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EMPIRICAL MODELLING AND OPTIMISATION OF PROCESS PARAMETERS IN MACHINING OF EN8 STEEL BY WIRE ELECTRICAL DISCHARGE MACHINING

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Abstract:

This experimental work is carried out to model the process parameters of machining EN8 carbon steel by using Wire Electrical Discharge Machining (WEDM). Since EN8 steel found its utilization in many general engineering components, gears, shaft, bolts, studs etc. Wire EDM is most widely used non-traditional machining process where the dimensional accuracy of the parts machined are far superior to conventional machining process. The modelling of process parameters helps to understand the importance of the individual parameter and their role in influencing the output responses. Further the optimisation helps to identify the best suitable input process parameters among all the available sets of input parameters. Four main influencing parameters namely Pulse On (T_{ON}), Pulse Off (T_{OFF}), Current (I) and Voltage (V) were chosen with three varying levels except voltage with two levels because of machine constraint. Response parameters considered are Material Removal Rate (MRR) and average surface roughness (R_a). Mixed level design is chosen with Taguchi's L18 Orthogonal Array (OA). Regression analysis is made to find the appropriateness of the experimental values with the input parameters. Also the empirical model is made from the responses which is found to be good and satisfactory. Combined Objective Function (Maximisation) is used to find the common optimal parameter balancing both MRR and R_a.

Key Words: EN8 Steel, Taguchi Method, Wire EDM, MRR, Surface Roughness & Modelling

1. Introduction:

Wire Electrical Discharge Machining (WEDM) is a superior unconventional process where the spark produced by the continuous high intense sparks erode the work material. The controlled erosion of the material takes place along the tool path (i.e. path of wire travel). As a result of the erosion, material is removed in very smaller volumes which helps to maintain the high accuracy of the machined parts. The heat affected zone (HAZ) is also very less when compared with traditional machining process. The dielectric medium stabilises the spark intensity, carry away the eroded material and keeps the wire electrode cool. The flexibility in controllingseveral input parameters makes wire EDM a preferred choice over any other machining process. It is easy to machine materials with varying levels of hardness without affecting the accuracy, surface finish. The chosen workpiece material EN8 (Euro Norm 8) is through-hardened medium carbon steel with eclectic industrial applications ranging from automotive, general engineering components, gears, shafts, studs, bolts etc. The molybdenum wire chosen is having high melting point, high running speed, excellent thermal stability, low elongation and high precision of cutting. This makes molybdenum wire most ideal for machining any kind of material in wire EDM. It gives lower kerf width and good surface finish in the machined components.

2. Literature Survey:

Tonday and Tigga [1] machined Inconel 825 material in wire EDM and optimised the machining variables with Taguchi method and regression equation to develop the correlation between the input and output variables. Pulse on time, spark voltage, flushing pressure and wire tension were taken as inputs, material removal rate and surface roughness were enumerated as output variables. Tilekar et al. [2] investigated the machining of aluminum and mild steel using wire EDM to study the effect of spark-on time, spark-off time, input current and wire feed rate on kerf width and surface roughness. ANOVA table clearly shows the spark-on time and the input current are the most influencing parameters. Tension of wire, length of cutting, dielectric fluid pressure and spark gap were kept constant throughout the machining process.Maher et al. [3] attempted to improve the process performance of wire EDM by varying input parameters. Significant WEDM parameters were determined with the help of ANFIS (Adaptive neuro-fuzzy inference system). ANFIS was used to predict the cutting speed, surface roughness and heat affected zone (HAZ) in WEDM.Matz et al. [4] probed the influence of the mesostructured parameters of aluminum metal foams on the wire EDM. The influence of flushing is studied keenly with the focus on increasing the cutting rate. It is found that low relative density of material and good flushing leads to higher cutting speeds. Also a strong correlation between the material removal rate and relative density was found.

Conde et al. [5] configured a new Artificial Neural Network (ANN) to predict Wire EDM accuracy. By linking the ANN and Simulated Annealing (SA) optimization technique predictions, wire paths of variable radius can be designed with increased accuracy. This configuration helps to overcome the thought of lacking the required level of precision to predict actual deviations in industrial products.Bhatia et al. [6] optimised the surface roughness of HCHCr steel using wire cut EDM by varying peak current, pulse on time, pulse off time and Wire tension while measuring the roughness of each machined workpiece. Significant factors were identified by ANOVA and validation of the experimental machining was made by confirmation test.Ashish Goyal [7] machined Inconel 625 by using a regular zinc coated wire and cryogenic treated zinc coated wire. Tool electrode, current intensity, pulse on time, pulse off time, wire feed and wire tension were varied for different levels and their effects were studied. It was observed that pulse on time, tool electrode and current intensity are the significant parameters on MRR and surface roughness from the ANOVA.Bobbili et al. [8] investigated the wire EDM of ballistic grade aluminium alloy using a multi response optimization technique created by Taguchi method coupled with Grey relational analysis. Input factors like pulse-on time, pulse-off time, peak current and spark voltage were varied to measure material removal rate (MRR), surface roughness (SR) and gap current (GC). It is found that the significant factors are pulse-on time, peak current and spark voltage and 6% of error.Sivakumar et al. [9] investigated the effect of input parameters like Pulse on, pulse off, current and voltage on responses namely MRR and R_a while machining AISI D3 steel of 50mm and 75mm thickness. Mathematical expression was created using the regression analysis.

Shanmuga Prakash et al. [10] recommended new ways of research progress in the Wire EDM process such as reducing the breakage of wire tool electrode, earlier indication of wire tool wear, modelling the input and output parameters, increasing the MRR and decreasing the surface roughness by optimising the input control variables, advanced optimisation techniques etc. Kumar and Ravikumar [11] modelled and optimised the Wire EDM parameters such as Time on, Time off, wire speed and wire feed on MRR and R_a. The level of influence on the responses by each input factors were analysed and studied independently. Taguchi optimisation technique was used to optimise the process parameters of L9 OA.Mustafa Kemal Külekci et al. [12] focussed on multiple regression modelling to predict the roughness on Wire EDM of Dievar hot-work tool steel surface by varying feed rate, current and pulse time in different levels. A mathematical model was developed and it was very successful in predicting the surface roughness. BagherianAzhiri and Reza Teimouri[13] studied the dry wire EDM of Al/SiC metal matrix composites by varying the pulse time, current, voltage, wire tension and feed on the cutting velocity and roughness of surface machined.

3. Investigational Material and Method:

Experimental Setup: Wire Electrical Discharge Machining process was performed by CNC Wire EDM. Maximum work dimension of the machine is 250mm length and 200mm width. Molybdenum wire electrode of 180 micron was utilised as cutting tool electrode.The machine setup is shown in the figure 1 below.

Figure 1: Wire EDM Machine Setup

Selection of Material: EN 8 steel was chosen as experimentation material with thickness of 60mm. The material is subjected to heat treatmentin order to maintain uniform hardness and microstructure to avoid variations caused by properties of the material during machining. Molybdenum wire electrode of diameter 180 micron was chosen as tool. The microstructure of the EN 8 steel before and after heat treatment is shown in the figure 2 below. Chemical composition of EN 8 steel is depicted below in the table 1.

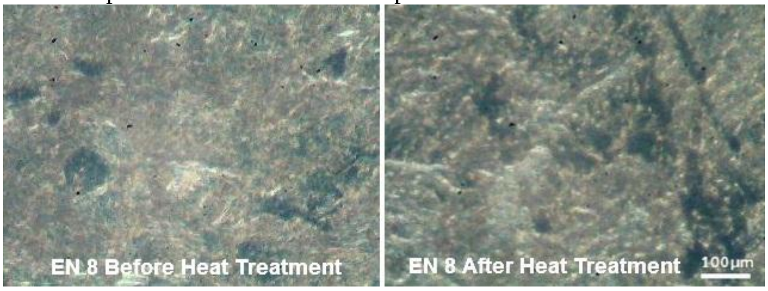

Figure 2: EN8 Microstructure

Table 1: Chemical Composition of EN8 Steel

Element	C	Si	Mn	P	S	Al	Fe
%	0.425	0.258	0.952	0.952	0.016	0.021	98.23

Design of Experiments: The experiments were planned with various levels of input parameters which are fixed on the basis of trial run machining of EN 8 steel in the Wire EDM machine. During trial run, the cutting velocity, wire breakage and short circuit were observed and noted carefully. From the trial run it was fixed to use three levels for pulse-on (20, 30 and 40µs), pulse-off (5, 6 and 7µs), current (3, 4 and 5A) and two levels for voltage (50 and 100V) which is due to machine limitation.

Input Parameters and their Levels: For optimal designing of three parameters with three levels and one parameter with two levels L18 is best choice. So there are 18 different sets of input parameters which are more useful to create an empirical model between the input and output responses. The parameters and their corresponding levels were tabulated in the below table2.

Table 2: Parameters and Levels

Parameters	**Level 1**	**Level 2**	**Level 3**
Pulse-on (µ-second)	20	30	40
Pulse-off (µ-second)	5	6	7
Current (Ampere)	3	4	5
Voltage (Volts)	75	100	-

Orthogonal Array (OA): Taguchi method is a robust statistical method widely used in improving the quality of the product as well as service.Here L18 orthogonal array was formed with the designated parameters and their levels. Table 3 portrays the values assigned for L18 orthogonal array.

Table 3: Orthogonal Array with Assigned Values

Standard Order	**Random Run**	**Pulse-On (µ-sec)**	**Pulse-Off (µ-sec)**	**Current (A)**	**Voltage (V)**
1	10	20	5	3	75
2	4	20	6	4	75
3	16	20	7	5	75
4	8	30	5	3	75
5	14	30	6	4	75
6	2	30	7	5	75
7	18	40	5	4	75
8	6	40	6	5	75
9	12	40	7	3	75
10	13	20	5	5	100
11	1	20	6	3	100
12	7	20	7	4	100
13	17	30	5	4	100
14	11	30	6	5	100
15	5	30	7	3	100
16	3	40	5	5	100
17	15	40	6	3	100
18	9	40	7	4	100

4. Experimental Work:

The experiments were carried out in the order of random run with two trials for each set of input parameters. The experimental specimen is machined as 5mmX5mm square size from the test workpiece. The wire electrode is allowed to machine the workpiece with 1mm gap between successive squares to perfectly measure the roughness on the surface for a particular set of input parameters. The tool path is shown in the figure 3 below where the arrows in the line indicates the travel path of the cutting tool electrode. The dimension is marked in the outside of the path.

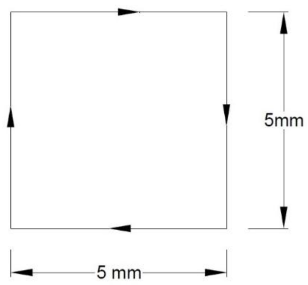

Figure 3: Electrode Tool Cutting Path and Dimension

Response parameters such as MRR and R_a were measured and tabulated carefully to avoid errors at any stage. MRR is calculated from the below formula,

$$MRR = Vc*b*h$$

Vc is the velocity with which the work material is cut by wire (mm/sec), b is the kerf width (mm) after machining in work material (Kerf width = 2*spark gap + wire electrode diameter) and h is the height of the work material (mm).

The formula for (Signal to Noise) S-N ratio is, Larger-is-better

$$\eta = -10 \log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right]$$

Smaller-is-better

$$\eta = -10 \log\left[\frac{1}{n}\sum Y_i^2\right]$$

For finding the optimum parameter which satisfies the maximum MRR and minimum R_a, combined objective function is used. It normalises the values from -1 to 1. The values are dimensionless and it is helpful to determine the optimum parameter set. In this experimental work, maximisation type objective function is utilised. The typical formula is given by,

$$Z = (0.5) * (MRR / MRR\ max) - (0.5) * (Ra / Ra\ max) \qquad \text{(Eqn. 1)}$$

5. Results and Discussion:

The Taguchi optimisation was done for the experimental data obtained from the machining using Minitab 16 software.Mean values of MRR and $R_a$were derived from their respective average of trial values noted during experimentation. The S-N ratio was calculated in the software with appropriate selection of quality factor. Normally it is expected that MRR should be as high as possible and surface roughness should be as low as possible. So Larger-is-better type quality factor was selected for MRR and smaller-is-better for average roughness (R_a). The regression equation is derived from the linear regression model available in the Minitab software for both MRR and R_a.

Table 4: Experimental MRR and Ra with S-N Ratio and Z

Expt. No	Mean MRR (mm^3/min)	S-N Ratio MRR	Mean Ra (µm)	S-N Ratio Ra	Combined Objective Function (Z)
1	6.4615	16.2067	4.346	-12.7618	-0.215504926
2	7.0831	17.0045	4.728	-13.4935	-0.233125616
3	8.7589	18.849	5.0648	-14.0912	-0.220884236
4	7.2972	17.2631	4.2972	-12.6637	-0.190714286
5	10.9471	20.786	4.8492	-13.7134	-0.148401478
6	9.3896	19.4529	5.323	-14.5231	-0.227608374
7	11.4627	21.1857	5.2942	-14.476	-0.174064039
8	11.8915	21.5047	5.8393	-15.3272	-0.210493842
9	5.9603	15.5054	4.9158	-13.8319	-0.276970443
10	18.6043	25.3923	4.2241	-12.5147	0.094087438
11	8.0463	18.1119	3.5085	-10.9024	-0.104272167
12	10.4063	20.3459	3.9463	-11.9238	-0.083885468
13	17.0482	24.6336	4.3817	-12.8329	0.042173645
14	18.8726	25.5166	4.7486	-13.5313	0.055480296
15	8.5104	18.599	3.9785	-11.9944	-0.133358374
16	20.2841	26.1431	4.8576	-13.7284	0.080849754
17	10.6289	20.5298	3.9731	-11.9826	-0.080713054
18	15.1106	23.5856	4.7053	-13.4517	-0.033447044

The mean experimental data for MRR and R_a from their trials were tabulated in the above Table 4. The S-N ratio calculated using Minitab software were also tabulated along with the combined objective function (Maximisation) to find the common optimal set of input parameter providing higher MRR and lower R_a.

Main effects plot for mean MRR and SN ratio is shown in the below figures 4 and 5 respectively. From the figure 4 displaying raw data graph, it is evident that the increase of pulse-on, current and voltage increases the MRR with contrast to the decrease of MRR with increase of pulse-off time. The optimum parameter to achieve higher MRR from the given input is pulse-on 40µs, pulse-off 5µs, current 5A and voltage 100volts.

The regression equation which is used to model the wire EDM process response MRR with the influence of input parameters such as pulse-on, pulse-off, current and voltage is formulated with accuracy of 92.6% where deviation lies within 7.4%. The equation obtained is shown in equation 2.

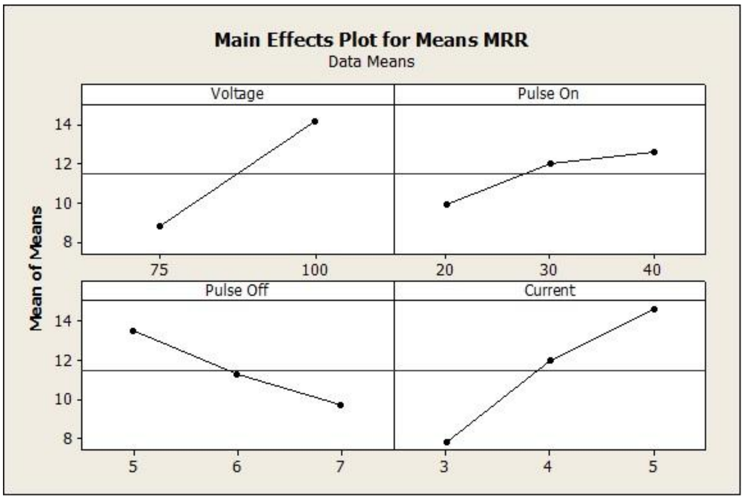

Figure 4: Raw Data Graph for MRR

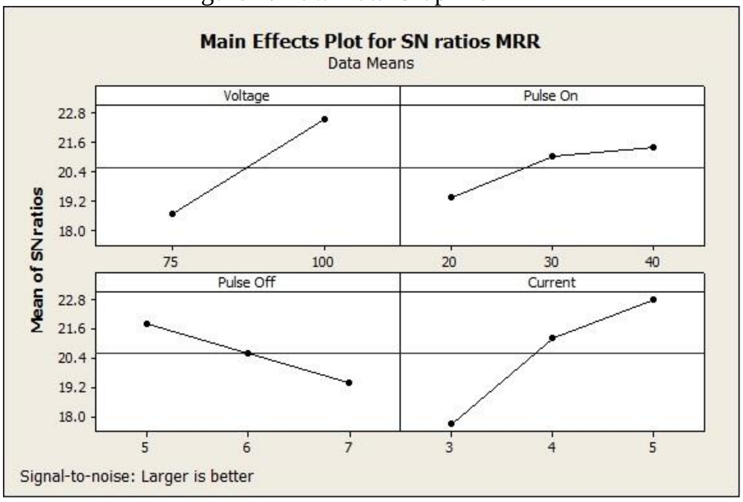

Figure 5: S-N Ratio Graph for MRR

The regression equation for MRR,

$$MRR = -13.4 + 0.133\, pulse - on - 1.92\, pulse - off + 3.41\, current + 0.214\, voltage \quad \text{(Eqn. 2)}$$

R-Sq = 94.3%   R-Sq(adj) = 92.6%

Figure 6 and 7 displays the raw data and S-N ratio for average surface roughness. Figure 6 shows the increase of pulse-on and current increases the roughness while the pulse-off didn't give appreciable variation. The increase in voltage decreases the roughness on EN8 steel. From Figure 7 we can conclude the optimum parameter to achieve lesser roughness is pulse-on 20µs, pulse-off 6µs, current 3A and voltage 100volt.

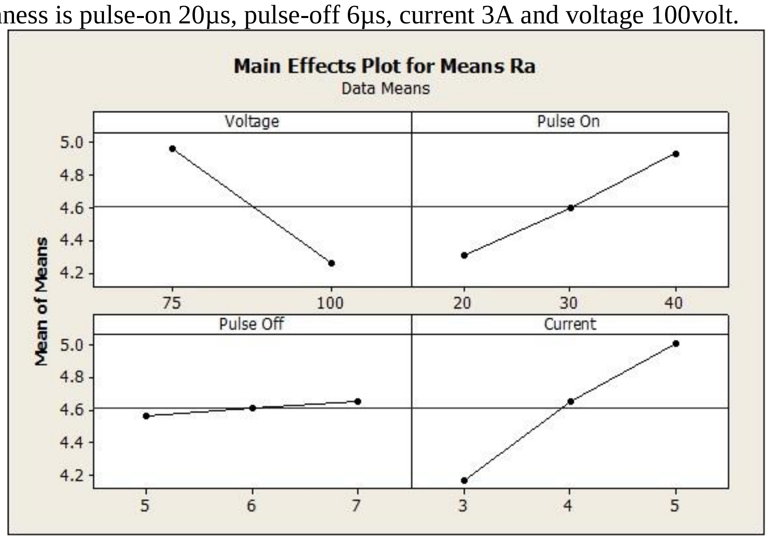

Figure 6: Raw Data Graph for Ra

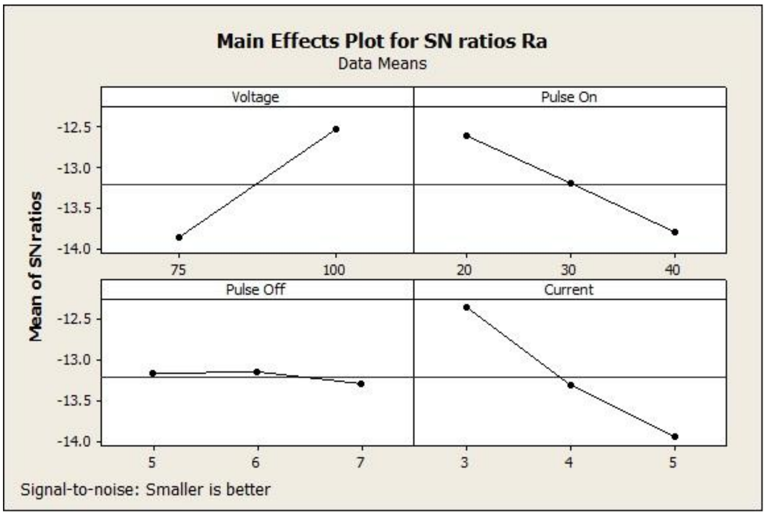

Figure 7: S-N Ratio Graph for Ra

Regression equation for $R_a$is mathematically derived with the help of Minitab software. This helps to understand the role of input parameters and their influence on the R_a. A mathematical equation with 94.9% truthfulness is obtained and shown in the below equation 3.

The regression equation for R_a,

$$Ra = 4.19 + 0.0314\, Pulse\ on + 0.0444\, Pulse\ off + 0.420\, Current - 0.0282\, Voltage \qquad \text{(Eqn. 3)}$$

R-Sq = 96.1%   R-Sq(adj) = 94.9%

From the Table 4 the 10^{th} value of z is maximum. So input parameters corresponding to 10^{th} set is common optimum parameter i.e. pulse-on 20µs, pulse-off 5µs, current 5A and voltage 100 volt to attain higher MRR and lower R_a.

6. Conclusion:

EN8 steel of 60mm thickness was machined in wire EDM while varying input parameters such as pulse-on, pulse-off, current and voltage with different levels successfully. The MRR and R_a were measured and noted as output response. Optimisation is done with the Taguchi method and optimal set of input parameters were noted for achieving higher MRR and lower R_a. Optimum set of input for higher MRR is pulse-on 40µs, pulse-off 5µs, current 5A and voltage 100volts and for lower R_a is pulse-on 20µs, pulse-off 6µs, current 3A and voltage 100 volt.Optimum input parameter balancing both MRR and R_a simultaneously is pulse-on 20µs, pulse-off 5µs, current 5A and voltage 100 volt which was found from the combined objective function.

The increase of pulse-on, current and voltage increases MRR while decreasing the surface finish of the machined surface. The increase pulse-off time reduces the MRR but eventually improves the surface finish. From the observations it is evident that there is a trade-off between the MRR and R_a in wire EDM. Modelling of the input parameters with respect to the individual responses was done effectively. The wire EDM process can be further improved by selecting novel and improved wire electrode materials or coatings, different input parameters like frequency of current and notably alternate optimisation techniques.

7. References:

1. Hulas Raj Tonday, Anand Mukut Tigga, Evaluation of the Influence of Wire Electrical Discharge Machining Parameters on Material Removal Rate and Surface Characteristics in Cutting of Inconel 825, Materials today Proceedings, Vol.4(9), pp.9865-9869, 2017.
2. Shivkant Tilekar, Sankha Shuvra Das, P. K. Patowari, Process Parameter Optimization of Wire EDM on Aluminum and Mild Steel by Using Taguchi Method, Procedia Materials Science, Vol.5, pp.2577-2584, 2014.
3. Ibrahem Maher, Liew Hui Ling, Ahmed A. D. Sarhan, M. Hamdid, Improve wire EDM performance at different machining parameters - ANFIS modelling, IFAC-Papers Online, Vol.48(1), pp.105-110, 2015.
4. Alexander Martin Matz, Dennis Kammerer, Norbert Jost, Kai Oßwald, Machining of Metal Foams with Varying Mesostructure Using Wire EDM, Procedia CIRP, Vol.42, pp.263-267, 2016.
5. A. Conde, A. Arriandiaga, J. A. Sanchez, E. Portillo, S. Plaza, I. Cabanes, High-accuracy wire electrical discharge machining using artificial neural networks and optimization techniques, Robotics and Computer-Integrated Manufacturing, Vol.49, pp.24-38, 2018.
6. Anmol Bhatia, Sanjay Kumar, Parveen Kumar, A Study to Achieve Minimum Surface Roughness in Wire EDM, Procedia Materials Science, Vol.5, pp.2560-2566, 2014.

7. Ashish Goyal, Investigation of material removal rate and surface roughness during wire electrical discharge machining (WEDM) of Inconel 625 super alloy by cryogenic treated tool electrode, Journal of King Saud University – Science, Vol.29(4), pp.528-535, 2017.
8. Ravindranadh Bobbili, V. Madhu, A. K. Gogia, Multi response optimization of wire-EDM process parameters of ballistic grade aluminium alloy, Engineering Science and Technology, an International Journal, Vol.18(4), pp.720-726, 2015.
9. Sivakumar M, Sivakumar K, R. Shanmuga Prakash, and S. Vignesh, Parameters Optimisation of Wire Electrical Discharge Machining on AISI D3 Steel with Different Thickness, International Journal of Applied Engineering Research, 10(62), pp.185–191, 2015.
10. R Shanmuga Prakash, M Sivakumar, M Jeevaraja, G Saravanan, Review on Wire Electrical Discharge Machining of Die and Tool Grade Steels, International Journal of Applied Engineering Research, Vol.10(85), pp.521-527, 2015.
11. Kumar K, Ravikumar R, Modeling and optimization of wire EDM process, International Journal of Mechanical and Mechatronics Engineering, Vol.14(5), pp.37-50, 2014.
12. Mustafa Kemal Külekci, Akkurt A, Esme U, Ozkul I, Multiple regression modeling and prediction of the surface roughness in the WEDM process, Materiali in Tehnologije, Vol.48(1), pp.9-14, 2014.
13. Bagherian Azhiri, Reza Teimouri, Ghasemi Baboly M, Leseman Z, Application of Taguchi, ANFIS and grey relational analysis for studying, modeling and optimization of wire EDM process while using gaseous media, International Journal of Advanced Manufacturing Technology, Vol.71(1-4), pp.279-295, 2014, doi:10.1007/s00170-013-5467-y