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Optimization of Tool Temperature and Surface Roughness in Wet and Dry Conditions During Turning of Mild Steel Using Response Surface Method

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Abstract—

The present study aimed at evaluating the best process environment which could simultaneously satisfy requirements of both quality and as well as productivity in less time. The predicted optimal setting ensured the minimization of surface roughness and tool temperature. Experimentation was conducted in a series of tests called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response using Response Surface Methodology (RSM). The obtained results were verified through confirmatory test. This indicates that the application feasibility of the aforesaid techniques correlated with multi-response optimization. Productivity and the quality of the machined parts are the main challenges of metal cutting industry during turning process. Therefore cutting parameters must be chosen and optimize in such a way that the required surface quality can be controlled. Hence statistical Design of Experiments (DOE) and statistical/mathematical model are used extensively for optimize.

Keywords— Surface roughness, Tool temperature, Runs, Response Surface Methodology, Multi-response optimization, Design of Experiments.

I. INTRODUCTION

Quality and productivity play significant role in today's manufacturing market. From customers viewpoint quality is very important because the extent of quality of the procured item (or product) influences the degree of satisfaction of the consumers during usage of the procured goods. Every manufacturing industry aims at producing a large number of products within relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss. The present study applied Factorial Method in straight turning of mild steel bar using HSS tool.

1.1 Turning Operation

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters.

1.2 Speed

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece.

$$V = \pi DN/1000 \quad m/min$$

Here, v is the cutting speed
D is the initial diameter of the work piece in mm,
N is the spindle speed in RPM.

1.3 Feed

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per r evolution (of the spindle), mm/rev.

$$Fm = f\,N \; mm/min$$

Here, Fm *is* the feed in mm per minute,
f *is* the feed in mm/rev and N is the spindle speed in RPM.

1.4 Depth of Cut

Depth of cut is practically self-explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

$$D_{cut} = (D - d) / 2 \text{ mm}$$

Here, D_{cut} represents the depth of cut
D and d represent initial and final diameter (in mm) of the job respectively

1.5 Surface Roughness

Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behaviour, corrosion resistance, creep life, etc. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. Before surface roughness, it is also necessary to discuss about surface structure and properties, as they are closely related.

1.6 Tool-Temperature

For the improvement of cutting performance, the knowledge of temperature at the tool-work interface with good accuracy is essential. Several experimental and analytical techniques have been developed for the measurement of temperatures generated in cutting processes. Due to the nature of metal cutting, it is not possible to measure temperature precisely in the cutting zone and thus it is difficult to verity the theoretical results in a precise manner. Because of nature of the metal cutting, determination of internal temperatures on the cutting tool are very difficult. For measuring of this temperatures generated in the cutting zone, several methods have been developed. Calorimetric method, thermocouple method, infrared photographic technique, thermal paints and PVD technique are some of them.

II. LITERATURE REVIEW

Patrick et al [1] analysed the “Effect of cutting fluids on the mechanical properties of mild steel in turning operation.” They analysed the effect of temperature and metal removal rate of the work piece on the variables such as cutting speed, feed, depth of cut, good chip formation, reduction of heat generated and realization of a good surface finish in the presence of cutting fluids.

M. Davami et al [2] investigated about the “Tool temperature and surface quality in hot machining of hard-to-cut materials”. They reported that the surface roughness and MRR parameters greatly depend on work piece materials. A gas flame heating source was used to preheating of the work piece surface up to 300°C, causing reduction of yield stress about 15%. Results obtained experimentally shows that the method adopted was considerably improved surface quality of the work piece.

M.K Vijaya Prabhu et al [3] presented a paper on “Performance of various cutting fluids by estimating surface roughness of mild steel in turning”. Totally twelve experiments are carried out and the results are plotted in the form of graphs. These graphs show the variation of surface roughness with respect to the cutting speeds and cutting fluids. By analysing the graph, the best cutting fluid under various cutting speeds and feeds was found.

S.R.Das [4] studied on “Optimization cutting parameters on tool wear, work piece surface temperature and material removal rate during turning of AISI D2 steel”. They investigated on the optimal machining parameters for continuous profile machining on AISI D2 steel to achieve minimum tool wear, low work piece surface temperature and maximum material removal rate. ANOVA was performed to identify the effect of the cutting parameters on the response variables. The results showed that depth of cut and cutting speed are the most important parameter influencing the tool wear.

YahyaIsik [5] presented a paper on “An experimental investigation on effect of cutting fluids in turning with coated carbide tool” The result of the present work indicate substantial reduction in tool wear, which enhanced the tool life ; this may be mainly attributed to reduction in cutting zone temperature and favourable change in chip-tool interaction

III. EXPERIMENTATION

3.1 Design of Experiment

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 the data and analyse the data. A mathematical model has been developed by Response Surface Methodology. Optimization and Desirability functions helps to optimize the quality characteristics considered in a DOE under a cost effective process.

3.2 Process Variables

Table 3.1: Process variables and their limits

Process variables			
Values in coded form	**Spindle Speed (*N*)**	**Feed (*f*)**	**Depth of cut (*d*) (RPM) (mm/rev) (mm)**
-1	125	0.5	0.50
0	300	0.75	0.75
1	460	`1	1

3.3 Minitab Software

Minitab is a statistics package. It was developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. Minitab began as a light version of MNITAB, a statistical analysis program by NIST. Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College. Pennsylvania, with subsidiaries in Coventry, England, Paris, France and Sydney, Australia Today, Minitab is often used in conjunction with the implementation of six sigma, CMMI and other statistics-based process improvement methods.

3.4 Full Factorial Method

Experiments have been carried out using full factorial method. Experimental design which consists of 27 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue prepared by factorial design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table 3.2 (all factors are in coded form). Factorial design is used for conducting experiments as it allows study of interactions between factors. Interactions are the driving force in many processes.

Table 3.2 DOE in Coded form

Experiment No	**Spindle speed**	**Feed**	**Depth of cut**
1	+1	0	0
2	+1	+1	-1
3	-1	0	+1
4	0	0	0
5	-1	-1	0
6	0	+1	0
7	-1	-1	-1
8	0	0	+1
9	0	-1	0
10	+1	-1	0
11	-1	+1	+1
12	+1	+1	+1
13	-1	+1	0
14	+1	-1	+1
15	0	0	-1
16	+1	-1	-1
17	+1	0	-1
18	-1	+1	+1
19	0	-1	+1
20	0	+1	-1
21	+1	+1	0
22	0	-1	-1
23	+1	0	-1
24	-1	0	-1
25	-1	0	0
26	-1	-1	+1
27	0	+1	+1

IV. RESULTS AND DISCUSSIONS

4.1 Response Surface Methodology

Response surface methodology uses statistical models, and therefore practitioners need to be aware that even the best statistical model is an approximation to reality. It is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments the objective is optimize a response which is influenced by several independent variables [6]. In practice, both the models and the parameter values are unknown, and subject to uncertainty on top of ignorance. Of course, an estimated optimum point need not be optimum in reality, because of the errors of the estimates and of the inadequacies of the model. Nonetheless, response surface methodology has an effective track-record of helping researchers improve products and services: For example, Box's original response-surface modelling enabled chemical engineers to improve a process that had been stuck at a saddle-point for years. The engineers had not been able to afford to fit a cubic three-level design to estimate a quadratic model, and their biased linear-models estimated the gradient to be zero. Box's design reduced the costs of experimentation so that a quadratic model could be fit, which led to a (long-sought) ascent direction.

4.2 Mathematical model of Response Surface Methodology

The Response Surface is described by a second order polynomial equation of the form

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_{i^2} + \sum \sum_{i<j} \beta_{ij} x_i x_j + \in$$

Y is the corresponding response
(1, 2. . . S) are coded levels of S quantitative process variables. The terms are the second order regression coefficients, Second term is attributable to linear effect, third term corresponds to the higher-order effects, Fourth term includes the interactive effects and the last term indicates the experimental error.

4.2 Dry Machining Process

Performing straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like:

Spindle speed, feed and depth of cut. Tabulating temperature of each machined bar at three different positions by the Laser digital Thermometer. Calculating the average temperature of each machined bars**.**

4.2.1 Mathematical Relationship between the Input Parameters and Temperature

As dry machining does not involve use of any kind of coolants while cutting metal s and alloys most of the energy required to form the chips is converted into heat. Therefore, the temperatures generated in the cutting zone are an important factor to take into consideration. This factor is of a major importance to the performance of the cutting tool and quality of the work piece.

Temperature= 32.92+0.00073*(SS) +6.09*(F) +13.99*(DOC) +0.000003*(SS*SS) +4.85*(F*F)-1.18*(DOC*DOC) +0.00863*(SS*F)-0.00738*(SS*DOC)-18.99(F*DOC)

Table 4.1 Predicted Temperature values with % error

Speed (RPM)	**Feed (mm/Rev)**	**Depth of Cut (mm)**	**Temperature (ºc)**	**Predicted Temperature(ºc)**	**Error Temperature**	**% Error**
460	0.5	0.5	42.511	42.782	-0.271	0.63
300	0.75	0.5	42.55	42.853	-0.303	0.71
460	0.75	1	45.12	45.117	0.003	0.006
460	1	0.5	46.92	46.591	0.329	0.7
300	1	1	42.56	42.404	0.156	0.36
125	1	0.75	41.069	41.168	-0.099	0.24
460	1	0.75	45.536	45.73	-0.194	0.42
300	0.75	1	43.165	42.951	0.214	0.49
125	0.75	1	40.22	40.64	-0.42	1.04
125	1	1	40.16	39.725	0.435	1.08
125	0.75	0.75	41.036	40.896	0.14	0.34
300	1	0.5	44.89	44.679	0.211	0.47
300	0.75	0.75	43.065	42.884	0.181	0.42
300	0.5	0.75	42.728	42.759	-0.031	0.072
125	0.5	0.5	40.56	40.244	0.316	0.77
300	0.5	0.5	41.42	41.542	-0.122	0.29
460	0.5	0.75	44.305	44.295	0.01	0.022
460	0.5	1	46.1	45.844	0.256	0.55
460	0.75	0.75	44.88	44.755	0.125	0.27
460	1	1	44.687	44.906	-0.219	0.49
125	1	0.5	42.42	42.646	-0.226	0.53
300	0.5	1	44.034	43.924	0.11	0.24
125	0.5	0.75	41.39	41.139	0.251	0.6

125	0.75	0.5	41.101	41.188	-0.087	0.21
460	0.75	0.5	44.72	44.217	0.503	1.12
125	0.5	1	41.775	42.07	-0.295	0.7
300	1	0.75	44.11	44.082	0.028	0.06

4.2.2 Effect Of Input Parameters

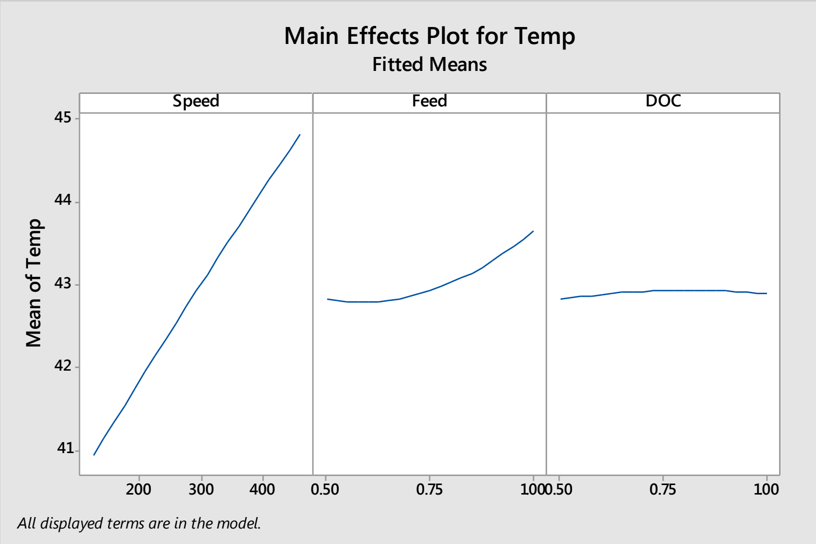

Fig: 4.1 Main Effects plot for Temperature

4.2.3 Interaction Effects

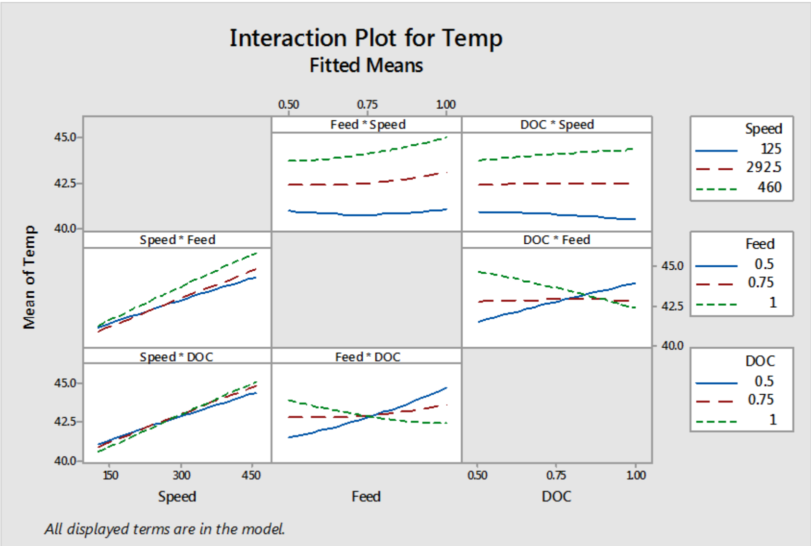

Fig: 4.2 Interaction Effects plot for Temperature

4.2.4 Mathematical Relationship between the Input Parameters and Surface Roughness

Surface roughness = -9.238+0.01354*(SS) +23.23*(F) +13.49*(DOC) +0.000003*(SS*SS)-9.235*(F*F) -4.211*(DOC*DOC) -0.003888*(SS*F) -0.007726*(SS*DOC) - 8.620(F*DOC)

Table 4.2 Predicted Surface Roughness values with % error

Speed (RPM)	**Feed (mm/Rev)**	**Depth of Cut (mm)**	**Surface Roughness (µm)**	**Predicted Surface roughness (µm)**	**Error Surface roughness**	**% Error Surface roughness**
460	0.5	0.5	8.043	8.131	-0.088	1.09
300	0.75	0.5	9.572	9.455	0.117	1.22
460	0.75	1	6.96	6.821	0.139	1.99
460	1	0.5	7.25	6.558	0.692	9.54
300	1	1	11.42	11.062	0.358	3.13
125	1	0.75	13.833	13.701	0.132	0.95
460	1	0.75	7.433	7.348	0.085	1.14

300	0.75	1	8.4	8.771	-0.371	4.41
125	0.75	1	11.326	10.846	0.48	4.23
125	1	1	14.271	14.285	-0.014	0.09
125	0.75	0.75	11.237	11.294	-0.057	0.5
300	1	0.5	9.736	9.682	0.054	0.55
300	0.75	0.75	9.467	9.151	0.316	3.33
300	0.5	0.75	8.049	7.82	0.229	2.84
125	0.5	0.5	9.945	10.218	-0.273	2.74
300	0.5	0.5	9.408	9.156	0.252	2.67
460	0.5	0.75	7.14	6.857	0.283	3.96
460	0.5	1	5.67	5.507	0.163	2.87
460	0.75	0.75	7.067	7.139	-0.072	1.01
460	1	1	8.264	8.062	0.202	2.44
125	1	0.5	12.834	13.041	-0.207	1.61
300	0.5	1	6.69	6.428	0.262	3.91
125	0.5	0.75	9.22	8.815	0.405	4.59
125	0.75	0.5	11.991	11.666	0.324	2.7
460	0.75	0.5	7.194	7.381	-0.187	2.59
125	0.5	1	6.791	7.355	-0.564	8.3
300	1	0.75	8.649	10.41	-1.761	20.36

4.2.5 Effect Of Input Parameters

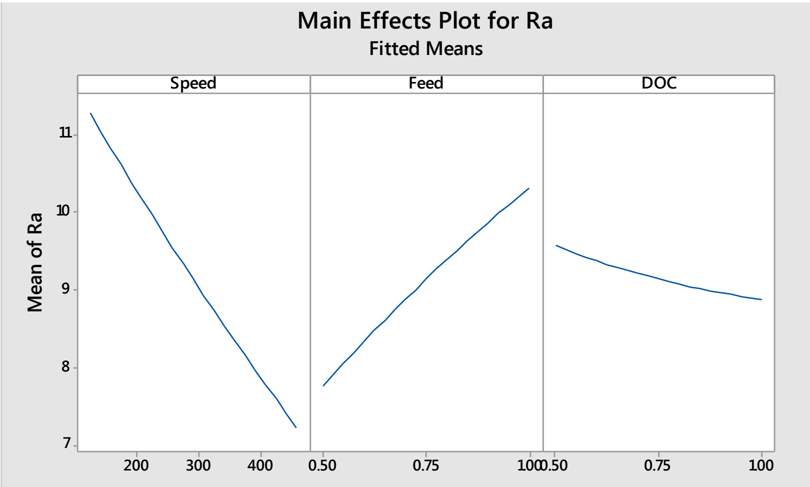

Fig: 4.3 Main Effects plot for Surface Roughness

4.2.6 Interaction Effects

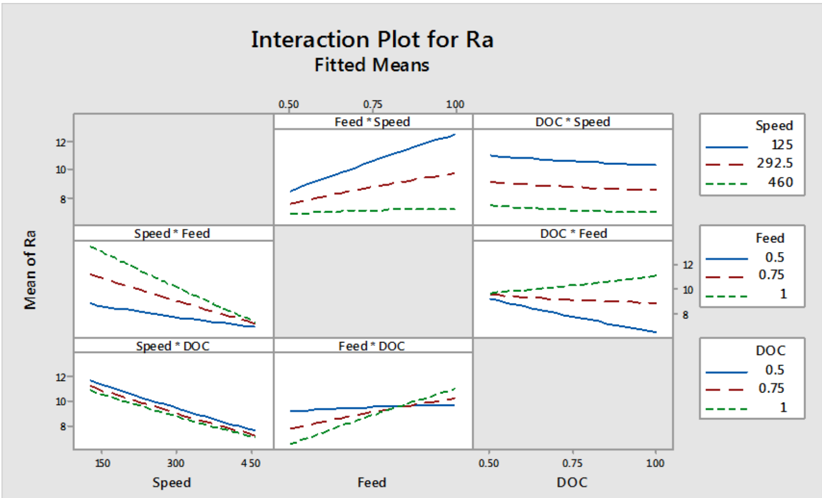

Fig: 4.4 Interaction Effects plot for Surface Roughness

4.2.4 Optimization Plot

Optimization is a way of finding the highest or least achievable performance under the given constraints by maximizing desired factors and minimizing undesired ones or minimizing desired factors and maximizing undesired factors. In comparison, maximization means trying to attain the highest or maximum outcome without regard to cost or expense and minimization means trying to attain least or minimum outcome. Minitab consists response optimizer; it provides an optimal solution the input variable combinations and an optimization plot. The optimization plot is interactive and by varying the input variable settings more desirable solutions can be obtained

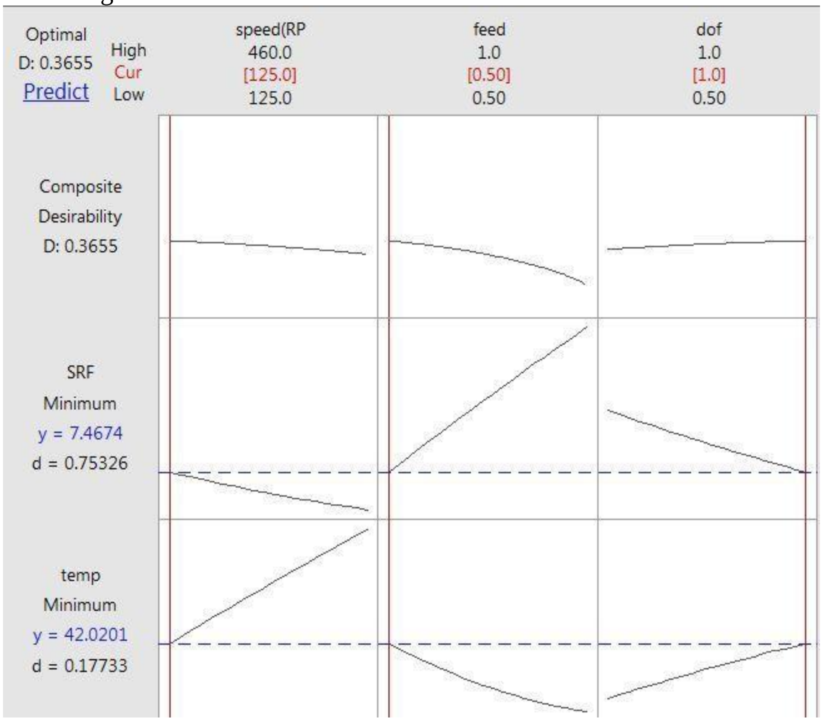

Fig 4.5 Optimization plot for surface roughness and temperature under dry machining conditions

The optimization plot as shown signifies the effect of each factor (columns) on the responses or composite desirability (rows). The vertical red lines on the graph represent the current factor settings. The numbers displayed at the top of a column show the current factor level settings (in red). The horizontal blue lines and numbers represent the responses for the current factor level. Minitab calculates the minimum temperature and minimum surface roughness.

From the optimization plot it can be said that the minimum temperature is 42.0201ºC and minimum surface roughness is 7.4674µm and is obtained when spindle speed=125rpm, fee d=0.5mm/rev, and depth of cut=1.0mm

4.3 Wet Machining Process

Wet machining has the advantage of better part quality and less tool wear. Cutting fluids have been introduced into the cutting process with the purpose to improve the characteristics of the tribological processes which are always present on the contact surfaces between the tool and the work piece. The use of cutting fluids increases the tool life, contributes to a more economical cutting speed and generally improves the efficiency of the production systems when taken as a whole [7]. When comes to quality wet machining more preferable than dry machining because of less heat generated and more better surface finish relative to that of job machined in dry conditions.

4.3.1 Mathematical Relationship between the Input Parameters and Temperature

Temp = 5.72 + 0.02707 Speed + 26.22 Feed + 39.34 DOC + 0.000011 Speed*Speed - 16.55 Feed*Feed - 22.39 DOC*DOC - 0.01892 Speed*Feed - 0.01555 Speed*DOC + 5.040 Feed*DOC

Table 4.3 Predicated Temperature values with %error

Speed (RPM)	**Feed rate (Mm/rev)**	**Depth of Cut (mm)**	**Temperature(°c)**	**Predicated(TE) (°c)**	**Error(TE)**	**%error(TE)**
460	0.5	0.5	36.79	36.87	-0.08	0.23
300	0.75	0.5	34.54	34.56	-0.022	0.06
460	0.75	1	37.657	37.87	-0.221	0.58
460	1	0.5	34.42	34.42	0.001	0
300	1	1	36.24	36.13	0.114	0.31
125	1	0.75	35.91	35.82	0.092	0.25
460	1	0.75	36.84	36.7	0.136	0.37
300	0.75	1	37.16	36.99	0.168	0.45
125	0.75	1	36.57	36.66	-0.097	0.26

125	1	1	36.6	36.65	-0.052	0.14
125	0.75	0.75	36.1	36.15	-0.048	0.13
300	1	0.5	33.18	33.07	0.114	0.34
300	0.75	0.75	37.29	37.15	0.137	0.36
300	0.5	0.75	36.34	36.24	0.097	0.26
125	0.5	0.5	31.57	31.43	0.141	0.44
300	0.5	0.5	33.81	33.97	-0.156	0.46
460	0.5	0.75	38.77	38.53	0.24	0.61
460	0.5	1	37.15	37.43	-0.281	0.75
460	0.75	0.75	38.85	38.66	0.188	0.48
460	1	1	36.38	36.24	0.145	0.39
125	1	0.5	32.34	32.23	0.109	0.33
300	0.5	1	35.87	35.76	0.104	0.29
125	0.5	0.75	34.21	34.01	0.185	0.54
125	0.75	0.5	32.75	32.87	-0.136	0.42
460	0.75	0.5	36.65	36.69	-0.042	0.12
125	0.5	1	34.65	34.59	0.06	0.17
300	1	0.75	35.45	35.97	-0.523	1.47

4.3.2 Effect Of Input Parameters

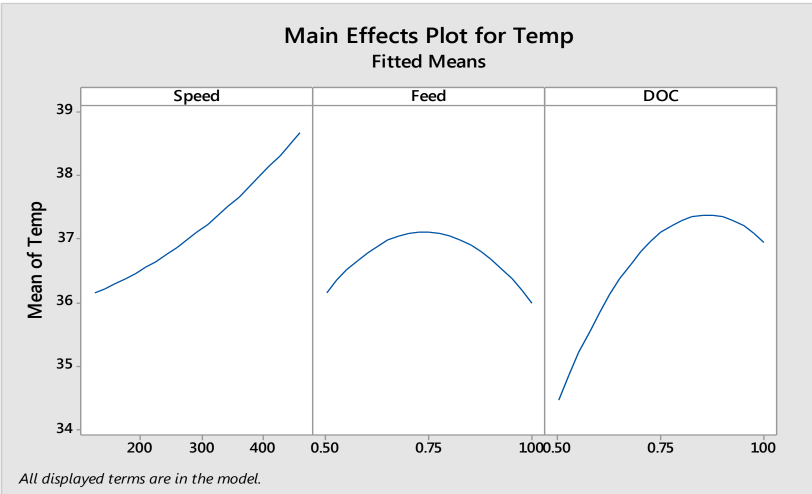

Fig: 4.5 Main Effects plot for Temperature

4.3.3 Interaction Effects

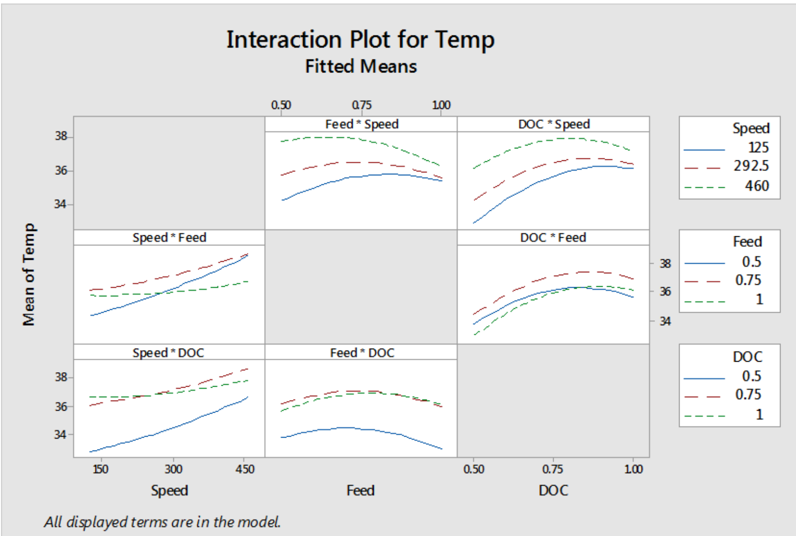

Fig: 4.6 Interaction Effects plot for Temperature

4.3.4 Mathematical Relationship between the Input Parameters and Surface Roughness

Ra = -9.238 + 0.01354 Speed + 23.23 Feed + 13.49 DOC - 0.000003 Speed*Speed - 9.235 Feed*Feed - 4.211 DOC*DOC - 0.003888 Speed*Feed - 0.007726 Speed*DOC - 8.620 Feed*DOC

Table 4.4 Predicted Surface Roughness with %error

Speed (RPM)	Feed rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (μm)	Predicated(SR) (μm)	Error(SR)	%error(SR)
460	0.5	0.5	6.78	7.094	-0.31	4.6
300	0.75	0.5	7.23	7.447	-0.22	2.9
460	0.75	1	6.61	7.075	-0.47	7.03
460	1	0.5	8.18	8.72	-0.54	6.6
300	1	1	5.69	5.954	-0.26	4.6
125	1	0.75	6.5	6.508	-0.01	0.13
460	1	0.75	7.17	7.723	-0.55	7.7
300	0.75	1	6.44	6.647	-0.21	3.2
125	0.75	1	6.14	6.178	-0.04	0.63
125	1	1	5.5	5.647	-0.16	2.8
125	0.75	0.75	6.544	6.492	0.05	0.8
300	1	0.5	7.622	7.832	-0.21	2.7
300	0.75	0.75	7.11	7.297	-0.19	4.6
300	0.5	0.75	5.99	6.283	-0.29	2.6
125	0.5	0.5	4.48	4.582	-0.1	4.8
300	0.5	0.5	5.667	5.894	-0.23	2.2
460	0.5	0.75	6.51	7.175	-0.66	4
460	0.5	1	6.19	6.755	-0.57	10.2
460	0.75	0.75	7.498	8.032	-0.53	9.14
460	1	1	5.75	6.227	-0.48	7.13
125	1	0.5	6.89	6.861	-0.03	8.29
300	0.5	1	5.93	6.172	-0.24	0.4
125	0.5	0.75	5.31	5.202	0.108	2.03
125	0.75	0.5	6.15	6.305	-0.19	2.9
460	0.75	0.5	7.83	8.491	-0.66	8.4
125	0.5	1	5.52	5.533	-0.01	0.23
300	1	0.75	7.036	7.14	-0.107	1.52

4.3.5 Effect Of Input Parameters

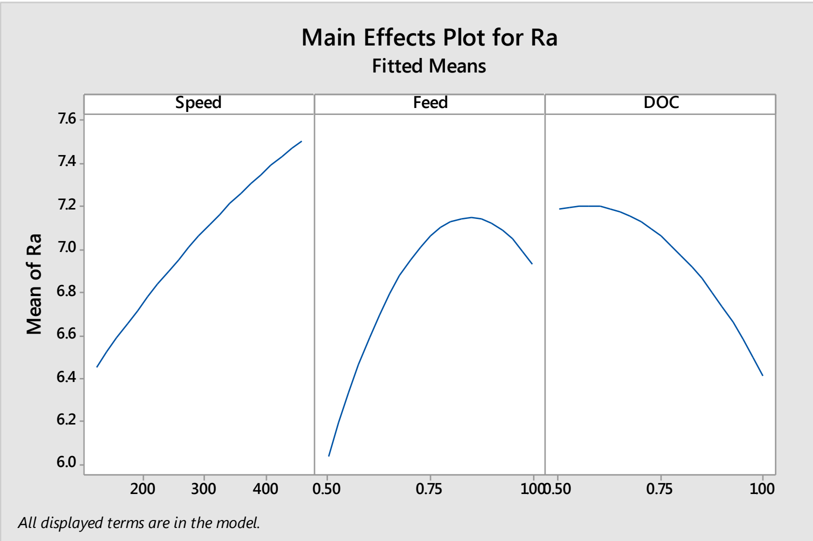

Fig: 4.7 Main Effects plot for Surface Roughness

4.3.3 Interaction Effects

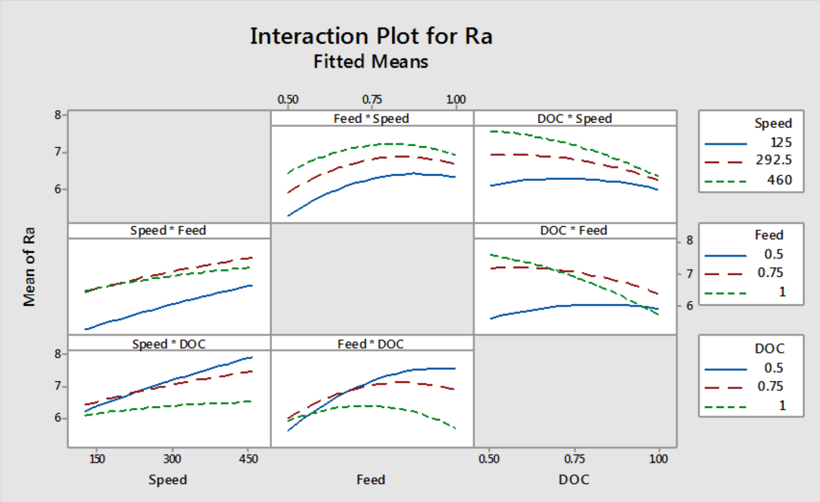

Fig: 4.8 Interaction Effects plot for Surface Roughness

4.3.4 Optimization Plot

Optimization is a way of finding the highest or least achievable performance under the given constraints by maximizing desired factors and minimizing undesired ones or minimizing desired factors and maximizing undesired factors. In comparison, maximization means trying to attain the highest or maximum outcome without regard to cost or expense and minimization means trying to attain least or minimum outcome. Minitab consists of response optimizer; it provides an optimal solution the input variable combinations and an optimization plot. The optimization plot is interactive and by varying the input variable settings more desirable solutions can be obtained

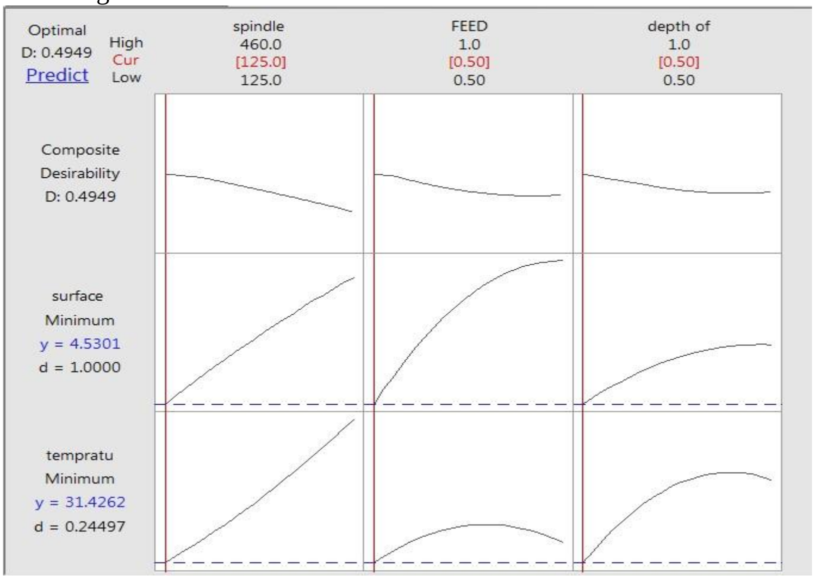

Fig 4.9 Optimization plot for surface roughness and temperature under wet machining conditions

The optimization plot signifies the effect of each factor (columns) on the responses or composite desirability (rows). The vertical red lines on the graph represent the current factor settings. The numbers displayed at the top of a column show the current factor level settings (in red). The horizontal blue lines and numbers represent the responses for the current factor level. Minitab calculates the minimum temperature and minimum surface roughness. From the optimization plot it can be said that minimum temperature is 31.4262ºC and minimum surface roughness is 4.5301µm and is obtained when spindle speed=125rpm, feed=0.5mm/rev, and depth of cut=1.0mm

V. CONCLUSIONS

In the present work, Multi-Response Optimization problem has been solved in both wet and dry conditions by using an optimal parametric combination of input parameters such as Spindle speed, Feed and Depth of Cut. These optimal parameters ensures in producing high surface quality turned product.

- Response Surface Methodology is successfully implemented for optimizing the input parameters.
- This project produces a direct equation with the combination of controlled parameters which can be used in industries to know the Values of tooltip temperature and Surface Roughness for any values of speed, feed and depth of cut instead of machining.
- Hence we conclude that the optimal solution

Under Dry conditions for temperature is 420201ºc and the surface roughness is 7.4674µm, when spindle speed=125 rpm, feed=0.5mm/rev, and depth of cut=1mm.

Under Wet conditions for temperature is 31.4262ºc and the surface roughness is 4.5301µm, when spindle speed=125 rpm, feed=0.5mm/rev, and depth of cut=00.5mm.

From the graphs we can say that the Surface Roughness is effected by speed and depth of cut. Similarly Temperature is effected by speed, feed, depth of cut and wet machining is more suitable for machining to maintain better tool life and better surface finish.

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