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Investigation on the Influence of Cutting Parameters in Hard Turning

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Abstract— **One of the main challenges in Engineering industries is to have materials with extra ordinary properties. Due to the difficulty of availability from open market and economical impact on pure hard materials such as titanium, vanadium, tungsten, titanium & its alloys, an alternative approach is performed through this project. The parent pure metal is bought to the difficulty to machine level of hardness and various parameters were analyzed on hard turning operation. Pure EN-31 round bar is considered for this purpose and this is bought to a hardness level of 60-64 HRC, so as to understand the variation in certain parameters, since limited studies were conducted towards the behavior of cutting tool during CBN hard turning. CBN tool were used for the this purpose. Thus this is an investigation on the influence of cutting parameters in hard turning .The combined effect of the process (cutting speed, feed rate and depth of cut) on performance characteristics (surface roughness and chip morphology) are investigated through the analysis of variance (ANOVA). The design of experiment has conducted through Taguchi approach and conformation of experiments is performed through Regression analysis by using MINITAB -17 software. The output variables considered are the surface roughness and the type of chips generated (chip morphology). Chip morphology analysis considers only for continues and discontinues chip as the cutting tool used is CBN. From the experiment it is found that the dependent parameter in surface roughness measurement for Ra, Rq and Rz is feed rate.**

Keywords— Anova, Cbn Tool, Hardened En-31 Steel, Regression Analyses, Surface Roughness, Taguchi Method.

I. INTRODUCTION

Hard materials are finding a wide range of applications in the present manufacturing scenario. Titanium and its alloys are commonly used now a days for such kind of specific applications. Considering the market availability and cost implications of such materials, it is a requirement in finding a suitable alternative solution. Thus our paper is intended in finding an alternate material as well as in optimizing certain operating parameters.

This paper involves hard turning operation, it is an important task to select cutting parameters for achieving high cutting performance. However, this does not ensure that the selected cutting parameters (cutting speed, feed rate, depth of cut). In this paper, the design is developed by Taguchi technique. Taguchi method is used to determine the desired cutting parameters more efficiently.

The experiment was conducted using hardened work piece of EN-31material and the tool used is of CBN. Work piece has a dimension of length 75mm and diameter 32mm. The basic use of EN-31material is for Ball and Roller Bearings, Spinning tools, Beading Rolls, Punches and Dies. By its character this type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading. Investigates the design parameters and to indicate which parameters are significantly affecting the output parameters. The optimization is conducted by ANOVA. The selected output parameters is surface roughness. Surface finish is one of the most important requirement in machining process, as it is considered as an index of product quality. It measures the finer irregularities of the surface texture. Achieving the desired surface quality is critical for the functional behavior of a part. Chip morphology is conducted at varying cutting conditions.

II. LITERATURE REVIEW

The performance of hard turning is measured in terms of surface finish, cutting forces, power consumed and tool wear. Surface finish influences functional properties of machined components. Surface finish in hard turning has been found to be influenced by a number of factors such as feed rate, cutting speed, work material characteristics, work hardness etc. Amit Vishwakarma et al. [1] have reported that CBN and ceramic cutting tools are widely used in industries for the machining of the various hard materials. In many applications, the cutting of ferrous materials in their hardened condition can replace grinding to give significant savings in cost and increase in productivity. Delvadiya Parth et al. [2] have investigated the work piece hardness on surface roughness in hard turning of EN-31 steel. This study shows the effect of machining on surface roughness. The effect of the work piece hardness on the surface roughness is also found to be important. S.R. Das et al. [5] have conducted the study on the influence of cutting speed and depth of cut on residual stresses in hard turning. The compressive stresses increase with the increased feed rate. In this study, surface roughness was evaluated at different machining conditions. Vickey Nandal et al. [6] have investigated the chip morphology and considered only continues and discontinues chip as the cutting tool used is CBN.

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III. OBJECTIVE OF WORK

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of dimensional accuracy and surface finishing, high production rate and cost effective, with a reduced environmental impact. Many authors have studied the performance and it is observed that surface roughness, cutting forces and chip formation are all affected with the type of cutting speed, feed and depth of cut. Very limited investigation in hard turning machining of hardened EN-31 steel which is difficult to cut has been available in literature. Hence the machining of hardened EN-31 has been selected to study the effect on surface roughness at different cutting parameters of hardened EN–31 steel.

IV. HARDENED EN–31 STEEL

Hardened EN-31 steel is used as the work piece. It is having hardness in between 60-65 HRC after heat treatment. Heat treatment is the controlled process of heating and cooling of metal to alter their mechanical and physical properties without changing the product shape. The heat treatment process is defined as heating a metal at various temperatures, holding them for various time duration and cooling at various rates, it helps to improve the machining, formability, restore ductility after a cold working operation. Cubic boron nitride (CBN) is used for this experiment and it is a high-performance tool material from a polycrystalline mass, that is produced in a high temperature-pressure process. CBN, its hardness only surpassed by a diamond, is suitable for the machining of materials that cannot be machined with PCD or monocrystalline diamond.

Fig.1 Work Pieces

V. HARD TURNING OPERATION

Hard turning is an emerging technology that can potentially replace many grinding operations due to improved productivity (increasing production efficiency, high speed machining), increased flexibility (increasing the range of material that can be machined), decreased capital expenses (saving in cost), and reduced environmental waste. In hard turning, ferrous metal parts that are hardened usually between (45-70 HRC) are machined with the single point cutting tools. This has become possible with the availability of the new cutting tool materials cubic boron nitride (CBN) and ceramics. Since a large number of operations is required to produce the finished product, if some of the operations can be combined, or eliminated, or can be substituted by the new process, product cycle time can be reduced and productivity can be improved. The traditional method of machining hardened materials includes rough turning, heat treatment, and then grinding process. This experiment is conducted in CNC machine.

Fig.2 CNC Machine

VI. SURFACE ROUGHNESS

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. surface roughness, also known as surface texture are terms used to express the general quality of a machined surface, which is concerned with the geometric irregularities and the quality of a surface. Surface Roughness measures as the arithmetic average Ra, Root mean square roughness (R_q) and Ten point height (R_z). Fig. 3 Mitutoyo SJ-410 surface roughness tester. The Ra value, also known as centre line average (CLA) and arithmetic average is obtained by averaging the height of the surface above and below the centre line. The Ra will be measured using a surface roughness tester from Mitutoyo, Model: SJ-410. The Ra values of the surface were obtained by averaging the surface roughness values of 4.5 mm measurement length.

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Fig.3 Surface Tester

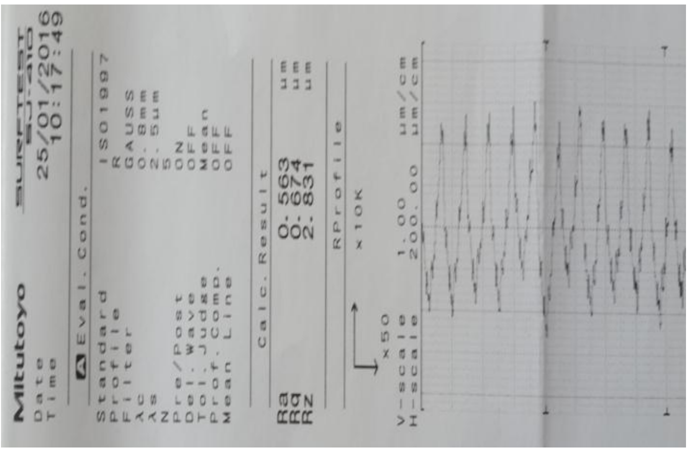

Fig. 4 Surface Tester Reading

VII. CHIP MORPHOLOGY

Chip morphology is the one of the output parameter. Chips are one of the major waste stream components of machining. Chips are formed as unwanted material is cut away from a work piece. Chips can be continuous or discontinuous. Continuous chips have a uniform amount of shear strain throughout their length. Discontinuous chips exhibit shear banding. That is, although the entire chip may have exhibit shear deformation, intense shearing is concentrated in narrow bands, causing slippage of planes and a discontinuous surface. As the chip curls, it impacts the uncut work. As the chips is being forced into the work piece, it develops a bending moment which ultimately causes fracture. This fracture is desirable, facilitating small, well broken, chips which are easier to handle and dispose off Long unbroken "snarl" chips are undesirable. They may damage the machine or work piece, and can even be dangerous to the machine tool operator.

Machining parameters which affect chip morphology include the speed, feed, depth of cut, tool nose radius, edge radius, rake angle, tool and work materials, ambient temperature, cutting fluid, generated vibration in the machine tool and others. This makes predicting the chip morphology extremely difficult. The volume of the chips will always be higher than the volume of the removed material. This is because the relative density of the chips is less than the work piece. The chips will not pack as densely as unmachined metal.

The chip morphology deals with the type of chip generated during varying machining conditions. The different type of chips commonly found in turning operation are continuous, discontinuous & continuous chips with built up edge. In this study only continuous and discontinuous chips were formed as the cutting tool used is CBN.

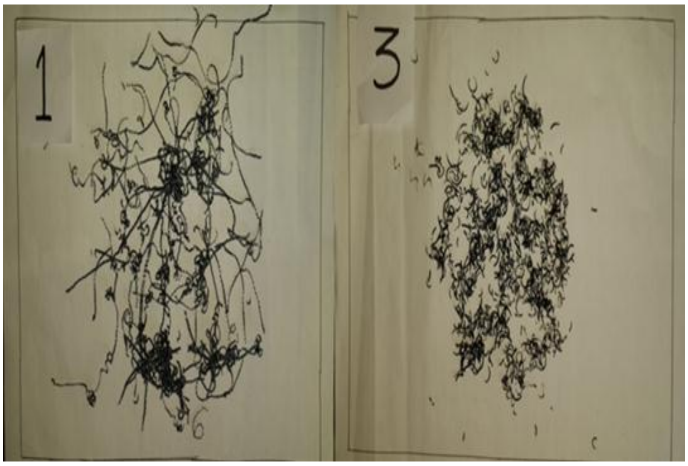

Fig.5 Chip Morphology

VIII. TAGUCHI METHOD OF EXPERIMENT

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. The desired cutting parameters are determined based on experience or by hand book. Steps of Taguchi method are as follows:

- Identification of main function, side effects and failure mode.
- Identification of noise factor, testing condition and quality characteristics.
- Identification of the main function to be optimized.
- Identification the control factor and their levels.
- Selection of orthogonal array and matrix experiment.
- Conducting the matrix experiment.
- Analyzing the data, prediction of the optimum level and performance.
- Performing the verification experiment and planning the future action.

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Vol. 5 Issue 03, March-2016

With Taguchi design of experiment L9 orthogonal array is selected for this study.

Table 1 Cutting parameter

Parameters / Levels	1	2	3
Cutting speed (m/min)	100	150	200
Feed Rate (mm/rev)	0.05	0.1	0.15
Depth of Cut (mm)	0.1	0.2	0.3

Table 2 Taguchi Design of Experiment

Test No	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

IX. MINI TAB SOFTWARE

Minitab is a statistics package 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 OMNITAB, a statistical analysis program by NIST; the documentation for OMNITAB was published 1986, and there has been no significant development since then.

Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College, Pennsylvania.

Today, Minitab is often used in conjunction with the implementation of six sigma, CMMI and other statistics-based process improvement methods.

Minitab Inc. produces two other products that complement Minitab;

- Quality Trainer, an eLearning package that teaches statistical tools and concepts in the context of quality improvement that integrates with Minitab 17 to simultaneously develop the user's statistical knowledge and ability to use the Minitab software
- Quality Companion 3, an integrated tool for managing Six Sigma and Lean Manufacturing projects that allows Minitab data to be combined with project management and governance tools and documents.

X. ANALYSIS OF VARIANCE (ANOVA)

ANOVA is a statistical technique introduced by prof. RA Fisher frequently used in agricultural scientific research and studies. The purpose of this technique is to examine the significance effects on different varieties of factors in flouncing yields. This is the test of equality of mean of tree or more samples. The total variation in any set of numerical data is due to a number of causes which may be classified as; Assignable causes and Random causes. The main aim of ANOVA is to investigate the design parameters and to indicate which parameters are significantly affecting the output parameters. In the analysis, the sum of squares and variance are calculated. F-test value at 95% confidence level is used to decide the significant factors affecting the process and percentage contribution is calculated. ANOVA can be useful for determining influence of any given input parameter from a series of experimental results by design of experiments for machining process and it can be used to interpret experimental data. Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes F-test to more than two groups.

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations .The analysis of variance (ANOVA) may be used to investigate which design factors and their interactions affect the response significantly. Taguchi recommends analyzing the mean and S/N ratio using two-dimensional response graphs, instead of ANOVA. For the validity of F-test in ANOVA. The following assumption are,

- The observation are independent.
- Parent population from which the observation are taken in normal.
- Various treatments and environmental effects are additive in nature.
- The error components are normally distributed with zero mean and common variance.
- Parameters considered (input & output)

XI. REGRESSION ANALYSIS

Generates an equation to describe the statistical relationship between one or more predictors and the response variable and to predict new observations. Regression generally uses the ordinary least squares method which derives the equation by minimizing the sum of the squared residuals. Regression results indicate the direction, size, and statistical significance of the relationship between a predictor and response. Models with one predictor are referred to as simple linear regression, otherwise it is known as multiple linear regression

- Sign of each coefficient indicates the direction of the relationship.
- Coefficients represent the mean change in the response for one unit of change in the predictor while holding other predictors in the model constant.

XII. Result And Discussion

Table 3 Experimental Result

SL NO	Cutting speed (m/min)	Feed rate (m/rev)	Depth of cut (mm)	Ra (µm)	Rq (µm)	Rz (µm)	Chip morphology
1	100	0.05	0.1	0.210	0.260	1.454	Continuous
2	100	0.1	0.2	0.294	0.360	1.847	Continuous
3	100	0.15	0.3	0.564	0.676	2.807	Discontinuous
4	150	0.05	0.2	0.232	0.284	1.420	Continuous
5	150	0.1	0.3	0.291	0.355	1.781	Continuous
6	150	0.15	0.1	0.508	0.605	2.635	Discontinuous
7	200	0.05	0.3	0.270	0.335	1.657	Continuous
8	200	0.1	0.1	0.390	0.470	2.233	Continuous
9	200	0.15	0.2	0.492	0.582	2.591	Discontinuous

For lower feed rates the chip obtained is continuous and as the feed rate increases the possibility of discontinuous chip formation is more. Thus it conform that the chip morphology depend on feed rate. Continuous chips deteriorate the quality of machining surface so proper selection of cutting parameters based on the requirement has to be considered.

Table 4 ANOVA Table For R_a (Typical)

Source	DF	SS	MS	F-Value
Regression	3	0.122208	0.040736	12.95
Cutting speed	1	0.001176	0.001176	0.37
Feed rate	1	0.120984	0.120984	38.47
Depth of cut	1	0.000048	0.000048	0.02
Error	5	0.015723	0.003145	
Total	8	0.137932		

Table 5 Regression Analysis For R_a (Typical)

Term	Coef	SE Coef	T-Value	P-Value
Constant	0.0296	0.0962	0.31	0.771
Cutting speed	0.000280	0.000458	0.61	0.568
Feed rate	2.840	0.458	6.20	0.002
Depth of cut	0.028	0.229	0.12	0.906

Response Relation (Typical)

$$R_a = 0.0296 + 0.000280 \text{ Cutting speed} + 2.840 \text{ Feed rate} + 0.028 \text{ Depth of cut}$$

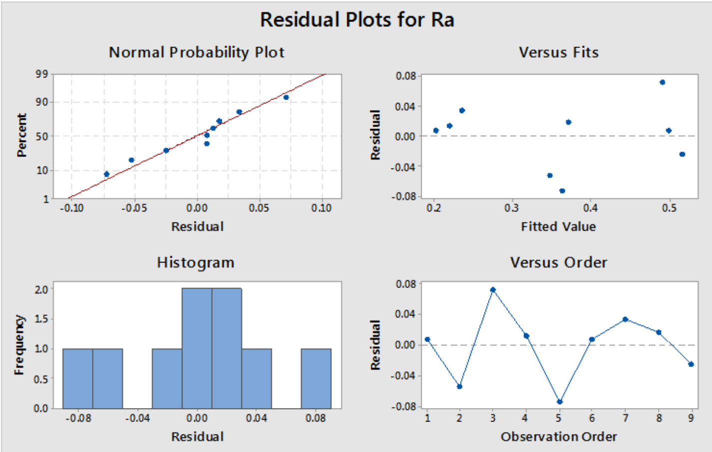

Fig. 6 Residual Plots For R_a (Typical)

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Vol. 5 Issue 03, March-2016

Table 6 Summary of ANOVA

SL No	Parameters	Dependant parameter
1	R_a	Feed rate
2	R_q	Feed rate
3	R_z	Feed rate

Form the study the surface roughness measurements R_a , R_q & R_z are dependant on feed rate.

Table 7 Summary Of Regression Analysis

SL NO	Parameters	Response Relation
1	R_a	0.0296 + 0.000280 Cutting speed + 2.840 Feed rate + 0.028 Depth of cut
2	R_q	0.052 + 0.000303 Cutting speed + 3.280 Feed rate + 0.052 Depth of cut
3	R_z	0.719 + 0.00124 Cutting speed + 11.67 Feed rate - 0.128 Depth of cut

Response Relation is generated in regression analysis. The relation is used to find the calculeted values for conformation test.

Table 8 Confirmation Of Experiment

SL No	Ra (A) µm	Ra (C) µm	Ra, A/C µm	Rq (A) µm	Rq (C) µm	Rq, A/C µm	Rz (A) µm	Rz (C) µm	Rz, A/C µm
1	0.210	0.202	1.03	0.260	0.251	1.03	1.45	1.41	1.03
2	0.294	0.347	0.847	0.360	0.420	0.860	1.85	1.98	0.930
3	0.564	0.492	1.14	0.676	0.590	1.14	2.81	2.55	1.10
4	0.232	0.219	1.06	0.284	0.272	1.04	1.42	1.46	0.970
5	0.291	0.364	0.80	0.355	0.441	0.810	1.78	2.03	0.880
6	0.508	0.500	1.01	0.605	0.594	1.02	2.64	2.46	1.07
7	0.270	0.236	1.14	0.335	0.292	1.14	1.66	1.51	1.10
8	0.390	0.372	1.05	0.470	0.446	1.05	2.24	2.12	1.06
9	0.492	0.517	0.952	0.582	0.615	0.950	2.59	2.69	0.963

A- Actual Reading, C- Calculated Reading

From the study it is found that the ratio of actual and calculated values of Ra, Rq and Rz are almost equal to unity. This confirms the competency of study and hence the accuracy of the physical measurements taken. This implies the optimal conditions of the cutting parameters on surface roughness physically obtained with the analytical method.

XIII. CONCLUSION

The following conclusions are derived during turning of hardened EN-31 steel with CBN insert. During experimentation the effect of various machining parameters on surface roughness are studied with the help of Taguchi design of experiments and determined the best combination of machining parameters such as depth of cut, feed and cutting speed. It is observed from the ANOVA that feed is the most significant parameter followed by cutting speed and the two level interactions were also found to be significant between cutting speed-feed and depth of cut-feed on surface roughness. From the experimentation it is found that, depth of cut did not impact the surface roughness in the studied range, significantly. For lower feed rates the chip obtained is continuous and as the feed rate increases the possibility of discontinuous chip formation is more, thus it conform that the chip morphology depend on feed rate. continuous chips deteriorate the quality of machining surface so proper selection of cutting parameters based on the requirement has to be considered. The type of chip so obtained can be considered as a base for similar machining operations. The present research work on turning of hardened EN-31 steel with CBN coated carbide insert will be useful for the advanced engineering industries those are working in the field of precision machining.

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