THE OPTIMIZATION OF CUTTING PARAMETERS AIMING THE DRY TURNING OF ABNT 1045 STEEL IN ROUGH OPERATIONS

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Abstract. *The main objective of using cutting fluids in machining operation is the reduction of temperature in the cutting region to increase tool life. However, the advantages offered by cutting fluids have been strongly debated because of their negative effects on the economic, environment and health of workers using them. A trend to solve these problems is cutting without fluid, named dry cutting, which has been made possible due to technological innovations. This work aims to seek conditions in which dry cutting shows satisfactory results when compared with the flood of abundant fluid (called here wet cutting) usually used. Aiming this goal, several experiments were carried out varying parameters such as cutting speed, feed, depth of cut and tool material in rough turning of ABNT 1045 steel in dry and wet cutting. The analysis of the results showed that wet turning is, as expected, better for tool life. The second conclusion is that dry cutting can not be used with large depth of cut. But, the main conclusion is that, if the tool material is changed to a more wear resistant one, dry cutting can be used with results very similar to those obtained with flood of abundant fluid.*

Keywords. turning, dry cutting, cutting fluid, rough operations, tool life, carbide class

1. Introduction

In machining processes, a large portion of mechanical energy is transformed in heat and which generates high temperatures in the cutting region. Because the higher is the temperature, the faster is the tool wear increase, the main objective of cutting fluid utilizations is the increase of tool life due to reduction of temperature in the cutting region by lubrication and/or refrigeration.

However, the advantages offered by cutting fluids have been strongly debated because of their negative effects on the environment, on the economic and on the health of workers using them. In environment aspect, the cutting fluids, when wrongly handled, go to the ground, fauna, flora and potable water. It causes serious impairments to the environment and to the people who uses these resources. In manufacturing shop floor, the machine workers are affected by cutting fluids, causing skin diseases and respiratory system diseases because the inhalation of their vapors (Sokovic and Mijanovic,2001; Ignacio, 1998). In process costs, the cutting fluids are responsible for a large part of total costs. Some papers (Novaski and Dörr,1999; Klocke and Eisennblätter,1997; Byrne and Scholta, 1993) describe that the costs with cutting fluids are higher than the costs with cutting tools or with labour salary. The use of cutting fluids will be increasingly more expensive as new regulations and standards are imposed, opening new alternatives to cutting processes.

A trend to solve these problems is cutting without fluid, named dry cutting, which has been made possible due to technological innovations. The advantages of dry cutting include: non-pollution of the atmosphere and water; no residue on the swarf and workpieces which will be reflected in reduced disposal and cleaning costs and no danger to worker health. Moreover, it can offers, in some cases, cost reduction in machining (Sreejith and Ngoi, 2000).

On the other hand, it is well known that in dry cutting new problems arise. When cutting fluids are not available in cutting operations there is a higher friction between tool and workpiece and between the chip and tool and, consequently, higher temperatures. The tool is submitted to larger thermal load, what can result in higher levels of abrasion, diffusion and oxidation and, therefore, reduction in tool life. The workpiece and machine tool, when receiving a large amount of heat, expands, hindering the obtainment of tight tolerances and, in some cases, causing metallurgical damages to workpiece superficial layer (Diniz et all, 2000).

Diniz & Micaroni (2002) carried out several finish turning experiments using coated carbide tools at two different cutting speed and feed in workpieces made of 1045 steel. They used two different cooling systems for the process: dry cutting and cutting with flood of abundant fluid (that will be called, from now on, wet cutting).Their main conclusion is that to remove cutting fluid from the process it is necessary to decrease cutting speed, increase feed and nose radius. Using the level of parameter variations experiments in that work, cutting time, cutting power and surface roughness will decrease and tool life will increase.

Continuing the research of these authors, this work aims to seek the best cutting conditions and tool material to make dry turning feasible in rough turning of ABNT 1045 steel. To reach this goal experiments were carried out varying parameters such as cutting speed, feed, depth of cut and carbide class. The main conclusions were: a) wet turning is, as expected, better for tool life; b) dry cutting can not be used with large depth of cut; c) if the tool material is changed to a more wear resistant one, dry cutting can be used with results very similar to those obtained with flood of abundant fluid.

2. Experimental procedures

The cutting tests were performed in workpieces made of ABNT 1045 steel with an average hardness of 97 HR_B. Their diameter varied from 100 to 60 mm as the cutting went on. The length of the workpiece was 200 mm.

The tools were TNMG 160408-PM (ISO P25 carbide inserts) and SNMG 120408-PM (ISO P25 and P15 carbide inserts) coated with three layers: TiCN, Al_2O_3 and TiN by CVD process. They were assembled in PTGNR 2525M16 and PSBNR 2525M12 tool holder respectively.

The cutting fluid was synthetic oil with 6% of concentration in water. Its flow rate was 4.3 l/min. This cutting fluid is recommended for turning and grinding operations of steel.

The experiments were carried out on a CNC lathe with power of 15 kW in main motor.

Tool wear was monitored using an optical microscope and, after the end of tool life, the carbide inserts were examined in a scanning electronic microscope (SEM) equipped with an EDS system. The machine tool motor electrical power was monitored using a A/D Lab Pc+ board and LabView 5.0 software installed in a PC computer.

One experiment consisted of turning the workpieces, starting with a fresh cutting edge up to the point it reached flank wear of VB_B = 0,3 mm. This value was considered the end of tool life. The cutting conditions are summarized in Table 1.

Table 1 - Cutting conditions used in experiments

Cutting Speed [m/min]	Feed [mm/rot]	Depth of Cut [mm]	Tool Geometry	Carbide Class	Cutting Fluid
350	0,40	2	SNMG 120408	P25	No
290	0,40	2	SNMG 120408	P25	No
350	0,40	2	TNMG 160408	P25	No
290	0,40	2	TNMG 160408	P25	No
350	0,40	2	SNMG 120408	P25	Yes
350	0,33	2	SNMG 120408	P25	No
290	0,33	2	SNMG 120408	P25	No
350	0,40	1	SNMG 120408	P25	Yes
350	0,40	1	SNMG 120408	P25	No
350	0,40	2	SNMG 120408	P15	Yes
350	0,40	2	SNMG 120408	P15	No
350	0,40	1	SNMG 120408	P15	Yes
350	0,40	1	SNMG 120408	P15	No

3. Results and Discussions

In the beginning of the experiments, tests were carried out to know the best tool geometry in rough dry turning comparing square and triangular geometry. Figure 1 shows the value of tool life (in volume of material removed) for the tests.

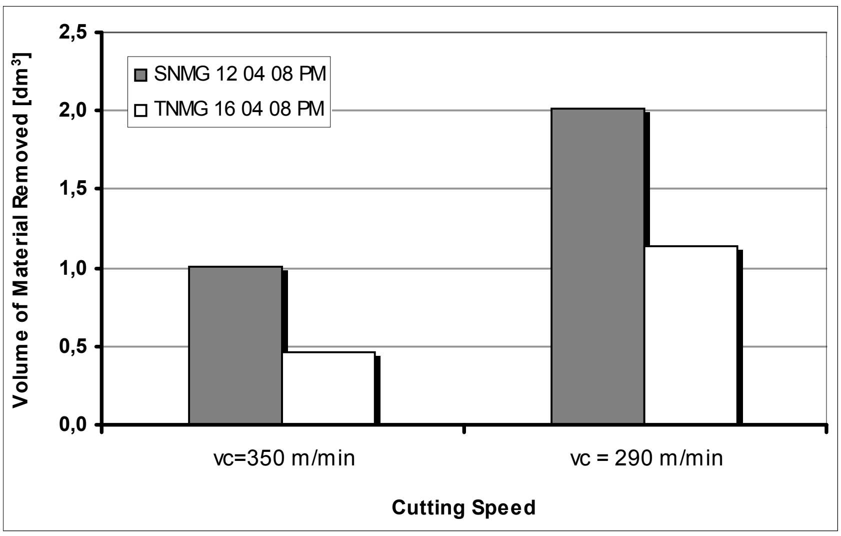

Fig. 1 – Tool life in volume of material removed vs tool geometry for tests with f = 0,4 mm/rot, a_p = 2 mm and P25 carbide class

Tool life was always bigger when square tool geometry was used (about twice in both cases). The explanations for this result are the bigger volume of square tools and the bigger edge-workpiece contact length which provide more tool material to receive and dissipate the heat generated during the cutting process. In other words, the heat dissipation when used square tool is easier, which maintain tool hardness in higher values and makes possible the the turning of a larger volume of material.

These results were decisive to use square tool geometry in the next tests because they are more suitable for dry turning.

After these results, experiments were carried out in order to know, in dry turning, the influence of feed and cutting speed in tool life (measured using volume of chip removed).

Figure 2 shows the values of tool life for the tests carried out in two levels of cutting speed and feed with a_p = 2 mm, square tools and P25 carbide class.

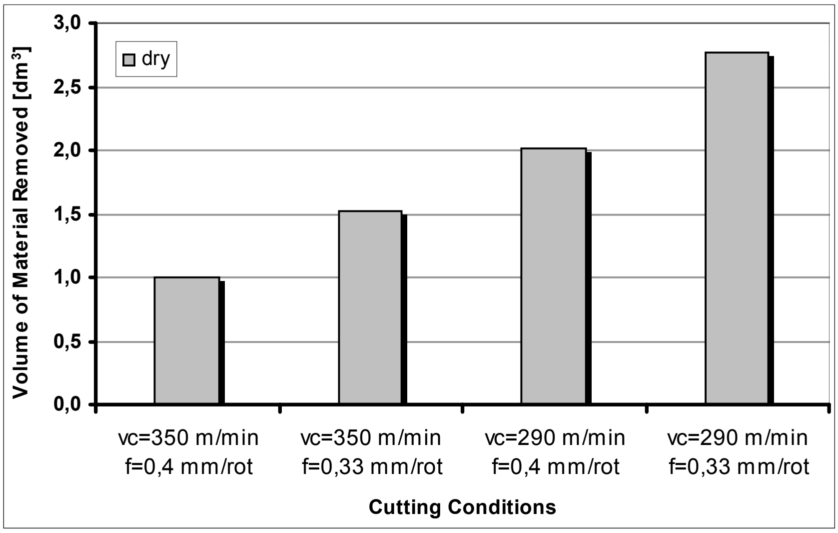

Fig. 2 – Tool life in volume of material removed vs cutting conditions for tests with a_p = 2 mm and P25 carbide class

As expected, the reduction in cutting speed (v_c) and feed rate (f) caused an increase in tool life (in volume of material removed). The reduction of 17% in cutting speed caused an increment, in average, of 91% in tool life and the reduction of 17,5% in feed rate caused, in average, an increment of 44% in tool life. The feed rate influence in tool life is associated with three factors:

a) the increase in feed rate increases the volume of material removed per time and, therefore, an increase in heat generation and tool temperature occurs, decreasing tool hardness and wear resistance.

b) when feed rate increases, the heat generation increases, but the area on the tool to dissipate this heat also increases. Moreover, when feed rate increases, the specific cutting force (force per unit of chip cross section area – Ks) decreases (Shaw, 1984). Therefore, heat generation did not increase in the same proportion of feed rate growth and, as the area of tool which receives this heat increased in the same proportion of feed rate, tool temperature should have decreased , which made the cutting more suitable for greater feed rate.

c) Moreover, the increase of feed rate causes the increase of heat generated per time, but decrease the time to cut a given volume of chip. Hence, with lower feed rate, the same workpiece portion rubs longer with the cutting edge which increases the temperature.

The combination of these three factors and the results obtained in the experiments show that, in steel rough turning operations, the increase in tool temperature, decreasing tool hardness and wear resistance, were more significant for tool life then other factors.

Figure 3 and 4 show the results for tool life when depth of cut (a_p), and carbide class were varied and the cutting fluid introduction was performed in the most severe condition.

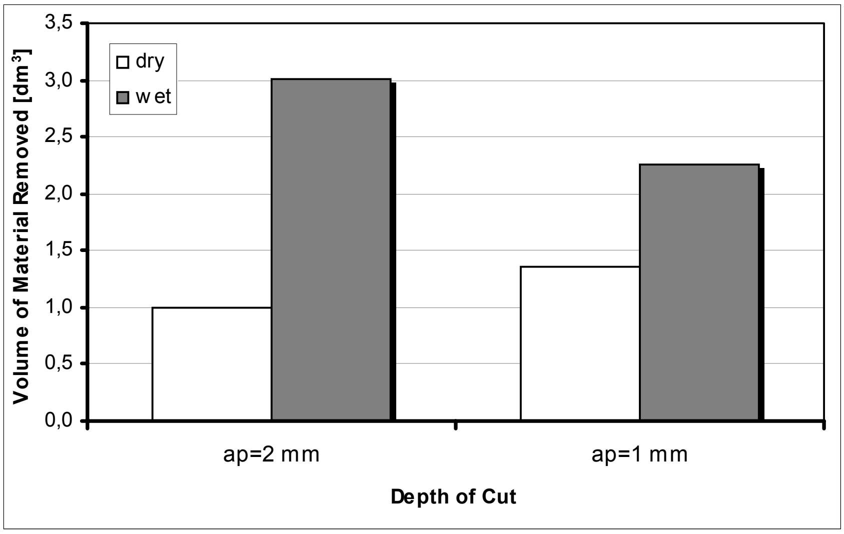

Fig. 3 – Tool life in volume of material removed vs depth of cut (a_p) for tests with v_c = 350 m/min, f = 0,4 mm/rot and P25 carbide class

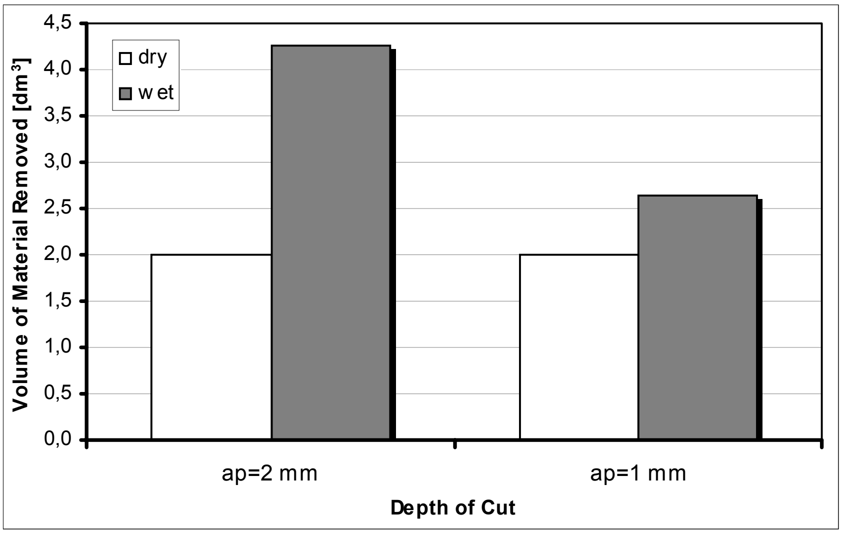

Fig. 4 – Tool life in volume of material removed vs depth of cut (a_p) for tests with v_c = 350 m/min, f = 0,4 mm/rot and P15 carbide class

In accordance with both figures, tool life was always bigger for wet cutting, but for minor depth of cut, dry cutting gets closer to it. When P25 carbide class and a_p = 2 mm were used the tool life with wet cutting/tool life with dry cutting ratio was 3,0 and when a_p = 1 mm the ratio was 1,65. When P15 carbide class and a_p = 2 mm was used this ratio was 2,12 and for a_p = 1 mm the ratio was 1,32.

The introduction de P15 carbide class increased the tool life in all the tested conditions and reduced the ratio between wet cutting/dry cutting tool life, i.e., this increase was higher for dry cutting operation. These results show that, for dry cutting, the utilization of a more wear resistant material with higher hot hardness compensates the lack of refrigeration and makes tool life closer to that obtained in wet cutting.

Hence, for the utilization of more wear resistant and with lower toughness tool material it is necessary to guarantee a high stiffness of the machine tool – workpiece – fixation device – tool system in order to avoid tool chipping and fracture.

Another result that must be pointed out in these figures is that tool life increased when depth of cut increased for wet cutting, but decreased for dry cutting. The depth of cut is, among the cutting parameters, the one that, when cutting fluid is used, presents the lowest influence in tool wear and tool life because its variation does not change the specific energy of cutting (consumed energy per chip cross section) and the chip speed. In the other hand, it causes more volume of material being machined, using proportionally a longer length of cutting edge (Diniz et all, 2000). However, in severe cutting conditions in absence of cutting fluid, the heat quantity in the insert is larger as depth of cut increases. Therefore, the increase of depth of cut in dry cutting increases the temperature in the bulk insert which reduces its hardness and enhances the growth of abrasive and diffusive wear and also makes possible plastic deformation of the cutting edge.

Therefore, these results show when dry cutting is used little stock material has to be removed and, so, dry cutting is more suitable for turning operations when near net shaping technology is used.

Figures 5 and 6 show the flank wear curves along tool life for the tests with P25 and P15 carbide class respectively.

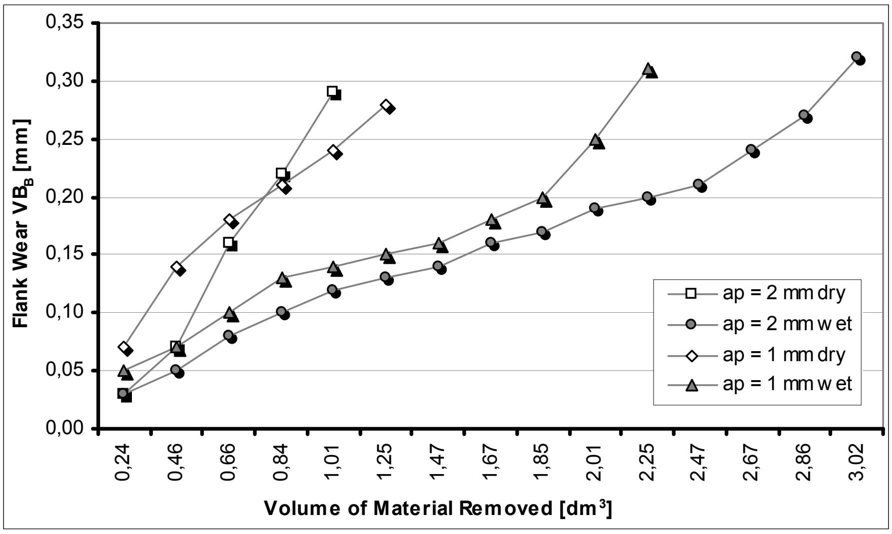

Fig. 5 –Flank wear VB_B vs volume of material removed for tests with v_c = 350 m/min, f = 0,4 mm/rot and P25 carbide class

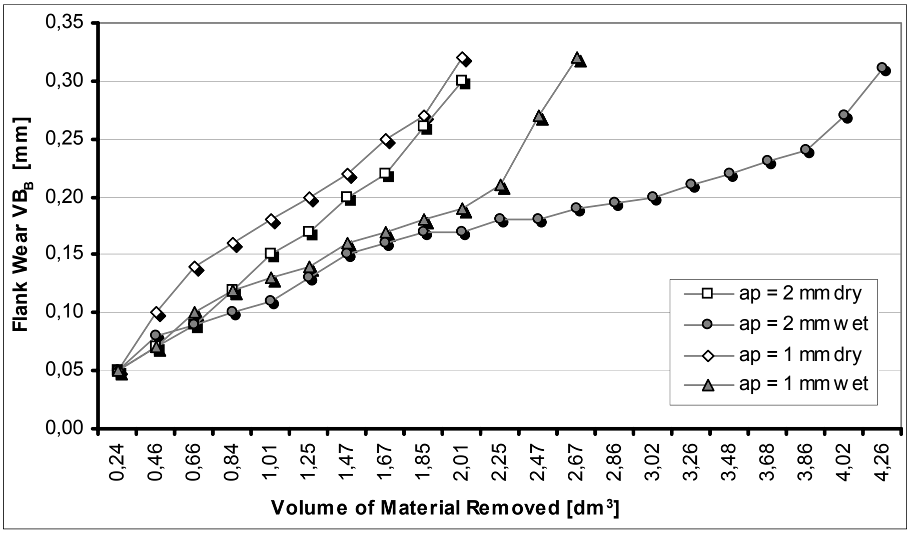

Fig. 6 –Flank wear VB_B vs volume of material removed for tests with v_c = 350 m/min, f = 0,4 mm/rot and P15 carbide class

These curves show that, as expected, for the P25 carbide class, a very fast growth of tool wear occurs in dry cutting and a mild growth of tool wear in wet cutting conditions. It can also be seen in these figures that, for wet cutting, the slope of the curves changes when VB_B reaches 0,20 mm, demonstrating an acceleration of the wear, in both tool materials used. This fact is related to a higher area of friction between workpiece and tool flank face which increases the tool temperature, with a consequent decrease in tool hardness, and accelerates abrasion. When dry cutting was used, this acceleration in tool wear was not noted, since the slope of the flank wear curves was already very high and, therefore, the increase of the contact are between workpiece and tool flank face was not significant.

A slower growth of tool wear can be seen for the P15 carbide class when compared to the experiments with the P25 class in the same cutting conditions. This result shows that the lower toughness of the P15 class was not important and its wear resistance was predominant. Probably, if the system were not as rigid as the one used in this work, this result would be different.

The specific cutting force (K_s) increases with the increase in flank tool wear (VB_B) due to the increase of the friction caused by the growth of the area of friction (Diniz et all,2000). Therefore, cutting force (F_c) and cutting power

(P_c) also increase. Figures 7 and 8 show the curves of cutting power against volume of material removed for the experiments carried out. It can be seen that cutting power remains almost constant along tool life and, just close to the end of it, it starts to grow. Therefore, it can be said that, at least for these experiments, flank wear just starts to influence cutting power and, of course, cutting force, when its values are already large (in the case of these experiments, close to VB_B = 0,2 mm – se figures 5 and 6) and, so, the friction between tool flank face and workpiece is also large.

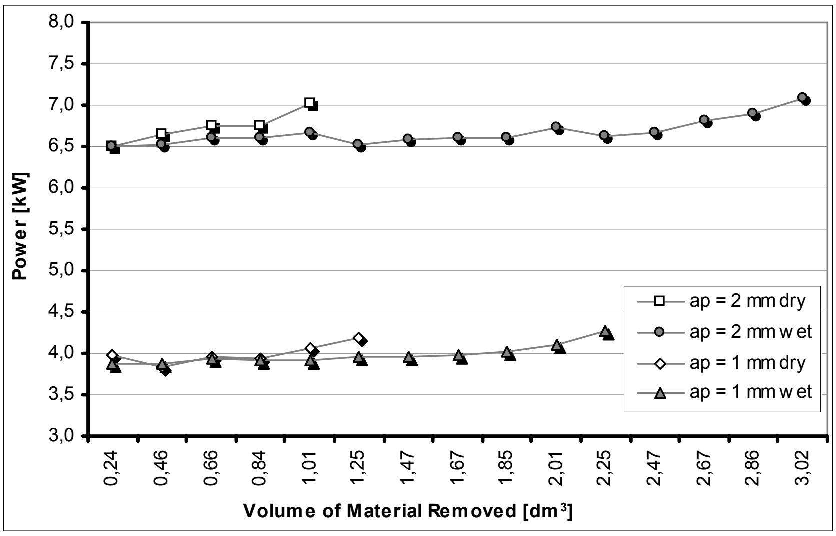

Fig. 7 –Consumed Power (kW) vs volume of material removed for tests with v_c = 350 m/min, f = 0,4 mm/rot and P25 carbide class

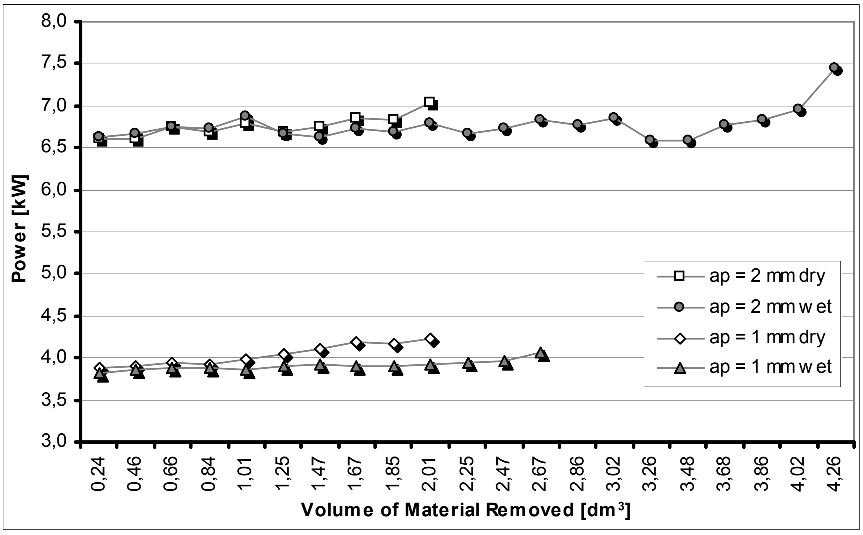

Fig. 8 –Consumed Power (kW) vs volume of material removed for tests with v_c = 350 m/min, f = 0,4 mm/rot and P15 carbide class

As expected, no difference of cutting power can be seen for the two tool materials tested. The coatings of both classes are similar and, probably, they provide the same friction coefficient to the tools up to the end of tool life, even as they are being removed as a consequence of tool wear.

Moreover, no difference of cutting power can be noted between dry and wet cutting. The little variations along tool life, which made cutting power for dry turning higher than for wet cutting, are related to the larger flank wear of the tools used in dry turning experiments. This result is contrary to which Diniz and Micaroni (2002) found out. In their work, these authors showed that, for finish steel turning operations, dry cutting consumes lower cutting power. They explain this occurrence saying that, when dry turning is used, the higher temperature of the cutting zone decreases the workpiece material strength and, so, makes the cutting easier. However, there is another phenomenon that influences cutting forces in dry turning. Due to the lower material resistance of the hotter workpiece, the chip deformation is higher and, so, the effective contact area between chip and tool rake face is larger in dry than in wet cutting. This phenomenon tends to increase cutting force due to the higher friction. It seems that, when rough turning conditions are used, this phenomenon is more significant than in finish conditions due to the higher amount of heat generated. Therefore, in these experiments, the lower resistance of the hotter workpiece material was compensated by the larger effective contact area between chip and tool, and consequently, the cutting power consumed in dry and wet cutting was similar.

4. Conclusions

Based on the results of this work, it can be concluded for the rough turning of steel:

a) the use of square inserts(SNMG 120408 PM) provides longer tool life than triangular inserts (TNMG 160408 PM) in dry cutting.
b) the use of cutting fluid provides longer tool life in all the cutting conditions used.
c) to remove cutting fluid from the process it is necessary to use P15 carbide class, low depth of cut, decrease cutting speed and increase feed rate.
d) the results of consumed power do not show significant difference between dry and wet cutting.

5. Acknowledgement

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