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Effect of Wire EDM Parameters on Surface Roughness of Stainless Steel 15-5 PH

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Abstract*— Wire electrical discharge machining (W-EDM) is a competitive process capable of machining hard materials with complex geometries accurately. SS 15-5 PH is a martensitic, precipitation hardening stainless steel. It has excellent strength, transverse toughness and ductility widely used in corrosive as well as high-pressure environments. Wire EDM is successfully implemented in common materials like aluminum alloys, mild steel. But its application in martensitic steels, super alloys etc. are still under investigation. This study investigates the effect of process parameters on wire edm of SS 15-5 PH. The settings of machining parameters were determined by using Taguchi experimental design method. The level of importance of the machining parameters for surface roughness is determined by using analysis of variance (ANOVA). The optimum machining parameter combination was obtained by using signal-to-noise (S/N) ratio.

Index Terms—**Wire EDM, Surface roughness, ANOVA**

I. INTRODUCTION

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional thermo-electrical material removal process used to manufacture components with intricate shapes and profiles. WEDM utilizes a continuously travelling wire electrode made of thin copper, brass, molybdenum or tungsten of diameter 0.05–0.3 mm, which is capable of achieving very small corner radii. The machining principle is based on erosion of the work-piece material using a successive discrete discharges occurring between the electrode (wire) and work piece [1, 2]. The wire-cut uses deionized water as its dielectric fluid. In addition, the WEDM process is able to machine exotic and high strength and temperature resistive (HSTR) materials and eliminate the geometrical changes occurring in the machining of heat-treated steels.

II. LITERATURE REVIEW

WEDM is a specialized thermal machining process capable of accurately machining parts of hard materials with complex shapes. Parts having sharp edges that pose difficulties to be machined by the main stream machining processes can be easily machined by WEDM process [3]. Y.B. Guo et al. [4] carried out study on the characteristics of surface integrity vs. discharge energy in W-EDM of Inconel 718 and found that EDMed surface topography shows dominant coral reef microstructures at high discharge energy, while random micro voids are dominant at low discharge energy. Surface roughness is equivalent for parallel and perpendicular wire directions. Rajurkarb et al. [5] carried out experimental investigation of Wire-EDM of titanium alloy to investigate the effect of seven process parameters including pulse width, servo reference voltage, pulse current, and wire tension on process performance parameters (such as cutting speed, wire rupture and surface integrity) and found that the cutting speed increases with peak current and pulse interval. Surface roughness was found to increase with pulse width and decrease with pulse interval. Klink et al. [6] carried out study on tool steel ASP2023 and found out average surface finish Ra of 0.1 μm and 0.2 μm for CH and water-based dielectrics is achieved. White layer, characterized by the top porous structure and bottom solid recast, was minimized. M. Durairaj et al. [7] carried out optimization study on stainless steel 304, to attain the minimum kerf width and the best surface quality simultaneously and separately, input parameters selected for optimization are gap voltage, wire feed, pulse on time, and pulse off time. Dielectric fluid pressure, wire speed, wire tension, resistance and cutting length are taken as fixed parameters. For each experiment surface roughness and kerf width was determined by using contact type surf coder and video measuring system respectively. Thomas R. [8] carried out experimental investigation to determine the main EDM parameters which contribute to recast layer formation in Inconel 718 and found that average recast layer thickness increased primarily with energy per spark, peak discharge current, and current pulse duration. Zhang et al. [9] carried out investigation of the material removal characteristics of the EDM process. The results were supposed to be helpful for material removal mechanism of EDM. A. Ikram et al. [10] studied the effect and optimization of eight process parameters and found out significant factors surface roughness are pulse on-time and open voltage.

III. MATERIALS AND EXPERIMENTAL SETUP

A. Work piece materials and general equipment

Work piece material was SS 15-5 PH martensitic, precipitation hardening stainless steel. Good in corrosive, high-pressure environments ideally suited for several industries, including aerospace, petrochemical and food processing. It offers exceptional performance for applications such as gears, shafts, fittings, valves and fasteners. In addition it has good strength, transverse toughness and ductility. The chemical composition is shown in Table 1.Workpiece materials of dimension 100 mm x 40 mm x 10 mm were used. The WEDM experiments were conducted in Charmilles cut 3000 machine. Zinc coated brass wire of 0.15 mm used as the wire electrode and deionized water as dielectric fluid.

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Table I. Chemical composition

Element	% Composition
Carbon (C)	0.07%
Chromium (Cr)	15.5 %
Manganese (Mn)	1%
Niobium (Nb) + Tantalum (Ta)	0.45%
Nickel (Ni)	5.5%
Phosphorus (P)	0.04%
Sulphur (S)	0.03%
Silicon (Si)	1%

B. Process Parameters and Design

Input process parameters such as Discharge current (A), Pulse duration (µs), and Wire speed (mm/min) used in this study are shown in Table II. Each factor is investigated at three levels to determine the optimum settings for the WEDM process. These parameters and their levels were chosen based on the review of literature, experience, significance and their relevance as per the few preliminary investigations [11].

Table II. Control parameters for Surface roughness

Parameters	Levels and Values		
	Level 1	Level 2	Level 3
Pulse Duration (µs)	40	43	46
Discharge Current (A)	1	3	5
Wire Speed (mm/min)	120	135	150

The Taguchi method is a traditional approach for robust experimental design that seeks to obtain a best combination set of factors/levels with the lowest societal cost solution to achieve customer requirements. In the Taguchi design method the design parameters (factors which can be controlled) and noise factors (factors which cannot be controlled, e.g. environmental), which influence product quality, are considered. Therefore, in the Taguchi design method, the objective is to select the levels of design parameters such that the performance of product or process is insensitive to noise factors. The standard 3-level orthogonal array (OA) L9, as in Table III.

Table III. Orthogonal Array for L9 Design

Sl. No.	Pulse Duration	Discharge Current	Wire Speed
1	40	1	120
2	40	3	135
3	40	5	150
4	43	1	135
5	43	3	150
6	43	5	120
7	46	1	150
8	46	3	120
9	46	5	135

C. Measurement procedures

The output response the average arithmetic surface roughness (Ra) was measured using Taylor Hobson's Form Taly Surf PGI. A cut-off length of 8mm was used. The surface roughness was measured three times and the average is reported herein.

D. S/N ratio calculation

The characteristics that lower value represent better machining performance such as surface roughness is called "lower is better" in quality engineering. The equation for calculating the S/N ratio is

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\left(y_i^{\,2}\right)\right]$$

Where 'n' is the number of measurements in a trial and 'yi' is the measured value in the trial.

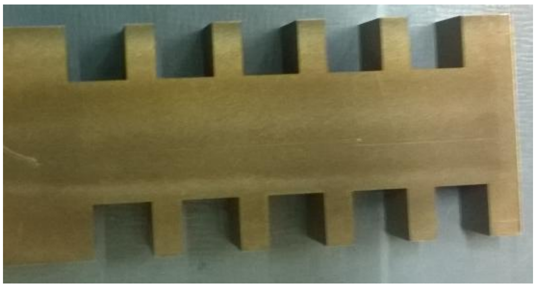

Fig.1: Work piece after machining

IV. RESULTS AND DISCUSSION

Experiments were conducted as per the L9 (33) orthogonal array. The surface roughness values were measured in surface roughness tester to determine the surface finish (Table IV). In this study most important output performance in WEDM, Surface Roughness (Ra) were considered for optimizing machining parameters. The surface finish value (in µm) was obtained by measuring the mean absolute deviation, Ra (surface roughness) from the average surface level using a Computer controlled surface roughness tester.

Table IV. Output response of Wire EDM

Expt. No.	Pulse Duration	Discharge Current	Wire Speed	S.R (Ra)
	µs	A	mm/min	µm
1	40	1	120	0.5037
2	40	3	135	0.5178
3	40	5	150	0.5010
4	43	1	135	0.5143
5	43	3	150	0.6053
6	43	5	120	0.5989
7	46	1	150	0.5795
8	46	3	120	0.6024
9	46	5	135	0.6896

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The response factors for surface roughness of machined surface were calculated from the observed data. A statistical analysis was performed using MINITAB 16 software and the signal to noise ratio values of surface roughness are tabulated in Table V. The S/N ratio could be the effective representation to find the significant parameter by evaluating the minimum variance. By applying the above equation, the S/N ratio values of machining performance for each experiment of L9 OA can be calculated for the SR values.

Table V. S/N ratio for surface roughness

Expt. No.	Pulse Duration	Discharge Current	Wire Speed	S.R.(Ra)	S/N ratio for S.R. (Ra)
	µs	A	mm/min	µm	db
1	40	1	120	0.5037	5.956
2	40	3	135	0.5178	5.716
3	40	5	150	0.5010	6.003
4	43	1	135	0.5143	5.775
5	43	3	150	0.6053	4.360
6	43	5	120	0.5989	4.452
7	46	1	150	0.5795	4.738
8	46	3	120	0.6024	4.402
9	46	5	135	0.6896	3.228

The analysis of variance was used to establish statistically significant machining parameters and the percent contribution of these parameters on the surface roughness. In Taguchi method, a loss function is used to calculate the deviation between the experimental value and the desired value. This loss function is further transformed into a signal-to-noise (S/N) ratio. The main effect values for each level of factors are represented in Table VI.

Table VI. Response table for S/N ratios

Level	A	B	C
1	5.892	5.490	4.937
2	4.863	4.827	4.907
3	4.123	4.561	5.034
Optimum	1	1	3
Delta	1.769	0.929	0.127
Rank	1	2	3

The values of main effects are plotted and shown in Figure. 2 for the pulse duration, discharge current and wire speed respectively. The main effects plot shows the influence of each level having major contribution are selected from the plot and are the optimized levels for the particular factor.

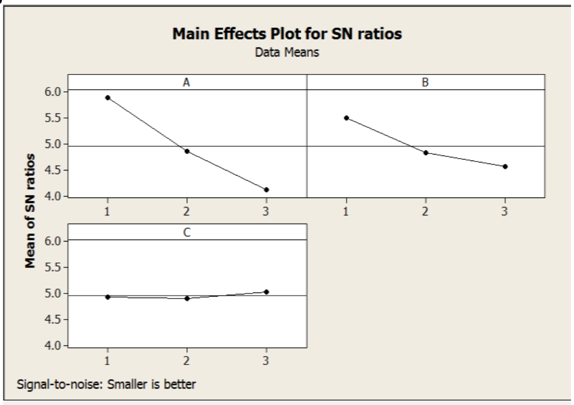

Fig.2: S/N ratio plot for surface roughness

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. ANOVAs are useful in comparing three or more means for statistical significance. The P value reports the significance level percentage (%) defined as the significance rate of process parameters on the output responses.

Source	DOF	Sum of square	Mean sum of squares	F ratio	% of contribution
Pulse Duration	2	4.73634	2.3681	4.09	64.92
Discharge Current	2	1.37399	0.687	1.19	18.83
Wire Speed	2	0.02657	0.0132	0.02	0.36
Error	2	1.15855	0.5792	0.36	15.88
Total	8	7.29546			

Table VII. ANOVA table for surface roughness

It can be observed from Table VII that pulse duration and discharge current affects surface roughness by 64.92 and 18.83. The wire speed has no significant effect respectively.

V. CONCLUSION

In this paper, the effect of optimization of process parameters on surface roughness of SS 15-5 PH on wire edm is carried out using Taguchi's design of experiment followed by comprehensive statistical analyses such as ANOVA and S/N ratio to identify the key factors affecting stated response variable. The optimum levels for pulse duration discharge current and wire speed is A1-B1-C3. The parameter pulse duration was found to be the most effective on the surface roughness followed by the discharge current.

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