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"EXPERIMENTAL INVESTIGATION AND OPTIMIZATION OF WIRE EDM PARAMETERS FOR SURFACE ROUGHNESS, MATERIAL REMOVAL RATE AND SURFACE TOPOGRAPHY IN MACHINING OF AISI D3"

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Abstract: **Wire electric discharge Machining is a crucial alternative machining technique. As a consequence of its superior precision, finish, machinability of any hard material, and ability to form complex shapes, demand for it continues to rise. In this research, we apply the Taguchi Method in conjunction with the Grey relational analysis approach to determine the optimal parameters in WEDM for the machining of AISI D3. WEDM machines allow for cutting by adjusting process parameters such as pulse on time, pulse off time, servo voltage, wire feed rate, current, and more to get the desired results in terms of response variables like surface roughness and material removal rate.**

Grey Relational Analysis is used for optimization of all these parameters with multi-response features. Best WEDM parameters are determined by studying grey relational grade.

Specifically, the findings demonstrate its improved surface roughness and material removal rate prediction skills and application to such industrial WEDM cutting, which leads to the effective selection of machining settings for improved Machining quality.

Keywords: **Wire EDM, Taguchi Method, Surface Roughness (SR), Material Removal Rate (MRR), Orthogonal Array L16**

I. INTRODUCTION:

New materials are needed or made for space-age technology. Cutting with traditional tools isn't always the best way to save money. Instead, it needs very specific and very expensive materials. WEDM can cut expensive industrial diamonds or diamond compounds that are hard to grind.

Because the kerf is small and the technique can cut complex shapes accurately, not much of the workpiece is wasted during the operation. Because of this, WEDM is used a lot in the manufacturing industry today to make accurate complex shapes on Advanced materials. WEDM is one of the oldest non-traditional ways to machine. It is often used to make machine dies and moulds, which are used to make parts for many different industries. WEDM's main benefit is that it can make complicated shapes with high levels of accuracy, no matter how the material moves (especially hardness, brittleness, and resistance).

Wire EDM uses electrode tool wires made of copper, tungsten, or brass. Deionised water is the dielectric fluid that is used in electronics. The wire is eroded while being gently fed, which is almost the same as regular EDM. Even though this process is the same as normal EDM, it goes faster because the currents are stronger and there are less breaks.

WEDM is a type of electrical discharge machining in which a moving wire is used as the electrode. As the wire electrode is moved through the workpiece (from a spool), spark erosion happens, which changes the rate of material removal.

Quick Pulses of DC electricity are made by the workpiece, wire electrode. A layer of deionized water serves as the dielectric fluid and is positioned between the wire and the workpiece. Water is an insulator when it is pure, but the minerals in common tap water make it all too conductive during wire EDM. Deionised water is water that has had a lot of its conductive parts taken out so that the conductivity can be controlled.

When there is enough voltage, the fluid ionises. Then, a controlled spark is used to carefully chip away at the workpiece, melting and vaporising a small amount of it. Electrical pulses are sent back and forth thousands of times per second. The dielectric, which is a pressurised Cooling fluid drives the eroded particles along with the vaporised metal. that have solidified back out of the gap.

Filtering the dielectric fluid gets rid of the solids that are in suspension. Filters get rid of particles that are in the air, while resins get rid of particles that are in water. To keep the accuracy of the machine and parts, the dielectric fluid flows through a chiller, which keeps the temperature of the fluid constant.

That is method, The workpiece is sliced by a slowly shifting wire that follows a predetermined path, comparable to shape cutting with such a band saw. Those sparks from the wire's discharge act like cutting teeth. With this method, you can cut plates up to 300 mm thick and make hard metal punches, tools, as well as dies. In addition be used to cutting tiny parts for the electronics industry.

Most of the time, the tool wire is made of brass, tungsten, or copper, (Zinc or brass coated) wires and wires with more than one coating are also used. For rough cuts, the wire is usually about 0.30mm in diameter, and for finishing cuts, it is about 0.20mm. High electrical conductivity and the capacity to sweep away material created whenever the wire was cut are further desirable qualities.

Most of the time, the tool wire is only used once because it gets bent as it weakens and loses power. The wire moves to a steady rate speed between 0.15 and 9.0 m/min, and a constant gap (called a "kerf") is kept while the cut is made.

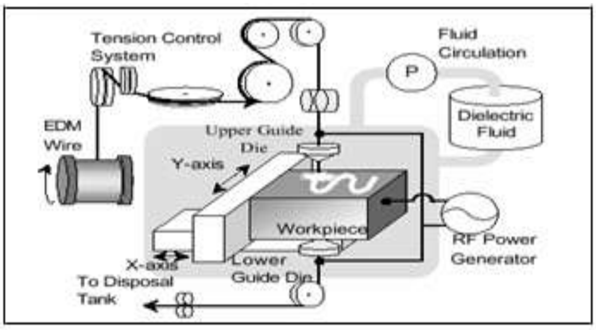

Figure 1.1 Wire Electrical Discharge machining system

II. LITERATURE SURVEY:

Prasath. K et.al Studied on to get the best results from the wire cut EDM process for mild steel and stainless steel. Material rate of removal and surface roughness were studied in relation to the parameters of the wire cut EDM process, like pulse on, voltage, and WFR. Both the SR and rate of material removal had regression models made for them.

Mangesh R. Phate, et.al Author's has analysed the WEDM entire process using composite materials. Experiments showed that the most cost-effective processing parameters for WEDM of AlSiCp20 were a Ton of 108µs , a peak current of 11 amps, a wire feed rate of 4 m/min, and a Toff of 56 µs.

Gurusamy Selvakumar et.al This research article deals with WEDM process allows for the machining of ultra-precision dies with the necessary corner accuracy and surface quality. It is well known that the issues with the WEDM process are wire deflection and wire rupture.

S. Suresh Kumar et.al The experimental analysis revealed the characteristics that were correlated with the input and output. At a wire feed rate of 10 mm / min and a current of 12 A, the least kerf width of 0.271 mm is reached. With a pulse-on time of 110 ms and a wire feed rate of 8 mm/min, the higher 4.76 millimetres per minute (mm/min) cutting speed is reached. According to the RSM method, the optimal circumstances for machining are as follows: a current of 20 A, a pulse on-time of 108.6 milliseconds, a wire feed rate of 10 millimetres per minute, and a B4C content in the composites of 5.65%.

Kingshuk Mandal et.al The parameters of the WEDM process and its current trends have been reviewed by Author. The impact of various electrical parameters and their impact on response variables were summarised in this study. Toff is rising, and the surface finish and MRR are both getting better. This article also offers a revision of the various optimization techniques.

Magesh .M, et.al Author's has analysed the general statistical software MINITAB was used to predict the performance characteristics, specifically the Material Removal Rate (MRR) and surface roughness. To conduct the experiments, Stainless Steel (ss410) material was chosen. Brass wire with a 0.25 mm diameter was used as a tool electrode to cut the material. The design of the experimentations followed Taguchi orthogonal array. Throughout every single test, conducted under alternative set of Input parameters, including Ton, wire speed, Toff, wire tension, dielectric pressure, and current.

III. MATERIAL AND TEST :

AISI D3 steel was used as the test material for the current work's machining. In industrial settings where high hardness and strength are required, such as in plastic moulding die and cold rolling rollers, AISI D3 steel is used. In high-speed applications, its concentricity, straightness, and extreme size accuracy reduce wear. The chemical makeup of the sample material is examined using spark spectroscopy. The chemical make-up and mechanical characteristics of AISI D3 steel are displayed in Table 3.1. A square plate of AIS D3 steel with dimensions of 50 mm in length and 50 mm in width serves as the test specimen for experimental work. Fig. 3 depicts the work piece before and after WEDM machining. 1. On the WEDM machine) depicted in Fig.3.2, wire-cut electrical discharge machining of AISI D3 steel is carried out in accordance with the design of experiment (DOE). The electrode wire that is used has a significant

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impact on how well the WEDM method performs. Wire made of brass is frequently used in WEDM. The wire electrode is made of brass and has a 0.25 mm diameter. The operation of all three axes is servo-controlled and has a 1 micron accuracy. To remove the erosion debris, de-ionized water is flushed through the tool-work piece gap.

Table no 3.1 : AISI D3 Chemical Composition

C	Si	Mn	P	S	Cr	V	W	Fe
2.3200	0.4480	0.4870	0.0215	0.0238	11.1300	0.0558	0.0368	85.47

Figure No 3.1 Work-piece after Machining

Figure No 3.2 WEDM machine

IV. EXPERIMENTATION:

The Electronica Eco cut-system has been used for the experiments. The experiments are carried out using an electrode with a diameter of 0.25mm that is coated in brass. The dielectric used was deionised water, which was maintained at a temperature of 21 °C. To provide the best dielectric flow, the top and lower flushing nozzles should both be fully open. The quality of the products that WEDM produces is influenced by the machining parameters. The experiments in the current study were carried out using the Taguchi-based design method. For the experiments, the L16 orthogonal array (mixed) design technique has been used. Five parameters are used in this instance's four-level design. The five-factor full factorial design with an L-16 orthogonal array (OA). However, the L16 OA fractional factorial design is employed in this instance. Based on preliminary research and previous literature review, pulse on time (Ton in ms), pulse off time (Sv in volt), servo voltage (Sv in volt), wire tension (Wt in m/min), and current (A) have been selected as controllable factors.

Table no: 4.1 AISI D3 WEDM input control Parameter And Their level

Factors levels	Pulse on-time (µs)	Pulse off-time (µs)	Servo voltage (volt)	Wire feed rate (m/min)	Current (A)
1	110	52	25	3	10
2	112	54	30	4	12
3	114	56	35	5	14
4	116	58	40	6	16

The orthogonal array is produced based on the choice of process parameters and their level. Input parameters have Four levels in this scenario. Therefore, Taguchi generates an L16 orthogonal array.

Table no: 4.2Observations for L_{16} Experimentation

Sr. No	Current	Ton	Toff	Servo	Wire Feed	MRR	SR
1	10	110	52	25	3	0.808	1.155
2	10	112	54	30	4	1.18	1.733
3	10	114	56	35	5	1.938	1.938
4	10	116	58	40	6	2.28	1.908
5	12	110	54	35	6	1.938	1.747
6	12	112	52	40	5	1.41	1.865
7	12	114	58	25	4	1.71	2.073
8	12	116	56	30	3	1.824	1.888
9	14	110	56	40	4	2.08	1.943
10	14	112	58	35	3	2.28	2.020
11	14	114	52	30	6	2.108	1.893
12	14	116	54	25	5	1.65	2.053
13	16	110	58	30	5	2.166	2.213
14	16	112	56	25	6	2.808	1.884
15	16	114	54	40	3	1.938	2.121
16	16	116	52	35	4	2.15	2.107

Analysis Using Taguchi and ANOVA for significant and sub-significant parameters:
Taguchi's experiment design use an orthogonal array to arrange the process's parameters and the levels at that they should be adjusted. By reducing the amount both time and effort spent on trial and error, this technique allows for the collection of data needed to determine which factor provides the largest effect on product quality. The average Ra values at various levels of voltage, WFR, Ton, and Toff The main effect plot for SR is displayed in Figure 4.1. It demonstrates how nearly proportional the SR value is to the current, voltage, cycle time, and Toff. The SR is influenced by discharge energy because when a lot of discharge energy is transferred to the workpiece surface, it creates deep, uneven craters that are larger in size, which raises the SR. However, due to the fact that SR values rise as these parameters are increased, current, voltage, WF, and Ton function as an energy source.

Analysis of Variance (ANOVA) for surface roughness (Ra):
The statistical procedure most frequently used to analyse experimental results to as certain analysis of variance, one may determine the weight of each factor. Which of the components require control and which do not can be determined by looking at the ANOVA table for the particular analysis. Running confirmation experiments is

typically a good idea once the ideal circumstance has been identified.
The study breaks down the elements into those that were random and those that could be influenced. Knowing the source and magnitude of the variation enables one to forecast the robust operating condition. The Taguchi L16 orthogonal array has become comfortable to analyse the variance for Ra. To discover the significant and sub-significant parameters for Ra, Mini Tab-17 does an ANOVA.

Table 4.3 Response table for means of surface roughness by ANOVA

Source	DF	SS	MS	F-value	P value
TON	2	1.658	1.255	24.37	0.000
TOFF	2	0.124	0.101	2.52	0.111
S.V	2	0.145	0.056	1.50	0.389
W.F	2	0.375	0.121	2.40	0.205
I	2	1.185	0.527	15.41	0.001
Error	16	0.528	0.042	-	
Total	26				

In table 4.3, an ANOVA analysis of the data means is presented. It shows that the pulse on time (s), followed by current and wire feed (m/min), pulse off time (s), and servo voltage (v), is a parameter that is also highlighted with the greatest impact on the surface roughness.

Analysis of Variance (ANOVA) for Material Removal Rate:

Table 4.4 displays the results of an ANOVA on the data means. It shows that the pulse on time (s) has the greatest impact on the rate at which material is removed, followed by the servo voltage and current, the pulse off time (s), and the wire feed rate (m/min), in that order.

Table: 4.4 ANOVA for Means MRR (L16)

Source	DF	SS	MS	F-value	P value
Ton	2	0.086	0.057	47.10	0.000
Toff	2	0.002	0.002	0.44	0.562
SV	2	0.034	0.022	10.86	0.004
WF	2	0.001	0.002	0.08	0.805
I	2	0.200	0.005	4.64	0.034
Error	16	0.030	0.004		
Total	26	0.355	-	-	-

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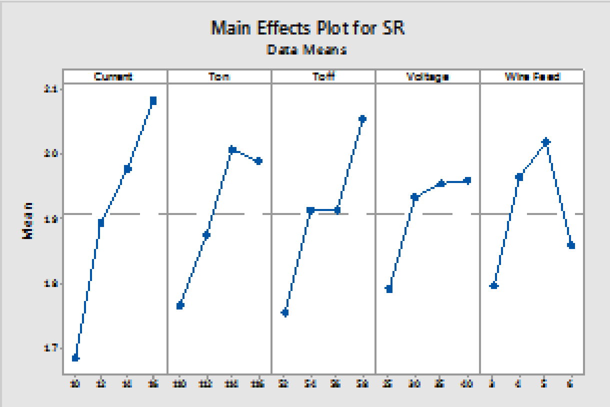

Figure 4.1 Main effect plot for Ra data means v/s pulse on time, pulse off time, servo voltage, wire feed, Current.

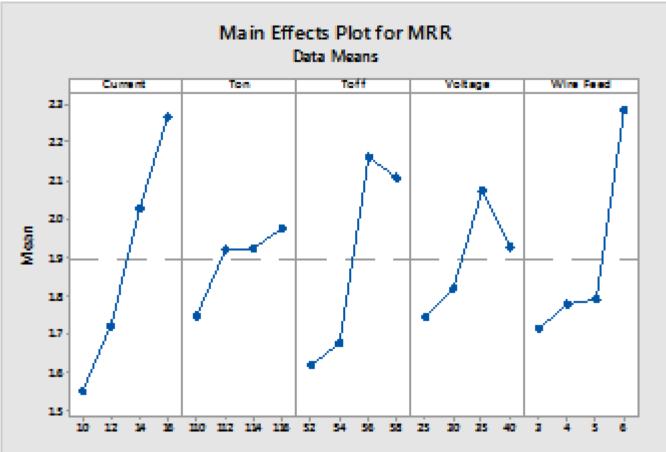

Figure 4.1 Main effect plot for MRR data means v/s pulse on time, pulse off time, servo voltage, wire feed, Current.

Grey Relational Analysis (GRA) :

A grey system is one that has information between black and white, according to the grey relational analysis, which suggests that the systems has no information indicated by black and all information indicated by white. Grey analysis helps to compensate for statistical regression's limitations in complex experiments or when a experimental technique cannot be followed precisely. Grey relation analysis may assess various elements that can compensate for the limitations of statistical approaches and is a useful tool for analysing the relationship between sequences with less data. A complicated multivariate system typically has many components, many of which are not clearly related to one another. Grey relational analysis, a method for measuring the influence of grey systems, looks at the ambiguous links between one key element and all other elements in a particular system. When studies are unclear or the experimental protocol cannot be followed properly, grey analysis might help to compensate for the shortcomings in statistical regression. Gray relational analysis typically requires data pre-processing because the range and unit in one data sequence may vary from the others. Additionally, the original sequence must be converted into a comparable sequence.

Indicators of better success in the PMWEDM process include "the lower surface roughness and the higher MRR," which are used during data pre-processing in grey relational analysis. The original sequence has the "bigger is better" quality if and only if its goal value is infinite. The initial order can be normalised as shown below

$$X_i^*(K) = \frac{MaxX_i^0(K) - X_i^0(K)}{MaxX_i^0(K) - MinX_i^0(K)} \qquad Eq.1$$

$$X_i^*(K) = \frac{X_i^0(K) - MinX_i^0(K)}{MaxX_i^0(K) - MinX_i^0(K)} \qquad Eq.2$$

The comparison sequence for "lower the better" and "higher the better" qualities, respectively, is obtained using Equations 1 and 2. After data pre-processing grey relational coefficient is calculated. Following is an expression for the grey relation coefficient (k) for the Kth performance characteristics in the ith experiment.

$$\xi_i^{(k)} = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \qquad Eq.3$$

Where the notation $\Delta 0i$ is used to designate the reference sequence's and the comparability sequence's of deviation sequence.

$\Delta 0i\ (k) = \|x_0^*(k) - x_i^*(k)\|$ Eq.4

$X_0^*(k) = 1$ ……… (Maximum normalized value)

$\Delta min = min\|x_0(k) - x_i(k)\| = \|1-1\| = 0$ Eq. 5

$\Delta max = max\|x_0(k) - x_i(k)\| = \|1-0\| = 1$ -----------Eq.6

ζ is the distinguishing or identification coefficient: ζ ϵ [0, 1] (the value may be adjusted based on the actual system requirements). The distinctive ability is greater and the value of ζ is smaller. It is typical to ζ =0.5. It is customary to use the grey relational grade as the average value of the grey relational coefficients. Below is the grey relationship grade.

$\gamma_i = \sum W_i(k) \times \xi_i(k)$ Eq. 7

Where,

γ_i= Grey relational grade

W_i= Weightage given to response variable

Table No 4.5: Grey Relational Analysis

Sr. No	I	Ton	Toff	V	Wire Feed	MRR	SR	MRR (GRR)	SR (GRR)	MRR (GRC)	SR (GRC)	GRG	Rank
1	10	110	52	25	3	0.808	1.155	0.000	1.000	0.500	1.000	0.750	11
2	10	112	54	30	4	1.18	1.733	0.186	0.454	0.551	0.647	0.599	8
3	10	114	56	35	5	1.938	1.938	0.565	0.260	0.697	0.575	0.636	13
4	10	116	58	40	6	2.28	1.908	0.736	0.289	0.791	0.584	0.688	5
5	12	110	54	35	6	1.938	1.747	0.565	0.440	0.697	0.641	0.669	12
6	12	112	52	40	5	1.41	1.865	0.301	0.329	0.589	0.599	0.594	14
7	12	114	58	25	4	1.71	2.073	0.451	0.133	0.646	0.536	0.591	16
8	12	116	56	30	3	1.824	1.888	0.508	0.307	0.670	0.591	0.630	9
9	14	110	56	40	4	2.08	1.943	0.636	0.255	0.733	0.573	0.653	6
10	14	112	58	35	3	2.28	2.020	0.736	0.182	0.791	0.550	0.671	7
11	14	114	52	30	6	2.108	1.893	0.650	0.302	0.741	0.589	0.665	4
12	14	116	54	25	5	1.65	2.053	0.421	0.152	0.633	0.541	0.587	2
13	16	110	58	30	5	2.166	2.213	0.679	0.000	0.757	0.500	0.629	10
14	16	112	56	25	6	2.808	1.884	1.000	0.311	1.000	0.592	0.796	1
15	16	114	54	40	3	1.938	2.121	0.565	0.087	0.697	0.523	0.610	15
16	16	116	52	35	4	2.15	2.107	0.671	0.100	0.752	0.526	0.639	3

Scanning Electron Microscope (SEM) Result Analysis at Different Magnifications:

Out of 16 readings, the top and worst readings were chosen based on GRA analysis. Micrographs had been taken at different magnification level (25X, 50X, 75X, 100, 150X, 200X) on scanning electron microscope (SEM).Reading No.14 is selected as the best reading.

Table No 5.1: Best readings parameters

Parameter	Ton	Toff	S.V.	WF	Current
	112	56	25	6	16

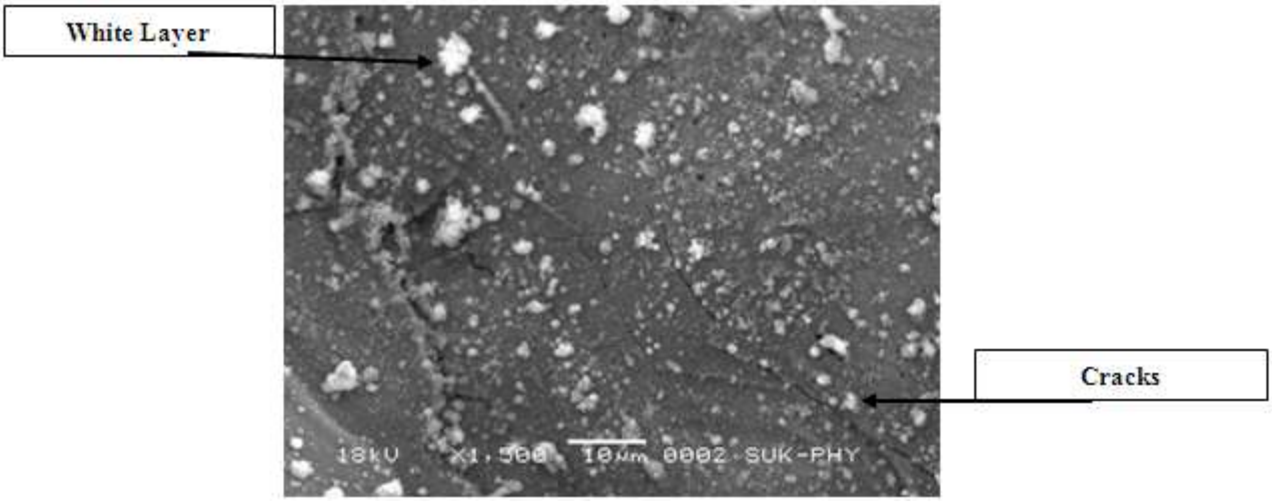

Figure 5.1: SEM image of 100X for best hole

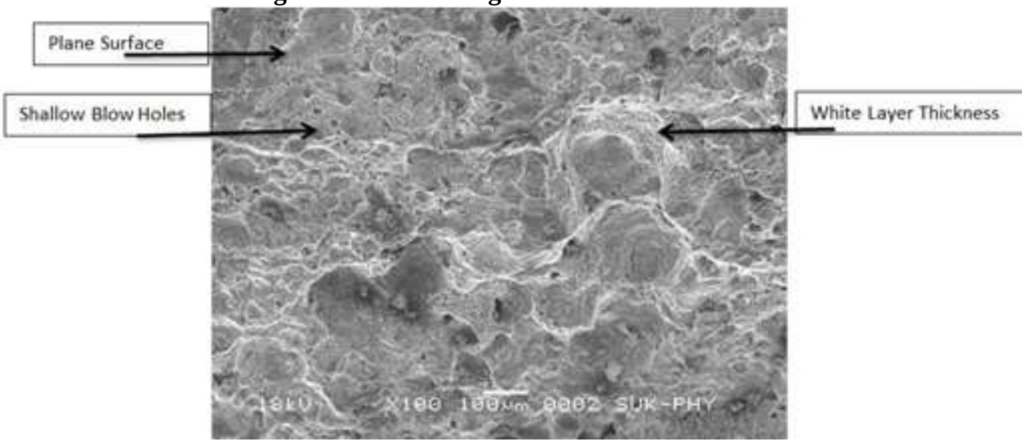

Figure 5.2: SEM image of 1500X for best hole

Fig 5.1 and 5.2 are the SEM Images of the best reading from GRA Analysis and they show that

- The finished surface is more and cracks are less.
- Shallow blow holes are present.
- Plane Maximum white layer thickness is present because of the heavy layer of dirt particles and high carbon deposition but at high magnification in fig 5.1 shows less formation of white layer thickness.

Table No 5.2: Worst readings parameters

Parameter	Ton	Toff	S.V.	WF	Current
	114	58	25	4	16

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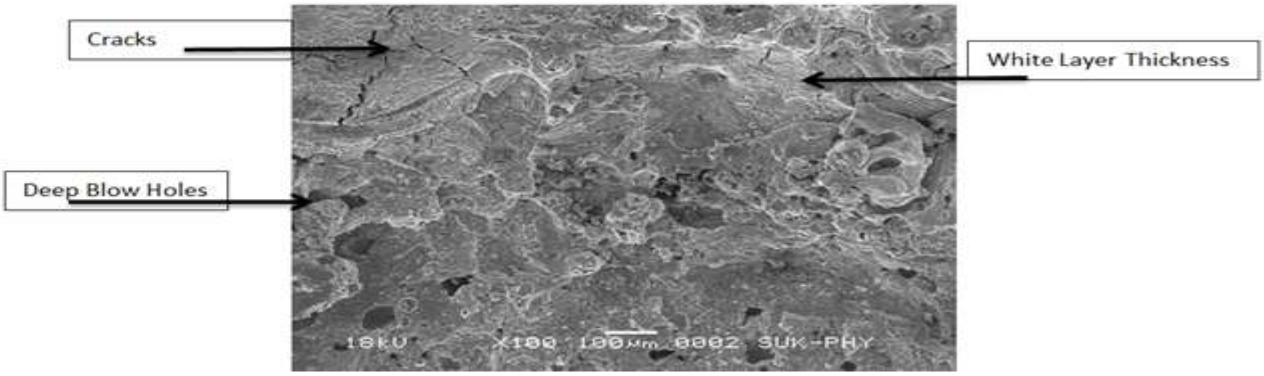

Figure 5.3 SEM image of 100X for worst hole

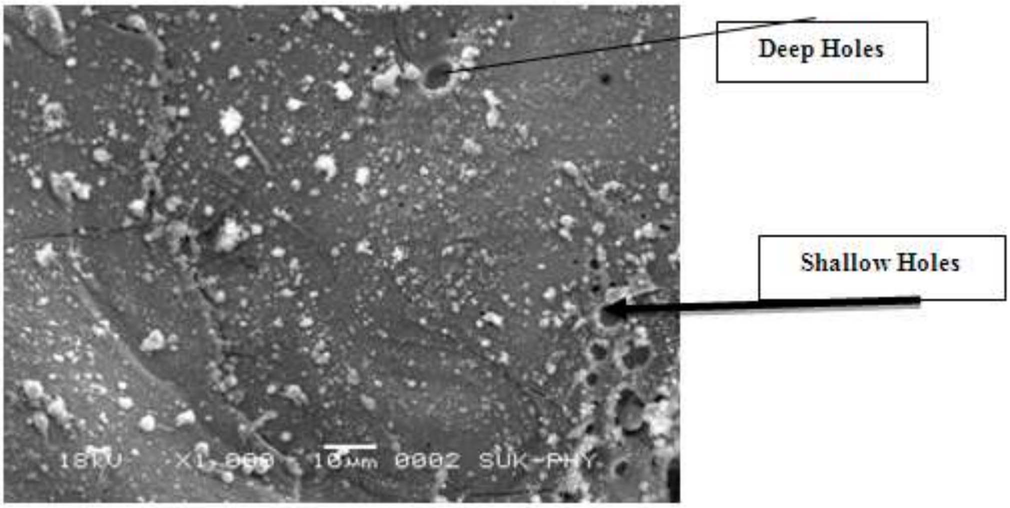

Figure 5.4 SEM image of 1000X for worst hole

Figure 5.3, and 5.4 shows the SEM image of the worst reading. From this figure, three observations are carried out.

- More cracks are present and the surface is rough as compared to figure 5.1 and 5.2
- In figures 5.3 and 5.4 deep blow holes are present because more air is trapped which causes blow hole defect.

Fig 5.4 shows the more rough surface area as compared to fig 5.3 at the same magnification and welded burr. White layer thickness is less because less deposition of carbon

V. CONCLUSION:

1. By using an ANOVA on the averages of the data, we can see that the Ton has the highest significance on SR (P = 0.000), followed by the current (P = 0.001). No real difference is made by the servo voltage, wire feed rate, or pulse off time.
2. Means-based analysis of variance for WEDM with L16 DOE data reveals that pulse on time (0.000 'p' value) has highest significance on MRR, followed by voltage (0.004 'p' value) and current (0.034 'p' value).
3. Based on the Grey-Taguchi analysis of L16 data, the optimal values for the WEDM parameters are I = 16 A, Ton = 112 s, Toff = 56 s, V = 25V, and WF = 6 m/the weights for Ra and MRR are equal. Where as the worst optimum setting rank 16 of WEDM parameters as I = 12 A, Ton = 114 µs, Toff = 58 µs,V = 25V and WF = 4 m/min. the weights for Ra and MRR are equal.
4. Recast layer of best readings is shown in fig 5.1. These readings are taken for rank 1 reading. And worst reading is in fig. 5.2 shows the reading at rank 16. It clearly shows that parameter setting for rank 1 helps to improve surface finish as well as to improve MRR. As a surface finish is good in fig 5.1 it shows less recast layer formation on surface. Recast layer is one type of defect which form because deposition of burr on surface. It reduces surface finish as well as MRR. The fig 5.2. Shows more formation of recast layer on surface also SR and MRR are low.

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