Effect of HSS and HCS Cutting Tools on Cutting Force in X-direction and Tool Temperature while Machining of EN24 Steel

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Abstract

The objective of this work is to optimize the cutting parameters in turning of EN24 steel to achieve Minimum Cutting Forces and Minimum Tool Temperature using HSS and HCS as tool materials. Nowadays as HSS and HCS are most commonly used tools for manufacturing industries, therefore a comparative study is conducted to study the machining abilities on EN24 material. In the present work Full Factorial Design is considered with three process parameters: Speed, Feed and Depth of Cut. By using the mathematical model the main and interaction effect of various process parameters on Cutting Force in X-direction and Tool Temperature are studied. The developed model helps in selection of proper machining parameters for the specific material and also helps in achieving the desired multiple responses.

Keywords: *Cutting Force in X-direction, Cutting Temperature, Response Surface Methodology.*

1. Introduction

The general process of turning involves in rotating a part while a single-point cutting tool is moved parallel to the axis of rotation. It is used to reduce the diameter of the work piece, usually to a specified dimension and to produce smooth surface finish on the metal. In turning, the major output characteristics that generally considered are material removal rate, surface roughness, tool life, tool temperature and etc. These performance characteristics were influenced by many factors like material properties, tool geometry, cutting conditions and etc.

M.Korat, et. al. studied Optimization of effects of cutting parameters on surface finish and MRR of EN24/AISI4340 work material by employing Taguchi techniques. Results were obtained minimum surface roughness (SR) and maximum material removal rate for optimal cutting parameters.

Krishankant, et. al. investigated optimization of turning process by the effects of machining parameters applying Taguchi methods to improve the quality of manufactured goods, and engineering development of designs for studying variation. EN24 steel is used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate. The MRR values measured from the experiments and their optimum value for maximum material removal rate.

V. Suresh Babu, et. al. studied development of an empirical second order model for the predicting the surface roughness in machining EN24 alloy steel using Response Surface Method. The experiments were conducted by varying cutting speeds, feed rates, and depths of cut under dry cutting condition. The effect of process parameters with the output variable were predicted which indicates that the highest cutting speed has significant role in producing least surface roughness followed by feed and depth of cut. The optimized parameters are verified and validated through a validation experiment, which concurs with the predicted optimal value in the design of experiment and also inline to the previous researches.

Kumar, et. al. investigated analysis the effects of input parameters such as speed (rpm), feed (mm/rev), depth of cut (mm) and nose radius (mm) on output parameter such as material removal rate and surface roughness. The experiment was performed with different combination values of input parameter. Equal weightage has been assigned to all input parameter and a (Multi attribute decision making) MADM approach then performed to find out the best result.

Koorapati, et. al. investigated the surface roughness produced during hard turning of hard chrome plated surfaces with various cutting inserts. The optimization of the surface roughness was carried out with Taguchi's Design of Experimentation technique. The results of the experimentations revealed that the hard turning operation can be extended to the hard chrome plated surfaces.

Rahul Davis, et. al. investigated that, optimal setting of these turning process parameters –spindle speed, feed rate and depth of cut, which may result in optimization of tool life of Carbide P-30 cutting tool in turning En24 steel (0.4 % C). Turning operations were performed by Carbide P-30 cutting tool under various dry cutting conditions by using sample specimens of EN-24 steel. The results depict that Spindle speed followed by feed rate and depth of cut was the combination of the optimal levels of factors that significantly affects the mean and variance of the tool life of the carbide cutting tool and gives the optimum tool life.

Adinarayana, et. al. investigated the study to optimize the effects of process variables on surface roughness, MRR and power consumption of En24 of work material using PVD coated tool. In the present investigation the influence of spindle speed, feed rate, and depth of cut were studied as process parameters. The optimal cutting parameters for minimum surface roughness, maximum MRR and minimum power consumption were obtained using Taguchi technique. The contribution of various process parameters on response variables have been found by using ANOVA technique.

2. Experimentation Details

A medium carbon steel EN24 has been selected as the work piece. The chemical composition and mechanical properties of EN24 steel are given in tables 1 and 2. For the experimentation HSS and HCS tools were used and shown in figures 1 and 2.

Table 1. Chemical Composition of EN24 Steel

C	Si	S	Mn	P	Mo	Cr	Ni
0.36-0.44	0.10-0.35	0.040	0.45-0.70	0.035	0.20-0.35	1.00-1.40	1.30-1.70

Table 2. Mechanical Properties of EN24 Steel

Parameters	**Values**
Maximum Stress	850-1000 N/mm^2
Yield Stress	680 N/mm^2
Hardness	248-302 BHN
Density	7850 kg/m^3

Figure 1. HSS Tool

Figure 2. HCS Tool Figure

3. Design of Experiments

Design of experiments is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters to output responses. DOE has wide applications especially in the field of science and engineering for the purpose of process optimization and development, process management and validation tests. DOE is essentially an experimental based modelling and is a designed experimental approach which is far superior to unplanned approach whereby a systematic way will be used to plan the experiment, collect and analyze the data. A mathematical model has been developed by Response Surface Methodology(RSM). Optimization and Desirability functions helps to optimize the quality characteristics considered in a DOE under a cost effective process. For the present work, three process parameters of spindle speed, feed and depth of cut at three different levels has been considered as given in table 3 and the suitable orthogonal array L27 given is used for the experimentation.

Table 3. Process Variables and their Limits

Values in coded form	Spindle speed(N) 'rpm'	Feed(F) 'mm/rev'	Depth of cut(D) 'mm'
-1	75	0.5	0.5
0	115	0.75	1
1	200	1	1.5

4. Results and Discussions

4.1 Response Surface Methodology

Response Surface Methodology(RSM) explores the relationships between several explanatory variables and one or more response variables. The method was introduced by George E. P. Box and K. B. Wilson in 1951. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but they use it because such a model is easy to estimate and apply, even when little is known about the process. Statistical approaches such as RSM can be employed to maximize the production of a special substance by optimization of operational factors.

4.2 Mathematical Model of Response Surface Methodology

A second-order polynomial is employed for developing the mathematical model for predicting weld pool geometry. If the response is well modelled by a linear function of the independent variables then the approximating function is the first order model as shown in Equation.

$$Y = \beta + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots \beta_x x_x + \epsilon$$

4.3 Mathematical Relationship between the Input Parameters and Tool Temperature by using HCS as a Tool

The mathematical relationship for correlating the Tool Temperature and the considered process variables has been obtained as follows:

Temp= -25.2+ 0.144*speed+ 130.2*feed+ 20.2*doc- 0.001034*speed*speed - 67.6*feed*feed - 4.2*doc*doc + 0.040*speed*feed + 0.1153*speed*doc - 13.1*feed*doc

Table 4. Comparison of predicted and experimental values of Tool Temperature

S.No.	Temp (pred.)	Temp (exp.)	% error
1	40.5906	36	-4.5906
2	50.9369	42.2	-8.7369
3	59.2053	62.4	3.1947
4	51.5612	48.8	-2.7612
5	60.2741	66	5.7259
6	66.9092	70	3.0908
7	54.0873	56.2	2.1127
8	61.1668	67	5.8332
9	66.1686	62.3	-3.8686
10	31.7301	32	0.2699
11	46.9773	41.1	-5.8773
12	60.1467	61.4	1.2533
13	43.5602	48.2	4.6398
14	57.1741	61.5	4.3259
15	68.7102	73	4.2898
16	46.9459	45.7	-1.2459
17	58.9264	55.6	-3.3264
18	68.8292	64.5	-4.3292
19	39.5904	47.5	7.9096
20	47.6303	53.8	6.1697
21	53.5924	54	0.4076

22	50.1564	47.9	-2.2564
23	56.5630	49.8	-6.7630
24	60.8917	50.6	-10.2917
25	52.2780	48.2	-4.0780
26	57.0512	59.7	2.6488
27	59.7467	66	6.2533

4.3.1 Various graphs for Temperature

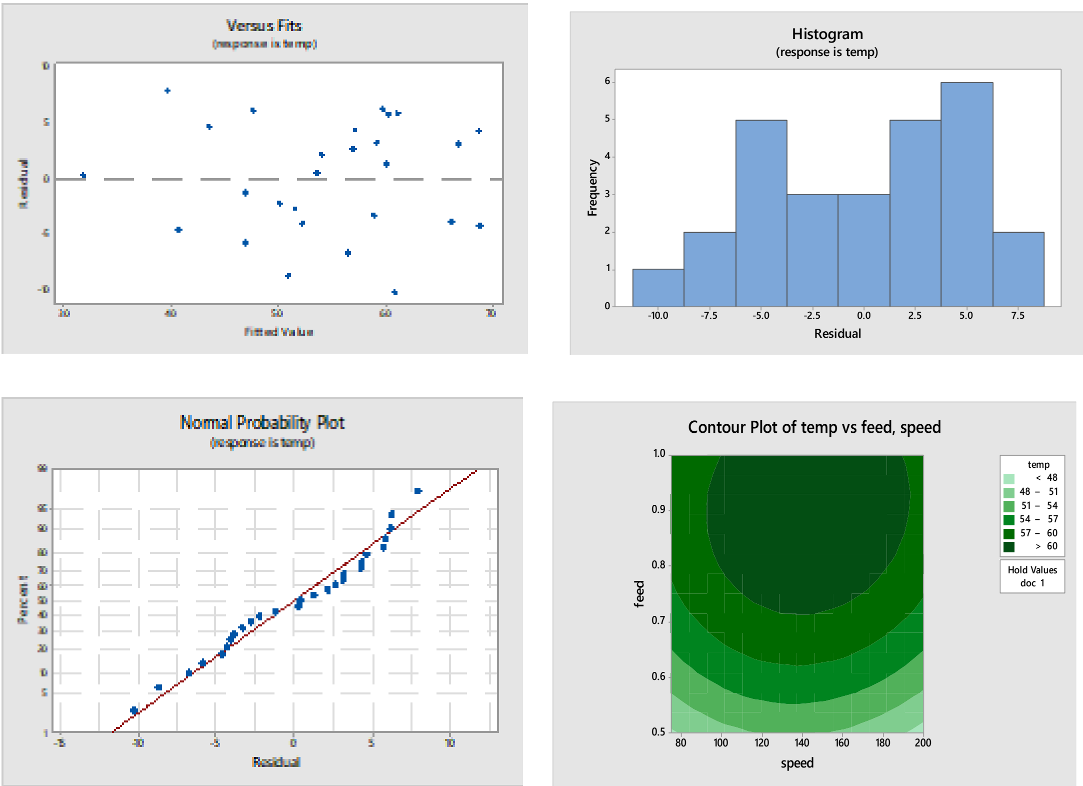


Figure 3. Various graphs for Temperature

4.4 Mathematical Relationship between the Input Parameters and Force in X-direction by using HCS as a Tool

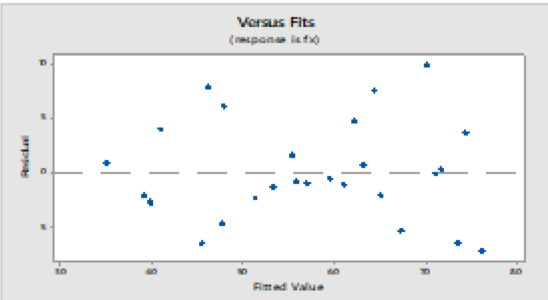
The mathematical relationship for correlating the cutting force in X-direction and the considered process variables has been obtained as follows:

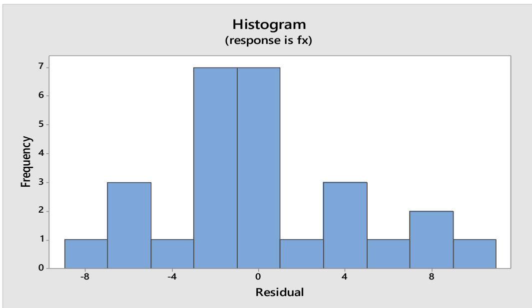
$$F_x = -6.3 + 0.187*speed + 59.0*feed + 29.1*doc - 0.000803*speed*speed - 27.6*feed*feed - 4.89*doc*doc - 0.052*speed*feed + 0.0436*speed*doc + 4.0*feed*doc$$

Table 5. Comparison of predicted and experimental values of F_x

S.No.	F_x (pred.)	F_x (exp.)	% error
1	41.0378	45	3.96222
2	55.4333	57	1.56669
3	67.3844	62	-5.38440
4	46.1785	54	7.82146
5	61.0741	60	-1.07407
6	73.5252	67	-6.52516
7	47.8749	54	6.12514
8	63.2704	64	0.72961
9	76.2215	69	-7.22148
10	35.0768	36	0.92320
11	51.3236	49	-2.32356
12	65.1259	63	-2.12588
13	39.1051	37	-2.10509
14	55.8519	55	-0.85185
15	70.1542	80	9.84583
16	39.6889	37	-2.68893
17	56.9357	56	-0.93570
18	71.7380	72	0.26199
19	39.8229	37	-2.82987
20	53.3542	52	-1.35424
21	64.4342	72	7.56584
22	45.4941	39	-6.49415
23	59.5185	59	-0.51852
24	71.0984	71	-0.09844
25	47.7140	43	-4.71399
26	62.2384	67	4.76165
27	74.3183	78	3.68172

4.41 Various graphs for F_x





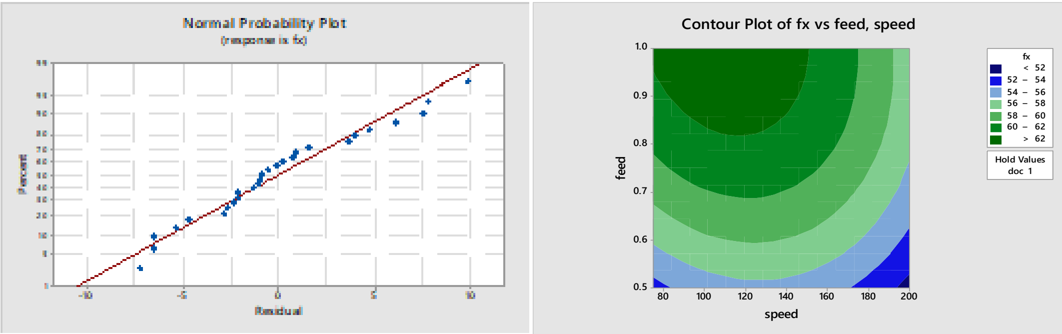


Figure 4. Various graphs for F_x

4.5 Mathematical Relationship between the Input Parameters and Tool Temperature by using HSS as a Tool

The mathematical relationship for correlating the Tool Temperature and the considered process variables has been obtained as follows:

Temp = 22.7 + 0.491 speed - 32.4 feed - 12.4 doc - 0.001894 speed*speed + 10.8 feed*feed - 2.2 doc*doc + 0.104 speed*feed + 0.0579 speed*doc + 27.7 feed*doc

Table 6. Comparison of predicted and experimental values of Tool Temperature

S.No.	Temp (pred.)	Temp (exp.)	% error
1	50.0884	35	-15.0884
2	52.4958	45.2	-7.2958
3	53.8253	50.1	-3.7253
4	51.8195	62.2	10.3805
5	57.6852	63.4	5.7148
6	62.4731	66.7	4.2269
7	54.9062	55.7	0.7938
8	64.2302	69.8	5.5698
9	72.4764	71.9	-0.5764
10	47.9931	52	4.0069
11	52.8618	53.2	0.3382
12	56.6527	59.8	3.1473
13	51.9249	55.2	3.2751
14	60.2519	57.8	-2.4519
15	67.5011	61.9	-5.6011
16	57.2121	52.2	-5.0121
17	68.9975	67.8	-1.1975
18	79.7050	83.2	3.4950
19	41.6045	46.4	4.7955

20	42.8536	51.8	8.9464
21	43.0248	47.9	4.8752
22	42.3000	42.6	-1.9000
23	47.0074	41.4	-5.6074
24	50.6370	40.4	-8.0370
25	44.3511	43.1	-1.2511
26	52.5168	48.5	-4.0168
27	59.6047	61.8	2.1953

4.5.1 Various graphs for Temperature

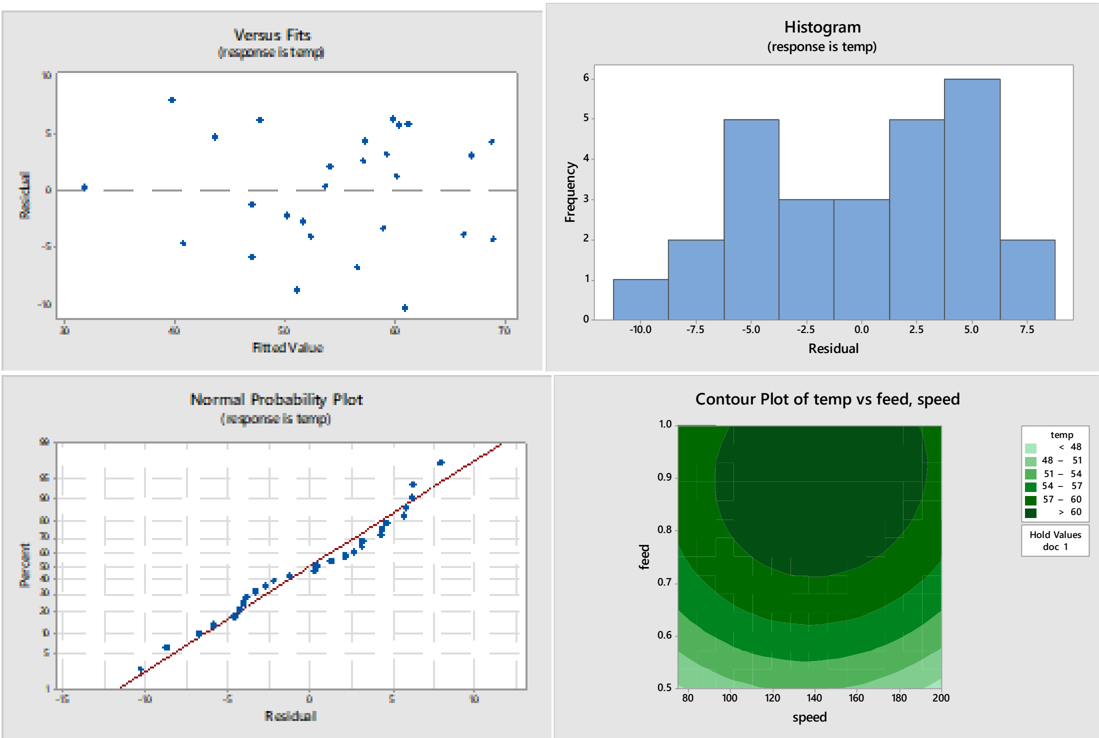


Figure 5. Various graphs for Temperature

4.6 Mathematical Relationship between the Input Parameters and Force in X-direction by using HSS as a Tool

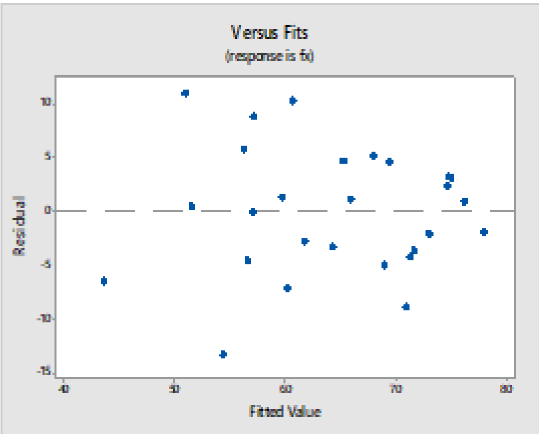
The mathematical relationship for correlating the cutting force in X-direction and the considered process variables has been obtained as follows:

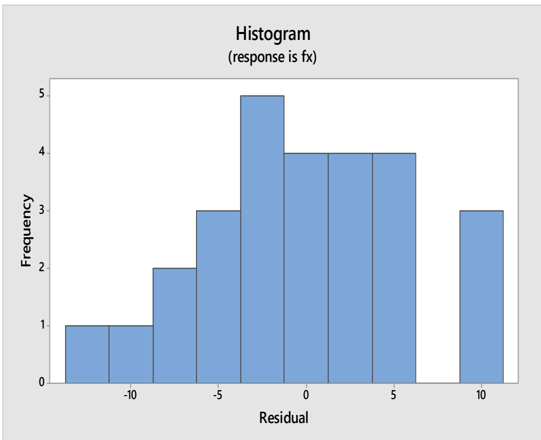
F_X = 25.1 - 0.001 speed + 139.3 feed - 38.1 doc + 0.000131 speed*speed - 54.2 feed*feed+ 8.4 doc*doc - 0.391 speed*feed + 0.1920 speed*doc + 8.7 feed*doc

Table 7. Comparison of predicted and experimental values of F_x

S.No.	F_x (pred.)	F_x (exp.)	% error
1	56.5742	52	-4.5742
2	57.0507	57	-0.0507
3	61.7494	59	-2.7494
4	64.2920	61	-3.2920
5	65.8519	67	1.1481
6	71.6339	68	-3.6339
7	65.2320	70	4.7680
8	67.8752	73	5.1248
9	74.7406	78	3.2594
10	51.5085	52	0.4915
11	60.1460	53	-7.1460
12	73.0057	71	-2.0057
13	50.9088	62	11.0912
14	60.6296	71	10.3704
15	74.5727	77	2.4273
16	43.5313	37	-6.5313
17	54.3355	41	-13.3355
18	69.3619	74	4.6381
19	59.6117	61	1.3883
20	56.2477	62	5.7523
21	57.1059	66	8.8941
22	71.2436	67	-4.2436
23	68.9630	64	-4.9630
24	70.9045	62	-8.9045
25	76.0978	77	0.9022
26	74.9004	78	3.0996
27	77.9253	76	-1.9253

4.61 Various graphs for F_x





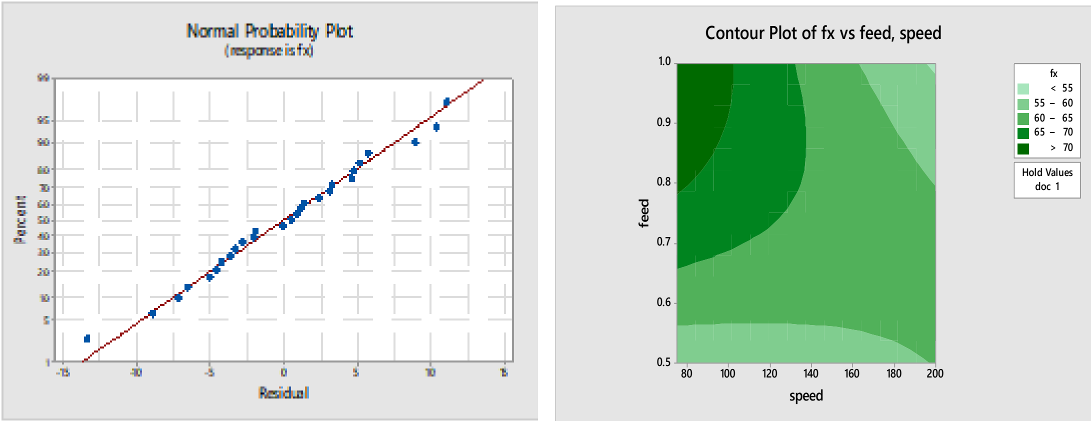


Figure 6. Various graphs for F_x

5. Conclusions

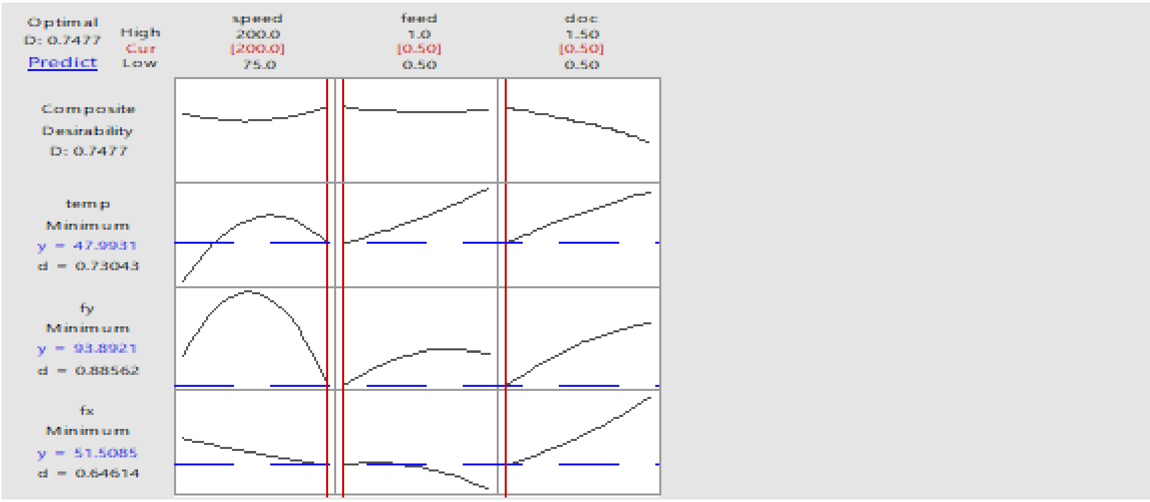


Figure 7. HSS Optimization Plot

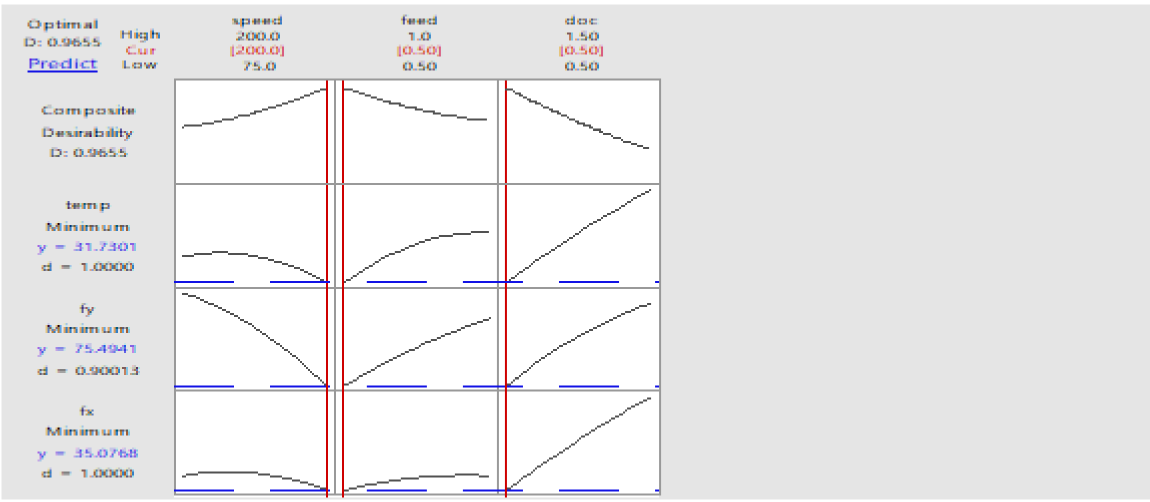


Figure 8. HCS Optimization Plot

- This paper produces a direct equation with the combination of controlled parameters which can be used in industries to know the values of cutting force on x direction and cutting tool temperature.
- The optimal solution for cutting force on x direction is 35.0768 N and temperature 31.7301°C will be obtained when the EN24 work piece is machined at speed 200rpm, feed 0.50(mm/rev) and depth of cut 0.50(mm) using **HCS** as a tool for turning.
- From the optimization plot it is clear that while machining an EN24 material a **HCS** tool is to be used when compared to **HSS** tool for better results.

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