TURNING OF HARDENED STEEL WITH CERAMIC TOOL

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1. INTRODUCTION

In our days the machining of steel parts in hard state has great significance. The primary goal is to substitute the grinding technology with turning, milling or drilling.

Turning operations are called hard turning, which are performed
- in order to required shape and surface roughness,
- to substitute grinding operation,
- on at least 45 HRc hard steel part,
- with hard metal, ceramic or polycrystal cubic boron nitride (PCBN) tools,
- in CNC lathe machines or a rigide conventional lathes.

The Table 1 shows the advantages and disadvantages of hard turning.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Short operation time</td>
<td>Heavy tool wear</td>
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<tr>
<td>Less investment cost</td>
<td>Cutting edge is reactive to break</td>
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<tr>
<td>Free grinding capacities</td>
<td>Rigid machine tool with high spindle speed</td>
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<tr>
<td>High accuracy in case of accurate blank</td>
<td>Up-to-date CNC control is needed (tool break control)</td>
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<td>The heat of cutting is removed by chips</td>
<td>Tool holders for high speed machining is required</td>
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<tr>
<td>2-4 times higher material removal speed</td>
<td>Application of up-to-date tool materials and coats</td>
</tr>
<tr>
<td>Good surface roughness</td>
<td>Inhomogeneous part material is unfavourable</td>
</tr>
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<td>More operation elements are performed in one setup</td>
<td>In case of grinding the sparking process can increase accuracy and decrease surface roughness</td>
</tr>
<tr>
<td>Appropriate for dry machining</td>
<td>In certain cases, better surface roughness is produced by grinding</td>
</tr>
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</table>
2. THE AIM OF THE STUDY AND TEST ENVIRONMENT

The aims of the tests were the following:
- all-round test of ceramic inserts with different edge geometry to study cutting capability by on-line cutting force measurement,
- all-round study of condition of inserts’ wear process: modelling of tool wear, tool life study by wear intensity, instrumental study and assessment of degradation of cutting capability,
- study of economic and quality attributes of hard turning [2].

The testing environment

The tests are performed in SU 50/1500 engine lathe, which has stepless speed variation. The machine tool has average technical condition and rigidity. The parts were turned in chuck, supported by centre. The material of the parts was C60 (~1.1221 – 1.1223, C% 0,6), an unalloyed, hardenable steel. The choice was this steel, because
- it is a standard steel in cutting research (ISO TC29),
- we have a certificate about the chemical characteristics,
- the hardened layer contains enough martensite for high hardness.

The hardness was measured after every removable layer, and the test was continued till the hardness was greater than 58 HRc.

The applied tools and equipments

During the test we used the following tools, which were insured by Hungarian SANDVIK distributor.

- CNGA120408T01020 shape code, ISO geometric, 650 material code, and
- CNGA120408S01525WH shape code, WIPER geometric, 6050 material code insert.

The following test equipments were used:
- KISTLER 5019 type 3 component force measurement system with DynoWare measurement software;
- Mobile surface roughness measure instrument;
- Pertheometer C3A type surface assessment system;
- PERTHEN-MAHR MarSurf PS1 type instrument;
- HI-TEC stereo microscope with digital camera;
- Wilson-Wolpert dyna TESTER®10 hardness measure instrument;
- Digital camera for video documentation.

3. TEST SETTINGS

Instead of use of several test setting we used the INFOS method for test plan. The “3v+c+3f+2a” named test method was introduced for determine the 3 component tool life model instead of the ISO TC29 recommendation. The used method has several advantages:
- The results are able to be presented in graphical way in case of constant speed and constant feed;
- In case of the appropriate selection of test environment, the test needs only six setups;
- Statement of the preliminary supposed model can cause a significant shortening of time period expended cutting tests without so much as model reliability get worst.

The field of applicable cutting parameters were available from previous preliminary tests and distributor’s catalogues.

The planned and performed research plan is shown in Table 2 and Table 3 [2].

<table>
<thead>
<tr>
<th>Test settings for ISO geometry</th>
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<tbody>
<tr>
<td>$V_c \times f \times a_p$</td>
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<tr>
<td>$100 \pm 0.05 \pm 0.2$</td>
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<tr>
<td>$125 \pm 0.08 \pm 0.2$</td>
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<thead>
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<th>Test settings for wiper geometry</th>
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<td>$V_c \times f \times a_p$</td>
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<td>$100 \pm 0.15 \pm 0.2$</td>
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The 650 material grade insert had conventional, ISO edge geometry, but the 6050 material grade insert had wiper edge geometry, so we applied different parameters, the wiper geometry was tested at higher feed.

4. RESULTS OF THE TESTS

**CC650 material, ISO geometric insert at fixed feed rate and depth of cut**

The effect of the cutting speed was studied in three settings. Two cutting parameters were fixed: the feed rate was set to the middle of the suggested field ($f=0.08$ mm), and the depth of cut was $a_p = 0.2$ mm.

The Figure 1 shows the results of first series of tool life study based on INFOS research plan. The view of points’ series there is not a line in the log-log coordinate system, as we can see in the figure, the curve can characterise a quadratic polynom (so called technical parabola).
The Kundrak’s tool life model, which is more sophisticated model, describes the tool life curve as a cubic polynomial [1]:

\[ T = \frac{C_T}{v_c^3 + C_T^2 \cdot v_c^2 + C_T^3 \cdot v_c} \text{ [min]} \]

There is not enough \( v_c - T \) point pair to determine the parameters of the model supplied, so we could not prove the conformance of this model.

The tool life data, which was measured at various cutting speed, were assessed based on \( T = A \cdot v_c^2 + B \cdot v_c + C \) [min] model, so the tool life of tested insert is determined in the searched field without long and expensive testing process. As apparent the deviation of measured and calculated data are low and the correlation of processed data is very high (up to 0.9) using our regression model. The developed computer software calculate the A, B and C values of the model, which ensure the application of our model: we can calculate the tool life in case of optional cutting speed or cutting speed can be determined from a given tool life data.

**CC6050WH, wiper edge insert at fixed feed rate and depth of cut**

During this test the feed rate was \( f=0.15 \text{ mm} \), and the depth of cut was \( a_p=0.2 \text{ mm} \). We observed, that in contempt of raised feed rate, the wiper edge insert had 30 minutes tool life, when the cutting speed was \( v_c=100 \text{ m/min} \), and we observed 20 minutes tool life in case of \( v_c=125 \text{ m/min} \) cutting speed.
Figure 2. Flank surface of the wiper insert in the initial state and at the wear criteria

For the sake of size limit of the article we can not discuss further detail results of other setups, the measured cutting forces and surface roughness data are summarized in the next chapter.

5. SUMMARY

During the test the CC650 inserts had 13…25 minutes tool life, and the CC6050WH inserts had 16…29 minutes tool life. These values are become in normal tool wear process, there was not any unexpected edge break or other trouble.

The wiper inserts are been worth underlining, because we used higher feed rate than the other case. The Figure 3 shows the tool life curves, and the lower wear speed and the higher tool life (2…4 minutes surplus) are observable. Based on tool life study we suggest the optimal cutting parameters for industrial practice, which are shown in the Table 4.

Table 4

<table>
<thead>
<tr>
<th>CC650 (ISO)</th>
<th>CC6050WH (wiper)</th>
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<tbody>
<tr>
<td>( v_c=125 \text{ m/min} ; f = 0,12 \text{ mm} ; a_p = 0,16 \text{ mm} )</td>
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The results of modelling of cutting forces and surface roughness are the next:

- the measured force components are modelled by the next model in case of CC650 insert, on the planned test parameter setups:
  \[ F_c = 5686 \cdot f^{0.88} \cdot a^{0.76} \cdot v_c^{-0.05} \text{ [N]} \]
  deviation: ± 1 N; correlation: 0.9992
  \[ F_p = 41613 \cdot f^{0.94} \cdot a^{0.73} \cdot v_c^{-0.57} \text{ [N]} \]
  deviation: ± 2 N; correlation: 0.9973
- the two parameters of surface roughness are charact erised the next regression formulas in case of CC650 inserts:
  \[ R_a = 191 \cdot f^{0.58} \cdot a^{0.76} \cdot v_c^{-0.58} \text{ [\(\mu m\)]} \]
  deviation: ± 0.08 \(\mu m\); correlation: 0.89
  \[ R_z = 71 \cdot f^{0.48} \cdot a^{0.62} \cdot v_c^{-0.08} \text{ [\(\mu m\)]} \]
  deviation: ± 0.4 \(\mu m\); correlation: 0.88
- During the wear process the cutting force components increased.
- The wear out of ceramic insert has not an effect the surface roughness, because the mechanical effect of radial force component decreases the negative process.

![Figure 4. Radial force component and Rz in function of flank wear](image)

(CC650 ISO \(v_c = 125 \text{ m/min}; f = 0.12 \text{ mm}; a_p = 0.16 \text{ mm}\))

As conclusion we can say, than the cutting capacity of the 6050WH wiper edged insert surpasses the CC650 insert, because the tool life is higher and the turned surface roughness is better in case of increased feed rate. This result is close to our previous research on turning of non-hardened steel [3].

REFERENCES