RECENT J. (2024), 73:130-137
https://doi.org/10.31926/RECENT.2024.73.130

Study of Surface Integrity after Hard Turning and Superfinishing

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Abstract
Both hard turning and superfinishing are manufacturing processes aiming to obtain high-quality surfaces, which lead to the fulfilment of high-quality requirements of the parts used in industrial applications subject to high loads. Using these two processes leads to very smooth surfaces, with low roughness, necessary to increase the lifetime of the parts. The aim of the experiment is to determine the capability of hard turning process, in achieving similar performances to superfinishing process, under certain technological conditions. Conical rolling elements were used in experiments, analysing the surface integrity, i.e. surface roughness, both after longitudinal and frontal hard turning, as well as after superfinishing. The results show that using hard turning as finishing process, a very good surface quality can be obtained, similar to those obtained by superfinishing, in terms of roughness.

Keywords
hard turning, superfinishing, surface integrity, surface roughness

1. Introduction

In industry, the technology is viewed like a method of achieving the aim, compared to a human activity, which aims to fulfil and apply specific tools to the process used by the organisation to achieve the goals [1, 2]. One of the most well-known machining processes used by various organizations in the manufacturing industry, noted for its yield in achieving high surface finish and geometrical tolerances, is hard turning process [3-5].

Over time, the hard turning process has been an economical solution for manufacturing plants. Hard materials processing has become increasingly popular, mainly in the automotive industry, due to the advanced tools used in machining processes, providing a substantial input in reducing the costs and the processing time, as well as on the improving the quality of the resulting product [6].

In their work, Singh & Rao [7] mentioned some of the advantages of hard turning, such as high productivity, finishing surface almost the same as at grinding process and the possibility of processing hard and complex parts. Also, the work focused on the development of a model for predicted the surface roughness obtained by the hard turning process, aimed at early identification of surface quality and optimize the process parameters (such as cutting speed, feed, cutting depth) or type of tool, in order to improve the quality of the products [7].

The second process analysed in this work is superfinishing, a process that aims to reduce the roughness of processed surface [3-5]. Superfinishing facilitates the removal of surface irregularities after the hard turning process, ensuring a uniform finish and improving the visual aspect of the part [6]. The result of this process mainly consists in improving the surface integrity, thus obtaining parts with superior performance, which meet the operating conditions in various industrial applications [6].

Nayak & Rathod [8] analysed the new methods used in hard turning process and shows a series of benefits of improving the quality of the process, such as the use of wiper inserts lead to an increase of cutting speed, as well as feed, in order to reduce the processing time, meaning lower production costs. Also, it mentions that the modern inserts used in processes have a longer product life cycle.

The main aspects regarding the integrity of the technological surface [9, 10], which are followed after submitting to technologic processes, are presented in the next figure (Figure 1).

In order to obtain the longest possible life cycle of the machined parts, these aspects must be continuously checked and improved, because maintaining the surfaces integrity is essential in current manufacturing processes, as well as in the development of more advanced technologies. While maintaining of proper integrity of the technological surfaces, there are ensured the reliability, durability and performance of the products in different industrial field and not only [8-10].

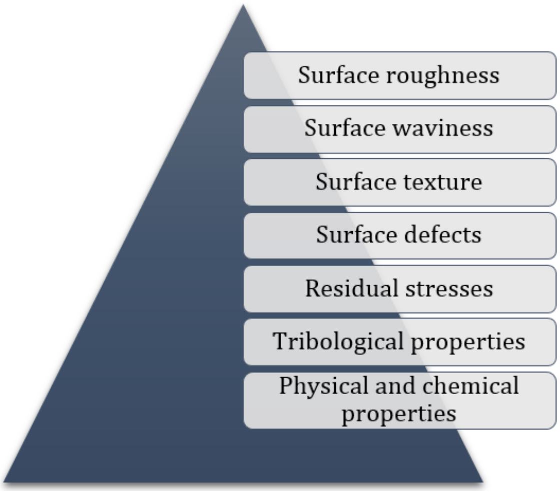

Fig. 1. Main aspects of surface integrity

Table 1 shows the main characteristics of the surface integrity aspects, according to Figure 1.

Table 1. The main characteristics of the surface integrity aspects [11, 12]

Aspects of the surface integrity	Influences
Surface roughness	friction, wear and component performance
Surface waviness	parts assembly parts operation may cause vibration and noise
Surface texture	behaviour of friction and wear
Surface defects	fatigue resistance hardness and corrosion resistance may cause cracks, scratches, pores, inclusions
Residual stresses	durability of parts behaviour of parts in operation fatigue resistance
Tribological properties (study of friction, wear and lubrication between contact surfaces)	may cause wear may cause energy loss
Physical and chemical properties	parts performance and durability

The performance and reliability of the parts obtained through the cutting processes are influenced by the integrity of the final surfaces, therefore the surface roughness represents a significant characteristic, because it can influence the functional properties of the surface, such as wear, friction and the ability to retain lubricates [9-11].

The quality of the surfaces is very important regarding to performance, life cycle, appearance and quality of products obtained through the cutting processes [12, 13]. The surface quality depends on the physical aspect the surface quality, i.e., the physic-mechanical and chemical condition (e.g., micro hardness, residual stresses, degree of deformation), but also by the geometric aspect of the surface quality, i.e., the geometry of surface layer [14-16].

Roughness, the surface shape deviation, is considered one of the most important characteristics in the cutting processes, because it can influence the functional properties of the product surface [11, 15].

The roughness profile parameters, which aid in the quantitative determination of roughness, are divided into two categories, physical parameters and statistical parameters [13, 15, 17]. The roughness is characterized by a series of parameters [15, 18, 19], analysed in this work:

R_t → total height of profile → represents the distance between the highest peak (maximum point) and the deepest valley (minimum point), on the evaluation length;
R_z → maximum height of profile → the average height of irregularities;
R_a → arithmetical mean deviation → the mean arithmetic of the absolute values;
R_k → Kernal or Core Roughness Depth → represents the depth of the roughness core profile;
R_{pk} → reduced peak height → mean height of the peaks detaching from the roughness profile;
R_{vk} → reduced valley depth → depth of the profile valleys into the material from the core;
R_p → the maximum profile height.

The surfaces roughness has an important role on the functional aspect of the components resulting from the technological processes. The aspects that can be influenced by the surface roughness are presented in Figure 2 [13, 14, 20].

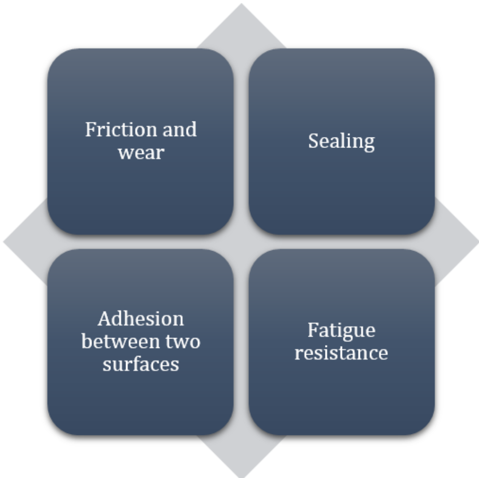

Fig. 2. Influence of the roughness on the product performance

In this work, an evaluation of the integrity of the technological surface following the two processes was carried out, from the perspective of the surface roughness. Regardless of the surface processing method, the integrity of the surface obtained after processing is very important, ensuring close monitoring of the quality and characteristics of the manufactured surfaces after mechanical processing.

2. Materials and Methods

In this experimental study, a conical rolling element was used, made of 100CrMnSi6-4 material, with the dimension Ø70×Ø66×165 mm and a turning cutting tool with CBN (cubic boron nitride).

For frontal hard turning, 20 mm length was machined on each face, starting from outer diameter to the centre of the part. The machine-tool used for hard turning was a precision horizontal lathe. For superfinishing process, a custom-made equipment for external round machining was used.

2.1. Chemical composition of material

The steel used for the tests was of 100CrMnSi6-4 type (EN 1.3520), heat treated, brought to a hardness of about 60 HRC. Table 2 summarizes the chemical composition of material according to [22].

Table 2. The alloying elements and their percentage of 100CrMnSi6-4, adopted from [22]

C	Mn	Si	P	S	Cr	Ni	Cu	AL
0.93-1.05%	1.00-1.20%	0.45-0.75%	<0.025%	<0.03%	1.40-1.65%	-	<0.30%	<0.05%

The material 100CrMnSi6-4 is a high-carbon steel for rolling element bearings, with high hardenability, especially used for elements with a cross-section greater than 30 mm, for balls, needles, bearing rings or precision shafts [22, 23].

The steel is suitable for working in corrosive environments, applications subject to corrosion and high temperatures. Also, it has a high abrasion resistance [22, 23]. Moreover, it can also be used for machine tools components that require high tensile strength and high hardness [24].

2.2. Cutting tools

The cutting insert used in experiments was ISO positive insert type VBGW 160412, grade BNX10, uncoated, manufactured by Sumitomo Electric Hardmetal [25], with corner radius 1.2 mm, conventional geometry, recommended for continuous high-speed hard finishing operation. This grade is a low content CBN (40-45%) according to supplier, while the edge preparation type T01225 consist of negative land width of 0.12 mm and 25° angle, without honing [25]. The tool holder was standard available type SVJBR 2020K16. The insert-holder combination provided a cutting-edge angle of 93°, orthogonal rake angle γ of 0° and effective rake angle, $\gamma_{ef} = -25°$ due to edge preparation (Figure 3) [25].

For superfinishing process, the cutting tool was a stone with grit size 800.

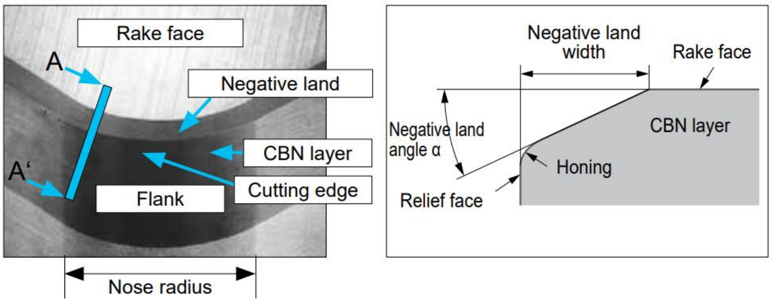

Fig. 3. Insert micro-geometry. Adapted from [25]

2.3. Machining conditions

The technological parameters (cutting parameters), such as cutting speed (V_c), cutting feed (f) and cutting depth (t), for the hard turning process, were set according to the instructions provided by the tool manufacturer and had the following values, presented in Table 3. The hard turning was performed in flood cooling conditions. Both in case of longitudinal and frontal hard turning, the machine tool automatically calculated the rotation per minute (rpm) of the part, in order to maintain constant cutting speed.

Table 3. Hard turning conditions

Cutting parameters		
	Longitudinal hard turning	Frontal hard turning
V_c [m/min]	200	200
f [mm/rev]	0.12	0.05
t [mm]	0.3	0.1

The technological parameters for the superfinishing process are shown in Table 4.

Table 4. Superfinishing conditions

Cutting parameters	
V_c [m/min]	120
Feed [mm/min]	4000
Stone pressure [N]	180
Double stroke [1/min]	10

2.4. Roughness measurement methodology

The measurement of the surface roughness was carried out with a roughness tester Hommel-Etamic, type W5. In longitudinal hard turning, the roughness R_z was measured at three different locations at about 120° apart. After the first measurement made approximately in the middle of the workpiece, with length 165 mm, two more measurements were made to validate the first measurement, at a distance of about 40 mm left and right, from first measurement. For frontal turning and superfinishing, the roughness was measured at a single point, located in the middle of the workpiece.

3. Results

In the case of longitudinal turning, the qualitative criteria is to obtain a roughness R_z lower than 3 µm. Table 5 describes the test results.

Table 5. Results of hard turning tests on the longitudinal surface

Longitudinal hard turning [µm]				
	R_{z1}	**R_{z2}**	**R_{z3}**	**$R_{z\ average}$**
Piece 1	1.897	1.888	1.865	1.883
Piece 2	2.131	2.145	2.146	2.141
Piece 3	2.348	2.409	2.362	2.373
Piece 4	2.651	2.623	2.674	2.649
Piece 5	2.348	2.211	2.215	2.258
Piece 6	2.777	2.789	2.763	2.776
Piece 7	2.214	2.256	2.284	2.251
Piece 8	2.635	2.666	2.689	2.663
Piece 9	1.895	1.948	1.999	1.947
Piece 10	2.011	2.149	2.196	2.119
Piece 11	2.232	2.316	2.419	2.322
Piece 12	2.596	2.494	2.484	2.525
Piece 13	2.463	2.494	2.484	2.480
Piece 14	2.516	2.601	2.482	2.533
Piece 15	2.632	2.704	2.891	2.742
Min	1.895	1.888	1.865	1.883
Max	2.777	2.789	2.891	2.776

The measurement was made in three points. Through longitudinal hard turning, with these parameters, the roughness requirement is achieved relatively easily. A high value of the cutting feed worsens the quality of the surfaces, but leads to increase the productivity.

However, through frontal hard turning, the quality requirements are tighter. The requirements are as follows: R_k = 0.4 µm, R_{pk} = 0.15 µm and R_{vk} = 0.05-0.35 µm. The test results are illustrated in Table 6.

As can be seen, the values obtained at the frontal hard turning satisfy the specifications for R_k, R_{pk} and R_{vk}. Also, it is important to specify that these values of roughness, most often specific to superfinishing process, were obtained by hard turning. The values of the roughness from R_k family correspond to a roughness R_z between 0.409 µm and 0.800 µm.

From these experiments, it is noted that using these parameters were obtained values of the R_{vk} parameter between 0.063 µm and 0.141 µm, a positive aspect for tribological applications, since the valleys, within cu certain limit, facilitate the retention of fluids or lubricants.

After frontal hard turning, the surfaces are not fine enough to meet the quality requirements. Therefore, they are superfinished. Through superfinishing process of the parts are obtained the following roughness parameters described in Table 7.

Based on the results presented in Table 7 it can be concluded that at the superfinishing process, it was obtained the roughness R_z between 0.500 µm and 1 µm. At least as good roughness was achieved at the frontal hard turning.

Table 6. Results of hard turning tests on the frontal surface

Frontal hard turning [μm]				
	R_k	**R_{pk}**	**R_{vk}**	**R_z**
Piece 1	0.293	0.083	0.068	0.709
Piece 2	0.282	0.089	0.074	0.615
Piece 3	0.213	0.076	0.068	0.591
Piece 4	0.221	0.089	0.092	0.673
Piece 5	0.192	0.081	0.076	0.714
Piece 6	0.212	0.096	0.083	0.631
Piece 7	0.219	0.099	0.083	0.799
Piece 8	0.194	0.073	0.079	0.800
Piece 9	0.234	0.072	0.076	0.409
Piece 10	0.213	0.091	0.063	0.741
Piece 11	0.224	0.083	0.071	0.768
Piece 12	0.238	0.102	0.141	0.549
Piece 13	0.202	0.081	0.079	0.419
Piece 14	0.241	0.096	0.082	0.594
Piece 15	0.210	0.091	0.086	0.683
Min	0.192	0.072	0.063	0.409
Max	0.293	0.102	0.141	0.800

Table 7. Results of superfinishing tests on the longitudinal surface

Superfinishing [μm]			
	R_a	R_z	R_t
Piece 1	0.077	1.015	2.307
Piece 2	0.110	1.136	1.727
Piece 3	0.088	0.822	1.077
Piece 4	0.065	0.684	0.862
Piece 5	0.078	0.758	1.050
Piece 6	0.076	1.058	1.662
Piece 7	0.053	0.544	0.831
Piece 8	0.061	0.676	0.874
Piece 9	0.075	0.698	0.934
Piece 10	0.086	0.944	1.248
Piece 11	0.065	0.672	0.736
Piece 12	0.094	1.041	1.383
Piece 13	0.074	0.992	1.348
Piece 14	0.054	0.653	0.097
Piece 15	0.088	1.142	1.592
Min	0.053	**0.544**	0.097
Max	0.110	**1.142**	2.307

4. Conclusions

The hard turning process is a sustainable and economical alternative to expensive grinding processes. Even if in the last years lot of research has been carried out to identify the performance of this process, there are still many unsearched aspects regarding the capabilities of hard turning in terms of the surface quality that can be achieved.

In this work were analyse two machining processes, hard turning and superfinishing, by means surface roughness. Thus, based on the test experiments, the following conclusions can be summarised from the research:

- using a cutting speed V_c = 200 m/min and a cutting feed f = 0.05 mm/rev, the roughness parameters such as R_z, similar to superfinishing, can be obtained from hard turning;

- at longitudinal hard turning the lowest value of roughness R_z was 1.883 μm and the upper 2.776 μm, while at the frontal hard turning the lowest value was 0.409 μm, and the upper 0.800 μm;
- the results obtained at superfinishing, regarding R_z roughness, are similar to results obtained at frontal hard turning, specifically 0.544 μm, respectively 1.142 μm;
- the R_z roughness values are similar between the two processes, which means the hard turning process has similar capabilities to the superfinishing process, under certain technological conditions.

Future research should be focus on investigating the optimal working conditions and parameters, using both dry machining and organic lubricants cooling, in order to obtain very fine surfaces through the hard turning process, thus fulfilling certain requirements of green manufacturing.

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