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Modeling and Analysis for Cutting Temperature in Turning of Aluminium 6063 Using Response Surface Methodology

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Abstract: *Deviation in machining process due to the temperature influence, cutting force, tool wear leads to highly inferior quality of finished product, especially in high speed machining operations where product quality and physical dimensions seems to be meticulous. Moreover, temperature is a significant noise parameter which directly affects the cutting tool and work piece. Hence the aim of this project work is to study the machining effect on 6063 Aluminium alloy at varies 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 L_{27} Orthogonal Array (OA) based Design of Experiments (DOE) approach and Response Surface Methodology (RSM) was used to analyse the machining effect on work material in this study. Using the practical data obtained, a mathematical model was developed to predict the temperature influence and surface quality of finished product. The ultimate goal of the study is to optimize the machining parameters for temperature minimization in machining zone and improvement in surface finish.*
Key words: *Aluminium 6063, Turning, Cutting Temperature, Cutting Force, Surface Roughness, Response Surface Methodology (RSM).*

I. Introduction

Increasing the productivity and the quality of the machined parts are the main challenges of metal-based industry; there has been increased interest in monitoring all aspects of the machining process. Surface finish is an important parameter in manufacturing engineering. It is a characteristic that could influence the performance of mechanical parts and the production costs. The ratio between costs and quality of products in each production stage has to be monitored and immediate corrective actions have to be taken in case of deviation from desired trend. The cutting temperature is a key factor which directly affects cutting tool wear, workpiece surface integrity and machining precision according to the relative motion between tool and work piece. 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 aluminium, 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 6063 aluminium 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. In this work, experimental results were used for modeling using response surface methodology. The RSM is practical, economical and relatively easy for use and it was used by lot of researchers for modeling machining processes. Response surface methodology (RSM) is a combination of experimental and regression analysis and statistical inferences. The concept of a response surface involves a dependent variable y called the response variable and several independent variables x1, x2,. .., xk. If all of these variables are assumed to be measurable, the response surface can be expressed as y = f (x1; x2; . . . ; xk) (1) Optimizing the response variable y, it is assumed that the independent variables are continuous and controllable by the experimenter with negligible error. The response or the dependent variable is assumed to be a random variable. In our experiments turning operation was selected due to, it is necessary to find a suitable combination of cutting speed (x1=ln V), feed rate (x2 = ln f), depth of cut (x3 = ln doc) and approach angle (x4 = ln K) that optimize cutting force (y = ln F).

II. Experimental Work

2.1. Experimental set-up

A Kistler force three component dynamometer (Type 9215A1, calibrated range: Fx.0±5000 N,Fy.0±5000 N, and Fz.0±3000 N) in conjunction with three Kistler charge amplifiers (Type 5070), used to convert the dynamometer output signal into a voltage signal appropriate for the data acquisition system, and a computer were used to measure and record the cutting forces. The instrument shown in figure 1 is a Kistler three component dynamometer and the figure 2 is a multi channel charge amplifier.

Figure 1: Kistler Three component Dynamometer

Figure 2: Charge Amplifier

Thermocouples are known to be very popular transducers for measuring temperature. The k-type thermocouple was chosen for measuring the temperature in this work. This technique was preferred as it is inexpensive, easy to calibrate, has a quick response time and good repeatability during experiments. A mineral insulated, metal sheathed, k-type thermocouple with Digital micro voltmeter of ranges between -200°C and 1200°C. The surface finish in machining can be measured directly. The TR Surface roughness tester shown in figure 3 was used in this work. Three types of λ values can be given and the lambda represents distance to be moved over the finished surface by the stylus probe. Kirloskar Turnmaster-35 all geared lathe shown in figure 4 was used in this research work. Distance between centres (max) is 800mm. Height of center is 175mm. The capacity of the motor is 3H.P/2.2KW.

Figure 3: TR Surface Roughness Tester

Figure 4: Kirloskar Turn master

1.2 Work Material

The work material used as the test specimen was Aluminium 6063. A cylindrical bar of Aluminium alloy (320mm long 60 mm diameter) was used for the tests. Details of the material properties are given in Tables 1 and 2.

Table 1: Chemical Composition

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
0.2-0.6	0.0-0.35	0.0-0.1	0.0-0.1	0.45-0.9	0.0-0.1	0.0-0.1	0.1max	Balance

Table 2: Physical Properties

Property	Value
Density	2.70 kg/m^3
Melting point	600°C
Modulus of elasticity	69.5 GPa
Electrical resistivity	$0.035 * 10^{-6}\Omega m$
Thermal conductivity	200W/mk
Thermal expansion	$23.5*10^{-6}/k$

1.3 Tool Material

Tungsten carbide inserts were used for the turning tests. These inserts are manufactured by Sandvik. Uncoated carbide inserts as per ISO specification THN SNMG 08 were clamped onto a tool holder with a designation of DBSNR 2020K 12 for turning operation. The parameter levels were chosen within the intervals based on the recommendations by the cutting tool manufacturer.

1.4 Design of Experiment

A commercial statistical analysis software "Design Expert" was employed for design of experiment. In Design Expert, RSM is used to find a combination of factors which gives the optimal response. RSM is actually a collection of mathematical and statistical technique that is useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objectives is to optimize the response. Three process parameters at three levels led to a total of 27 tests for turning operation. Three levels were specified for each of the factors as indicated in Table 3. The standard orthogonal array chosen was L_{27}, which has 27 rows and 26 degrees of freedom. Two tests were performed for each combination for turning operation resulting that 54 tests were conducted. Table 4 presents the experimental details and their results.

Table 3: Factors and Levels

Factor	Assignment	Levels		
		Level 1	Level 2	Level 3
Speed(N) m/min	A	100	150	200
Depth of cut(d)mm	B	0.25	0.5	1
Feed rate(f)mm/rev	C	0.05	0.075	0.1

Table 4: Orthogonal array and their results

Runs	Cutting Speed (m/min)	Feed Rate (mm/rev	Depth of cut	Temperature (Degree Celsius)	Surface Finish (Micrometer)	Cutting force (Newton)
1	100	0.05	0.25	90.8	1.024	51.59
2	100	0.05	0.5	98	1.064	134.74
3	100	0.05	1	121.4	1.035	184.69
4	100	0.075	0.25	97.4	1.194	88.27
5	100	0.075	0.5	104.6	1.234	163.99
6	100	0.075	1	128	1.205	217.86
7	100	0.1	0.25	107	1.314	161.87
8	100	0.1	0.5	114.2	1.354	243.06
9	100	0.1	1	137.6	1.325	291.45
10	150	0.05	0.25	103.65	1.137	56.15
11	150	0.05	0.5	110.85	1.77	146.74
12	150	0.05	1	134.25	1.147	186.74
13	150	0.075	0.25	110.25	1.307	98.72
14	150	0.075	0.5	117.45	1.347	179.91
15	150	0.075	1	140.85	1.317	220.87
16	150	0.1	0.25	119.85	1.427	172.32
17	150	0.1	0.5	127.5	1.467	253.51
18	150	0.1	1	150.45	1.437	295.47
19	200	0.05	0.25	96.5	0.9546	21
20	200	0.05	0.5	103.7	0.994	102.19
21	200	0.05	1	127.1	0.965	150.59
22	200	0.075	0.25	103.1	1.124	41.56
23	200	0.075	0.5	110.3	1.164	135.36
24	200	0.075	1	133.7	1.135	183.76
25	200	0.1	0.25	112.7	1.244	127.77
26	200	0.1	0.5	119.9	1.284	208.96
27	200	0.1	1	143.3	1.355	241.78

III. Mathematical Modeling

The second order response surface equations have been fitted using Design Experts Software for all the three response variables Cutting Temperature (T), Cutting Force (F_z) and Surface Roughness (Ra). The equations can be given in terms of the coded values of the independent variables as the following:

T=122.2479167+2.85*A+8.124107143*B+15.3*C+0*A*B+0*A*C-0.008035714*B*C-10.05*A^2+1.525*B^2+3.31875*C^2...... (1)

The R-Squared value of the above developed model was found to be 0.999977 which enable good prediction accuracy.

Fz=204.4285943-18.12900357*A+53.18909179*B+64.11073167*C-1.7234675*A*B -0.86332143*A*C-2.163118929*B*C-26.13381111*A^2+20.55340389*B^2-45.57261*C^2...... (2). The R-Squared value of the above developed model was found to be 0.997634 which enable good prediction accuracy.

Ra=1.353075463-0.034971429*A+0.145004167*B+0.005327778*C-5E-05*A*B-4.2857*E-05*A*C+8.75E-05*B*C-0.147688889*A^2-0.024938889*B^2-0.040929167*C^2...... (3)

The R-Squared value of the above developed model was found to be 0.999998 which enable good prediction accuracy.

IV. Results and Discussions

The purpose of the analysis of variance (ANOVA) is to investigate which turning parameters significantly affect the performance characteristics. Usually, the change of the turning parameter has a significant effect on the performance characteristics when the F value is large. The percentage contribution indicates the relative power of a factor to reduce the variation. For a factor with a high percentage contribution, there is a great influence on the performance. The percentage contributions of the cutting parameters on the cutting temperature are shown in Table 5.

Table 5: ANOVA Results for cutting temperature

Source Term	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio	Probability level	%Contribution
Model	9	6556.890804	728.5434226	83012.96689	<0.0001	
A-Cutting Speed	1	143.64	143.64	16366.87971	< 0.0001	2.19062
B-Feed Rate	1	1167.177646	1167.177646	132992.5935	< 0.0001	17.80037
C-Depth of cut	1	4213.62	4213.62	480115.6481	< 0.0001	64.26101
AB	1	0	0	0	1.0000	0
AC	1	0	0	0	1.0000	0
BC	1	0.000803571	0.000803571	0.091561939	0.7659	0
A2	1	606.015	606.015	69051.61939	< 0.0001	9.2422
B2	1	13.95375	13.95375	1589.942549	< 0.0001	0.21281
C2	1	50.35017857	50.35017857	5737.087971	< 0.0001	0.76788
Residual	17	0.149196429	0.008776261			0.00228
Cor.Total	26	6557.04				
Std.Dev.		0.093681698		R-Squared		0.999977246
Mean		117.2		Adj R-Squared		0.9999652
C.V%		0.079933189		Pred R-Squared		0.999954619
PRESS		0.297567831		Adeq Precision		1047.977743

The depth of cut was found to be the major factor affecting the cutting temperature (64.26%), whereas the feed rate (17.8%) and the squared cutting speed (9.24%) were found to be the second and third ranking factors respectively. The model F-value of 83012.96689implies the model is significant. Values of “Prob>F” less than 0.0500 indicate model terms are significant

. The estimated response surfaces for the cutting temperature components are illustrated in figure 5. From the response surface plots, it is noted that depth of cut increases cutting temperature also increases drastically; also increase in feed rate will lead to produce more temperature. The main factor which affects the cutting temperature is depth of cut. The factor cutting speed was the less influence for cutting temperature.

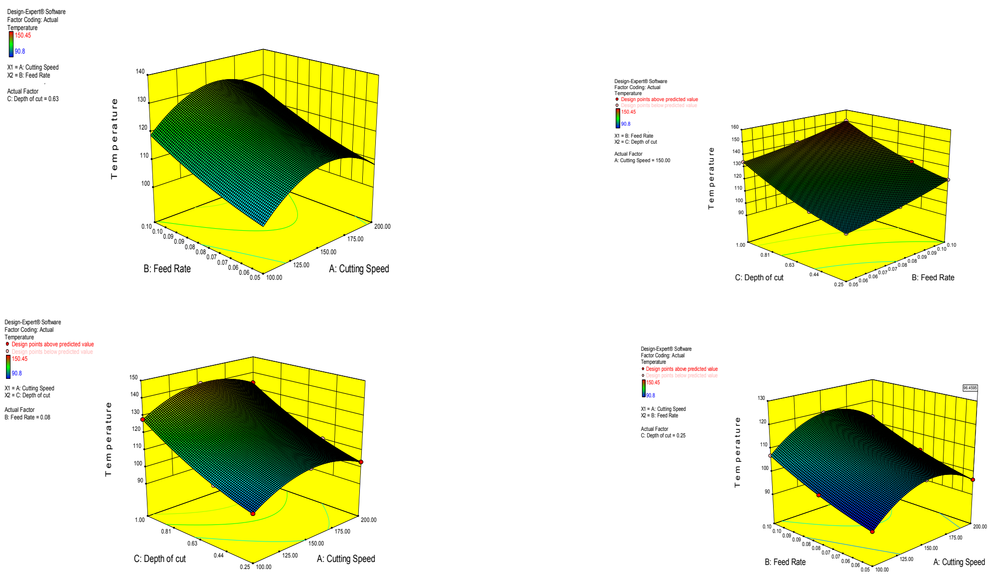

Figure 5: Estimated response surface of cutting temperature

V. Optimization analysis of cutting temperature

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 center lathe to obtain minimum temperature and minimum surface roughness and minimum cutting force is possible at a cutting speed of 200 m/min, depth of cut of 0.25 mm and feed rate of 0.05 mm/rev. The figure 6 shows the combined desirability at the optimum conditions.

Table 6: Optimal parameters for the turning operations.

Cutting Speed(m/min)	Feed Rate(mm/rev)	Depth of cut(mm)	Desirability
200	0.05	0.25	0.967317

VI. Conclusion

Reliable cutting temperature model have been plotted versus cutting parameters to enhance the efficiency of the turning of aluminium 6063 alloy. The following conclusions and recommendations could be made from the test results.

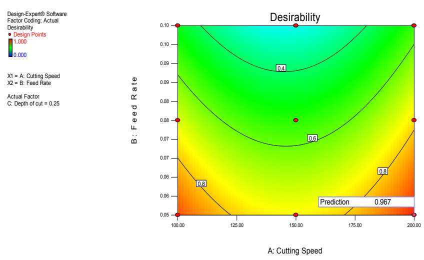

Figure 6: Combined Desirability plot

1. The surface and generated profile show that the temperature, surface finish and cutting force can be minimized using these set of parameters which significantly improves the surface finish and reduce power consumption.

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 200 m/min, depth of cut of 0.25mm and feed rate of 0.05 mm/rev minimum surface roughness of the turned profile as well as minimum cutting temperature and minimum cutting force can be achieved.
4. From the ANOVA results the depth of cut is the dominant parameter for temperature followed by feed rate and squared value of the cutting speed.

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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