductivity. It is well known fact that a good surface quality and high material removal rate cannot be achieved simultaneously. Ramkrishanan and Karunamurthy (2010) suggested a mathematical model based on response surface methodology to predict the performance characteristics of the WEDM process. Further Taguchi's robust design approach was used for optimization of MRR, SR and wire wear.

Lee (2008) has optimized the wire EDM parameters on various tool steelsand other materials under different heat treated conditions. Whereas Chakravorty (2012) tried to correlate and optimize the responses of EDM process.Das et al. (2009) has conducted a series of wear tests on AISI D2 steel samples subjected to cryo treatment at – 196^{O} C for different time periods. Various tests were conducted at different loads and sliding velocities for evaluating the critical period of cryo treatment for achieving the good wear resistance properties.Based on wear debris pattern and worn out surface morphologies,it is suggested that the AISI D2 tool steel gives better wear resistance when cryo treated for 36 hrs at -196 ^{O} C(Das et al. 2009).

In literature the researchers have considered number of parameters, however out of these parameters the pulse on time, pulse off time, servo voltage and spark current are major parameters affecting response quality (Fuzhu Han 2007, Pujari et al.2011) hence considered in this paper. Taguchi's design of experiments (DOE) technique is used for preparing and conducting efficient, less time consuming and more accurate experiments. The data obtained from various experiments is analyzed in three different ways. Firstly, the significant factors were determined using analysis of variance (ANOVA). Secondly, Regression analysis model is used to establish a relationship between selected parameters and response variables.Thirdly, Signal to noise ratio is calculated and analyzed to find out the optimal parameter settings and their levels. Finally, confirmation experiments were conducted with the optimized parameter combination to identify the effectiveness of the proposed method.

Nowadays the industries has started using cryo treated AISI D2 tool steel for manufacturing dies and punches because of its improved wear resistant characteristics. The tool steel become sufficiently hard and tough when hardened and cryo treated (Li et al. 2010). It has been referred that the cryo treatments of AISI D2 tool steel improves wear characteristics due to change in micro structural properties of steel (Das et.al 2009).No evidence has been found in any literature on optimization of WEDM parameters for cryo treated AISI D2 tool steel. Therefore, it is tried to study, investigate and optimize the effect of WEDM parameters on cryo treated tool steel. For the experimental work, the cryogenic treatment was sequenced with the heat treatment based on the references (Das et al. 2009).

2. Experimental

The work piece material considered is AISI D2 tool steel having the chemical composition as C-1.05%, S-0.05 %, Cr-11.5 %, V-0.25%, Mg- 0.05%. The work pieces of 50 X 50 X 10 mm size were prepared by milling and then cryo treated as per heating and cooling cycle shown in the Figure 1. The cryo treated samples were further WEDMed for the size 10 X 10 X 5 mm using Electronica make "SPRINT CUT CNC" wire cut Electro Discharge Machine. The surface roughness of machined surface was measured in forward and transverse direction using a portable surface roughness measuring instrument "Surfcon 480 A". The procedure was repeated for 5 times at different locations to obtain the average value. The average values of surface roughness for each experiment performed are presented in Table 2. For all the measurements the cut-off length of stylus was 0.8 mm at a speed of 0.3 mm/sec as per DIN EN ISO 3274:1998.

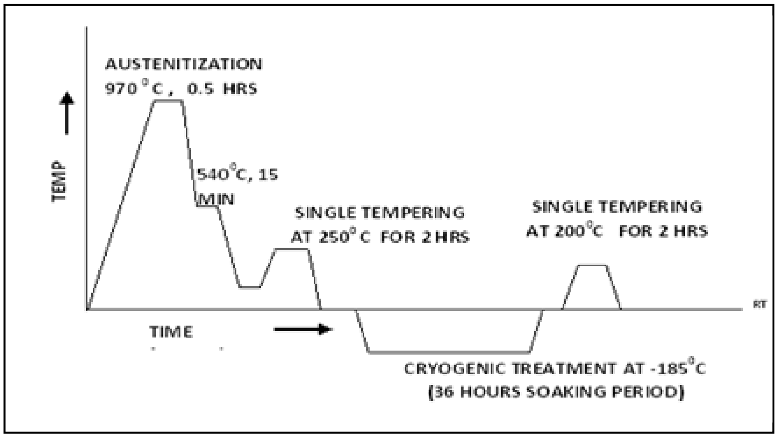


Figure 1: Sequence of conventional and cryogenic treatment for AISI D2 tool steel.

3. Design of Experiments

The four major WEDM parameters and their levels considered for the experimentation arepulse on time, pulse off time, peak current as shown in Table 1. The other parameters and their values kept constant for all trials are Wire Feed rate W_f= 5, Wire tension Wt= 9, Servo fed Setting S_f= 2100, Flushing pressure of dielectric fluid Wp= 1. Dielectric fluid conductivity S= 12, Wire Dia. = 0.25mm, Supply Voltage Vp = 2 units.

Table 1: Wire EDM Parameters and their levels.

Sr.No	Parameter	Symbol	Level 1	Level 2	Level 3
1	Pulse On time (μ sec)	T_{on}	105	115	125
2	Pulse Off time(μ sec)	T_{off}	40	50	60
3	Spark gap Voltage (Volts)	S_v	15	30	45
4	Peak current (Ampere)	I_P	70	90	110

As the main factors and their effects are of interest, these factors are considered and their interactions are excluded from the data analysis. Therefore, the degree of freedom (DOF) for this experimentation was calculatedusing equation (1):-

DOF = (no. of factor levels -1) X (no. of factors) (1)

DOF = (3-1) X 4 = 2X4= 8.

An orthogonal L_9 array was selected based on DOF, number of parameters and their levels.Table 2 shows the various experiments assigned as per orthogonal array L_9 along with the data acquired for surface roughness (Ra) and (S/N) Ratio.The Taguchimethod is used to measure the quality by calculating signal(S) to Noise (N) ratio (i.e. S/N ratio) and the effect of many factors simultaneously on machining performance.The advantage in using orthogonal array is that it requires lessnumber of trialscompared to full factorial experiments.Thereby it reduces the time required for experimentation, evaluating machining performance and deciding significant and non significant parameters.

Table 2: Experiments designed using L9 orthogonal array

Sr.No	T_{on}	T_{off}	S_v	I_P	SR	S/N ratio
1	105	40	15	70	1.337	-2.5226
2	105	50	30	90	1.154	-1.2441
3	105	60	45	110	1.38	-0.7405
4	115	40	30	110	2.99	-9.8581
5	115	50	45	70	2.32	-5.7783
6	115	60	15	90	2.65	-9.2838
7	125	40	45	90	2.78	-7.7335
8	125	50	15	110	3.21	-10.0403
9	125	60	30	70	2.95	-7.4361

4. Data Analysis

4.1. Analysis of Variance (ANOVA)

The Analysis of Variance helps to identify the significant and non significantparameters affecting the performance and can be used to control the process variation. Before ANOVA analysis the assumptions made for the analysis can be verified by Anderson (AD) statistics.The normal probability plot of residuals for surface roughness and p-value are shown in the Figure2. Normal probability plot is nothing but a graph of the cumulative distribution of the residuals on the graph paper with the scaled ordinate so that a straight line can be obtained for the cumulative normal distribution.The p value (0.293) is higher than α –level of confidence (0.05), hence it can be concluded that the residual error is normally distributed. This shows that the error normality has been proved, so the ANOVA analysis can be performed and the conclusions made on the basis of its table will be correct.

The ANOVA Table3 shows the effect of individual parameters and Fisher test values for surface roughness of AISI D2 tool steel. Here D.F. is the degree of freedom, SS is the sum of square, V is the variance, F is the Fisher value and % P is the percentage of contribution. Based on ANOVA calculations and P values it is observedthat, the parameterT_{on} (77.78 % contribution) is most significant, I_p(11.70 % contribution) and S_v (9.18% contribution) are significant and T_{off}(1.32% contribution) is less significant on performance measures as shown in Figure 3.

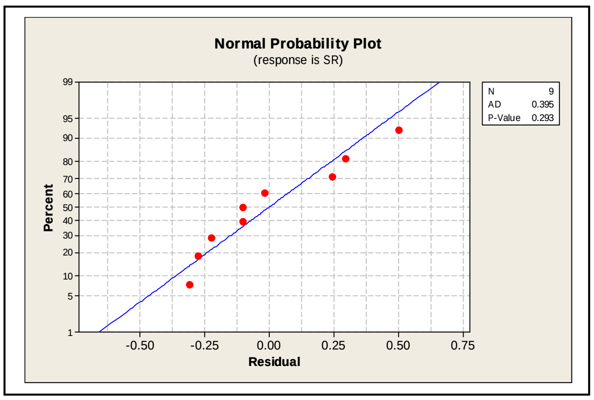


Figure 2: Normal probability plot of residuals for surface roughness

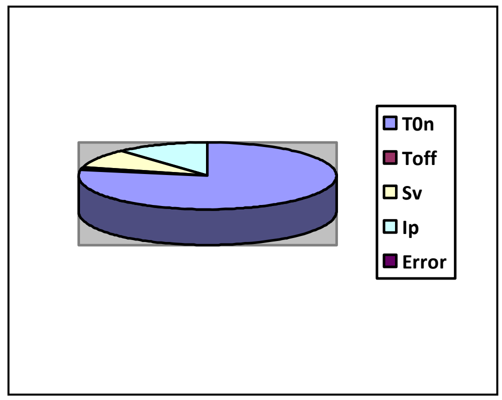


Figure 3: Percentage contribution of parameters

Table 3: ANOVA Table for Surface Roughness

Sr. No	Parameters	DF	SS	V	F	% P
1	Ton	1	4.278	2.139	10.50	77.78
2	Toff	1	0.073	0.036	0.04	01.32
3	Sv	1	0.505	0.253	0.30	09.18
4	Ip	1	0.644	0.322	0.40	11.70
5	Error	4	1.10291	0.27573		0.02
6	Total	8	5.5			

4.2. Signal to Noise Ratio

The variations caused in surface roughness during the repetitive experiments areexpressed by calculating the S/N ratio value. Out of all available options of the S/N ratio "smaller the better" is considered for the surface roughness.Equation (2) givesthe S/N ratio for surface roughness as the logarithmic transformation of loss function, where it is denoted by "η" and is expressed in dB.

$$\eta = -10 \log 1/n \sum^{n}_{i=1} y^2 \quad (2)$$

The surface roughness and S/N values calculatedfor the experiments designed and conducted on cryo-treated AISI D2 tool steel using L9 orthogonal array are shown in Table 2. Table 4 shows the mean S/N ratio values of surface roughness for each parameter level and are graphically represented in Figure 4.

Table 4: Mean S/N ratio for SR at each level of all the parameters

Sr. No	Level	T_{on}	T_{off}	S_v	I_p
1	1	-2.188	-6.972	-7.039	-6.410
2	2	-8.429	-6.228	-6.718	-6.197
3	3	-9.469	-6.886	-6.329	-7.480

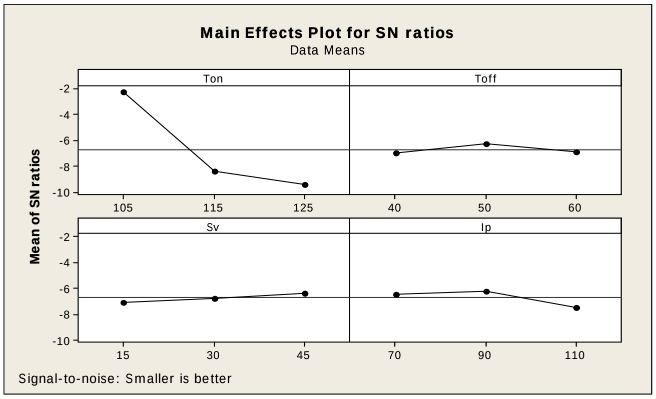


Figure4: Mean S/N ratio for SR at each level for all the parameters

Generally the S/N ration are selected based on their characteristics; and a higher value of S/N represents the better performance. Therefore, out of all the three levels, the optimal level parameters are selected corresponding to the higher values of S/N ratio. The optimal parameter combination obtained is $A_1B_2C_3D_2$ (Table 4) for getting optimum surface roughness. At this optimal parametric combination a separate experiment was conducted and the improved surface roughness obtained was 1.339 µm. This value is 1.64times less than the initial surface roughness (2.209 µm) obtained at $A_2B_2C_2D_2$.The S/N ratio has also improved by 4.322dB. This is an indication of improvement in machining performance.

5. Mathematical Model

Multiple regression (MLR) modelsare suitable to formulate the complicated problems with many dependant variables and independent variables within certain range. It gives the relationship between independent variables and response. In this paper the simple regression analysis is carried out to estimate the surface roughness as aresponse. The mathematical model suggested is as given in Equation 3.

$$SR= -7.79261+ 0.08448* T_{on} - 0.00212* T_{off} - 0.00797 * S_v + 0.00811* I_p \quad (3)$$

Figure 5 shows the comparison between experimental SR with predicted SR values as per suggested mathematical model. There is close agreement between experimental values and the predicted values of surface roughness. Thus the suggested mathematical model is very much useful for predicting the surface roughness of cryo treated AISI D2 tool steel in WEDM.

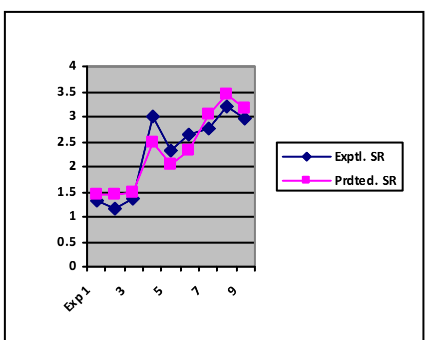
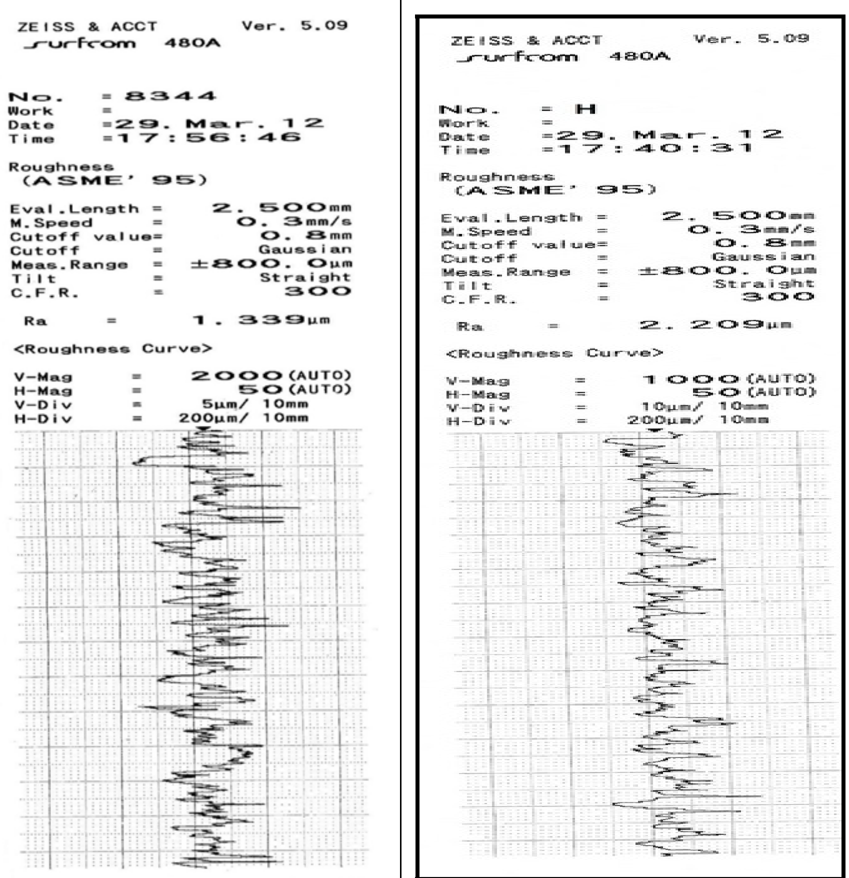


Figure5: Comparison between Experimental and Predicted SR



a) Optimum Condition

b) Initial condition

Figure 6: Surface Roughness graphs for experimental conditions a & b

6. Confirmation Experiment

The results obtained by Taguchi's design of experiments analysis are to be validated by conducting the confirmation experiments. The experiments were conducted as per the optimized levels of machining parameters. The last step in the process is to verify improvement in performance characteristics. This is done by comparing the predicted values and theexperimental results obtained with optimum parameters.The predicted S/N ratio of machining parameters at optimum level can be calculated by Equation (4)

$$\eta_{opt} = \eta_m + \sum_{j=1}^{k} (\eta_j - \eta_m) \quad (4)$$

where:η_{opt}The predicted optimal S/N ratio , η_m -Total mean of the S/N ratios,
η_jMean S/N ratio at the optimal levels and k -Number of main design parameters.

Table 5 gives the comparison between predicted values of surface roughness and S/N ratio calculated using developed mathematical model along withthe actual experimental results. The S/N ratio has been improved by 4.32 dB from the initial machining parameter settings ($A_2 B_2C_2D_2$) to that of optimum machining parameter combination ($A_1B_2C_3D_2$). The surface roughness is decreased by 1.64 times. This shows that the approach used in this paper is justified and provides corrective indication of improvement in surface roughness considerably.

When the SR values predicted by proposed mathematical model are compared with respect to experimental values at optimum and initial conditions the error observed is of 0.01% and 0.098% respectively. This indicates close agreement between two values. Thereby it confirms the validity in applying the Taguchi method for selecting and optimizing machining parameters for improving the machining performance of cryo treated AISI D2 tool steel. The surface roughness graphs obtained with initial and optimum experimental conditions are shown in the Figure 6.

Table 5: Comparison between mathematical model results and experimental results

Sr. No.	Description	Experimental model		Mathematical model	
		SR µm	S/N ratio	SR µm	S/N ratio
1	Initial condition	2.209	-6.8725	2.3074	-7.262
2	Optimum condition	1.339	-2.535	1.34	-2.54
3	Improvement	1.64times	4.322dB	0.967times	2.85dB

7. Result and Discussion

Based on ANOVA and S/N ratio calculations, it is observed that the parameters T_{on} is the most significant factor (77.78 % contribution), $I_P$and $S_V$are significant factors (11.70 % & 9.18% contribution respectively) whereas T_{off} is the least significant factor (1.32% contribution) for surface roughness.The product of pulse on time and current is known as discharge energy. With increase in Ton and I_p the discharge energy increases. This increases the surface irregularities due to the increased melting and re solidified metal. This forms the large debris on the surface which cannot be machined by wire as it moves forward and increases the roughness. Soin order to compensate the higher current, its time period should be minimized and the frequency of higher density spark can be increased by keeping T_{on} and T_{off} values at minimum level. This helps in continuous machining and avoids the formation of debris and re solidification of molten metal.Thus, the surface qualityis improved by reducing the roughness.Here, the reduced surface roughness is obtained at T_{on} = 105, T_{off}= 50 and I_p = 90.

The spark gap voltage is related to the generation of electric field in the gap. The increase in spark voltage means generation of strong electric field with the same gap. This helps to discharge the spark more easily forcontinuous removal of material with each discharge and thereby reduces the roughness. Since the AISID2 tool steel is tough and hard enough due to cryotreatment higher values of S_v are preferred for generation of strong spark for easy machining.The minimum surface roughness is obtained at S_v=45.

Conclusion

In this research work the effect of pulse on time, pulse off time, sparkgap voltage and peak current are experimentally investigated in wire electro discharge machining of cryo treated AISI D 2 tool steel. The factor Pulse on time (Ton) is the most significant factor and Spark gap voltage (S_v) and Peak current (I_p) are significant factors where as Pulse off time (T_{off}) is the least significant factor in improving the surface roughness.The S/N ratio analysis is useful for selecting the optimum parameter level combination ($A_1B_2C_3D_2$.) for achieving the minimum surface roughness in WEDM.The mathematical model developed using linear regression method and analysis of variance (ANOVA) confirms the suitability of model in predicting the surface roughness in WEDM of cryotreated AISI D2 tool steel. The confirmation test results and improved S/N ratio shows that the surface quality of cryotreated AISI D2 tool steel can be improved by reducing surface roughness using present statistical analysis.The proposed regression model has successfully predicted the result which matches with the experimental values. Based on experimental results and the present analysis it can bestated that the optimum parameter combination and developed mathematical model is useful for predicting and machining hard cryo treated tool steel materials with reduced surface roughness. Thereby, it confirms the usefulness of cryo treated AISI D2 tool steeland WEDM formanufacturing dies and punches in sheet metal industries.

Acknowledgement

Authors express their sincere thanks to the Metallurgy and Material science Department, VNIT, Nagpur, Marathwada Institute of Technology, Aurangabad, Department of Engineering Metallurgy, Government College of Engineering, Pune, Vision Tool Tech., Avinash Enterprises (Tool Design and Manufacturing), Sidheshwar wire cut and Shree Saigan Industries MIDC Waluj, for supporting and extending testing and machining facilities.

References

1) AminollahMohammadi,AlirezaFadaeiTehrani, EshanEmanian, DavoudKarimi, A new approach to surface roughness and roundness improvement in wire electrical discharge turning based on statistical analysis, *International Journal of Advance Manufacturing Technology*, vol. 39, pp. 64-73, 2008.
2) Choi K.K., Nam W.J. and Lee Y.S., Effect of hat treatment on the surface of a die steel STD 11 machined by WEDM, *Journal of Material processing and technology*, vol. 201, pp. 580-584, 2008.
3) Chakravorty R.,Susanta Kumar G.,Chakraborty S., optimization of Correlated Responses of EDM Process. *Materials and Manufacturing Process*, vol. 27, pp. 337-347, 2012.

4) Das D, Dutta A.K., Ray K.K., Influence of varied cryo treatment on wear behavior of AISI D2 Tool steel, *Wear*, vol. 266, pp. 297- 309, 2009.
5) Das D, Ray K.K. Dutta A.K., Influence of sub- zero treatment on the wear behavior of die steel, *Wear*, vol. 267, pp. 1361- 1370, 2009.
6) Esme U., Sabas A.and Kahraman F., Prediction of surface roughness in wire electrical discharge machining using design of experiments and neural network, *Iranian Journal of science and technology, Transaction B. Engineering*, vol. 33, pp. 231-240, 2009.
7) Fuzhu Han, Jun Jiang, Yu. Dingwen, Influence of machining parameters on surface roughens in finish cut of WEDM, *International Journal of Advance Manufacturing Technology*, vol. 34, pp. 538-546, 2007.
8) Khan A.A., Electrode Wear and material removal rate during EDM of aluminum and mild steel using copper and brass electrodes,*International Journal of Advance Manufacturing Technology*, vol. 39,pp. 482-487, 2008.
9) Li S, Xie Y, Wu X Hardness and toughness investigations of deep cryogenic treated cold work die steel. *Cryogenics* vol. 50, no.2 pp.89–92, 2010.
10) Manna A and Bhattacharya B, Taguchi and gauss elimination method: a dual response approach for parametric optimization of CNC wire cut EDM PRAISiCMMC , *International Journal of Advance Manufacturing Technology*, vol. 28, pp. 67-75,2006.
11) Mahapatra S.S., Amar Patnaik, Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method, *International Journal of Advance Manufacturing Technology,* vol.34, pp. 911-925, 2007.
12) PujariSrinivasRao, KoonaRamji, Beelasatyanarana, Effect of Wire EDM conditions on surface roughness: A parametric optimization using Taguchi Method, *International Journal of Advanced Engineering Sciences and Technologies*, vol. 6, no.1, pp. 41-46, 2011.
13) Puri A.B., Bhattacharyya B., Modeling and analysis of white layer depth in a wire-cut EDM process through response surface methodology, *International Journal of Advance Manufacturing Technology*, vol. 25 pp. 301–307, 2005.
14) Rajurkar KP, Pandit SM, Recent progress in electrical discharge machine technology and research, *proceedings of Manufacturing International* 1998 Atlanta, Georgia, April, vol. 1, pp. 219-226,1998.
15) Ramkrishanan R, Karunamurthy L., Surface roughness model for CNC wire electro discharge machining, *Journal ofManufacturing Technology Today,* vol. 3, no. 5, pp. 8-11, 2010.
16) RossP.J.,Taguchi techniques for quality engineering, McGraw-Hill Book Company, New York, 1996.

Biography

Dr. I. K. Chopde is currently working as full-time Professor of Mechanical Engineering at "Visvesvaraya National Institute of Technology"; an Institute National Importance in India Mr. Chopde has a PhD in Mechanical engineering. He has more than 40 years of experience of Teaching & Research in Mechanical Engineering. He has worked as Dean; Faculty of Engineering & Technology and member of Executive Council at Nagpur University. Prof. Chopde has worked as Head & Chairman Department of Mechanical Engineering. He has worked as Dean (Administration) of VNIT from 2002 to 2006; during its transition from affiliated college to A Deemed University. He is a life Fellow of The Institution of Engineers (India).He has presented number of research papers in National and International Conferences organized in Australia, China, USA, Russia and India. He has taught various courses in Engineering and Management at graduate & post-graduate level and guided students for research leading to degrees like M.Tech., Ph.D and M.B.A.

Chandrashekhar Gogte is currently a full time Professor and Principal of The Marathwada Institute of Technology, Aurangabad, India. Dr. Gogte holds a Bachelor of Engineering degree in Metallurgy and Materials Engineering, Master of Technology in Alloy Steels and Ferroalloys technology, and Doctorate from VNIT, Nagpur. His doctoral research is in the area cryogenic treatment of tool steels and has several national and international publications to his credit. He has undertaken number of projects in collaboration with the institutes of national repute and currently working on a joint project on friction stir welding of age hardenable aluminum alloys with the Singapore Institute of Manufacturing Technology, Singapore. He is also an expert for the evaluation of projects for Department of Science and Technological evaluations of Kazakhstan. He is vice chairman of the Indian Institute of Metals, Pune chapter in India.

Dhobe Milind is currently a full time Associate Professor and Head of Mechanical Engineering Department, P.E.S. College of Engineering, Aurangabad, India. Mr. Dhobe holds a Bachelor of Engineering degree in Mechanical Engineering and Master of Engineering in Mechanical Design from Dr. Babasaheb Ambedkar Marathwada University, Aurangabad. He is a life Fellow of The Institution of Engineers (India).He has presented number of research papers in National and International Conferences organized in Singapore, USAand India. He has taught various courses in Engineering and Management at graduate & post-graduate level and guided students for research leading to degrees like B.E. and M.E. He has undertaken number of projects in collaboration with the industries from this area.