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Development Of Model For Predicting Cutting Parameters At Optimum Surface Roughness For Turning Mild-Steel Under Wet Condition

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***Abstract*—Input parameters play important role on the surface finish of machined materials. The Surface finish of these machined materials determines their quality and performance expectations. Thus, manufacturers need to obtain optimal cutting conditions that will minimize the work-time, eliminate rework, attain the best surface finish and reduce machining costs. The cutting speed, depth of cut and feed rate are important input cutting parameters. This research work examined these cutting parameters in an experiment to investigate the surface roughness of turning mild steal on ENC2060 CNC Lathe using Tungsten Carbide-insert Tool under wet condition. A mathematical models were developed to show the correlation of the varying input parameters. The optimum cutting conditions where the least roughness occurs was determined with Spindle speed ranges from 1000-2200rpm, feed rate ranges from 100-700mm/min and depth of cut ranges from 0.3-0.9mm. From the optimized result with output of Fifty (50) solutions, the minimum surface roughness was 4.835 at cutting speed of 982 rpm, Feedrate of 543mm/min and depth of cut of 0.301mm. The Respond Model generated for this experiment yielded an F-value of 11.18 which implies that the model is significant. There is only a 0.81% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant.**

Keywords—Surface; Roughness; Mathematical Model; Optimum cutting Parameters; Respond Model; F-Value

I. INTRODUCTION

There are several parameters used to test the accuracy and functionality of a machined component under varying cutting parameters. One of those parameters is surface roughness value which is quantified by the deviations on the real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness is typically considered to be the high-frequency, short-wavelength components of a measured surface. However, in practice it is often necessary to know the amount of deviations to ensure that a surface is fit for a particular purpose. Roughness plays an important role in determining how a real object will interact with its environment [1]. Rough surfaces usually wear more quickly and have higher frictional coefficients than smooth surfaces. Roughness is often a good predictor of the performance of mechanical components, since irregularities in the surface may form nucleation sites for cracks or corrosion. In the other words, roughness may promote adhesion of these irregularities which causes deformation on the surfaces [2]. Although a high roughness value is often undesirable, it can be difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase its manufacturing cost. This often results in a trade-off between the manufacturing cost of a component and its performance in application [3]. Cutting parameters for mild still machining are always given in ranges meanwhile the quality and accuracy of the machined part depend on precise selection of cutting parameters that give good surface finish [4]. This study was established to predict the cutting parameters for mild steel turning under wet condition.

A. Significance of Surface Roughness Measurement in Component Manufacturing

Many works had been done on surface roughness determination for several materials under different cutting conditions and application. In recent machining operation, tool life is one of the most demanding tasks in production process, especially in the automotive industry [1]. According to Abbas, artificial neural network could be used for predicting the surface roughness for different cutting parameters in CNC turning operations. These parameters were investigated to get the minimum surface roughness. In addition, a mathematical model for surface roughness could be obtained from the experimental data using a regression analysis method. The experimental data could then be compared with both the regression analysis results and ANFIS (Adaptive Network-based Fuzzy Inference System) [5]. In present competitive world, the demand for high quality and fully automated production keeps attention on the surface roughness of the products. Surface roughness is contributed by the shape and average size of grains for the material.

B. Surface Roughness Measuring Principles

The **actual profile** is the profile resulting from the intersection of the work piece surface and a plane normal to that surface and in a direction that maximizes the surface roughness value, normally at right angles to the lay of the machining marks.
The **measured profile** is the profile resulting from scanning the actual profile with a probe which mechanically filters this profile due to the probe tip radius r_{tip} and, if fitted, by the skid of the probe system. Surface imperfections, such as cracks, scratches and dents are not part of the profile and should not be included in the recording. If necessary, tolerances according to DIN EN ISO 8785 can be set for them.
The **primary profile** (**P-profile**) is the profile resulting from electronic low-pass filtering of the measured profile with a cut-off wavelength λ_s. This process removes the shortest wavelength components that are judged not relevant to a roughness measurement. The parameters are designated **P** and evaluated within the sampling lengths.

C. Evaluation of Roughness Measurements

Roughness measurement values, particularly the vertical parameters Rt, Rz, Rz1max and Ra, vary in the approximate range of -20% to +30%. A single measurement may, therefore, not give a complete picture of compliance with the tolerance parameters. In DIN EN ISO 4288 Annex A the following procedure is stipulated:

1) ***Max rule***

All roughness parameters with the suffix "max" represent the maximum mean value measured within the five sampling lengths. Measurement should be made at three positions, at least, on the surface where the greatest values can be expected; at no position should the limit be exceeded.

2) ***16% rule***

All roughness parameters without the "max" suffix represent the mean value measured within the five sampling lengths:
16% of the measured values may exceed the limit. Step-by-step method:

1. If the first measured value is below 70% of the limit, this is considered to comply.
2. Failing this, take two additional measurements at other points on the surface; if all three measured values are below the limit, this is considered to comply.
3. Failing this, take nine additional measurements at other points on the surface; if a total of not more than two measured values are greater than the limit, this is considered to comply.

II. RESEARCH METHODOLOGY

Mild steel was used in this research because not only common, its price is relatively low whilst it provides material properties that are acceptable for many applications. This steel usually contains between 0.04% to 0.30% carbon content and insignificant amounts of alloying elements. The material exhibits good weldability properties and is used in most general fabrication and structural steel applications.

Samples of Mild Steel (1025) rods of Φ20x200mm length were prepared and turned with given cutting parameters with the aid of GSK890TDa CNC Lathe. The samples of the materials before and after machining are represented in Fig 1 and Fig 2 respectively.

Figure 1: Sample before Machining

Figure 2: Sample after Machining

Autodesk Inventor was used to prepare the Computer Aided Design, CAD and post processed with the aid of Computer Aided Manufacturing, CAM to generate the programming codes for straight turning operation. Fig 3 represents the working drawing.

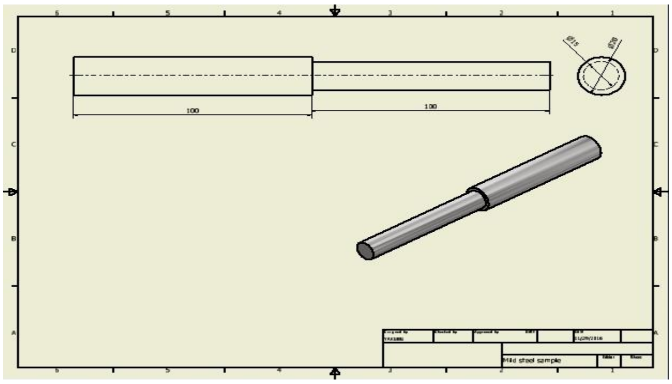

Figure 3: Working Drawing

A. The Turning Operation Programming Codes

The codes for turning the mild steel per run from Φ20x100mm using varying cutting parameters are as shown below. The spindle speed, feedrate and depth of cut at varying cutting parameters as highlighted. These codes are the format for input into GSK980TDa CNC lathe

N10 T0101 (This select tool position 01 with offset of 01 for turning operation)
N20 G00X40.0Z5.0 (Rapid movement of tool to X40.00, Z5.0 position for absolute programming)
N30 M03S**1000** (Start Spindle with 1000rpm)
N40 M08 (Coolant On)
N50 X20.0 (Rapid movement of tool to X20.0 position)
N60 G01X**19.4**Z-100.0F**100** (Taking a depth of cut 0.3mm along X)
N70 G00X30.0 (Retract and rapid movement of tool to X30.0 position)
N80 Z5.0 (Retract and rapid movement of tool to Z5.0 position)
N90 M09 (Coolant off)
N100 M05 (Spindle stop)
N110 M30 (Program End)

B. *Experimental Design*

The prediction of surface roughness values according to the mathematical model are very precisely analysis and determining of surface roughness values is a very practical tool by the experimental design method. It enables a high quality range in analyzing experiments and achieving optimal exact values. A rather small experimental data are required to generate useful information and thus develop the predictive equations for surface roughness values as Ra, Rt and Rz. Depending on the surface roughness data provided by the experimental design.

C. *Experimental Runs*

In this project, a design expert tool was used to generate the experimental runs, considering three factors; cutting speed, depth of cut and feedrate and a measurable response; surface roughness. Table 8 represents the experimental designs. The generated input parameters were based on minimum and maximum cutting parameters, considering response surface analysis and optimum design solution from design expert environment.

Table 1: Experimental Design Table

Notes for MyDesign
Design (Actual)
Summary
Graph Columns
Evaluation
Analysis
R1:Surface Roughn
R2:Temperature
Optimization
Numerical
Graphical
Post Analysis
Point Prediction
Confirmation
Coefficients Table

Select	Run	Factor 1 A:Cutting Sp... rpm	Factor 2 B:Feedrate mm/min	Factor 3 C:Dept of cut mm	Response 1 Surface Rou... µm	Response 2 Temperature oC
	1	2200	100	0.68		
	2	2200	477	0.3		
	3	1444	100	0.3		
	4	1444	100	0.3		
	5	1660	685	0.57		
	6	1000	700	0.9		
	7	2200	700	0.9		
	8	1660	685	0.57		
	9	1660	370	0.89		
	10	1018	370	0.57		
	11	1000	100	0.9		
	12	1018	370	0.57		
	13	1660	370	0.89		
	14	1660	685	0.57		
	15	1000	700	0.3		

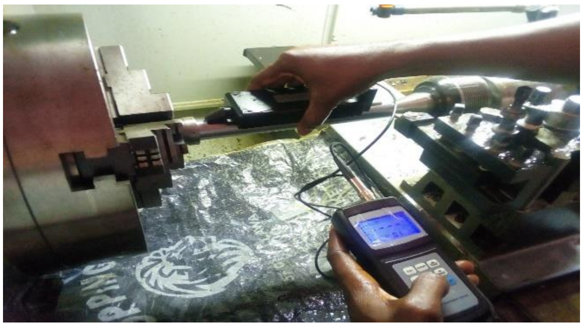

Figure 4: Surface Roughness Measurement

III. Results and Discussions

Upon running the experiment designs of varying depth of cut, cutting speed, and federate as generated from design expert tool, the responds from digital surface tester were recorded in Table 2. In this work, ANOVA for Response Surface Quadratic model analysis of variance was used to generate the mathematical model showing the analytical relationship between the cutting parameters. Table 3 represents Anova Model Analysis.

Table 2: Surface Roughness Response

Select	Run	Factor 1 A:Cutting Sp... rpm	Factor 2 B:Feedrate mm/min	Factor 3 C:Dept of cut mm	Response 1 Surface Rou... µm
	1	2200	100	0.68	9.36
	2	2200	477	0.3	7.21
	3	1444	100	0.3	5.34
	4	1444	100	0.3	5.38
	5	1660	685	0.57	6.23
	6	1000	700	0.9	11.17
	7	2200	700	0.9	12.35
	8	1660	685	0.57	8.32
	9	1660	370	0.89	7.53
	10	1018	370	0.57	6.27
	11	1000	100	0.9	10.66
	12	1018	370	0.57	7.57
	13	1660	370	0.89	7.79
	14	1660	685	0.57	6.87
	15	1000	700	0.3	5.34

Table 3: ANOVA MODEL ANALYSIS

ANOVA for Response Surface Quadratic model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	63.86	9	7.10	11.18	0.0081	significant
A-Cutting Speed	3.03	1	3.03	4.77	0.0807	
B-Feedrate	0.50	1	0.50	0.78	0.4164	
C-Dept of cut	30.31	1	30.31	47.76	0.0010	
AB	0.96	1	0.96	1.51	0.2739	
AC	1.23	1	1.23	1.94	0.2227	
BC	1.17	1	1.17	1.84	0.2332	
A^2	12.33	1	12.33	19.43	0.0070	
B^2	4.60	1	4.60	7.25	0.0432	
C^2	4.385E-003	1	4.385E-003	6.909E-003	0.9370	
Pure Error	3.17	5	0.63			
Cor Total	67.04	14				

The Model F-value of 11.18 in Table 3 implies the model is significant. There is only a 0.81% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case C, A^2, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.

Table 4: Signal to Noise Ratio Value

Std. Dev.	0.80	R-Squared	0.9527
Mean	7.83	Adj R-Squared	0.8675
C.V. %	10.18	Pred R-Squared	N/A
PRESS	N/A	Adeq Precision	10.777
-2 Log Likelihood	19.27	BIC	46.35
		AICc	94.27

Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 10.777 in Table 4 indicates an adequate signal. This model can be used to navigate the design space

A. *Model Equations*

Final Equation in Terms of Coded Factors for Surface Roughness Value, Ra is given by equation (1)

$$Ra=5.86+0.65A+0.24B+1.93C+0.46AB-0.51AC+0.47BC+2.02A^2+1.29B^2-0.039C^2 \quad (1)$$

Where; A-Cutting Speed, B-Feedrate and C-Depth of cut. The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Final Equation in Terms of Actual Factors for Surface Roughness Values, **Ra** $_{\text{(actual)}}$

$$Ra_{(actual)} = 16.55431-0.016138(\text{Cutting Speed}) - 0.017826(\text{Feedrate}) +9.41899(\text{Depth of cut}) +2.53367E-006(\text{Cutting Speed} * \text{Feedrate}) -2.85682E-003(\text{Cutting Speed} * \text{Depth of cut}) +5.24141E-003(\text{Feedrate} * \text{Depth of cut}) +5.59963E-006(\text{Cutting Speed})^2 +1.42814E-005(\text{Feedrate})^2 -0.42874(\text{Depth of cut})^2 \quad (2)$$

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. Various graphs were generated to show the relationships between the actual and predicted surface roughness as modeled. Fig 5-10 show the interactions between the cutting parameters

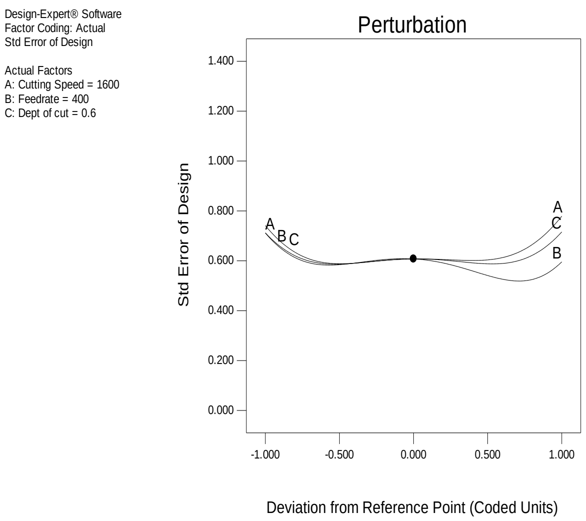

Figure 5: Perturbation Showing Deviation from Reference Point

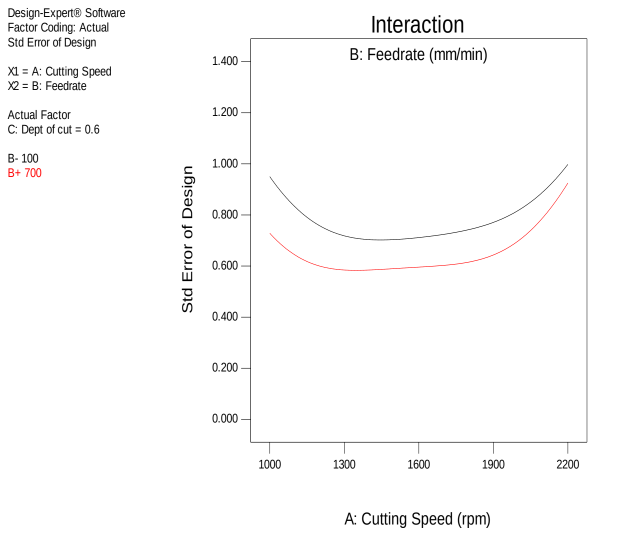

Figure 6: Interaction between Cutting Speed and Feedrate

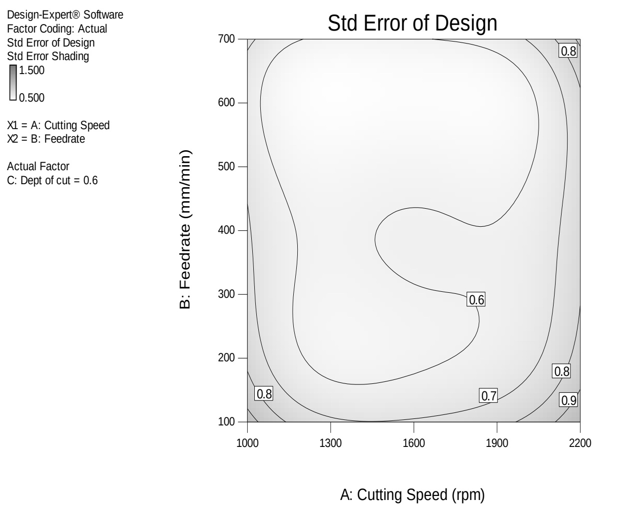

Figure 7: Standard Error of Design between Cutting Speed and Feedrate

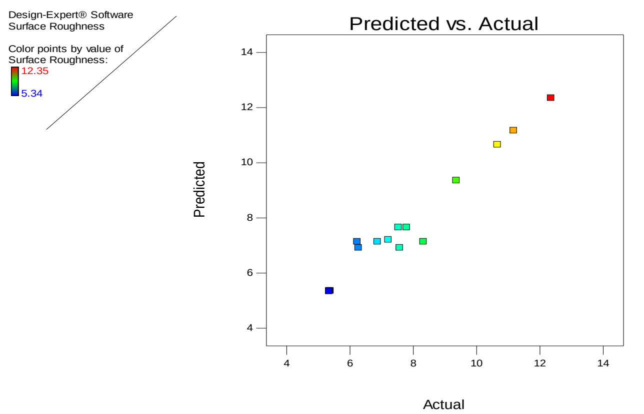

Figure 8: Interaction between Predicted and Actual Surface Roughness

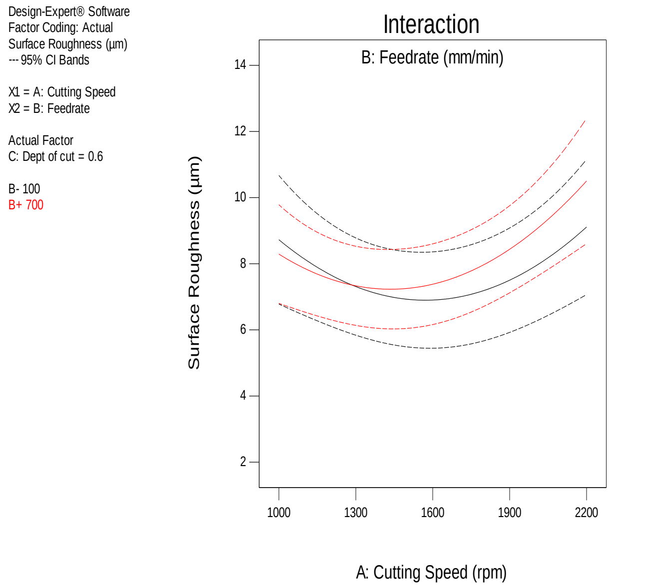

Figure 9: Interaction between Cutting Speed, Feedrate and Surface Roughness at 95% Confidence Level

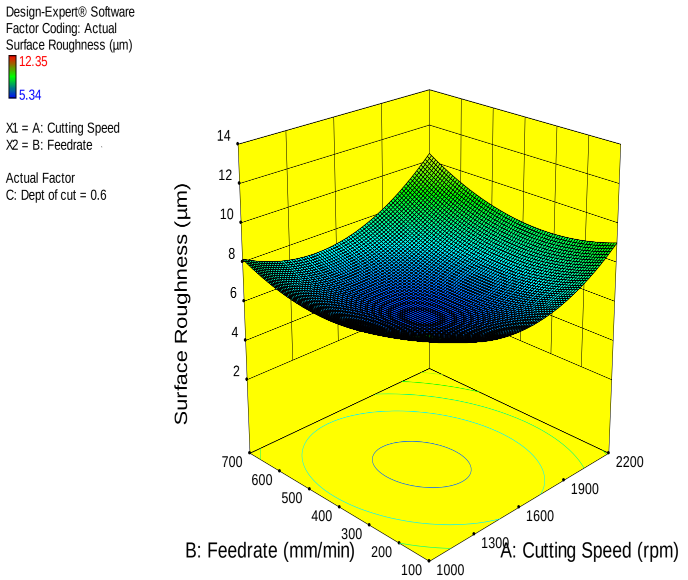

Figure 10: Interaction between Cutting Speed, Feedrate and Surface Roughness at 95% Confidence Level in 3D

IV. RESULT OPTIMIZATION FOR SURFACE ROUGHNESS

Design Expert has optimization tool for best fit with the objective of combining cutting parameters to minimize the surface roughness for quality job [6]. In this this work the upper and lower limits of surface roughness was 5.34 and 12.35µm respectively as shown Table 5. Fifty solutions were predicted and the cutting parameters that yielded good surface finished at minimum surface roughness are shown in Table 6.

Fig. 1. *Example of a figure caption. (figure caption)*

Table 5: Numerical Method for Surface Roughness

Constraints						
		Lower	Upper	Lower	Upper	
Name	Goal	Limit	Limit	Weight	Weight	Importance
A:Cutting Speed	is in range	700	1000	1	1	3
B:Feedrate	is in range	100	700	1	1	3
C:Dept of cut	is in range	0.3	0.9	1	1	3
Surface Roughness	Minimize	5.34	12.35	1	1	5

Table 6: Optimized Solutions for 50 Runs

Number	Cutting Speed	Feedrate	Depth of cut	Surface Roughness(μm)	Temp
1	998.703	364.496	0.332	5.112	25.292
2	878.716	540.254	0.301	5.329	25.839
3	925.000	590.000	0.310	5.273	26.049
4	926.226	589.952	0.302	5.185	25.996
5	942.544	360.004	0.316	5.289	25.231
6	932.330	392.638	0.313	5.221	25.304
7	983.304	352.464	0.307	5.028	25.125
8	993.267	314.506	0.324	5.268	25.151
9	924.111	604.796	0.301	5.239	26.072
10	955.449	405.387	0.342	5.313	25.492
11	954.107	404.668	0.307	5.025	25.279
12	951.645	526.669	0.322	5.111	25.792
13	996.977	402.607	0.310	4.837	25.250
14	979.898	540.032	0.350	5.250	25.969
15	954.766	521.491	0.307	4.950	25.675
16	915.641	527.358	0.317	5.260	25.822
17	909.157	588.666	0.305	5.303	26.040
18	949.243	425.314	0.303	4.970	25.315
19	914.851	525.971	0.307	5.168	25.756
20	953.266	383.364	0.326	5.246	25.342
21	987.855	487.780	0.323	4.912	25.601
22	889.870	434.980	0.300	5.268	25.406
23	977.977	604.900	0.310	5.066	26.035
24	982.146	365.703	0.302	4.940	25.118
25	969.293	374.348	0.343	5.325	25.407
26	957.277	390.271	0.304	5.013	25.214
27	968.988	427.339	0.312	4.948	25.360
28	963.934	322.146	0.310	5.273	25.094
29	957.398	470.643	0.321	5.046	25.567
30	930.218	521.483	0.304	5.052	25.695
31	992.703	295.752	0.315	5.291	25.064
32	935.689	551.149	0.326	5.276	25.947
33	991.218	488.100	0.359	5.214	25.808
34	888.770	468.523	0.302	5.252	25.535
35	942.729	626.123	0.300	5.217	26.144
36	931.660	547.258	0.312	5.159	25.854
37	971.002	458.789	0.307	4.856	25.423
38	912.206	435.021	0.304	5.167	25.397
39	999.235	296.749	0.302	5.150	24.978
40	922.021	460.166	0.319	5.218	25.561
41	994.631	309.307	0.319	5.243	25.108
42	986.763	388.080	0.301	4.849	25.167
43	992.226	451.600	0.363	5.241	25.707
44	946.404	478.601	0.308	4.986	25.531
45	924.791	473.435	0.302	5.050	25.505
46	958.481	448.237	0.337	5.190	25.584
47	908.968	418.461	0.302	5.204	25.341
48	982.662	542.991	0.305	4.835	25.717
49	904.970	462.272	0.318	5.305	25.587
50	952.480	377.954	0.305	5.085	25.196

V. Conclusion

From Optimization result with output of Fifty (50) solutions, the minimum surface roughness was 4.835 at cutting speed of 982 rpm, Feedrate of 543mm/min and depth of cut of 0.301mm. The Respond Model generated for this experiment yielded an F-value of 11.18 which implies that the model is significant. There is only a 0.81% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. Also “Adequate Precision” measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 10.777 in Table 4 indicates an adequate signal. This model can be used to navigate the design space.

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