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Comparison of Output Responses after Machining Holes on Aluminum Alloy by Die Sinking EDM and CNC Drilling

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Abstract— In recent years, the use of advanced machining processes has increased for machine hard to cut materials. So, there is a vast field of research in this area in order to know the difference between conventional and advanced machining processes.

The present work is aimed to give a comparison of output responses like surface finish, form errors, diametric overcut, and dimensional accuracy after machining Aluminium alloy HE-30 by CNC drilling and Die sinking EDM process.

Firstly, holes of particular diameter have been made on Aluminium alloy by varying the input parameters (Speed, feed rate etc.) of CNC drilling machine. Then, holes of same diameter have been machined by the help of die sinking EDM on the same material by changing the input parameters which are (Pulse on time, pulse off time, current) available in the machine.

Then, the responses like surface roughness, diametral overcut have been measured for both these cases. The objective of this work was to find out the best possible way to obtain good Surface finish and also to minimize the form error and diametric overcut for machining holes by single operation.

***Keywords*—component; formatting; style; styling; insert (key words)**

I. INTRODUCTION

CNC Drilling & die sinking EDM are the two machines selected for machining holes on AL-alloy HE 30 material. Input parameters selected for this experimentation are speed, feed, depth of cut, flushing rate for CNC drilling[4] & pulse on time, pulse off time, peak current & flushing rate for die sinking EDM. [5]The input values were selected based on Taguchi Orthogonal Array Method. The output responses taken were surface roughness & diametral overcut for both CNC drilling & Die sinking EDM. So, the output responses will be compared based on the experimentation values.

II. TAGUCHI ORTHOGONAL ARRAY METHOD

Taguchi method is systematic and efficiency approach to find the optimal combination of input parameter his method utilizes the orthogonal array of experiments to reduce the no of experiment in any machining process for this study we have selected, L9 orthogonal array [3]using the orthogonal array 9 experiment have been conducted. It is also used to study the effects of input parameters on response variables it analyses result based on s/n ration. Taguchi method involves reducing variation in a process through Design of experiment the overall objective of this method is to produce high quality product at low cost to the manufacturer.

The experiment design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and levels at which they should be varied.

Taguchi design method is to identify the parameter setting which render the quality of a product or process design of experiment is based on L9 orthogonal array experiment are conducted on aluminium alloy HE(30).

The Taguchi's method of quality engineering design is built around three integral elements, S/N ratio, orthogonal arrays (loss function) which are each closely related to the definition of quality.

Taguchi method is a scientifically disciplined mechanism for evaluating & implementing improvements in product, process, materials equipment's & facilities. These improvements are aimed at improving the desired character& simultaneously reducing No. of defects by studying key variables controlling the process & optimizing the procedure or design to yield the best results. Taguchi proposed a standard procedure for applying his method for optimizing any process.

It is a type of experiment where the columns for the independent variables are "Orthogonal"[3] to one another. Orthogonal arrays are employed to study the effect of several control factors. Orthogonal array are to use to investigate the quality, orthogonal array are not unique to Taguchi, they were discovered considerably earlier (Bendell, 1998) However, Taguchi has simplified their use by providing tabulated sets of standard.

Selection of orthogonal array:

To select an appropriate orthogonal array for the experiments, the total (degree of freedom) need to be computed, the degree of freedom are defined as the no of comparisons between design of parameters that need to be made to determine which level is better & specifically how much better it is. For example, a three-level design parameter counts for two design parameter are given by the product of the degree of freedom for the to design parameter.

Table 1. Variables and number of experiments selected

Variables	A	B	C	D
Level 1	1	1	1	1
Level 2	2	2	2	2
Level 3	3	3	3	3

Table 2. Taguchi Orthogonal (L9) array

Experiment No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Signal-to-noise Ratio:

The S/N Ratio concept is related to the (robustness) of product design. A robust design of product delivers strong signal. It performs its expected function & can cope with variation (“noise”) both internal & external. In S/N ratio signals represent the desirable values & noise represents the undesirable value.

In the Taguchi method, the term signal represents desirable value for output character & the term “noise” represents the undesirable value (standard deviation) for the output character. The S/N ratio measures the sensitivity of the quality character being investigated in a controlled manner to those external influencing factor (noise factor) not under control so, Taguchi uses the S/N ratio to measure the quality character value there are mainly three S/N ratio available … [Depending on design different S/N ratios are applicable, including “Lower is better” (LB),”Nominal is better” (NB)”Higher is better” (HB)].

III. ANALYSIS OF VARIANCE

Analysis of variance (ANOVA) is a statistical technique to analyse variation in a response variable (continuous random variable) measured under conditions defined by discrete factors (classification variables, often with nominal levels). Frequently, we use ANOVA to test equality among several means by comparing variance among groups relative to variance within groups (random error).

Sir Ronald Fisher pioneered the development of ANOVA for analysing results of agricultural experiments. Today, ANOVA is included in almost every statistical package, which makes it accessible to investigators in all experimental sciences. It is easy to input a data set and run a simple ANOVA, but it is challenging to choose the appropriate ANOVA for different experimental designs, to examine whether data adhere to the modelling assumptions, and to interpret the results correctly.

Steps of ANOVA

1. The Sums of Squares:

Computing SS_{total}: The SS_{total} is the SS based on the entire set of scores in the study. So computing this SS is the same as if we just stacked our different treatment samples together to form a single sample and then computed the Sum of Squares on that one larger sample in terms of

$$\boxed{SS_{total} = \Sigma X^2 - \frac{G^2}{N}}$$

2. Computing SS_{within}:

To compute SS_{within}, we first need to compute the SS_{within} each level using the regular SS formula:

$$\boxed{SS = \Sigma X^2 - \frac{(\Sigma X)^2}{n}}$$

Then to get SS_{within} all the SS values should be added up.

$$\boxed{SS_{within} = \Sigma SS}$$

3. Computing $SS_{between}$:

The variance between treatments measures the differences or variance between the treatment means. This implies one way we could find the $SS_{between}$ would be to compute a SS using the X-'s as the scores. That is, we could consider our deviations (that we will square and sum) as the deviation of each individual mean from the grand mean (the grand mean is the overall mean of the entire set of data or G/N). Of course, there is a computational formula that looks different

$$\boxed{SS_{between} = \left[\Sigma\frac{T^2}{n}\right] - \frac{G^2}{N}}$$

From that, but is much easier to use.

In computing the degrees of freedom, we should keep in mind that:

1) Each df is associated with a specific SS.

2) The df are approximately equal to the number of items that went into computing the corresponding SS minus 1. So if n things went in, then df = (n – 1).

4. Computing the df:

1) df_{total} = N - 1Because SS_{total} was computed using the entire set of N scores.

2) df_{within} = N - k to get the SS_{within} we first computed the SS for each level and then added them up. This is the same for df_{within} in a sense. For each level we have "n - 1" degrees of freedom. Then we sum those n - 1 degrees of freedom across the levels: (n - 1) + (n - 1) + (n - 1) + ... If you simplify this, you get N - k which is the right number for the df_{within}.

3) $df_{between}$ = k - 1 Because $SS_{between}$ is really based on the deviations of each treatment mean from the grand mean, the number of items in this SS is the number of treatment means = k. So the $df_{between}$ = k - 1.

Now,

$df_{total} = df_{between} + df_{within}$

5. Computing the between and within variances:

Recall that a variance is SS/df. In ANOVA the variances we compute are called Mean Squares, symbolized "MS" (Because they are essentially mean squared deviations)

So we can compute:

$$\boxed{MS_{between} = \frac{SS_{between}}{df_{between}} = \text{the varience between treatments}}$$

and

$$\boxed{MS_{between} = \frac{SS_{within}}{df_{within}} = \text{the varience within treatments}}$$

Finally, because the F test is the variance between divided by the variance within, we get our F-ratio:

$$\boxed{F = \frac{MS_{between}}{MS_{within}}}$$

IV. MATERIAL

The material selected for this experimentation process by CNC drilling and die sinking EDM is Aluminium alloy HE-30. Aluminium alloy HE-30 also corresponds to the following specifications:

- HE30
- AA6082
- DIN 3.2315
- EN AW-6082
- ISO: Al Si1MgMn

Table 3. The chemical composition for aluminium alloy 6082

Elements	% Present
Si	0.7-1.3
Fe	0.0-0.5
Cu	0.0-0.1
Mn	0.4-1.0
Mg	0.6-1.2
Zn	0.0-0.2
Ti	0.0-0.1
Cr	0.0-0.25
Al	Balance

V. EXPERIMENTATION

A. CNC Drilling

Tool in the CNC drilling process, a drill bit tool is used to drill the holes on the work material. In the present work, a HSS (High Speed Steel) drill bit is used to drill holes on the work material. The diameter of the drill bit used for drilling is of 8.5mm.

Chosen three levels with four factors based on Taguchi orthogonal array (L9) technique which are speed, feed, depth of cut and flushing rate. The three levels taken for each factors are in the ranges of,

Table 4. Selected input variables and its levels for CNC drilling.

Variables	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Flushing rate (kg/cm^2)
Level 1	1000	40	0.3	3
Level 2	1500	45	0.4	5
Level 3	2000	50	0.5	7

Table 5. Experimental design table for CNC drilling.

Experiment No.	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Flushing rate (kg/cm^2)
1	1000	40	0.3	3
2	1000	45	0.4	5
3	1000	50	0.5	7
4	1500	40	0.4	7
5	1500	45	0.5	3
6	1500	50	0.3	5
7	2000	40	0.5	5
8	2000	45	0.3	7
9	2000	50	0.4	3

Experimental Procedure:

Firstly trial experiments were conducted to fix the parameters for machining aluminium alloy HE-30 with drill bit with ϕ8.5mm. After fixing the drill bit the above mentioned parameters were selected. Then, holes of diameter 8.5mm were drilled using CNC drilling for each combination of setup from the design table. Trial experiments were performed at first based on which the input parameters range was selected.

B. Die Sinking EDM

The electrode selected for this experimentation in die sinking EDM process was a copper electrode with the diameter 8.5mm; it is used to drill the hole on an aluminium alloy 6082.Chosen three levels with four factors based on Taguchi orthogonal array (L9) technique which are pulse on time, pulse off time, peak current, flushing rate. The three levels taken for each factors are in the ranges of,

Table 6. Selected input variables and its levels for die sinking EDM

Variables	Pulse on time (micro sec)	Pulse off time (micro sec)	Peak current (amps)	Flushing rate (kg/cm^2)
Level 1	6	5	9	3
Level 2	7	6	12	5
Level 3	8	7	15	7

Table 7 Experimental design table for die sinking EDM.

Experiment No.	Pulse on time (micro sec)	Pulse off time (micro sec)	Current (amps)	Flushing rate (kg/cm^2)
1	6	5	9	3
2	6	6	12	5
3	6	7	15	7
4	7	5	12	7
5	7	6	15	3
6	7	7	9	5
7	8	5	15	5
8	8	6	9	7
9	8	7	12	3

VI. RESULTS

A. *CNC Drilling Results*

The output responses obtained after machining holes by CNC drilling on Aluminium alloy are shown in the table as follows,

Table 8. Input parameters and output responses for CNC drilling

Experiment no.	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Flushing rate (kg/cm^2)	SR	Dia Over cut
1	1000	40	0.3	3	1.65	0.23
2	1000	45	0.4	5	2.32	0.25
3	1000	50	0.5	7	1.12	0.17
4	1500	40	0.4	7	1.69	0.26
5	1500	45	0.5	3	2.38	0.17
6	1500	50	0.3	5	1.09	0.18
7	2000	40	0.5	5	1.71	0.20
8	2000	45	0.3	7	2.41	0.20
9	2000	50	0.4	3	1.07	0.23

Table 9. Average effect response table for Surface Roughness of Al HE30

Levels	A (rpm)	B (mm/min)	C (mm)	D (kg/cm^2)
1	1.69	1.68	1.71	1.7
2	1.72	2.37	1.69	1.70
3	1.73	1.09	1.73	1.74
Δmax-min	0.04	0.04	0.04	0.04
Rank	4	1	2	3

Table 10. Average effect response table for Diametral Overcut of Al HE30

Levels	A (rpm)	B (mm/min)	C (mm)	D (kg/cm^2)
1	0.2211	0.2356	0.2045	0.2145
2	0.2078	0.2100	0.2500	0.2156
3	0.2145	0.1978	0.1845	0.2134
Δmax-min	0.0133	0.0378	0.0655	0.0002
Rank	3	2	1	4

Table 11. Results of S/N ratio for Surface roughness of Al HE30

Experiment No	Ra_1	Ra_2	Ra_3	Average	S/N ratio
1	1.68	1.63	1.65	1.65	-4.3496
2	2.33	2.31	2.32	2.32	-7.3097
3	1.12	1.10	1.14	1.12	-0.9843
4	1.70	1.72	1.67	1.69	-4.5577
5	2.39	2.38	2.39	2.38	-7.5315
6	1.10	1.07	1.12	1.09	-0.7485
7	1.7	1.7	1.74	1.71	-4.6599
8	2.39	2.44	2.40	2.41	-0.76403
9	1.07	1.07	1.07	1.07	-0.5876

Table 12 Average effect response table for S/N ratio for surface roughness of Al HE30

Levels	A (rpm)	B (mm/min)	C (mm)	D (kg/cm^2)
1	-4.2145	-4.5224	-4.2461	-4.1562
2	-4.2792	-7.4938	-4.1516	-4.2393
3	-4.2959	-0.7854	-3.0344	-4.3941
Δmax-min	0.0814	6.7084	1.2117	0.2379
Rank	4	1	3	2

Table 13. Results of S/N ratio for Diametral Overcut of Al HE30

Experiment No	D_1	D_2	D_3	Average	S/N ratio
1	8.25	8.34	8.20	0.2367	12.516
2	8.34	8.34	8.06	0.2534	11.9238
3	8.35	8.34	8.29	0.1734	15.2190
4	8.20	8.26	8.25	0.2634	11.5876
5	8.33	8.33	8.32	0.1734	15.2190
6	8.33	8.31	8.30	0.1867	14.5771
7	8.34	8.24	8.30	0.2067	13.6931
8	8.24	8.32	8.33	0.2034	13.8329
9	8.27	8.21	8.32	0.2334	12.6379

Table 14. Average effect response table for S/N ratio for diametral overcut of Al HE30

Levels	A (rpm)	B (mm/min)	C (mm)	D (kg/cm^2)
1	13.2196	12.5989	13.642	13.4576
2	13.7945	13.6585	12.0497	13.398
3	13.3879	14.1446	14.7103	13.5465
Δmax-min	0.5749	1.5457	2.6606	0.1485
Rank	3	2	1	4

Table 15 ANOVA results for surface roughness

Source of variation	DOF	SS	MS	F-Ratio	Contribution (P %)
A	2	0.0027	0.0013	0.0001	0.0122
B	2	2.4627	1.2313	0.1253	11.1364
C	2	0.0024	0.0012	0.0001	0.0108
D	2	0.0033	0.0016	0.0001	0.0149
Error	20	19.6428	9.8214	-	-
Total	28	22.1139	-	-	-

Table 16. ANOVA results for diametral overcut

Source of variation	DOF	SS	MS	F-Ratio	Contribution (P%)
A	2	0.0002	0.0001	0.0036	0.3244
B	2	0.0022	0.0011	0.0308	2.7298
C	2	0.0067	0.0033	0.0933	8.2646
D	2	0	0	0	0
Error	20	0.0362	0.0362	-	-
Total	28	0.0818	-	-	-

B. Die Sinking EDM Results

The output responses obtained after machining holes by die sinking EDM on Aluminium alloy are shown in the table as follows

Table 17. Input parameters and output responses of die sinking EDM

Experiment no.	T_{on} (μ sec)	T_{off} (μ sec)	Ip (amps)	Flushing rate (kg/cm^2)	SR	Dia Over cut
1	6	5	9	3	1.64	0.1
2	6	6	12	5	2.08	0.22
3	6	7	15	7	1.2	0.17
4	7	5	12	7	1.46	0.22
5	7	6	15	3	1.16	0.18
6	7	7	9	5	2.02	0.14
7	8	5	15	5	0.74	0.16
8	8	6	9	7	2.14	0.05
9	8	7	12	3	1.66	0

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Table 18. Average effect response table for Surface Roughness of Al HE30

Levels	A (μ sec)	B (μ sec)	C (amps)	D (kg/cm^2)
1	1.64	1.94	1.93	1.48
2	1.54	1.79	1.73	2.28
3	2.18	1.62	1.7	1.6
Δmax-min	0.64	0.32	0.23	0.8
Rank	2	3	4	1

Table 19. Average effect response table for Diametral Overcut of Al HE30

Levels	A (μ sec)	B (μ sec)	C (amps)	D (kg/cm^2)
1	0.1644	0.1633	0.1010	0.0944
2	0.1844	0.1533	0.1477	0.1777
3	0.0744	0.1066	0.1744	0.1510
Δmax-min	0.11	0.0567	0.0734	0.833
Rank	1	4	3	2

Table 20: Results of S/N ratio for Surface roughness of Al HE30

Experiment No	Ra_1	Ra_2	Ra_3	Average	S/N ratio
1	1.20	2.08	1.64	1.64	-4.2968
2	2.08	2.06	2.10	2.08	-6.3612
3	1.3	1.19	1.11	1.20	-1.5836
4	1.48	1.47	1.43	1.46	-3.2870
5	1.16	1.11	1.21	1.16	-1.2891
6	2.01	2.07	1.98	2.02	-6.1070
7	2.77	2.89	2.58	2.74	-8.7550
8	2.15	2.08	2.2	2.14	-6.6082
9	1.66	1.67	1.66	1.66	-4.4021

Table 21. Average effect response table for S/N ratio for surface roughness

Levels	A (micro sec)	B(micro sec)	C (amps)	D (kg/cm^2)
1	-4.0805	-5.4462	-4.0647	-3.3293
2	-3.5610	-4.7528	-4.6834	-7.0744
3	-6.5884	-4.0309	-3.8759	-3.8262
Δmax-min	3.0274	1.4153	0.8075	3.7451
Rank	2	3	4	1

Table 22. Results of S/N ratio for Diametral Overcut of Al HE30

Experiment No	D_1	D_2	D_3	Average	S/N ratio
1	8.67	8.54	8.51	0.1	20
2	8.72	8.67	8.77	0.22	13.1515
3	8.54	8.69	8.79	0.1733	15.2240
4	8.73	8.66	8.78	0.2233	13.0222
5	8.68	8.62	8.75	0.1833	14.7367
6	8.69	8.60	8.65	0.1466	16.6773
7	8.69	8.81	8.50	0.1666	15.5665
8	8.54	8.59	8.54	0.0566	24.9436
9	8.60	8.49	8.41	0	0

Table 23. ANOVA results for surface roughness

Source of variation	DOF	SS	MS	F-Ratio	Contribution (P%)
A	2	0.7116	0.3558	0.0433	3.8456
B	2	0.1539	0.0769	0.0093	0.8317
C	2	0.0942	0.0471	0.0057	0.5090
D	2	1.1172	0.5586	0.0680	6.0376
Error	20	16.4271	8.2135	-	-
Total	28	18.504	-	-	-

Table 24. ANOVA results for diametral overcut

Source of variation	DOF	SS	MS	F-Ratio	Contribution (P%)
A	2	0.0206	0.0103	0.1143	9.035
B	2	0.0054	0.0027	0.0299	2.3684

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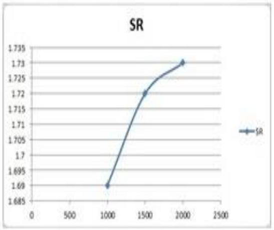
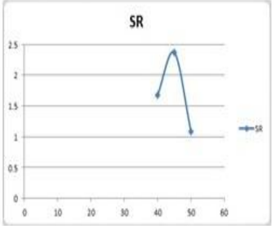
C	2	0.0082	0.0041	0.0455	3.5964
D	2	0.0108	0.0054	0.0599	4.7368
Error	20	0.1803	0.0901	-	-
Total	28	0.2280	-	-	-

VII. GRAPHS

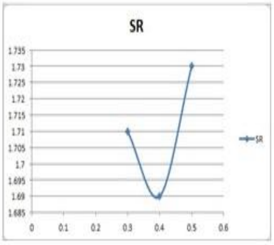
GRAPHS OBTAINED FOR CNC DRILLING



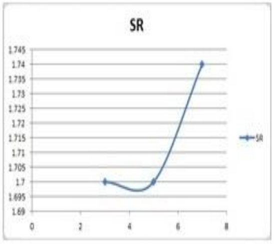
Graph 1 Speed Vs Surface Roughness



Graph 2 Feed Vs Surface Roughness

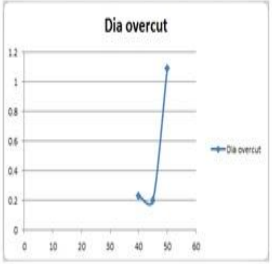


Graph 3 Depth of cut Vs SR

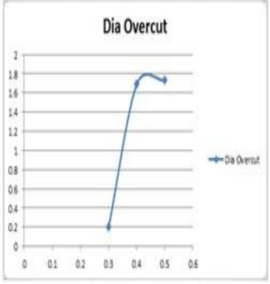


Graph 4 Flushing Rate Vs SR

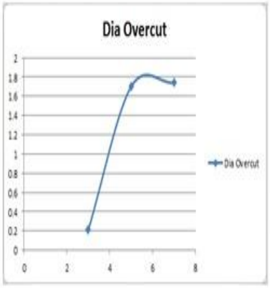
Graph 5 Speed Vs Dia Overcut



Graph 6 Feed Vs Dia Overcut

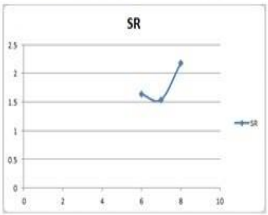


Graph 7 Depth of cut Vs Dia overcut

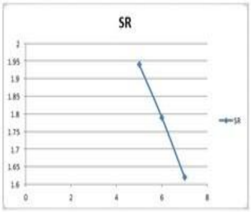


Graph 8 Flushing rate Vs Dia overcut.

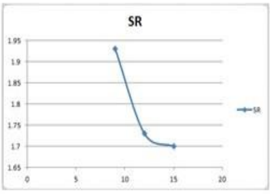
GRAPHS OBTAINED FOR DIE SINKING EDM



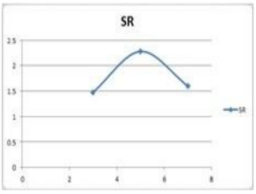
Graph 9 T_{on} Vs surface roughness



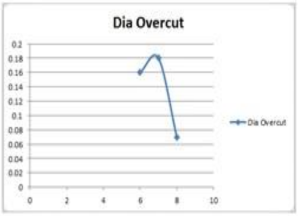
Graph 10 T_{off} Vs surface roughness



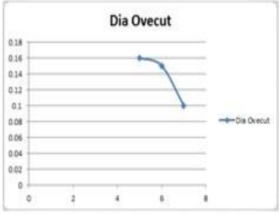
Graph 11 Ip Vs surface roughness



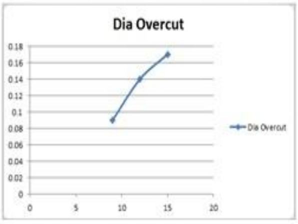
Graph 12 Flushing rate Vs SR



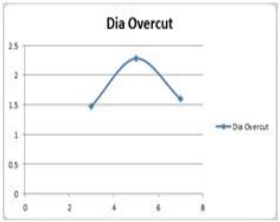
Graph 13 T_{on} Vs Dia overcut



Graph 14 T_{off} Vs Dia overcut



Graph 15 Ip Vs Dia overcut



Graph 16 Flushing rate Vs Dia overcut

VIII. CONCLUSION

It is found that for CNC drilling by increasing the speed there was a gradual increase in the surface roughness, when the feed is increased there was a little increase and then gradually decreased its surface roughness. Depth of cut and flushing rate had a gradual increase in its surface roughness. The diameter over cut also has increased in the case of speed and feed inputs but it has decreased for the depth of cut and flushing rate.

For the die sinking EDM as the pulse on time increased the surface roughness also increased in the case of pulse on time there was constant increase, by increasing the current surface roughness has gradually decreased. Also, diameter overcut has decreased for pulse on time and pulse off time inputs but it has increased when current has increased in both the outputs of surface roughness and diameter overcut

So, it is found from the ANOVA results that surface roughness and diameter overcut has increased for die sinking EDM but, whereas there were better results obtained in the case of CNC drilling.

IX. FUTURE SCOPE

- The range and the parameters can be changed individually, the process parameters can be optimized for CNC drilling and die sinking EDM.
- The form errors any formed can be checked.
- Different tool materials can be chosen for EDM specially to check the output responses.

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