Analysis of Process Parameters in Machining of 7075 Aluminium Alloy Using Response Surface Methodology

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ABSTRACT

One of the significant machining operations is Metal cutting. Amongst, Turning is one of the oldest machining processes. Variation during the machining process due to tool wear, surface roughness, temperature changes, and other disturbances make it highly inefficient for perfection, especially in high quality machining operations where product quality specifications are very restrictive. Therefore, to assure the quality of machined products, reduce costs and increase machining efficiency, cutting parameters must be optimized to minimize various response variables such as tool wear, surface roughness, temperature, cutting force etc. for which several optimization methodologies are being analyzed. Optimization of the parameters to provide the best solution to minimize tool wear, cutting force, surface roughness have been presented using software optimization techniques. This attempt to optimize can provide insight into the problems of controlling the finishing of machined surfaces, when the process parameters are adjusted to obtain a certain surface finish. Using the optimum combination of these parameters enables minimizing surface roughness and determining quality of machined part. Owing to the significant role that turning operations play in today's manufacturing world, there is a significant need to optimize machining parameters for this operation. Accordingly this paper describes the development of optimization models and their use of machining parameters using Response Surface Methodology (RSM). The main idea of RSM is to use a sequence of designed experiments in an optimal response.

Keywords: Response Surface Methodology, Turning, 7075 Aluminium alloy

INTRODUCTION

1.1 7075 Aluminum alloy

The use of light weight materials are very much essential in the present day Automotive world, hence the need for study and design of machines and its parts using light weight materials such as aluminum, titanium, magnesium and their alloys have increased extensively. Aluminium alloys are widely used for demanding structural applications due to good combination of formability, corrosion resistance, weldability and mechanical properties. Hence the present work is about machining of 7075 aluminum alloy at various combinations of process parameters such as speed, feed rate and depth of cut and to determine the effect these parameters on surface quality. Thus the aluminium alloy needs to undergo several machining operations. Variation during the machining process due to tool wear, temperature, changes and other disturbances make it highly inefficient for perfection, especially in high quality machining operations where product quality specifications are very restrictive. Therefore, to assure the quality of machining products, reduce costs and increase machining efficiency, cutting parameters must be optimized in real-time according to the actual state of the process. Parameters such as cutting speed, depth of cut and feed have influence on overall success of machining operation. The constituent elements of 7075 aluminium alloy and its weight percentage is presented in Table 1.

Table 1 The alloy composition of 7075 Aluminium alloy

Component	**Wt.%**
Aluminium	87.1-91.4
Chromium	0.18-0.28
copper	1.2-2
Iron	Max0.5
Silicon	Max0.4
Titanium	Max0.2
Zinc	5.1-6.1
Magnesium	2.1-2.9
Manganese	Max 0.3
Other	Each max 0.05
other	Total max 0.15

1.2 EXPERIMENTAL DETAILS:

7075 aluminium alloy is used in this experiment. The material was obtained in the form of cylindrical work piece. The experiments were designed by following full factorial design of experiments. Design of experiments is an effective approach to optimize the parameters in various manufacturing related process, and one of the best intelligent tool for optimization and analyzing the effect of process variable over some specific variable which is an unknown function of these process variables. The selection of such points in the design space is commonly called design of experiments (DOE). In this work related to turning of 7075 aluminium alloy, the experiments were conducted by considering three main influencing process parameters such as Speed, Feed rate and Depth of cut at three different levels namely Low, Medium and High. So according to the selected parameters a three level full factorial design of experiments (3^3=27) were designed and conducted. The level designation of various process parameters are shown in Table 2 and the conditions at which 27 experimental runs were conducted are detailed in Table 3.

Table 2 Level designation of process parameters

Parameters	**Level 1**	**Level 2**	**Level 3**
Cutting speed(m/min)	100	150	200
Feed rate(mm/rev)	0.05	0.08	0.1
Depth of cut(mm)	0.25	0.5	1

Table 3 Machining conditions for full factorial design of experiments

Runs	Cutting speed(m/min)	Feed rate(mm/rev)	Depth of cut(mm)
1	150	0.1	1
2	150	0.05	0.25
3	100	0.05	0.5
4	150	0.05	1
5	200	0.1	1
6	200	0.08	0.25
7	100	0.05	0.25
8	100	0.08	0.5
9	150	0.08	1
10	200	0.05	0.5
11	200	0.08	0.5
12	100	0.08	0.25

13	200	0.08	1
14	150	0.08	0.25
15	100	0.1	0.25
16	150	0.1	0.25
17	200	0.05	0.25
18	100	0.1	0.5
19	200	0.1	0.25
20	150	0.05	0.5
21	100	0.1	1
22	200	0.1	0.5
23	200	0.05	1
24	150	0.08	0.5
25	100	0.05	1
26	150	0.1	0.5
27	100	0.08	1

By taking the above said parameters as input parameters, the parameters evaluated are tool wear, surface roughness and cutting force. The tool wear is measured using tool making microscope in mm, surface roughness is measured using surface roughness tester in mm, and cutting force (Fx) is measured using Kistler dynamometer in Newton and the readings are listed in Table4.

Table 4 Experimental output for surface roughness, tool wear, and cutting force at varying input parameters

Runs	Cutting speed(m/min)	Feed rate(mm/rev)	Depth of cut(mm)	Surface roughness(mm)	Tool wear (mm)	Cutting force(Fx)N
1	150	0.1	1	1.5	0.31	10.19
2	150	0.05	0.25	1.23	0.21	14.69
3	100	0.05	0.5	1.59	0.14	20.69
4	150	0.05	1	1.62	0.11	22.35
5	200	0.1	1	1.29	0.27	10.8
6	200	0.08	0.25	1.85	0.28	18.46
7	100	0.05	0.25	1.45	0.16	17.75
8	100	0.08	0.5	1.78	0.26	11.17
9	150	0.08	1	1.65	0.26	14.56
10	200	0.05	0.5	1.15	0.13	13.8
11	200	0.08	0.5	1.72	0.27	16.93
12	100	0.08	0.25	1.82	0.3	7.82
13	200	0.08	1	1.24	0.21	12.45
14	150	0.08	0.25	1.89	0.35	13.5
15	100	0.1	0.25	2.12	0.35	1.78
16	150	0.1	0.25	2.31	0.4	12.38
17	200	0.05	0.25	1.15	0.15	13.46
18	100	0.1	0.5	1.98	0.33	1.83
19	200	0.1	0.25	2.5	0.35	22.97
20	150	0.05	0.5	1.39	0.18	17.52
21	100	0.1	1	1.7	0.27	1.93
22	200	0.1	0.5	2.1	0.32	19.01
23	200	0.05	1	1.14	0.07	14.48
24	150	0.08	0.5	1.78	0.32	13.26
25	100	0.05	1	2.13	0.08	29.93
26	150	0.1	0.5	2.04	0.37	10.42
27	100	0.08	1	1.87	0.22	13.13

2. RESPONSE SURFACE METHODOLOGY

Use of many methods has been reported in the literature to solve optimization problems for machining parameters. These methods include various nomograms, graphical methods, performance envelope, linear programming, Lagrangian multipliers, geometric programming, dynamic programming, and artificial intelligence. In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The method was introduced by G. E. P. Box and K. B. Wilson in 1951. The main idea of RSM is to use a set of designed experiments to obtain an optimal response. By this technique, the cause and effect relationships between true mean responses and input control variables influencing the responses are determined and represented as a two or three dimensional hyper surface. RSM enables to (i) determine the factorial levels that will simultaneously satisfy a set of desired specifications. (ii) Determine the optimum combination of factors that yield a desired response and describes the response near the optimum. (iii) Determine how a specific response is affected by changes in the level of factors over the specified levels of interest. In this paper, work is done to develop a mathematical model for correlating the interactive and higher order influences of various turning parameters on surface roughness at various locations during the turning phenomena using RSM.

2.1 RSM PROCEDURE :

The steps involved in response surface methodology towards optimization are:

1. Identifying the important process control variables.
2. Finding the upper and lower limits of the control variables, viz., cutting speed (Vc), Feed rate (F), and depth of cut (C) as in table 5
3. Developing the design matrix.
4. Conducting the experiments as per the design matrix.
5. Recording the responses, viz, surface roughness, tool wear, and cutting force
6. The development of mathematical models.
7. Calculating the coefficients of the exponential form.
8. Checking the adequacy of the model developed.
9. Testing the significance of the regression coefficients, recalculating their values and arriving at the final mathematical model.
10. Presenting the main effects and the significant interaction effects of process parameters on the responses in two and three dimensional (contour) graphical form.
11. Analysis of results.

Details about Control parameters, their notation and their limits are described in Table 5.

Table 5 Control parameters and their limits

Parameters	Notation	Limits		
		-1	0	1
Cutting speed(m/min)	S	100	150	200
Feed Rate(mm/rev)	f	0.05	0.08	0.1
Depth of Cut(mm)	d	0.25	0.5	1

2.2 MATHEMATICAL MODELING

RSM methodology was used to develop models for predicting response parameters such as Force along X direction (F_x), Surface roughness (R_a) and Tool wear (t_w). The mathematical models developed for the above parameters are given below.

Fx = +48.76268-0.24558 * speed-717.42982 * feed+48.12684* depth+4.9073 * speed *feed-0.1547 * speed * depth-311.16792 * feed * depth. →1

The developed model for predicting surface roughness is given in equation 2.

Ra = +0.63487-6.17076E-003 * speed+10.28070* feed+3.50967 * depth+0.12114* speed * feed-9.72381E-003 * speed * depth-30.9398 * feed * depth →2

The relationship between the turning parameters and the Force along X direction (F_x) is given in equation 1. The R-squared value of the above developed model was found to be 0.9856 which enable good prediction accuracy.

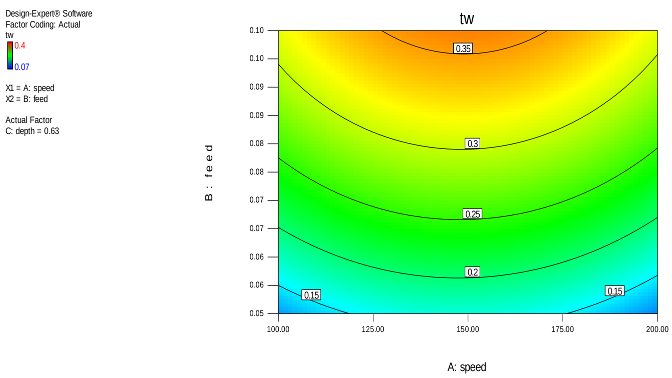
R-Squared value for the above model was 0.9918 which also enables better prediction capability for estimating average surface roughness (R_a) of turned profile. With the help of experimental data, a mathematical model was also developed to predict tool wear using RSM approach. R-Squared value for this model was found to be 0.9971 which proved its capacity in predicting the tool wear accurately.

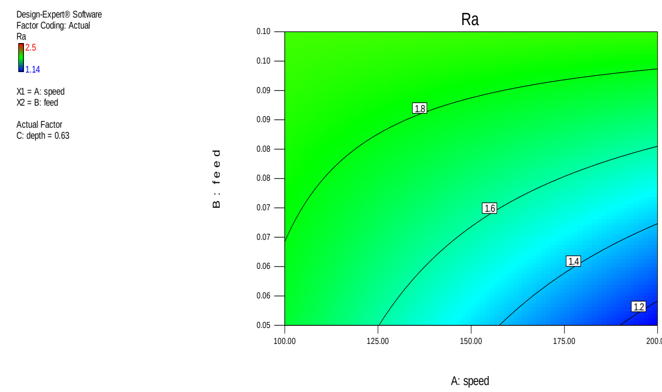
t_w =-0.54309+5.54912E-003* speed+9.03626 * feed-0.10336* depth+1.31579E-003 * speed *feed+2.85714E-

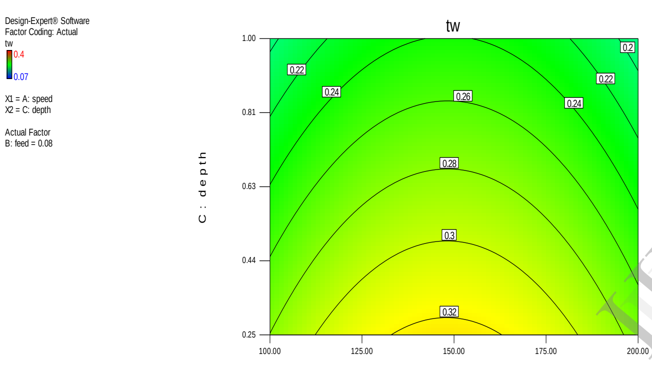
005 * speed * depth+0.13283 * feed * depth-1.91111E-005* speed^2 - 36.29630 * feed^2-0.017778 * depth^2 →3

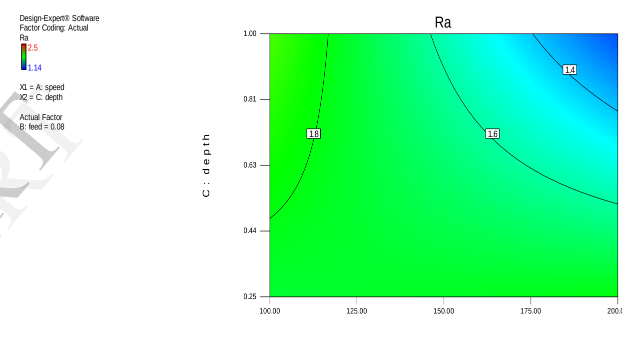
3. ANALYSIS OF EXPERIMENTAL

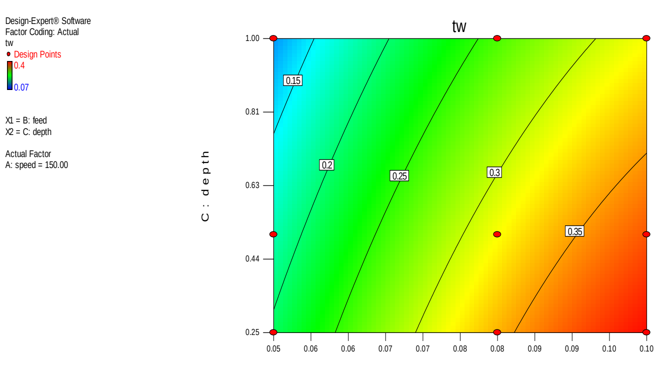
Studies were carried out to analyze the effect of various process variables on surface roughness, tool wear, cutting force for a turning operation, based on the equation developed through experimental observations and response surface methodology. Figures below show the effect of cutting speed, feed rate, depth of cut on surface roughness, tool wear and cutting force

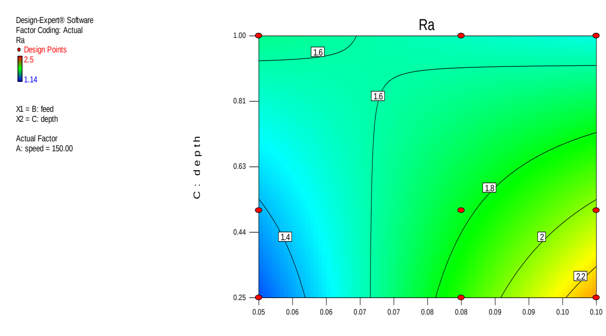


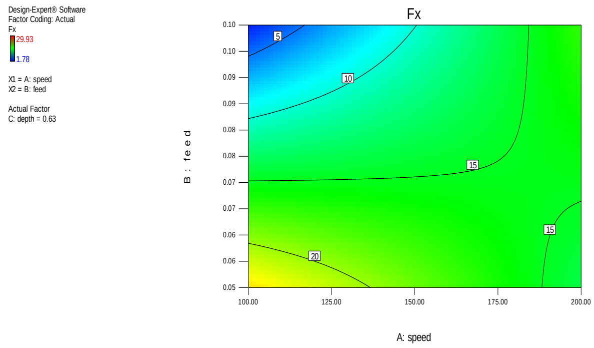


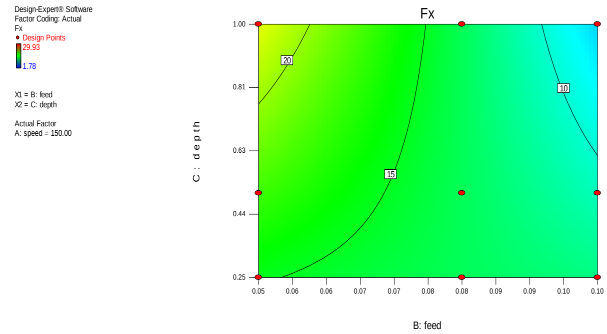


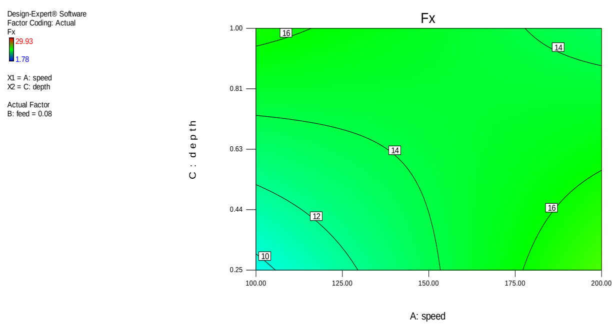












4. OPTIMISATION OF PARAMETERS

This involves an optimality search model, for the various process variables conditions for maximizing the responses after designing of experiments and determination of the mathematical model with best fits. The optimization is done numerically and the desirability and response cubes are plotted. The parameters for the turning operations were determined using Response Surface Methodology and the optimum condition obtained is listed in Table 6. The optimal levels for turning of 7075 alluminium alloy in center lathe to obtain minimum surface roughness and minimum tool wear is possible at a cutting speed of 150 m/min, depth of cut of 0.50 mm and feed rate of 0.05 mm/rev.

Table 6 optimal parameters for the turning operations

Number	Speed	Feed Rate	Depth of cut	Desirability
1	150	0.05	0.5	1.000

5. CONCLUSION

By the mathematical modeling results the obtained conclusions can be drawn as follows:

1. The mathematical models were developed based on RSM, utilizing the practical data obtained from turning experiments conducted on a center lathe turning machine.
2. The optimal control variables have been found using one of the new optimization techniques namely Response surface Methodology.
3. When turning is performed at a cutting speed of 150 m/min, depth of cut of 0.50 mm and feed rate of 0.05 mm/rev minimum surface roughness of the turned profile as well as minimum tool wear can be achieved.

Hence, this article represents not only the use of RSM for analyzing the cause and effect of process parameters on responses, but also on optimization of the process parameters themselves in order to realize optimal responses.

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