FINISH MACHINING OF TITANIUM ALLOY (6 4)

Marcos Roberto Vargas Moreira
Faculadade de Engenharia Química de Lorena - DEMAR – Lorena/SP - Brasil
mzenga@ppgem.faenquil.br
Elias Alves da Cunha
Faculadade de Engenharia Química de Lorena - DEMAR – Lorena/SP - Brasil
eliasac@ppgem.faenquil.br
Marcos Valério Ribeiro
Faculadade de Engenharia Química de Lorena - DEMAR – Lorena/SP - Brasil
mvalerio@demar.faenquil.br

Abstract. *Metal machining is a complex process due the several cutting parameters used. Moreover, the material properties involved in the process have a great influence in the deformation. Titanium alloys have been classified as “difficult-to-machine” materials. Titanium and its alloys have low thermal conductivity (7 W/m K) and to its reactivity with the cutting tolls. This indicated that the wear is developed by an abrasive process rather than by a thermally activated mechanism, such as chip and tool atom diffusion, the machining of the Ti-6Al-4V alloy, forms segmented chips. The titanium alpha-beta alloys is used widely in the manufacture of different aircraft turbine parts, considering their excellent mechanic properties and their resistance to high temperature. This work studies the influence of the cutting parameters (speed cutting and feed) in conventional turning finish process of the Ti-6Al-4V alloy, using uncoated cemented carbide, coating cemented carbide (PVD) and cermet tools were used for the turning of Ti-6Al-4V alloy in finish turning. Details of some aspects of the roughness of workpiece are studied. Tool wear mechanisms characterization and morphology of the chip was performed using scanning electron microscopy (SEM).*

Keywords*. Machining, titanium, flank wear, chip.*

1- Introducion

Aeronautical industries manufacture components of engine with titanium alloys, nickel alloys and special stainless steels. They are characterized by a great cost in the production of these pieces and one of the great reasons of this high cost is the time/machine costs. The cost can be high as 90% of the total cost in machining, Wang et all (2000). For this reason it is interesting to reduce the machining times of the workpiece, because the costs in the aeronautical industries are higher than in the conventional industries. The choice of the appropriated tool for a certain operation and the correct determination of the machining conditions, they represent an important role in the work with metals. The relationship between tool life and optimization of the process is very important, because the cost factor acquires a character of extreme importance in this scenery of intense competitiveness in which quality and productivity are fundamental items. Titanium alloys is very used in the aeronautical industry, mainly, due high strength-to-weight ratio, lower density of titanium when compared with stell, creep and fatigue resistance, corrosion resistance in high temperatures, etc. Advanced engineering materials, such as structural ceramics, titanium alloys, inconel alloys, offer unique combination of properties like high strength at elevated temperaures, resistance to chemical degreadation and wear resistance. The titanium structure alpha phase is hexagonal close-packed (hcp), at temperature of 980 ^{o}C (Beta transus), the alpha phase forms into beta phase, structure to the body centred cubic (bcc). The alfa/beta alloys, in private have, in most part, alpha phase at room temperature, but they do have more of the beta phase, the high temperature allotrope, than the former class of alloys. These alloys, include Ti-6Al-4V (Ti-6-4), Ti -6Al-6V-2Sn (Ti -6-6-2) and Ti -6Al-2Sn-4Zr-6Mo (Ti-6-2-4-6). The titanium is used thoroughly in the production advanced industrial equipments, in the generation of energy and in the transport. Ti-6-4 is the workhorse of the titanium industry, does it accounts go about 60% of the total titanium production (Boyer, 1996)**.** Considering the two-phase alloy (Ti-6Al-4V), can be identified two evolution types be: the first improved the creep resistance and the second improved the mechanical resistance and the resistance to low cycle fatigue (Vigneau, 1997). The machining of the titanium alloy is difficulted basically due to its high chemical reaction with the materials of the tool and its low thermal conductivity (about 7,3 W/m K) generating high temperature in chip/tool/workpiece interface (Bhaumik, 1995), wich favors the wear mechanisms. About 80% this generated heat, it is retained in the tool and 20% in the chips Ezugwo et all (1997). During the machining of titanium alloy, tool wear progress rapidly because of the high cutting temperature and strong adhesion between the tool and the material work, owing to their high chemical reactivity, Zoya et all (2000)**.** Some specific studies in tool failure modes and wear mechanisms when machining titanium alloy have been conducted (Dearnley, 1986; Hartung, 1982; Ezugwo, 1988). Due to the low elasticity module of the titanium the tool is subject to a pulsation load (spring back) during the machining causing attrition and vibration, Ezugwo (1997). The Ti-6Al-4V alloy has a low thermal conductivity doing with most of the heat generated during the machining it is retained in the tool. The combination of pulsant efforts and high temperature accelerates the tool wear mechanisms these factors contribute to its low acting.

In machining, three different types of chips are know to forms: continuous chips, segmented chips and completely separated segmented if extreme cutting conditions are used. Ti-6Al-4V forms segmented chips for a wide range of cutting parameters (Siemers, 2001; Komanduri, 1983). For turning of titanium alloy, the cemented carbide (WC/Co) represents the best cutting tool for machining of Ti-6Al-4V (Lopez of Lacalle, 1988).

2 - Materials and methods

The machining tests were accomplished through external cylindrical turning using a titanium alloy (Ti-6Al-4V) with tools VBMT 110304 PF ISO P10 class, titanium based cermet (Sandvik CT 5015), VBMT 110304 MF ISO M15 class, cemented carbide (Sandvik GC 1025) coating by TiAlN (PVD) with thickness of 4 μm, which provide toughness and wear resistence to cutting tool and VBMT 110304 UF ISO S15 class, uncoating cermented carbide (Sandvik H13A). The tests are conducted without cooloant. The initial hardness of this alloy it was around to 400 VHN. Figure (1) shows microstructure of the alloy Ti-6Al-4V, in dark region there is beta phase and clear region there is alpha phase. The initial microstructure consists of equiaxed alpha grains and intergranular beta phase.

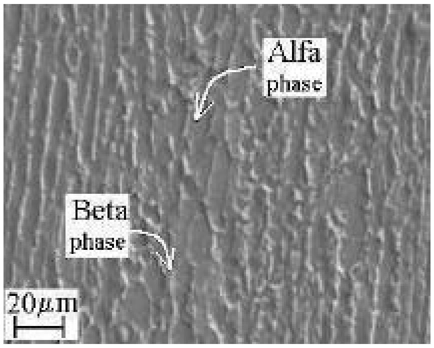


Figure 1. Microstructure of the titanium alloy (Ti-6Al-4V).

The temperature in the contact area between workpiece and the cutting edge was measured using a infrared radiation pyrometer, model Cyclops-52, manufactured by Minolta-Land. The characterization of the tool wear and chip was accomplished with the aid of an electronic microscope of sweeping LEO, model 1450 - VP, in mode of secondary electrons and an optic microscope, Leica model DM coupled IRM an image analyzer Leica QWIN for analyses of microstructure and morphologic. All of the cutting tests were conducted in a CNC lathe (ROMI Centur 30D), with maximum rotation of 4000 rpm and 10 KW power. The used cutting parameters are shown in Table (1).

Table 1. Turning test conditions

Cutting speed v_c (m/min)	Varied from 85 to 120
Feed rate f (mm/rev)	0,1
Depth cutting a_p (mm)	0,5
Cutting fluid	no
Tools (ISO Class)	S15, M15 and P10
Position angle κ_r	91^o
nose radius (mm)	0,4

The roughness was mensured using a portable roughness meter coupled to machine-tool, the mensurement was made in 60^o intervals with relation to workpiece axis.

3-Results and discussion

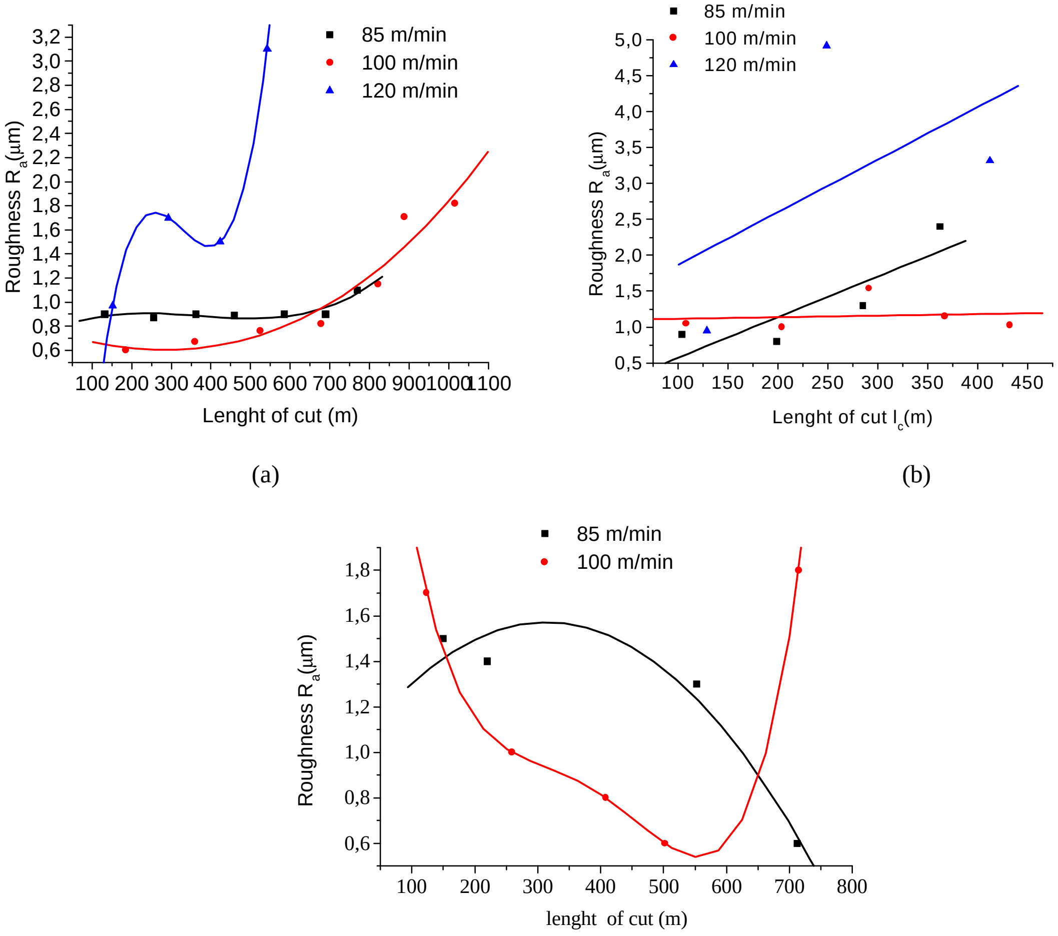
There are usually three used criteria for discussing machinability: tool life, surface finish (roughness) and power required to cutting. In this case the choose criterion is the measument of surface roughness obtained after the machining. The fixed value of roughness used as criterion was 0,9 μm.

The experiments were divided in three sets of tests for turning Ti-6Al-4V, which were conducted to measure the progress of roughness. Figures (2a, 2b and 2c) shows the effects of cutting speed in surface roughness. Two distincts regions are observed in Fig (2a): firstly the roughness tendency is similar (v_c= 85 m/min and 100 m/min) with cutting length of 700m ($R_{amáx}$=0,9 μm); the second aspect is related with speed of 120 m/min, when the workpiece presents a more several roughness (3 μm). The life of cutting tool is very small, around 120 m.

The excessive increase of the roughness its observed using ISO P10 tool fig 2b up to 120 m/min. Only using speed of 85 m/min (l_c=170 m) the roughness was down of 0,9 microns.

Can be observed in Fig. (2c) for ISO M15 tool a down tendency of obtained roughness for all tested speeds (85 and 100 m/min). With the increase of the length of cutting, there is a progressive better in surface roughness, Fig.(2c). This is due the integrity of the edge cutting, however, the abrasive process of the chip in tool surface, Fig. (5a), and excessive flank wear, Fig. (5b), was important criterion for stop the test.

In the case of 100 m/min, in particular, was a fall until a minimum value (0,6 μm) and next an abrupt grown in the roughness value (1,8 μm) due a cutting edge deformation (Figs. 5c and 5d).



(a) (b)

(c)

Figure 2: The surface roughness in turning of Ti-6Al-4V: a) Using ISO S15, b) Using ISO P10, c) Using ISO M15

The Figs. (3a) (3c) and (3e) shows the comparison of the cutting edge using cermented carbide with cutting speed of 85, 100 and 120 m/min. Crater wear was observed in all conditions in function of the adhesion and to remove of the chip in tool surface. With the formation of notch and chips deposited on the tool surface (Figs. 3b 3d and 3f), the flank wear occour mainly due the grains agglomerates removal of tool material by the adherent chip or workpiece, which was the major contributor to the flank wear.

Through the following tool micrographies can be possible to observ the minor deterioration of cutting edge occurs to ISO S15 tools (Fig. 3), the same was present the better results in relation to its behaviour roughness, in the other hand, the others cutting tools, ISO P10 and ISO M15, present a great degree deterioration of the cutting edge, in special the ISO M15 tools (Fig. 5) shows a great flank wear, together chipping and plastic deformation.

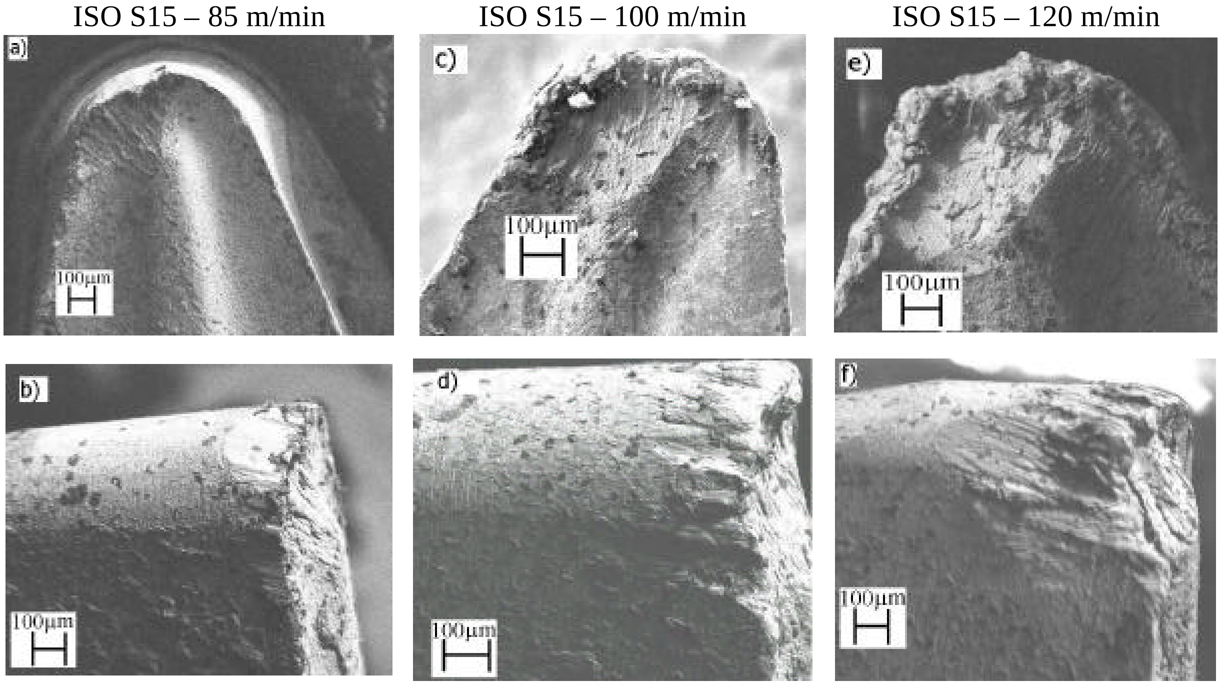


Figure 3: Tool surface and flank wear in the machining of Ti-Al-4V for different cutting speeds using ISO S15.

Severe wear of the cutting edge was observed, in Figs. 4b, 4d and 4f, with chip adhesion in cutting edge (Figs. 4a and 4c) and surface of the tool (Fig. 4e). The excessive flank wear can be observed in Figs. 4b, 4d and 4f. In the ISO P10 tool, didn´t observed plastic deformation, but its cutting edge was deformed by flank wear and chip adhesion to making worse the chip formation (Fig. 6b). A better behaviour of roughness obtained can be explained by the maintenance of cutting edge form for more time than ISO M15 tool.

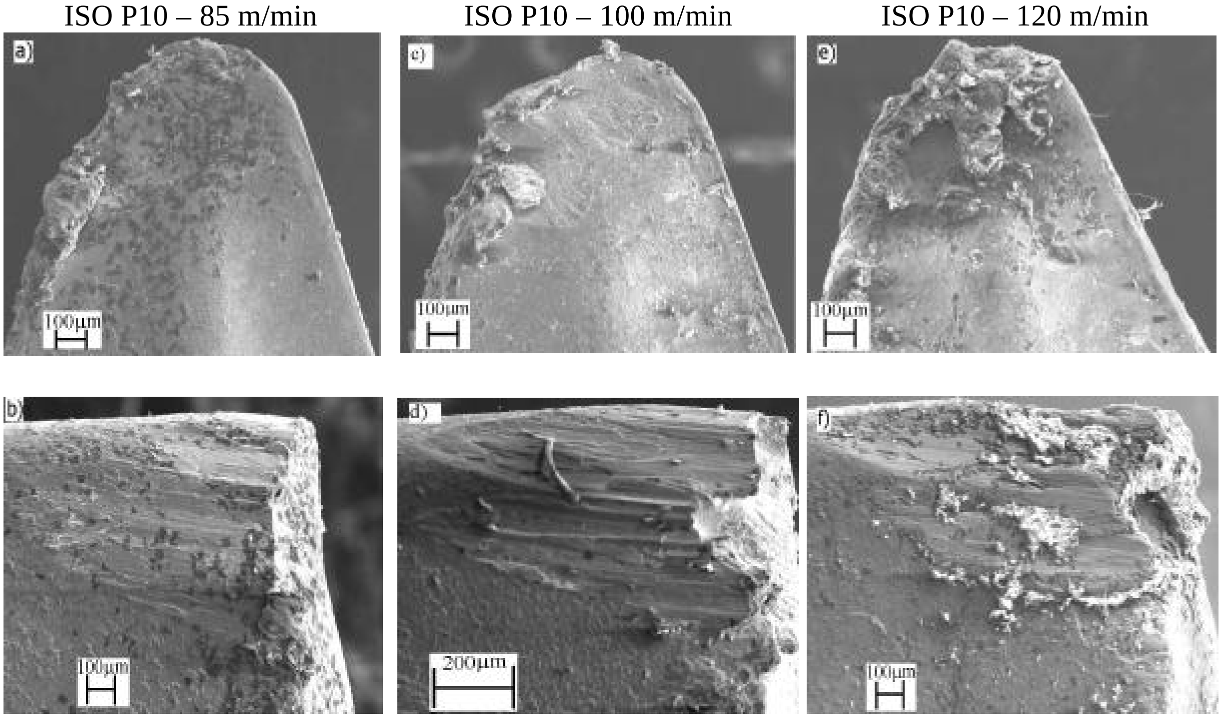


Figure 4: Tool surface and flank wear in the machining of Ti-Al-4V for different cutting speeds using ISO P10.

About the presented tool wear for the ISO M15 (Fig. 5) can be observed the great chipping wear in 85 and 100 m/min conditions, after the removal of layer coating the tool wear increase provides these results, in the case of 120 m/min only one step was possible to make, due the great deformation of cutting edge obtained, which carry out a worse value of roughness. Ins these cutting tools can be noted a certain degree of plastic deformation in its cutting edges.

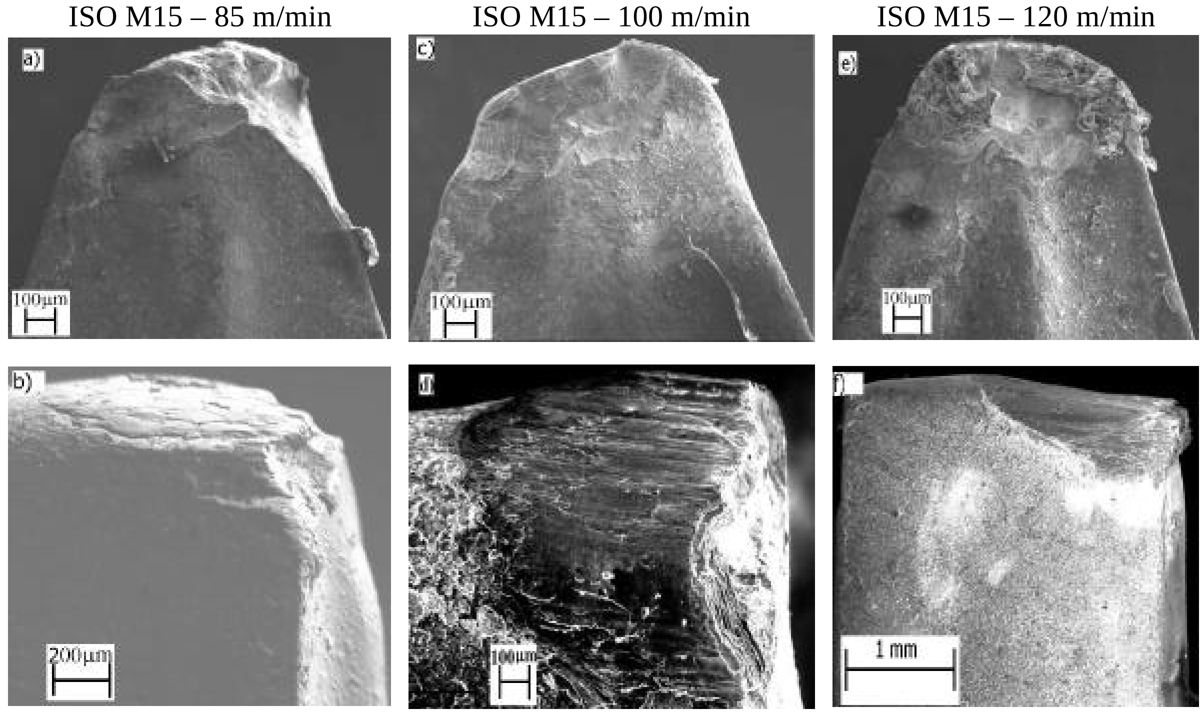

ISO M15 – 85 m/min
ISO M15 – 100 m/min
ISO M15 – 120 m/min

Figure 5: Tool surface and flank wear in the machining of Ti-Al-4V for different cutting speeds using ISO M15.

In the figure 6 can be observed the generated chip in the better cutting condition (ISO S15 in 85 m/min), which shows a very uniform morphology in relation to other test conditions. In this condition the chip presents very distinct zones of primary and secondary deformations, which characterize a major easily in the cutting. Yet in this figure can be noted the others conditions ISO M15 and ISO P10 both in 85 m/min, which produce very deformed chips, thus the major severity in cutting operation was demonstrated.

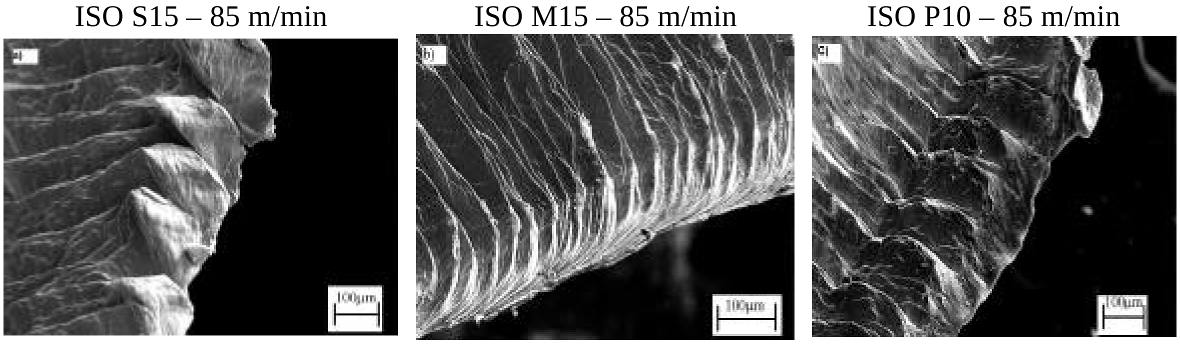

ISO S15 – 85 m/min
ISO M15 – 85 m/min
ISO P10 – 85 m/min

Figure 6: Chip formed in the machining of Ti-Al-4V for different cutting tools.

5- Conclusions

How can be noted by the obtained results, the nature of chip formation influences in the quality of machining surfaces, in the tool wear and in the quantity of heat generated during the cutting operations. Thus, can be possible to identify a relationship between deformation chip and machining quality, such as low roughness and heat generation.

Using cutting tool ISO S15 class was obtained the better results (85 and 100 m/min) in relation to tool life (cutting length) and surface roughness. The ISO P10 class, with break chip PF own for steel machining, but also indicate for titanium (by Sandvik), moreover best results can not be obtained in relation to ISO S15 tool.

The performance of the ISO M15 class was worse among the tested tools, however, the coating stability of PVD layer (TiAlN) was satisfactory, mainly if the results were comparated with the behaviour of CVD Coating (TiN), which not resist to attrition in the cutting edge, in presence of high temperature, favors the reactivity between coating and chip causing a great deformation in cutting edge.

6 – Acknowledgment

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7 - References

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