Qualitative Analysis of Replacing Grinding with Hard Turning

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Abstract
Because of the development and rising of the manufacturing industry, the cutting tools and machine-tools manufacturers had to innovate and develop newer solutions for industry, a more efficient, from an economic point of view, and more environment friendly, to maintain the competitiveness in the market. Therefore, with the help of the last generation of cutting tools with high hardness and specific geometry, as with very rigid and high precision machine tools (lathes), hard turning became quickly a serious alternative for replacing grinding in many applications. The concerns for this solution started about one decade ago and is applied in high-end industries that have stronger directions to be the best in class. Current papers limited themselves just on highlighting test results performed by different tool manufacturers and users. This paper refers to a systematic approach of replacing grinding with hard turning, incorporating relevant experiences presented both in literature and in the author's direct research. We have highlighted the advantages of hard turning in relation with grinding, as well as the limits of replacing hard turning with grinding.

Keywords
manufacturing, cutting tools, hard turning, grinding, competitiveness

1. Introduction

The precision manufacturing industry is characterized by high precision and low roughness levels. The aim of this paper is to identify the conditions where the hard turning can replace grinding while maintaining technical conditions required from the technical drawing. This aspect may lead to a high flexibility of the manufacturing system as well as a decrease in cycle time and production costs. All these optimization will generate an increase of competitiveness of the manufacturing system.

The technological changes plays a key role in handling manufacturing limits and represent one of the main factor of competition. Furthermore, it plays an important role in changing the industries structure and contributes to launching new industries [1]. Generally, in manufacturing, grinding is considered a precision manufacturing process. In conventional machining, the precision parts need to be ground after soft turning and heat treatment. Once with the development of cutting tools with high hardness level, with specific geometries, as well as the development of rigid lathes, hard turning process was able to reach the high requirements of finishing machining [2].

At finishing machining of heat-treated steel parts, with 45-64 HRC unit hardness, the inserts, which contain polycrystalline cubic boron nitride (PCBN) or polycrystalline diamond (PCD), combined with the last turning techniques can generate roughness and tolerances similar or better than grinding.

At hard turning, the tool wear is an essential indicator that makes the difference between the possibilities to apply or not this method. Characteristics like, low roughness of the machined parts, minimum structural changes and high dimensional accuracy of parts can be obtain with adequate low-wear tools and precise machine tool. Because the cost of tools used for hard turning is significantly higher than other tools, they need to have high durability to ensure the economic efficiency of the process [3].

The materials which meet the hardness requirements for cutting tools manufacturing used at hard turning are: ceramic materials (aluminium oxide -Al_2O_3 and silicon nitride-Si_3N_4) and very hard material (PCBN and PCD) [4]. Over these materials, usually is added physical (PVD - Physical Vapor Deposition) or chemical (CVD - Chemical Vapor Deposition) a layer (coating) of 3-7μm thickness with the purpose to obtain a longer tool life. The most usually coatings are: titanium nitride (TiN), titanium carbo-nitride (TiCN), titanium aluminum nitride (TiAlN) and aluminum oxide (Al_2O_3).

In Figure 1 is presented the hardness of most common cutting tools materials.

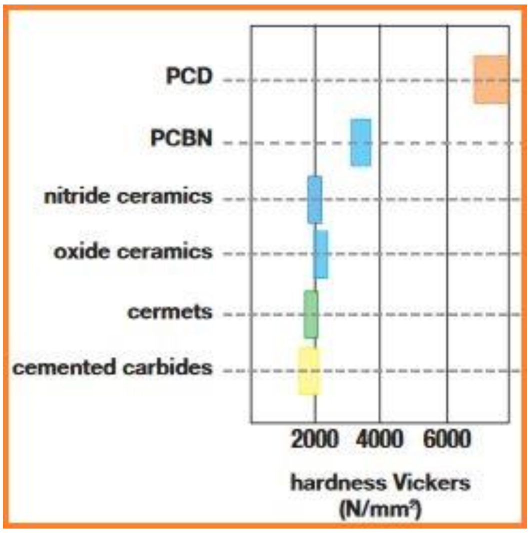

Fig. 1. Cutting tools materials hardness (HV units) [5]

2. The Advantages of Replacing Grinding with Hard Turning

In literature [2, 5, 6, 7, 8] are presented some advantages and benefits of replacing grinding with hard turning:

- hard turning process represents a significant way to increase the efficiency of finishing machining - all operations can be done by one clamp;
- the grinding operation produces a large quantity of heat on the contact area, the part can be slowly deformed and very often can appear burns - by turning these risks can be avoided;
- can be machined complex surfaces, profiled, in many cases with only one tool;
- hard turning has a higher material remove rate than grinding;
- lathe setup time is lower than grinding machine setup time;
- machining time lower on hard turning;
- internal and external machining performed on the same machine-tool;
- green manufacturing - environment requirements in manufacturing processes are increasing. At hard turning, we can use dry machining, without coolant, the chip can be recycled and these are major advantages in environment protection compared to grinding;
- the chip can be recycled.

In addition, beside these, there are other economic advantages identified, like:

- the possibility to recondition the inserts used for hard turning;
- a lathe is a lower asset than grinding machine;
- lathe energy efficiency is higher compared with grinding machine.

Many researches and test focused to obtain some characteristics by hard turning that can be very close to grinding characteristics, or even higher [9, 10, 11]. It was found that the cutting tool edge geometry directly influences the quality of the finished surface, together with feed rate, in mm/rev, that is the most important factor [9, 10, 11]. The right choice of cutting insert, the right choice of tool holder geometry and the right choice of cutting parameters on hard turning lead to precisions and roughness similar to those obtained by grinding. If it is considered only roughness, the cutting insert designed with Wiper geometry (multi-radii) are more advanced than classic cutting insert with one nose radius. The roughness that can be obtained on machining with this kind of inserts is similar or better then roughness obtained by grinding.

In figures 2 and 3 are presented the difference between standard insert and wiper insert.

Through test [10] conducted on a OHNS (Oil Hardening Non Shrinking) steel, 55 HRC hardness, using a wiper geometry insert (cutting speed 120 m/min, feed rate 0.08 mm/rev, and depth of cut 0.1 mm), it was obtained Ra = 0.109 μm and using a ceramic insert [11], AISI H13 steel, 54 HRC units hardness (cutting speed 160 m/min, feed rate 0.1 mm/rev and depth of cut 0.2 mm), it was obtained Ra = 0.09 μm.

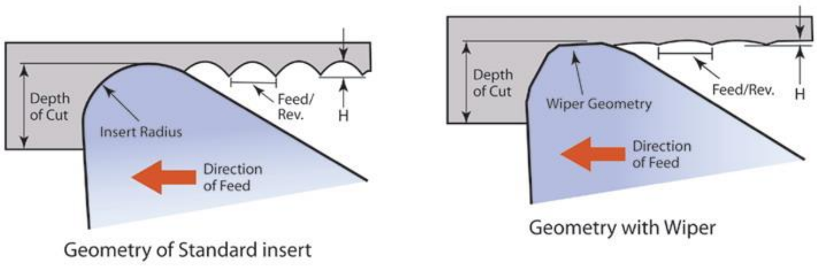

Fig. 2. Standard nose radius vs. wiper geometry [12]

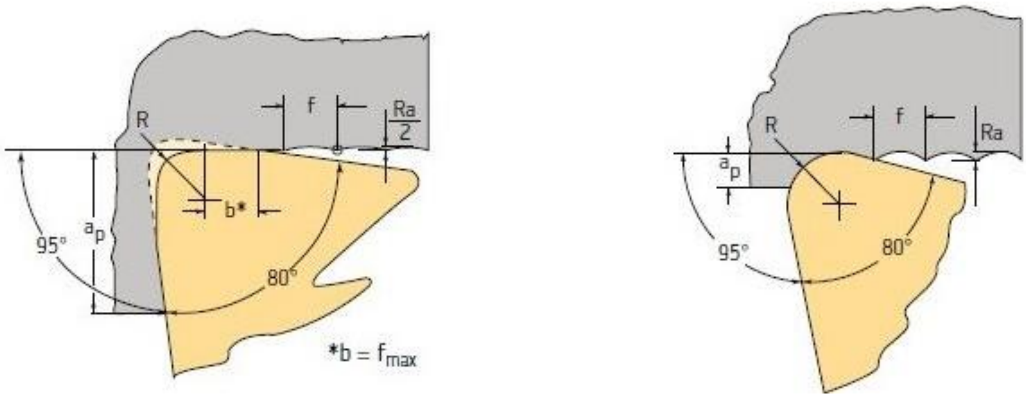

Fig. 3 Wiper geometry vs. standard nose radius - 80˚ insert [13]

3. The Process Limits

Although the hard turning can replace grinding in many applications, there are other areas where grinding remains, for the moment, the right finishing operation. The inserts used for hard turning are brittle and have a low resistance in front of the shocks produced by interrupted cuts [14]. For this reason, the hard turning is rarely used, at interrupted cuts, as for example, on low dimension parts with low depth of cut. When dealing with large applications that have high interrupted surfaces, grinding still remain the most economic finishing process.

An application where hard turning can replace grinding was presented in [14] where, at radial interrupted turning of some low dimension parts and depth of cut 0.15 [mm] there weren't present insert cracking or chipping, and the tool life was higher than continues turning due to the fact that the temperature generated at the tip of the insert was lower. An application where hard turning cannot replace grinding it is represented by some parts (ex. for rotating), with high dimensions and high depth of cuts, that have some holes or millings before heat treatment. Depending of heat treatment, the parts can achieve up to 60 HRC units hardening and in this case, the interrupted turning is not an economic operation because the inserts will crack or chip.

The hard machining materials, like alloys rich in chromium, nickel or titanium also represent an obstacle in replacing grinding with hard turning. The tool wear is very fast and pronounced being an expensive and decisive factor. In this case, the replacing of grinding is not an economic solution. Moreover, the unpredictable tool wear is a process risk, because the tool wear can lead to machined surface damage and being final finishing operation can lead to parts scrapping.

From shape and position deviations point of view, grinding is superior at roundness and cylindricity and hard turning is superior at concentricity and perpendicularity because the parts can be finished by one clamp, as well as flatness and parallelism [15, 16]. From tolerances point of view, by hard turning is harder to obtain accuracy down to microns when compared with grinding.

For the parts which the final surface can't be fully obtained with the same tool and an additional tool is required, this change would not be possible due to multiple factors such as: tools measurement errors, cutting tools manufacturing accuracy, machine-tool components movement errors etc., which can affect the accuracy and the quality of the part.

4. The Qualitative Analysis of Replacing Grinding with Hard Turning

Many researches focused on the characteristics of surfaces obtained by hard turning and grinding, 2D and 3D [6, 17…22]. From the most important characteristics that were analysed, are mentioned:

- roughness and surface topography;
- white layers;
- surface hardness;
- surface profile;
- residual stress;
- fluid retention ability.

From these researches it was concluded that hard turned and ground surfaces have different characteristics. These characteristic influences the part lifespan but is not known certainly how and how much each of these characteristic influences the lifespan of the part. Also, from paper [22] resulted that ground surfaces have a hardened zone (white layers) which is thinner that turned surfaces, hard turning causes a ticker plastically deformed zone than grinding and heat affected zone is larger at grinding because it can generate higher temperatures which penetrate deeper into the part.

The white layers, whose composition can be different [3], are generated at hard turning as well as by grinding. The austenitic white layers are characterized by fine-grained structure, corrosion resistance and higher hardness [3, 23, 24] and probably can influences some characteristics of the part [23, 24]. The thickness of this layer usually is higher on turning than on grinding [25, 26, 27] and major factors in appearance of this are cutting speed and tool wear [25, 26].

Some researches [23, 26, 28] focused on elimination or minimization of these white layers on hard turning and some possible solution can be:

- cryogenic machining, with liquid or gaseous substances, like nitrogen or carbon dioxide;
- the use of adequate cutting speed;
- the use of a new corner of insert at finishing operation.

The roughness like, arithmetic mean surface roughness (Ra) and maximum height of the roughness profile (Rz) resulted by hard turning can be similar or better than those resulted by grinding if the cutting conditions are chosen right. In case of grinding, the roughness is influenced by grinding wheel grain, in terms of a fine grain of grinding wheel lead to a fine machined surface [29], and in case of turning, the roughness is influenced by cutting conditions (feed rate, depth of cut, cutting speed) and cutting tool type.

In Table 1, there is a comparison between these two methods, based on several characteristics. The comparison model can be found in [30].

Table 1. Comparison between methods

Characteristic	Hard turning	Grinding
Machine-tool cost	+	
Material Remove Rate - MRR	+	
Roughness		+
Dimension and shape accuracy		+
Using of coolant	+	
Chip recycle (tools + material)	+	
Tool cost reported to tool life *	=	=
Machine setup time	+	
Flexibility **	+	
Interrupted cutting		+
Risk of burns	+	
Worker qualification	+	

(+)advantage, (=)equality

* the cutting inserts (CBN/PCBN) can be reconditioned and used for roughing machining;

** ID and OD cuts, profiles, radii.

In this comparison machining time was not considered because is influenced by cutting parameters and machining allowance.

4. Conclusions

Hard turning can be a flexible and economic alternative of replacing grinding, especially on the parts where the depth of cut are high, but we need to keep account about process limits and application fields of these parts. Low purchasing and low repair costs of machine-tool and possibility to reconditioning the PCBN tools (the cost of this reconditioning is about 20-50% of initial price) and used for roughing machining, are key factors that can lead in achieving maximum economic efficiency of the process.

For the moment, in medical engineering, aerospace engineering and some automotive divisions it is almost impossible, that this process change, to be implemented due to customers severe requirements that necessitate some ground surfaces, also because there are no proven results, which can demonstrate that the turned and ground surfaces have similar characteristics.

The economic efficiency of replacing grinding with hard turning, there where is allowed and it can be done, it should be determined by keeping into account the production size, too.

The cutting inserts for hard turning showed their value and performance, moreover in the authors opinion the second brilliant factor in achievement of this process change among the cutting tools, is the machine tool.

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