PERFORMANCE EVALUATION OF TiN COATED AND UNCOATED CARBIDE TOOLS IN TURNING AISI 4140 STEEL

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Abstract

Tool wear is one of the most important aspects in metal cutting, especially when machining hardened steels. The present work shows the results of tool wear and surface finish obtained from the turning operation on hardened AISI 4140 using TiN coated and uncoated edges. Machining tests were performed under dry cutting conditions by varying cutting speeds and feeds. The effect of cutting speed and feed rate on tool wear (tool life) and surface roughness of the TiN coated carbide inserts was experimented. For coated tools the tool life obtained was relatively higher values. For comparison, uncoated tool was also tested under the similar cutting conditions. The surface roughness of the work pieces were found out using Taylor Hobson Surface Roughness Tester. Turning with coated tool is more economical than the uncoated in terms of energy and power requirements. Results show that the tool life is influenced principally by the depth of cut and on the other hand, both feed rate and workpiece hardness have statistical significance on surface roughness. Stresses occurring on nose of the coated as well as uncoated inserts were checked using ANSYS analysis.

Keywords: Speed, Feed, Depth of Cut, Surface Roughness

1 Introduction

Surfaces of cemented carbide cutting tools need to be abrasion resistant, hard and chemically inert to prevent the tool and the work material from interacting chemically with each other during machining. Cutting tools with regards to tool life travel path, the required power for machining, and the surface quality of the generated workpieces improves remarkably using coated cemented carbide cutting tools [1-2]. Layers of titanium carbide (TiC), titanium nitride (TiN), titanium carbonitride (TiCN), titanium aluminum nitride (TiAlN), and aluminum oxide (Al2O3) are most commonly used when machining metals [3-4]. The cutting speed significantly affects the machined surface roughness values. With increasing cutting speed, the surface roughness values decreased [5]. Higher values of feed rates are necessary to minimize the specific cutting force. The machining power and cutting tool wear increases almost linearly with increase in cutting speed and feed rate.

The combination of low feed rate and high cutting speed is necessary for minimizing the surface roughness [6]. The approach angle has little effect on the cutting force, and increasing the speed causes the cutting force to decrease slightly. The feed force increased with increasing depth of cut and decreased with increasing approach angle, speed, and feed rate [7]. Samir K. Khrais [8] did a detailed study on the tribological influences of TiAlN coatings on the wear of cemented carbide inserts. The cutting speed significantly affects the machined surface roughness values. Low cutting speed and low feed produces the longest tool life. [9] Turning of AISI 4340 steel using low feed rates and depths of cut, the forces were higher when machining the softer steel and that surface roughness of the machined part was improved as cutting speed was elevated and deteriorated with feed rate.

In this paper, the experimental results of an investigation on the effect of cutting speed and feed rate on tool wear and surface roughness to optimize the machining conditions for turning applications using the TiN coated carbide inserts are presented. In addition, a comparison is made between TiN coated carbide inserts and uncoated carbide inserts in terms of tool wear and surface roughness for the same machining conditions. Further, stresses occurring on tip of the coated as well as uncoated inserts were checked using ANSYS analysis.

2 Experimental details

The following experimentation was performed to check the effect of speed, feed and depth of cut over the tool life and surface roughness.
2.1. Workpiece material

The workpiece material used in this study was thoroughly hardened AISI 4140 steel (~50 HRC), which typically has a chemical composition of 0.4% carbon, 1.85% nickel, 0.8% chromium, 0.25% molybdenum, 0.68% manganese, and 0.25% silicon. The solid bars have a diameter of 60 mm and a length of 200 mm.

2.2. Cutting inserts

The inserts used were DNMG 432 (55° diamond with chipbreaker) coated carbide inserts and DNMG 431 uncoated carbide inserts. DNMG 432 is coated with TiN coating. The inserts were rigidly mounted on a tool holder with an ISO designation of MDJNR20-4D.

2.3. Experimental techniques

Cutting tests were carried out on a Type R5 Gottwaldov Precision Capstan lathe under dry conditions. The photographic view of the machine is shown in Plate 1.

3 Results and discussion

Based on the experimentation, the result of turning has been presented as follows

3.1 Surface Roughness Measurement

Surface roughness is one of the important indicators of the surface integrity of machined parts. Surface finish in turning has been found to be influenced by a number of factors such as cutting speed, feed rate and depth of cut. The surface roughness values observed for TiN coated inserts and uncoated carbide inserts at different feed rates and speeds are shown in Tables 1 and 2 respectively.

Table 1 Experimental data for Surface Roughness

<table>
<thead>
<tr>
<th>Cutting Speed V (m/min)</th>
<th>Feed F (mm/rev)</th>
<th>DOC= 0.2 mm</th>
<th>DOC= 0.5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SR (µm)</td>
<td>SR (µm)</td>
</tr>
<tr>
<td>100</td>
<td>0.1</td>
<td>1.1</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td>1.74</td>
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</tr>
<tr>
<td></td>
<td>0.2</td>
<td>1.87</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>1.98</td>
<td>2.12</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>2.46</td>
<td>2.58</td>
</tr>
<tr>
<td>130</td>
<td>0.1</td>
<td>0.97</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td>1.68</td>
<td>1.77</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>1.72</td>
<td>1.83</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>1.91</td>
<td>1.98</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>2.37</td>
<td>2.57</td>
</tr>
</tbody>
</table>

From the Table 6.1.2 it can be shown that, for cutting speed V= 100 m/min, depth of cut (d) = 0.5 mm and feed (f) = 0.3 mm/rev, the surface roughness comes out to be 2.58 µm. But as the cutting speed increases to 130 m/min then for depth of cut (d) = 0.5 mm and feed (f) = 0.3 mm/rev the surface roughness is 2.57 µm. Now, Results of surface roughness tests for Titanium Nitride coated inserts are presented in terms of graphs as shown below.
The Figure 1 indicates that as the cutting speed increases, the surface roughness decreases. Similarly results of Surface Roughness for depth of cut 1 mm are calculated. As machining time increases, tool sharpness deteriorates and leads to a degraded surface roughness.

Now, Table 2 shows the surface roughness values for the uncoated inserts. It is seen that the surface roughness for uncoated carbide tool is decreased with the increase in cutting speed.

**Table 2 Experimental data for Surface Roughness**

<table>
<thead>
<tr>
<th>Cutting Speed V (m/min)</th>
<th>Feed F (mm/rev)</th>
<th>DOC= 0.2 mm</th>
<th>DOC= 0.5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SR (µm)</td>
<td>SR (µm)</td>
</tr>
<tr>
<td>100</td>
<td>0.1</td>
<td>2.42</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td>2.61</td>
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<td>0.3</td>
<td>2.96</td>
<td>2.98</td>
</tr>
<tr>
<td>130</td>
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<td>2.39</td>
<td>2.48</td>
</tr>
<tr>
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<td>2.52</td>
<td>2.57</td>
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<td>2.69</td>
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<tr>
<td></td>
<td>0.3</td>
<td>2.83</td>
<td>2.82</td>
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</table>

Results of surface roughness tests for Uncoated inserts are presented in Table 2 and also in terms of graphs. The Surface Roughness values of uncoated inserts are much higher than the coated inserts. From the Table 2 it can be shown that, for cutting speed V= 100 m/min, depth of cut (d) = 0.5 mm and feed (f) = 0.3 mm/rev, the surface roughness comes out to be 2.98 µm. But as the cutting speed increases to 130 m/min then for depth of cut (d) = 0.5 mm and feed (f) = 0.3 mm/rev the surface roughness is 2.82 µm. Now, Fig 2 shows the graph of surface roughness values for the uncoated inserts.

The Fig 2 shows the graphical representation of cutting speed, feed rate and depth of cut v/s surface roughness at cutting speeds of 100 and 130 m/min with feed rates of 0.1, 0.15, 0.2, 0.25 and 0.3 mm/rev and depth of cut of 0.2 and 0.5 mm. Fig 2 indicates that as the cutting speed increases, the surface roughness decreases. Similarly results of Surface Roughness for depth of cut 1 mm are calculated.

**3.2 Tool Wear measurement**

The mechanisms involved in the wear of cutting tools, especially in hard machining, are rather complicated and may include different interacting effects linked together in a complex manner. Tool wear depends on the tool, work piece material (physical, mechanical and chemical properties), tool geometry, cutting parameters, cutting fluid, etc. The cutting speed is kept constant and tool life for various feeds is found by varying the depth of cuts. Table 3 indicate the values of tool life variations of TiN coated inserts for different depth of cuts.
From the table it is clear that as the depth of cut increases, the tool life goes on decreasing. The TiN coated inserts exhibited a maximum tool life of 56 minutes at cutting speed V= 100 m/min, depth of cut (d) = 0.2 mm and feed (f) = 0.1 mm/rev. The Figure 3 shows the graphical representation of Flank wear v/s Cutting time at cutting speeds of 100 m/min and at different depth of cuts.

Now, the tool wear values of the uncoated carbide tools for cutting speed V=100m/min are plotted in Table 4. The same tests were done on uncoated tip inserts as on coated carbide inserts. The uncoated inserts exhibited a maximum tool life of 35 minutes at cutting speed V= 100 m/min, depth of cut (d) = 0.2 mm and feed (f) = 0.1 mm/rev. When the depth of cut is gradually increased to 1mm, the tool life is reduced to just 25 minutes.

<table>
<thead>
<tr>
<th>Sr no.</th>
<th>Cutting Speed (V)</th>
<th>Depth of cut (d)</th>
<th>Feed (f)</th>
<th>Tool Life (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>0.2</td>
<td>0.1</td>
<td>56</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>0.2</td>
<td>0.15</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>0.2</td>
<td>0.2</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>0.2</td>
<td>0.25</td>
<td>33</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>0.2</td>
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<tr>
<td>6</td>
<td>100</td>
<td>0.5</td>
<td>0.1</td>
<td>54</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>0.5</td>
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<td>45</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>0.5</td>
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<td>30</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>0.5</td>
<td>0.25</td>
<td>28</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>0.5</td>
<td>0.3</td>
<td>24</td>
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<td>11</td>
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<td>12</td>
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<td>100</td>
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<td>15</td>
<td>100</td>
<td>1</td>
<td>0.3</td>
<td>16</td>
</tr>
</tbody>
</table>

Fig 3 Flank wear v/s Cutting time (Tool life for TiN coated tool, V= 100 m/min)
Fig 4 Flank wear vs Cutting time (Tool life for Uncoated tool, V= 100 m/min)

Similar graphs and tables are plotted for tool life of uncoated carbide insert when the cutting speed $V=130$ m/min. The uncoated inserts exhibited a maximum tool life of 28 minutes at cutting speed $V=130$ m/min, depth of cut $(d) = 0.2$ mm and feed $(f) = 0.1$ mm/rev.

3.3 Comparison of stresses using ANSYS

An insert of specification, length of cutting edge to be 12 mm, thickness of the insert to be 4 mm and the nose radius to be 8 mm is taken. The main objective is to analyze the stresses occurring in both coated and uncoated tool during cutting operation using ANSYS 14.0 Software. First the insert of $12\times12\times04$ mm$^3$ volume is made with value of Poisson’s ratio= 0.3, Density $(\rho)= 15630$ kgm$^{-3}$, Young’s Modulus = $5\times10^5$ MPa, then meshing of insert is done and the area where the contact between work piece and tool is going to take place is made much denser to obtain better view of stress profile. In this case hexahedral meshing is done along the volume.

The following Structural analysis parameters are used

1. Insert specifications: 12 mm length, 4 mm thickness, 0.8 mm nose radius
2. Type of element: Solid 186
3. Type of mesh: 2nd order Hex mesh
4. Boundary condition: Insert fixed at the base.
5. Cutting forces:
   i) For Uncoated Insert $Fx=1062$ N, $Fy=1200$ N, $Fz=1127$ N
   ii) For Coated Insert $Fx=745$ N, $Fy=887$ N, $Fz=804$ N.

Now, Figure 5 shows the stress occurring over the nose of TiN coated insert.

Fig 5 Stress distribution on Coated inserts

The maximum stress over the nose of Coated carbide insert is $\tau$ (tau) = 237.635 N/mm$^2$ which is approximately equal to the theoretically calculated stress $\tau$ (tau) = 224.51 N/mm$^2$.

Similarly, Figure 6 shows the stress occurring over the nose of uncoated insert.

Fig 6 Stress distribution on Uncoated inserts

From the above analysis, the maximum stress over the nose of Uncoated carbide insert is $\tau$ (tau) = 342.408 N/mm$^2$ which is approximately equal to the theoretically calculated stress $\tau$ (tau) = 329.57 N/mm$^2$.

The above comparison shows that the stress over the coated inserts is less than the uncoated inserts due to the coating. Chip slides more efficiently over coated inserts. As a result the forces over coated inserts are less than the uncoated inserts which results
in less amount of stress over coated inserts than uncoated inserts.

4 Conclusion

Based on the experimental results presented and discussed, the following conclusions are drawn on the effect of cutting speed and feed on the performance of TiN coated and uncoated carbide tools when turning AISI 4140 steel.

- The forces over coated inserts are less than the uncoated inserts which results in less amount of stress over coated inserts than uncoated inserts.
- Coated carbide tools perform better than uncoated carbide tools as far as tool life is concerned. Tool life obtained with coated carbide tool was higher than those obtained with uncoated carbide tools under experimental conditions.
- This study concluded that the TiN coated carbide tool produce better surface roughness with respect to high speed and low feed rate. But the depth of cut has minimum effect on surface roughness. The combination of low feed rate and high cutting speed is necessary for minimizing the surface roughness.
- Coated carbide tools are superior to uncoated carbide tools and its flank wear grows smoothly than uncoated carbide tools.
- Results show that, the machining of hard materials at higher speed is improved by using coated tools. From the experimental investigation it is observed that coated tools give better results as compared to uncoated tools in turning.
- The stresses occurring over the coated inserts is much less than the uncoated inserts due to the coating.
- The feed rate has highest influence on surface roughness, cutting speed and followed by depth of cut. The surface finish was improved as cutting speed was increased and deteriorated with feed rate. The optimum parameter setting for better surface finish is obtained at a higher cutting speed with low feed rate.

References