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Procedia CIRP 77 (2018) 634–637

www.elsevier.com/locate/procedia

8th CIRP Conference on High Performance Cutting (HPC 2018)

Study of the performance of PCBN and carbide tools in finishing machining of Inconel 718 with cutting fluid at conventional pressures

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Abstract

Inconel 718 is a nickel-based superalloy widely used in the aerospace industry, nuclear plants and gas turbines due to the exceptional mechanical properties and resistance to corrosion at elevated temperature. For these reasons Inconel 718 have a low machinability due to the high temperatures that appear in the cutting area in addition to the wear caused in the tools as abrasion, chemical affinity, diffusion, flank and notch wear. Carbide and recently Polycrystalline Cubic Boron Nitride (PCBN), are the cutting tool materials used in finishing operations of nickel-based superalloys. This paper focuses on the comparative analysis of carbide and PCBN tools in finishing operations on Inconel 718 using cutting fluid at conventional pressure (7.5 bar). Experimental tests were performed at different cutting speeds, feed rate and depths of cut depending of the cutting tool. PCBN tools were used at speeds within the range of 250-300 m/min, feed between 0.1 and 0.15 mm/rev and depth of 0.15mm. Carbide tools are not used at such speeds because of their lower hardness at high temperature. Speeds five times lower than those were used for PCBN (50-70 m/min), the same feeds (between 0.1 and 0.15 mm/rev) and a depth of 0.25 mm were used. Tool life and machined surface has been analyzed with the aim of studying the viability of these tools in finishing conditions of Inconel 718. The results indicate that PCBN tools have a shorter life in minutes than carbide tools; however, the machined surface by cutting edge is larger at higher cutting speeds, so PCBN tools are an interesting alternative in this type of machining.

Keywords: PCBN; carbide tools; Inconel 718; finishing; cutting fluid

1. Introduction

Nickel based superalloys are one of the most difficult materials to machine due to the exceptional mechanical properties that have at high temperatures. In this case Inconel 718 is a nickel based superalloys whose main property is the high strength and the chemical properties with an exceptional heat resistance. Due to these properties this superalloy has been widely used in the aerospace industry, especially in turbines, but it is also used in other industries and applications as marine industry, nuclear plants, rocket engines, petrochemical equipment and in general high temperature applications. [1]

However the wide use in the industry due to the excellent properties it is necessary to investigate how to machine these materials. The early tool wear found in nickel based superalloys machining leads to numerous problems and challenges in manufacturing processes Wear is produced by different causes such as the presence of hard carbides in the superalloy that causes abrasive wear in the contact area between tool and workpiece. Also the chemical affinity, the poor thermal diffusivity and the conductivity that had brought to a high temperature the cutting edge has to be taken into account. [2]

Carbide tools have been used in machining nickel based superalloys, but recently the PCBN (Polycrystalline Cubic

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10.1016/j.procir.2018.08.189

boron nitrides) tools have been developed for the finishing operations [3]. Carbide tool can machine alloys at cutting speeds around 50m/min, but cannot be used at higher speeds due to the elevated stress and temperature generated during the chip formation. On the other hand, CBN is the second hardest material after diamond, in addition at high temperatures it retains the hardness [4]. CBN can be synthetize with other materials such as metallic or ceramics. They can be classified on high content or low content of CBN. Recent research has shown that a low CBN content have a greater tenacity and therefore obtain better results in finishing operations [5]. Sein Leung Soo et al. [6] studied the effect of different coatings for PCBN tools, results indicated that coating at cutting speeds of 200m/min increased tool life, however at higher cutting speeds, no benefit were observed.

Cutting fluid has traditionally been used to reduce the cutting forces, the temperature and consequently increase the life of the tool and to improve the surface finish of the piece, because of that this procedure has to be taken into account for the machining processes [7]. The proper use of cutting fluid can improve the surface quality and a saving in tool costs. Depending on the costs that machining with cutting fluid and environmental impact can cause, in some particular cases the use of dry machining can be an alternative [8]. The pressure of the cutting fluid can affect the machining behavior.

2. Experimental

2.1. Materials

The workpiece was Inconel 718 cylinder with a length of 130mm and an approximate diameter of 100mm. The chemical composition of the nickel-based superalloy is shown in Table 1. This material was hardened and aged to be similar to what would be found in actual finishing operations [9].

Table 1. Composition of Inconel 718

Element	%	Element	%
Ni	53.02	Al	0.55
Cr	18.49	Co	0.10
Fe	18.12	Si	0.06
Nb	5.40	Cu	0.05
Mo	3.06	Mn	0.06
Ti	0.96	C	0.03

Two cutting tools have been tested to analyze the efficiency in finishing machining processes, the first is a carbide tool and the second a PCBN tool. In Table 2 the dimensions, compositions and coatings can be observed.

For the PCBN tool it was employed a negative insert (CNGA120408) mounted on a tool holder (PCLNR2525M12). The tip angle of the tool is 80°, and the tip radius 0.8mm. The angles of the configuration were a clearance angle of 6°, and normal rake and inclination angle of -6°. Carbide tools with a positive insert (CCMT 09T304F1) mounted in a tool holder (SCLCR 2525M09JET) was used. The tip angle was 80° and the tip radius was 0.4mm, with a clearance angle of 7°, normal rake and inclination angles of 17°.

Table 2. Characteristics of the cutting tools

Material	Carbide	PCBN
Tool (*Grade*)	TS2000	EA 7015
Manufacturer	SECO	SANDVIK
Nose radius (*mm*)	0.4	0.8
Geometrical edge	Round honing: r= 25µm	Round honing: r= 25µm
Composition	Carbide substrates	50% CBN, ceramic binder.
Coating	TiAlN + TiN coated	TiN coated.

2.2. Instrumentation and set-up

The tests were performed on a lathe CNC lathe Pinacho Smart turn 6/165. The experimental setup can be observed in Figure 1 with the work piece, the tool and the cooling system.

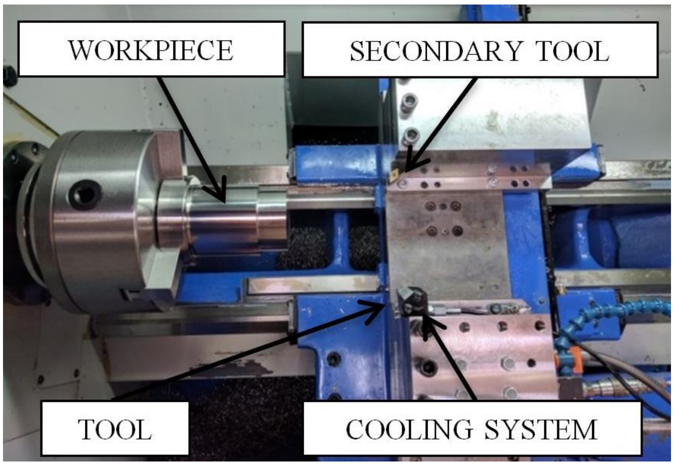

Fig. 1. Experimental tests.

In addition, a secondary tool was used to eliminate the hardened material at the end of the pass that could not be cut due to the nose radius. This material causes a higher contact area producing an increment of almost double on the in cutting forces. This phenomenon also can cause some fragile break in the tool. The material at the end of the pass can be seen in Figure 2.

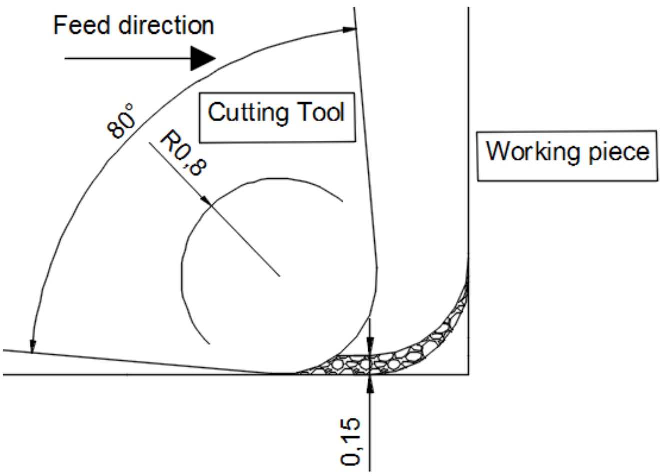

Fig. 2. End of the pass.

2.3. Experimental procedure

Different cutting conditions were used depending on the recommendations provides by the manufacturers of each tool. Table 3 shows the parameters. For PCBN tools cutting speeds between 4 and 6 times higher and a lower depth.

Table 3. Cutting conditions.

Tool	Cutting speed [m/min]	Feed [mm/rev]	Depth [mm]	Fluid pressure [bar]
PCBN	250	0.1 and 0.15	0.15	7.5
	300	0.1 and 0.15	0.15	7.5
Carbide	50	0.1 and 0.15	0.25	7.5
	70	0.1 and 0.15	0.25	7.5

The cutting fluid was introduced by a Jetstream Tooling at the optimum point of the area of detachment which, as a result, the cutting edge receives refrigerant from two opposite directions, up and down.

3. Results and discussions

3.1. Tool wear

Tool life was analyzed in finishing machining for PCBN and carbide tools with different cutting conditions to study the machining efficiency. In the carbide tools, wear was mainly caused by chipping of the edge, in addition flank wear and some adhesion was observed. The wear of the edge leads to a catastrophic rupture causing the end of life. In the PCBN tools, the main wear observed was abrasive wear in the form of flank wear, also due to the presence of high temperatures, a crater wear and a lot of adhesion to the cutting edge was originated. The end of life of the PCBN tools was considered when flank wear reached 0.4mm of depth.

For the cutting speeds considered for the two tools used, it is observed that the lower cutting speed obtain higher life values. The feed in the machining of PCBN tools does not have a significant effect on the tool life. However, the feed in the carbide tools has more influence, increasing from 0.1mm/rev to 0.15mm/rev a decrease in life between 43 and 45% is observed. Tool life is between 2 and 4 times higher in carbide tools, this can be seen in Figure 3.

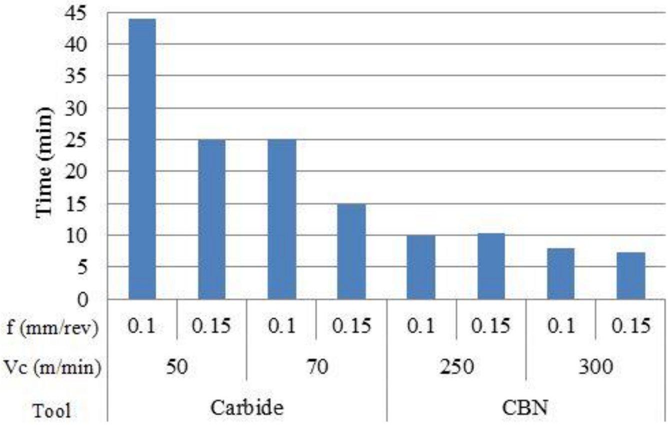

Fig. 3. Total life of Carbide and PCBN tools.

In finishing operations it is convenient to eliminate the effect of the depth of pass from the magnitudes, since the result of the process is to remove a certain surface independently of the volume of chip removed. Therefore, to analyze the efficient of the tool in this work will be considered the surface machined by edge. The expression to determine the machined surface is:

$$S_{machined} = V_c \cdot f \cdot T_m \cdot 1000 \qquad (1)$$

Where:

- $S_{machined}$: machined surface [mm^2]
- Vc: cutting speed [m/min]
- f: feed [mm/rev]
- T_m: tool life [min]

Despite the lower life of the PCBN tools, it is observed that in terms of machined surface per edge they are comparable to carbide tools because it allows machining at higher speeds. At lower feed (0.1mm/rev) the same order of magnitude was observed on the machined surfaces for both tools. However, it was observed that at higher feed (0.15mm/rev) PCBN tools obtained a machined surface per edge superior to carbide tools. The improvement observed at 0.15mm/rev in PCBN tools is due to the high cutting speeds reached by these tools, together with the fact that the feed does not affect the life of the tool. Figure 4 shows the machined edge surface of the two tools for all cutting conditions.

3.2. Roughness

The roughness was measured periodically with a rugosimeter Mitutoyo model SJ-201 using the Arithmetic Average Roughness (Ra). In the tests carried out with the carbide tools, a high initial roughness was observed in the first minutes of life, during the life of the tool it was reduced with the increase of wear. Figure 5 shows the surface finish when machining with the carbide tool. For the PCBN tool a constant roughness is observed during the life of the tool, besides it is observed that the roughness values are more reduced than the carbide tools. The average roughness obtained by carbide tools is shown in Figure 6.

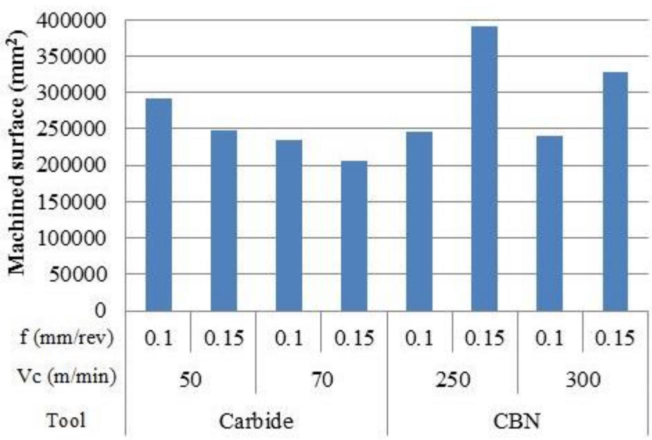

Fig. 4. Machined surface per cutting edge of carbide and PCBN tools.

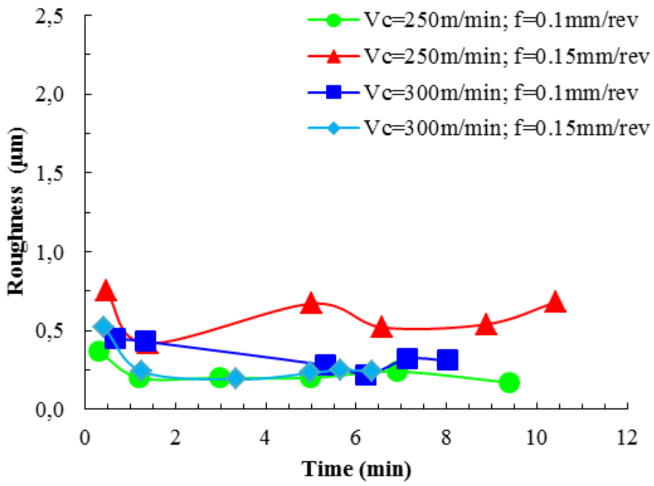

Fig. 5. Average roughness (Ra) on the surface machined by PCBN tools.

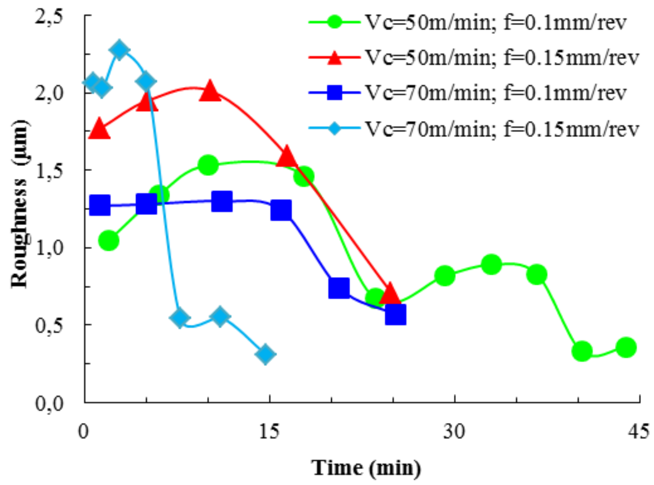

Fig. 6. Average roughness (Ra) on the surface machined by carbide tools.

The average roughness was more constant during the life of the PCBN tools than in carbide tools, this behavior makes PCBN tools ideal for finishing operations that require an exceptional surface finish and enough repeatability.

Values of Ra between 0.8 and 0.2 µm were reached in the PCBN tools. The carbide tools reaches acceptable surface finish at the end of the tool life, but during their life they had values between 2.3 to 0.4 µm. High values of roughness in finishing operations of some specific part cannot be accepted due to the demanding tolerances.

4. Conclusions

Influence of the cutting conditions has been analyzed for finishing operations with PCBN and carbide tools. The following conclusions were obtained after analyzing life and roughness:

- Carbide tools have a longer tool life than PCBN tools but PCBN tools allow speeds between 4 and 6 times higher. In terms of machined surface per edge it has been proven that at the feed of 0.15mm/rev more machined surface is obtained, and for feed of 0.1mm/rev the machined surface is maintained in the PCBN tools. For this reason the viability of using PCBN tools in finishing operations in Inconel 718 is demonstrated.
- The best combination found for PCBN tool was at lower cutting speed and higher feed (250m/min and 0.15mm/rev). This is because the life of the tool increases at low cutting speeds, however the feed does not affect significantly.
- The finished surface machined with PCBN tool obtain a more constant behavior and excellent roughness during most of the machining, however, no significant changes were observed depending on the cutting conditions.

Acknowledgements

This work was supported by the Spanish Ministry of Economy and Competitiveness and FEDER program under grant DPI2014-56137-C2-2-R.

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