FINISH TURNING OF INCONEL 718

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Summary

Paper presents comparison of cutting performance of several cemented carbide and CBN tools in finish turning (a_p = 0.2 mm and f = 0.08 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

Toczenie wykończeniowe Inconelu 718

Streszczenie

W pracy przedstawiono wyniki badań właściwości skrawnych narzędzi z węglików spiekanych oraz CBN przy toczeniu wykończeniowym (a_p = 0,2 mm i f = 0.08 mm/obr) stopu Inconel 718. Kryterium oceny skrawności były: siła skrawania i trwałość ostrza. Główna siła skrawania F_c decyduje o mocy skrawania, a więc i wytwarzaniu ciepła wpływającego na jakość warstwy wierzchniej przedmiotu obrabianego. Szczególnie istotna jest wartość siły odporowej F_p, skierowanej w kierunku powierzchni obrobionej. Wpływa znacznie na uszkodzenia warstwy wierzchniej przedmiotu, decydując zwłaszcza o wartości naprężenia resztkowego. Trwałość ostrza i prędkość skrawania wpływają bezpośrednio na wydajność obróbki. Za kryterium trwałości przyjęto widoczne pogorszenie się powierzchni obrobionej. Analiza wyników badań wykazała, że siły skrawania nie zawsze są większe przy zastosowaniu CBN w porównaniu z uzyskanymi dla narzędzi z węglików spiekanych. Stwierdzono także, że trwałość ostrza najlepszych narzędzi węglikowych jest porównywalna z niektórymi narzędziami CBN.

Słowa kluczowe: Inconel 718, toczenie wykończeniowe, skrawalność

1. Introduction

Nikel-based superalloys are widely used in aircraft industry as they are exceptionally thermal resistant retaining mechanical properties up to 700°C [1]. 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 [2].

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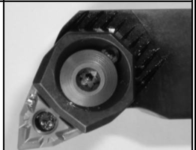
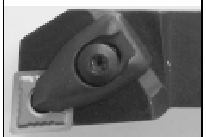
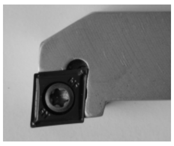
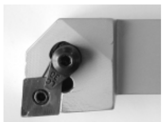
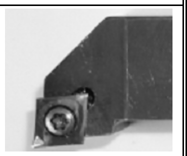
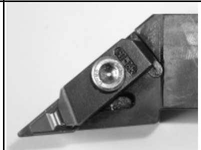
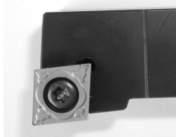
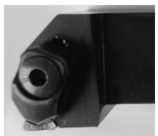
Conventionally they are machined using coated carbide tools, with the cutting speed in the order of 50 m/min [3, 4]. Recently more and more often ceramic and CBN tools are used for machining of nikel-based superalloys [2]. The choice between the tools offered by different producers, insisting, that their 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 mm, f = 0.08 mm/rev. General purpose emulsion was used as coolant in this tests.

Table 1. Tools selected for turning

No	Toolholder, insert, tool material	Photo	No	Toolholder, insert, tool material	Photo
1	PWLNR, WNMG 060404-MF1 CC PVD TiAlN		5	DCLNL, CNGP 120408 CC MT-CVD TiCN-Al_2O_3-TiN	
2	SCLCR, CCMT 120404-SM CC PVD TiAlN		6	MCLNR, CNMA 120408T CBN	
3	SCLCR, CCGT 09T302HP CC PVD TiAlN		7	NVLCR, VCGN160408 CBN	
4	SCLCL, CCMT 120404-MM CC PVD TiAlN		8	CTJNR, TNGN 110212e25 CBN	

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 1. The first four were PVD TiAlN coated carbide tools, the fifth one was MT-CVD TiCN-Al_2O_3-TiN coated, and the last three were CBN tools.

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 100 mm 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° (Fig. 1). Tool wear was measured using toolmakers microscope.

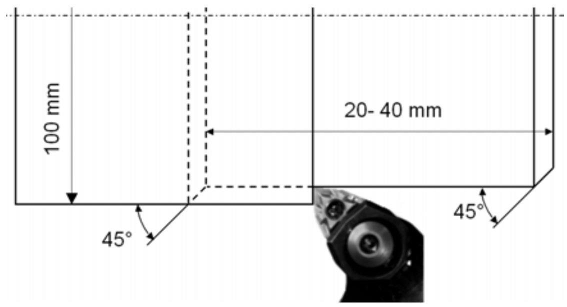


Fig. 1. Workpiece preparation and scheme of cut in tool life testing

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.

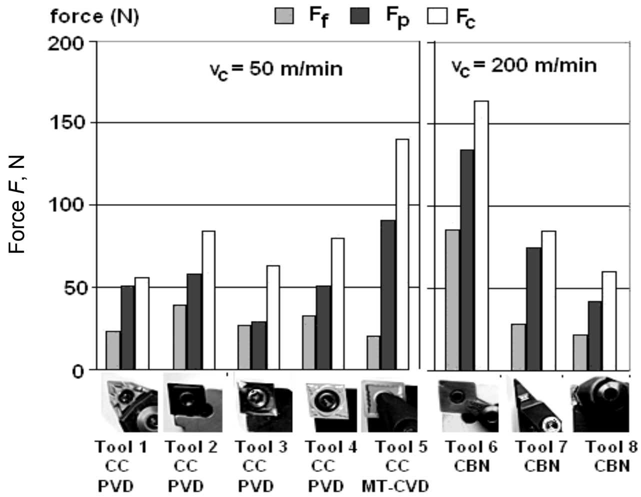


Fig. 2. Average cutting forces values in finish turning,
a_p = 0.2 mm, f = 0.08 mm/rev

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 = 0.025mm, while the Tool 6 has phase 0.14 mm/20°. Relatively good result was achieved by tool 7.

3.2. 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 VB_C for tool life determination was selected for each tool individually.

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

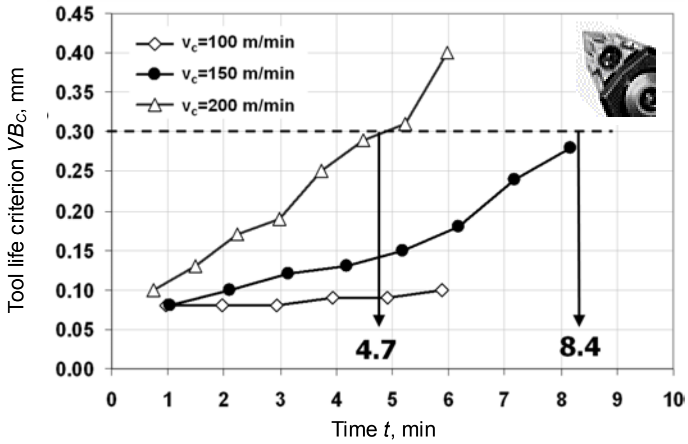


Fig. 3. Tool life test results for tool 1, $v_c = 100$, 150 and 200 m/min

Tool 2. Both tests performed with this tool with cutting speed $v_c = 200$ and 150 m/min were finished because of deterioration of the machined surface. Tool life criterion for this tool, ensuring good surface finish, was $VB_C = 0.20$ mm. The results of these test are presented in Fig. 4.

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 $VB_C = 0.15$ mm. Test carried out with cutting speed $v_c = 250$ m/min ended with catastrophic tool failure. The results of these test are presented Fig. 5.

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

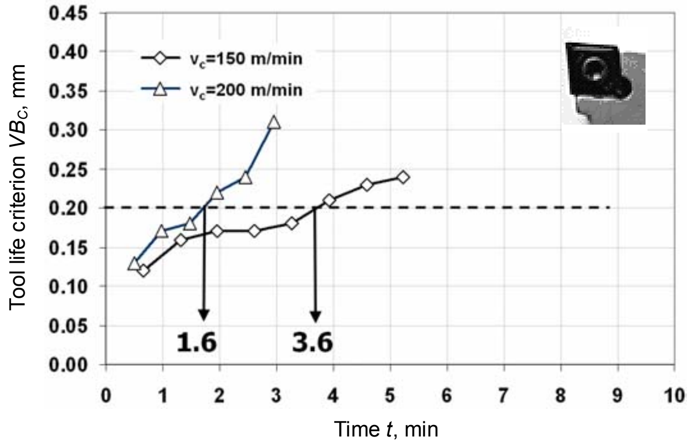


Fig. 4. Tool life test results for tool 2, v_c = 150 and 200 m/min

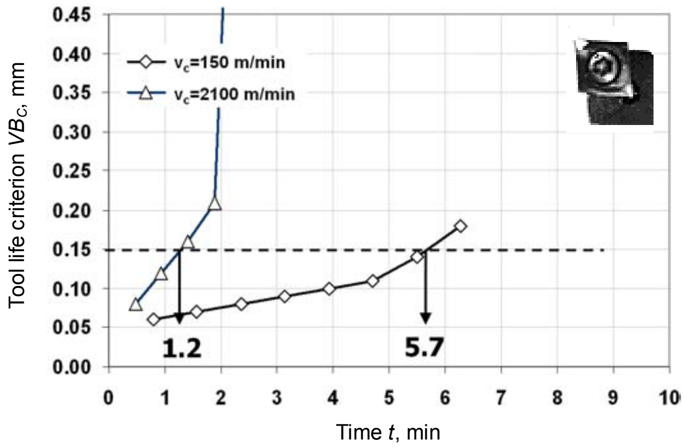


Fig. 5. Tool life test results for tool 3, v_c= 150 and 250 m/min

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 VB_C = 0.30 mm. The results of these test are presented in Fig. 7.

Tool 6. Both tests performed with tool 6 with cutting speed v_c = 150 and 200 m/min were finished because high value of the tool wear VB_C = 0.40 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 Fig. 8.

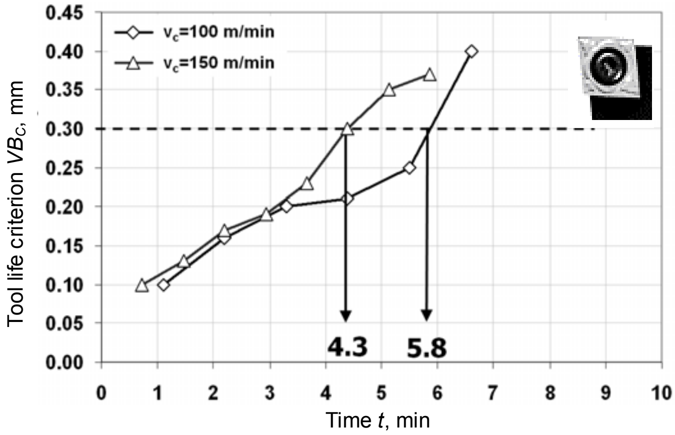


Fig. 6. Tool life test results for tool 4 , v_c = 100 and 150 m/min

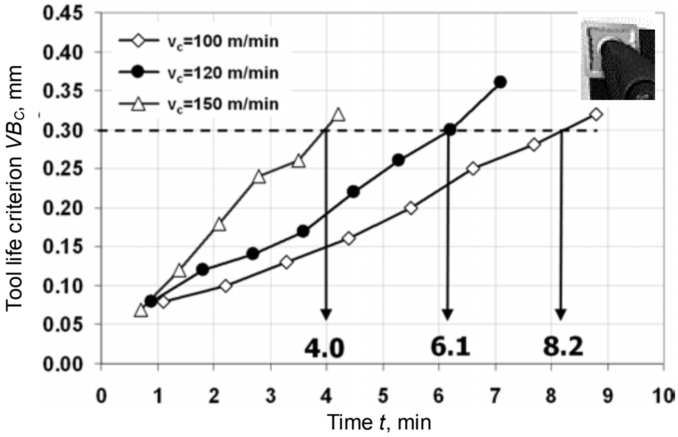


Fig. 7. Tool life test results for tool 5, v_c = 100, 120 and 150 m/min

Tool 7. All three tests performed with tool 7 with cutting speed v_c = 200, 250 and 300 m/min were finished because high value of the tool wear VB_C = 0.40 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 Fig. 9.

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 VB_C = 0.40 mm. Also in this case, no deterioration of the machined surface was noticed. The results of these test are presented in Fig. 10.

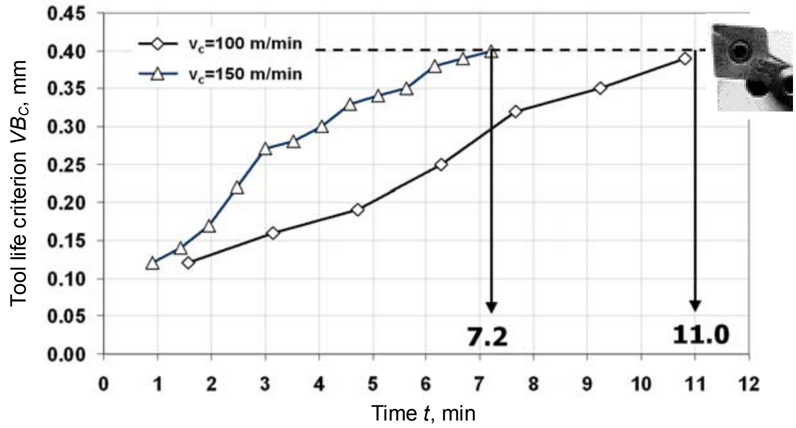


Fig. 8. Tool life test results for tool 6, v_c = 100 and 150 m/min

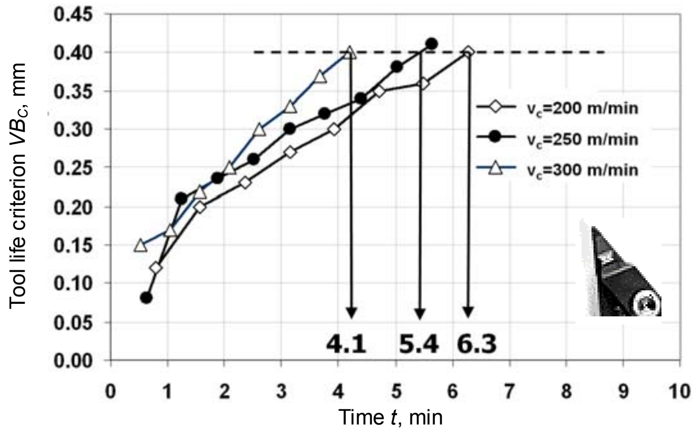


Fig. 9. Tool life test results for tool 7, v_c = 200, 250 and 300 m/min

Summary of tool life test. All tool life values obtained in tests described above are presented in Fig. 11 as Taylor T-v_c relationships. The results shows, 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.

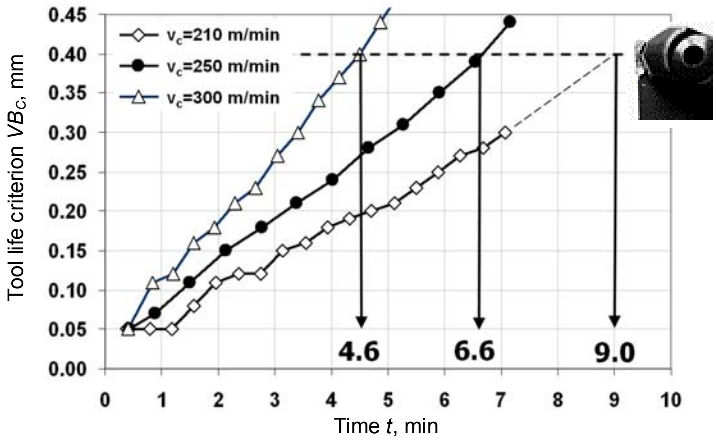


Fig. 10. Tool life test results for tool 8, v_c = 200, 250 and 300 m/min

4. Conclusisons

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.

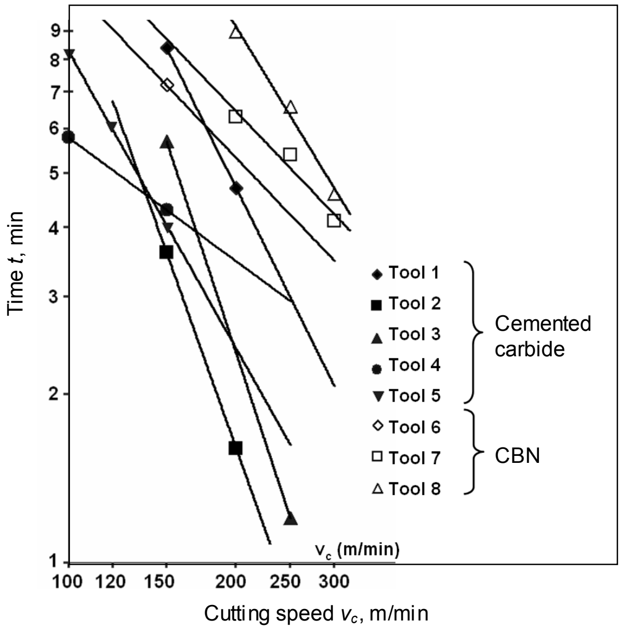


Fig. 11. Taylor relationships obtained in finish turning of Inconel 718

The first criterion always important, however it must give way to the second for finishing. Results of all experiments were summarized in Table 2, altogether with tool evaluation based on above criteria.

Table 2. Finish turning

No	Tool material	Cutting forces	T - v_c	
1	Cemented carbide	+++	++	Second
2		++	– –	
3		+++	–	
4		++	–	
5		–	–	
6	CBN	–	++	
7		+	+++	
8		+++	+++	Best

+++ the best ++ good + acceptable – not acceptable

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, TNGN110212e25, CBN

a_p = 0.2 mm, f = 0.08 mm/rev, v_c = 250 m/min,

productivity Q = 2 cm^3/min, $T \approx$ 7 min,

material removed during one tool life $V \approx$ 14 cm^3

2: Tool 1 PWLNR2020K6 , WNMG060404-MF1, cemented carbide

a_p = 0.2 mm, f = 0.08 mm/rev, v_c = 150 m/min,

productivity Q = 1.2 cm^3/min, $T \approx$ 8 min,

material removed during one tool life $V \approx$ 10 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.

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Received in February 2009