ANALYSIS OF SURFACE ROUGHNESS IN HARD TURNING BY USING TAGUCHI METHOD

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Abstract : Hard turning is defined as the turning of hardened ferrous metals with Rockwell-C hardness ratings ranging from 45 to 70. Hard turning has the potential to reduce production costs by replacing more costly and less agile grinding operations on hard materials especially in finishing processes (Konig et al., 1990). PCBN tools tend to be damaged more severely than conventional cutting tools of mild turning under vibrations because of their relatively brittle property. In addition, the finishing process, which is often involved with hard turning, has a much smaller tolerance of surface precision than other machining processes.

This paper is focused on hard turning of 20 MnCr5 Steel. The purpose of this paper is to analyze optimum cutting conditions to get lowest surface roughness in turning of 20 MnCr5 Steel. Taguchi method has been used for this. An orthogonal array, the signal to noise ratio and analysis of variance (ANOVA) are employed to investigate the cutting characteristics. The results indicate that feed rate has significant role to play in producing lower surface roughness followed by cutting speed. The cutting insert used is ceramic based TNGA 160404 .

Keywords: Hard turning, Optimization, Surface roughness, Taguchi method, S/N ratio, ANOVA.

1. Introduction

Today’s modern machining industries face challenge to achieve high quality in terms of work piece dimensional accuracy, surface finish, less wear on cutting tools, economy of machining in terms of cost saving. Surface roughness of the machined part is the most important criteria to judge the quality of operation. Over the years , cutting fluids have been used in machining operations to reduce friction and wear by improving tool life and surface finish , to cool the cutting zone. But the application of cutting fluid proved to be harmful to the health as well as environment. To overcome the serious problems of cutting fluids , hard turning has been used quite easily. This reduces the manufacturing cost as well as risk of danger to the health.

2. Literature Review

It is required to identify the tool materials that are capable of longer service lives, and to decide the required operations for turning the materials into finished products that are capable of maintaining higher geometric tolerances and improved surface finish.

Lin et al. (2001) adopted an abdicative network to construct a prediction model for surface roughness and cutting force. Once the process parameters: cutting speed, feed rate and depth of cut were given; the surface roughness and cutting force could be predicted by this network. Regression analysis was also adopted as second prediction model for surface roughness and cutting force. Comparison was made on the results of both models indicating that additive network was found more accurate than that by regression analysis [1]. Suresh et al. (2002) focused on machining mild steel by TiN-coated tungsten carbide (CNMG) cutting tools for developing a surface roughness prediction model by using Response Surface Methodology (RSM). Genetic Algorithms (GA) used to optimize the objective function and compared with RSM results. It was observed that GA program provided minimum and maximum values of surface roughness and their respective optimal machining conditions.[2].

Ahmed (2006) developed the methodology required for obtaining optimal process parameters for prediction of surface roughness in Al turning. For development of empirical model nonlinear regression analysis with logarithmic data transformation was applied. The developed model showed small errors and satisfactory results.
The study concluded that low feed rate was good to produce reduced surface roughness and also the high speed could produce high surface quality within the experimental domain [3]. Mahmoud and Abdelkarim (2006) studied on turning operation using High-Speed Steel (HSS) cutting tool with 45° approach angle. This tool showed that it could perform cutting operation at higher speed and longer tool life than traditional tool with 90° approach angle. The study finally determined optimal cutting speed for high production rate and minimum cost, tool life, production time and operation costs[4]. Doniavi et al. (2007) used response surface methodology (RSM) in order to develop empirical model for the prediction of surface roughness by deciding the optimum cutting condition in turning. The authors showed that the feed rate influenced surface roughness remarkably. With increase in feed rate surface roughness was found to be increased. With increase in cutting speed the surface roughness decreased. The analysis of variance was applied which showed that the influence of feed and speed were more in surface roughness than depth of cut.[5]. Kassab and Khoshnaw (2007) examined the correlation between surface roughness and cutting tool vibration for turning operation. The process parameters were cutting speed, depth of cut, feed rate and tool overhanging. The experiments were carried out on lathe using dry turning (no cutting fluid) operation of medium carbon steel with different level of aforesaid process parameters. Dry turning was helpful for good correlation between surface roughness and cutting tool vibration because of clean environment. The authors developed good correlation between the cutting tool vibration and surface roughness for controlling the surface finish of the work pieces during mass production. The study concluded that the surface roughness of work piece was observed to be affected more by cutting tool acceleration; acceleration increased with overhang of cutting tool. Surface roughness was found to be increased with increase in feed rate[6]. Thamizhmanii et al. (2007) applied Taguchi method for finding out the optimal value of surface roughness under optimum cutting condition in turning SCM 440 alloy steel. The experiment was designed by using Taguchi method and experiments were conducted and results thereof were analyzed with the help of ANOVA (Analysis of Variance) method. The causes of poor surface finish as detected were machine tool vibrations, tool chattering whose effects were ignored for analyses. The authors concluded that the results obtained by this method would be useful to other researches for similar type of study on tool vibrations, cutting forces etc. The work concluded that depth of cut was the only significant factor which contributed to the surface roughness[7].

3. Experimental Setup

3.1 Work piece Material

Stainless tool steels have sufficient corrosion resistance to resist rusting in countless applications where they can resist high temperature better than other materials and they have fabrication characteristics that allow their use in cold formed shapes and in cast shapes. The applications of this type of tool are for all type of moulds, especially for larger tools where corrosion in production is unacceptable and where high surface finish is required. Apart from that hardened stainless tool steel used widely in aerospace applications, turbine blades and nuclear waste casks. According to Senthil et al. (2006) hardened stainless steels are used in thermal power plants, nuclear power plants and in other demanding environments for its high temperature properties and high creep rupture strength. Recently, it is used in aeronautics industry to make stator parts of aircraft engine instead of using titanium for saving material cost . 20MnCr5 medium carbon steel with a hardness range of HRC 45 to 46 is chosen as the work piece material to evaluate the performance of the ceramic based TNGA 160404 insert.

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.17 / 0.22</td>
<td>1.10 / 1.40</td>
<td>0.035 max.</td>
<td>0.035 max.</td>
<td>0.15 / 0.35</td>
<td>1.00 / 1.30</td>
<td>0.020 min.</td>
</tr>
</tbody>
</table>

3.2 Machine

CNC lathe machine been in order to establish the correlation between cutting conditions and the surface roughness evaluating parameter. ACE Jobber Jr.lathe machine was used to test cut the hardened material. The CNC lathe has max. 7.5 kW spindle power and a maximal machining diameter of 250 mm with 300 mm distance between the centers, a maximum spindle speed of 4000rpm.

3.3 Measuring Equipment

Taylor Hobson Surtronic 3+ Portable surface profilometer is used to measure surface roughness of the work piece machine during experiment. The surface roughness was measured at four locations around work piece circumference. The value of the surface roughness is the average of four points taken for each measurement.
3.4 Design of Experiment

Design of Experiment is an effective tool for maximizing the amount of information gained from a study while minimizing the amount of data to be collected, which, in this case, is minimizing the number of experimental runs. Factorial experimental designs investigate the cause and effects of many different factors in a single study, instead of conducting many separate studies, each varying one factor at a time. Factorial designs allow estimation of the sensitivity to each factor and also to combinations of two or more factors at a time (called interactions). It should be noted that classical studies using one factor at a time while holding the other factors (“system”) constant will not result in knowledge about interactions. Thomas et al. (1997) used a full factorial design involving six factors to investigate the effects of cutting and tool parameters on the resulting surface roughness and on built-up edge formation in the dry turning of carbon steel. The Taguchi method was used by Yang and Tarn (1998), to find the optimal cutting parameters for turning operations. Choudhury and El-Baradie (1997) had used RSM and 23 factorial design for predicting surface roughness when turning high-strength steel. Thiele and Melkote (1999) had used a three-factor complete factorial design to determine the effects of work piece hardness and cutting tool edge geometry on surface roughness and machining forces.

The Taguchi method with multiple performance characteristics was used by Nian et al. (1999) in the optimization of turning operations. A polynomial network was used by Lee et al. (2000) to develop a machining database for turning operations. On the other hand, Lin et al. (2001) used an abductive network to construct a prediction model for surface roughness and cutting force. In combination, cutting speed, feed rate and depth of cut were the primary factors investigated.

4. Tool Material

The cutting tool (insert) used for this experiment is supplied by Sandwich. The insert used is TNGA160404. It is a ceramic based cutting tool. Cutting tool is ideal for finishing to general machining of most work piece materials at higher speeds. It is excellent for machining most steels, stainless steels, cast irons, non-ferrous materials and super alloys under stable conditions. It also performs well machining hardened and short chipping materials. The code TNGA160404 indicates that the insert is of triangular geometries. The length of the cutting edge is 16 mm with a thickness of 4 mm and cutting point radius of 0.4 mm.

It was placed on a right-hand tool holder with a designation of MCLNR 2525M12.

Three input parameters Cutting speed, feed and Depth of Cut were selected according to the insert profile.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed (m/min.)</td>
<td>290</td>
<td>175</td>
<td>232.5</td>
</tr>
<tr>
<td>Feed (mm/rev.)</td>
<td>0.25</td>
<td>0.15</td>
<td>0.2</td>
</tr>
<tr>
<td>Depth of Cut (mm)</td>
<td>0.4</td>
<td>0.07</td>
<td>0.23</td>
</tr>
</tbody>
</table>

With combinations of these three parameters readings for surface roughness and machining time were observed

5. Design and Analysis of Cutting Parameters

The results of experiments are studied using signal to noise (S/N) and ANOVA analysis. Based on the results, optimal cutting parameters for surface roughness are obtained.

5.1 Analysis of the signal to noise(S/N) ratio

In Taguchi method, ‘signal’ represents the desired value(mean) for the output characteristics and ‘noise’ represents the undesirable value(S.D.) for the output characteristics. It means that S/N ratio is the ratio of the mean to S.D.

\[ \eta = -10 \log_{10}(\text{MSD}) \]  - (1)

**Smaller the better**

It is used when the occurrence of some undesirable product characteristic is to be minimized. It is given by

\[ \eta = -10 \log_{10} \left( \frac{1}{N} \sum y_i^2 \right) \]  - (2)

Here \( \eta \) is the resultant S/N ratio, \( N \) is the number of observations on particular product and \( y \) is the surface roughness.
The factor 10 ensures that this ratio measures the inverse of bad quality, the more flaws in the part, the greater is the sum of sum of squared number of flaws and the smaller (i.e. more negative) the S/N ratio. Thus maximizing this ratio will increase quality. It is better suitable for quality like surface roughness.

6. Responses for TNGA160404 Insert

<table>
<thead>
<tr>
<th>Exp.No.</th>
<th>SPEED m/mint</th>
<th>FEED mm/revol</th>
<th>DOC mm</th>
<th>Ra µm</th>
<th>S/N ratio (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>290</td>
<td>0.25</td>
<td>0.4</td>
<td>6.37</td>
<td>-4.74203</td>
</tr>
<tr>
<td>2</td>
<td>232.5</td>
<td>0.2</td>
<td>0.23</td>
<td>1.21</td>
<td>-4.74713</td>
</tr>
<tr>
<td>3</td>
<td>175</td>
<td>0.15</td>
<td>0.07</td>
<td>0.96</td>
<td>-4.75484</td>
</tr>
<tr>
<td>4</td>
<td>290</td>
<td>0.2</td>
<td>0.07</td>
<td>0.95</td>
<td>-4.75909</td>
</tr>
<tr>
<td>5</td>
<td>175</td>
<td>0.2</td>
<td>0.4</td>
<td>2.84</td>
<td>-4.72658</td>
</tr>
<tr>
<td>6</td>
<td>232.5</td>
<td>0.25</td>
<td>0.07</td>
<td>6.27</td>
<td>-4.75329</td>
</tr>
<tr>
<td>7</td>
<td>232.5</td>
<td>0.15</td>
<td>0.4</td>
<td>0.91</td>
<td>-4.74041</td>
</tr>
<tr>
<td>8</td>
<td>290</td>
<td>0.15</td>
<td>0.23</td>
<td>1.08</td>
<td>-4.75415</td>
</tr>
<tr>
<td>9</td>
<td>175</td>
<td>0.25</td>
<td>0.23</td>
<td>5.54</td>
<td>-4.73550</td>
</tr>
</tbody>
</table>

6.1 Analysis of Variance

Analysis of variance (ANOVA) is done to determine the parameters which affects most the result of experiments. This is possible by separating tool variability of S/N ratio, which is measured by the sum of squared deviation (SS_f) from total mean S/N ratio into contribution by each design parameter and the error. Initially the total sum of squares (SS_T) is calculated by using following equation.

\[
SS_T = \sum (n_i - m)^2
\]

where \( n_i \) is the number of experiments in the orthogonal array and \( n_i \) is the mean S/N ratio for \( i^{th} \) experiment. 

SS_j and SS_e are calculated by using equation

\[
SS_j = \sum (n_j - m)^2
\]

\[
SS_e = \sum SS_j + SS_e
\]

Total sum of squares (SS_T) is divided into two sources, the sum of squared deviation SS_j due to each design parameter and sum of squared error SS_e. 

Percentage contribution \( (P_j) \) and F- value of each of the parameter is calculated by using equation

\[
P_j = \frac{SS_j}{SS_e} \times 100
\]

\[
F_j = \frac{MS_j}{MS_e}
\]

F- test is carried out to test the parameter having significant effect on quality characteristics. F – value is a ratio of mean squared deviations to the mean squared error. If the value of F comes more than 4 then it means change of design parameter have a significant effect on quality characteristics.

From ANOVA for surface roughness it is found that cutting speed and feed rate are the most significant factors affecting the surface roughness.
### Analysis of Variance for C1

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>8</td>
<td>19837.5000</td>
<td>2479.6875</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>19837.5000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Variance Components

<table>
<thead>
<tr>
<th>Source</th>
<th>Var Comp.</th>
<th>% of Total</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>2479.688</td>
<td>100.00</td>
<td>49.796</td>
</tr>
<tr>
<td>Total</td>
<td>2479.688</td>
<td></td>
<td>49.796</td>
</tr>
</tbody>
</table>

### Expected Mean Squares

1. C4 1.00(1)

### Analysis of Variance for C2

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>8</td>
<td>0.0150</td>
<td>0.0019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>0.0150</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Variance Components

<table>
<thead>
<tr>
<th>Source</th>
<th>Var Comp.</th>
<th>% of Total</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>0.002</td>
<td>100.00</td>
<td>0.043</td>
</tr>
<tr>
<td>Total</td>
<td>0.002</td>
<td></td>
<td>0.043</td>
</tr>
</tbody>
</table>

### Expected Mean Squares

1. C4 1.00(1)

### Analysis of Variance for C3

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>8</td>
<td>0.1634</td>
<td>0.0204</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>0.1634</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Variance Components

<table>
<thead>
<tr>
<th>Source</th>
<th>Var Comp.</th>
<th>% of Total</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>0.020</td>
<td>100.00</td>
<td>0.143</td>
</tr>
<tr>
<td>Total</td>
<td>0.020</td>
<td></td>
<td>0.143</td>
</tr>
</tbody>
</table>

### Expected Mean Squares

1. C4 1.00(1)

### Error Terms

**Denominator of F-test is zero or undefined. S = *  

### Expected Mean Squares, using Adjusted SS

- **Source**
  - Each Term
    1. C4 (2) + (1)
    2. Error (2)

### Error Terms for Tests, using Adjusted SS

- **Source**
  - DF MS of Error MS
    1. C4 * * (2)

### Variance Components, using Adjusted SS

- **Estimated**
  - Source Value
    1. C4 0.02042
7. Summary

The surface roughness data was obtained by considering various combinations. The Ra data was collected during the experiment and was summarized using line chart. The measured Ra values ranges from 0.91 to 6.37 μm. The horizontal axis of the graphs represents the cutting speed and feed and the vertical axis gives the values of the Ra. From the graphs it can be observed that the Ra improved when the cutting speed increased. When the feed speed increases the Ra values also increases. As per the findings and calculations ceramic based TNGA160404 inserts can be used as an alternative to the costly PCBN inserts and also with this hard turning can be the best other choice to the time consuming grinding process.

Cutting Speed Vs Feed

Depth of Cut Vs Surface Roughness

References