Study of CBN Tools Performance Cutting Interrupted Hardened Steels

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Abstract.* Turning hardened steels is a modern tendency, which is growing due to the constant search for optimization of the fabrication processes. This kind of cutting, make possible to reduce manufacture costs and improve the productive system flexibility through the replacement of grinding process. This tendency is becoming feasible, due to technological advances in many areas, such as the cutting tools. Due to its properties, CBN cutting tools have presented a good performance in this kind of machining operation. Most of the researches in turning hardened steels are carried out on smooth surfaces, where the cut occurs in a continuous way. Little has been researched in interrupted turning, aiming to know the influence of this kind of cut on the behaviour of the cutting tools. On the other hand, most of workpieces used in factories, which need a finishing operation, have interrupted surfaces. This work tested 2 CBN cutting tools, namely, CBN almost pure (90% volume of CBN) and CBN with a ceramic phase (60% volume of CBN), in face turning of hardened steels (SAE 01, quenched and tempered, mean hardness of 58 HR_C) with 3 shapes of surfaces (continuous, semi interrupted and completely interrupted). The results showed that the CBN cutting tool with a ceramic phase, usually indicated to the continuous cut, presented a longer life when cutting the continuous surface as well as the semi interrupted one. In the turning operation of the completely interrupted surface, this cutting tool had a performance, in terms of life, sometimes better, in other times worst than the pure CBN. So, it was showed that the almost pure CBN cutting tool is not supposed to be used neither in continuous cut nor semi interrupted cut. On the other hand, the CBN with a ceramic phase cutting tool can be, in some situations, used in completely interrupted cuts, because it has toughness enough to withstand this operation.

Keywords.* hard turning; interrupted surfaces; CBN.*

1. Introduction

Turning hardened steels with mean hardness around 60 HR_C (Rockwell C) became possible due to the development of cutting tool materials such as ceramics and cubic boron nitride (CBN) as well as the development of more rigids machine tools that are able to achieve higher spindle rotations.

Turning hardened steels has, many times, replaced with advantages the grinding process. The main advantages of the former process are (Tönshoff et. al., 1995, Klocke et al., 1995): possibility of eliminating manufacturing stages, higher productivity, use of more simple and cheaper machine tools, possibility of accomplishing multiple operations in an unique workpiece fixture, higher process flexibility, lower costs of the cutting tools and workpiece surfaces less harmed by the heat. Usually are used lathes with high rigidity and power.

Although the evidents advantages of turning hardened steels instead grinding them, its industrial utilisation has been little if compared with the possibilities of application. The reasons for that are: the lack of knowledge about some parameters, like workpiece dimensional and surface qualities, cutting tool life and the need to analyse individually each application, considering the type and condition of the workpiece, design requirements, available equipment as well as their conditions and the size of the worpieces batches (König et al., 1993; Abrão & Aspinwall, 1996). Besides, as the cutting tools used in this kind of operation are very brittle, machining interrupted surfaces, that are very common in the metal mechanics workpieces industry, are prejudiced.

To obtain adequate levels of quality and productivity when turning hardened steels, it is necessary the use of cutting tools made with materials that meet some requirements like (König et al.,1984): high hardness at room and high temperatures, high transverse rupture stress (higher than 390 N/mm^2), high fracture toughness, high compression strength, high termical shock resistance and high resistance to chemical reactions. Nowaday, the available cutting tools in the market that satisfy the majority of these requirements, are those made with CBN or ceramics materials. Next, it will be done some considerations about the cutting tools used in this work:

Mixed Ceramic – It belongs to the group of ceramics cutting tools whose basis is alumina, containing 25% to 40% of titanium carbide (TiC) in volum as a second phase, disperse in the aluminium oxide matrix (Al_2O_3 + TiC), also named black ceramic. Another new composition (~1983), has approximately 23% titanium nitride (TiN), in weight, plus TiC, disperse in the aluminium oxide matrix. This material is dark brown and has higher transverse rupture stress, higher hardness and higher thermal conductivity than other ceramics. So it has, a broader field of application. (Brink smeier & Bartsch, 1988; Jack. 1986).

The presence of TiC and TiN in the alumina matrix allow these cutting tools to be applied with higher cutting speeds and less risk of abrupt fracture. Nevertheless, these tools have low toughness, and this is the main limitation of its application. Besides, the mixed alumina presents a superior hot hardness related to others tools whose basis is the alumina, so, it can be used in the machining of hardened steels and cast irons with high hardness (Gruss, 1988). These tools are indicated by tool manufacturers like Sandvik (1994) as well as by some researchers (Costa, 1993; Abrão & Aspinwall, 1996), to turn hardened steels.

Polycrystalline Cubic Boron Nitride (PCBN) - The cubic boron nitride is chemically more stable than the diamond, so, it can be used in the machining of ferrous alloys without high rates of diffusion wear. Its toughness is very superior when compared to mixed ceramics. Its hardness is only overcame by diamond, being almost twice the mixed ceramics one (Sorrel & McCartney, 1986).

There are several types of PCBN available in the market. Each manufacturer uses differents materials and contents of binders and differents sizes and distributions of particles (Costa, 1993; Abrão, Aspinwall & Wise, 1995). However, in general, one can divide the PCBNs in two categories, according to their applications:

- PCBNs to rough machining (a_p among 0,5 and 0,8 mm);
- PCBNs to finish machining(a_p smaller than 0,5 mm).

The rough machining PCBNs have higher content of cubic boron nitride (90% in volum) what increase the crystal to crystal bond as well as their toughness. Besides, due to the high content of CBN, these materials are the ones that present the highest hardness among the PCBNs. Due to these properties, this kind of CBN is much more efficient when the main wear mechanism involved is abrasion (it is difficult to verify an adhesive or chemical wear) and/or when the cutting forces are very high or the cut is interrupted, as in rough turning and in rough milling of hardened steels and gray cast iron, where the hardness are among 45 and 65 HR_C

The PCBNs indicated to finishing are those where a ceramic phase is added, in such a way that they have lower toughness and hardness, but higher chemical and thermal stability than the PCBNs indicated to roughing, since the ceramic has, in general, higher diffusion resistance than CBN.

An important feature that must be considered when comparing the cutting tools with high and small content of CBN is its thermal conductivity. Since in finishing operations the heat generated is very high. A cutting tool with high content of CBN has higher thermal conductivity, herewith the heat is removed from the cutting zone, without causing the necessary softening of the workpiece nearby the tool nose, what would make the cut easier. On the other hand a tool with less content of CBN and higher content of ceramics, has smaller thermal conductivity. So it will not remove a large quantity of heat from the cutting zone, what make possible, to some extent, the softening of the workpiece material nearby the cutting zone and the cut easier (Bossom, 1991).

In turning of hardened steels, the cutting tool life has been a factor of high importance due to the high cost of the tools and little knowledge about the behaviour of the wear and damages of them, mainly when the machine tools available in the market are used. Moreover, not much is understood about the application of these tool materials in turning interrupted surfaces, that are commom in the industry.

This work, tried to verify the performance, in terms of life, of two kinds of PCBN cutting tools (one of them with high content of CBN and another with lower content of CBN and a ceramic phase added) when machining 3 differents surfaces (that configure continued cutting, semi-interrupted cutting and interrupted cutting) in 3 different cutting speeds.

2. Materials and Experimental Procedures

The workpiece material used was the SAE 01 steel from Villares. It was tested 3 different kinds of workpieces, all of them with hardness around 57±2 HR_C. The figure 1 presents a sketch of these 3 kinds of workpieces. They were designed in such a way that, in the first kind of workpiece, only continuous cutting was accomplished when machining its face, in the second kind of workpiece part of the cutting was continuous and part interrupted (what will be called semi interrupted) and, in the third kind of workpiece, totally interrupted cut took place.

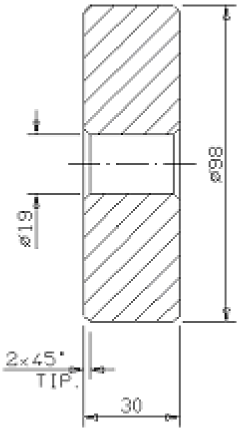
They were used 2 different CBN cutting tools. The first one was a CBN 7050 code SNGA 120412T01020A and the second one a CBN 7020 code SNGA 120412 S 01020 A. At the manufacturer catalog, it is described that CBN 7020 "is a CBN class based in common CBN plus TiN. This class is resistant to wear and chemical alterations. So, it is indicated to finishing operations in hardened steels and cast iron". For its turn the CBN 7050 is described as "a CBN class pure with a high wear resistance. It is mainly recommended to machine cast iron and hardened materials in tough conditions" (Sandvik, 2000). The inserts were coated with TiN. This coating lowers the cutting forces, due to its low friction coefficient. Besides, due to the fact that this layer is very hard (at room as well as high temperature) and also due to the little friction, there are less wear, mainly at the clearance surface of the cutting tool (Diniz, 2000).

The table 1 shows the cutting conditions used in each test. A test consisted in successive face turning of the workpieces (radial feed) until the flank wear of the cutting tool reach the value of V_B = 0,2 mm and/or the mean roughness of the workpiece reach the value of Ra = 0,6 μm.

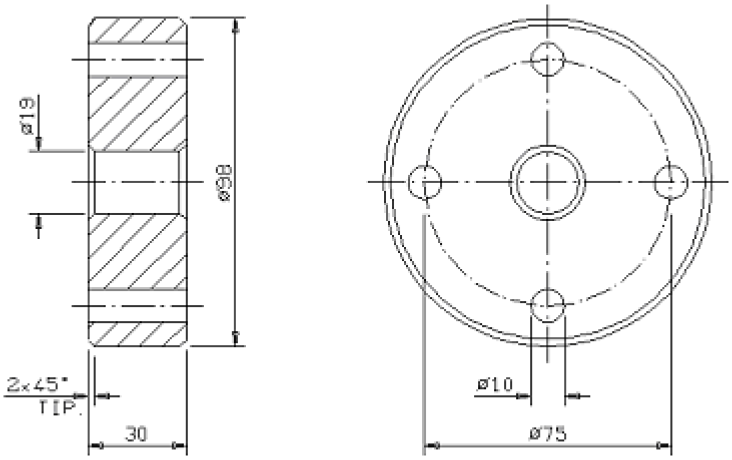
The equipment used in the tests were:

- CNC Lathe Romi; model Cosmos 30, McS 500 series command, with 22 kW of power and maximum rotation of 3000 rpm;
- Optic microscope Leica plus a image analyser software (Global Image) to measure the cutting tools wear;

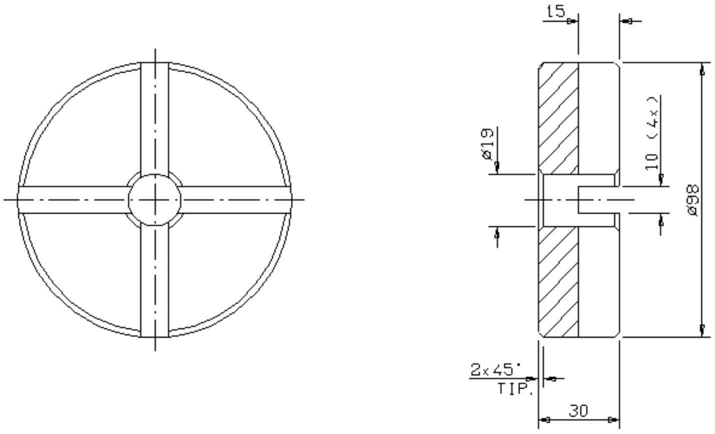
- Rugosimeter Mitutoyo, using a cut-off of 0,8;
- Electrical current of the lathe motor data acquisition system with a Hall effect sensor.



a) Workpiece to interrupted cut (called P1)



b) Workpiece to semi interrupted cut (called P2)



c) Workpiece to totally interrupted cut (called P3)

Figure 1 – Workpieces drafts

The cutting tool flank wear dimensions and the workpiece roughness were measured periodically through the tests. The measurement of the roughness parameters Ra and Ry were done in three random points, being the first one next to the outer diameter, the second one at the middle diameter and the third next to the inner diameter of the workpieces and, to analysis purposes, the roughness of each workpiece was an average of these three values.

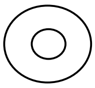
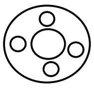
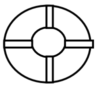
Table 1 – Cutting conditions used in the tests

Cutting tool	Operation	WP	Vc m/min	fn mm/r	ap mm
7020	Continuous cut	P1	150	0,08	0,3
			180		
7020	Semi interrupted cut	P2	150		
			180		
7020	Interrupted cut	P3	120		
			150		
			180		
7050	Continuous cut	P1	150		
			180		
7050	Semi interrupted cut	P2	150		
			180		
7050	Interrupted cut	P3	120		
			150		
			180		

3. Results and Discussions

At table 2 it can be verified the cutting tools, used in the tests, lifes. The results of this table are showed in a graphic way in figure 2.

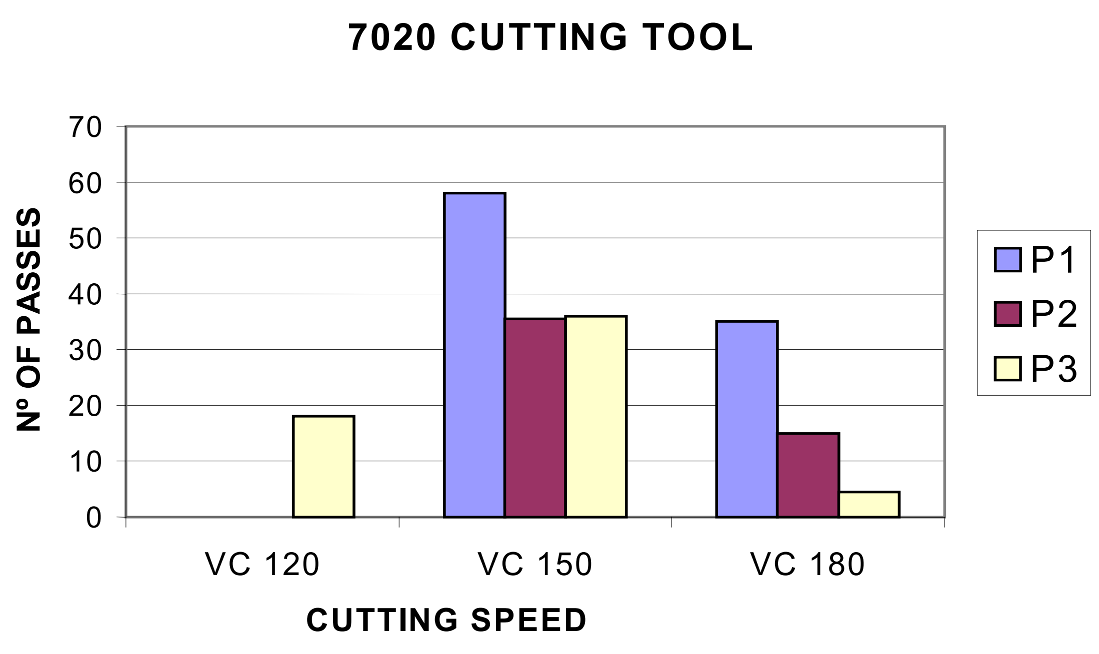
Table 2 – Tool life/Kind of test

TOOL LIFE (PASSES)							
WORKPIECE TYPE		**P1** 		**P2** 		**P3** 	
	TEST	F1	F2	F1	F2	F1	F2
V_C 120	1					24	26
	2					40	10
	MEAN					**32**	**18**
V_C 150	1	24	60	12	32	38	36
	2	16	56	16	39	20	36
	3					44	
	MEAN	**20**	**58**	**14**	**35,5**	**34**	**36**
V_C 180	1	13	48	7	11	6	1
	2	16	22	6	19	12	8
	MEAN	**14,5**	**35**	**6,5**	**15**	**9**	**4,5**

As expected, the CBN 7020 (F2) tool presented a very superior life compared to the CBN 7050 (F1) tool for all continuous cut done, (workpiece P1). The 7020 tool has a ceramic phase added to the CBN, what increases its thermal and chemical characteristics in relation to the 7050 tool, which is made with a higher percentage of CBN. Moreover, the 7020 tool presents higher hardness, in conformity with table 3, that shows some characteristics of the two tool materials used. Thus, even with regard to the mechanical wear (abrasive wear), the 7020 tool has a tendency to be more resistant than the 7050. The most surprising result was how longer is the 7020 tool life compared with the 7050 in continuous cut: In all the tests done with workpiece P1, the mean 7020 tool life was more than twice longer than the 7050 tool. Definitely, a tool with high percentage of CBN, as is the case of 7050, can not be applied to the continuous cut of hardened steels, since it does not have enough wear resistance to this task.

Even in the semi interrupted cut (workpiece P2) the 7020 tool presented a better performance. Its higher wear resistance still prevailed. Despite the schoks occurred during part of the tool path, the tool lives presented were longer than twice compared to that obtained with the 7050 tool.

Just in the interrupted cut (workpiece P3) that the higher toughness of the 7050 tool was able to show up and improve its performance in relation to the 7020 tool. At 150 m/min (cutting speed), the life of the two tools were very close and at 120 m/min and 180 m/min the 7050 tool presented a mean life longer than the 7020. However as in the tests done with the workpiece P3, the dispersion of the results, mainly in the tests with v_c = 180 m/min, was very high. So, the affirmation that the 7050 tool behaved better than the 7020 lacks statistic accuracy.



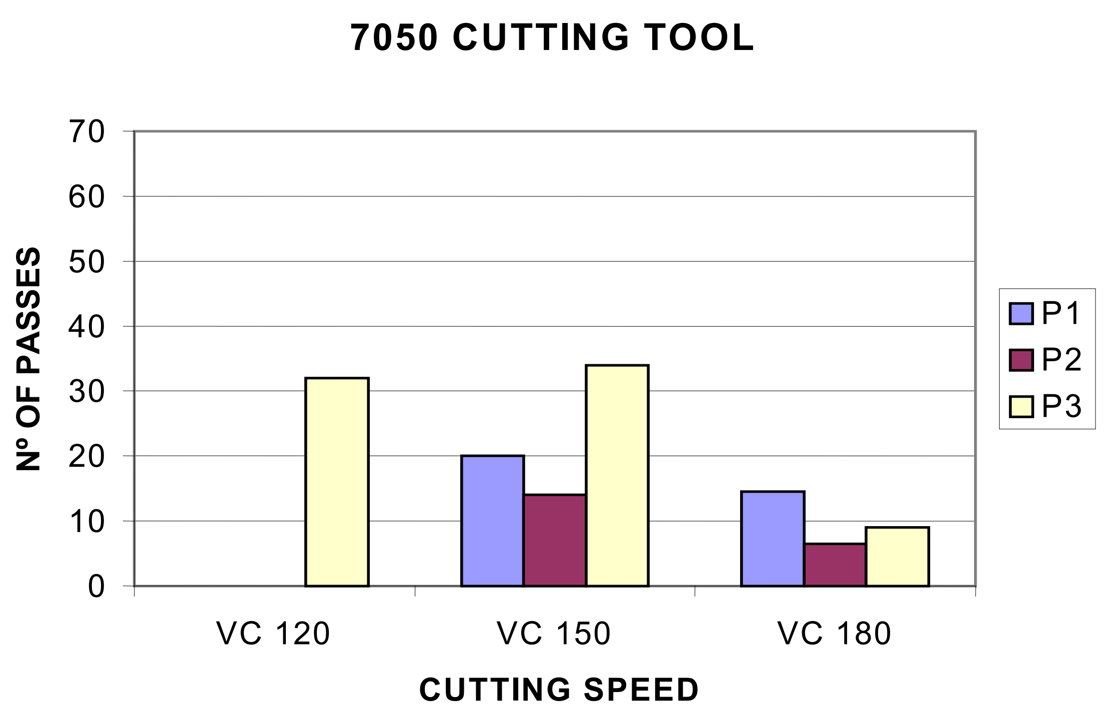


Figure 2 – Mean life of the tools

Table 3 – Properties of CBN 7050 X CBN 7020

	CBN 7020	CBN 7050
CBN	60%	90%
Mean grain size	3 μm	2,5μm
Mean hardness (HV3)	>2900	>2700
Young's modulus (GPa)	690	650

- Values from Sandvik Coromant, tool manufacturer

Concluding the comparison between the 7020 tool (CBN + ceramic) and the 7050 tool (only CBN), it can be said that the first one is more suitable to cut workpieces without interruption and to the cut where the workpieces have some interruption. When the workpieces have more frequent interruptions, the tests done do not allow to extract a secure conclusion about what cutting tool is the most suitable.

Increasing the cutting speed (v_C) caused a decrease in the tool life. The exception of this fact happened when the cutting speed was increased from 120 m/min to 150 m/min and the workpiece P3 was used. In these conditions, when the 7020 tool (F1) was used, its life increased and when the 7050 tool (F1) was tested, its life remained almost constant. The increase of the cutting speed tends to decrease the tool life, since there is an increase in the cutting temperature and this fact decreases the resistance of the tool to most of the wear phenomena (abrasion and diffusion mainly). On the other hand, this increase in temperature tends to decrease the shear strenght of the chip, what is important when machining high strenght hardened materials and, herewith, tend to increases the tool life. Thus, when the cutting speed was increased from 150 m/min to 180 m/min the influence of the temperature in the resistance of the tool wear were stronger than in the chip material and the tool life decreased. When the cutting speed changed from 120 m/min to 150 m/min, the influence in the chip shear strenght was the most important and the tool life remained constant or even increased. It is still necessary emphasize that the highest decrease in the tool life happened when the cutting speed changed from 150 m/min to 180 m/min and the workpiece P3 (interrupted cut) was used. This occurred with both tools. It can be explained due the fact that, in the interrupted cut, a higher cutting speed, besides stimulate the tool wear as mentioned above, increase the frequency and the energy of the schoks, making easier the occurrence of damage in the tools.

It can be noticed, analysing the table 2 and the figure 2, that the cutting speed of 150 m/min provide the highest tool life, independent of the quantity of interruption and the tool used.

It was expected, initially that the tests with the workpiece P1 (continuous cut) presented longer tool lives, followed by the tests with workpiece P2 (semi interrupted cut) and lastly by tests with workpiece P3 (interrupted cut). It can be said that this happened to 7020 cutting tool (F2). When this tool was used, the increase in the cut interruptions and in the number of the schocks on the tool to accomplish one pass, actually caused decreasing of the tool life (except to v_c = 150 m/min, when the tool life remained the same to the workpieces P2 and P3). As it was seen previously, due to the ceramic addition, this tool is less tough, therefore, less susceptible to schoks than the 7050. Hence, as the cut became more interrupted, the 7020 tool life dropped. However, this did not happen when the 7050 tool was used. When machining the workpiece P3, the tool life for v_c = 150 m/min was much longer than that obtained with the other two kinds of workpieces. At the velocity of 180 m/min, the tool life with interrupted cut (workpiece P3), was still longer than that obtained in the semi-interrupted cut (workpiece P2) and a little shorter than that obtained in the continued cut (workpiece P1). This shows once again that the tool with high percentage of CBN is not suitable to the continuous cut. When the cutting speed is not so high, the frequency and the power of the schoks over the tool are not so high (as in the case where v_c = 150 m/min was used) so, the performance of this tool in the interrupted cut is better than in the continued cut and in the semi-interrupted cut. Just when the cutting speed and, therefore, the frequency and the power of the schoks are very high is that the toughness of this tool is not enough and it presents better performance in the continuous cut.

The fact that the interrupted cut (workpiece P3) has presented, in many cases, a longer tool life than in the semi-interrupted cut (workpiece P2), to the toughest tool, probably was due to the phenomenon reported following.

In the workpiece P2 the interruption is done through holes at the workpiece face, according to Fig 3. These holes make the distance without cutting (empty cutting) unequal, depending on the diameter that the tool is cutting. In another words, the maximum distance without cutting (A2 to A3) is approximately the diameter of the hole, but the minimal distance (A1) is equal to zero. Herewith, when the tool traverse the hole it has the first point of contact of the cutting edge with the workpiece varying through the cutting edge and, as the schok is done against a curved surface (circular hole), the total schok time (time necessary to all the tool edge penetrate in the workpiece) is very short. This make that, at the moment of the collision of the tool with the workpiece in a curved surface, all the collision energy be transfered very quickly to the cutting edge. Herewith, the high value of Ks and the variation of the point of contact in the collision (at the moment when the tool traverse the hole of the workpiece), could generate mechanical cracks, that would initiate the damage process of the cutting edge. On the other hand to the workpiece P3, whose interruption is done through a straight groove, the schok at the entrance of the edge in the workpiece, after traversing the interruption, is always done against the same point of the edge, but the total time of the schok is longer, making the tool suffering less with the impact.

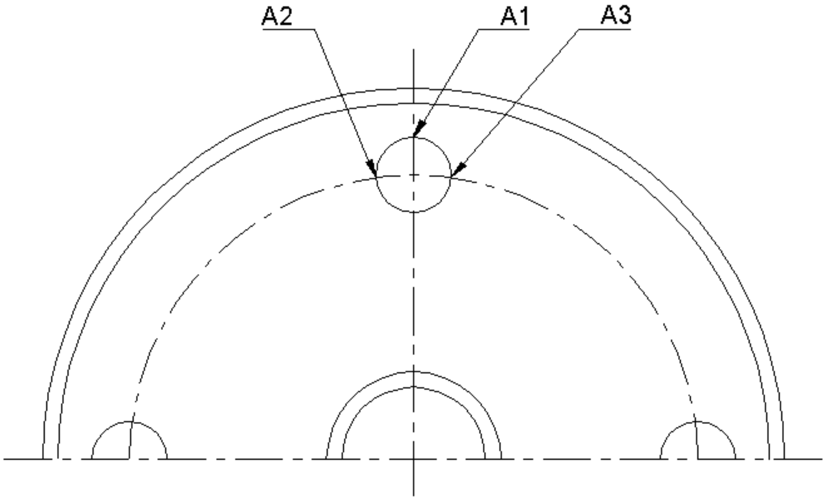


Figure 3 – Detail of the workpiece P2

4. Conclusions

Based on the results and discussions presented in this paper it can be concluded that:

The CBN 7020 (low content of CBN) cutting tool presented longer lives than the CBN 7050 (high content of CBN) tool, for all tests done with continuous cut;

A CBN cutting tool with high content of CBN, (CBN 7050), is not supposed to be used in hardened steels continuous cut, because its wear resistance is not enough for this task;

Even in the semi interrupted cut, the 7020 tool presented longer life, than the 7050 tool. Only in the interrupted cut that the higher toughness of the 7050 tool could be noticed and its performance was better than the 7020;

The CBN 7020 tool is more suitable for the continuous and semi interrupted cut. When the workpiece has several interruptions, the tests done do not allow to conclude, safetily about the best cutting tool to be used;

The increase in cutting speed from 120m/min to 150m/min increased ou kept Constant the 7020 and 7050 tool lives;

The increase in cutting speed from 150m/min to 180m/min decreased the 7020 and 7050 too lives;

Using high hardness and low toughness cutting tools, the results and the behaviour of the wear presented high dispersion;

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