Nonconventional Technologies Review
Romania, June, 2015

INFLUENCE OF THE THIN LAYERS THICKNESS, DEPOSITED BY PVD METHOD ON DURABILITY OF THE CUTTING INSERTS

Ana Bădănac[1], Dragoş Paraschiv[2], Octavian Lupescu[3], Mădălina Popa[4] and Sorin Popa[5]

[1]"Gheorghe Asachi" Technical University of Iasi, Romania, badanac_ana@yahoo.com
[2]"Gheorghe Asachi" Technical University of Iasi-Romania, dragosparaschiv21@yahoo.com
[3]"Gheorghe Asachi" Technical University of Iasi-Romania, olupescu@tcm.tuiasi.ro
[4]"Gheorghe Asachi" Technical University of Iasi-Romania, popa.madalina20@yahoo.com
[5]SNTFC "CFR" Călători S.A., Bucharest, Romania, sorin_popa65@yahoo.com

ABSTRACT: Deposition of some materials as thin layers on cutting tools, to increase the wear resistance of these, has become a major interest for the cutting tool industry in recent years. Coating the cutting inserts with some different materials improves their wear resistance and prolongs the life. There are known many researches concerning the cutting inserts coated with materials by the vacuum deposition, using methods as: physical vapor deposition (vacuum thermal evaporation and condensation from the vapor phase, ionic plating and pulverization) or chemical vapor deposition. In this study it is measured the influence of coatings thickness deposited by the physical vapor deposition (PVD), namely by ionic plating method on the machining performance of the cutting inserts.

KEY WORDS: physical vapor deposition, cutting inserts, ionic plating method, thin layers, durability.

1. INTRODUCTION

Due to the mechanical loading (the cutting efforts unevenness), to variation of temperature (occurs plastic deformation phenomenon), of the chemical reactions which exist between cutting tool and worpiece, but also because of the abrasion phenomenon and of the adhesion phenomenon, the cutting tools surfaces are subject to wear. In the last period there was an increased interest for surface treatments, which reduce the reconditioning cost of the cutting tools surfaces. Depositions of thin layers are applied on cutting tools in order to improve the desired properties of the surface, such as corrosion resistance, wear resistance, hardness, or friction.

The research problems regarding the production of coatings are one of the most important surface engineering development directions, ensuring the production of coatings with superior properties in the field of applications to the mechanical characteristics and wear resistance [1, 2].

For those surfaces of the cutting tools, which are the most exposed to wear, to be used at maximum capacity, they can be hardened by several methods, of which there are mentioned the coatings processes: physical vapor phase deposition (PVD) and chemical vapor phase deposition (CVD). These are efficient thermo-chemical treatments by which there were realized coatings compounds such as aluminum titanium nitride (AlTiN or TiAlN), titanium carbide (TiC), titanium-chromium nitride (TiCrN) and titanium nitride (TiN). The coatings realized by physical vapor phase deposition (PVD) or chemical vapor phase deposition (CVD), have gained special attention because of their unique physical and chemical properties, for example, extremely high hardness (40-80 GPa), corrosion resistance, excellent resistance to oxidation at high temperatures, as well as high abrasion and erosion resistance. The main characteristics which must be checked in the deposition process of thin layers are: composition, structure, thickness, adherence, hardness, wear resistance, corrosion resistance, porosity [3, 4].

2. METHOD AND EQUIPMENT USED FOR DEPOSITION

This study presents some researches made by the authors regarding the thickness influence of the thin layers deposition one of titanium and one of titanium aluminum, deposed by PVD method, namely the ion plating, on the cutting inserts durability. The ion plating is the method that combines an arc evaporation process with ion bombardment during the coating deposition, which helps to achieve better stoichiometric ally balance within the coating. For the deposition of titanium layer and the titanium aluminum, it was used the equipment DREVA 400, presented in figure 1, which includes: a rotary table, a vacuum chamber, supports of supply (air, water, gas), components for completing the installation and the electrical equipments. The deposition of the titanium a layer takes place inside the recipient in which a certain vacuum is generated, where the material that must be deposited on the substrate (workpiece to be covered, meaning the cutting insert), being in solid state, is brought in vapor state as a result of its heating, up to evaporation of the target (Ti) and re-condensation on the substrate, when its temperature is lower than that of the vapors [5].

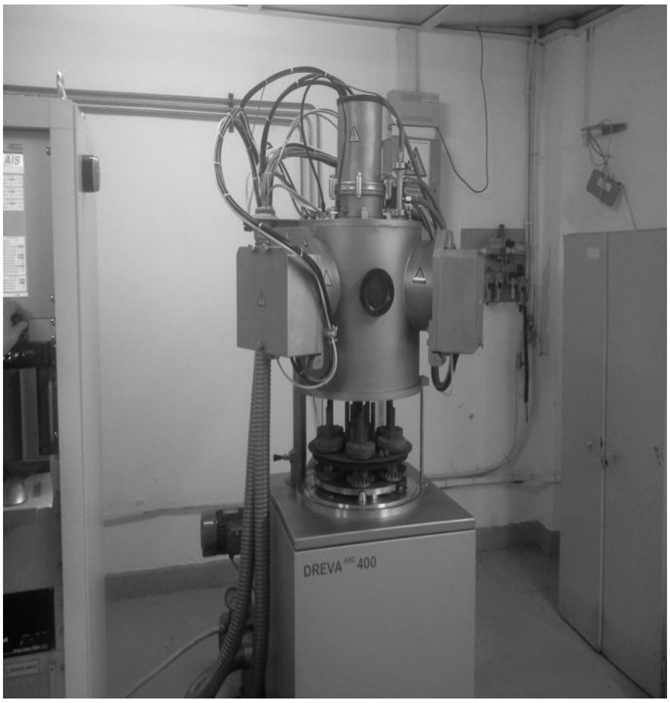

Figure 1. General view of the equipment DREVA 400

3. METHOD AND EQUIPMENT USED FOR THICKNESS DETERMINATION

The determination of the layer thickness of coatings and layer systems was realized by means of indentation and ball-cratering, kaloMax (figure 2), tests. The adhesion and surface quality was qualitatively analyzed by means of microscopic examination of the coating fracture, which occurred under heavy load, using Rockwell adhesion test and by morphology for the coatings.

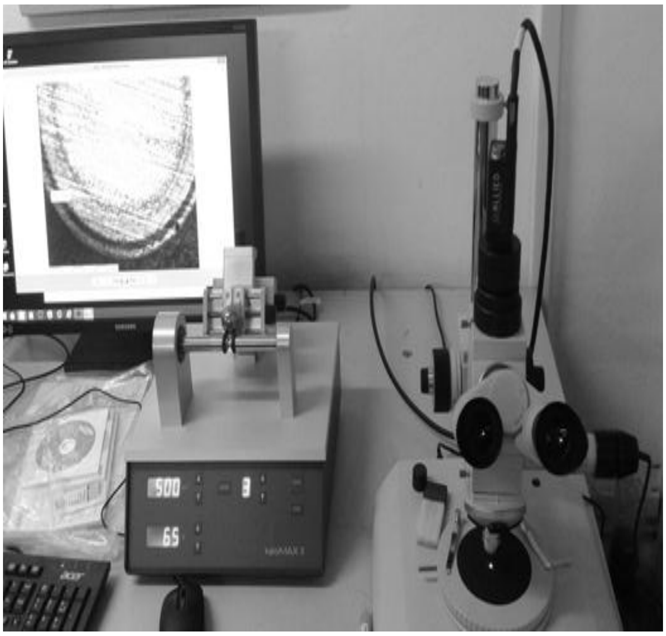

Figure 2. General view of the installation kaloMAX

The kaloMax of BAQ is a spherical cap grinder, originally developed for the determination of the coating thickness. The result of the grinding process depends on both parts of the tribosystem, of the sample and kaloMax. The kaloMax parameters, which influence the result, are the following: grinding paste, number of revolutions, grinding period, diameter and normal force exerted by the ball (figure 3). The advantage of kaloMax is the construction of the driveshaft, preventing horizontal and vertical movement of the ball, which greatly reduces the uncertainty of measurement [6, 7].

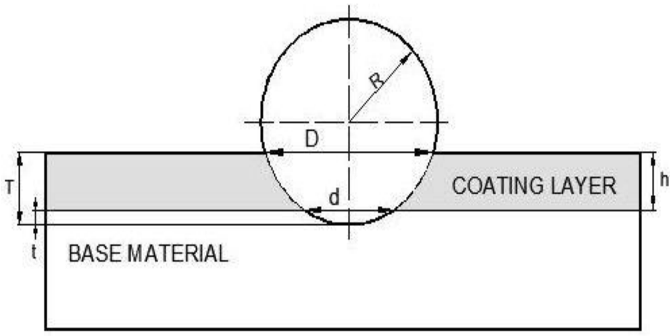

Figure 3. Operating scheme of ball-cratering test
h- desired layer thickness; *R*- radius of the ball; *D*- diameter of the spherical cap at the surface of the sample; *d*-diameter of the boundary between coating and base material; *T*- total penetration depth of the ball; *t*-depth of penetration in the base material

With a rotating steel ball and an abrasive slurry, a spherical cap is ground through the coating into the base material of the sample. At the examination with the microscope, the layer/base material interface appears as a circle. The layer thickness can be calculated from the diameters of these circles and the diameter of the grinding ball.

4. RESEARCH AND RESULTS

In the experimental researches, there were used some cutting inserts coated with titanium layer (Ti) and some coated with titanium aluminum (AlTiN). The cutting inserts were used in turning different surfaces (radius, chamfers and profiled surfaces). After the cutting inserts were used, their thickness was measured with ball-cratering, kaloMax.

According to [7], to calculate the thickness of the titanium thin layer from the cutting inserts, first there was found the diameter of the spherical cap at the surface of the sample (*D*), then the diameter of the boundary between coating and base material (*d*) and after that calculated the total penetration depth of the ball (*T*) using the equation (1) and the depth of penetration in the base material (*t*) using equation (2). The thickness of the titanium layer results from the difference between total penetration depth of the ball (*T*) and the depth of penetration in the base material (t) shown in equation (3), or like in equation (4).

$$T = R - \sqrt{R^2 - \frac{D^2}{4}} \qquad (1)$$

$$t = R - \sqrt{R^2 - \frac{d^2}{4}} \qquad (2)$$

$$h = T - t \qquad (3)$$

$$t = R - \sqrt{R^2 - \frac{D^2}{4}} - \sqrt{R^2 - \frac{d^2}{4}} \qquad (4)$$

In figure 4 it is shown a cutting insert coated with titanium thin layer and in the figure 5 there are shown the measurements made with kaloMax for the diameter of the spherical cap at the surface of the sample (*D*) and the diameter of the boundary between coating and base material (*d*), in order to calculate the cutting inserts thickness.

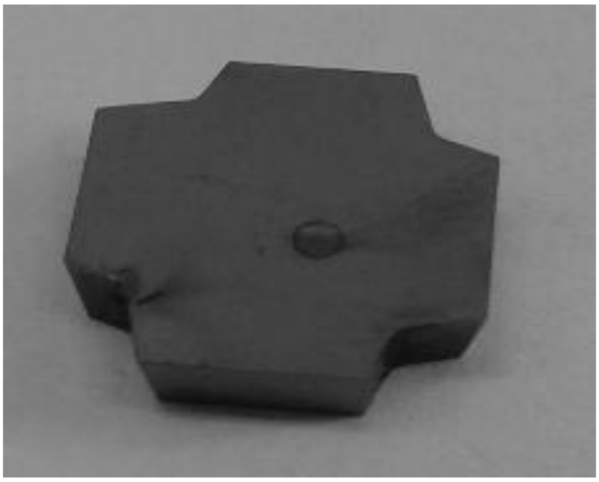

Figure 4. Cutting insert with titanium deposition

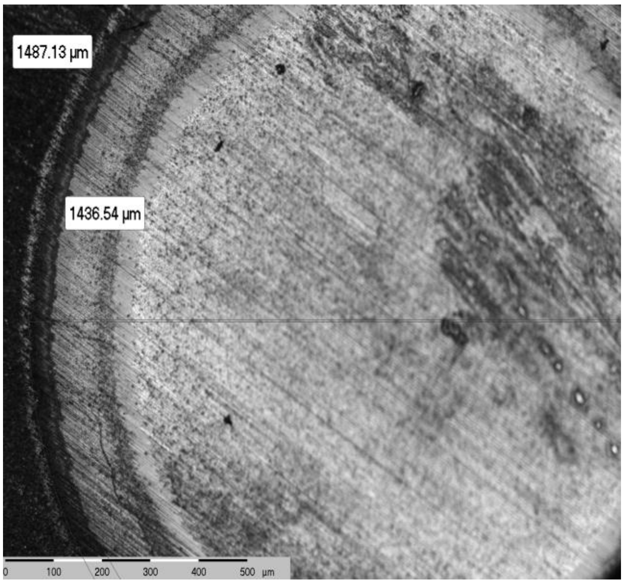

Figure 5. Measurements for cutting insert coated with Ti

In figure 6, it is shown another cutting insert coated with titanium thin layer and in the figure 7 it is shown the measurement made with installation kaloMAX for the diameter of the spherical cap at the surface of the sample (D) and the diameter of the boundary between coating and base material (*d*), in order to calculate the cutting inserts thickness.

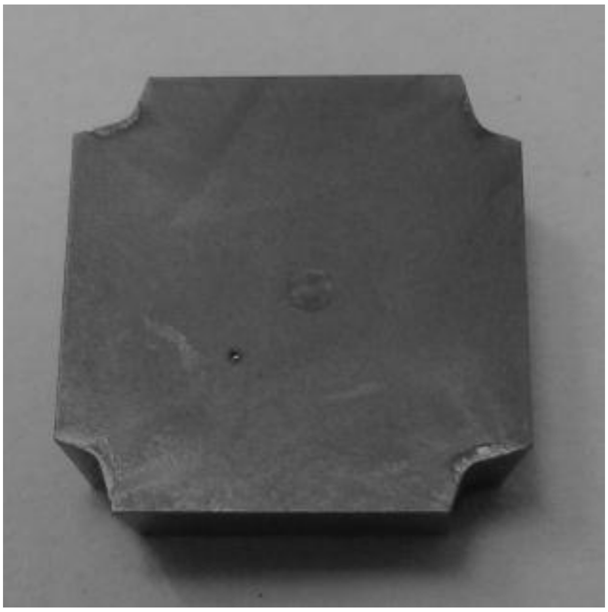

Figure 6. Cutting insert coated with titanium

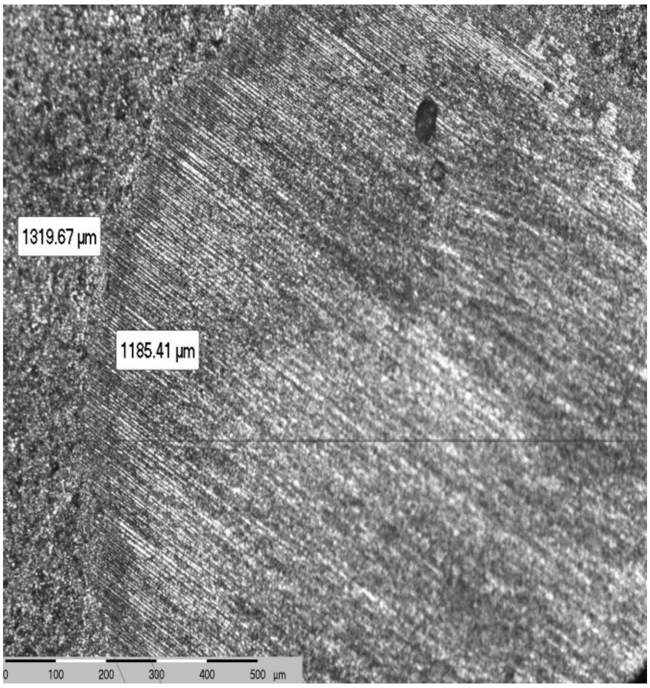

Figure 7. Measurements for cutting insert coated with titanium

Also in figure 6 it is shown other cutting insert coated with titanium thin layer and in the figure 7 it is shown the measurement made with installation kaloMAX for the diameter of the spherical cap at the surface of the sample (*D*) and the diameter of the boundary between coating and base material (*d*), in order to calculate the cutting inserts thickness.

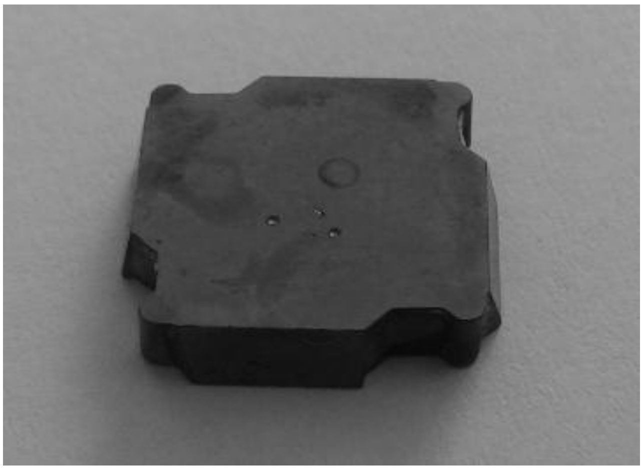

Figure 7. Cutting insert coated with Ti

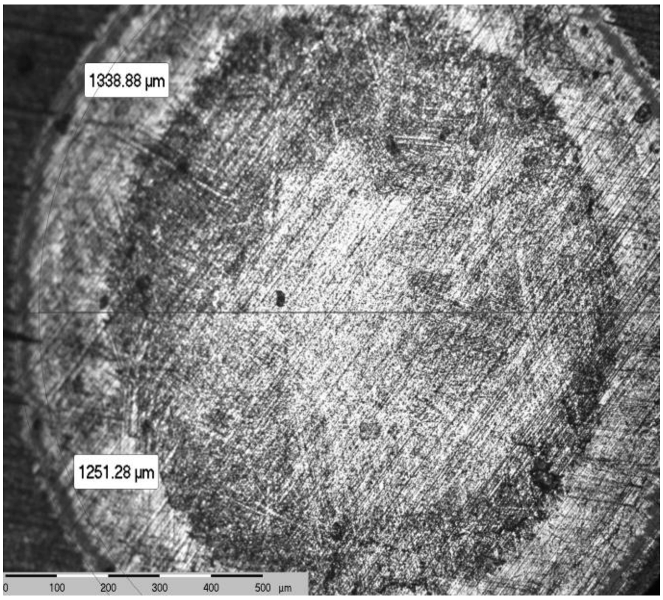

Figure 8. Measurements for cutting insert with titanium deposition

In figure 9, it is shown a different cutting insert, namely an insert coated with titanium and aluminum thin layer. Figure 10 shows the measurements made with installation kaloMax for the diameter of the spherical cap at the surface of the sample (*D*) and the diameter of the boundary between coating and base material (*d*), in order to calculate the cutting inserts thickness.

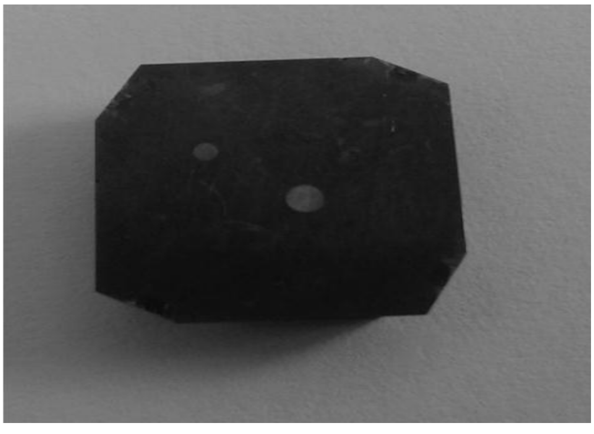

Figure 9. Cutting insert with AlTiN deposition

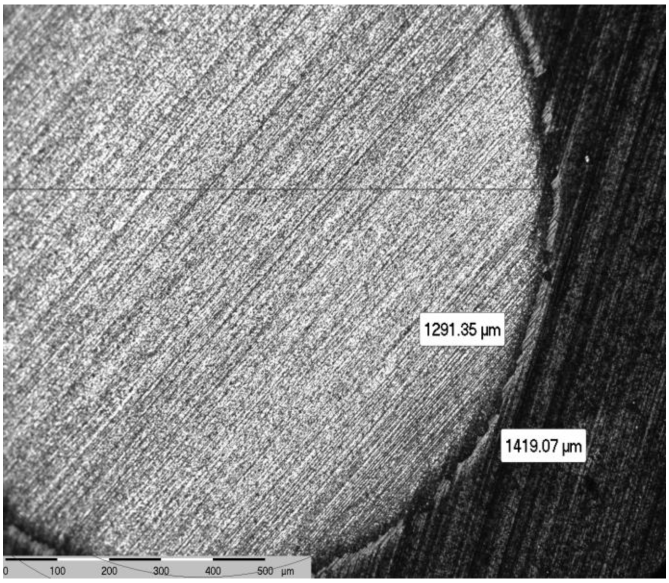

Figure 10. Measurements for cutting insert coated with AlTiN

Figure 11 shows another cutting insert coated with titanium and aluminum thin layer. Figure 12 shows the measurements made with kaloMax for the diameter of the spherical cap at the surface of the sample (*D*) and the diameter of the boundary between coating and base material (*d*), in order to calculate the cutting inserts thickness.

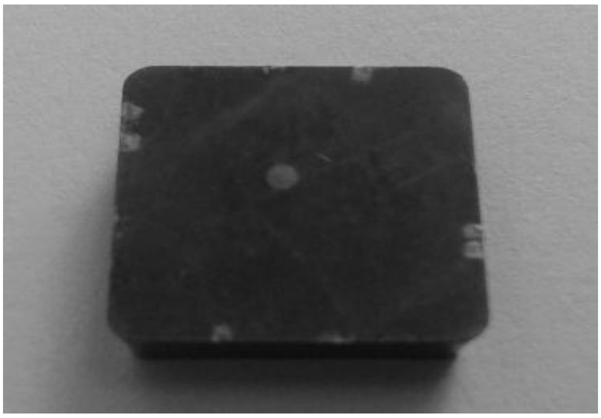

Figure 11. Cutting insert with AlTiN deposition

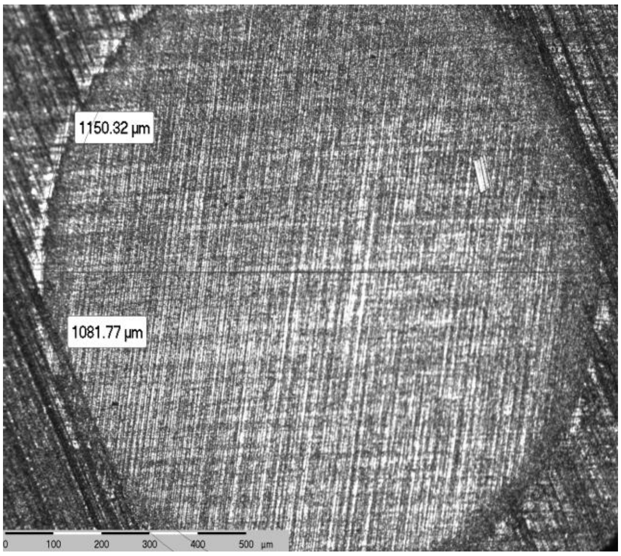

Figure 12. Cutting insert coated with AlTiN deposition

Table 1. The values obtained for thickness layer

Type of layer deposited	Revolutions per minute	Grinding period	Layer thickness (μm)	Ball diameter	*D* (μm)	*d* (μm)	*R* (μm)	Durability tested [min]
TiN	500 1/min	25 s	1.23	30	1487.13	1436.54	15000	6’40”
TiN	500 1/min	25 s	2.80	30	1319.67	1185.41	15000	9’47”
TiN	500 1/min	25 s	1.89	30	1338.88	1251.28	15000	21’33”
AlTiN	500 1/min	25 s	2.88	30	1419.07	1291.35	15000	48”30”
AlTiN	500 1/min	25 s	1.275	30	1150.32	1081.77	15000	33’49’

Values obtained for thickness are shown in Table 1, the cutting inserts showing a remarkable durability growth of the cutting inserts undergo the process of thin TiN coating and thin AlTiN coating by a PVD process, for all types of used cutting inserts.

Measurements made allowed also a graphical representation of how is the variation in time of the cutting inserts wear (fig. 13).

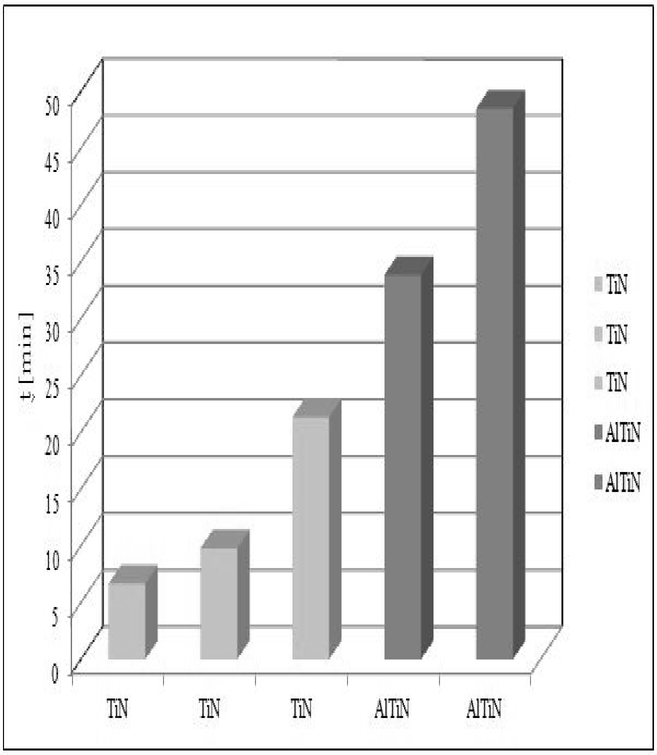

Figure 13. Graphical representation of how is the variation in time

5. CONCLUSION

The results obtained open new opportunities for continuing the studies in this domain, future researches following: diversification of the qualitative types of cutting inserts coated with thin layers of titanium and titanium-aluminium through a PVD process and the study of their behavior in the processes of turning; realization of coatings and with other types of layers: Ti-Cr, Ti-Al, Ti-Cr-Al and the analyze of their influence on the hardness increase and, implicitly, the durability of the cutting tools; determination of hardness, micro hardness, of deposited layers and determining their optimum values (depending on the layer structure), which allow achieving the highest values of durability.

6. REFERENCES

1. Dobrzanski, L.A., Lukaszkowicz, K., Zarychta, A., Cunha, L., Corrosion resistance of multilayer coatings deposited by PVD techniques on to the brass substrate, *Journal of Materials Processing Technology*, vol. 164-165, pp. 816-821, ISSN 0924-0136, (2005).
2. Lukaszkowicz, K., Dobrzanski, L.A., Structure and mechanical properties of gradient coatings deposited by PVD technology on to X40CrMoV5-1 steel substrate, *Journal of Materials Science*, vol. 43, pp. 3400-3407, ISSN 0022-2461, (2008).
3. Veprek, S., Mannling, H.D., Karvankova, P., Prochazka, J., The issue of the reproducibility of deposition of super hard nan composites with hardness of ≥ 50 GPa., *Surface and Coatings Technology*, vol. 201, pp. 6064-6070, ISSN 0257-8972, (2006).
4. Zou, C.W., Wang, H.J., Li, M., Yu, J.F., Liu, C.S., Guo, L.P, Fu, D.J., Characterization and properties of TiN-containing amorphous Ti-Si-N nan composite coatings prepared by arc assisted middle frequency magnetron sputtering Vacuum, vol. 84, pp. 817-822, ISSN 0042-207X, (2010).
5. Bădănac, A.**,** Lupescu, O., Manole, V., Rusu, O. T., Researches to improving durability of the cutting inserts coated with titanium thin layers, *Academic Journal of Manufacturing Engineering*, Vol. 12, pp 6-11, ISSN**:** 1583-7904, (2014).
6. Podgursky, V., Gregor, A., Adoberg, E., Kulu, P., Wear of hard coatings, valuated by means of kaloMax, *Proc. Estonian Acad. Sci. Eng.*, **12**, 4, 419–426, (2006).
7. The BAQ kaloMax Manual, Version 1.01.
8. Cat, A.-S., Mice, M.O., Cheese, G., Night behaviours, *6th International Conference on the Management of Behavioural Changes*, Vol. II, pp. 191-199, City, State, (2009).