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USA CODEN: JETRB4

Journal of Engineering And Technology Research, 2014, 2 (6):43-52

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PARAMETRIC OPTIMIZATION FOR MRR AND SURFACE ROUGHNESS IN WIRE EDM OF D2 STEEL USING TAGUCHI METHOD

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ABSTRACT

AISI D2 tool steel are the important materials having excellent mechanical properties including improved wear resistance and are finding extensive applications in many manufacturing industries for preparing dies and punches. Wire Electro Discharge Machining (WEDM) is an advanced technique employed to generate intricate shapes when heat treated tool steels are to be machined. The efficient heat treated AISI D2 tool steel machining involves a proper selection of process parameters to optimize the performance characteristics including Material Removal Rate (MRR) and Surface Roughness (R_a). This paper presents an investigation on the effect and optimization of four different machining parameters on material removal rate (MRR) and Surface Roughness in WEDM process for AISI D2 tool steel. The experimental studies were conducted under varying peak current, pulse on time, and pulse off time and servo voltage. Taguchi experimental design method was employed for choosing the settings of machining parameters for proper conduction of experiments. The level of importance of each machining parameter on the performance characteristics is determined by using analysis of variance (ANOVA). It has been found that peak current and pulse on time are the most significant factors effecting the material removal rate and surface roughness.

Keywords: Wire Electro Discharge Machining, Taguchi method, Analysis of variance, MRR, Surface roughness.

INTRODUCTION

AISI D2 tool steel is widely used in industries for manufacturing dies and punches because of its excellent mechanical properties like hardness and improved wear resistant characteristic (Li et al. 2010). It has been referred that the heat treatment of AISI D2 tool steel improves wear resistance due to change in micro structural properties of steel (Das et al.2009). High toughness of these steels make them suitable candidate for making moulds and machine parts (Pujari et al.2011). AISI D2 is one of the most widely used tool steel, which is an alloy steel containing 1.5%C, 12% Cr, 0.6% V, 1% Mo, 0.6% Si, 0.6% Mn and balance Fe (S S Mahapatra et al. 2006). However tool steels are difficult to machine owing to several inherent properties of the metals like high melting point and low thermal conductivity for obtaining material removal rate, good finished quality and dimensional accuracy. The low thermal conductivity of these materials does not allow the heat generated during machining to dissipate quickly from tool edge (Hong et al. 1993). This causes high tool tip temperatures and excessive tool deformation and wear which affect the life of cutting tool adversely. The use of traditional methods like broaching, milling or grinding to cut the hard metals like D2 tool steel, it results in tool wear. Thus these tool steel materials are difficult to machine economically by using traditional machining techniques like turning, drilling, reaming, tapping and grinding. These materials however can be machined by many non-traditional methods like plasma cutting, water jet cutting, laser cutting but these processes are limited to linear cutting only. For this purpose, it has become obvious to use the WEDM process. The material properties of the AISI D2 tool steel are given in the Table.1.

Table.1 Material properties of the AISI D2 tool steel

Property	Units	Value
Hardness	HRC	64
Density	g/cm^3	7.7
Melting point	K	1694
Thermal Conductivity	W / m K	20
Modulus of Elasticity	GPa	210
Compressive yield strength	MPa	1650 - 2200
Modulus of elasticity	GPa	190 - 210
Poisson ratio	No units	0.27-0.30
Specific Heat Capacity	J / kg K	461
Electrical resistivity	$\mu\Omega$.m	0.65

WEDM is an important non-conventional machining process, mainly used for machining a variety of difficult-to-cut materials including metals and their alloys which have complex two and three dimensional shapes, not possible to generate by conventional machining methods (Barry et al.2001). It is one of the two basic types of Electrical Discharge Machining (EDM) methods, namely Die-sinking EDM method and the Wire-Cut EDM method (Lok et al.1997). Fig.1 shows the basic working principle of the wire cut EDM machine (Mc Geough et al. 1988). The working principle of WEDM is based on erosion of the material using a successive discrete discharges occurring between work piece and the electrode (Huang et al.1997). The significance of this technique is that no physical contact is required between the work piece and the wire electrode. Various WEDM parameters i.e., peak current, pulse on time, pulse off time and servo voltage affect the most important performance characteristics namely material removal rate and surface roughness which affects the economics of the process and determines the quality of the machined part. Optimal selection of process parameters is essential since this is a costly process that can increase production rate and reduce machining time (Tosun et al. 2004). Over the years researchers have used different approaches to improve the performance measures of WEDM process (11-22). Proper selection of machining parameters for the best process performance is still challenging task. Liao et al. (1997) investigated the effect of wire electrical discharge machining on SKD11 alloy steel. Taguchi method has been applied and identified that pules-on time has a significant influence on the MRR and gap width. Ramaswamy et al. (2004) conducted an experimental investigation by using Taguchi’s robust design approach on die steel by using WEDM. By using analysis of variance it was indentified that pulse on time and ignition current had more influence over the other parameters. Tosun et al.(2004) in their investigation presented the effect and optimization of machining parameters on cutting width and material removal rate in Wire electrical discharge machining of operations. Experimental studies were conducted under varying pulse duration, open circuit voltage, wire speed and die electric flushing pressure. It was observed that, the wear increases with the increase in pulse duration and open circuit voltage while machining AISI 4140 steel. Mahapatra et al. (2006) made an attempt to analyze the material removal rate and surface roughness on D2 tool steel using WEDM

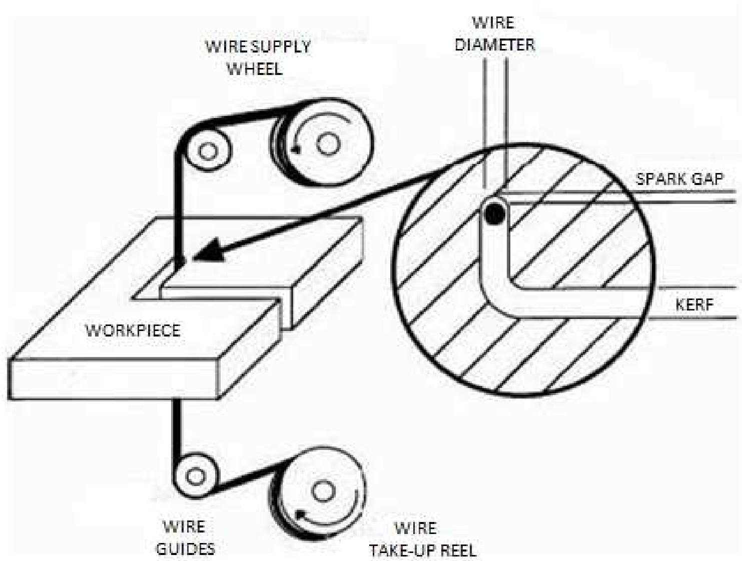

Fig.1 Basic WEDM principle

The relationship between control factors and responses like MRR and SF are established by means of non linear regression analysis resulting in a valid mathematical model. Ramakrishnan et al. (2006) conducted experiments that were planned by using Taguchi's L_{16} orthogonal array. Three responses namely material removal rate, surface roughness and wire wear ratio for D3 tool steel in WEDM process was studied. It was identified that the pulse on time and ignition current intensity had influenced more than the other parameters. Kanlayasiri et al. (2007) investigated the effects of machining parameters on surface roughness of wire EDMed DC53 die steel. The investigated machining parameters were pulse on time, pulse off time and wire tension. From the experiment, it was concluded that Surface roughness increased when Pulse on time and peak current increased. Sanchez et al. (2007) also conducted similar experiments on D2 tool steel. It was found that wire lag phenomenon is responsible for the back-wheel effect in corner cutting when corner radius, influence of work thickness was chosen as machining parameters. Haddad et al. (2008) choose DOE method for selection of optimal cutting parameters in WEDM of AISI D3 tool steel. From the experimental details it was concluded that material removal rates can be obtained with fixed high values of pulse on time and voltage. Kamal Jangra et al. (2010) in his study presents optimization of performance characteristics in WEDM using Taguchi and Grey Relational Analysis. Process parameters (pulse on time, pulse off time, peak current, wire speed and wire tension) were investigated using mixed L_{18} orthogonal array. Zinc coated brass wire of dia. 0.25mm was used as electrode. It was found that surface roughness was poor when machining was done at cutting speed of 3.8mm/min. Lokesh et al. (2013) investigated the effect of wire electrical discharge machining process parameters including Pulse on time, Pulse off time, Spark gap voltage and Peak current on D-2 tool steel using Response surface methodology. The analysis of results indicates that pulse on time, servo voltage have the maximum effect compare to pulse off time and peak current. Chopde et al. (2014) investigated the effect of WEDM parameters on surface finish while machining cryo treated AISI D2 tool steel. Taguchi method was chosen for designing and conducting the experiments. Behavior of four control parameters such as pulse on time, pulse off time, spark gap voltage and peak current on machine performance, surface roughness was studied using ANOVA. From the experiment, it was concluded that the factor pulse on time (T_{on}) is the most significant factor and spark gap voltage (SV) 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. Vates et al. (2014) modeled the electrical parameters of WEDM of D2 Steel using RSM and artificial neural network (ANN). A Chromium coated cylindrical copper wire having 0.25 mm in diameter was selected for conducting machining operation and concluded that surface roughness is proportional to the material removal rate.

MATERIALS AND METHOD

Experimental procedure and design of experiments

In the present work, Taguchi method, a powerful tool for parameter design of performance characteristics, was used based on L_9 plan Ross et al (1985). Taguchi was used to determine optimal machining parameters for minimum surface roughness, maximum MRR in WEDM. Four process variables namely current (I_p), pulse on time (T_{on}), pulse off time (T_{off}) and servo voltage (SV) were chosen each at three levels as shown in Table.2. According to the Taguchi quality design concept, a L_9 (3^4) orthogonal array table with four columns and nine rows (corresponding to the number of experiments) was chosen for the experiments as shown in Table.3.

Table.2 Machining Parameters and their control factors levels used in the experiments

Symbols	Control factors used	Level 1	Level 2	Level 3	Units
A	Peak Current (I_p)	10	15	20	A
B	Pulse on time (T_{on})	105	115	125	µs
C	Pulse off time (T_{off})	75	85	95	µs
D	Servo Voltage (SV)	40	50	60	V

Table.3 Taguchi experimental model (L_9 orthogonal array with interaction between factors)

Sl. No.	A	B	C	D
1	10	105	75	40
2	10	115	85	50
3	10	125	95	60
4	15	105	85	60
5	15	115	95	40
6	15	125	75	50
7	20	105	95	50
8	20	115	75	60
9	20	125	85	40

Experimental setup

A series of cuts were made along the length of the work using WEDM machine (Maxicut-E, Electronica Machine Tools Ltd, India) which is a four axis Computer Numerical Control (CNC) type WEDM, as shown in Fig.2. WEDM consists of machine tool, power supply unit and dielectric unit. During the experiment, work piece was held on the worktable with the help of clamps and bolts. The work piece and the wire electrode were connected to positive and negative terminals of power supply, respectively. Machine uses an iso-frequent pulse generator with a maximum operating current of 30 A. The maximum travel of the machine was 300 mm (X) x 400 mm (Y) x 225 mm (Z).

Fig.2 Experimental Setup

Different settings of peak current (I_p), pulse on time (T_{on}), pulse off time (T_{off}) and servo voltage (SV) were chosen as input parameters in the experiments. There are other factors like work piece geometry (size and shape), thickness of metal (25 mm), cutting length (60 mm), dielectric pressure, wire tension (1300g) and dielectric fluid which can be expected to have an effect on the measure of performance and hence were kept constant throughout the experiments. The work piece material used for conducting the experiments was D2 tool steel that was cut to dimensions

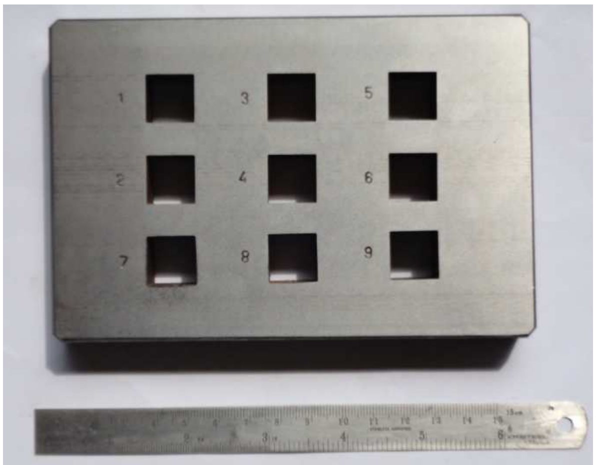

Fig.3 Openings made on D2 tool steel

150 x 100 x 25 mm. The chemical composition of the work material is presented in Table 4. By using a brass wire, which is of 0.25 mm diameter, an opening of square 15mm and 25 mm depth was made as shown in Fig.3. The MRR and SR of the machined surface were the performance

characteristics to evaluate the machining quality in this study. During machining the material removal rate (mm^3/min) was calculated from the cutting speed data directly displayed by the machine tool with the help of equation 1 which is shown below:

$$MRR = \text{Cutting speed} \times \text{Width of cut} \times \text{Height of work piece } (mm^3/min)$$

In the experiments, the surface roughness of the WEDMed work piece in terms of commonly used R_a was measured by a surface roughness tester (Mitutoyo, Surftest SJ-201) which is shown in Fig.4. It possesses a 0.8 mm cut off length and stylus radius of 0.0025mm. Average of readings taken at 9 places in each specimen perpendicular to direction of lay was chosen as surface finish value.

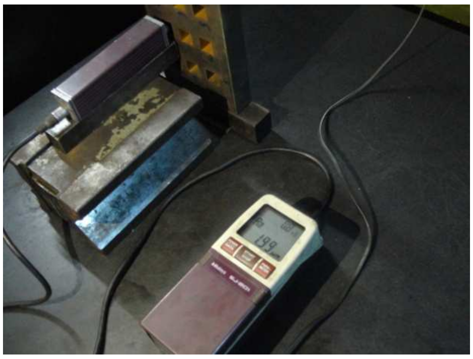

Fig. 4 Surface roughness tester

Basically, MRR is higher-the-better and SR is lower-the-better category of performance characteristics in the Taguchi method in WEDM Process.

Analysis and discussion of experimental results

The design matrix and the results from the experimental plan of MRR and R_a are shown in Table.5. In order to analyze the results of the experimental runs, analysis of variance (ANOVA) was utilized to examine the influence of cutting parameters of WEDM on the MRR and Ra. If some cutting parameters do no significantly affect the MRR and R_a, they can be fixed at the recommended values and can be excluded in predictive model generation and optimization process. The ANOVA was executed and the results are shown in Table.6 and Table.8.

Table.5 Results of experimental runs by Taguchi L_9 methods

Sl. No.	Peak current	Pulse on time	Pulse off time	Servo voltage	MRR	Ra
1	10	105	75	40	5.68	5.34
2	10	115	85	50	6.38	6.65
3	10	125	95	60	6.54	7.14
4	15	105	85	60	7.80	6.78
5	15	115	95	40	8.27	8.09
6	15	125	75	50	6.94	7.61
7	20	105	95	50	7.82	7.06

8	20	115	75	60	7.34	7.14
9	20	125	85	40	8.66	8.76

Material Removal Rate (MRR)

Table.5 shows the orthogonal array based experimental results of material removal rate and its corresponding signal-to-noise (S/N) ratio. Table.6 lists the corresponding ANOVA results, where the contribution of each parameter was calculated. Viewing the contribution of each parameter given in the table, it is found that peak current dominates the performance characteristics of the material removal rate, contributing to almost 75% followed by the pulse on time 12%. The S/N response graph in Fig.5 shows that MRR increases with increase in peak current (I_p) and pulse on time (T_{on}). As the current is increased a greater amount of energy is supplied for cutting operation because of which a increase in cutting speed is observed. Increase in the current value will increase the pulse discharge energy which in turn can improve the cutting rate further. In other words, higher peak current is the key factor to obtain the higher material removal rate in the WEDM of D2 tool steel. Pulse on time is directly proportional to cutting speed. The pulse off time (T_{off}) and servo voltage (V) can be regarded as less significant parameters owing to their percentage contributions being smaller than those of peak current (I_p) and pulse on time (T_{on}).

Table.5 Experimental results for the Material Removal Rate and S/N ratio

Exp	A	B	C	D	MRR	S/N
1	10	105	75	40	5.68	15.087
2	10	115	85	50	6.38	16.096
3	10	125	95	60	6.54	16.311
4	15	105	85	60	7.80	17.841
5	15	115	95	40	8.27	18.350
6	15	125	75	50	6.94	16.827
7	20	105	95	50	7.82	17.864
8	20	115	75	60	7.34	17.313
9	20	125	85	40	8.66	18.750

Table.6 Analysis of variance (ANOVA) results for the Material Removal Rate (MRR)

Factor	S/N ratio (dB)			Degree of freedom	Sum of square	Variance	Contribution (%)
	Level 1	Level 2	Level 3				
A	15.83	17.67	17.98	2	5.2614	2.630	75.92
B	16.93	17.25	17.30	2	1.7186	0.859	12.41
C	16.41	17.56	17.51	2	0.3686	0.184	08.62
D	17.40	16.93	17.16	2	0.1338	0.066	03.05
Total				8	7.4824		100

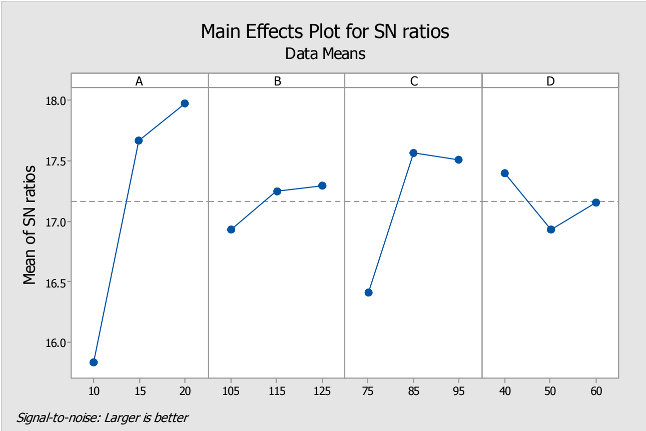

Fig.5 S/N graph for the Material Removal Rate

Surface Roughness (SR)

Surface roughness with its S/N ratio and the corresponding ANOVA results are listed in Table.7 and Table.8 respectively. The S/N response graph in Figure 6 shows that the surface roughness decreases upon decreasing the peak current (I_p) and pulse on time (T_{on}). It can be said that peak current (I_p) and pulse on time (T_{on}) have significant effects on surface roughness in WEDM of the D2 tool steel. These two parameters affect the energy input and it can be said that at lower energy input the surface finish improves.

Table.7 Experimental results for the surface roughness and the S/N ratio

Exp	A	B	C	D	Ra	S/N
1	10	105	75	40	5.34	-14.550
2	10	115	85	50	6.65	-16.456
3	10	125	95	60	7.14	-17.074
4	15	105	85	60	6.78	-16.624
5	15	115	95	40	8.09	-18.159
6	15	125	75	50	7.61	-17.627
7	20	105	95	50	7.06	-16.976
8	20	115	75	60	7.14	-17.074
9	20	125	85	40	8.76	-18.850

Table.8 Analysis of variance (ANOVA) results for the surface roughness (R_a)

Factor	S/N ratio (dB)			Degree of freedom	Sum of square	Variance	Contribution (%)
	Level 1	Level 2	Level 3				
A	-9.309	-8.252	-6.156	2	1.400	0.570	64.83
B	-9.148	-7.671	-6.919	2	0.490	0.245	24.59
C	-7.221	-7.228	-9.289	2	0.653	0.326	04.56
D	-7.407	-7.708	-8.623	2	0.211	0.105	06.02
Total				8	2.7559		

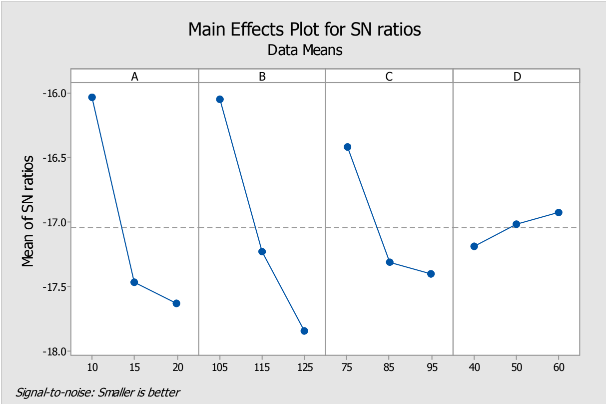

Fig.6 S/N graph for the surface roughness

CONCLUSION

An investigation on the effect of machining parameters on the material removal rate and surface roughness in WEDM operations for D2 tool steel is presented. Experiments were conducted to study the performance characteristics of various machining parameters on material removal rate and surface roughness using Taguchi method. Level of importance of the machining parameters on the MRR and R_a was determined by using analysis of variance. Based on the investigations performed the most significant parameters on both MRR and R_a were found be peak current and pulse on time, whereas pulse off time and servo voltage were less effective factors. Both MRR and R_a increase or decrease simultaneously. In other words high MRR can be obtained at cost of surface finish.

REFERENCES

[1]. 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**.
[2]. 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**.
[3]. 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**.
[4]. 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, **2006**
[5]. Hong, H., Riga, A.T., Cahoon, J.M.,Scott, C.G.,Wear, **1993**. 162, 34-39
[6]. Barry, J., Byrne, G., Lennon, D.,**2001**. Observation of chip formation and acoustic emission in machining of Ti-6Al-4V alloy. International Journal of Machine Tools Manufacturing 41, 1055-1070.
[7]. Lok, Y.K., Lee, T.C., **1997**. Processing of Advanced Ceramics using the Wire-Cut EDM Process, Journal of Materials Processing Technology 63, 897-843.
[8]. Mc Geough, J.A., **1988**. Advanced Methods of Machining, Chapman & Hall, London.
[9]. Huang, J.T., Liao, Y.S., H.C, Su., W.J.,**1997**. A Study on the Machining parameters optimization of wire electrical discharge machining. Journal of Materials Processing Technology 71, 487-493
[10]. Tosun, Nihat., Cogan, Can., Tosun, Gul., **2004**. A Study on Kerf and Material Removal Rate in wire electrical discharge machining based on Taguchi method. Journal of Materials Processing Technology 152, 316-322.

[11]. Liao Y.S., Huang J.T., Su H.C.(**1997**), "A study on the machining –parameters optimization of wire electrical discharge machining", Journal of Materials Processing Technology, Vol. 71, pp:487-493
[12]. Ramaswamy, H. and Blunt, L.(**2004**), "Effect of EDM process parameters on 3D surface topography", Journal of Materials Processing Technology, 148, pp:155-164
[13]. Tosun, Nihat, Cogun, Can and Gul Tosun (**2004**), "A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method", Journal of Material Processing Technology, 152, pp.316-322.
[14]. Mohapatra S.S., Patnaik Amar (**2006**), "Parametric optimization of wire electrical discharge machining (WEDM) process using taguchi method", Journal of the Brazilian Society of Mechanical Science of Engineering. Vol.28, pp:422-429
[15]. Ramakrishnan, R. and Karunamoorthy, L. (**2006**), "Multi response optimization of wire EDM operations using robust design of experiments". International Journal of Advanced Manufacturing Technology, Vol.29, pp:105-112
[16]. Kanlayasiri K., Boonmung S. (**2007**), "Effects of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel: design of experiments and regression model", Journal of Materials Processing Technology, Vol. 192-193, pp:459-464.
[17]. Sanchez J.A., Rodil J.L., Herrero A., Lopez de Lacalle L.N., Lamikiz A.(**2007**), "On the influence of cutting speed limitation on the accuracy of wire-EDM corner-cutting", Journal of Materials Processing Technology, Vol.182, pp:574-579
[18]. Hadded M.J., Tehrani Fadaei Alireza(**2008**), "Material removal rate (MRR) study in the cylindrical wire electrical discharge turning (CWEDT) process", Journal of Materials Processing Technology, 199, pp.369-378
[19]. Jangra Kamal, Jain Ajai, Grover Sandeep(**2010**), "Optimization of multiple-machining characteristics in wire electrical discharge machining of punching die using grey relational analysis", Journal of Scientific and Industrial Research, Vol.69, pp.606-612
[20]. Lokesh Goyat, Rajesh Dubi, Neeraj Sharma(**2013**), "Investigation of process parameters contribution and their modeling in WEDM for D-2 tool steel using ANOVA", Global journal of Engineering, Design & Technology, Vol. 2(3)2013.41-46
[21]. I K Chopde, Chandrashekhar Gogte and Dhobe Milind (**2014**), "Modeling and Optimization of WEDM Parameters for Surface Finish Using Design of Experiments", Journal of International Conference on Industrial Engineering and Operations Management
[22]. U.K.Vates, N.K.Singh, R.V.Singh (**2014**), " Modelling of Processing Parameters on D2 Steel using Wire Electrical Discharge Machining with combined approach of RSM and ANN", International Journal of Science & Engineering Research, Volume 5, Issue 1
[23]. Ross, P.J., **1985**. Taguchi Techniques for Quality Engineering, Int. 2nd Edition. Mc Graw Hill book company, New York