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IFLUENCE OF THE TOOL OVERHANG AND MATERIAL IN SURFACE QUALITY OF HARDENED STEEL'S INTERNAL TURNING

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Abstract. *The quality of a machined surface is directly related to the vibrations which the tooling system is subjected and this behavior is even more pronounced in internal turning operations. The correct choice of the boring bar and the overhang that would be used plays a fundamental role in the machining performance. Tests were conducted in a ROMI CNC lathe, using steel and carbide boring bars. Finishing machining conditions were maintained throughout the tests and the tool overhang was gradually increased until the surface roughness (Ra) did not exceed the value of 0.8 µm. For each overhang, impact hammer and cutting tests were carried out. Results showed that within the steel boring bar overhang range the surface quality obtained was close to both bar materials. Carbide boring bars are able to work with higher overhangs*

Keywords: *internal turning, vibrations, surface quality*

1. INTRODUCTION

Most of the parts made by machining operations have at least one hole. When arising from former operations as casting, the holes don't have good geometry and dimension quality and finishing operations, as boring, are necessary. However, due to the cantilever shape of boring bars, excessive vibrations (as chatter) are a usual problem that must be minimized. Different approaches for understanding and minimizing the vibration were taken as: reviews on chatter vibration (Quintana and Ciurana, 2011, and Siddhpura and Paurobally, 2012), simulation of boring process dynamics (ATABEY et al., 2003, and Moetakef-Imani and Yussefian, 2009), manufacturing of different kinds of boring bars (Lee, 1988, and Suzuki et. al., 2012) and the use of dampers (Rivin and Kang, 1989, and Ema and Marui, 2000).

Hole finishing is tougher when it is done in hardened materials (above 45 HRc). This meant grinding was the recommended operation for obtaining holes with the desired surface quality. And this scenario started to change when ceramics and the cubic boron nitride (CBN) were used widely as tool materials.

The hard internal turning (also known as hard boring) is a possible solution in order to increase the surface finish in holes of hardened parts. However, for deep holes and situations when the length of the hole increases above the diameter of the boring bar, the lack of stiffness of the tool may lead to chatter occurrence in the finishing operation. Other difficult that occurs is the fact that, according to tool's manufacturers, damped bars are not recommended due to small depth of cut usually used.

This work aims to evaluate the effect of the tool overhang in the hole finish quality produced by hard boring using steel and carbide bars.

2. LITERATURE REVIEW

When dealing with the machining of hardened materials, some concepts should be enlightened. The literature review has been divided into 2 sections.

2.1 Hard part machining

Traditionally, the finishing of hardened (with hardness over 45 HRc) is produced by grinding. Recently, however, the use of ultra-hardened tools with defined geometry (as CBN and ceramics) has become able to replace the grinding operations and ensure surface quality (with mean roughness - Ra - values below 0,8 μm) and dimensional tolerance (IT3) (GRZESIK, 2008). Fig. 1 below shows a qualitative comparison between the hard machining and grinding.

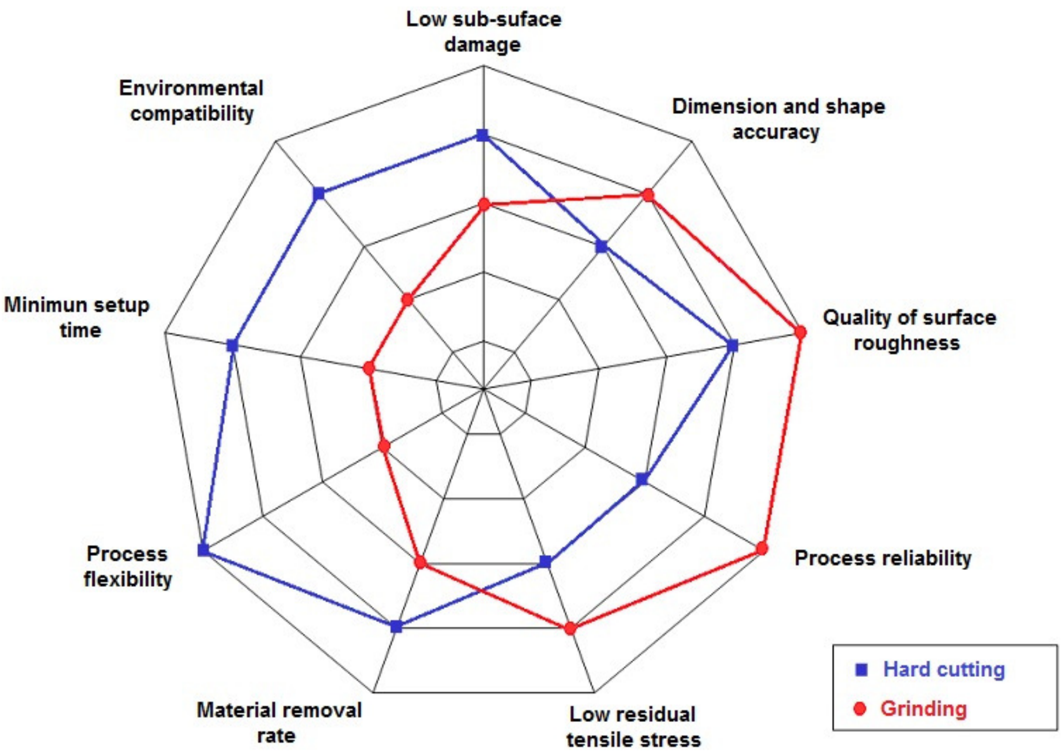

Figure 1. Qualitative comparison between grinding and hard machining (GRZESIK, 2008).

Because it is highly reactive with iron, diamond tool is not recommended for machining steel and other ferrous alloys. Abrasive wear resistance and chemical stability are the most important properties for a material tool intended for turning of hardened steel, so it is recommended the use of ceramic and CBN tools (GODOY and DINIZ, 2011).

The ceramic material has some properties that are important for tool materials, such as hardness at high temperatures and high chemical stability. However, its low thermal conductivity and low toughness makes the use is restricted mainly to the operations which presents stable cutting conditions (continuous cutting and rigid machine tool).

The CBN is more chemically stable than diamond, and can be used in machining ferrous and depending on the concentration of cubic boron nitride under conditions roughing or finishing (the higher the content of CBN tool is tougher), they are used in situations where the diamond can not be used and the carbide does not have sufficient hardness to perform cutting (machining of hardened steels - 45 to 65 HRc - for example). The CBN then competes with the grinding process (DINIZ, MARCONDES and COPPINI, 2006).

The ceramic tools can have better performance than the CBN in the machining of hardened materials. But its fragility (shown mainly by chipping) limits its application (MATSUMOTO, 1998).

The robust nature of the tool holder for external turning with small balance does not present insurmountable difficulties during hard machining. However, the overhangs used in boring operations leads to low L/D ratios (up to 5) and the use of relatively robust boring bars (Smith, 2008).

Even when tools are used robust and rigid systems, there is the occurrence of vibrations and deflections of the tool tip and this situation is amplified when in hard machining.

2.2 Vibrations in machining

According Altintas (2002), Benhabib (2003) and Scheffer and Heyns (2005), the vibrations of the cutting tool and workpiece during machining can be quite detrimental to tool wear and adversely affect the dimensional accuracy and surface finish of parts.

Usually, the internal machining of large diameter holes, deep holes, and a combination of both requires stability, which is maximized by combinations of tools solutions. Beyond the basics (such as the use of maximum diameter possible for the bar, efficient chip flow, positive insert geometry, adequate choice of insert shape, small nose radius and

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cutting edge acute), need to be considered special features tools in order to equip boring bar with all appeals against tendencies to vibration, especially when tolerances are narrow and the surface finish is critical.

Generally, the machining up to 4 times the diameter of the boring bar does not cause any problems in terms of vibration, provided the right conditions are applied on the data and the cutting inserts. But when talking about tool overhangs over 10 times the diameter, must be taken into consideration damped boring bars and reinforced carbide, or a combination of both. The coupling of the cutting unit is a critical link, and must eliminate any risk of instability. The front tip of the tool should also be lightweight. This means that, if the goal is to reduce the diameter of the cutting unit or the last part of the bar, this issue should be taken into consideration. It is the main part and the rear end of the boring bar should be as large as allowing the operation - even conical rods are appropriate for some applications.

To obtain enough processing stability, the rate of metal removal is often reduced or a cutting tool is changed. But, as usual productivity in manufacturing is a priority, this is the wrong path to follow. Instead, a means must be examined to eliminate vibrations and power machine the higher removal rates. The use of damped boring bars with integrated damping elements in boring bars, improves the dynamic behavior of the tools, making it more stable.

3. EXPERIMENTAL PROCEDURE

The specimens are made of SAE 4340 steel, whose composition is shown in table 1 below.

Table 1. Chemical composition of material (% weight).

C	Si	Mn	Cr	Ni	Mo	V	Ti	Al	Cu	P	S	Ceq
0.40	0.25	0.65	0.76	1.68	0.23	0.003	0.002	0.015	0.11	0.018	0.02	0.83

The material was quenched and its hardness was increased to 53.6 ± 0.6 HRc and the specimens design is shown in Fig. 2 below.

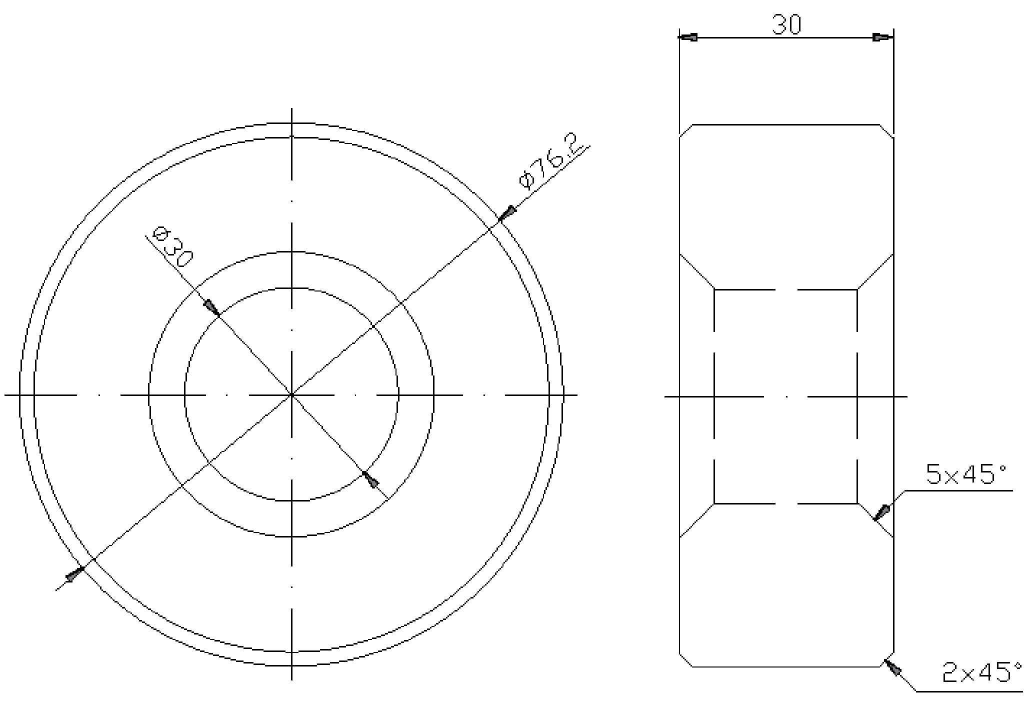


Figure 2. Specimen design and dimension.

The preparation before thermal treatment and the machining tests were conducted in a 20 kW ROMI CNC lathe (4500 RPM maximum speed). CBN inserts, whose codification is CCGW09T308S01020F grade 7015, were used together with 2 boring bars: steel (A20S-SCLCR 09-R 1M 0866943) and carbide (E20S-SCLCR 09-R 1M 0903414).

The accelerometers were fixed 30 mm from the tip of the insert in the tangential and radial directions. Then the specimen was machined for 12 mm. The cutting parameters are show in table 2.

Table 2. Cutting Parameters.

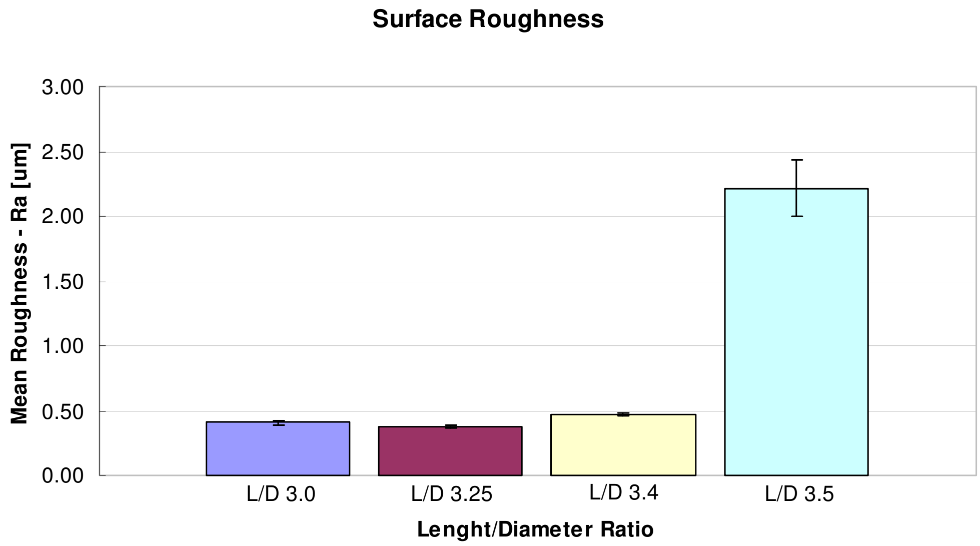
v_c	360 [m/min]
f	0.08 [mm/rev]
a_p	0.1 [mm]

The tool overhang was increased from the L/D equal to 3 until the mean surface roughness achieved the threshold of 0.8 µm.

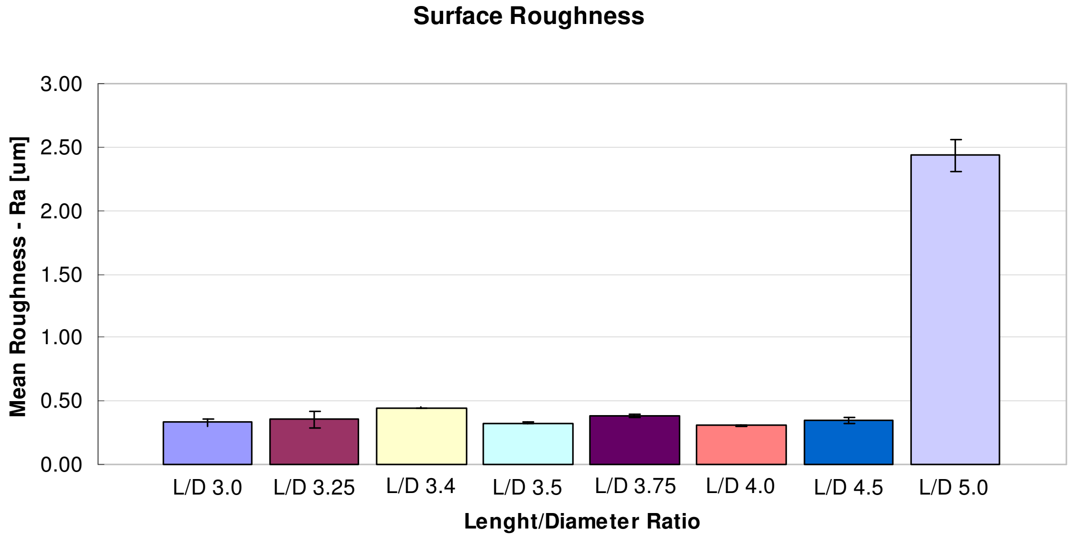
4. RESULTS AND DISCUSSIONS

One of the goals of the hard part machining is its use in exchange of grinding operations. Because of this, the surface roughness should be at least equal to those.

Together with the cutting parameters, the tool overhang plays a fundamental role in the internal turning in order to achieve good finish. Then, Fig 3 shows the behavior of the mean surface roughness (Ra) as a function of the overhang.



(a)



(b)

Figure 3. Mean surface roughness (Ra) versus tool lenght-diamenter ratio for (a) steel, and (b) carbide bars.

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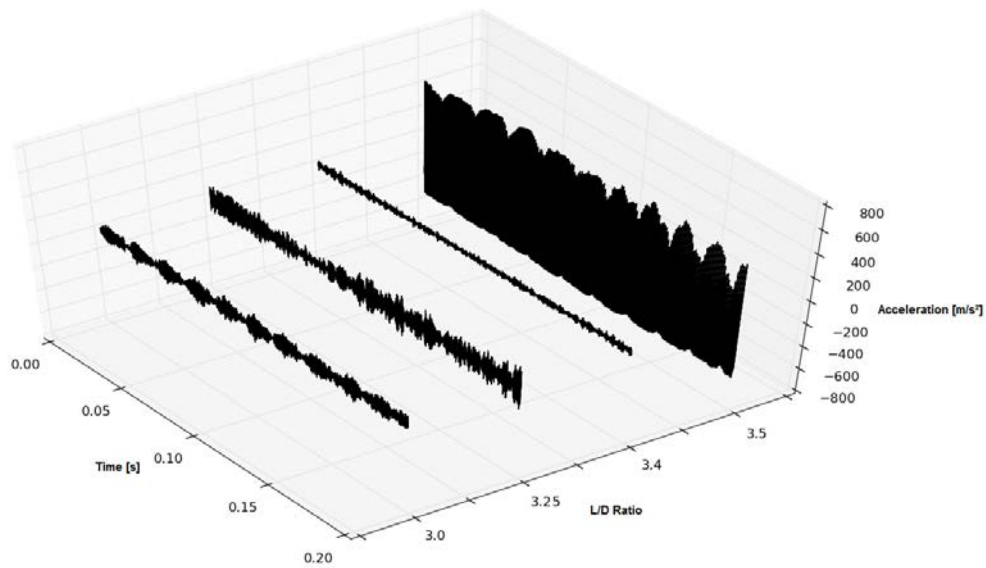
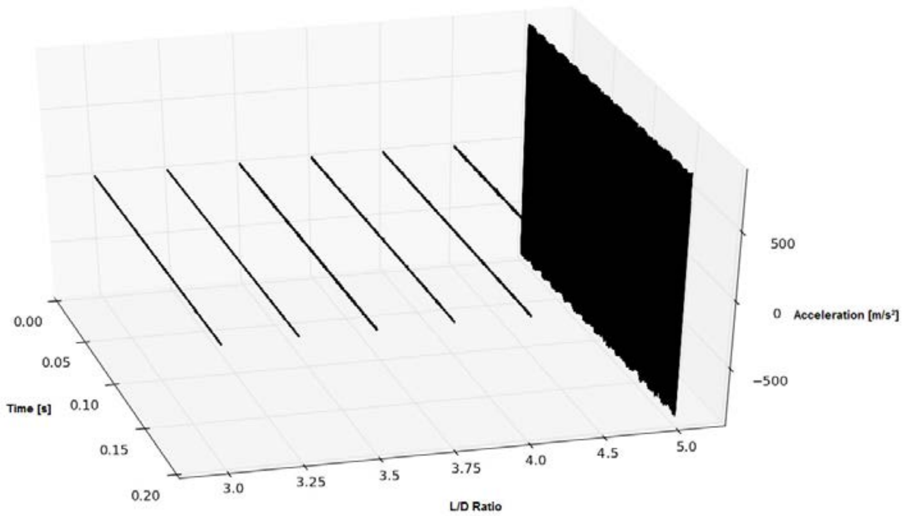
From Fig 3, it can be observed that grinding operations can be satisfactorily replaced by hard turning when finishing is needed. Mean roughness values stayed above the theory values of 0.26 µm but below of the values usually obtained by grinding (08 µm).

The maximum tool overhang for steel bars is 68 mm (L/D equals to 3.4). When the overhang is taken to 70 mm an expressive deterioration of the roughness takes place. In carbide bars, this behavior only occurs when the overhang is equal to 100 mm.

As the cutting parameters were the same for all runs, the high surface roughness values were due to the vibration caused by the tool overhang. So, a more rigorous evaluation of the tool vibration is shown in Fig 4.



(a)

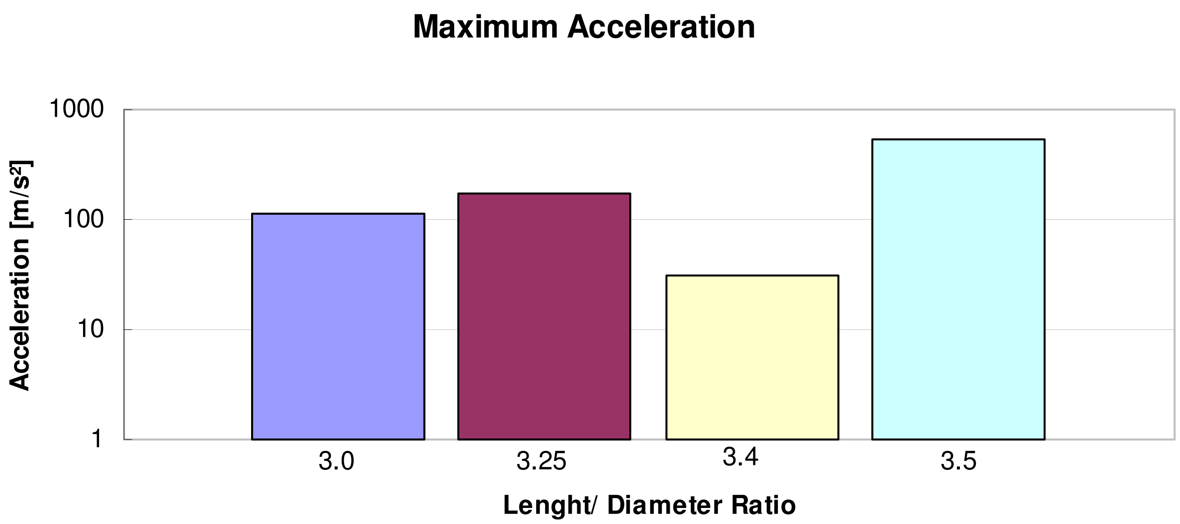


(b)

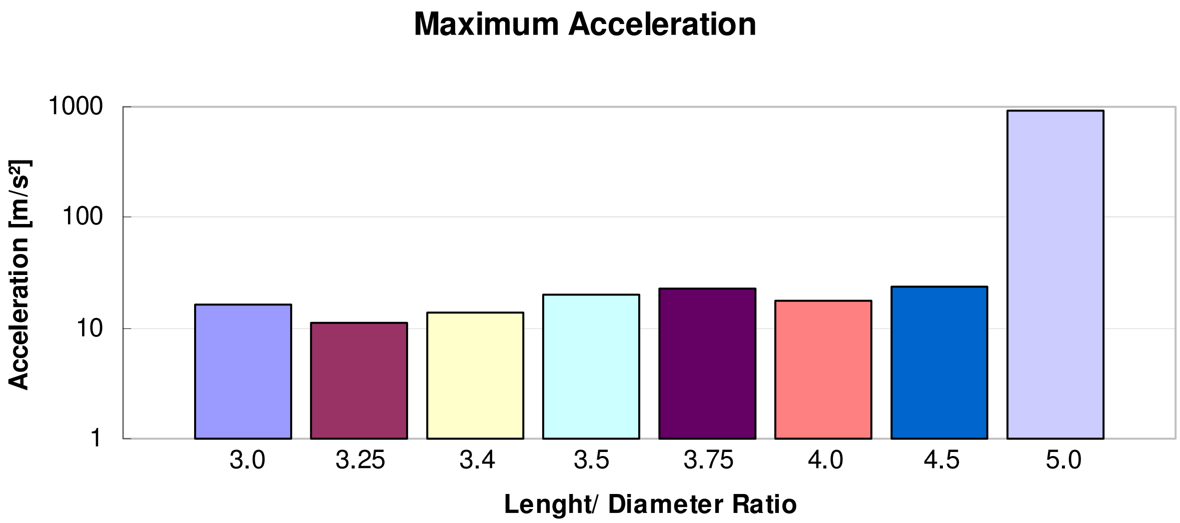
Figure 4. Vibrations in time domain for (a) steel, and (b) carbide bars in different L/D ratios.

The increase in the tool overhang causes a decrease of the tool system stiffness. However it does not cause an increasing pattern in the vibration signal (and consequently increase in the surface roughness) until it reaches a threshold value.

Due to the difference in acceleration amplitude, Fig. 5 below shows the maximum acceleration value in logarithmic scale.



(a)



(b)

Figure 5. Comparison of maximum acceleration for (a) steel, and (b) carbide bar.

The signal amplitude is smaller in the carbide bar for most of overhangs (this only change when the cut became unstable). The L/D ratio equals to 3.5 causes instability in steel bar, however it still allows stable cut in carbide bar (its instability occurs when the L/D ratio is equal to 5). This way the analysis may be divided into stable and unstable cut, because the difference between signals is high (about 10 times greater for steel bar and 100 times greater for carbide bar).

In Fig 6, the signals which lead to instability were removed and the analysis in time domain can be detailed.

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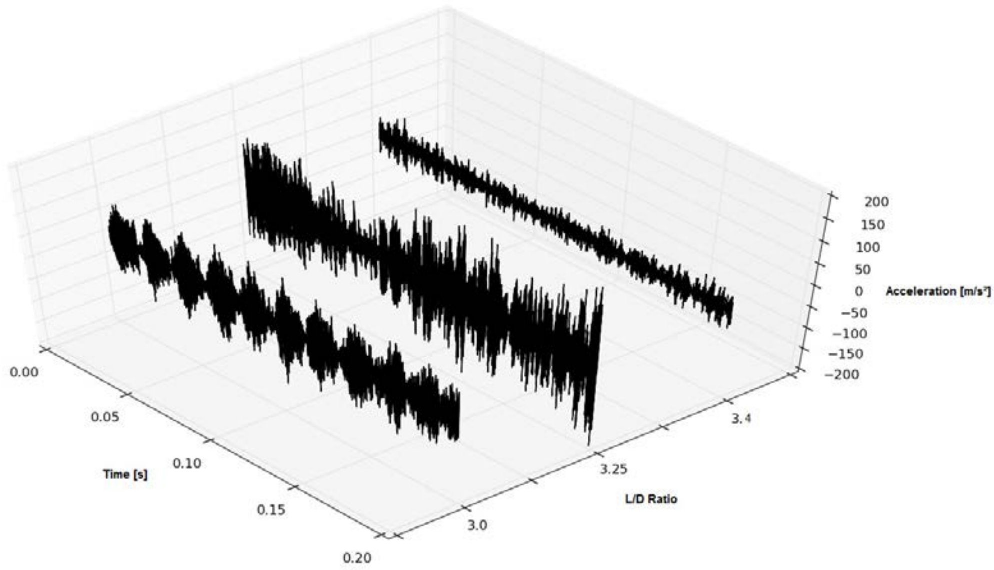
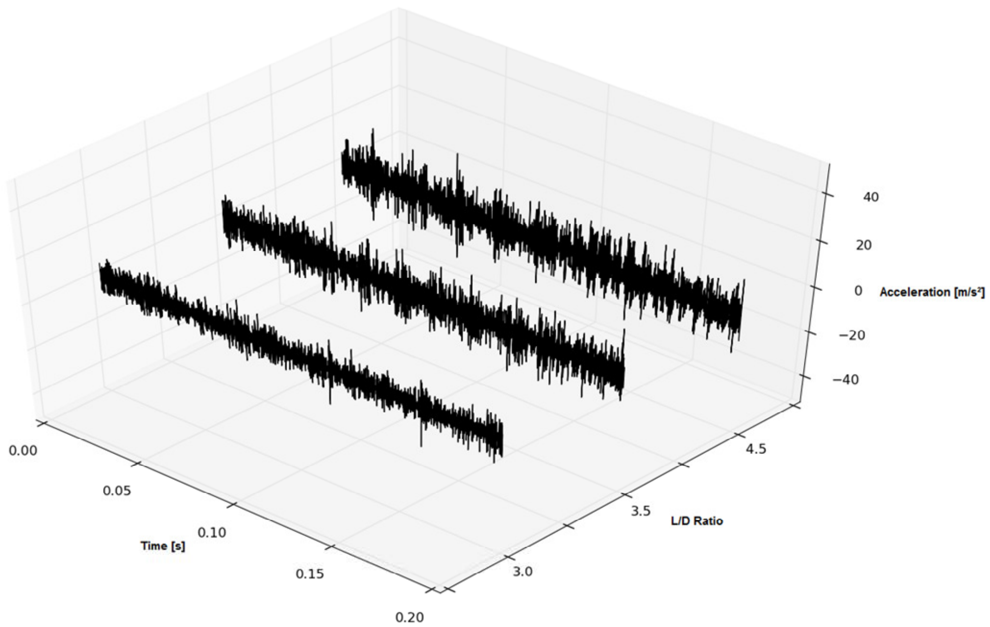


(a)



(b)

Figure 6. Vibration signals in stable cut (a) steel, and (b) carbide bar.

From Fig. 6 above, it can be observed that in the overhangs which the cut is stable, the carbide bar presents vibration amplitude about 10 times smaller than the steel bar (even with higher overhangs). This behavior is related to the higher stiffness of the carbide bar, due to its higher modulus of elasticity.

Even if the higher vibration level, surface roughness obtained when using steel bar was not worse than that obtained when using carbide bar. This means that up to a certain machining configuration, surface finish is ruled by machining parameters (specially feed) and tool geometry.

The use of carbide bar is only recommended for tool overhangs which the steel bar is not applicable. The surface finish is not much better than the obtained by steel bar, however the cost of a carbide bar is higher.

5. CONCLUSIONS

According to the results obtained, it can be concluded that:

- Within the range of application of the steel boring bar, it is indifferent the use or not of the carbide boring bar;
- The carbide boring bar does not provide higher surface quality than the steel bar;
- Carbide boring bars are recommended for overhangs where the steel boring bar is not applicable;
- Considering surface quality, the hard internal turning could be used in exchange for the grinding operations;
- In process vibrations plays a fundamental role in the surface roughness formation.

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