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Cryogenic Hard Turning of ASP23 steel using Carbon Dioxide

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Abstract

Due to rising worldwide industrial competitiveness the machining sector is compelled to improve day by day. In this way, CO2 cryogenic machining is presented as alternative to conventional hard turning. So, in the tests carried out in this research, dry and CO2 cryogenic hard turning with two types of inserts were compared. The variables measured were tool life, superficial roughness and the piece microstructure. The results show an increase of tool life over 60%, a similar superficial roughness and, when positive insert is used, the absence of the white layer.

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Keywords: Hard turning; CO_2; Cryogenic machining; ASP23; Ecologic machining

1. Introduction

Grinding technique is used usually to finish revolution parts in which material hardness is over 45 HRc. As consequence, the range of piece geometries is limited and it implies long manufacturing times. As alternative, hard turning with cubic boron nitride (CBN) inserts was developed to replace grinding processes. With this technique, geometry limitations are suppressed and manufacturing times are reduced up to 60% [1].

CBN inserts are used in hardened steels because surface damages and geometrical and dimensional accuracy problems are avoided. Hard turning with CBN inserts implies dry machining because the CBN resistance to fatigue is not high. Because of that, high cutting temperatures are reached which can modify the part surface integrity,

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mainly producing a hard surface layer formed by ferrous materials. This layer is known as white layer because in the microscope is shown as thin white layer.

Usually, it is believed that the white layer is produced by a superficial quick heating over austenitizing temperature followed by a fast cooling produced by coolants or simple convection with the atmospheric air during the machining. But Hosseini et al. demonstrated that the white layer can be also produced below austenitizing temperature (550^{O}C) by mechanical effects [2].

Regarding the white layer influence, in Smith et al. [3] it is not found conclusive evidence which suggests the white layer has any impact on axial fatigue. Nevertheless, Guo et al. [4] concluded the fatigue strength reduction on AISI 52100 is up to 8 times its initial value. Probably, these opposite affirmations are concluded because in Smith et al. the white layers studied had 2 micrometres instead of the 7 micrometres studied by Guo et al. Also, it should be noted that when comparing the same white layer produced by hard turning or grinding, the first one presents more fatigue strength [4].

Concerning surface roughness, in Tönshoff et al. it was concluded that the average surface roughness was similar between hard turning and grinding [1]. For example, in some critical jet turbine components in which an average roughness below 0.8 micrometres is required [5], hard turning could be an alternative.

Although the replacement of grinding by hard turning provides substantial economic advantages, the biggest process obstacle is tool wear. The insert wear effects not only affects tool life, also changes the values of surface roughness, increases cutting forces and produce a wider white layer on the surface.

Due to all these effects, in this paper Liquid Dioxide Carbon (CO_2) cryogenic hard turning is presented as alternative to conventional hard turning processes. Cryogenic machining is used habitually to reduce or suppress liquid coolants, but also it is a good choice when cutting temperatures are high, as it happens in hard turning.

In cryogenic machining Liquid Nitrogen (LN2) usually is used as cooling gas. The reasons are because nitrogen is in the atmosphere in huge quantities and it has a high cooling capacity (-196^{O}). In several operations its effectiveness has been demonstrated, although in hardened materials this cooling capacity can be excessive, resulting in a material hardness increment [6].

On the other hand, CO_2 is presented as alternative. CO_2 is obtained of primary process, that is, it is reused instead of being exhausted to the atmosphere directly as waste. Nowadays, it is possible to apply CO_2 in the main machining processes. Figure 1 shows how it is applied to turning, milling and drilling.

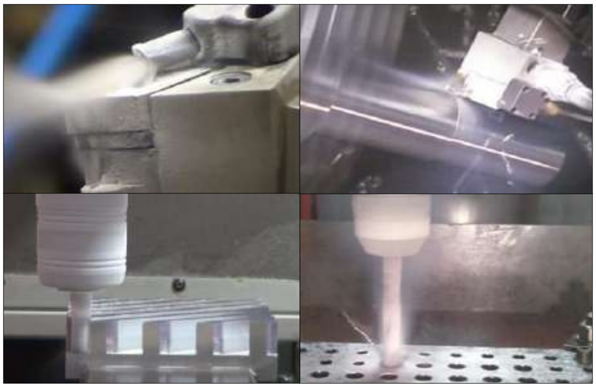

Fig. 1. Cryogenic machining images.

Although CO_2 cooling capacity is lower than LN2 (-78^{O}C), it leads to less piece hardness, doing it suitable to use in hard alloys. Furthermore, it can be stored at ambient temperature and it is relatively cheap. For this reason the CO_2 is more attractive industrially than other cryogenic gases [7].

As it has been said, in this article CO_2 cryogenic hard turning is tested. The principal objective is to increase tool life whereas white layer formation is avoided as much as possible. Also, surface average roughness is measured with the purpose of checking it does not increase with respect to conventional hard turning.

2. Experimental tests

The material chosen to carry out the experimental tests was an ASP23 high speed steel (3 times tempered). Among its properties, it must be noted a high hardness (66 HRC), high resistance to wearing, high resistance to compression, good toughness and dimensional stability. These properties are obtained because it has a high concentration of carbides of chromium, molybdenum, tungsten and vanadium. The tests were carried out in a CMZ TC25-BTY lathe as it is shown in Figure 2.

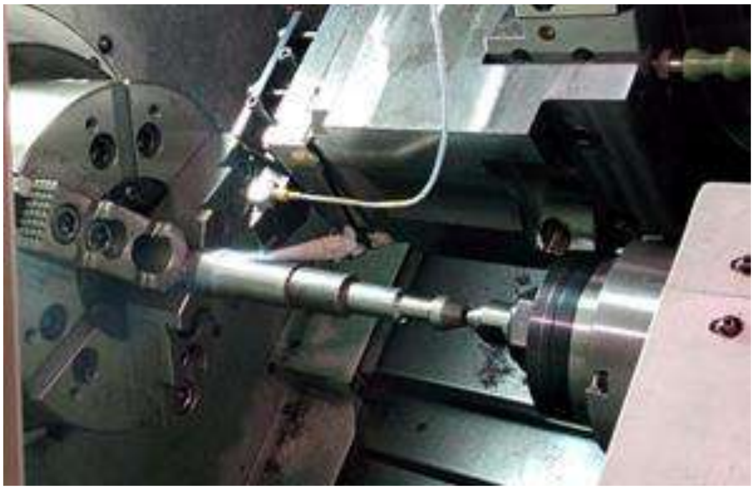

Fig. 2. Experimental set-up.

Straight turnings were carried out with two different inserts under dry and CO_2 cryogenic conditions. Two types of inserts were tested taking into consideration that an increasing of incidence angle implies a reduction of flank wear at the expense of reducing cutting edge toughness. The first insert was a VNGA160408 negative insert with 0^{o} incidence angle and a DVVN2525M16 toolholder. The second one was a VCGW160408 positive insert with 7^{o} incidence angle and a SVVCN2525M16 toolholder. In Table 1 the technical characteristics of these inserts are shown in detail.

Table 1. Technical characteristics of tested tools.

Insert	VNGA160408	VCGW160408
Material	CBN	CBN
Shape	Rhombic 35º	Rhombic 35º
Incidence angle	0º	7º
Circumcircle diameter	9.525	9.525
Thickness	4.76	4.76
Radius tip	0.8	0.8

Super finishing cutting conditions were selected. That is, the tests were conducted at a cutting speed of 160 m/min, 0.05 mm of depth of cut and 0.05 mm/rev of feed rate. Additionally, with the purpose of reproducing industrial conditions, the machined parts were slender with 290mm between the clamps and the tailstock. After each turning pass, tool wear and part superficial roughness were measured. In each test, the insert was used until breakage. Finally, when each turning test was concluded, the parts were cut and polished to observe the microstructure and measure the height of the white layer.

3. Results

Regarding to the obtained results, Figure 3 shows the tool life evolution for each test carried out. A 100% value is associated to dry machining. In both cases, when the test is carried out with CO_2 cryogenic machining, an improvement is shown. With the VNGA160408 insert, tool life grows up to 18.96%, but with the VCGW160408 insert tool life is a 69.5% better than dry hard turning.

To anticipate insert breakage is useful in order to having a stable cutting zone. When CO_2 cryogenic technique is combined with the VNGA160408 insert, this zone is more stable than when dry conditions are used. Nevertheless, when the VCGW160408 insert is used, only under dry machining conditions there is a little stable cutting zone.

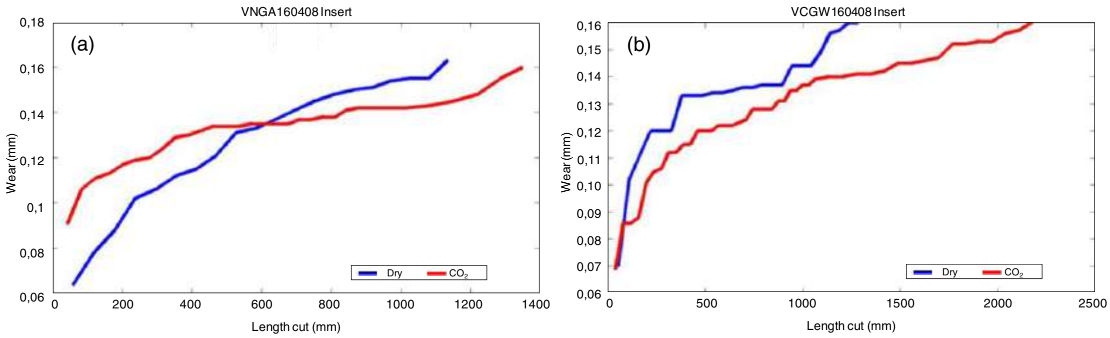

Fig. 3. Tool life. (a) VNGA160408; (b) VCGW160408.

Regarding surface roughness, in the case of using the VNGA160408 insert the average roughness with CO_2 is clearly below dry machining. However with the VCGW160408 insert the values are similar, but the roughness evolution is softer with the use of CO_2 cryogenic technique than dry hard turning, as it is shown in Figure 4. Getting the jet turbine requirements as basis, an average roughness below 0.8 µm is needed. As it can be appreciated in both cases the average roughness is below this value. Even in the worst case, it does not exceed a 90% of the reference value.

Finally, the microstructures were analysed. To obtain the grain microstructures, the etching reagent Nital 4 was applied to the specimens. The microstructure obtained after turning with the VNGA160408 insert is shown in Figure 5. On the left side the part is turned with dry conditions. As it can be seen, white layer is not present. However, on the right side CO_2 conditions were used and the white layer is present. The white layer thickness in this case is 2 micrometres. In the same way, in Figure 6 the microstructure obtained after machining with the VCGW160408 is shown. In this case white layer was not found. Furthermore, in both figures it can be appreciate the homogeneous distribution of the carbides. It is noted that this distribution is maintained even in the superficial layers with the exception of turning with CO_2 and the VNGA160408 insert.

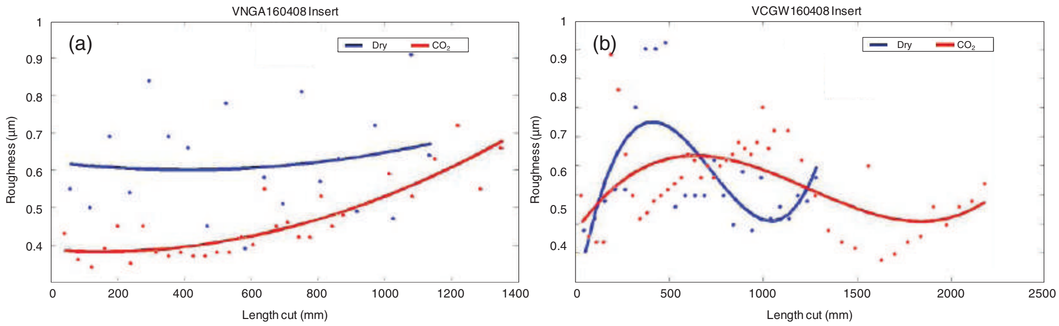

Fig. 4. Surface average roughness. (a) VNGA160408; (b) VCGW160408.

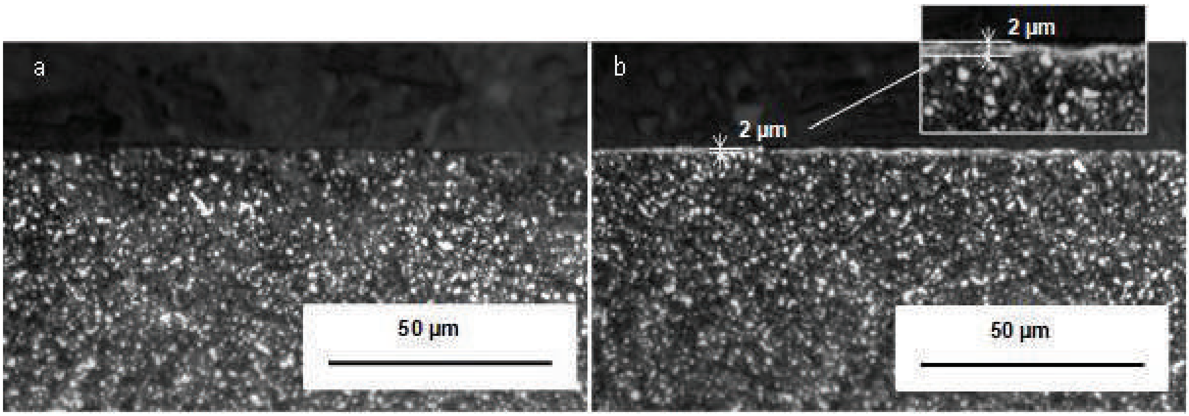

Fig. 5. Microstructure after turning with VNGA160408. (a) Dry machining; (b) CO_2 machining.

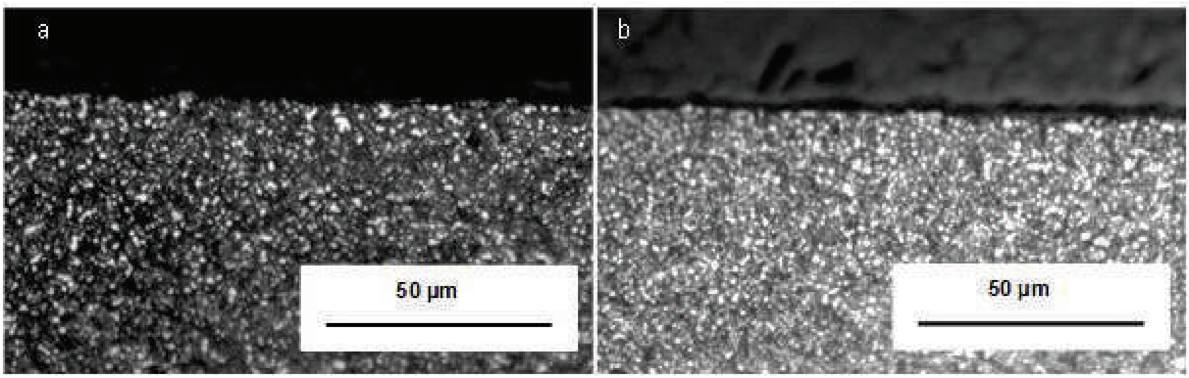

Fig. 6. Microstructure after turning with VCGW160408. (a) Dry machining; (b) CO_2 machining.

4. Conclusions

Tool life, superficial roughness and microstructure have been analysed in this paper. From the results obtained the following conclusions are achieved:

It has been demonstrated the effectiveness of CO_2 cryogenic machining applied to hard turning with CBN inserts in what tool life is referred. The improvement with negative inserts when CO_2 cryogenic technique is used ascends to 19.96% versus dry turning. However this value increases until 69.5% when a positive insert is used instead of a negative insert.

Regarding superficial roughness, similar values are obtained in the four tests carried out. However, when CO_2 cryogenic technique is used, the average value is more stable than when dry hard turning is applied. Also with cryogenic machining the average roughness is maintained below the jet turbine requirements.

Finally, with respect to microstructure, in dry hard turning the white layer is not present, that is, the austenitizing temperature is not reached with both inserts. Nevertheless, when CO_2 is used, only the positive insert leads to an absence of white layer. In the case of the negative insert, there is white layer due to the pressure applied by the worn insert. Even so, the white layer thickness obtained does not exceed 2 micrometres.

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