Analysis of Feed Force, Tangential Force and Surface Roughness in Turning of EN-353 Steel with Uncoated Ceramic Cutting Tool using Taguchi Method

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Abstract—The aim of the present paper is to investigate the effects of process parameters (cutting speed, feed rate and depth of cut) on performance characteristics (feed force, tangential force and surface roughness) in turning of EN-353 steel using uncoated ceramic cutting tool inserts. Experiments are designed and conducted based on Taguchi L9 orthogonal array carried out under dry cutting conditions for feed force, tangential force and surface roughness. The responses such as feed force, tangential force and surface roughness were recorded for each experiment. The depth of cut was identified as the most influential process parameters in the responses of both feed force and tangential force. The feed rate was identified as the most influential process parameter on the surface roughness.

Key words: Feed Force, Tangential Force, Surface Roughness, Taguchi Method

I. INTRODUCTION

Advanced development in machine tool rigidity and the development of ceramic and CBN cutting tools have allowed the machining of hardened steel to replace many cutting operations due to the numerous advantages of hard turning. The small depth of cut and feed rates are required for hard turning, material removal rates in hard turning can be much higher than grinding. It estimated that resulting reduction in machining time could be as high as 60%. A reduction in the number of required machine tools may also be observed as a result of the increased flexibility of the turning process as compared to grinding. The possibility of eliminating cutting coolant is another economic and environmental advantage of hard turning. In turning operation the important task is to select cutting parameters for achieving high cutting performance. Usually the cutting parameters are determined based on literature survey or handbook.

Usually, the Taguchi method is a powerful tool for the design of high quality systems. This method provides a simple, efficient and systematic approach to optimize the designs for performance, quality, and cost. Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods and more recently to biotechnology, marketing and advertising. Taguchi method is considered controversial among some traditional Western statisticians but others accept many of his concepts as being useful additions to the body of knowledge.

Taguchi's principal contributions to statistics are Taguchi loss-function, the philosophy of off-line quality control and Innovations in the design of experiments. Taguchi is the developer of the Taguchi method. He proposed that engineering optimization of a process or product should be carried out in a 3-step approach, i.e. system design, parameter design, and tolerance design. In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and the process design stage. In the product design stage, the selection of materials, components, tentative process parameter values, etc., are involved. Taguchi approach is used to obtain the optimal settings of these process parameters, finally ANOVA is used to analyze the influence of these cutting parameters during turning process.

II. LITERATURE REVIEW

Hari Singh and Pradeep Kumar [1], adopted a design of experiment based approach and obtained an approach setting of turning process parameters (speed, feed rate, and depth of cut) which yield optimal tool wear to titanium carbide coated carbide inserts while machining EN24 steel. The results indicated that the selected process parameters affect the tool wear significantly.

Thamizhmani S. et al. [2], found that the surface roughness from various tests shows a decrease in value at higher cutting speed and feed rate. The cutting tool has produced micro chipping and has not affected the surface finish Micro cracks were obtained from the edge of micro chipping. The notch wear might have been caused due to hard particles and other impurities present in the material. There is no formation of built-up edge that is usually occurring during machining cast iron at lower cutting speed. Further work can be carried in the direction of measuring the residual stresses by turning and formation of built-up edge under high speed machining.

P.Munoz Escalonza, Z. Cassier [3], have studied the influence of the critical cutting speeds on the surface finish of turned steel. Variables such as feed rate and the tool’s nose radius and cutting speed can provide a control on the quality and the surface finish in a given machining process.

Hamid, Aquici et.al. [4], experimentally studied the treated AISI H11 steel when machined with cubic boron nitride which is essentially made of TiCN. Results showed that the cutting force components were influenced principally by the depth of the cut and workpiece hardness, on the other hand both feed rate and workpiece hardness have statistical significance on surface roughness.

Sahoo et. al. [5], studied for optimization of machining parameters combinations emphasizing on fractal characteristics of surface profile generated in CNC turning operation. The authors used L27 Taguchi orthogonal array design with machining parameters: speed, feed and depth of...
cut on three different work piece materials namely Aluminium, Mild Steel and Brass.

W.H. Yang, Y.S. Tarng [6], studied for the design optimization for quality is used to find the optimal cutting parameters for turning operations. An orthogonal array, the signal to noise ratio and analysis of variance are employed to investigate the cutting characteristics of S45C steel bar using tungsten carbide tools.

S.Lo Casto et al. [7], had studied wear rates and wear mechanisms of alumina-based tools cutting steel at a low cutting speed. Three ceramic insert materials, Zirconia-toughened alumina (Al2O3-7vol%ZrO2), mixed-based alumina (Al2O3-TiN-TiC-ZrO2) and alumina reinforced with SiC Whiskers (Al2O3-SiCw) were used to cut AISI 1040 steel at 3.9m/s. In addition, a traditional grade P10 insert (WC-TiC-Co) was rested. The worn zone was observed with scanning electron microscopy techniques.

G.Brandt et al. [8], had studied crater wear of alumina-based ceramic cutting tools when machining steel is predominantly dependent upon superficial plastic deformation. Such tool surface deformation may be greatly affected by chemical reactions with workpiece material. It has found that the deformed surface layer had increased concentrations of iron and magnesium. Both these elements were probably present as spinal phases FeO.Al203 and MgO. nAl203 in solid solution.

III. EXPERIMENTAL DETAILS

Experimental evaluation was carried out by using uncoated and coated ceramic cutting tool inserts, to perform turning operations on hard steel material EN-353 of hardness 60 HRC at different cutting conditions for evaluating the machining characteristics. The following process parameters were selected for the present work Cutting speed - (A), feed rate – (B), Depth of cut (C). The EN-353 steel rods of 60 mm diameter and length of 300 mm was machined on HMT A28-2847 lathe using uncoated ceramic cutting tool inserts having the designation of TNGA332T0420.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Level 1 (A)</th>
<th>Level 2 (B)</th>
<th>Level 3 (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed</td>
<td>171.94</td>
<td>131.94</td>
<td>101.73</td>
</tr>
<tr>
<td>Feed Rate</td>
<td>0.187</td>
<td>0.148</td>
<td>0.125</td>
</tr>
<tr>
<td>Depth Of Cut</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 1: Machining Parameters And Their Levels

The workpiece is machined as per the process parameters listed in the Table I using L9 orthogonal array. The feed force (Fy), tangential force (Fx) and surface roughness (Ry) were measured for each trial using lathe tool dynamometer. For each trial the new insert is used in order to have the uniformity of cutting conditions. The results for the experiments for 9 trials were reported in Table II for uncoated ceramic cutting tool insert.

The ANOVA results for feed force is tabulated in Table III and its Signal–to–Noise (S/N) ratio is tabulated in Table IV for uncoated ceramic cutting tool inserts. The ANOVA results for tangential force is tabulated in Table V and its Signal – to – Noise (S/N) ratio is tabulated in Table VI for uncoated ceramic cutting tool inserts. The Signal–to–Noise ratio for feed force, tangential force, and surface roughness are calculated using Lower the Better (LB) characteristics is,

\[
S/N_{LB} = -10 \log (\sum_{i=1}^{n} y_i^2)
\]

The ANOVA results for surface roughness is tabulated in Table VII and its Signal – to – Noise (S/N) ratio is tabulated in Table VIII for uncoated ceramic cutting tool inserts.

IV. FORCE MEASUREMENT AND CALCULATIONS FOR UNCOATED INSERT

![Table 2: Recorded Value of Forces for a Trial Test](image)

![Table 3: Anova Results For Feed Force (Fy)](image)

![Table 4: Anova Results For Feed Force S/N Ratio (Fy)](image)

![Table 5: Anova Results For Tangential Force (Fx)](image)

![Table 6: Anova Results For Tangential Force Sn Ratio (Fx)](image)

![Table 7: Anova Results For Surface Roughness(Ry)](image)

<table>
<thead>
<tr>
<th>Factor</th>
<th>DoF</th>
<th>Ss</th>
<th>Mss =</th>
<th>Fcal =</th>
<th>P = (Ss/DoF) * Mss/Mss</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>67.16</td>
<td>3.18</td>
<td>1.2</td>
<td>19.68</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>16.28</td>
<td>8.49</td>
<td>2.89</td>
<td>46.67</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>6.36</td>
<td>3.18</td>
<td>1.08</td>
<td>17.48</td>
</tr>
<tr>
<td>Error</td>
<td>2</td>
<td>0.081</td>
<td>0.040</td>
<td>0.040</td>
<td>15.57</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>36.38</td>
<td></td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Table 8: Anova Results For Surface Roughness Sn Ratio ($R_s$)

V. RESULT AND DISCUSSION

Table III indicates that for feed force, the depth of cut has a significant contribution (89.96%) when compared to cutting speed (5.63%) and feed rate (1.98%). The S/N ratio also exhibits similar trend and these are tabulated in table IV.

Table V indicates that for tangential force, the depth of cut has a significant contribution (98.04%) when compared to cutting speed (1.55%) and feed rate (0.39%). The S/N ratio also exhibits similar trend and these are tabulated in table VI.

Table VII indicates that for surface roughness, the feed rate has a significant contribution (42.31%) when compared to cutting speed (32.7%) and depth of cut (9.42%). The S/N ratio also exhibits similar trend and these are tabulated in table VIII.

VI. CONCLUSION

- The depth of cut has a significant percent contribution for both feed force and tangential force using uncoated ceramic cutting tool inserts.
- The feed rate has a significant contribution for the surface roughness using uncoated ceramic cutting tool inserts.
- During the experimental investigation, it is observed from the table of ANOVA that the feed rate is the most influential control factor among three turning process parameters for minimization of tangential force and surface roughness when simultaneously considered.

REFERENCES