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OPTIMIZATION OF MACHINING PARAMETERS IN HARD TURNING OF AISI 4340 STEEL

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ABSTRACT

Producers of machined components and manufactured goods are continually challenged to reduce cost, improve quality and minimize setup times in order to remain competitive. Frequently the answer is found with new technology solutions. Such is the case with grinding where the traditional operations involve expensive machinery and generally have long manufacturing cycles, costly support equipment, and lengthy setup times. However, the grinding process itself may require several machine tools and several setups to finish all component surfaces. Because grinding can be a slow process with low material-removal rates, there has been a determined search for replacement processes. The newer solution is a hard turning process, which is best performed with appropriately configured turning centres or lathes. Hard turning really started to develop at the beginning of the nineties. The reason for this was the availability of new tool materials and the capability of designing a turning machine that was rigid, stable and accurate enough to successfully finish hard turn. The result of these developments have made finish hard turning a viable alternative to grinding, as an accurate finishing operation.

The present work concerned an experimental study of turning on AISI 4340 alloy steel by a carbide insert tool. The primary objective of the ensuing study was to use the Response Surface Methodology in order to determine the effect of machining parameters viz. cutting speed, feed, and depth of cut, on the surface roughness of the machined material. The objective was to find the optimum machining parameters so as to minimize the surface roughness. The experiment was conducted in an experiment matrix of 20 runs designed using a full-factorial Central Composite Design (CCD). Surface Roughness was measured using a Talysurf. The data was compiled into MINITAB for analysis. The relationship between the machining parameters were modelled and analysed using the Response Surface Methodology (RSM). Analysis of Variance (ANOVA) was used to investigate the significance of these parameters on the response variables, and to determine a regression equation for the response variables with the machining parameters as the independent variables, with the help of a quadratic model

I. BACKGROUND

Hard turning attracts great interests since it potentially provides an alternative to conventional grinding process for machining high hardness, high precision components in small production [1] During the past few years, unprecedented progress has been made in the hard turning. The greatest advantage of using hard turning is the reduced machining time and complexity required to manufacture metal parts. In order to substitute grinding process and minimize tool wear, cutting parameters in hard turning are generally adapted for finishing operations [3]. Small depth of cut and low feed rates are chosen to improve finished surface and reduce the mechanical and thermal impacts on the tools to acceptable limits. Many studies have been conducted to investigate the performance of ceramics tools in the cutting of various hardened materials. Wiper inserts are increasingly being utilized during the last years. The influences of the wiper inserts on the surface roughness were described in turning [2]. While machining, the wiper ceramic performed better in respect to surface roughness and tool wear whereas the conventional ceramic exhibited less machining force and power.

The turning operation is a basic metal machining operation that is used widely in industries dealing with metal cutting. The selection of machining parameters for a turning operation is a very important task in order to accomplish high performance. By high performance, we mean good machinability, better surface finish, lesser rate of tool wear, higher material removal rate, faster rate of production etc.

The surface finish of a product is usually measured in terms of a parameter known as surface roughness. It is considered as an index of product quality. Better surface finish can bring about improved strength properties such as resistance to corrosion, resistance to temperature, and higher fatigue life of the machined surface. In addition to strength properties, surface finish can affect the functional behaviour of machined parts too, as in friction, light reflective properties, heat transmission, ability of distributing and holding a lubricant etc. Surface finish also affects production costs. For the aforesaid reasons, the minimization of the surface roughness is essential which in turn can be achieved by optimizing some of the cutting parameters.

Tool wear is an inherent phenomenon in every traditional cutting operation. Researchers strive towards elimination or minimization of tool wear as tool wear affects product quality as well as production costs. In order to improve tool life, extensive studies on the tool wear characteristics have to be conducted. Some of the factors that affect tool wear and surface roughness are machining parameters like cutting speed, feed, depth of cut etc., tool material and its properties. work material and its properties and tool geometry. Minimal changes in the above mentioned.

factors may bring about significant changes in the product quality and tool life . In order to achieve desired results, optimization is needed. Optimization is the science of getting most excellent results subjected to several resource constraints. In the present world scenario, optimization is of utmost importance for organizations and researchers to meet the growing demand for improved product quality along with lesser production costs and faster rates of production [9]. Statistical design of experiments is used quite extensively in optimization processes. Statistical design of experiments refers to the process of planning the experiments so that appropriate data can be analysed by statistical methods, resulting in valid and objective conclusions [10]. Methods of design such as Response Surface Methodology (RSM), Taguchi‟s method, factorial designs etc., find unbound use nowadays replacing the erstwhile one factor at a time experimental approach which more costly as well as time-consuming [11]. Neseliet. al [4] used RSM method and Nose radius, approach angle and rake angle as the input variables and found that the nose radius has the most significant effect on surface roughness. Nanavati and Makadia [3] used feed, cutting speed and tool nose radius as predictors in the RSM method and determined that feed was the most significant factor affecting the surface roughness followed by the tool nose radius. Yang and Tarng [2] used the Taguchi method to find the optimal cutting parameters. A study conducted by Bouacha [5], showed that feed rate was the most influential parameter in determining surface finish of a product followed by the cutting speed. Halim [14] found that tool wear is most significantly affected by the depth of cut while other factors were seemingly insignificant. The present study uses cutting speed, feed, and depth of cut as the machining parameters and the objective is to optimize these parameters so as to find the minimum surface roughness and tool wear.

Benefits From Hard Turning.

Hard turning is typically defined as the turning of a part or barstock of harder than 45HRC on a lathe or turning center. Since surface roughness of Rmax/Rz=1.6s can be achieved, hard

turning is often considered a replacement for grinding operations or as a pre-grinding process. Hard turning is most often performed on post-heat treated parts with surface hardness ranging from 45HRC to 68HRC or even higher. The process of hard turning shares many fundamentals with its “soft turning” sibling. As with any new application, there is a learning curve for hard turning, but the fundamental principles follow those of the same turning operations that are commonly performed in shops today. This gives it an inherent advantage over grinding, which requires specific knowledge and experience that not all machinists possess. While any new process can be learned, most machinists and programmers today will have an easier time absorbing the hard turning process compared with grinding.

While hard turning can achieve impressive results, it is not an alternative for all parts typically finished through grinding. Polished mirror surface finishes of Rz=0.3~0.8z that can be achieved through grinding are not possible by hard turning alone. Grinding has the additional advantage of being able to achieve higher dimensional roundness and cylindricity accuracies compared with hard turning. However, since parts can typically be finished in a single chucking, hard turned parts often show superior concentricity and perpendicularity characteristics to their ground counterparts.

The “sweet spot” for hard turning applications are for parts that have roundness accuracy requirements between 0.5 and 12 microns, and surface roughness requirements between Rz 0.8 micron and Rz 7.0 microns (see chart on page 26). This includes a variety of parts such as gears, injection pump components, hydraulic components, seat surfaces, and hard disk drive shafts.

The cost advantages of hard turning compared with grinding are numerous. The immediately apparent cost advantage is the reduced cost in capital equipment, as CNC turning centers are generally less expensive than grinding machines. Additionally, several types of grinding machines may be needed to perform the operations able to be performed on a single turning center, further opening the possibilities for equipment cost savings.

As mentioned above, a turning center can complete ID turning, OD turning, taper turning, and grooving in a single chucking. In addition to improving the accuracy of squareness, concentricity and straightness, this drastically reduces cycle and setup times as well. High precision threading operations can also be performed, guaranteeing concentricity with other part features compared with offline threading operations.

Hard turning also allows for the finishing of radius and free-curved surfaces. Grinding processes require a custom-dressed wheel, which is time consuming to produce, or highly customized grinding machines that can be expensive.

In addition to the inherent cost advantages of combining multiple operations into one, hard turning cycle times are drastically shorter than comparable turning operations. Metal can be removed much faster in hard turning operations, and high speed turning is possible with both CBN and ceramic cutting tools. Changing grinding wheels is also time consuming, whereas switching out inserts on turning centers can be quick. Part loading and unloading times are also shorter for turning centers, and turning centers are typically more easily automated for additional productivity. A number of features of the hard turning process reduce environmental impact as well as cost. Turning centers consume less electricity than grinding machines, reducing both electrical consumption and the monthly electrical bill. Hard turning is often performed dry, eliminating both coolant costs and the need for coolant disposal. Hard turning produces easily recycled chips, whereas grinding produces sludge that must go through a costly separation process or be disposed of as industrial waste.

II. EXPERIMENTAL PROCEDURES

RSM is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimise this response [1]. RSM also quantifies relationships among one or more measured responses and the vital input factors The version 6 of the Design Expert software was used to develop the experimental plan for RSM. The same software was also used to analyse the data collected by following the steps as follows

Choose a transformation if desired. Otherwise, leave the option at “None”.

Select the appropriate model to be used. The Fit Summary button displays the sequential F-tests, lack-of-fit tests and other adequacy measures that could be used to assist in selecting the appropriate model.

Perform the analysis of variance (ANOVA), post-ANOVA analysis of individual model coefficients and case statistics for analysis of residuals and outlier detection Inspect various diagnostic plots to statistically validate the model.

If the model looks good, generate model graphs, i.e. the contour and 3D graphs, for interpretation. The analysis and inspection performed in steps (3) and (4) above will show whether the model is good or otherwise. Very briefly, a good model must be significant and the lack-of-fit must be insignificant. The various coefficient of determination, R2 values should be close to 1. The di-agnostic plots should also exhibit trends associated with a good model and these will be elaborated subsequently.analysing each response, multiple response optimisation was performed, either by inspection of .the interpretation plots, or with the graphical and numerical tools provided for this purpose.It was mentioned previously that RSM designs also help in quantifying the relationships between one or more measured responses and the vital input factors. In order to determine if there exist a relationship between the factors and the response variables investigated, the data collected must be analysed in a statistically sound manner using regression. A regression is performed in order to describe the data collected whereby an observed, empirical variable (response) is approximated based on a functional relationship between the estimated variable,y and one or more regressor or input variable x1,x2, . . . , xi. In the case where there exist a non-linear relationship between a particular response and three input variables, a quadratic equation

y =b0 + b1x1 + b2x2 + b3x3 + b4x1x2 + b5x1x3 + b6x2x3 +b7x2 1 + b8x2 2 + b9x2 3 + error may be used to describe the functional relationship between the estimated variable, yest and the input variables x1, x2 and x3. The least square technique is being used to fit a model equation containing the said regressors or input variables by minimising the residual error measured by the sum of square deviations between the actual and the estimated responses. This involves the calculation of estimates for the regression coefficients, i.e. the coefficients of the model variables including the intercept or constant term. The calculated coefficients or the model equation need to however be tested for statistical significance. In this respect, the following test are performed.

Work Material

Table 1: Chemical composition (wt %) of AISI 4340 Steel

ELEMENT	CONTENT(%)	
Iron, Fe	95.195 - 96.33	
Nickel, Ni	1.65	- 2.00
Chromium, Cr	0.700	- 0.900
Manganese, Mn	0.600	- 0.800
Carbon, C	0.370	- 0.430
Molybdenum, Mo	0.200	- 0.300
Silicon, Si	0.150	- 0.300
Sulfur, S	0.0400	
Phosphorous, P	0.0350	

Layout of Experiment for RSM

The experiment layout was obtained in accordance with the 3-level full-factorial Central Composite Design with 8 cube points, 6 axial points, 4 centre points, and 2 centre points in axial, resulting in a total of 20 runs. α was chosen as 1 to make the design face centred.

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III. RESULTS AND DISCUSSIONS

3.1 Experimental Results

The results obtained from the experimental work are summarized in the Table.

Table2: Results Obtained

Std Order	Run Order	Cutting Speed(m/min)	Feed (mm/rev)	Depth of Cut (mm)	Ra (µm)
2	1	112	0.15	0.4	1.513
3	3	112	0.05	0.8	1.353
4	2	66	0.15	0.8	1.7
5	15	89	0.1	0.6	0.86
6	16	89	0.1	0.6	0.887
7	7	112	0.05	0.4	0.88
8	6	66	0.15	0.4	1.947
9	8	66	0.05	0.8	1.893
10	5	112	0.15	0.8	1.673
11	17	89	0.1	0.6	1.053
12	18	89	0.1	0.6	1
13	10	66	0.1	0.6	1.16
14	9	112	0.1	0.6	0.96
15	13	89	0.05	0.6	2.16
16	11	89	0.15	0.6	2.013
17	12	89	0.1	0.4	1.413
18	14	89	0.1	0.8	1.007
19	19	89	0.1	0.6	0.967
20	20	89	0.1	0.6	0.96

3.2 Analysis of results

The results obtained from the experiment were fed into MINITAB ® 17 for further analysis

The analysis of variance (ANOVA) was used to study the significance and effect of the cutting parameters on the response variables i.e. Ra

Table 3: ANOVA for Surface Roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	2.7542	0.30602	3.47	0.033
Linear	3	0.50671	0.1689	1.92	0.191
Cutting Speed	1	0.16078	0.16078	1.82	0.207
Feed	1	0.26018	0.26018	2.95	0.117
Depth of Cut	1	0.08575	0.08575	0.97	0.347
Square	3	1.96078	0.65359	7.41	0.007
Cutting Speed*Cutting	1	0.16281	0.16281	1.85	0.204

Speed					
Feed*Feed	1	1.68678	1.68678	19.13	0.001
Depth of Cut*Depth of Cut	1	0.02395	0.02395	0.27	0.614
2-Way Interaction	3	0.28671	0.09557	1.08	0.4
Cutting Speed*Feed	1	0.00266	0.00266	0.03	0.865
Cutting	1	0.00054	0.00054	0.01	0.939
Speed*Depth of Cut					
Feed*Depth of Cut	1	0.2835	0.2835	3.21	0.103
Model	9	2.7542	0.30602	3.47	0.033
Linear	3	0.50671	0.1689	1.92	0.191
Error	10	0.88184	0.08818		
Lack-of-Fit	5	0.8564	0.17128	33.66	0.11
Pure Error	5	0.02545	0.00509		
Total	19	3.63604	Total		

From Table, we can see that the P-Value for the model is 0.033 which is lesser than the significance value of 0.05. Hence, the model is significant. The lack-of-fit has a P-value of 0.11 and hence, it is insignificant, which is desirable. Feed is found to be the most influential parameter affecting the surface roughness with the lowest P-value among all three parameters.

The regression coefficients obtained from MINITAB ® 17 are laid out in Tables.

Table 4: Estimated Coded Regression Coefficients for Surface Roughness.

Term	**Effect**	**Coef**	**SE Coef**	**T-Value**	**P-Value**
Constant		1.094	0.102	10.72	0
Cutting Speed	0.2536	-0.1268	0.0939	-1.35	0.207
Feed	0.3226	0.1613	0.0939	1.72	0.117
Depth of Cut	0.1852	0.0926	0.0939	0.99	0.347
Cutting					
Speed*Cutting	-0.487	-0.243	0.179	-1.36	0.204
Speed					
Feed*Feed	1.566	0.783	0.179	4.37	0.001
Depth of Cut*Depth of Cut	-0.187	-0.093	0.179	-0.52	0.614
Cutting Speed*Feed	0.037	0.018	0.105	0.17	0.865
Cutting Speed*Depth of Cut	-0.017	-0.008	0.105	-0.08	0.939
Feed*Depth of Cut	-0.376	-0.188	0.105	-1.79	0.103

Regression Equation in Un-coded Units:

Ra = -1.45 + 0.0758Vc – 49.5f + 5.30d – 0.00046Vc2 + 313.3f2 – 2.33d2 + 0.0519Vc*f – 0.0018Vc*d – 18.8f*d

3.3 Optimum settings

The three best optimal settings are shown in Table below. The best setting is found to be V c = 112 m/min, f = 0.0540404 mm/rev and d = 0.4 mm

Table 5: Top three optimum settings

Solution	Cutting Speed	Feed	Depth of Cut	Ra Fit
1	112	0.0540404	0.4	0.869883
2	66	0.0723647	0.410652	0.860066
3	66	0.062364	0.4	0.977706

IV. SUMMARY

RSM was successfully applied in optimizing the surface for the chosen tool-work combination and for the selected domain of the input machining parameters. ANOVA analysis was carried out and it is observed that feed is the most significant factor affecting the surface roughness, closely followed by cutting speed and depth of cut. The optimum running condition was found to be at V c (112 m/min), f (0.0540404 mm/rev) and d (0.4 mm). Empirical models for surface roughness have been determined based on which predictions can be carried out for output responses for appropriate applications.

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