Abstract. Paper presents comparison of cutting performance of several cemented carbide and CBN tools in finish turning \((a_p=0.2\text{mm} \text{ and } f=0.08\text{mm/rev})\) of Inconel 718. The evaluation of the tools was based on two criteria: cutting forces and tool life. Main cutting force \(F_c\) decides on cutting power, thus on heat generation, which is important for surface integrity. Especially important is the passive force \(F_p\) directed against the machined surface, strongly influencing the surface integrity distortion like residual stress. The second criterion of the cutting ability evaluation was the tool life, and cutting speed, as they influence productivity. Tool life criterion was visible worsening of machined surface. Results showed that cutting forces not always are higher using CBN tools than using carbide tools. On the other hand, tool life of the best carbide tools appeared to be comparable with some of CBN tools.

Key words: Inconel 718, finish turning, cutting ability

1 INTRODUCTION

Nikel-based superalloys are widely used in aircraft industry as they are exceptionally thermal resistant retaining mechanical properties up to 700°C [Balazinski et al., 1995]. On the other hand, they are very difficult to machine, due to their high shear strength, work hardening tendency, highly abrasive carbide particles, tendency to weld and form build-up edge and low thermal conductivity [Choudhury, et al., 1998]. Conventionally they are machined using coated carbide tools, with the cutting speed in the order of 50 m/min [Dudzinski et al., 2004, Jindal et al., 1999]. Recently more and more often ceramic and CBN tools are used for machining of nickel-based superalloys [Choudhury, et al., 1998]. The choice between the tools offered by different producers, insisting, that their products are the best, and competitors are far behind, is not easy, and necessitates appropriate comparative tests, which is costly and time consuming, thus not carried out very often in factory floor.

The project described in this paper aimed at selection of the best tools for finish turning of Inconel 718 in WSK "PZL-RZESZOW" in Poland. Four leading tools producers were invited to the project and recommended their best solutions of the problem. The producers suggested several tools for the task, and after preliminary analysis the potentially best out of each producer proposal were selected. The producers also suggested initial cutting parameters for their tools. To make the comparison possible, uncut chip cross section was constant in all tests: \(a_p=0.2\text{ mm}, f=0.08\text{ mm/rev}\). General purpose emulsion was used as coolant in this tests.
The evaluation criteria were: tool life, productivity and cutting forces, especially $F_p$ which is perpendicular to the machined surface, thus strongly influences possible surface integrity distortions like residual stress. Tools selected for finish turning Inconel 718 are presented in Table I. The first four were PVD TiAlN coated carbide tools, the fifth one was MT-CVD TiCN-Al$_2$O$_3$-TiN coated, and the last three were CBN tools.

Table I Tools selected for turning of rigid parts

<table>
<thead>
<tr>
<th>No</th>
<th>Toolholder, insert, tool material</th>
<th>photo</th>
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<th>Toolholder, insert, tool material</th>
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<td>1</td>
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<td>CTJNR, TNGN 110212e25 CBN</td>
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<td>MCLNR, CNMA 120408T CBN</td>
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<td>4</td>
<td>SCLCL, CCMT 120404-MM CC PVD TiAlN</td>
<td></td>
<td>8</td>
<td>NVLCR, VCGN160408 CBN</td>
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</tbody>
</table>

2 EXPERIMENTAL PROCEDURE

Workpieces were Inconel 718 bars of diameter 100 mm. The cutting force sensor Kistler 9263 was used for cutting force measurements. In each test cutting force signals were registered during 15 seconds with sampling frequency $f_s=10$kHz. In those signals central, stable parts were selected for average cutting force values calculation. During cutting force measurements cutting speed $v_c=50$ m/min for carbide tools and $v_c=200$ m/min for CBN tools were used.

Tool life tests were performed basically up to 7 min of cutting time or to eminent worsening of surface finish. Cutting speed selection was based on producers’ recommendations. Length of single pass corresponded with 20÷40 mm on 100mm diameter workpiece. In order to avoid negative influence of entering of tool into material, workpiece edge was phased with angle 45°, and tool was always withdrawn under 45° (see Figure 1). Tool wear was measured using toolmakers microscope.
3 RESULTS OF EXPERIMENTS

3.1. Cutting forces
Figure 2 presents average cutting force values obtained during finish turning tests. The forces obtained while machining with carbides were close for each tool with the exception of Tool 5, which is the worst here – the passive force $F_p$ is more than three times higher than the smallest one. Out of four other tools the best result was achieved using Tool 3 – the smallest passive force $F_p$ while the cutting force $F_c$ was the second best.

Figure 2; Average cutting forces values in finish turning, $a_p=0.2$ mm, $f=0.08$ mm/rev.
Generally cutting force values obtained using CBN tools were higher than those obtained using carbide tools, which is understandable having in memory special preparation of cutting edge of such tools. Surprisingly good result was achieved by Tool 8 – in the same range force values as obtained with carbide tools, thus this tool is leading in high speed group. It is due to very small honed cutting edge radius $r_n=0.025\text{mm}$, while the Tool 6 has phase $0.14\text{mm}/20^\circ$. Relatively good result was achieved by tool 7.

3.1. Tool life
Cutting speeds for tool life tests were selected for each tool individually. Because of small depth of cut, dominant form of the tool wear was a flank wear at the rounded cutting edge Tool life criterion was visible worsening of machined surface. This deterioration of the surface finish emerged with different values of the tool wear, which is understandable taking into consideration different tool materials and tool geometries. Therefore critical value of the width of flank wear land at the rounded cutting edge $V_{BC}$ for tool life determination was selected for each tool individually.

Tool 1
The first test with this tool was executed with $v_c=100\text{m/min}$ which supposed to be quite high for a cemented carbide tool. This cutting speed however appeared to be too low as the tool wear proceeded very slowly. Therefore test was aborted after $t=6\text{min}$ of cutting. Test with $v_c=200\text{m/min}$ was terminated after $t=5.97\text{min}$, because of high tool wear and deterioration of the machined surface. Test conducted with $v_c=150\text{m/min}$ was terminated after $t=8.17\text{min}$ without any negative effects on the surface. Tool life criterion for this tool was $V_{BC}=0.30\text{mm}$. Optically it seemed that the higher the speed, the better surface finish. The results of these test are presented in Figure 3.

![Figure 3; Tool life test results for tool 1, $v_c=100, 150$ and $200\text{ m/min}$.]
**Tool 2**

Both tests performed with this tool with cutting speed $v_c=200\text{m/min}$ and $150\text{ m/min}$ were finished because of deterioration of the machined surface. Tool life criterion for this tool, ensuring good surface finish, was $VB_C=0.20\text{mm}$. The results of these test are presented in Figure 4.

![Figure 4](image)

*Figure 4: Tool life test results for tool 2, $v_c=150$ and 200 m/min.*

**Tool 3**

While using tool 3 the machined surface deterioration emerged very early, meaning for quite small wear value. Therefore tool life criterion for this tool was $VB_C=0.15\text{mm}$. Test carried out with cutting speed $v_c=250\text{m/min}$ ended with catastrophic tool failure. The results of these test are presented Figure 5.

![Figure 5](image)

*Figure 5: Tool life test results for tool 3, $v_c=150$ and 250 m/min.*
**Tool 4**

Both tests carried out with tool 4 with cutting speed $v_c=100\text{ m/min}$ and 150 m/min were finished because of deterioration of the machined surface. Tool life criterion for this tool was $V_B=0.30\text{ mm}$. The results of these test are presented in Figure 6.

![Figure 6; Tool life test results for tool 4, $v_c=100$ and 150 m/min.](image)

**Tool 5**

All three tests performed using tool 5 with cutting speed $v_c=100$, 120 and 150 m/min were finished because of deterioration of the machined surface. Tool life criterion for this tool was $V_B=0.30\text{ mm}$. The results of these test are presented in Figure 7.

![Figure 7; Tool life test results for tool 5, $v_c=100$, 120 and 150 m/min.](image)
**Tool 6**
Both tests performed with tool 6 with cutting speed $v_c=150 \text{m/min}$ and $200 \text{m/min}$ were finished because high value of the tool wear $V_B=0.40 \text{mm}$. Despite this high tool wear, assumed as tool life criterion here, no deterioration of the machined surface was noticed. The results of these test are presented in Figure 8.

![Figure 8](image)

Figure 8: Tool life test results for tool 6, $v_c=100$ and $150 \text{m/min}$.

**Tool 7**
All three tests performed with tool 7 with cutting speed $v_c=200$, $250$ and $300 \text{m/min}$ were finished because high value of the tool wear $V_B=0.40 \text{mm}$. Despite this high tool wear assumed as tool life criterion here, no deterioration of the machined surface was noticed. The results of these test are presented in Figure 9.

![Figure 9](image)

Figure 9: Tool life test results for tool 7, $v_c=200$, $250$ and $300 \text{m/min}$.
**Tool 8**

All three tests performed with tool 8 with cutting speed $v_c=200$, 250 and 300 m/min were finished because high value of the tool wear $V_B=0.40\text{mm}$. Also in this case, no deterioration of the machined surface was noticed. The results of these tests are presented in Figure 10.

![Figure 10: Tool life test results for tool 8, $v_c=200$, 250 and 300 m/min.](image)

**Summary of tool life test**

All tool life values obtained in tests described above are presented in Figure 11 as Taylor $T-v_c$ relationships. The results show that the most wear resistant appeared to be CBN tool 8, and only little shorter tool lives were achieved by another CBN insert – tool 7. Very good wear resistance of CBN tools is not surprising of course. Out of all carbide tools markedly best results were accomplished by tool 1, comparable with those achieved by CBN tool 6! Tools 2, 3, 4 and 5 achieved similar results, keeping in mind small accuracy of $T-v_c$ relation evaluation based on 2-3 tests.

4 CONCLUSIONS

Selection of cutting tools and cutting parameters for turning of Inconel 718 was based on two criteria:

- tool life and cutting speed, as they influence productivity
- cutting forces, as they influence surface integrity distortion

The first criterion always important, however it must give way to the second for finishing. Results of all experiments were summarized in Table II, altogether with tool evaluation based on above criteria, marked as:
+++ the best
++ good
+ acceptable
– not acceptable

Figure 11: Taylor relationships obtained in finish turning of Inconel 718.

Table II Finish turning

<table>
<thead>
<tr>
<th>Tool material</th>
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<tr>
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<td>+++</td>
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<tr>
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<td>2</td>
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</table>
Taking into consideration assumed criteria of evaluation, the best results were achieved by tool 8. Not only this CBN tool has superior wear resistance – the highest tool life-cutting speed relationship, but also causes very low cutting force components values, comparable with the best carbide tools. The second wear resistant tool 7 causes much higher cutting forces.

High energy caused by high cutting speed can cause surface integrity damage, unacceptable for aircraft engine parts. Therefore application of cemented carbides should be also taken into consideration. Here sweeping victory was achieved by tool 1 not much less wear resistant than leading CBN tools, with cutting forces as small as those of the best tools. Another advantage of this tool is its 6 cutting edges making it even much less expensive than CBN tools.

So finally for finish turning of Inconel 718 the following tools can be recommended:

1: Tool 8: CTJNR 2525M11, TNGN110212c25, CBN
   \( a_p=0.2\text{mm}, f=0.08\text{mm/rev}, v_c=250\text{m/min}, \) productivity \( Q=2\text{cm}^3/\text{min}, \) 
   \( T\approx 7\text{ min}, \) material removed during one tool life \( V\approx 14\text{ cm}^3 \)

2: Tool 1 PWLNR2020K6 , WNMG060404-MF1, cemented carbide
   \( a_p=0.2\text{mm}, f=0.08\text{mm/rev}, v_c=150\text{m/min}, \) productivity \( Q=1.2\text{cm}^3/\text{min}, \) 
   \( T\approx 8\text{ min}, \) material removed during one tool life \( V\approx 10\text{ cm}^3 \)

It should be underscored, that cutting parameters presented above, selected for particular tools should be treated as preliminary choice, which has to verified in shop floor conditions.

REFERENCES


