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Research Paper

AN INVESTIGATION TO STUDY THE EFFECT OF DRILLING PROCESS PARAMETERS ON SURFACE FINISH USING TAGUCHI METHOD

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The major operation carried out in the machining industry is drilling process. In Shanthala Machining Technologies Pvt. Ltd., it is observed that the produced parts under the drilling process have high rejection because of surface roughness in drilled hole. Here an effort is made to solve the above problem using Robust design methodology. We identified five factors with three levels and one factor with two levels and experiment is carried out using L18 orthogonal array. The data obtained is analyzed using manual method and solver (Minitab). Feed rate and Type of coolant are the factors which affect the surface finish severely. Optimal level for these factors are 36 mm/min and through coolant respectively. In this study, a confirmation experiment was conducted by utilizing the optimal levels of the process parameters (A1 B1 C1 D2 E2 F3) resulted in response values of 3.210, 3.203, 3.208 µm. Each Ra measurement was repeated at least three times. Therefore the optimum surface finish (Ra = 3.207 µm) can be obtained under the above mentioned cutting condition. This methodology can be used for process improvement of similar kind.

Keywords: Drilling process parameters, Taguchi's techniques, Minitab solver, Control factors, Noise factors, Statistical process improvement, Optimization and orthogonal array

PROBLEM DEFINITION

The major operation carried out in the machining industry is drilling process. Drilling process is carried out on SG Iron components. It is observed that the SG Iron components produced using the drilling process has high rejection, because of surface roughness in drilled hole. Daily 2000 number of components is produced in the company. There is a rejection of 8 parts out of 100 parts because of surface roughness in drill hole. So there is need to reduce the rejection ratio to avoid huge loss to company because of high machining cost, high labor cost, high tooling cost and, etc. The defective part will creates problems like wear out, leakage, difficulty in assembling and surface friction.

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LITERATURE SURVEY

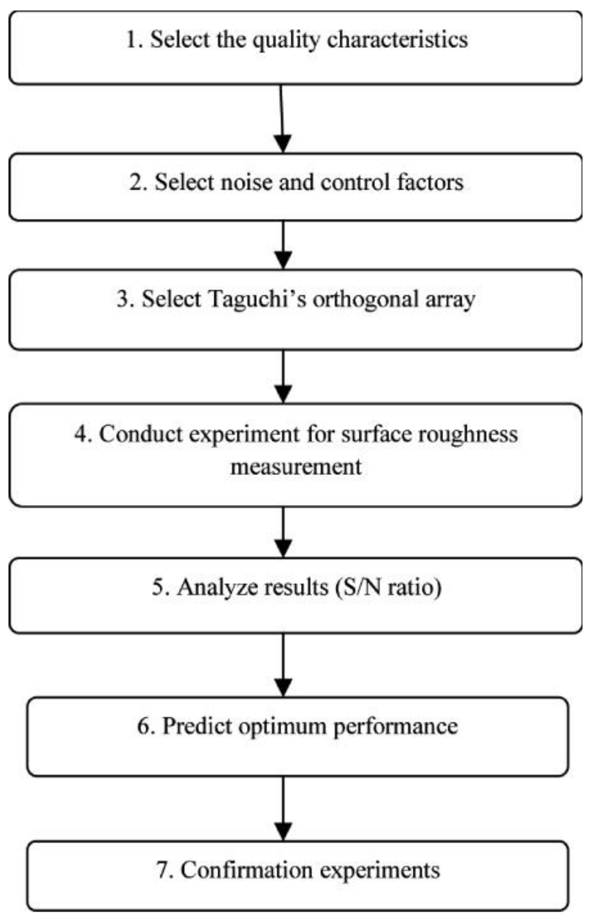
In Dobrzanski *et al.* (2007) conducted a research on application of Taguchi method in optimization of filament winding of thermoplastic composites. In their paper "Application of Taguchi method in the optimization of filament winding of thermoplastic composites"[International Scientific Journal of the Committee of Materials Science of the Polish Academy of Sciences] suggested the use of Taguchi method in process improvement of filament winding process. In Ugur Esme (2009) published a paper titled "Application of Taguchi method for the optimization of resistance spot welding process" in *The Arabian Journal for Science and Engineering*, Vol. 34, No. 2B, October 520 and he emphasized on the application of Taguchi method in the optimization of welding process. In Adem Cicek *et al.* (2011) conducted a study and published a paper "Application of Taguchi Method for Surface Roughness and Roundness Error in Drilling of AISI 316 Stainless Steel" in the *Journal of Mechanical Engineering*, Vol. 58 (2012), No. 3, pp. 165-174 and obtained good results.

TAGUCHI'S METHOD

Taguchi's robust design is the powerfulll tool for the design of a high quality system. He considered three steps in a process and product development: System design, Parameter design and Tolerance design. In system design, the engineer uses scitific and engineering principles to determine the fundamental configuration. In the parameter design step, specific values for the system parameters are determined. Tolerance design is used to determine the best tolerance for the parameters.

In addition to the signal-noise ratio, a statistical analysis of variance can be employed to indicate the impact of process parameters on surface finish values. In this way, the optimal values of process parameters can be estimated.

Figure 1: Steps Applied in Taguchi's Optimization



Select the Quality Characteristics

Surface finish in the drilled hole is considered as quality characteristics as it is the measure of performance of the drilling process.

Define the Number of Control and Noise Factors with Their Levels

A primary goal in conducting a matrix experiment is to optimize the product or process design that is to determine the best or optimum level for each factor is the level that gives the highest value of efficiency in the experimental region. The estimated main effects can be used for this purpose provided the variation of efficiency as a function of the factor levels follows the additive model.

In the optimization of cutting parameters for surface finish in drilling process we identified the following number of factors and their levels which is mentioned in the Table 1.

Table 1: Factors and Their Levels Considered for Surface Finish

Type of Shank	Feed Rate (mm/min)	Cutting Speed (m/min)	Drill Material	Spindle Speed (rpm)	Type of Coolant
Taper Shank	36	30	HSS	454	Without Coolant
Straight Shank	68	45	Brazed Carbide	682	External Coolant
–	110	60	Carbide	909	Through Tool

According to above table we have six factors namely type of shank, drilling material, type of coolant used, cutting speed, feed rate and spindle. Type of shank have two levels, drilling material have three levels, type of coolant used have two levels, speed have three levels, feed rate have three levels and revolution have three level. No noise factors are selected.

Selection of Taguchi's Orthogonal Array

Determine the Degrees of Freedom

The main step in selecting orthogonal array is to determine the degrees of freedom because the total degrees of experiment tells the minimum experiments that must be performed to study all the chosen control factors. In general, the number of degrees of freedom associated with a factor is equal to one less than the number of levels for that factor. Degrees of freedom can be determined by using following Formula:

(Number of levels-1) for each factor. (Number of levels-1) (Number of levels-1) for each interaction. In our experiment we have 2 factors at 2 levels, 4 factors at 3 levels and there will be no interaction therefore total number of degrees of freedom is as follows:

Table 2: Counting the Degrees of Freedom for Surface Finish

No. of Factors	No. of Levels	Degree of Freedom
1 factor	2 level	1*(2-1) = 1
5 factor	3 level	5*(3-1) = 10
		for mean = 1
Total Degrees of Freedom		= 12

Conduct Experiments for Surface Roughness Measurement

The first column is assigned to Type of shank (A), the second column to feed rate (B), the third column to Cutting speed (C). The fourth column to Drill Tool (D), the fifth column to Spindle Speed (E), the sixth to Type of Coolant (F), the remaining two columns are assigned to error columns respectively.

Analyze Results

Analysis can be done in following two ways

1. Manual method
2. Using Software (Mini tab)

Manual Method

As discussed earlier OA18 was used for design. The effect of each factor and its level are calculated as follows:

Table 3: Experimental Values for Surface Finish

TL No.	Designation	Type of Shank (A)	Feed Rate (mm/min) (B)	Cutting Speed (m/min (C)	Drill Material (D)	Spindle (rpm) (E)	Type of Coolant (F)	Surface Finish in hole-Ra Micron
1	A1 B1 C1 D1 E1 F1	1	1	1	1	1	1	5.71
2	A1 B1 C2 D2 E2 F2	1	1	2	2	2	2	5.58
3	A1 B1 C3 D3 E3 F3	1	1	3	3	3	3	3.75
4	A1 B2 C1 D1 E2 F2	1	2	1	1	2	2	5.81
5	A1 B2 C2 D2 E3 F3	1	2	2	2	3	3	5.28
6	A1 B2 C3 D3 E1 F1	1	2	3	3	1	1	7.48
7	A1 B3 C1 D2 E1 F3	1	3	1	2	1	3	5.23
8	A1 B3 C2 D3 E2 F1	1	3	2	3	2	1	7.32
9	A1 B3 C3 D1 E3 F2	1	3	3	1	3	2	7.70
10	A2 B1 C1 D3 E3 F2	2	1	1	3	3	2	5.83
11	A2 B1 C2 D1 E1 F3	2	1	2	1	1	3	5.34
12	A2 B1 C3 D2 E2 F1	2	1	3	2	2	1	3.95
13	A2 B2 C1 D2 E3 F1	2	2	1	2	3	1	6.01
14	A2 B2 C2 D3 E1 F2	2	2	2	3	1	2	5.68
15	A2 B2 C3 D1 E2 F3	2	2	3	1	2	3	7.28
16	A2 B3 C1 D3 E2 F3	2	3	1	3	2	3	5.63
17	A2 B3 C2 D1 E3 F1	2	3	2	1	3	1	7.49
18	A2 B3 C3 D2 E1 F2	2	3	3	2	1	2	8.10

$A1 = (5.71 + 5.58 + 3.75 + 5.81 + 5.23 + 7.48 + 5.23 + 7.32 + 7.70)/9 = 5.984$ ...(1)

$A2 = (5.83 + 5.34 + 3.95 + 5.01 + 5.68 + 7.28 + 5.63 + 7.49 + 8.10)/9 = 6.145$ ...(2)

$B1 = (5.71 + 5.58 + 3.75 + 5.83 + 5.34 + 3.95)/6 = 5.026$ ...(3)

$B2 = (5.81 + 5.28 + 7.48 + 6.01 + 5.68 + 7.28)/6 = 6.256$ ...(4)

$B3 = (5.23 + 7.32 + 7.70 + 5.63 + 7.49 + 8.10)/6 = 6.911$ ...(5)

$C1 = (5.71 + 5.81 + 5.23 + 5.83 + 6.01 + 5.63)/6 = 5.703$ ...(6)

$C2 = (5.58 + 5.28 + 7.32 + 5.34 + 5.68 + 7.49)/6 = 6.115$ ...(7)

$C3 = (3.75 + 7.48 + 7.70 + 3.95 + 7.28 + 8.10)/6 = 6.376$ ...(8)

$D1 = (5.71 + 5.81 + 7.70 + 5.34 + 7.28 + 7.49)/6 = 6.516$ ...(9)

$D2 = (5.58 + 5.28 + 5.32 + 3.95 + 8.10 + 6.01)/6 = 5.691$ ...(10)

$D3 = (3.75 + 7.48 + 7.32 + 5.83 + 5.68 + 8.10)/6 = 5.948$ ...(11)

$E1 = (5.71 + 7.48 + 5.23 + 5.34 + 5.68 + 8.10)/6 = 6.256$ ...(12)

$E2 = (5.58 + 5.81 + 7.32 + 3.95 + 7.28 + 5.63)/6 = 5.928$ ...(13)

$E3 = (3.75 + 5.28 + 7.70 + 5.83 + 6.01 + 7.49)/6 = 6.01$ ...(14)

$F1 = (5.71 + 7.48 + 7.32 + 3.95 + 6.01 + 7.49)/6 = 6.326$ ...(15)

$F2 = (5.58 + 5.81 + 7.70 + 3.95 + 5.83 + 8.10)/6 = 6.45$ ...(16)

$F3 = (3.75 + 5.28 + 5.23 + 5.34 + 7.28 + 5.63)/6 = 5.418$ ...(17)

Response Table: The values from the above calculations are placed in response table, as shown in the table, the absolute difference Δ, between maximum level and minimum level is calculated and placed in Table 4.

From the response table it can be concluded that among all the factors, Feed rate is the most significant factor on surface finish in hole DIA, followed by, type of Coolant. Drill tool, Cutting Speed, Spindle Speed and type of Shank. It also leads to the conclusion that factor combination of B1 F3 D2 C1 E2 and A1 gives good surface finish.

ANNOVA Table: In order to find out statistical significance of various factors like Type of shank (A), Feed rate (B), Cutting speed (C), Drill tool (D), Spindle speed (E) and Type of coolant (F) on Surface finish in hole DIA, analysis of variance (ANOVA) is performed on experimental data. Table shows the results of the ANOVA. This analysis is undertaken for a level of confidence of significance of 5%. P-values less than 0.05 are considered to have a statistically significant contribution to the performance measures.

The first step is to calculate the sum of square for each of the factor and total:

$SS_A = \Sigma(A^2/n) - T^2/n = (53.86^2/9 + 55.31^2/9) - (109.17^2/18) = 0.1168$ ...(18)

Table 4: Response Table

Levels	Type of Shank	Feed Rate (mm/min)	Cutting Speed (m/min)	Drill Tool	Spindle Speed (rpm)	Type of Coolant
Level 1	5.984	5.027	5.703	6.555	6.257	6.327
Level 2	6.146	6.257	6.115	5.692	5.928	6.450
Level 3		6.912	6.337	5.948	6.010	5.418
Delta	0.161	1.885	0.673	0.863	0.328	1.032
Rank	6	1	4	3	5	2

Table 5: Analysis of Variance for Surface Finish

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)	Rank
Type of Shank (A)	1	0.177	0.117	0.117	0.09	0.768	0.44	6
Feed Rate (B)	2	10.990	10.990	5.495	4.47	0.065	41.64	1
Cutting Speed (C)	2	1.333	1.333	0.691	0.56	0.598	5.24	4
Drill Tool (D)	2	2.359	2.359	1.179	0.96	0.435	8.938	3
Spindle Speed (E)	2	0.351	0.359	0.175	0.14	0.870	1.32	5
Type of Coolant (F)	2	3.809	3.809	1.905	1.55	0.287	14.3	2
Error	6	7.384	7.384	1.231			27	
Total	**17**	**26.392**						

$SS_B = \Sigma(B^2/n) - T^2/n = (30.16^2/6 + 37.54^2/6 + 41.47^2/6) - (109.17^2/18) = 10.99$ ...(19)

$SS_C = \Sigma(C^2/n) - T^2/n = (34.22^2/6 + 36.69^2/6 + 38.26^2/6) - (109.17^2/18) = 1.328$ ...(20)

$SS_D = \Sigma(D^2/n) - T^2/n = (34.15^2/6 + 35.69^2/6 + 37.54^2/6) - (109.17^2/18) = 2.359$ ...(21)

$SS_E = \Sigma(E^2/n) - T^2/n = (37.54^2/6 + 36.06^2/6 + 35.57^2/6) - (109.17^2/18) = 0.350$ ...(22)

$SS_F = \Sigma(F^2/n) - T^2/n = (37.96^2/6 + 38.7^2/6 + 32.51^2/6) - (109.17^2/18) = 3.809$ ...(23)

The fifth column AdjMS can be calculated MS = SS/df.

The sixth column F can be calculated F = MS_{factor}/MS_{error}.

It can be observed from the table, that the load has the highest influence (P = 41.64%) on the Surface finish in Hole DIA. Hence Feed rate is an important control factor to be taken into consideration during drilling process followed by Drilling Material and the remaining Factors, Type of coolant, Drill tool and spindle speed, Type of Shank shows less significance on Surface Finish. From the analysis of variance and S/N ratio, it is inferred that applied Feed rate as the highest contribution on Surface Finish. And the graph shows effects of factors on surface finish in Hole DIA.

Figure 2: Taguchi Design

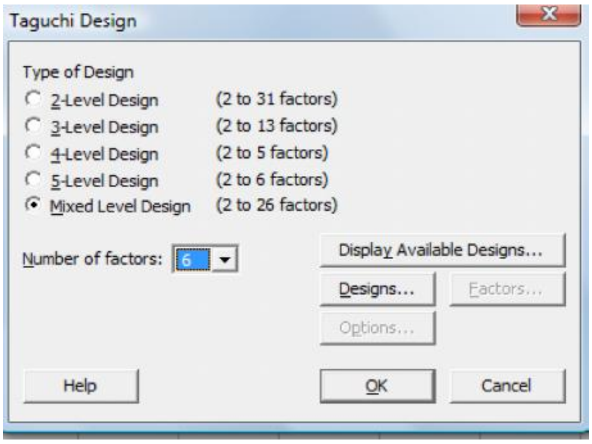
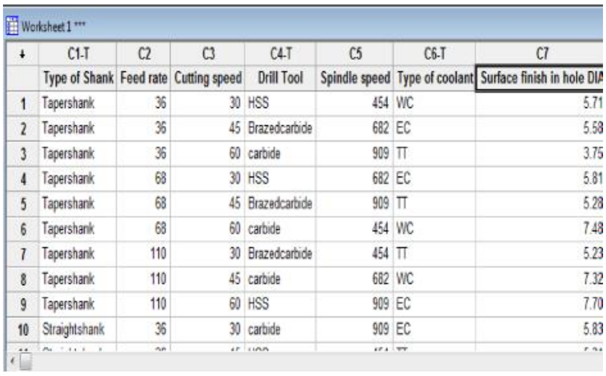


Figure 3: Worksheet



Worksheet 1 ***

	C1-T	C2	C3	C4-T	C5	C6-T	C7
	Type of Shank	Feed rate	Cutting speed	Drill Tool	Spindle speed	Type of coolant	Surface finish in hole DIA
1	Tapershank	36	30	HSS	454	WC	5.71
2	Tapershank	36	45	Brazedcarbide	682	EC	5.58
3	Tapershank	36	60	carbide	909	TT	3.75
4	Tapershank	68	30	HSS	682	EC	5.81
5	Tapershank	68	45	Brazedcarbide	909	TT	5.28
6	Tapershank	68	60	carbide	454	WC	7.48
7	Tapershank	110	30	Brazedcarbide	454	TT	5.23
8	Tapershank	110	45	carbide	682	WC	7.32
9	Tapershank	110	60	HSS	909	EC	7.70
10	Straightshank	36	30	carbide	909	EC	5.83

Using Software (Mini Tab)

In order to find out statistical significance of various factors like Type of shank (A), Feed rate (B), Cutting speed (C), Drill tool (D), Spindle speed (E) and Type of coolant (F) on Surface finish in hole DIA, analysis of variance

Table 6: Response Table for Surface Finish (Smaller is Better)

Levels	Type of Shank	Feed Rate (mm/min)	Cutting Speed (m/min)	Drill Tool	Spindle Speed (rpm)	Type of Coolant
Level 1	5.984	5.027	5.703	6.555	6.257	6.327
Level 2	6.146	6.257	6.115	5.692	5.928	6.450
Level 3		6.912	6.337	5.948	6.010	5.418
Delta	0.161	1.885	0.673	0.863	0.328	1.032
Rank	6	1	4	3	5	2

Figure 4: Main Effects Plot for Surface Finish in Hole DIA

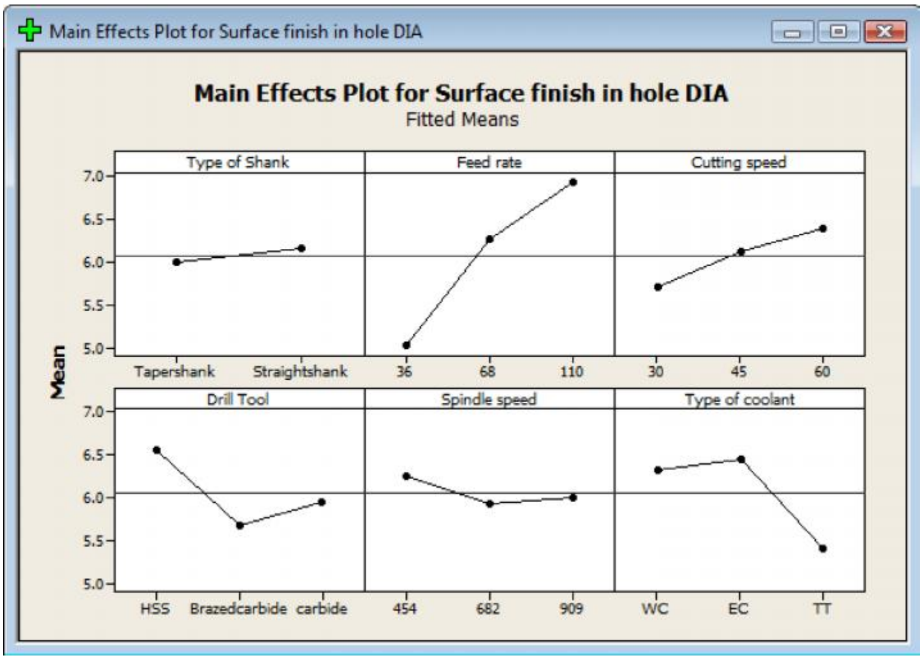


Table 7: Optimum Level of Control Factors for Surface Finish

Control Factors	Optimum Level	Ra Response Valve	S/N Response Valve
Type of Shank	A1	5.984	–15.36
Feed rate	B1	5.027	–13.90
Cutting Speed	C1	5.703	–15.12
Drill tool	D2	5.692	–14.91
Spindle Speed	E2	5.928	–15.28
Type of Coolant	F3	5.418	–14.52

(ANOVA) is performed on experimental data. Table 5 shows the results of the ANOVA. This analysis is undertaken for a level of confidence of significance of 5%. P-values less than 0.05 are considered to have a statistically significant contribution to the performance measures.

The last column of the table indicates the order of significance among factors and interactions. It can be observed from the table, that the load has the highest influence (P = 41.64%) on the Surface finish in Hole DIA. Hence Feed rate is an important control factor to be taken into consideration during drilling process followed by Drilling Material and the remaining Factors, Type of coolant, Drill tool and spindle speed, Type of shank shows less significance on Surface Finish. From the analysis of variance and S/N ratio, it is inferred that applied Feed rate as the highest contribution on Surface Finish. And the graph shows effects of factors on surface finish in Hole DIA.

RESULTS AND DISCUSSION

Confirmation Test

A confirmation experiment is the final step in the design of experiment process. The confirmation test is used to verify the estimated (predicted) result with the experimental results. From the main effect plots of Surface Finish in hole DIA, it was concluded that the optimum condition for surface finish.

After evaluating the optimum parameter setting, the next step of the Taguchi approach is to predict and verify the enhancement of quality of characteristics using the optimal parametric combination. If the optimal combination of parameters and their levels coincidently match with one of the experiments in the OA, then the confirmatory test is not required. In the present study the optimum combination of parameters and their levels is not matching with any one of the experiments in the OA and hence confirmation test was required.

Now the estimated or predicted S/N ratio using the optimal design parameter is obtained by following prediction equation

¦1 = ¦*m* + (¦*A*1 – ¦*m*) + (¦*B*1 – ¦*m*) + (¦*C*1 – ¦*m*) (¦*D*2 – ¦*m*) + (¦*E*2 – ¦*m*) + (¦*F*3 – ¦*m*) ...(24)

where

¦1 is the predicted value ¦*m* is the total mean S/N ratio = –15.47

¦*A*1 is the S/N ratio of parameter *A* at the optimal level one = –15.36

¦*B*1 is the S/N ratio of parameter *B* at the optimal level one = –13.90

¦*C*1 is the S/N ratio of parameter *C* at the optimal level one = –15.12

¦*D*2 is the S/N ratio of parameter *D* at the optimal level two = –14.91

¦*E*2 is the S/N ratio of parameter *E* at the optimal level two = –15.28

¦*F*3 is the S/N ratio of parameter *F* at the optimal level three = –14.52

¦1 = ¦*m* + (¦*A*1 – ¦*m*) + (¦*B*1 – ¦*m*) + (¦*C*1 – ¦*m*) (¦*D*2 – ¦*m*) + (¦*E*2 – ¦*m*) + (¦*F*3 – ¦*m*) ...(25)

¦1 = –15.47 + (–15.36 – (–15.47)) + (–13.90 – (–15.47)) + (–15.12 – (–15.47)) + (–14.91 – (–15.47)) + (–15.28 – (–15.47)) + (–14.52 – (–15.47))

¦1 = –11.3 db

Now the estimated or predicted Mean (Ra) using the optimal design parameter is obtained by following prediction equation

¦ = *Y* + (*A*1 – *Y*) + (*B*1 – *Y*) + (*C*1 – *Y*) + (*D*2 – *Y*) + (*E*2 – *Y*) + (*F*3 – *Y*) ...(26)

Y = Total mean of surface finish = –15.47

*A*1 = 15.36, *B*1 = 13.90, *C*1 = 15.12

*D*2 = 14.91, *E*2 = 15.28, *F*3 = 14.52

¦= 6.065 + (5.984 – 6.065) + (5.027 – 6.065) + (5.703 – 6.065) + (5.692 – 6.065) + (5.928 – 6.065) + (5.418 – 6.065)

¦ = 3.427 µm

The conformation Experiment is a crucial step and is highly recommended by to verify the experimental results. In this study, a confirmation experiment was conducted by utilizing the levels of the optimal process parameters (A1 B1 C1 D2 E2 F3) resulted in response values of 3.210, 3.203, 3.208 µm. Each Ra measurement was repeated at least three times. Therefore the optimum surface finish (Ra = 3.207 µm) can be obtained under the above mentioned cutting condition.

S/N = –10log10(mean square of Quality Characteristics)

–10log10 1/*n*(Σyi^2) ...(27)

–10log10((3.210)2 + (3.203)2 + (3.208)2)/3

S/N = –10.69 db

The value of the Surface finish obtained from the experiment was compared with the estimated value as shown in Table 8. The difference between estimated and experimental result is found to be 0.2 this shows that the experimental result is strongly correlated with the estimated result.

Table 8: Results of the Confirmation Experiment

	Optimal Control Parameters		
	Prediction	Experimental	Difference
Level	A1 B1 C1 D2 E2 F3	A1 B1 C1 D2 E2 F3	–
Surface Finish in Ra (micron)	3.427	3.207	0.2
S/N Ratio for Surface Finish (dB)	–11.3	–10.69	0.61

CONCLUSION

This project has been discussed an application of the Taguchi method for investigating the effects of cutting parameters on the surface finish in the drilling process of SG Iron.

Statistical Results (at 95% confidence level) Show that Type of shank (A), Feed rate (B), Cutting speed (C), Drill tool (D), Spindle speed (E) and Type of coolant (F) affect the surface finish by 44%, 41.64%, 5.24%, 8.94%, 1.32%, and 14.3% for the drilling of SG Iron.

The analysis of the confirmation experiments for surface finish has Shown that Taguchi's parameter design can successfully Verify the optimum cutting parameters (A1 B1 C1 D2 E2 F3) which are Type of shank (A) = Taper shank, Feed rate (B) = 36 mm/min, Cutting speed (C) = 30 m/min, Drill tool (D) = Brazed carbide, Spindle speed (E) = 682 rpm and Type of Coolant (F) = Through tool.

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