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Surface Roughness Evaluation Using Factorial Design in Turning Operation

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Abstract. In this work, a factorial experimental design was employed for studying the surface roughness of 195 BHN Cast Iron material in turning using High Speed Steel (H.S.S.) tool. Based on experimental results, first order predictive models for surface roughness with 95% confidence interval covering cutting speed varying from 16 to 64 m/min., feed from 0.075 to 0.3 mm/rev., depth of cut from 0.15 to 0.6 mm, and tool nose radius from 0.4 to 1.6 mm under dry condition were developed. The developed models have been tested by analyzing the variances. Based on the developed surface roughness models, contour curves were obtained to relate surface roughness to material removal rate for different cutting speeds and feeds which can be utilized for improving the efficiency of the cutting process.

1. Introduction

To keep the highest possible efficiencies in machining processes, understanding the relationships between process outputs and the process controlling factors must be attained. There are needs to obtain the best possible cutting conditions for machining. These conditions may be obtained by understanding the factors affecting the process output and their significance using response surface methodologies directed by factorial design of experimental techniques.

Choudhury and El-Baradie (1999) studied machinability assessment of inconel 718 using coated and uncoated tools by factorial design of experiment coupled with response surface methodology. They concluded that the surface roughness is mostly influenced by the change of feed and they mentioned that the dual-response contours of tool life and surface roughness are very useful in assessing the maximum attainable tool life for the same surface finish.

Arbizu and Perez (2003) developed a model to determine the surface quality of parts obtained through turning processes using the response surface methodology. They concluded that the factorial design of experiments combined with techniques of regression may be applied for modeling the behavior of functions depending on several variables in an efficient way with smaller number of experiments.

Benga and Abrao (2003) studied the turning of hardened 100Cr6 bearing steel. They stated that the response surface concept appears to be a suitable methodology in order to establish optimum machining conditions because it determines the significance of each process factor. In their study, they showed that cutting speed is the most effective in determining tool life and that the feed rate has a higher significance on the surface roughness value for all cutting tool materials used.

Dabnun *et al.* (2005) predicted a surface roughness model using a design of experiments for turning machinable glass-ceramic (Macro). They concluded that the response surface methodology combined with a factorial design of experiment is a useful technique for surface roughness tests using a small number of experiments to develop the required predicting equations. They also concluded that the first order equation was statistically adequate to show that the feed rate was the main influencing factor on the roughness, followed by the cutting speed and depth of cut. They mentioned that the surface roughness contours are useful in determining the optimum cutting conditions for a given surface roughness.

Sahin and Motorcu (2006) developed a first-order and second-order models to predict surface roughness in terms of cutting speed, feed rate and depth of cut, using response surface methodology applied to experimental data. The established equations show that the feed rate was the main influencing factor on surface roughness. Moreover, it is seen that the first-order effect of feed rate and cutting speed is significant while the depth of cut is insignificant.

Palanikumar *et al.* (2006) conducted machining experiments with two levels of factors influencing surface roughness on the machining of glass fiber-reinforced polymer composites to predict the main and interaction effects of different combinations of machining parameters. They also concluded that the feed rate has greater influence on the surface roughness, followed by cutting speed. They added that the parameters were optimized to attain minimum surface roughness using response graph, response table, normal probability plot, interaction graphs and analysis of variance (ANOVA) technique.

Saglam *et al.* (2007) studied the effect of tool geometry and cutting speed on main cutting force and tip temperature according to the full factorial design. They concluded that the optimum rake angle was found as 12 degrees. They added that the rake angle had a significant effect on cutting forces components, while the cutting speed was effective on tool tip temperature.

In the present work, mathematical model for surface roughness was developed when machining Gray Cast Iron of hardness 195 BHN using high speed steel tools under dry cutting conditions. The model was developed in terms of cutting speed, feed rate, depth of cut and nose radius of the cutting tool. The rate of metal removal and surface roughness diagrams were generated by utilizing this model. These diagrams illustrate how machinability can be enhanced though the proper selection of cutting conditions.

2. Experimental Conditions and Results

The experiments are designed using factorial design in which cutting speed in m/min., "V", feed rate in mm/rev., "f", nose radius in mm, "r", and depth of cut in mm, "d", are selected for investigating their effects. The simplest and most common type of factorial design is the one that uses two level values, and it is called 2n factorial design where the factors set at their lower limits are indicated (-1) and those at higher limits as (+1) where a complete factorial arrangement for n variable are made over the range of factor levels chosen. In the design of the experiment, three levels for each variable are chosen as given in Table 1 to cover the ranges selected. The tool geometry is shown in Table 2.

Table 1. Cutting factors

Code	Cutting Speed V (m/min)	Feed f (mm/rev)	Nose Radius r (mm)	Depth of Cut d (mm)
-1	16	0.075	0.4	0.15
0	32	0.15	0.8	0.3
+1	64	0.3	1.6	0.6

Table 2. Tool geometry

Specified Angle, Degree	Values in Degrees
Back rake angle	0
Side rake angle	12
End relief angle	6
End clearance angle	10
Side relief angle	15
Side clearance angle	10
End cutting edge angle	15
Side cutting edge angle	15

The experimental design consisting of 32 experiments has been used to develop the first order model based on partial factorial design. Basically, eight experiments representing a 23 factorial design are selected by changing the levels between three factors and keeping the fourth factor constant at its central value at zero level as shown in Table 1. In addition, eight experiments at the center points are chosen to ensure the evaluation of the related terms to the factors in such ways that the error and unbiased analysis can be tested. Hence, a total of 40 experiments as shown in Table 3 gives the complete design of the experiments.

Figure 1 shows the set-up of the experiments on a center lathe. The workpiece was prepared for the turning test as shown in Fig. 2. The workpiece material is commercial Cast Iron with 195 BHN (measured at different locations on the workpiece face) obtained from the local market in Riyadh. The structure of C.I. before and after etching were shown in Fig. 3. This indicates that this material contains graphite flakes embedded in a ferritic-pearlitic matrix.

The chemical composition test for the specimens shows 95% Fe, 3% Carbon and 2% Silicon. The cutting tool is High Speed Steel (H.S.S.) with grade ASSAB 17 SWEDEN as recommended by *Machining Data Handbook* (1980). Nose radius values were measured using tool maker microscope and always checked after each cut.

Surface roughness results were measured using Perthometer 3A and Perthograph 40 and were recorded in Table 3.

Table 3. Experimental design and surface roughness results

Groups	Exp. No.	Variable Code				Levels Interaction	Ra (Mm)
		X1	X2	X3	X4		
	1	-	-	-	0	-	4.7
	2	+	-	-	0	+	4.15
	3	-	+	-	0	+	10.1
Group	4	+	+	-	0	-	8.03
	5	-	-	+	0	+	5.28
I	6	+	-	+	0	-	3.65
	7	-	+	+	0	-	8.73
	8	+	+	+	0	+	7.95
	9	0	-	-	-	-	4.2
	10	0	+	-	-	+	7.83
	11	0	-	+	-	+	4.33
Group	12	0	+	+	-	-	6.38
	13	0	-	-	+	+	4.1
II	14	0	+	-	+	-	9
	15	0	-	+	+	-	3.4
	16	0	+	+	+	+	4.95
	17	-	-	0	-	-	4.58
	18	+	-	0	-	+	3.28
	19	-	+	0	-	+	8.68
Group	20	+	+	0	-	-	5.2
	21	-	-	0	+	+	7.15
III	22	+	-	0	+	-	5.4
	23	-	+	0	+	-	8.85
	24	+	+	0	+	+	8.7
	25	-	0	-	-	-	5.9
	26	+	0	-	-	+	5.55
	27	-	0	+	-	+	5.1
Group	28	+	0	+	-	-	4.6
	29	-	0	-	+	+	6.25
IV	30	+	0	-	+	-	5.5
	31	-	0	+	+	-	4.7
	32	+	0	+	+	+	4.55
	33	0	0	0	0	0	4
	34	0	0	0	0	0	4.98
	35	0	0	0	0	0	4.88
Group	36	0	0	0	0	0	4.65
	37	0	0	0	0	0	5.1
V	38	0	0	0	0	0	4.68
	39	0	0	0	0	0	4.55
	40	0	0	0	0	0	4.9

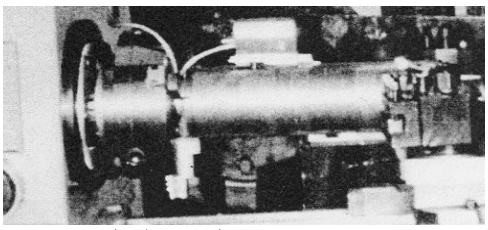


Fig. 1. Experimental set-up.

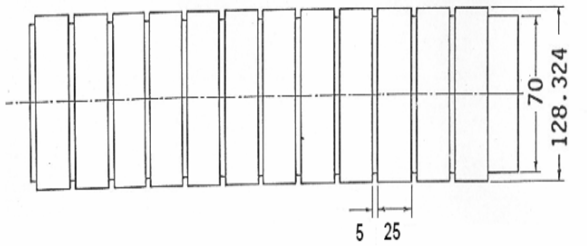
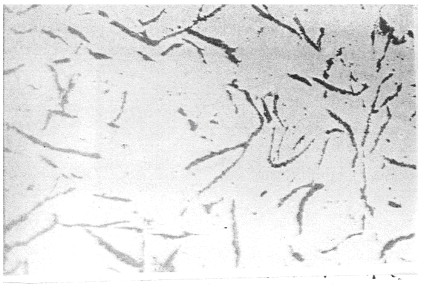
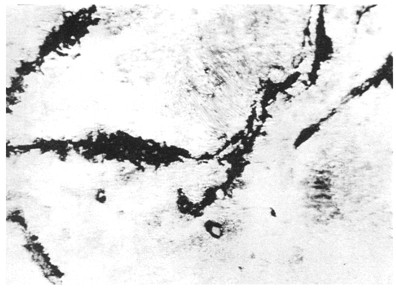


Fig. 2. Workpiece preparation (dimensions in mm).



Magnification of 80x graphite flakes before etching



Magnification of 80x perlite gray C.I. after etching

Fig. 3. Cast Iron micro-structure test.

3. Analysis of the Results

3.1. Factors main effect and interaction plots with surface roughness response

The relative significance of each of the main effect of each process factors on the surface roughness Ra is presented in Fig. 4. It can be observed that the feed is the most significant factor which influences the surface roughness Ra. Figure 5 shows the interaction plots for different factors with Ra. Mainly, there is nearly no interaction between factors.

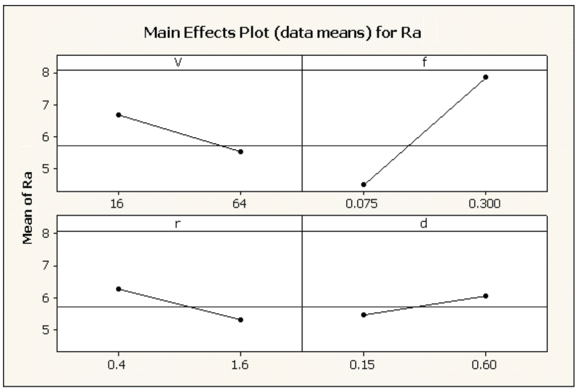


Fig. 4. Main effect plot for Ra.

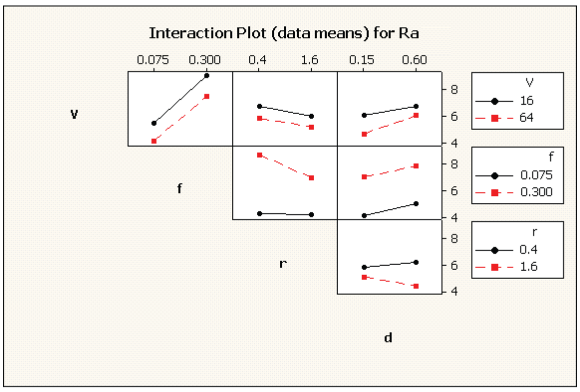


Fig. 5. The interaction plot for Ra.

3.2. Variance and effect analysis

The analysis of variance and the lack of fit test for the surface roughness results were performed as given in Table 4. This analysis includes the effects of the process factors and their interactions which gives correlation coefficient between surface roughness and the factors R Squared = 0.988 (Adjusted R Squared = 0.933).

Table 5 shows the effect of machining factors V, f, r, d and their interactions on surface roughness Ra was performed according to the experimental design shown in Table 3. The average data of a factor or an interaction between factors is obtained by dividing the total value of the observed points for -1 values and +1 values by the number of the observed values. Then, the effect is obtained by the difference between the average -1 value and the average +1 value as shown in Table 5 and are plotted in Fig. 6. In this figure, the larger the vertical height of the bar-chart, the larger the change in surface roughness when going from level one to level two for a factor. It should be pointed out that the statistical significance of a factor is directly related to the height of the vertical line. Consequently, the feed factor have the highest value as it also.

Table 4a. Variance analysis of process factors

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.625[a]	32	1.953E-02	17.968	.000
Intercept	20.729	1	20.729	19066.888	.000
V	4.104E-02	1	4.104E-02	37.751	.000
f	.350	1	.350	321.505	.000
r	2.943E-02	1	2.943E-02	27.073	.001
d	8.724E-03	1	8.724E-03	8.024	.025
V * f	7.715E-04	1	7.715E-04	.710	.427
V *r	3.647E-05	1	3.647E-05	.034	.860
f * r	7.351E-03	1	7.351E-03	6.761	.035
V *f * r	3.413E-03	1	3.413E-03	3.140	.120
V * d	3.598E-03	1	3.598E-03	3.310	.112
f * d	7.879E-04	1	7.879E-04	.725	.423
V * f * d	4.609E-03	1	4.609E-03	4.239	.078
r *d	6.665E-03	1	6.665E-03	6.131	.042
V * r * d	4.453E-04	1	4.453E-04	.410	.543
f * r * d	7.249E-04	1	7.249E-04	.667	.441
Error	7.610E-03	7	1.087E-03		
Total	22.410	40			
Corrected Total	.633	39			

Table 4b. Lack of fit tests (surface roughness response: Ra)

Source	Sum of Squares	df	Mean Square	F	Sig.
Lack of Fit	.000	0	.	.	.
Pure Error	7.610E-03	7	1.087E-03		

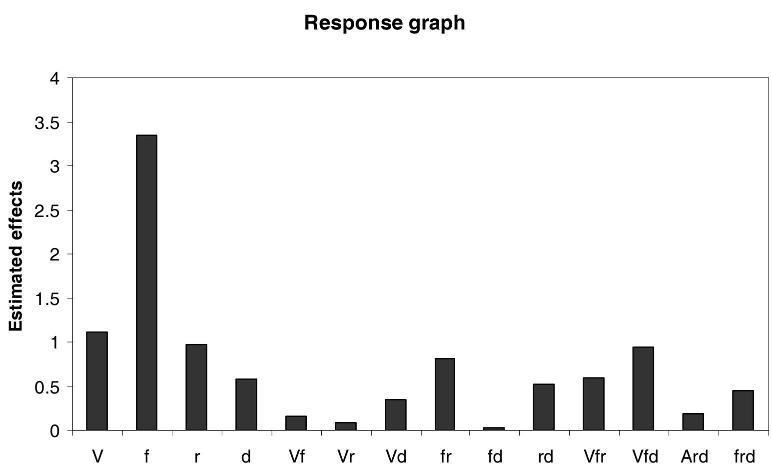


Fig. 6. The factors effect and their interactions on surface roughness.

Table 5. Factors response effect on surface roughness

N	Ra	V		f		r		d		Vf		Vr		Vd		fr		fd		rd		Vfr		Vfd		Vrd		frd	
		-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1
1	4.7	4.7		4.7		4.7					4.7		4.7				4.7					4.7							
2	4.15		4.15	4.15		4.15				4.15		4.15					4.15						4.15						
3	10.1	10.1			10.1	10.1				10.1			10.1			10.1							10.1						
4	8.03		8.03		8.03	8.03					8.03	8.03				8.03						8.03							
5	5.28	5.28		5.28			5.28				5.28	5.28				5.28							5.28						
6	3.65		3.65	3.65			3.65			3.65			3.65			3.65						3.65							
7	8.73	8.73			8.73		8.73			8.73		8.73					8.73					8.73							
8	7.95		7.95		7.95		7.95				7.95		7.95				7.95						7.95						
9	4.2			4.2		4.2		4.2									4.2		4.2		4.2							4.2	
10	7.83				7.83	7.83		7.83								7.83		7.83			7.83								7.83
11	4.33			4.33			4.33	4.33								4.33			4.33	4.33									4.33
12	6.38				6.38		6.38	6.38									6.38	6.38		6.38								6.38	
13	4.1			4.1		4.1			4.1								4.1	4.1		4.1									4.1
14	9				9	9			9							9			9	9								9	
15	3.4			3.4			3.4		3.4							3.4		3.4			3.4							3.4	
16	4.95				4.95		4.95		4.95								4.95		4.95		4.95								4.95
17	4.58	4.58		4.58				4.58			4.58				4.58				4.58					4.58					
18	3.28		3.28	3.28				3.28		3.28				3.28					3.28						3.28				
19	8.68	8.68			8.68			8.68		8.68					8.68			8.68							8.68				
20	5.2		5.2		5.2			5.2			5.2			5.2				5.2						5.2					
21	7.15	7.15		7.15					7.15		7.15			7.15				7.15							7.15				
22	5.4		5.4	5.4					5.4	5.4					5.4			5.4						5.4					
23	8.85	8.85			8.85				8.85	8.85				8.85					8.85					8.85					
24	8.7		8.7		8.7				8.7		8.7				8.7				8.7						8.7				
25	5.9	5.9				5.9		5.9					5.9		5.9						5.9					5.9			
26	5.55		5.55			5.55		5.55				5.55		5.55							5.55						5.55		
27	5.1	5.1					5.1	5.1				5.1			5.1					5.1							5.1		
28	4.6		4.6				4.6	4.6					4.6	4.6						4.6						4.6			
29	6.25	6.25				6.25			6.25				6.25	6.25						6.25							6.25		
30	5.5		5.5			5.5			5.5			5.5			5.5					5.5						5.5			
31	4.7	4.7					4.7		4.7			4.7		4.7							4.7					4.7			
32	4.55		4.55				4.55		4.55				4.55		4.55						4.55						4.55		
Total		80.02	66.56	54.22	94.4	75.31	63.62	65.63	72.55	52.84	51.59	47.04	47.7	45.58	48.41	51.62	45.16	48.14	47.89	45.26	41.08	25.11	27.48	24.03	27.81	20.7	21.45	22.98	21.21
Value		12	12	12	12	12	12	12	12	8	8	8	8	8	8	8	8	8	8	8	8	4	4	4	4	4	4	4	4
Average		6.668	5.547	4.518	7.867	6.276	5.302	5.469	6.046	6.605	6.449	5.880	5.963	5.698	6.051	6.453	5.645	6.018	5.986	5.658	5.135	6.278	6.870	6.008	6.953	5.175	5.363	5.745	5.303
Effect		1.122		3.348		0.974		0.577		0.156		0.082		0.354		0.807		0.031		0.523		0.593		0.945		0.188		0.443	

By analyzing Table 5 and Fig. 6, by using the following equation (Palanikumar *et al.*, 2006; Barker, 1985; Lochner and Mater, 1990), the minimum value of surface roughness can be obtained:

Ra(min) = [Grand mean] + [Contribution of V] + [Contribution of f] + [Contribution of r] + [Contribution of d] + [Contribution of Vd] + [Contribution of fr] + [Contribution of rd] + [Contribution of Vfr] + [Contribution of Vfd] + [Contribution of frd]

Ra(min) = Ra(mean) + [V(+1) - Ra(mean)] + [f(-1) - Ra(mean)] + [r(+1) - Ra(mean)] + [d(-1) - Ra(mean)] + [Vd(-1) - Ra(mean)] + [fr(+1) - Ra(mean)] + [rd(+1) - Ra(mean)] + [Vfr(-1) - Ra(mean)] + [Vfd(-1) - Ra(mean)] + [frd(+1) - Ra(mean)]

For achieving minimum value of surface roughness, the required levels of the factors from Table 5 are:

1. Cutting speed at high level (64 m/min).
2. Feed at low level (0.075 mm/rev).
3. Nose radius at high level (1.6 mm).
4. Depth of cut at low level (0.15 mm).

Therefore, the minimum value of surface roughness is:

Ra(min) = 5.962 + [5.547 - 5.962] + [4.518 - 5.962] + [5.302 - 5.962] + [5.469 - 5.962] + [5.698 - 5.962] + [5.645 - 5.962] + [5.135 - 5.962] + [6.278 - 5.962] + [6.008 - 5.962] + [5.303 - 5.962] = 1.245 µm.

This indicates that the minimum surface roughness on machining of C.I. within the range of factors under investigation is 1.245 µm.

4. Model Equation

The functional relationship between surface roughness in µm, "Ra" and the investigated machining factors (cutting velocity, "V", feed, "f", nose radius "r", and depth of cut, "d") can be represented by:

Ra = C * Vn1 * fn2 * rn3 * dn4

where C, n1, n2, n3, and n4 are constants to be determined by the regression of experimental data. This equation can be written as a linear equation as follows:

$$LnRa = \ln C + n1 \ln V + n2 \ln f + n3 \ln r + n4 \ln d + \varepsilon$$

where ε is the experimental error.

The analysis of data has been carried out by grouping the data to 7 data types as follows:

1. Data representing all 40 experiments.
2. Data representing a block for the positives interaction levels of groups I to IV and 4 experiments of group V.
3. Data representing a block for the negatives interaction levels of groups I to IV and 4 experiments of group V.
4. Data representing experiments of groups I & V.
5. Data representing experiments of groups II & V.
6. Data representing experiments of groups III & V.
7. Data representing experiments of groups IV & V.

4.1. Model constants and coefficient of regression

Table 6 shows the constants of the equations and their coefficient of regression R2 for the 7 data types using SPSS. It should be noted that this equation is valid for turning C.I. (195 BHN) using high speed steel tool under dry condition and for the same ranges of cutting conditions used in this research. The table shows that data type number 2 possesses higher correlation than data type number 3 due to its higher R2. It can be shown also in Data type number 7 that the model is deteriorated when the feed is kept constant at zero level by possessing the lowest R2 value. Hence, the feed is the most important factor in the model.

Table 7 presents the correlation with independent variables. The worst significant values were clear when the feed is kept constant at zero level as shown from data type 7 and the feed ‘f’ has the highest correlation coefficient followed by the nose radius ‘r’ and the cutting speed ‘V’ ended by the depth of cut ‘d’.

4.2. Test of the model

The ANOVA test for the model for data type number 1, shown in Table 8a, indicates that the factors contribute to the model. Table 8b gives the coefficient of regression and the standard error of estimate. The 95% confidence intervals for the individual constants is shown in Table 8c. Figure 7 shows the residual distribution against the fitted values. These residuals can be assumed to be independently distributed and can be of normal probability as shown in Fig. 8. Table 9 illustrates the Confidence intervals of the developed model for data type 1 at 95% confidence.

Table 6. Model constants and coefficients of regression R2

Data type	C	n1	n2	n3	n4	R^2
1	19.724	-0.137	0.401	-0.116	0.0633	0.678
2	17.579	-0.0956	0.411	-0.136	0.0938	0.75
3	22.182	-0.179	0.391	-0.0967	0.0328	0.642
4	22.439	-0.147	0.488	-0.03026		0.735
5	9.247		0.392	-0.173	-0.0686	0.791
6	27.797	-0.206	0.323		0.267	0.673
7	5.821	-0.05854		-0.146	0.00794	0.511

Table 7. Correlation with independent variables

Data type	Output	V	f	r	d
1	Ra	-0.255	0.743	-0.216	0.117
	Significance	0.056	0	0.091	0.235
2	Ra	-0.83	0.786	-0.26	0.179
	Significance	0.22	0	0.134	0.225
3	Ra	-0.325	0.708	-0.175	0.06
	Significance	0.081	0	0.23	0.402
4	Ra	-0.247	0.819	-0.051	
	Significance	0.178	0.00	0.426	
5	Ra		0.803	-0.3555	-0.141
	Significance		0.00	0.089	0.302
6	Ra	-0.363	0.568		0.469
	Significance	0.084	0.011		0.034
7	Ra	-0.266		-0.662	-0.036
	Significance	0.16		0.003	0.447

Table 8a. ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	.429	4	.107	18.391	.000
1	Residual	.204	35	5.828E-03		
	Total	.633	39			

Table 8b. Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.823	.678	.641	7.634E-02	.678	18.391	4	35	.000

Table 8c. t-test of coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
	(Constant)	1.295	.093		13.880	.000	1.106	1.485
	LOG V	-.137	.052	-.255	-2.654	.012	-.242	-.032
1	LOG f	.401	.052	.743	7.744	.000	.296	.506
	LOG r	-.116	.052	-.216	-2.247	.031	-.221	-.011
	LOG d	6.333E-02	.052	.117	1.223	.229	-.042	.168

a Dependent Variable: LOG Ra

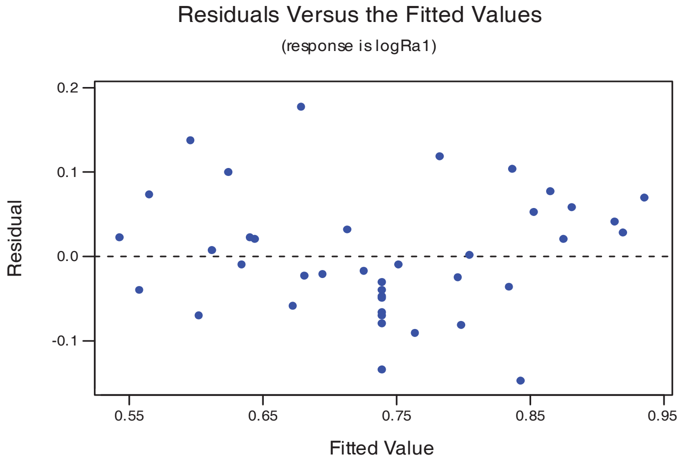


Fig. 7. The residuals versus the fitted values.

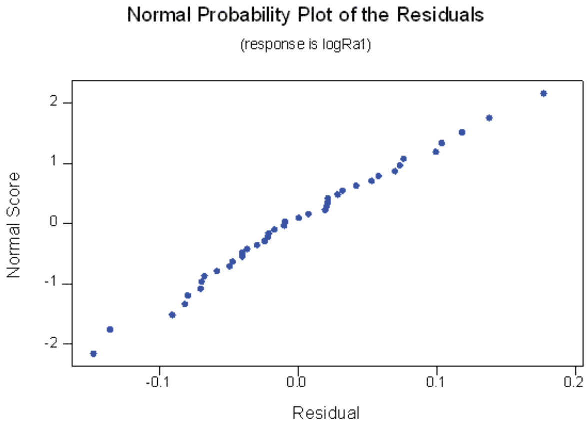


Fig. 8. The normal probability plot of the residuals.

Table 9. The confidence intervals of the developed model for data type 1

Exp. No.	Ra(Exp)	Ra(Imp)	Confidence Interval of Ra	
			Lower Level	Upper Level
1	4.7	4.936415	4.300329	5.670227
2	4.15	4.082530	3.554646	4.687003
3	10.1	8.606721	7.496556	9.884635
4	8.03	7.117959	6.196644	8.170624
5	5.28	4.203129	3.659844	4.825711
6	3.65	3.476086	3.025222	3.988927
7	8.73	7.328224	6.380029	8.412428
8	7.95	6.060613	5.273724	6.953703
9	4.2	4.296505	3.741826	4.933810
10	7.83	7.491028	6.522946	8.600873
11	4.33	3.658275	3.184524	4.198974
12	6.38	6.378263	5.551426	7.319870
13	4.1	4.690571	4.085211	5.386582
14	9	8.178088	7.121551	9.390169
15	3.4	3.993804	3.476765	4.584311
16	4.95	6.963264	6.060877	7.991608
17	4.58	4.359503	3.796791	5.006284
18	3.28	3.605411	3.138423	4.138288
19	8.68	7.600865	6.618763	8.727214
20	5.2	6.286093	5.471061	7.213903
21	7.15	4.759347	4.145219	5.465707
22	5.4	3.936091	3.426433	4.517946
23	8.85	8.298000	7.226162	4.517946
24	8.7	6.862640	5.973136	7.875919
25	5.9	6.238346	5.433958	7.164981
26	5.55	5.159258	4.491703	5.922565
27	5.1	5.311663	4.624632	6.097839
28	4.6	4.392869	3.822715	5.040467
29	6.25	6.810514	5.932629	7.822506
30	5.5	5.632454	4.903904	6.466074
31	4.7	5.798837	5.049031	6.657432
32	4.55	4.795774	4.173523	5.503026
33	4	5.469707	5.168255	5.785941
34	4.98	5.469707	5.168255	5.785941
35	4.88	5.469707	5.168255	5.785941
36	4.65	5.469707	5.168255	5.785941
37	5.1	5.469707	5.168255	5.785941
38	4.68	5.469707	5.168255	5.785941
39	4.55	5.469707	5.168255	5.785941
40	4.9	5.469707	5.168255	5.785941

5. Model Utilization

The developed model can be utilized to build graphs of material removal rate with different surface roughness Ra at different cutting speeds and feed values at constant depth of cut and nose radius of the model as shown in Fig. 9. The curves in the graph help to select cutting velocity and feed for required surface finish and metal removal rate. The desired roughness can be achieved by adjusting cutting speed and feed rate values at various levels of rate of metal removal without the sacrifice of the surface quality using horizontal lines so that one can gain an increase in the metal removal rate for the same surface quality. For example, consider 6.2 µm surface roughness is required using 0.4 mm nose radius and 0.15 mm depth of cut, 16.125 m/min. cutting speed and 0.15 mm/rev. feed rate could be selected to give 0.5

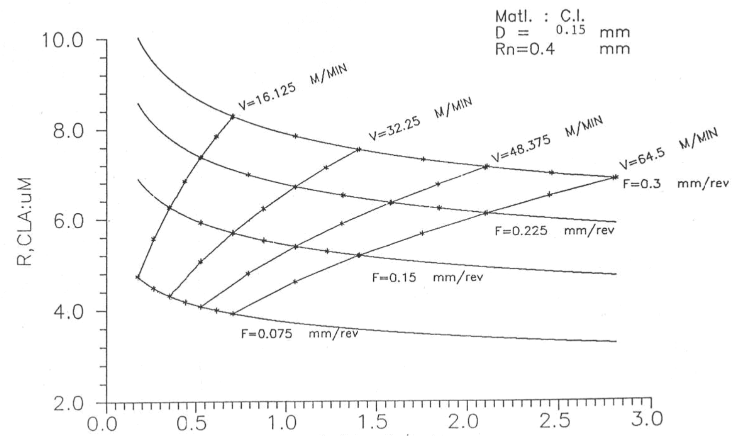


Fig. 9. R-Q response surface at 0.15 mm depth of cut and 0.4 mm nose radii.

cm^3/min. metal removal rate, while when selecting 64.5 m/min. cutting speed and 0.225 mm/rev feed rate are selected to give 2.1 cm^3/min. metal removal rate for the same surface roughness. It is obvious now that an increase in the metal removal rate can reach as high as four times their common values can be achieved without sacrificing the surface quality. In addition, the curves can be used to determine cutting process factors at required surface quality and the material removal rate.

6. Conclusions

Reliable surface roughness model has been developed and utilized to enhance proper selection of machining factors when turning C.I. (195 BHN) using H.S.S. tool. The model is obtained by a few experimental results and tested statistically for validity. This model can be used to predict the surface quality at any condition within the specified ranges of the machining factors within the boundary of this present experimental results. Using experimental design, the process factors influencing the surface roughness on the machining of C.I. has been assessed.

1. Response surface methodology combined with the factorial design of experiment are useful techniques to predict the main and interaction effects of machining parameters on surface roughness. Relatively, a small number of experiments are used to develop the predicting equations for surface roughness.
2. The surface roughness equation shows that the feed rate is the main influencing factor on the roughness, followed by the nose radius and the cutting speed.
3. The model can be utilized to enhance the efficiency of turning cast iron within the range of machining factors studied for improving the material removal rate at certain required surface finish and also it can predict the surface roughness at a particular material removal rate.

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تقييم نعومة السطح لعمليات الخراطة باستخدام منهج تصميم التجارب

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(قدم للنشر في ٢٠٠٧/١٠/٢٣م ؛ وقبل للنشر في ٢٠٠٩/٢/١م)

الكلمات المفتاحية: التشغيل، قطع المعادن، تصميم العوامل، تجربة العوامل، النموذج المستجاب، السطح المستجاب، الأشكال المتفاعلة، المتغيرات المستجابة.

ملخص البحث. تم في هذا العمل استخدام منهج تصميم التجارب لدراسة تشغيل حديد زهر ذو صلابة ١٩٥ "برنل" بواسطة أداة قطع من الصلب العالي السرعة. وبناء على نتائج التجارب، تم استنتاج نماذج لمعادلة تجريبية لنعومة السطح بدرجة مستوى ثقة ٩٥٪ واستخدم تحليل التباين تحت ظروف تشغيلية تتراوح كالتالي : (سرعة القطع ما بين ١٦ إلى ٦٤ متر/دقيقة ؛ وعمق قطع مابين ٠,٠١ إلى ٠,٦ مم ؛ وتغذية ما بين ٠,٠٧٥ إلى ١,٦ مم/دورة ؛ ونصف قطر مقدمة أداة القطع مابين ٠,٤ إلى ١,٤ مم). وقد صممت التجارب وفقاً لقوالب تجريبية جزئية تعمل على تقليل الخطأ عند تقييم تأثير مستويات المتغيرات.

ومن النموذج المطور، تم إعداد رسوم بيانية لهذه النماذج لخارطة تحديد نعومة السطح ومعدلات إزاحة المعدن تحت تلك الظروف التي منها يتم إيجاد أفضلية قيم متغيرات ظروف التشغيل لتعطي أفضل نعومة للسطح مع أكبر معدلات إزاحة للمعدن نظراً لتأثيرها المهم لتحسين جودة المشغولة.