Optimization Of Temperature, Tool Wear And Surface Finish In Turning Of 6063 Aluminium Alloy Using Rsm

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Abstract— **Machining, the most widespread process for shaping metal, has become a very significant aspect of modern society and industry. The aim of this project work is to study the machining effect on 6063 Aluminium alloy at various combinations of process parameters such as speed, feed rate and depth of cut; and also to determine the effect of those parameters over the quality of finished product. A Central Composite Design (CCD) based Design of Experiments (DOE) approach and Response Surface Methodology (RSM) was used to analyze the machining effect on work material in this study. Using the practical data obtained, a mathematical model is developed to predict the temperature influence and surface quality of finished product.**

Keywords - AA6063, Central Composite Design, Response Surface Methodology

1. INTRODUCTION

1.1 OPTIMIZATION

In today's rapidly changing scenario in manufacturing industries, applications of optimization techniques in metal cutting processes is essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand of quality product in the market. Optimization methods in metal cutting processes, considered to be a vital tool for continual improvement of output quality in products and processes include modelling of input–output and in-process parameters relationship and determination of optimal cutting conditions. However, determination of optimal cutting conditions through cost-effective mathematical models is a complex research endeavour, and over the years, the techniques of modelling and optimization have undergone substantial development and expansion.

1.2 MACHINING PARAMETERS IN METAL CUTTING

One of the most significant manufacturing processes in the area of material removal is metal cutting. It can be defined as the removal of metal chips from a work piece in order to obtain a finished product with desired attributes of size, shape, and surface quality.

The imperative objective of the science of metal cutting is the solution of practical problems associated with the efficient and precise removal of metal from work piece. It has been recognized that the reliable quantitative predictions of the various technological performance measures, preferably in the form of equations, are essential to develop optimization strategies for selecting cutting conditions in process planning The most essential cutting performance measures, such as, tool life, cutting force, temperature of the work piece during machining, etc., should be defined using experimental studies. Therefore, further improvement and optimization for the technological and economic performance of machining operations depend on a well-based experimental methodology.

Establishment of efficient machining parameters has been a problem that has confronted manufacturing industries for nearly a century, and is still the subject of many studies. Optimum machining parameters are of great concern in manufacturing environments, where economy of machining operation plays a vital role in competitiveness in the market. Economic machining is of greater importance where NC machines are employed.

1.3 MACHINABILITY OF ALUMINIUM ALLOYS

Machinability is reported to be the ease or the difficulty with which a material can be machined under a given set of operating conditions including; cutting speed, feed rate and depth of cut, resulting in acceptable tool life and at the same time providing good surface finish and acceptable functional characteristics of the components. The Machinability of a material is mainly assessed by measuring the temperature, tool life, surface finish generated and component forces during a machining operation. The principle problems associated with machining Aluminium alloys are related to high cutting temperatures, high cutting pressures, chatter, and the high chemical reactivity.

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1.4 6063 ALUMINIUM ALLOY

Weight saving materials is becoming increasing important, especially in the automotive and aerospace industries. Design engineers would thus like to make more extensive use of light metals such as aluminium, titanium, magnesium and their alloys. Aluminium alloys are widely used for demanding structural applications due to good combination of formability, corrosion resistance, weldability and mechanical properties. Aluminium alloys represent the highest volume (90%) of extruded aluminium products in western countries. Aluminium alloys are alloys in which aluminium is the predominant metal. Aluminium alloys with a wide range of properties are used in engineering structures. 6063 is an aluminium alloy, with magnesium and silicon as the alloying elements. It has generally good mechanical properties and is heat treatable and weldable.

Table 1 Chemical composition of AA 6063 in % of weight

Alloy	**Weight %**
Si	0.47
Fe	0.20
Cu	0.061
Mn	0.006
Mg	0.54
Zn	0.009
Ti	0.015
Cr	0.006
Ni	0.0088
Pb	0.05
Sn	0.015
Na	0.007
Ca	0.009
B	0.0008
Zr	0.002
V	0.017
Be	0.00005
Sr	0.0003
Co	0.017
Cd	0.0007
Sb	0.009
Ga	0.012
P	0.006
Al	98.45

1.5 EXPERIMENTAL DETAILS

6063 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 6063 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 (Not center points – 14, center points – 6) were designed and conducted. The level designation of various process parameters are shown in Table 2 and the conditions at which 20 experimental runs were conducted are detailed in Table 3.

Table 2 Level designation of process parameters

Parameter	**Level 1**	**Level 2**	**Level 3**
Cutting speed(m/min)	100	150	200
Feed rate(mm/rev)	0.03	0.05	0.07
Depth of cut (mm)	0.25	0.5	1

Table 3 Machining conditions for design of experiments

Runs	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	150	0.05	0.5
2	100	0.03	0.25
3	150	0.05	0.25
4	100	0.05	0.5
5	150	0.03	0.5
6	100	0.07	1
7	150	0.07	0.5
8	200	0.03	1
9	200	0.03	0.25
10	150	0.05	0.25
11	200	0.07	0.25
12	150	0.05	1
13	150	0.05	0.5
14	150	0.05	0.5
15	100	0.07	0.25
16	150	0.05	0.5
17	100	0.03	1
18	200	0.07	1
19	150	0.05	0.5
20	200	0.05	0.5

By taking the above said parameters as input parameters, the parameters evaluated are temperature, surface roughness and tool wear. The temperature is measured using Pyrometer in °c, surface roughness is measured using Surface roughness tester in µm, and tool wear is measured using Profile projector in mm and the readings are listed in Table4.

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

Runs	Temperature (°c)	Surface roughness (µm)	Tool wear (mm)
1	36.62	1.12	0.884
2	34.12	0.62	0.23
3	35.15	0.99	0.27
4	35.49	0.98	0.088
5	36.07	0.89	0.084
6	38.12	1.90	0.35
7	37.16	1.35	0.092
8	40.89	0.15	0.21
9	35.27	0.94	0.23
10	35.15	0.99	0.27
11	36.27	2.07	00.31
12	39.56	1.37	0.28
13	36.62	1.12	0.088
14	36.62	1.12	0.0884
15	34.92	0.35	0.316
16	36.62	1.12	0.0884
17	36.74	2.07	0.2196
18	42.47	1.38	0.3564
19	36.62	1.12	0.0884
20	37.74	1.26	0.09

2. RESPONSE SURFACE METHODOLOGY (RSM)

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing the design process. RSM

- Encompasses a point selection method (also referred to as Design of Experiments, Approximation methods and Design Optimization) to determine optimal settings of the design dimensions.
- Have important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs.

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. Box and Wilson suggest using a first-degree polynomial model to do this.

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, temperature, surface roughness, and tool wear.
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.

Table 5 Control parameters and their limits

Parameters	**Notation**	**Limits**		
		-1	**0**	**1**
Cutting speed(m/min)	Vc	100	150	200
Feed Rate(mm/rev)	F	0.03	0.05	0.07
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 Temperature (T), Surface roughness (R_a) and Tool wear (t_w). The mathematical models developed for the above parameters are given below.

The relationship between the turning parameters and the Temperature (T) is given below.

T = + 32.75581 + 3.61983e-004 * cutting speed + 10.89544 * feed rate - 1.10337 * depth of cut + 0.050000 * cutting speed * feed rate + 0.040000 * cutting speed * depth of cut + 19.34783 * feed rate * depth of cut - 1.20661e-006 * cutting speed^2 - 7.54132 * feed rate^2 + 0.012929 * depth of cut^2

The R-squared value of the above developed model was found to be 1.0000 which enable good prediction accuracy.

The developed model for predicting surface roughness is given below

R_a = +0.36818 - 5.10600e-005 * cutting speed - 43.10456 * feed rate + 4.83837 * depth of cut + 0.35000 * cutting speed * feed rate - 0.029878 * cutting speed * depth of cut + 3.34783 * feed rate * depth of cut + 7.93388e-007 * cutting speed^2 + 4.95868 * feed rate^2 - 0.013737 * depth of cut^2

R-Squared value for the above model was 1.0000 which also enables better prediction capability for estimating average surface roughness (R_a) of turned profile.

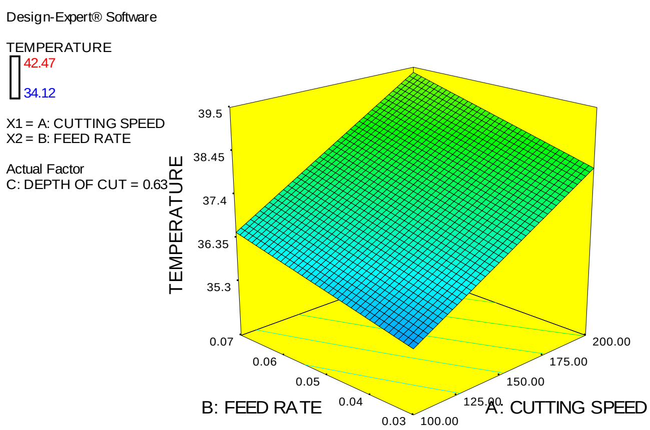
With the help of experimental data, a mathematical model was also developed to predict tool wear using RSM approach. R-Squared value for this model was found to be 0.9827 which proved its capacity in predicting the tool wear accurately.

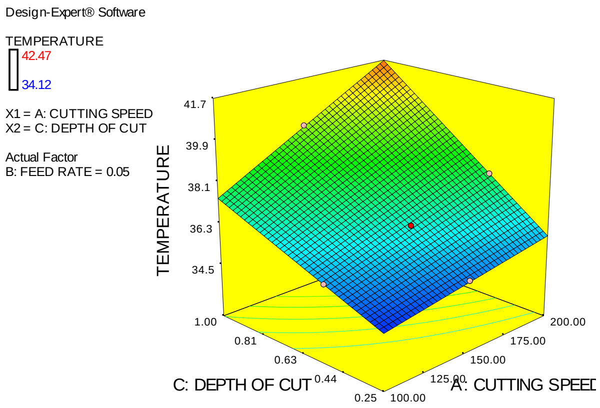
t_w = + 0.62114 - 2.63865e-004 * cutting speed + 0.58864 * feed rate - 1.95521 * depth of cut + 1.25000e-003 * cutting speed * feed rate + 1.07826e-005 * cutting speed * depth of cut + 2.25304 * feed rate * depth of cut + 6.01653e-007 * cutting speed^2 + 1.26033 * feed rate^2 + 1.48548 * depth of cut^2

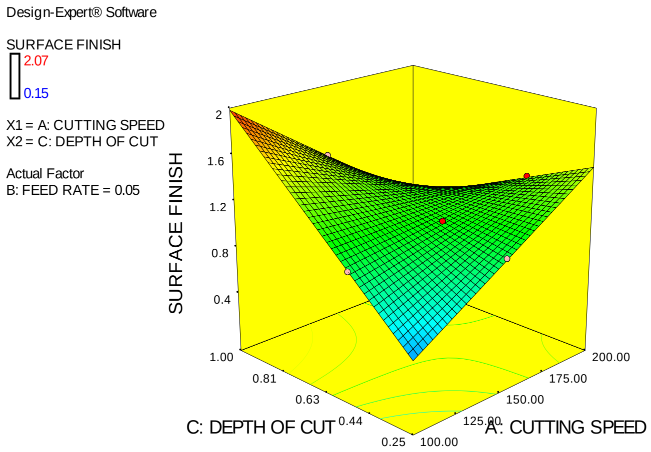
3. ANALYSIS OF EXPERIMENTAL

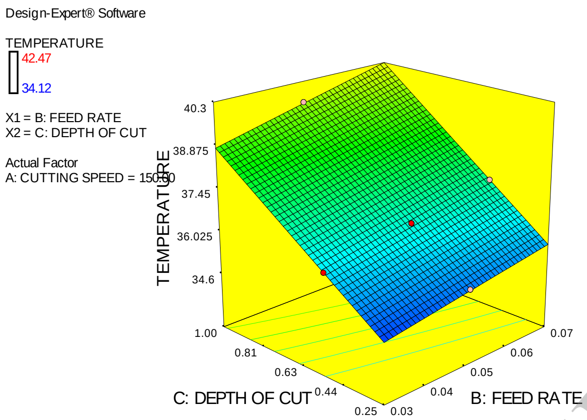
Studies were carried out to analyze the effect of various process variables on temperature, surface roughness, tool wear, for a turning operation, based on the equation developed through experimental observations and response surface methodology. Figures below show the effect of cutting speed, feed rate,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

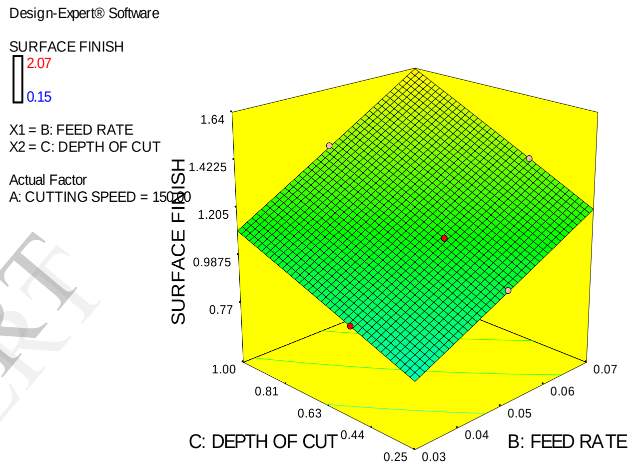
3D Graphs for temperature



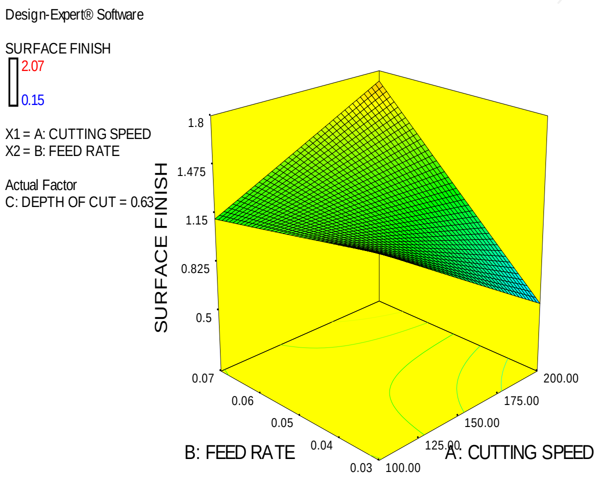




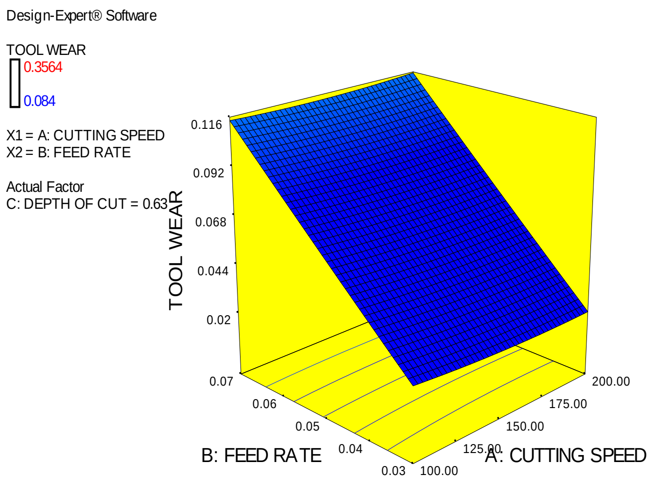


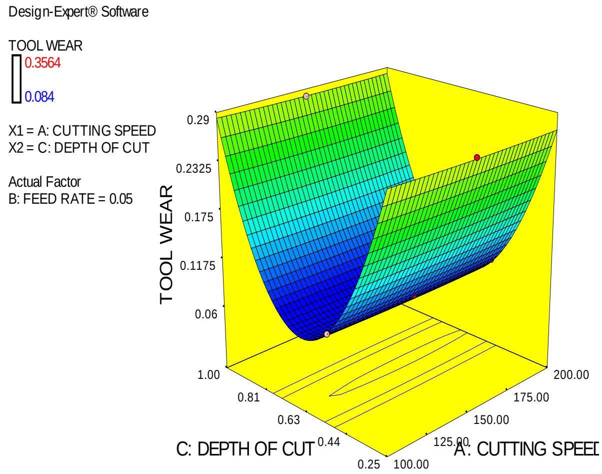


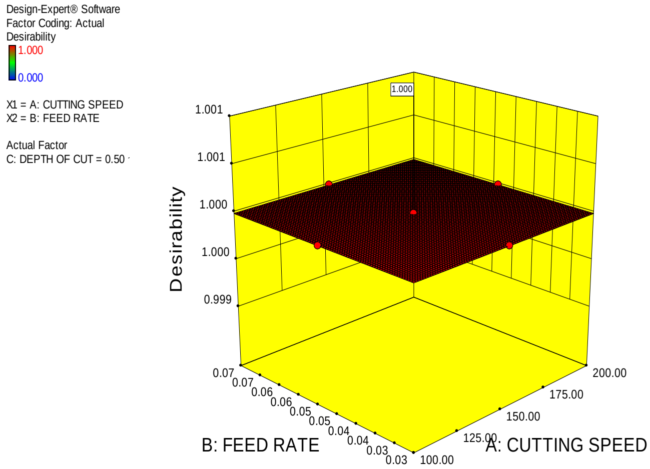
3D Graphs for surface finish

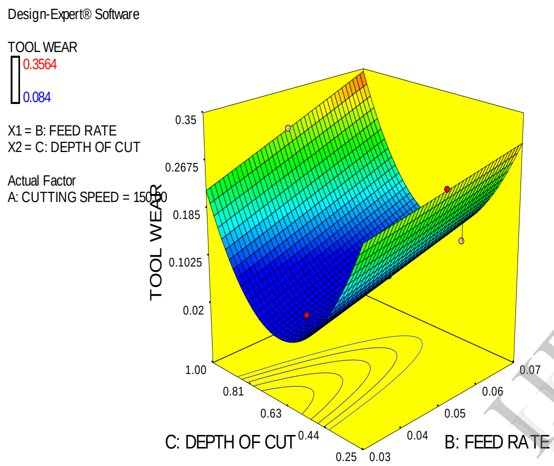


3D Graphs for tool wear









4. OPTIMIZATION 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 6063 aluminium alloy in CNC turning center to obtain minimum surface roughness and minimum tool wear is possible at a cutting speed of 150 m/min, feed rate of 0.05 mm/rev. and depth of cut of 0.50 mm.

Table 6 optimal parameters for the turning operations

Number	Speed	Feed Rate	Depth of cut	Desirability
1	150	0.05	0.50	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 CNC turning center 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, feed rate of 0.05 mm/rev, and depth of cut of 0.50 mm to obtain 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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