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Optimization of Machining Parameters for AISI 316L And 317L Austenitic Stainless Steels using Eco-Cut Wire-EDM Technique

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Abstract-Austentic stainless steel is one of the most suitable engineering material based on their superior resistance to corrosion and compatibility at high temperatures and high vacuum. However, the machinability of austenitic stainless steel is not very promising owing to lower thermal conductivity, higher degree of ductility and work hardenability. For meeting these challenges, unconventional machining procedures were evolved and can make any impenetrable design/profile on any work substance by acceptable controlling of various machining procedures. The main importance of this paper is to show the impact of machining parameters on Eco-cut Wire Electric Discharge Machining (WEDM) for disparate austenitic stainless steels (AISI 316L & 317L). Initially both the metals are machined on WEDM. Machining parameters like pulse on time(P_{on}), pulse off time(P_{off}), voltage(V) and wire tension(WT) are observed for both 316L and 317L stainless steel materials. A Box-Behnken Design (BBD) of response surface methodology (RSM) has been used for experimental work. The reaction of procedure is estimated by ANOVA analysis and response optimizer is used for optimum level checking. A series of trial runs were carried out on both the machined specimens for identifying better material removal rate(MRR), cutting speed(CS) and surface roughness(Ra).

Keywords - Cutting Speed(CS), Material Removal Rate(MRR), Surface Roughness(Ra), pulse on time(P_{on}), pulse off time(P_{off}), voltage(V), wire tension(WT), Response Surface Methodology(RSM) and ANOVA.

I. INTRODUCTION

Modern advances in aerospace and nuclear engineering industries is partly reflects to the use of impenetrable-to-machine materials like alloys, nimonics, carbides, stainless steel etc. Many of these substances found various applications in the industrial fields by exploiting their elevated strength–to-weight relationship, hardness and heat-resisting qualities. Conventional machining processes instead of present technological improvement it is impenetrable to machine these substances from the perspective of low-cost production. Un-conventional machining procedures are necessary to control these hard substances. Electrical discharge machining(EDM) is the most favored non-traditional material removal procedures and enhances basic principles of machining in manufacturing industries like aerospace, automotive, nuclear, medical and die-mould production.

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Crucial advances of EDM was noticed when computer numerical influence apparatus were tried for machine tool production. Thus, EDM procedure became automatic and unattended machining. Klocke et al [1] explained about the structure and composition of the white layer In the Wire-EDM process. In EDM procedure thermal (heat) energy is pre-owned to fabricate heat that liquefies and vaporizes work piece by ionization within dielectric medium. The electrical discharges fabricate impulsive pressure by dielectric explosion to detach liquefied material.

Thus, all detached material can be effectively made to fabricate impenetrable & precisely machine components. Liquefied material is not completely flushed away but remaining material resolidifies to form discharge craters. EDM processes are categorized into die-sinking EDM & Wire- EDM. Electrode of die-sinking EDM has reversed design/profile of part to be machined, while Wire-EDM utilizes thin wire, varying from 0.01 - 0.36 mm in diameter, as electrode. WEDM was first applied in manufacturing production in the late 1960s. The advancement of the procedure was the denouement of seeking an approach to restore the machined electrode pre-owned in EDM. In 1974, D.H. Dulebohn claimed the optical-line follower apparatus to automatically impact the design/profile of the element/component to be machined by the WEDM procedure. As an outcome, the broad facility of WEDM procedure was extensively exploited for any through-hole machining payable to the wire, which has to pass between the parts to be machined. Several mathematical models are incorporated by researchers to optimize the machine parameters of WEDM [2],[3].

II. FUNDAMENTAL WORKING OF WEDM PROCEDURE

WEDM is a procedure of material removal of electrical conductive materials by thermo-electric source of energy. The material removal is by commanded erosion between a series/run of repetitive flash/twinkles in between electrodes, i.e. work piece and tool. In WEDM, the erosion apparatus has been explained as liquefying and/or evaporation of surface material by heat fabricated in the plasma channel. A flash is fabricated in between wire electrode and work piece through deionized water and erodes work piece to fabricate complex 2D and 3D object profiles.

III. MATERIAL AND EXPERIMENTAL WORK

Austenitic stainless steels (AISI 316L & 317L) are pre-owned in this work [4],[5] and the specifications of Wire EDM Machine is shown in Table I and levels of input limitations is shown in Table II.

The dimensions of the work piece for the work is taken as, Plates of 100×150×5mm thick respectively, and these plates were machined by Wire EDM shown in Fig. 1.

Fig. 1. Eco-cut Wire EDM Machine

Table-I: Specifications of Wire EDM machine

Traverse	250×350×200mm
Taper	+/- 5^0 on 100mm job height
Max Cutting Speed	702mm/min with ø0.25 special brass wire on 50mm thick HCHCR
Surface Finish	1.2 μ Ra
USB Port For Data Transfer	

Table-II: Levels of input limitations

Limitations	Nota-tion	Level 1	Level 2	Level 3
Pulse on Time P_{on} (μs)	A	112	113	114
Pulse off Time P_{off} (μs)	B	44	45	46
Voltage V (V)	C	20	22	24
Wire TensionWT (m/min)	D	9	10	11

IV. EXPERIMENTAL DESIGN AND ANALYSIS

WEDM of eco-cut has been pre-owned to machine Austentic Stainless Steels AISI 316L and 317L with P_{on}, P_{off}, V and WT as input limitations. Varying the above limitations a cut of 10mm length are fabricated on the work piece of two disparate materials. The aim of the present work is to optimize the WEDM procedure parameters for better performance [6],[7]. In this work the showing measures are material removal rate (MRR), surface roughness (Ra) and cutting speed (CS).

The level of input limitations is fixed based on the trial runs displayed in the work table, response surface methodology-Box Behnken Design method has been used for experimentation (Table III and Table IV). The measured and calculated responses are given in the work table after conducting the experiments. ANOVA [8],[9],[10] has been used to know the significant parameter and their contribution.

The trial run defines as in the following steps:

1. Selecting the machining limitations and levels of these limitations.
2. Conducting the trial runs at all feasible level of the combinations.

MRR was calculated using the following equation,

$$\text{MRR calculation: MRR} = [WLT]/T_m$$

T – THICKNESS OF WORK PIECE (mm),
L – LENGTH OF CUT (mm),
W – WIDTH OF CUT OR WIDTH (mm),
T_m – MACHINING TIME (min)

$$\textbf{MRR} = (0.345)\ (10)\ (5)\ /\ 449 = 0.038\ \text{mm}^3/\text{min}$$

MITUTOYO SURFTEST SJ 201P surface roughness tester is pre-owned to measure the surface roughness value (Ra).

Table-III: Experimental Plan & Responses of 316L

	Inputs				Outputs		
Run order	P_{on} (μs)	P_{off} (μs)	V (V)	WT (m/min)	MRR (mm/ min)	CS (mm/ min)	Ra (μm)
1	112	44	22	10	0.025	3.07	2.0669
2	114	44	22	10	0.0384	3.01	2.12
3	112	46	22	10	0.019	2.85	1.9686
4	114	46	22	10	0.0312	2.85	2.13
5	113	45	20	9	0.035	3.12	1.95
6	113	45	24	9	0.035	3.1	1.95
7	113	45	20	11	0.0332	3	1.84
8	113	45	24	11	0.038	3.15	2.27
9	112	45	22	9	0.023	3.01	2.12
10	114	45	22	9	0.0375	2.85	2.03
11	112	45	22	11	0.025	3.1	2
12	114	45	22	11	0.0365	2.62	2.19
13	113	44	20	10	0.0365	3.17	2.06
14	113	46	20	10	0.0259	3.12	1.85
15	113	44	24	10	0.036	3.2	2.06
16	113	46	24	10	0.0315	2.85	2.24
17	112	45	20	10	0.022	2.99	1.95
18	114	45	20	10	0.0410	2.49	1.99
19	112	45	24	10	0.0301	2.85	2.24
20	114	45	24	10	0.0375	2.44	2.24
21	113	44	22	9	0.0324	2.18	2
22	113	46	22	9	0.0296	2.88	1.96
23	113	44	22	11	0.0635	3.18	2.1
24	113	46	22	11	0.025	3.07	2
25	113	45	22	10	0.037	2.7	2.07
26	113	45	22	10	0.037	2.7	2.07
27	113	45	22	10	0.037	2.7	2.07

Table-IV: Experimental Plan and Responses of 317L

	Inputs				Outputs		
Run order	P_{on} (μs)	P_{off} (μs)	V (V)	WT (m/min)	MRR (mm/ min)	CS (mm/ min)	Ra (μm)
1	112	44	22	10	0.0455	2.53	2.12
2	114	44	22	10	0.0549	3.35	2.12
3	112	46	22	10	0.0508	2.387	1.83
4	114	46	22	10	0.0511	3.71	2.07
5	113	45	20	9	0.062	3.15	2.25
6	113	45	24	9	0.0573	3.21	2.10
7	113	45	20	11	0.065	3.2	2.22
8	113	45	24	11	0.055	3.10	2
9	112	45	22	9	0.042	2.67	1.191
10	114	45	22	9	0.0456	3.67	2.01
11	112	45	22	11	0.041	2.58	1.78
12	114	45	22	11	0.0477	3.71	2.06
13	113	44	20	10	0.061	3.17	2.315
14	113	46	20	10	0.068	3.21	2.29

15	113	44	24	10	0.065	3.12	2.16
16	113	46	24	10	0.068	3.31	2.181
17	112	45	20	10	0.047	2.84	2.17
18	114	45	20	10	0.04	3.63	2.06
19	112	45	24	10	0.039	2.44	1.63
20	114	45	24	10	0.0573	3.89	1.95
21	113	44	22	9	0.062	3.15	2.19
22	113	46	22	9	0.069	3.25	2.3
23	113	44	22	11	0.059	3.04	2.18
24	113	46	22	11	0.069	3.26	2.28
25	113	45	22	10	0.0452	2.69	1.99
26	113	45	22	10	0.0452	2.69	1.99
27	113	45	22	10	0.0452	2.69	1.99

V. RESULTS AND DISCUSSION

ANOVA has been applied on the exploratory out-comes for MRR, CS, Ra for both steels 316L and 317L are given Table V, Table VI, Table VII, Table VIII, Table IX and Table X respectively. By using surface optimizer, optimum level has been observed and measured as shown from Fig. 2 to Fig. 7.

Table-V: Outcomes of ANOVA for MRR 316L

Source	DF	SS	MS	F-Value	P-Value	% Contribution
Model	14	0.000930	0.000066	443.53	0.000	99.78540
A	1	0.000499	0.000499	3330.45	0.000	53.65591
B	1	0.000150	0.000150	1004.32	0.000	16.12903
C	1	0.000019	0.000019	127.72	0.000	2.043011
D	1	0.000000	0.000000	1.39	0.261	0
A^2	1	0.000104	0.000104	694.20	0.000	11.1828
B^2	1	0.000103	0.000103	685.15	0.000	11.07527
C^2	1	0.000000	0.000000	0.02	0.899	0
D^2	1	0.000020	0.000020	132.94	0.000	2.150538
A*B	1	0.000000	0.000000	2.18	0.166	0
A*C	1	0.000038	0.000038	254.45	0.000	4.086022
A*D	1	0.000002	0.000002	15.01	0.002	0.215054
B*C	1	0.000019	0.000019	62.38	0.000	0.967742
D*B	1	0.000019	0.000019	126.62	0.000	2.043011
C*D	1	0.000006	0.000006	37.96	0.000	0.645161
Error	12	0.000002	0.00000015			0.215054
Total	26					100

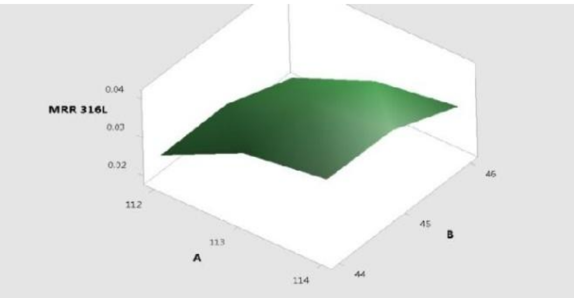

Fig. 2. Surface plot of MRR 316L vs. A and B

$$MRR\ for\ 316L = -72.25 + 1.0589\ A + 0.4286\ B + 0.1345\ C + 0.2084\ D - 0.004416\ A^2 - 0.004388\ B^2 + 0.000005\ C^2 - 0.001933\ D^2 - 0.000286\ A*B - 0.001544\ A*C - 0.000750\ A*D + 0.000764\ B*C - 0.002178\ B*D + 0.000596\ C*D$$

Table-VI: Outcomes of ANOVA for CS 316L

Source	DF	SS	MS	F-Value	P-Value	% Contribution
Model	14	0.00093	0.000066	443.53	0.000	87.8251723
A	1	0.11288	0.112889	11.53	0.005	11.6989481
B	1	0.11842	0.118425	12.10	0.005	12.2726566
C	1	0.00163	0.001633	0.17	0.690	0.16923157
D	1	0.00002	0.000021	0.00	0.964	0.002176288
A^2	1	0.00066	0.000664	0.07	0.799	0.06881186
B^2	1	0.26011	0.260112	26.57	0.000	26.9560081
C^2	1	0.13117	0.131175	13.40	0.003	13.5939686
D^2	1	0.21296	0.212969	21.75	0.001	22.07047
A*B	1	0.00083	0.000838	0.09	0.775	0.08684388
A*C	1	0.07022	0.070225	7.17	0.020	7.27757915
A*D	1	0.02496	0.024964	2.55	0.136	2.58707705
B*C	1	0.02250	0.022500	2.30	0.155	2.33172703
D*B	1	0.00902	0.009025	0.92	0.356	0.93528162
C*D	1	0.00722	0.007225	0.74	0.407	0.74874346
Error	12	0.11748	0.009790			12.1751386
Total	26					100

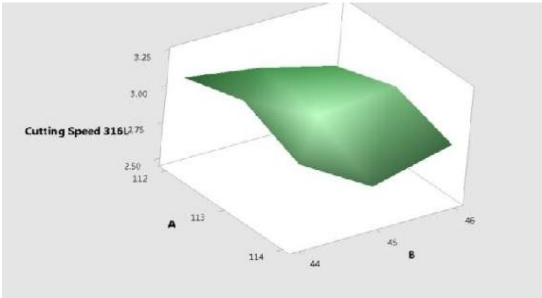

Fig. 3. Surface plot of CS 316L vs. A and B

$$CS\ for\ 316L = 500 + 1.11\ A - 21.26\ B - 7.73\ C + 2.32\ D - 0.0112\ A*A + 0.2208\ B*B + 0.0392\ C*C + 0.1998\ D*D + 0.0145\ A*B + 0.0663\ A*C - 0.0790\ A*D - 0.0375\ B*C + 0.0475\ B*D + 0.0213\ C*D$$

Table-VII: Outcomes of ANOVA for Ra 316L

Source	DF	SS	MS	F-Value	P-Value	% Contribution
Model	14	0.318135	0.022724	16.09	0.000	94.94017

A	1	0.010878	0.010878	7.70	0.017	3.246292
B	1	0.005526	0.005526	3.91	0.071	1.649109
C	1	0.153952	0.153952	108.99	0.000	45.94348
D	1	0.012237	0.012237	8.66	0.012	3.651855
A^2	1	0.008962	0.008962	6.34	0.027	2.674505
B^2	1	0.002354	0.002354	1.67	0.221	0.702498
C^2	1	0.000582	0.000582	0.41	0.533	0.173685
D^2	1	0.007883	0.007883	5.58	0.036	2.352502
A*B	1	0.002932	0.002932	2.08	0.175	0.874989
A*C	1	0.000400	0.000400	0.28	0.604	0.119371
A*D	1	0.018660	0.018660	13.21	0.003	5.568653
B*C	1	0.037869	0.037869	26.81	0.000	11.30114
D*B	1	0.000900	0.000900	0.64	0.440	0.268585
C*D	1	0.046225	0.046225	32.73	0.000	13.7948
Error	12	0.016950	0.001413			5.0583438
Total	26					100

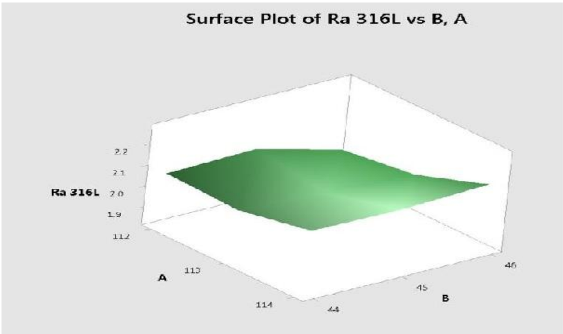

Fig. 4. Surface plot of Ra 316L vs. A and B

Ra for 316L = 730 - 11.03 A - 2.11 B - 1.99 C - 7.42 D + 0.0410 A*A - 0.0210 B*B -0.00261 C*C - 0.0384 D*D + 0.0271 A*B - 0.00500 A*C + 0.0683 A*D + 0.04865 B*C - 0.0150 B*D + 0.05375 C*D

Table-VIII: Outcomes of ANOVA for MRR 317L

Source	DF	SS	MS	F-Value	P-Value	% Contribution
Model	14	0.002411	0.000172	18.21	0.000	95.29644
A	1	0.000081	0.000081	8.61	0.012	3.201581
B	1	0.000068	0.000068	7.18	0.020	2.68774
C	1	0.000000	0.000000	0.02	0.898	0
D	1	0.000000	0.000000	0.01	0.912	0
A^2	1	0.000295	0.000295	31.19	0.000	11.66008
B^2	1	0.000865	0.000865	91.48	0.000	34.18972
C^2	1	0.000331	0.000331	34.97	0.000	13.083
D^2	1	0.000234	0.000234	24.75	0.000	9.249012
A*B	1	0.000021	0.000021	2.19	0.165	0.83004
A*C	1	0.000160	0.000160	16.92	0.001	6.324111
A*D	1	0.000002	0.000002	0.25	0.623	0.079051
B*C	1	0.000004	0.000004	0.42	0.528	0.158103
D*B	1	0.000002	0.000002	0.24	0.635	0.079051
C*D	1	0.000007	0.000007	0.74	0.406	0.27668
Error	12	0.000114	0.000009			4.505929
Total	26					100

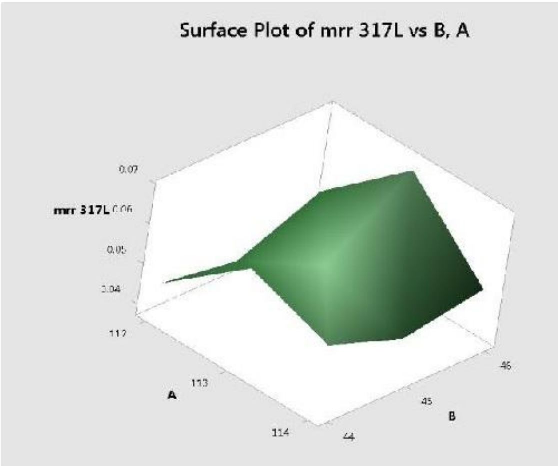

Fig. 5. Surface plot of MRR 317L vs. A and B

MRR for 317L = -71.1 + 1.709 A - 0.883 B - 0.4149 C - 0.239 D - 0.00744 A*A + 0.01274 B*B + 0.001969 C*C + 0.00663 D*D - 0.00228 A*B + 0.003162 A*C + 0.00078 A*D - 0.000500 B*C + 0.00075 B*D - 0.000662 C*D

Table-IX: Outcomes of ANOVA for CS 317L

Source	DF	SS	MS	F-Value	P-Value	% Contribution
Model	14	4.42615	0.31615	58.64	0.000	98.55929
A	1	3.55069	3.55069	658.57	0.000	79.06499
B	1	0.04843	0.04843	8.98	0.011	1.078415
C	1	0.00121	0.00121	0.22	0.644	0.026944
D	1	0.00350	0.00350	0.65	0.436	0.077936
A^2	1	0.17587	0.17587	32.62	0.000	3.916185
B^2	1	0.19577	0.19577	36.31	0.000	4.359308
C^2	1	0.44986	0.44986	83.44	0.000	10.01726
D^2	1	0.34797	0.34797	64.54	0.000	7.748422
A*B	1	0.06597	0.06597	12.24	0.004	1.468987
A*C	1	0.10890	0.10890	20.20	0.001	2.424931
A*D	1	0.00422	0.00422	0.78	0.393	0.093969
B*C	1	0.00563	0.00563	1.04	0.327	0.125366
D*B	1	0.00360	0.00360	0.67	0.430	0.080163
C*D	1	0.00599	0.00599	1.11	0.313	0.133382

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Error	12	0.06470	0.00539			1.440707
Total	26					100

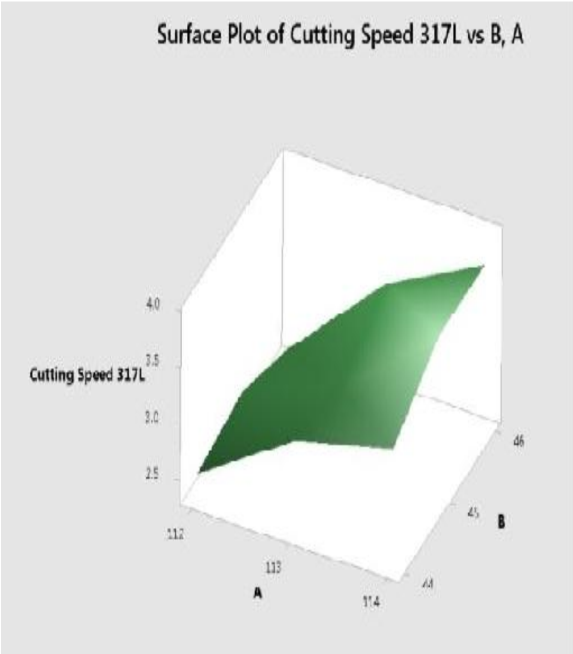

Fig. 6. Surface plot of CS 317L vs. A and B

CS for 317L = 3629 - 48.41 A - 32.40 B - 13.17 C - 9.72 D + 0.1816 A*A + 0.1916 B*B + 0.07261 C*C + 0.2554 D*D + 0.1284 A*B + 0.0825 A*C + 0.0325 A*D + 0.0188 B*C + 0.0300 B*D - 0.0193 C*D

Table-X: Outcomes of ANOVA for Ra 317L

Source	DF	SS	MS	F-Value	P-Value	% Contribution
Model	14	0.660208	0.047158	8.98	0.000	91.2873
A	1	0.058702	0.058702	11.18	0.006	8.116756
B	1	0.001385	0.001385	0.26	0.617	0.191505
C	1	0.137174	0.137174	26.12	0.000	18.96712
D	1	0.004840	0.004840	0.92	0.356	0.669229
A^2	1	0.077742	0.077742	14.80	0.002	10.74943
B^2	1	0.154436	0.154436	29.41	0.000	21.35394
C^2	1	0.033818	0.033818	6.44	0.026	4.676032
D^2	1	0.028992	0.028992	5.52	0.037	4.008739
A*B	1	0.014292	0.014292	2.72	0.125	1.976162
A*C	1	0.046225	0.046225	8.80	0.012	6.391554
A*D	1	0.008100	0.008100	1.54	0.238	1.119991
B*C	1	0.000557	0.000557	0.11	0.750	0.077017
D*B	1	0.000025	0.000025	0.00	0.946	0.003457
C*D	1	0.001260	0.001260	0.24	0.633	0.174221
Error	12	0.063013	0.005251			8.712840
Total	26					100

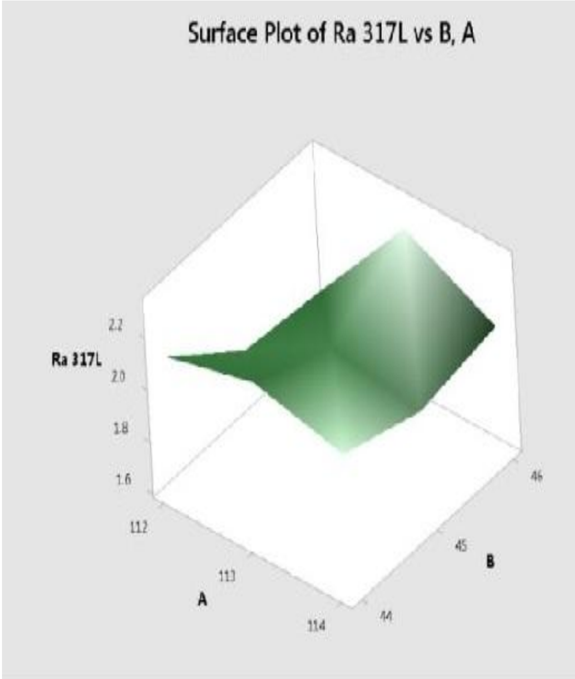

Fig. 7. Surface plot of Ra 317L vs. A and B

Ra for 317L = -693 + 23.03 A - 22.19 B - 7.18 C - 6.27 D - 0.1207 A*A + 0.1702 B*B+ 0.01991 C*C + 0.0737 D*D + 0.0598 A*B + 0.0537 A*C + 0.0450 A*D+ 0.0059 B*C - 0.0025 B*D - 0.0089 C*D

VI. CONCLUSIONS

Response surface methodology (RSM) process has been used in the present work to optimize the WEDM performance measures [material removal rate-MRR cutting speed-CS and surface roughness-Ra]. Pulse on time(P_{on}), Pulse off time(P_{off}), Voltage(V) and Wire tension(WT) have been considered as input limitations.The reaction of procedure limitations have been identified by registering ANOVA analysis for MRR, CS and Ra.

For MRR, it is seen from ANOVA outcomes that,

1. For 316L, P_{on}, P_{off}, V, squares of P_{on}, P_{off}, WT, interaction of P_{on} & V, P_{off} & V, P_{off} & WT, V & WT are more influencing than other model terms.
2. For 317L, squares of P_{on}, P_{off}, interaction of V & WT are more influencing than other model terms.

For CS it was develop from ANOVA outcomes that,

1. For 316L, squares of P_{off} are more influencing than other model terms.
2. For 317L, P_{on}, squares of P_{on}, P_{off}, interaction of V & WT are more influencing than other model terms.

For Ra it was develop from ANOVA outcomes that,

1. For 316L, V, interaction of P_{off} & V, V & WT are more influencing than other model terms.
2. For 317L, V & squares of P_{off} are more influencing than other model terms.

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