EXPERIMENTAL INVESTIGATIONS ON MRR AND SURFACE ROUGHNESS OF EN 19 & SS 420 STEELS IN WIRE-EDM USING TAGUCHI METHOD

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ABSTRACT

Quality and sophistication of the parts / products are the main requirements of the customer in the present global market. Therefore, the manufacturing / Production industries are searching for un-conventional machining processes to achieve production requirements. One among such production processes is the Wire-EDM. As such, a solemn attempt is made in this paper to investigate the response parameters, viz., Material Removal Rate (MRR) and Surface Roughness (Ra) a by experimentation on EN 19 & AISI 420 (SS420) Steels in Wire-EDM process. The Design of experiments is carried-out considering Taguchi Technique with four input parameters, namely, pulse-on, pulse-off, Bed speed and Current. The experiments are conducted considering the above two materials for L_{16} and then the impact of each parameter is estimated by ANOAVA. Then the regression analysis is carried-out to find the trend of the response of each material. A comparison made between the two materials indicates that the EN 19 Material is more suitable for better MRR and AISI 420 for better Surface finish.

Key Words: Wire-EDM, Taguchi Technique, MRR, Ra, EN19, SS420, Experimental Parametric Values, Regression Analysis.

1. INTRODUCTION

Wire-EDM is one of the most popular techniques of the Unconventional Production / Manufacturing processes in the present global manufacturing scenario. The Wire-EDM utilises the wire which acts as a tool upon passing the current so as to erode the work material by the generation of spark(s) between the work and tool. The work and the tool are immersed in a die-electric fluid and then allowed to pass through to remove the material by erosion and such machining helps to produce parts with good surface quality and dimensional accuracy. The experimental investigation on P20 Die - Tool Steel reveals that the current applied and pulse-on and pulse-off duration influence the out-put of MRR and Surface Quality, [Bhaskar Reddy *et al*. (2102)]. The other important capabilities of wire-EDM in production of parts are: (i) micro-level accuracy [Ravindra *et al*. (2008)], (ii) improved productivity, [Nixon and Ravindra (2011)] and in the reduction of cutting speeds in machining AlSI7 Mg / Al_2O_3 Steels. Thus, in the present paper, the experiments are conducted on two different AISI steels materials to estimate the MRR and quality surface. Effect of two machining methods and dry and wet EDM and surface integrity and the effect of pulse current and gap voltage on surface roughness during wet and dry wire EDM of stainless steel are investigated, [Abdul Kareem, *et al*. (2011)]. As such, the Wire-EDM is gaining importance in the present modern manufacturing industry to meet the not only the customer demand but also at the Global level. Therefore, the present work is taken-up to conduct experiments on two different materials.

2. LITERARTURE REVIEW AND OBJECTIVE

Research on Wire-EDM is an unending process and many researchers are doing the experimental works and modelings to establish the response parameters depending on the necessity. In the research, it is common to bring-out the review on the relevant research from time-to-time and to note worthy are (i) State of the Art in Wire-EDM, [Ho (2004)] and (ii) Growth of EDM and its applications, [Bhaskar Reddy, *et al*. (2012)]. A careful analysis reveals that the response parameters, such as MRR, Surface Roughness, Dimensional Accuracy, oversize, etc., are studied by changing input parameters, namely, Voltage, Current, Pulse-on, Pulse-off, wire speed and so-on either by experimentation and or modeling. In the process, multiple performance characteristics like MRR and Surface finish are investigated on different Die-steels by experimentation on (i) high Chromium and high Carbon Die-tool steel [Puri and Deshpande (2004)], (ii) Press tool steel with coated

Copper wire of 0.25 mm diameter [Vijaya Bhakar Reddy, *et al*, (2008)], (iii) AISI D5 Tool steel with Brass wire of 0.25 mm diameter [Ulas Caydas, *et al.* (2009)] followed by Oil hardened non-sinking Steel with Molybdenum Wire [Ravindra, *et al*. (2008)] and the results have been validated with models.

Wire EDM is a profile machining technique for Al based materials also as it is shown in the literature where-in experiments are conducted on 6060 Al alloys based composites: (i) with 10% and 20% Al_2O_3 particles using negative polarity of Brass wire of diameter 0.25 mm [Yan, *et al*. (2005)], (ii) Al/Sicp composites with 10%, 20%, 30% Sicp particles using coated Brass wire of 0.25 mm [Patil and Brahmankar (2008)] and (iii) Al BIS 24345 [Srnivasa Rao and Ramji (2011)].

Wire-EDM can machine the Die steels also irrespective of the work material and is proved by experimentation on (i) hard die steel with Molybdenum wire as Electrode, [Ravindra, *et al.* (2008)]; (ii) Die steel with Brass wire as electrode[Kamal Jangra, *et al.*(2010)], (iii) SUS304 Stainless steel [Abdul Kareem, *et al* (2011)] and (iv) P20 Die tool steel with Molybdenum wire as electrode and standard performance characteristics such as MRR, SR and Dimensional Error [Bhaskar Reddy, *et al*. (2012)].

The wire EDM is extended to investigate the effects of input parameters of Alloy materials like (i) Nimonic (C 263) material with uncoated brass wire of 0.25 mm diameter as electrode, [Niladri, *et al*. (2010)]; Titanium Alloy (Ti 6 Al 4v), [Danial Ghodsiyeh, *et al*. (2012)] and (iii) Nimonic 80A with Brass wire as tool electrode, [Goswami and Jatinder (2012)].

Further, the growth of the computational capabilities of the Computers, the Fault Diagnosis is modeled to eliminate manufacturing the architecture of the prototype Wire-EDM Maintenance & Fault-diagnosis Expert System (WMFES) - a hybrid object-oriented expert system and integrated with an artificial neural network (ANN) inferring algorithm, [Huang, *et al*. (2009)]. Such growth in Computers also the Mathematical models to become fast and are common to validate the wire EDM experiments; to cite (i) the RSM for Inconel 601 material, [Hewidy, *et al*. (2005)]; Gaussian process regression for chrome alloy C12 [Jin Yuan, *et al*. (2008)]; (ii) Kurf variation in machining of stainless steel using tool lateral vibration model, [Di Shichun, et al. (2009)]; (iii) RSM using Box Bhakem Design of Experiments, [Anish Kumar, *et al*. (2012)].

The continuous research on development of models in Wire-EDM led to the approaches such Grey Relational Analysis in selection of possible optimal operating parameters to obtain better multiple performance characteristics of (i) 606 Alloy with Al_2O_3 particle reinforcement [Ko-Ta Chiang and Fu-Ping Chang (2006)]; (ii) Inconel material [Al Rafie, *et al.* (2010)] followed by D2 tool steel with stratified wire, [Saurav Datta and Mahapatra (2010)].

(ii) Objective: The Literature reveals that there is a lacuna in the experimentation on two different materials and a comparative study. With the above back ground, a solemn attempt is made to investigate the response parameters and compare the performance characteristics on the two AISI materials, viz., EN 19 and SS 420 steels by experimentation on Wire-EDM so as to find the better machining parameter combination to obtain maximum MRR and with possible good surfaceness.

3 TAGUCHI IN DESIGN OF EXPERIMENTATION

Taguchi's approach has been built on traditional concepts of Design of Experiments (DOE), such as full factorial, fractional factorial design and orthogonal arrays based on signal –to-noise ratio, robust design and parameter and tolerance designs. DOE is a powerful statistical technique introduced by R.A. Fisher in England in 1920s to study the effect of multiple variables simultaneously [Philips (1989)].

Since, the research work concentrates on the experimental work, the number of experiments is to be conducted, the effect of the individual parameters on the Wire-EDM, either independently or combinedly have to be studied. Therefore, the well known Taguchi technique is chosen and adopted in the present research work. In order to reduce the total number of experiments "Sir Ronald Fisher" has developed the solution: "Orthogonal Arrays". The orthogonal array is a distillation mechanism by which the engineers can select the experimental process. The array allows the researcher / engineer to vary multiple variables at one time and obtain the effects such that set of variables has an average and the dispersion. Taguchi employs the design of experiments using specially constructed table, known as "Orthogonal Arrays" (OA) to treat the design process, such that the quality is build into the product during the product design stage.

Orthogonal Arrays are the special set of Latin squares, constructed by Taguchi to lay-out the product design experiments. A typical Orthogonal Array selected 'L_{16}' and also suitable to the present work is given Table –1. The 16 indicates the nine rows, configurations, or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table. Thus 'L_{16} (4^4) means that sixteen experiments are to be carried-out to study four variables with four levels. The number of experiments is reduced to 16. A configuration to 16 experimental evaluations is as shown in Table –1.

Table-1: Selection of L_{16} Orthogonal array

Symbol / Expt	M	N	O	P	Symbol / Expt	M	N	O	P
1	1	1	1	1	9	3	1	3	4
2	1	2	2	2	10	3	2	4	3
3	1	3	3	3	11	3	3	1	2
4	1	4	4	4	12	3	4	2	1
5	2	1	2	3	13	4	1	4	2
6	2	2	1	4	14	4	2	3	1
7	2	3	4	1	15	4	3	2	4
8	2	4	3	2	16	4	4	1	3

4 EXPERIMENTAL SET-UP AND METHODOLOGY

The equipment involved in the Wire-EDM experimentation is shown before the methodology is explained. The machine and the configuration are shown in Figure – 1 and the Control unit is shown in Figure – 2 followed by the experimental set-up in Figure -3.

Figure -1: Concord 4-axis, CNC Wire Cut EDM

Figure -2 : Controller of CNC WEDM (WEDM) (CONCORD DK7720C)

Table-2: Chemical composition

Material → Composition	**EN 19**	**SS 420**
C	0.362	0.237
Si	0.258	0.384
Mn	0.850	0.310
Cr	1.050	13.208
P	0.013	0.040
S	0.020	0.030

Figure - 3: Experimental Setup of the Wire-EDM

4.1 Experimental Methodology

The methodology consists of (i) set-up of the equipment as shown in Figure – 3 on CONCORD DK7720C CNC WEDM. The materials selected and their compositions are given in the Table -2. First the material is loaded on the Table and then the wire electrode is allowed to pass over the guiding rollers. The dielectric media is arranged such that it is pumped at the eroding zone. Once the experiment is set-up, the input parameters, ie., pulse-on, pulse –off, bed speed and current are set through control panel. The program is written and a simulation run executed on the controller. Once, the simulation run is found correct, then the machine is started and input parameters are adjusted as decided and the out-put result such as eroding time is noted. Each experiment is repeated for four times and the average time is taken. Then job is removed and then the experiments are conducted on the second material is loaded. The same procedure explained above is followed. The materials considered in the present work are (i) EN 19 Steel and (ii) SS 420 Steel. The experiments are conducted considering the fixed parameters as given in Table-3 and control factors in Table – 4. Figure-4 shows the eroded particles during experiment. The orthogonal array based on the experimental results is shown in Table – 5 for ES19 and SS 420 Materials.

Table -3: Fixed parameters

Fixed Parameters	
Wire used	Molybdenum wire of dia. 0.180 mm
Shape cut	10mm square
Location of the work piece on work table	At the center of table
Angle of cut	Vertical
Thickness / Height of the work piece	43mm
Stability	Servo control
Number of passes	one

Table-4: Control Factors

Control Factors	**Sym-bols**	**Levels**
Pulse-on (P-on)	M	12,16,20,24
Pulse-off (P-off)	N	6,7,8,9
Bed Speed (BS)	O	20,25,30,35
Current (C)	P	2,3,4,5

Steps involved in Wire EDM process

Step 1: Power Supply Generates Volts and Amps: De ionized water surrounds the wire electrode as the power supply generates volts and amps to produce the spark.

Step 2: During Pulse-on Time: The Controlled Spark Erodes Material. It shows the precisely the generation of Sparks to melt and vaporize the material.

Step 3: During Pulse-off Time: It Allows Fluid to Remove Eroded Particles During the off cycle, the pressurized dielectric fluid immediately cools the material and flushes the eroded particles.

Step 4: Filter Removes Chips While the Cycle is repeated

The eroded particles are removed and separated by a filter system as shown in Figure - 4.

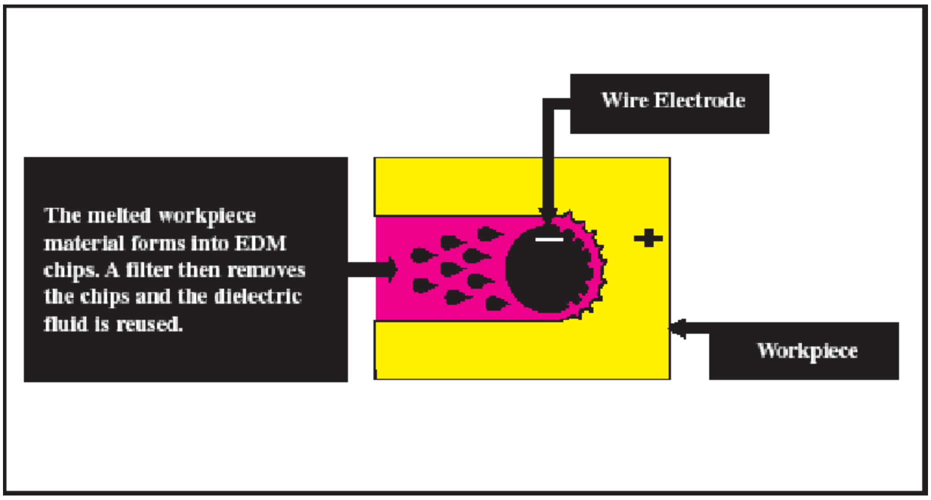

Figure -4: Eroded particles removed and separated by filter system

Table- 5: Taguchi Orthogonal Array and Experimental Results

Expt. No	Control factors				Responses for EN19		Responses For SS420	
	M	N	O	P	MRR	Ra	MRR	Ra
1	1	1	1	1	3.649	3.23	2.449	1.68
2	1	2	2	2	4.812	3.13	3.933	2.18
3	1	3	3	3	5.733	3.33	4.636	2.50
4	1	4	4	4	7.182	3.63	5.513	2.50
5	2	1	2	3	6.969	3.57	4.464	2.48
6	2	2	1	4	6.538	4.03	4.754	2.63
7	2	3	4	1	3.707	3.40	3.313	2.38
8	2	4	3	2	5.409	3.43	4.333	2.60
9	3	1	3	4	9.479	3.90	6.839	3.28
10	3	2	4	3	7.761	3.30	6.321	2.83
11	3	3	1	2	5.299	3.73	4.045	2.75
12	3	4	2	1	3.815	3.60	3.323	2.56
13	4	1	4	2	7.403	3.83	6.030	3.05
14	4	2	3	1	4.353	3.73	4.007	2.73
15	4	3	2	4	7.693	4.10	6.033	3.20
16	4	4	1	3	6.074	4..00	4.824	3.25

5 RESULTS AND DISCUSSION

The experiments are conducted based on L_{16} orthogonal array considering Pulse–on, Pulse-off, Bed speed, Current as controllable parameters and the responses measured are Material removal rate and Surface Roughness. A sample of the image of the surface on the SS 420 material obtained by SEM is shown in Figure – 5. The optimization is performed based on Taguchi's Technique and the relation between controllable and response variables are modeled using regression Analysis.

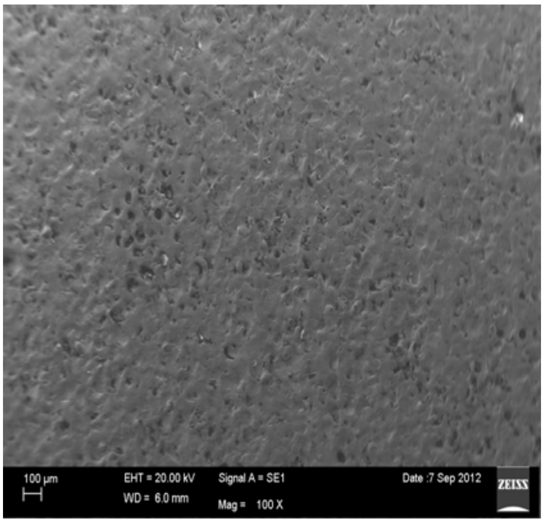

Figure – 5 (a): MRR (Max) Condition

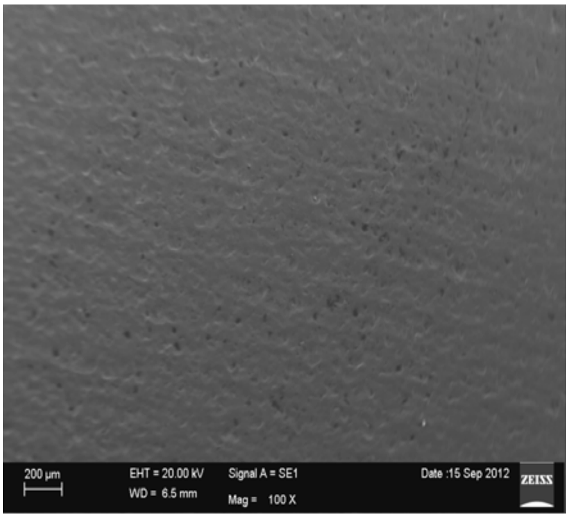

Figure – 5(b) : Better Surface Condition

Figure – 5: Sample Image on the SS 420 material

5.1 MRR Analysis on SN 19 and SS 420 materials

The analysis of S/N ratios of MRR considering "Larger is the Better" characteristic and S/N ratio of Surface Finish (Ra) "Smaller is the Better" characteristic are calculated as in equation (1) and (2) respectively. $\eta = -10 \log_{10} (1/n \;\; \Sigma\, 1/_{y}{}^{2})$ ------- (1) and $\eta = -10 \log_{10} (1/n \;\; \Sigma\, {}_{y}{}^{2})$ ------- (2)

Where n is the number of measurements in a trail. In the present case, n = 1 and y is the measured in each experimental run. The calculated S/N ratio of MRR and Ra for EN19 & SS420 steels are shown in Table-6 followed by the S/N Ratio response for MRR in Table-7. Whereas the Figure -6 shows the effect of Process parameters on MRR for EN19 material followed by Figure-7 on MRR for SS420 material.

Table-6: S/N Ratios to responses

Expt. No	Control factors				S/N Ratios for EN19		S/N Ratios for SS420	
	M	N	O	P	MRR	Ra	MRR	Ra
1	1	1	1	1	11.25	-10.18	7.78	-4.51
2	1	2	2	2	13.64	-9.91	11.89	-6.77
3	1	3	3	3	15.16	-10.45	13.32	-7.96
4	1	4	4	4	17.12	-11.20	14.83	-7.96
5	2	1	2	3	16.87	-11.05	12.99	-7.89
6	2	2	1	4	16.31	-12.11	13.54	-8.40
7	2	3	4	1	11.39	-10.63	10.40	-7.53
8	2	4	3	2	14.66	-10.71	12.74	-4.15
9	3	1	3	4	19.54	-11.82	16.70	-5.16
10	3	2	4	3	17.80	-10.37	16.02	-9.04
11	3	3	1	2	14.46	-11.43	12.14	-4.39
12	3	4	2	1	11.64	-11.13	10.43	-8.16
13	4	1	4	2	17.39	-11.66	15.61	-9.69
14	4	2	3	1	12.77	-11.43	12.06	-8.72
15	4	3	2	4	17.72	-12.26	15.61	-10.10
16	4	4	1	3	15.66	-12.04	13.67	-10.24

5.2 Parametric Analysis on EN19 & SS420 for MRR

It can be seen from the Figure-6 that the MRR for EN19 reaches its maximum at (i) a Pulse-of 24 µs; (ii) Bed speed of 35 µ m/s; (iii) Current of 5 Amp and (iv) and the Pulse-off at 6 µs. Thus the Larger the Better for MRR is achieved. Similarly, by the observation of the Figure -7, the MRR for SS420 material is obtained at (i) a pulse of 24 µs; (ii) Bed speed of 35 µ m/s; (iii) Current of 5 Amp. and (iv) Pulse-off of 7 µs. From Response Table-7 and ANOVA, it is clear that current is the major influencing parameter contributing 80.02 % followed by Pulse-on 7.79 %, Pulse-off 6.57% and Bed speed 5.37 % for EN19 material. Similarly, the Table-7 shows that the current is the major influencing factor contributing 65.23% followed by Pulse-on 17.11%, Bed speed 16.58 % and pulse-off 0.92 % for SS420 material. The suitable and better machining conditions for MRR and Ra are shown in Table – 8.

Table-7: S/N ratios response for MRR

Level	Pulse –on		Pulse –off		Bed Speed		Current	
	EN19	**SS420**	**EN19**	**SS420**	**EN19**	**SS420**	**EN19**	**SS420**
1	14.29	11.96	16.26	13.27	14.42	11.78	11.76	10.17
2	14.81	12.42	15.13	13.38	14.97	12.73	15.09	13.09
3	15.86	13.82	14.68	12.87	15.53	13.70	16.37	14.00
4	15.89	14.24	14.77	12.92	15.93	14.21	17.67	15.17
Delta	1.6	2.28	1.58	0.51	1.51	2.43	5.91	5.00
Rank	2	3	3	4	4	2	1	1
% contribution from ANOVA	7.79	17.11	6.57	0.92	5.37	16.58	80.02	65.23

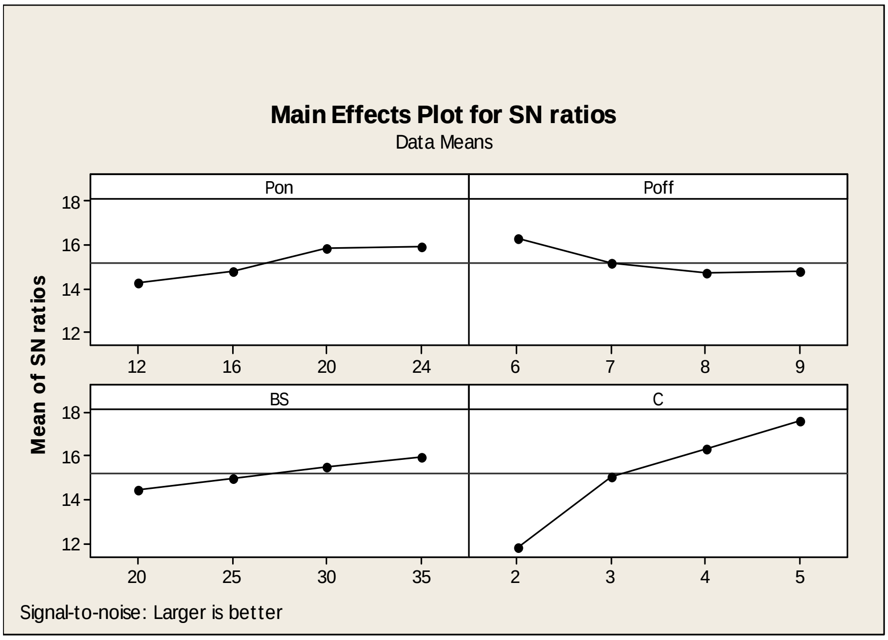

Figure -6: Effect of Process parameters on MRR for EN19

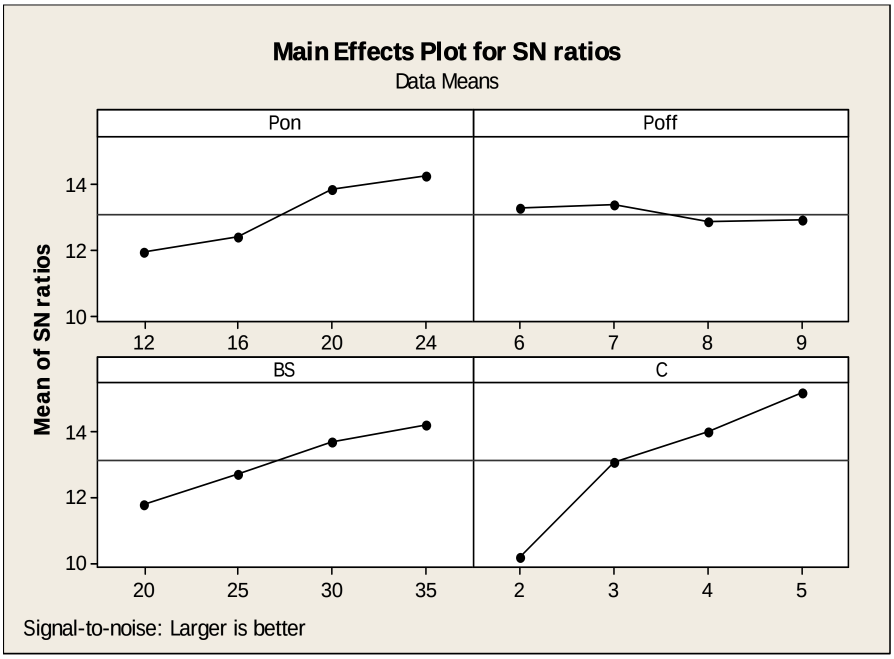

Figure-7: Effect of process Parameters on MRR for SS420

5.2 Ra Analysis for EN19 and SS 420 materials

It can be seen for the material EN19 from Figure-8, that the Pulse-on is the maximum at 12 µs and reaches its minimum at 24 µs; (ii) the effect of Bed Speed on Ra is maximum at 30 µ m/s; (iii) The Pulse-off influence seems to be non-uniform between 6 µs and 9 µs showing the maximum at 7 µs; and (iv) The effect of Current is maximum at 2 Amp. Thus, Smaller the Better characteristic for Ra is achieved for EN 19 with P-on 12 µs, P-off 7 µs, Bed speed 30 µ m/s and Current 2 Amps. Similarly, by the observation of the Figure -9, the Ra for SS420 material is obtained as minimum at (i) P-on of 12 µs (ii) Bed speed of 20 µ m/s; (iii) Pulse-off of 6 µs. and (iv) a Current of 2 Amp. Thus, the Smaller is the Better for Ra is achieved for SS 420 Material. From Response Table-9 and ANOVA, it is clear that the Pulse-on is the major influencing parameter contributing 50.84 % followed by the Current 33.48% and Bed speed 6.33 %. The least is being the Pulse-off for EN19 material. Similarly, it is clear that the Pulse-on is the major influencing parameter contributing 40.84% followed by the Current 22.70 % and the Bed speed 19.96 %. The least is being the Pulse-off for SS420 material.

Table-8: Better machining conditions for EN19 and SS420 Materials

Parameter	MRR		Ra	
	EN19	SS420	EN19	SS420
Pulse-on (µ s)	24	24	12	12
Pulse-off (µ s)	6	7	7	6
Bed speed(µm/ s)	35	35	30	20
Current (Amp)	5	5	2	2

Table-9: S/N Ratio Response table for Ra on EN19 &SS420

Level	Pulse-on		Pulse-off		Bed Speed		Current	
	EN19	SS420	EN19	SS420	EN19	SS420	EN19	SS420
1	-10.44	-6.798	-11.18	-8.100	-11.44	-7.982	-10.84	-7.231
2	-11.13	-8.030	-10.96	-8.232	-11.09	-8.231	-10.93	-8.385
3	-11.19	-9.076	-11.19	-8.595	-11.10	-8.825	-10.98	-8.780
4	-11.85	-9.687	-11.27	-8.665	-10.97	-8.553	-11.85	-9.195
Delta	1.41	2.889	0.31	0.566	0.47	0.842	1.01	1.963
Rank	1	1	4	4	3	3	2	2
% contribution	50.84	40.86	2.80	6.73	6.33	19.96	33.58	22.70

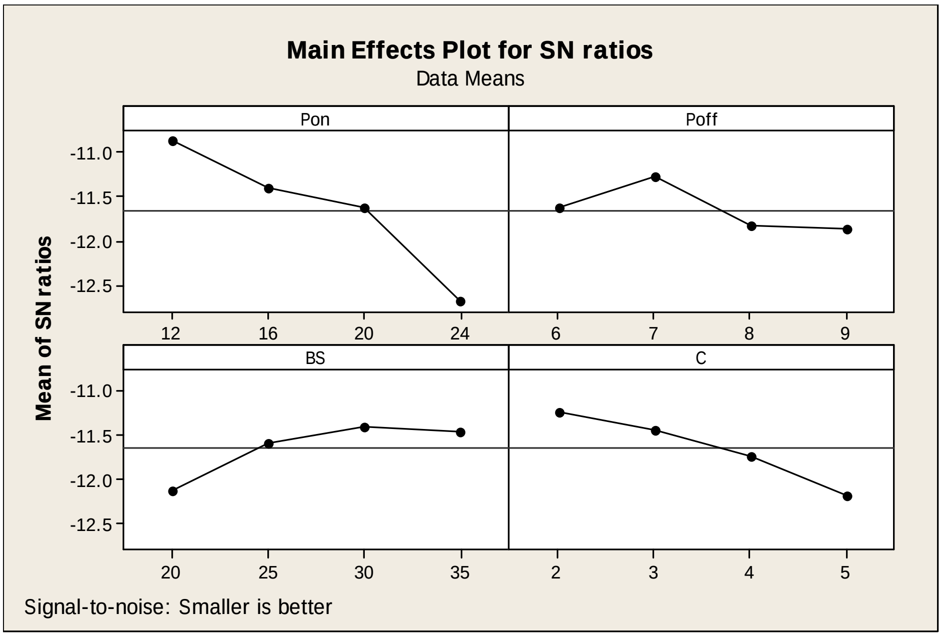

Figure -8: Effect of control factors on Ra of EN19

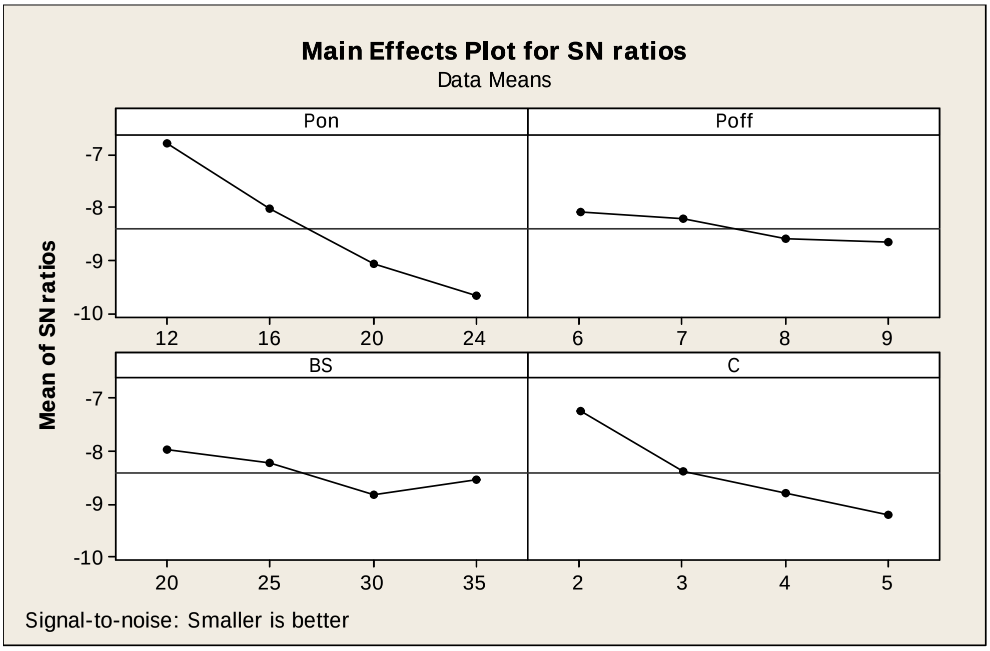

Figure-9: Effect of control factors on Ra of SS420

6 DEVELOPMENT OF REGRESSION EQUATIONS

The Regression Analysis is carried-out considering the parametric values used in the experiments so as to obtain generalised equations to predict the responses as out-put for implementation.. The equations are shown in the following. The MiniTAB is used for calculation to run-on IBM Compatible PC-AT.

Regression Equation of MRR for EN19 material

$$MRR= 0.878 \times (P0n)^{0.293} \times (P\ off)^{-0.430} \times (BS)^{0.312} \times (C)^{0.733} \quad \text{--------- (1)}$$

Regression Equation of Ra for EN19 material

$$Ra = 2.145 \times (P0n)^{0.214} \times (P\ off)^{0.039} \times (BS)^{-0.089} \times (C)^{0.106} \quad \text{--------- (2)}$$

Regression Equation of MRR for SS420 material

$$MRR = 0.164 \times (P\ on)^{0.407} \times (P0ff)^{-0.132} \times (BS)^{0.513} \times (C)^{0.614} \quad \text{-------- (3)}$$

Regression Equation of Ra for SS420 material

$$Ra = 0.212 \times (P\ on)^{0.488} \times (P0ff)^{0.176} \times (BS)^{0.47} \times (C)^{0.243} \quad \text{---------- (4)}$$

7 COMPARISON OF EXPERIMENTAL AND PREDICTED VALUES

The results obtained from the Experimentation and Regression Analysis for both the EN 19 and SS 420 materials are shown in Table-10 for convenience and easy comparison. The results from Table-10, it can be seen that the deviation of the effects of all the parameters lie within 5% of error between the experimental and predicted results. The results are also represented in the form of Graphs to show the trend of the characteristics of the parametric influences. It can be observed from Figure -10, that better MRR is obtained for EN 19 material for all conditions where as the surface roughness (Ra) obtained is better for SS420 for similar conditions as shown in Figure – 11.

Table -10: Comparison of experimental and predicted values

Exp. No	EN19			SS420			EN19			SS420		
	MRR			MRR			Ra			Ra		
	Expt.	Predicted	Deviation %	Expt.	Predicted	Deviation %	Expt.	Predicted	Deviation %	Expt	Predicted	Deviation %
1	3.65	3.56	2.38	2.45	2.53	-3.23	3.23	3.22	0.28	1.68	1.80	-7.02
2	4.81	4.81	0.02	3.93	3.56	9.43	3.13	3.32	-5.94	2.18	2.11	3.35
3	5.73	5.94	-3.56	4.64	4.59	1.10	3.33	3.38	-1.53	2.50	2.38	4.96
4	7.18	6.97	2.90	5.51	5.60	-1.65	3.63	3.43	5.51	2.50	2.62	-4.76
5	6.97	6.91	0.90	4.46	4.88	-9.23	3.57	3.61	-1.23	2.48	2.53	-2.06
6	6.54	7.10	-8.58	4.75	4.89	-2.80	4.03	3.80	5.73	2.63	2.66	-0.99
7	3.71	4.09	-10.0	3.31	3.65	-10.02	3.40	3.30	3.09	2.38	2.36	0.71
8	5.41	4.97	8.06	4.33	4.25	1.82	3.43	3.50	-2.13	2.60	2.60	-0.12
9	9.48	9.19	3.04	6.84	6.73	1.67	3.90	3.82	2.08	3.28	3.06	6.74
10	7.76	7.66	1.26	6.32	6.22	1.63	3.30	3.70	-12.15	2.83	3.05	-7.63
11	5.30	4.92	7.13	4.05	3.84	4.99	3.73	3.79	-1.69	2.75	2.68	2.62
12	3.82	3.72	2.36	3.32	3.31	0.48	3.60	3.58	0.61	2.56	2.56	-0.04
13	7.40	7.00	5.51	6.03	5.73	5.01	3.83	3.71	3.13	3.05	3.02	0.92
14	4.35	4.64	-6.47	4.01	4.04	-0.90	3.73	3.63	2.82	2.73	2.75	-0.73
15	7.69	8.09	-5.20	6.03	6.35	-5.25	4.10	4.08	0.46	3.20	3.43	-7.03
16	6.07	6.09	-0.31	4.82	4.86	-0.79	4.00	4.09	-2.13	3.25	3.20	1.39
Ave. deviation %			4.23			3.75			3.16			3.19

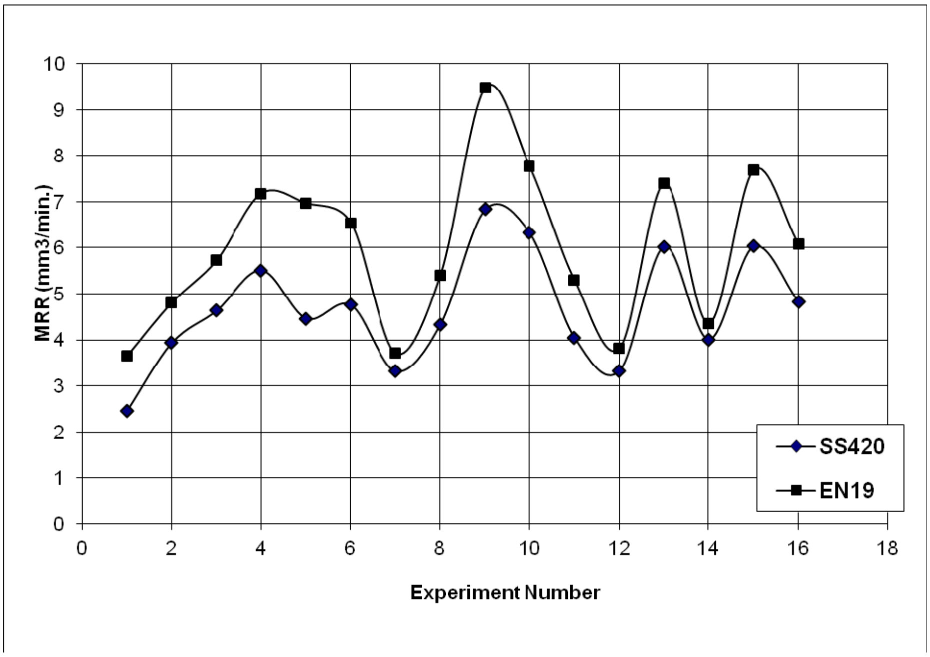

Figure -10: Comparison of Deviation of MRR for EN19 & SS420

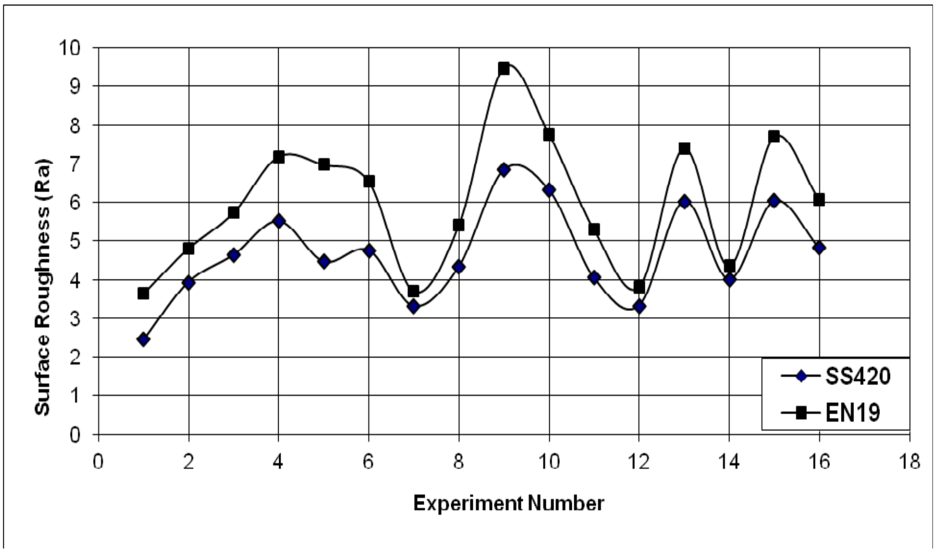

Figure -11: Comparison of Deviation on Surface roughness for EN19& SS420

8 CONCLUSIONS

The final conclusions based on the results are presented in the following**.**

(i) The author, for the first time, has conducted experiments on WireEDM considering two different materials for same parametric values and compared the performance characteristics in terms of MRR and Surface Roughness.

(ii) From the Analysis, it is found that the current is major influencing parameter for MRR on both the materials. Such experiments will be useful in the manufacturing processes where the MRR is the major desired response characteristics.

(iii) The effect of Pulse-on is higher side on Surface Roughness for both the materials. Such experiments will be useful in the manufacturing of sophisticated equipment and machinery such as Robotics, Aerodynamic Industry and Scientific Research.

(iv) Based on the results, it is recommended that the EN 19 material is suitable for better MRR. Then the SS 420 material is recommended to obtain better surface.

(v) The Regression models are useful to predict the MRR and Ra with an accuracy of 95%.

8.1 Future Scope

The experiments are conducted in the present on AISI Hard Steels considering two materials. The procedure can be extended to other AISI Tool steels and Composite Materials.

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