Development of Models for the Prediction of Responses from Fine Tuning EN8 Mild Steel using HSS Tool.

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ABSTRACT

In this paper, a response surface experimental modelling approach is presented for the prediction of surface roughness (Ra, Rz, Rq, Rt), tool-life, and machining time in ENC lathe operation.

The experimental data was obtained based on a 15-run Box-Behnken design for the three process parameters (cutting speed, feed rate and depth of cut) taken at three levels while orthogonally fine cutting EN8 mild steel using HSS cutting tool. The developed response surface models have 0.5605, 0.5604, 0.4847, 0.5606, 0.9962, and 0.9910 coefficient of determination, respectively. The Akaike information Criteria (AIC) and Bayesian Information Criteria (BIC) of 80.03, 111.22, 89.08, 111.51, 181.48, 54.71; 127.95, 159.14, 100.12, 159.43, 229.40, and 102.63 for Ra, Rz, Rq, Rt, Tool-life, and machining time models, respectively indicated that they are suitable for prediction.

(Keywords: HSS tool-life, surface roughness, fine cutting of mild steel)

INTRODUCTION

Turning operation on a lathe machine is a technological system that comprises the cutting tool, the work-piece and the machine tool. The responses from turning operation are interrelated and based on these components of the technological system. The machine tool deployed accounts for the machining time, work-piece that was machined is examined for its surface roughness and the tool used for the cutting of this work-piece is checked for its tool-life. Machining time is a major parameter determining the production cost (a major market factor) of the machined product and it is dependent on process parameters (cutting speed and feed rate), and work-piece dimension (diameter and cutting length), as modelled by [1].

Machine elements with cylindrical shapes in equipment such as hydraulic jacks and prime movers are bound to fail when in use due to craters formed on their mating surfaces during their useful life. The surface texture of these machine elements comprises waviness, lay, flaws, and surface roughness. The surface roughness is widely investigated because it can be easily related to process parameters and it determines the quality of the machined products.

According to [2], it is a measure of the technological quality of a product and it is a factor that influences manufacturing cost, greatly. The absolute value of the average surface roughness, Ra, has been the focal point of experimental investigations [3, 4, 5] while other surface roughness profile parameters have only been theoretically modelled by authors such as [6, 7].

The machined workpiece's surface texture is affected by the cutting tool used during fine cutting process. This interaction between machined work-piece and the nature of the cutting tool used prompted the investigation of the tool-life. The purpose of this research was to develop models, based on Design of Experiment's Response Surface Methodology that can provide information regarding the surface roughness profile in four parameters, machining time and tool-life, using the process parameters namely, cutting speed, feed rate and depth of cut, incorporated to the selected work-piece material's dimension. To the best of our knowledge, collective modelling of surface roughness in four parameters, tool-life, and machining time has not been widely reported.

THEORETICAL BACKGROUND

Theory of Surface Roughness

There are four elements of surface texture namely, roughness, waviness, lay and flaws. Surface technology is concerned with defining the characteristics of a surface, surface texture, surface integrity, and relationship between manufacturing processes and characteristics of resulting surface. This research focused on four parameters of surface roughness namely, arithmetic average of absolute values (Ra), average distance between the highest peak and lowest valley in each length (Rz), root mean squared (Rq), and maximum height of the profile (Rt).

The first parameter, Ra, is theoretically determined based on the expression in Equation (1):

$$Ra = \frac{1}{n}\sum_{i=1}^{n}|y_i| \quad \textbf{(1)}$$

Where, n is the evaluation length, y_i is the area between the roughness profile and its center line [8].

The second parameter, Rz, is determined using the expression in Equation (2):

$$Rz = \frac{\sum_{i=1}^{n} y_i + \sum_{i=1}^{n} y_v}{n} \quad \textbf{(2)}$$

Where, n is the number of maximum profile peaks, yv is the depth of the deepest valley in the ith sample. The third parameter, Rq, is determined using the expression in Equation (3):

$$Rq = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2} \quad \textbf{(3)}$$

The fourth parameter, Rt, is obtained using the expression in Equation (4).

$$Rt = \max y_i + \min y_i \quad \textbf{(4)}$$

Theory of Tool-Life Prediction

Tool-life is related to temperature, in tests, as an inverse proportion with an index usually determined experimentally. Equation (5) depicts this relationship.

$$T \approx \theta^{-n} \quad \textbf{(5)}$$

where, T = tool life; θ = temperature;
n = index ranging from 6-12.

The effect of temperature on tool-life is hard to control even with the application of cutting fluids which do not penetrate to interface, thereby having small effect on tool-life. The adjustable factors are mainly machining parameters namely cutting speed, which is highly sensitive; feed rate, which is slightly sensitive and contributes to the determination of surface finish of work-piece; and depth of cut, which is not very sensitive.

Taylor originally postulated a relationship between tool-life and cutting speed in a widely known expression shown in Equation (6).

$$VT^n = C \quad \textbf{(6)}$$

where, V = cutting speed; T = tool life; n, C = Taylor's empirical constants.

A log linear plot of cutting speed and tool-life shows that C is the intercept on cutting speed axis and n is the gradient.

[9] postulated an extension of (6) tool-life prediction model that incorporated depth of cut as expressed in Equation (7):

$$T = C\left(V^l f^m d^n\right) + e \quad \textbf{(7)}$$

Where, C, l, m, n are constants and e is a random error.

A log linear model of the expression in Equation (8) is shown in (9).

$$\ln T = \ln C + l\ln V + m\ln f + n\ln d + \ln e \quad \textbf{(8)}$$

A regression linear model was further related to the expression in (8) as shown in (9).

$$y = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + e \qquad \textbf{(9)}$$

Where y is the measured tool-life to a logarithmic scale, $x_0 = 1$ (dummy variable), $x_1 = \ln V$, $x_2 = \ln f$, $x_3 = \ln(cap)$, $e = \ln e$, where e is assumed to be a normally distributed uncorrelated random error with zero mean and constant variance, $\beta_0 = \ln C$, β_1, β_2 and β_3 are the model parameters. The developed estimated response is expressed in Equation (10).

$$y = b_0 x_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 \qquad \textbf{(10)}$$

[9] was able to establish parametric relationship for the estimation of tool life in orthogonal cutting based on certain process parameters and cutting length as shown in Equation (11).

$$T = Lx\frac{60}{mmPM} \qquad \textbf{(11)}$$

Where, mmPM = RPM x mmPR; L is the cutting length in millimetres; mmPR = feed rate in millimetre per revolution; mmPM = feed rate in millimetre per minute.

The current study was able to incorporate dimensional analysis into the parametric relationship adopted by [10] and empirical tool life estimates were obtained based on the Box-Behnken response surface design. These values were analysed using the response surface regression technique.

The quadratic response surface regression modeling for empirical tool-life was carried out based on the interaction of the process parameters, cutting speed, feed rate and depth of cut in S.I. units as shown in Equation (12).

$$T_L = \beta_0 + \beta_1 v + \beta_2 f + \beta_3 (ap) + \beta_4 v^2 + \beta_5 f^2 + \beta_6 (ap)^2 + \beta_7 vf + \beta_8 v(ap) + \beta_9 f(ap) + \varepsilon$$

Where, β_0 to β_7 are the regression parameters, ε is the white noise.

Similarly, models for the surface roughness (Ra, Rz, Rq, Rt) and machining time (m/ctime) were developed.

Materials and Experiments

The work-piece material, tool type and the experimental procedure employed while carrying out this research were reported under this section.

Materials

The experiment was carried out based on the developed design matrix. Mild steel (EN8) that is used for various industrial applications ranging from mechanical shafts to fasteners, screw and hydraulic jack. These machine elements require high degree of surface finish. High Speed Steel (HSS) cutting tool which widely used was selected based on its predominance in the Nigerian machine tool industry. The chemical compositions of the tool material are based on the information provided by the manufacturer.

Experimental Procedure

ENC lathe machine with a spindle speed range from 100 to 2500 rpm was utilised for the experiment. The machining center was driven by 10kW electric motor. The experiment was carried out under dry machining environment. The cutting length a tool will effectively cut was programmed using the –ve z-coordinates of the travel distance of the cutting tool. The surface roughness of the machined work-piece was measured in four-parameter (R_a, R_z, R_q, R_t) using the Landtek surface profilometer and the RS232 digital computer interface enabled the measurement data to be transmitted to the TestR232(En) software.

The data for the response surface optimisation process were obtained through designed experiments. The surface roughness data in four parameters were obtained using surface profilometer; the machining time was measured using Tecno digital stop watch, which allowed the operator to count the duration for each experimental run, the empirical tool life was derived based on the expression developed by [10].

RESULTS

Experimental and Predicted Responses

The quadratic response surface models developed have the characteristics of both polynomial regression and fractional factorial regression designs. These models were used to predict the responses from fine cutting of mild steel using HSS tool and the input process parameters, experimental responses and predicted values are shown in Tables 1, 2 and 3, respectively.

The developed response surface models have model diagnostic test results as shown in Table 4.

Table 1: Input Process Parameters.

Runs	L(mm)	Input Process Parameters						
		v(mpm)	f(mm/rev)	ap(mm)	v(m/s)	f(mmPM)	f(m/s)	ap(m)
1	10	90	0.05	0.2	1.50003	0.196354	0.011781	0.0002
2	10	150	0.05	0.2	2.50005	0.327257	0.019635	0.0002
3	10	90	0.15	0.2	1.50003	0.589062	0.035344	0.0002
4	10	150	0.15	0.2	2.50005	0.98177	0.058906	0.0002
5	10	90	0.1	0.1	1.50003	0.392708	0.023562	0.0001
6	10	150	0.1	0.1	2.50005	0.654513	0.039271	0.0001
7	10	90	0.1	0.4	1.50003	0.392708	0.023562	0.0004
8	10	150	0.1	0.4	2.50005	0.654513	0.039271	0.0004
9	10	120	0.05	0.1	2.00004	0.261805	0.015708	0.0001
10	10	120	0.15	0.1	2.00004	0.785416	0.047125	0.0001
11	10	120	0.05	0.4	2.00004	0.261805	0.015708	0.0004
12	10	120	0.15	0.4	2.00004	0.785416	0.047125	0.0004
13	10	120	0.1	0.2	2.00004	0.52361	0.031417	0.0002
14	10	120	0.1	0.2	2.00004	0.52361	0.031417	0.0002
15	10	120	0.1	0.2	2.00004	0.52361	0.031417	0.0002

Table 2: Experimental Responses.

Runs	L(mm)	Experimental Responses					
		M/Ctime	Ra	Rz	Rq	Rt	TL(sec)
1	10	31.52	3.64	10.29	4.2	10.39	3055.7066
2	10	19.84	4.12	11.65	4.86	11.76	1833.4240
3	10	12.12	4.46	12.61	5.881	12.73	1018.5689
4	10	8	3.36	9.503	4.66	9.597	611.1413
5	10	16.76	5.1	14.42	5.761	14.56	1527.8533
6	10	11.12	4.34	12.27	5.161	12.39	916.7120
7	10	15.64	6.681	18.89	8.76	19.08	1527.8533
8	10	11.24	2.42	6.844	4.1	6.911	916.7120
9	10	23.56	3.42	9.672	4	9.768	2291.7800
10	10	9.2	0.68	1.923	0.715	1.942	763.9267
11	10	24.4	9.521	26.92	15.2	27.19	2291.7800
12	10	9.8	7.841	22.17	12.32	22.39	763.9267
13	10	13.12	5.681	16.06	8.641	16.22	1145.8900
14	10	13.08	4.72	13.34	6.76	13.48	1145.8900
15	10	13.12	6.681	18.89	8.521	19.08	1145.8900

Table 3: Predicted Responses.

Runs	Ra	Rz	Rq	Rt	TL	Mc/time
1	4.95621397	14.0127896	5.96579095	14.1508933	2810.00101	28.8952721
2	4.23142201	11.965443	5.24024461	12.0782243	1872.28986	20.3177147
3	4.2651057	12.0585321	5.23836079	12.1735719	956.286662	11.3511641
4	2.56476235	7.25387938	3.59518426	7.32482374	760.064906	9.59116313
5	2.68878689	7.60263555	2.44046012	7.67419494	1723.15648	18.6068485
6	3.13211302	8.85583922	3.04580115	8.94328866	781.49791	9.32507892
7	7.97088996	22.5362728	10.9575316	22.7611598	1640.52679	17.1864275
8	4.31154305	12.1918528	6.90024016	12.311731	864.126921	10.965515
9	4.47393844	12.650643	5.51379848	12.7756061	2353.43872	24.461837
10	3.24505436	9.1758879	4.63722573	9.26691785	642.169096	8.24582124
11	7.55248294	21.3545315	12.099161	21.5696391	2307.58326	24.2278599
12	6.62804296	18.7416502	10.4233737	18.928292	688.02387	8.69981355
13	5.54811566	15.6841796	7.82797812	15.8431315	1185.95018	13.5479905
14	5.54811566	15.6841796	7.82797812	15.8431315	1185.95018	13.5479905
15	5.54811566	15.6841796	7.82797812	15.8431315	1185.95018	13.5479905

Table 4: Results of Model Diagnostic Checks.

Model	Rsq	Adj Rsq	Adequacy of Precision	BIC	AIC
Ra (quadratic)	0.5605	-0.2306	2.792	80.03	127.95
Rz (quadratic)	0.5604	-0.2308	2.791	111.22	159.14
Rq (2FI)	0.4847	0.0982	3.676	89.08	100.12
Rt (quadratic)	0.5606	-0.2302	2.792	111.51	159.43
TL (quadratic)	0.9962	0.9893	38.971	181.48	229.40
M/ctime	0.9910	0.9748	25.022	54.71	102.63

Response Optimization

The results of the response optimization carried out are shown in Figure 1. The global solutions of the response parameters, cutting speed, feed rate and depth of cut are 1.50003m/s (90 mpm), 0.0279656 m/s (0.12 mm/rev) and 0.0001m (0.1mm). Hence, the optimized (minimum) values for the surface roughness (Ra, Rz, Rq, Rt) are 2.52, 7.13, 2.32, and 7.20 microns.

The optimized (maximum) values for the tool life and machining time are 1392.58 and 15.54 seconds. These results are the recommended values for the process parameters when fine cutting mild steel work-piece material using HSS cutting tool. The work-piece materials produced with these optimized surface roughness values will have minimum flaws and there will be no crater formed on their surfaces while in use. The produced work-piece can be used as machined element in equipment that requires high quality surface texture.

Similarly, the information provided by the response optimization on tool life and machining time can enable machine shop production planners to carry out near accurate estimates on the cost of production of machine elements made of mild steel and fine cut using high speed steel cutting tool. The associated desirability for these optimum responses are 0.791566, 0.791648, 0.888966, 0.306308, 0.276492, and 0.679450 respectively. Also, the composite desirability for the mild steel workpiece and HSS tool turning operation on ENC lathe machine is 0.563616.

Figures 2a and 2b show surface and contour plots for Ra while considering the cutting speed (v) and feed rate (f). The response, Ra, has highest value when the cutting speed was around 2.0 m/s (120mpm) and feed rate was between 0.015-0.02m/s (0.05 – 0.064mm/rev). Whereas, the minimized value for Ra based on the surface response plot was attained when the cutting speed was below 2.0 m/s (120mpm) and the feed rate was below 0.02m/s (0.064mm/rev).

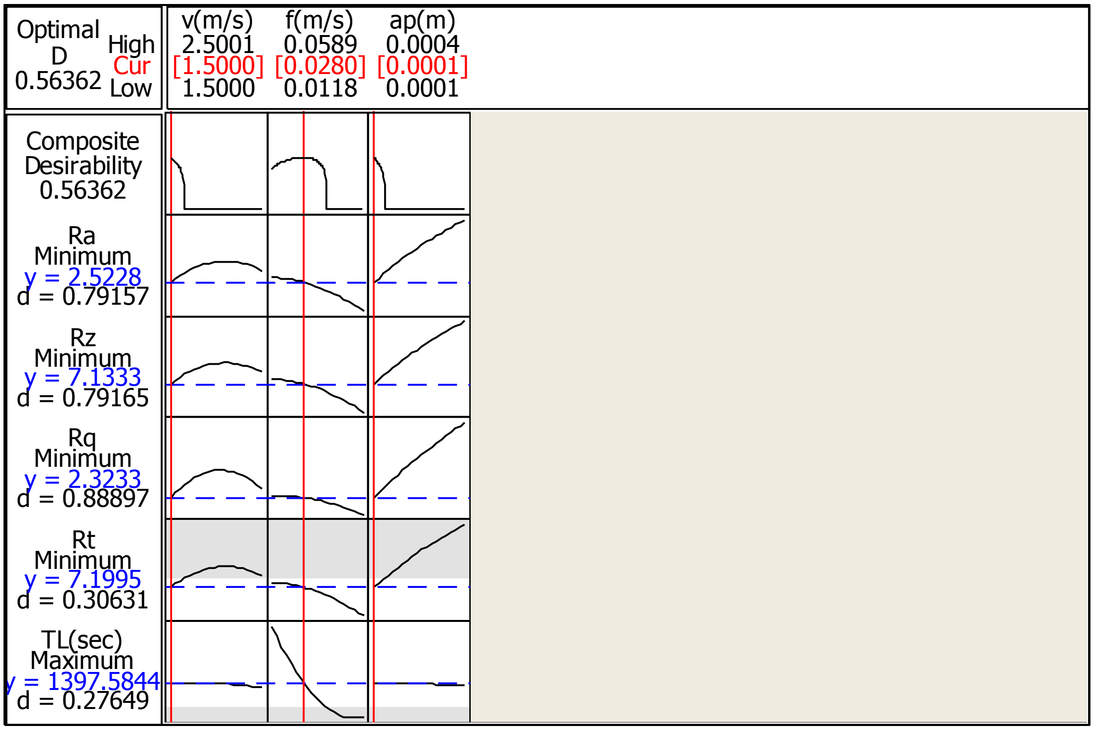

Figure 1: Response Optimization Plot for Mild Steel and HSS Combination.

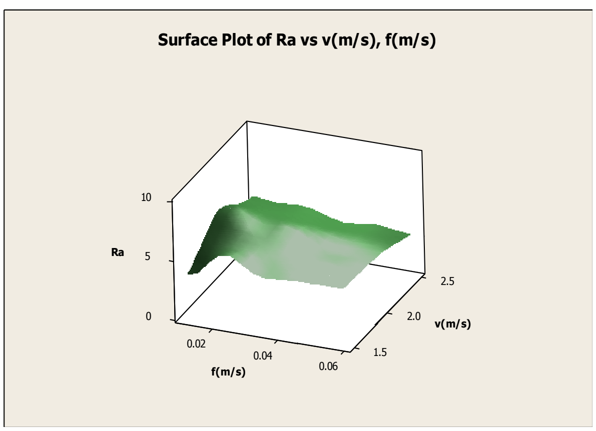

Figure 2a: Surface Plot Ra vs v(m/s), f(m/s).

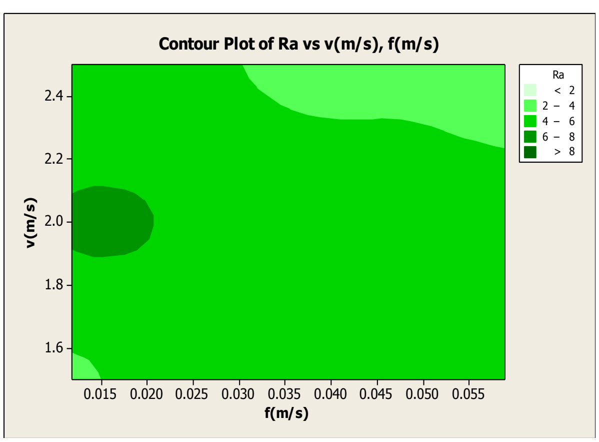

Figure 2b: Surface Plot Ra vs v(m/s), f(m/s).

Therefore the recommended range of process parameter settings for HSS tool while machining mild steel work-piece for a minimized Ra was cutting speed at 1.5 – 1.9 m/s (90-114 mpm) and feed rate at 0.04 to 0.06m/s (0.17 – 0.201mm/rev). The contour plot in Figure 2b shows the regions within which the process parameters settings should be selected for optimized Ra from the selected operation. The contour plot suggests that the cutting speed should be below 1.6 m/s (96mpm) while the feed rate should be below 0.015m/s (0.06mm/rev) for a minimized surface roughness (Ra) of values between 2 and 4 microns. Also when the process parameter settings are kept within cutting speed of 2.2 – 2.4 m/s (132 - 144mpm) for feed rate values of 0.030-0.055m/s (0.087 – 0.146mm/rev), the surface roughness Ra value would be between 2 and 4 microns when machining mild steel work-piece using HSS cutting tool on a ENC lathe machine.

Increase of cutting speed from about 1.92 to 2.1 m/s (115 - 126mpm) and maintaining feed rate of less than or equal to 0.020m/s (0.061mm/rev), resulted in an extremely high value of Ra between 6 and 8 microns. However, when the feed rate was between 0.02m/s (0.084 mm/rev) and below 0.04 m/s (0.170mm/rev) and cutting speed slightly above 1.5 m/s (90mpm), there was a sharp decrease in the Ra from about 7 microns to about 4 microns. The possible explanation for this could be that increasing feed rate to a range of 0.02 – 0.04m/s (0.064 – 0.170mm/rev) accelerates metal removal rate which resulted in the lower surface roughness when machining mild steel with HSS tool.

Figures 3a and 3b show surface and contour plots for Rz while considering the cutting speed (v) and feed rate (f). The response, Rz, has highest value when the cutting speed was at 2.5 m/s (150mpm) and feed rate was at 0.02m/s (0.051mm/rev). Whereas, the minimized value for Rz based on the surface response plot was attained when the cutting speed was below 2.0 m/s (120mpm) and when the feed rate was below or above 0.02m/s (0.064mm/rev). Therefore the recommended range of process parameter settings for HSS tool while machining mild steel work-piece was cutting speed at 1.5 – 1.9 m/s (90 - 114mpm) and feed rate at 0.04 – 0.06m/s (0.170 – 0.201mm/rev).

The contour plot in Figure 3b shows the regions within which the process parameters settings should be selected for optimized Rz from the selected operation. The contour plot suggests that the cutting speed should be above 2.42 m/s (145mpm) while the feed rate's value is kept within 0.035 – 0.040; 0.0505m/s (0.092 – 0.105; 0.133mm/rev) for a minimized surface roughness (Rz) of values within 5 and 10 microns. Also when the process parameter settings are kept within cutting speed of 1.8 – 2.2m/s (108 - 132mpm) and feed rate of 0.015-0.035m/s (0.064 – 0.149mm/rev), the surface roughness Rz value would be extremely high between 12 -20 microns when machining mild steel work piece using HSS cutting tool on a ENC lathe machine.

Increase of cutting speed from 1.5 to 2.0 m/s (90 - 120mpm) and increase of feed rate from 0.02 to 0.003m/s (0.085 – 0.095mm/rev), resulted in an increase of Rz from around 10 microns to about 28 microns. However, when the feed rate was over 0.02m/s (0.005mm/rev) and cutting speed slightly over 1.5 m/s (90mpm), there was a sharp decrease in the Rz from about 15 microns to almost 10 microns. The possible explanation for this could be that increasing cutting speed accelerates metal removal rate which resulted in the lower surface roughness when machining mild steel with HSS tool.

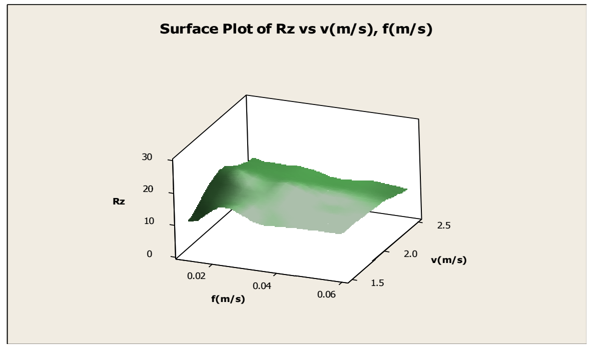

Figure 3a: Surface Plot of Rz vs v(m/s), f(m/s).

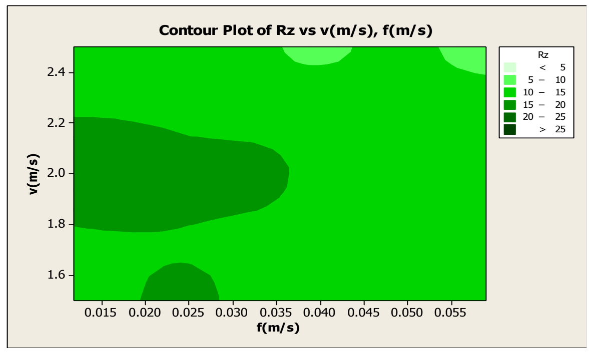

Figure 3b: Contour Plot of Rz vs v(m/s), f (m/s).

Figure 4a and 4b show surface and contour plots for Rq while considering the cutting speed (v) and feed rate (f). The response, Rq, has highest value when the cutting speed was at 2.0 m/s (120 mpm) and feed rate was at 0.02m/s (0.064mm/rev). The minimized value for Rq based on the surface response plot was attained when the cutting speed was below or above 4.0 m/s (240mpm) and when the feed rate was at 0.02m/s (0.032mm/rev). Therefore the recommended range of process parameter settings for HSS tool while machining mild steel work-piece was cutting speed below 1.5m/s (90mpm) and feed rate below 0.02m/s (0.085mm/rev).

The contour plot in Figure 4b shows the regions within which the process parameters settings should be selected for optimized Rq from the selected operation. The contour plot suggests that the cutting speed should be below 1.75 m/s (105mpm) while the feed rate's value is kept at 0.0155, 0.035 or 0.015 to 0.055m/s (0.056 – 0.127 mm/rev, or 0.055 – 0.2mm/rev) for a minimized surface roughness (Rq) of values less than 2 microns. Also when the process parameter settings are kept within cutting speed of 1.5 – 2.0m/s (90 - 120mpm) and feed rate of 0.04 – 0.06m/s (0.170 – 0.191mm/rev), the surface roughness Rq value would be minimized below 5 microns when machining mild steel work piece using HSS cutting tool on a ENC lathe machine. Increase of cutting speed from 1.8 to 2.15 m/s (108 – 129mpm) and increase of feed rate from 0.015 to 0.025m/s (0.053 – 0.074mm/rev), resulted in an increase of Rq from 8 microns to about 10 microns. However, when the feed rate was over 0.025m/s (0.072mm/rev or 0.088mm/rev) and cutting speed above 2.2 m/s or below 1.8m/s (132 or 108mpm), there was a sharp decrease in the Rq from about 10 microns to almost 6 microns.

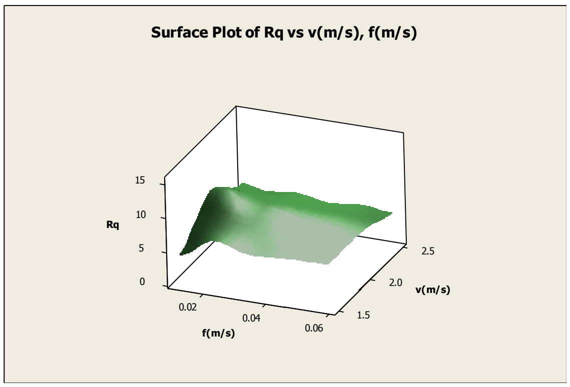

Figure. 4a Surface plot of Rq vs v(m/s), f(m/s).

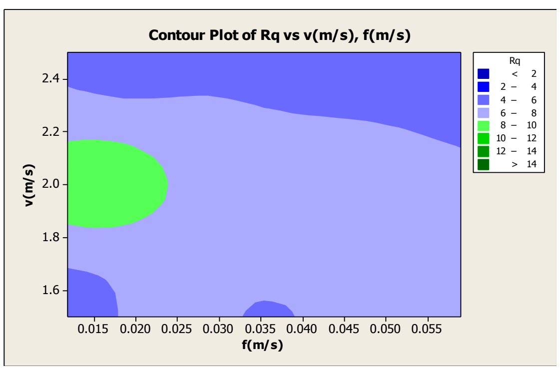

Figure 4b: Contour plot of Rq vs v(m/s), f(m/s).

Figures 5a and 5b show surface and contour plots for Rt while considering the cutting speed (v) and feed rate (f). The response, Rt, has highest value when the cutting speed was at 2.0 m/s (120mpm) and feed rate was at 0.02m/s (0.064mm/rev). Whereas, the minimized value for Rt based on the surface response plot was attained when the cutting speed was below 2.0 m/s (120mpm) and when the feed rate was at 0.02m/s (0.064mm/rev). Therefore the recommended range of process parameter settings for HSS tool while machining mild steel work-piece was cutting speed at 2.4m/s m/s and above (144mpm) and feed rate at 0.035 and 0.055m/s (0.093 – 0.146mm/rev).

The contour plot in Figure 5b shows the regions within which the process parameters settings should be selected for optimized Rt from the selected operation. The contour plot suggests that the cutting speed within 1.8 – 2.2 m/s (108 - 132mpm) and feed rate value within 0.015 – 0.035m/s (0.053 – 0.101 mm/rev) resulted into very high surface roughness (Rt) values within 20 and 25 microns. Also when the process parameter settings are kept within cutting speed above 2.4m/s (144mpm) and feed rate of 0.06m/s (0.159mm/rev), the surface roughness Rt value would be minimized to between 5 and 10 microns when machining mild steel work piece using HSS cutting tool on a ENC lathe machine. Increase of cutting speed from 1.5 to 2.0 m/s (90 – 120mpm) and increase of feed rate from 0.04 to 0.06m/s (0.17 – 0.191 mm/rev), resulted in reduced value of Rt from around 15 microns to value below 5 microns.

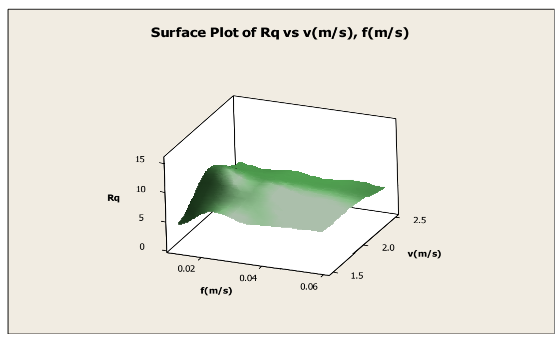

Figure 5a: Surface plot of Rt vs v(m/s), f(m/s).

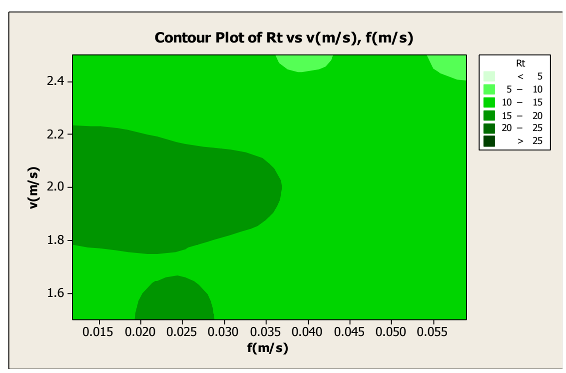

Figure 5b: Contour plot of Rt vs v(m/s), f(m/s).

Figure 6a and 6b show surface and contour plots for TL while considering the cutting speed (v) and feed rate (f). The response, TL, has highest value when the cutting speed was at 1.5 m/s (90mpm) and feed rate was at 0.002m/s (0.061mm/rev).

Whereas, the minimized value for TL based on the surface response plot was attained when the cutting speed was below or above 2.0 m/s (120mpm) and when the feed rate was at 0.004m/s (0.016mm/rev). Therefore the recommended range of process parameter settings for HSS tool while machining mild steel work-piece, was cutting speed at 1.5 – 1.9 m/s (90 - 120mpm) and feed rate at 0.015 and 0.02m/s (0.064 – 0.067mm/rev).

The contour plot Figure 6b shows the regions within which the process parameters settings should be selected for optimized TL from the selected operation. The contour plot suggests that the cutting speed should be below 1.6 m/s (96mpm) while the feed rate's value is kept below 0.015 m/s (0.060mm/rev) for a maximized tool life (TL) of values within 2000 and 3000 seconds. Also when the process parameter settings are kept within cutting speed of 1.8 – 2.4m/s (108 - 144mpm) and feed rate of 0.045-0.055m/s (0.159 – 0.233mm/rev), the Tool Life value would be below 1000 seconds when machining mild steel work piece using HSS cutting tool on a ENC lathe machine.

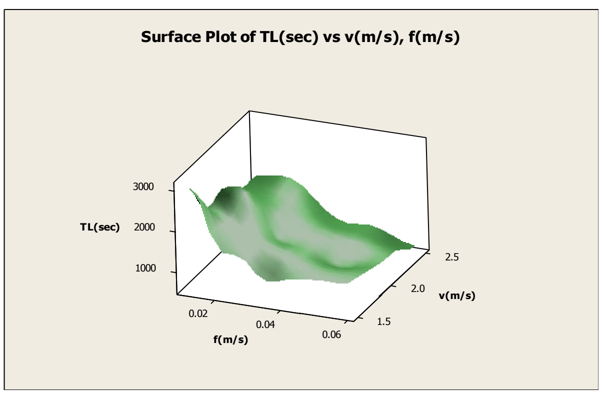

Figure 6a: Surface Plot of TL(sec) vs v(m/s), f(m/s).

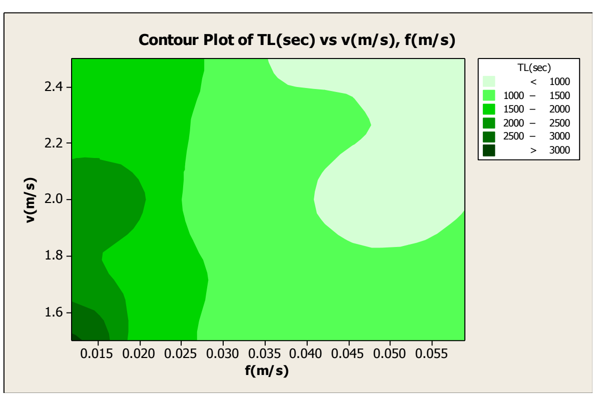

Figure 6b: Contour Plot of TL(sec) vs v(m/s), f(m/s).

Figure 7a and 7b show surface and contour plots for M/Ctime while considering the cutting speed (v) and feed rate (f). The response, M/Ctime, has highest value when the cutting speed was at 1.5 m/s (90mpm) and feed rate was at 0.02m/s (0.085mm/rev). Whereas, the minimized value for M/Ctime based on the response surface plot was attained when the cutting speed was below 2.0 m/s (120mpm) and the feed rate was at 0.04m/s (0.127 mm/rev). Therefore the recommended range of process parameter settings for HSS tool while machining mild steel work-piece was cutting speed between 1.5 – 1.9 m/s (90 - 114mpm) and feed rate at 0.04m/s (1.170mm/rev and 0.134mm/rev).

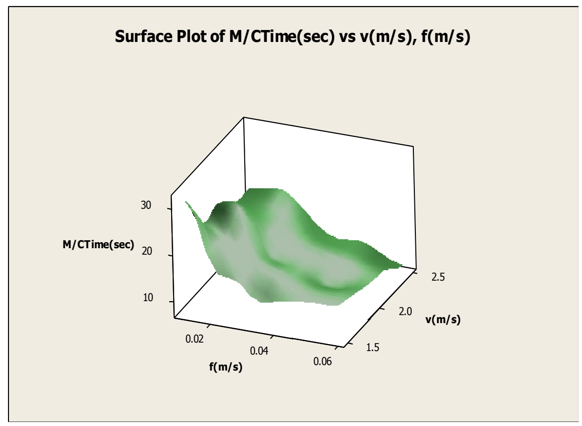

Figure 7a: surface plot of M/CTime(sec) vs v(m/s),f(m/s).

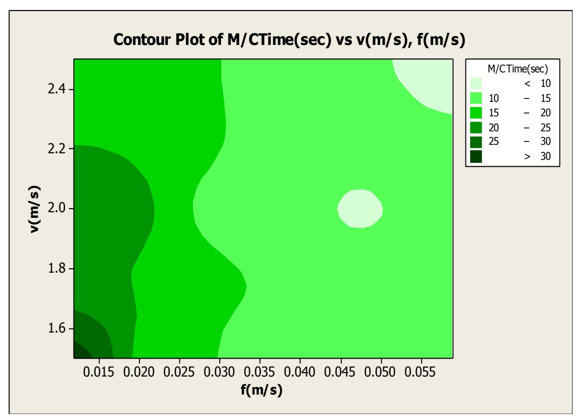

Figure 7b: Contour plot of M/CTime(sec) vs v(m/s), f(m/s

The contour plot in Figure 7b shows the regions within which the process parameters settings should be selected for optimized M/Ctime from the selected operation. The contour plot suggests that the cutting speed should be within 1.5 – 2.5 m/s (90 - 150mpm) while the feed rate value is kept at 0.04 – 0.06m/s (0.170 – 0.153mm/rev) for a minimized machining time of values below 20 seconds. Also when the process parameter settings are kept within cutting speed of 2.0m/s (120mpm) and feed rate of 0.045-0.05m/s (0.143 – 0.159mm/rev), the machining time value would be very low (below 10 seconds) when machining mild steel work piece using HSS cutting tool on a ENC lathe machine.

Decrease of feed rate from 0.04 to 0.02 m/s (0.170 – 0.051 mm/rev) for cutting speed between 1.5 and 2.5m/s (90 - 150mpm), resulted in an increase of M/Ctime from around 10 seconds to above 20 seconds. However, when the feed rate was over 0.05m/s (0.145mm/rev) and cutting speed over 2.2 m/s (132mpm), there was a decrease in the M/Ctime from about 15 seconds to below 10 seconds. The possible explanation for this could be that increasing feed rate accelerates metal removal rate which resulted in the lower machining time when machining mild steel with HSS tool.

CONCLUSION

The response optimisation carried out, for the experimental observations from fine cutting mild steel using HSS tool, showed that the global solutions of the response parameters, cutting speed, feed rate and depth of cut are 1.50003m/s (90mpm), 0.0279656 m/s (0.12 mm/rev) and 0.0001m (0.1 m). Hence, the optimised (minimised) values for the surface roughness (Ra, Rz, Rq, Rt) are 2.52, 7.13, 2.32 and 7.20 microns.

The optimised (maximum) values for the tool life and machining time are 1397.58 and 15.54 seconds. These results indicated the recommended values for the process parameters when fine cutting mild steel work-piece using HSS cutting tool. The work-piece materials produced with these optimised surface roughness values will have minimum flaws and there will be no crater formed on their surfaces while in use. The produced work-piece can be used as machined element in equipment that require high quality surface texture.

Similarly, the information provided by the response optimisation on tool life and machining time can enable machine shop production planners to carry out near accurate estimates on the cost of production of machine elements made of mild steel and fine cut using High Speed Steel cutting tool. The process parameters have global solutions with responses have composite desirability of 0.56362 which indicates that the optimised response values are 43.7% close to their targets.

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SUGGESTED CITATION

Onifade, M.K, A.C. Igboanugo, and J.O. Osarenmwinda. 2016. “Development of Models for the Prediction of Responses from Fine Tuning EN8 Mild Steel using HSS Tool”. *Pacific Journal of Science and Technology*. 17(2):14-24.

Pacific Journal of Science and Technology