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Cemented carbide cutting tools life with nanocrystalline Al_2O_3 layer deposited by MOCVD

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ABSTRACT

The work presents the results of tool life tests of uncoated cemented carbide cutting tools as well as tools coated with $\text{Al}_2\text{O}_3\text{-C}$ and $\text{Al}_2\text{O}_3\text{-C}/\text{Al}_2\text{O}_3$ composite layer synthesized by MOCVD method using $\text{Al}(\text{acac})_3$. $\text{Al}_2\text{O}_3\text{-C}$ layers were deposited in argon. The composite layer was synthesized in argon initially in order to obtain thin and continuous $\text{Al}_2\text{O}_3\text{-C}$ layer about 70 nm thick and outer, thicker pure Al_2O_3 layer deposited in air. The layers were deposited at 800 °C. Some samples were additionally annealed or synthesized at 1000 °C. The most advantageous results were obtained when the layers were annealed. This way enables controlling the grain size in the layer. In the work, comparative tool life tests were also performed for commercial cemented carbide cutting tools without and with $\text{Ti}(\text{C}, \text{N}) + \text{Al}_2\text{O}_3$ layers from Sandvik Baildonit.

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1. Introduction

Cemented carbide cutting tools have been commonly used for many years and nowadays they represent in value about 50% of all produced cutting tools, wherein 90% of them is covered with thin films: TiN , TiC , $\text{Ti}(\text{C}, \text{N})$, Al_2O_3 , HfO_2 , Si_3N_4 . Thin layers should assure an increase of tools durability. They are deposited by CVD (Chemical Vapour Deposition) or PVD (Physical Vapour Deposition) methods [1–3].

Cemented carbide substrate contains mainly grains of WC and TiC as well as binding metal (for example cobalt). Cemented carbides ensure high hardness of tools, also at elevated temperatures, what is especially important in the

case of cutting tools. High cutting speeds cause rising of tool edges temperature [4]. The metal, binding cemented carbide grains, provides mechanical and impact strength. Ceramic films protect the substrate against its main failure mechanism, resulting from diffusion of cobalt from the substrate to metal subjected to cutting and this metal to a tool. As a consequence, on the tool edge a built-up is formed [5]. When a built-up edge reaches considerable size, it will be broken with a part of tool edge by sliding chip. Therefore, in order to prevent this process, cemented carbide substrates are covered with mono-layer or multi-layers [e.g. 1–3].

Among presented coating materials, Al_2O_3 seem to be especially interesting, because of its properties. Al_2O_3 is characterized by a high melting point and resistance to a

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number chemicals and metals. It does not oxidize. Cutting tools with Al_2O_3 layer may be used for high speed cutting.

Now, on commercial scale, Al_2O_3 layers are deposited by CVD method using $\text{AlCl}_3\text{-H}_2\text{-CO}_2$ or $\text{AlCl}_3\text{-H}_2\text{O}_{(\text{steam})}\text{-CO}$ [6]. The temperature of synthesis process is above 1000 °C. Mono- or multi-layers with total thickness of 5 μm are deposited on the intermediate layer of TiN, TiC or Ti(C, N) [3,4] with thickness of a few micrometres. An intermediate layer prevents cobalt diffusion from the substrate to synthesized Al_2O_3 layer. Its presence favours growth of the $\alpha\text{-Al}_2\text{O}_3$ phase crystallites with elongated shapes, at high temperatures [7].

Deposited layers may contain $\kappa\text{-Al}_2\text{O}_3$ and/or $\alpha\text{-Al}_2\text{O}_3$ phase. The $\kappa\text{-Al}_2\text{O}_3$ phase is metastable, relatively soft and is characterized by presence of small grains. Their size is in the order of nanometers in multi-layers. The $\alpha\text{-Al}_2\text{O}_3$ phase is stable and characterized by high hardness and larger grains (in order of micrometres) [8]. It should be noticed that reducing of the grain size in the layer, contributes to increasing of its strength (it is the exponential dependence). It is resulting from well known Cook-Gordon mechanism of crack blocking on intergranular boundaries in a brittle materials. Due to this mechanism, crack in the material may develop under internal or thermal stresses. In order that crack in material was initiated at least one crack having critical size for the internal stress must be. For example pores or microstructure defects (microcracks, scratches on the surface) may be such cracks. Stress concentration is followed at the top of crack. The value of the maximum stress at the top of crack $\sigma_{||(\text{max})}$ may be calculated from known Griffith's equation [e.g. 9].

$$\sigma_{||(\text{max})} = \sigma_z(c/\rho)^{1/2}, \quad (1)$$

where: σ_z – the average internal tensile strain applied to the sample, $\sigma_{||(\text{max})}$ – the maximum tensile strain at the top the crack in parallel to the direction of the internal strain, c – the crack length, ρ – the radius of the crack top.

Strain $\sigma_{||}$ generates perpendicular strains to this strain. The maximum value of $\sigma_{\perp(\text{max})}$ may be calculated from the following formula:

$$\sigma_{\perp(\text{max})} = S_{||(\text{max})} \nu, \quad (2)$$

where: ν – Poisson number.

It may be also theoretically demonstrated that $\sigma_{\perp(\text{max})}$ is located at the distance from the crack and when the cracking is moving, the localization of $\sigma_{\perp(\text{max})}$ is also moving. The crack may develop when $\sigma_{||(\text{max})}$ is greater than the tensile strength of material near the top of the crack. When the crack approaches to the intergranular boundary laid at the angle close to 90 °C then first $\sigma_{\perp(\text{max})}$ is applied to this boundary. If the value of $\sigma_{\perp(\text{max})}$ is greater than tensile strength of intergranular boundary this boundary will be broken before the developing crack under $\sigma_{||(\text{max})}$ comes to it. When this crack will connect to crack formed by breaking of the intergranular boundary then the radius of curvature of developing crack will increase rapidly and according to the formula (1) $\sigma_{||(\text{max})}$ value will decrease. It will cause blocking of the crack development. Therefore, according to this formula the crack will develop further when σ_z will increase.

From the above, it results that tensile strength of brittle polycrystalline materials is higher than tensile strength of

amorphous or monocrystalline materials because of lack of intergranular boundaries in these materials.

It is evident that the smaller grains in material the shorter distance in which the forming crack will be blocked and therefore real strain σ_z in material containing this crack will be smaller than in the case of when this crack is at greater distance what is present in the case of larger grains. I should be noted that in the case of pores their shape is important, because it influences on the magnitude of stress concentration $\sigma_{||(\text{max})}$. When pores are, for example, spherical, then $\rho = c$ and according to the formula (1) $\sigma_{||(\text{max})} = \sigma_z$. If pore shape will be elongated (longer axis will be perpendicular to the direction of σ_z), then stress concentration on a such crack will increase. From the above, it results that the smaller grains, the greater tensile strength of brittle material. Presence of pores, particularly of an elongated shape and large size will decrease material strength significantly. It should be also noted according to known statistic Weibull's theory the greater brittle materials strength, the smaller their volume. It is related to volume of solid material (e.g. layer thickness) as well as grain size in this material. According to this theory increase of brittle materials strength results from that the finding probability of cracks of critical sizes is less in materials, which volumes are smaller.

Fine grained layers are also smoother, what it is important in the case of high speed cutting, which enables an increase of the process efficiency and obtaining high smoothness of machined surfaces. In this case, finishing of these surfaces by grinding and polishing is not required. High-speed cutting causes also fast edge heating to a temperature above 800 °C. The rougher layers make the edge heating process more intense. Therefore, it seems that the layers on cemented carbide cutting tools should contain only $\kappa\text{-Al}_2\text{O}_3$ phase, with very fine grains. It is possible in the case of multilayer, because the growth of the subsequent layers in multilayer is not realized continuously. When the synthesized layer reaches the desired thickness, the synthesis process is interrupted. The growth of a new layer is carried out from the beginning (the nucleation process and then the growth of grains) [10]. In consequence, for the thinner layers, the smaller grains are obtained.

As it was already mentioned, the $\kappa\text{-Al}_2\text{O}_3$ phase is metastable and undergoes the transformation to the $\alpha\text{-Al}_2\text{O}_3$ phase during machining. It causes formation of microcracks at the interface during this transformation as a result of smaller molar volume of $\alpha\text{-Al}_2\text{O}_3$ phase (about 8%) than $\kappa\text{-Al}_2\text{O}_3$ phase [1].

In mono-layers microcracks are larger and statistically distributed in the entire volume. In the case of multi-layers, they are smaller and formed mainly at the interface between layers, because mostly in these areas the transition process takes place. In consequence, it leads to the destruction of the edges as a result of the delamination process [3,11].

It should be noticed that a method of this transition process inhibiting is currently not known. Therefore, it seems advisable to search for new method of Al_2O_3 layers deposition. The deposited layers should be smooth and contain fine grained $\alpha\text{-Al}_2\text{O}_3$ phase. They should be also synthesized with a high growth rate.

This work shows results of investigation on aluminium oxide layers deposition by MOCVD (Metal Organic Chemical

Table 1 – Conditions for the synthesis of Al₂O₃-C/Al₂O₃ composite layers by MOCVD method.

Parameter	Synthesis conditions
Summary gas pressure in the CVD reactor [Pa]	3.7–1013.3 × 10 ²
Flow rate [Nl/h]	
Ar	0–30
Air	0–100
NH ₃	0–3
The temperature of the carrier gases [°C]	140–200
The temperature of evaporator [°C]	140–170
The temperature of substrate [°C]	700–1050
Synthesis time of Al ₂ O ₃ -C layer [min]	2–15
Synthesis time of Al ₂ O ₃ layer [min]	15–25
Weight of Al(O ₂ C ₅ H ₇) ₃ [g]	0.2
The annealing temperature of layers synthesized at 800 °C [°C]	900–1050
Annealing time [min]	10–30
The value of the developed criterion Gr_x/Re_x^2 [12,13]	<0.1

Vapour Deposition) method, using aluminium acetyloacetate as a precursor. Application of metalorganic compounds enables obtaining layers with a high growth rate at significantly lower temperatures than in traditional CVD process. At lower temperatures, the probability of unfavourable homogeneous nucleation process occurrence is considerably lower. Thus, it is possible to use a high reactant concentration and obtain layers with a high growth rate (even 5 μm/h).

A model research on synthesis of aluminium oxide layers by MOCVD [12,13] indicates that additional annealing of the layers synthesized at 800 °C, at temperature above 950 °C causes their crystallization and formation of α-Al₂O₃ phase. The grain size in the layer may be controlled by selection of appropriate temperature and duration of the process. This method makes possible obtaining smooth nanocrystalline mono-layers.

Cemented carbide cutting tools covered with Al₂O₃-C and Al₂O₃-C/Al₂O₃ composite layers, deposited by MOCVD method, were subjected to the cutting tests. For comparison, cutting tests were also performed using commercial cemented carbides with Ti(C, N) + Al₂O₃ and Ti(C, N) (Sandvik Baildonit), cemented carbides with TiN layer deposited by traditional CVD process and uncoated cemented carbides (two grades, Sandvik Baidonit).

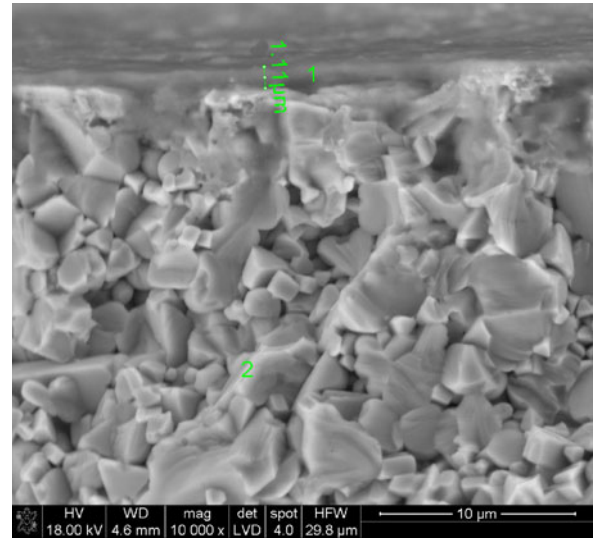


Fig. 1 – The surface and fracture of the sample no. 10 (Table 2), with Al₂O₃-C/Al₂O₃ layer synthesized at 800 °C (synthesis time: 17 min) and annealed at 1000 °C (time: 15 min).

2. Materials and methods

Aluminium oxide layers were deposited onto cemented carbide cutting tools by MOCVD method using aluminium acetyloacetate (Sigma Aldrich). The cemented carbides in S30S and NMK-30/K30 grades (Sandvik Baildonit) were selected as substrates. Argon and/or air were used as carrier gases. Air was also a source of oxygen necessary for elimination of carbon (a solid product of Al(acac)₃ pyrolysis). The synthesis process was realized in two steps. In the first step, synthesis process was conducted only in the presence of argon. The layer deposited in a such way contained carbon (Al₂O₃-C). It was “intermediate layer”. This layer should be thin and continuous. In the second step, process was realized in the presence of Ar and air. In this case, the synthesized layer did not contain carbon. This layer was significantly thicker. Selected samples, covered with Al₂O₃-C/Al₂O₃ composite layers, were additionally annealed. Synthesis conditions are presented in Table 1. A

Table 2 – Characteristics of the samples for cutting tests.

Sample no.	Substrate	Layer (layers)	The layer thickness [μm]	Comments
1	S30S	Al ₂ O ₃ + C	0.77	Layers obtained by MOCVD (AGH UST)
2	NMK-30/K30	–	–	Sandvik Baildonit S.A.
3	S30S	T(C, N)/Al ₂ O ₃	7 + 4	Sandvik Bailonit S.A.
4	NMK-30/K30	T(C, N)/Al ₂ O ₃	7 + 4	Sandvik Bailonit S.A.
5	S30S	Tin	4	Layers obtained by CVD from TiCl ₄ (AGH UST)
6	S30S	Al ₂ O ₃ + C	0.6	Layers obtained by MOCVD (AGH UST)
7	S30S	–	–	Sandvik Baildonit S.A.
8	S30S	Ti(C, N)	7	Sandvik Baildonit S.A.
9	S30S	Al ₂ O ₃ + C/Al ₂ O ₃	0.07 + 1.65	Layers obtained by MOCVD (AGH UST)
10	S30S	Al ₂ O ₃ + C/Al ₂ O ₃	0.07 + 1.04	Layers obtained by MOCVD (AGH UST)

Label A: 10prz 001p1

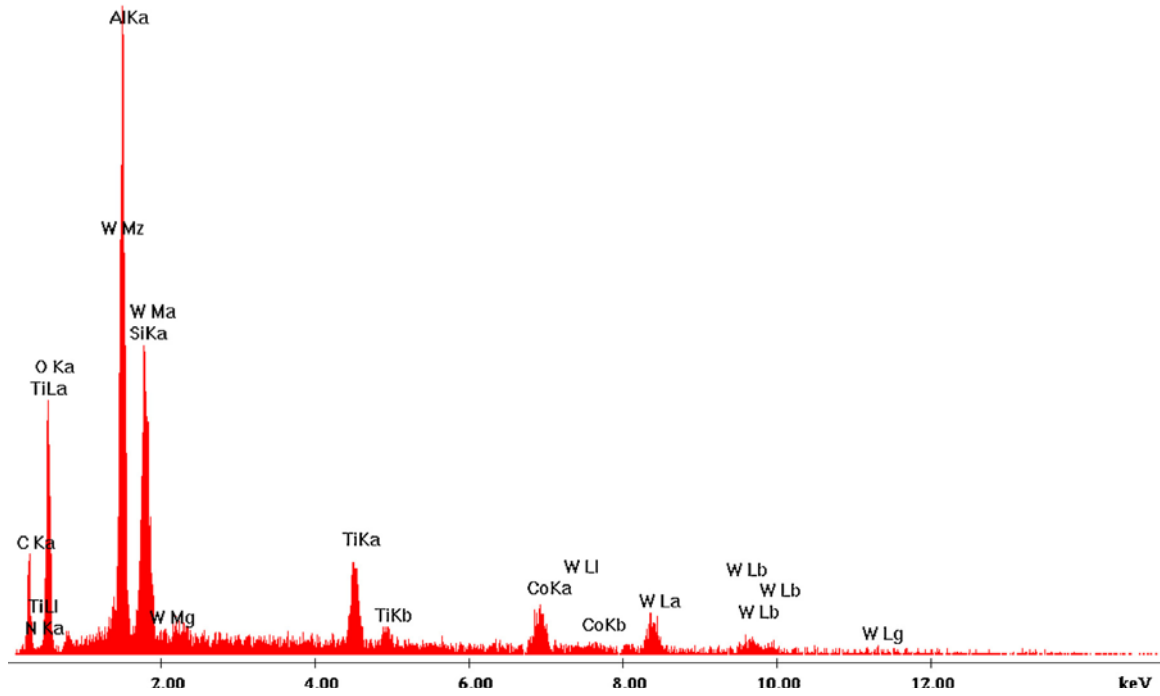


Fig. 2 – The EDS analysis results for point 1 in Fig. 1.

Label A: 10prz 001p2

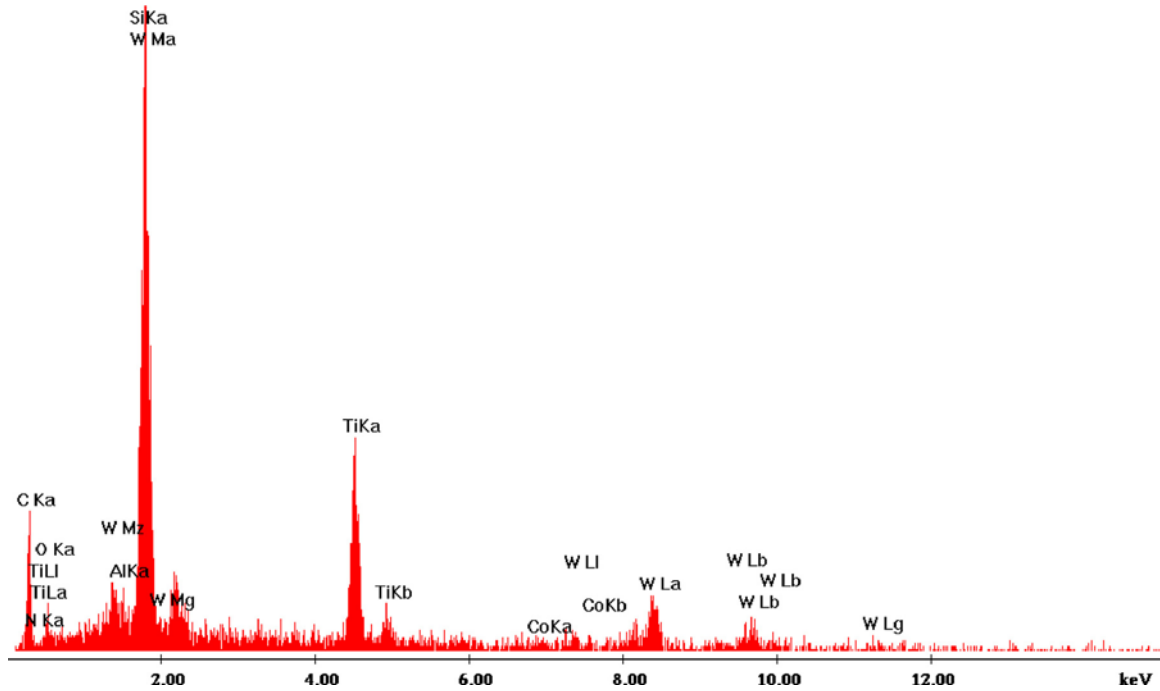


Fig. 3 – The EDS analysis results for point 2 in Fig. 1.

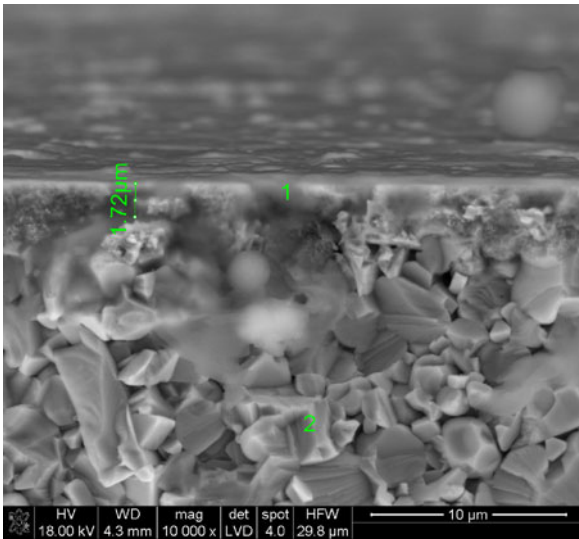


Fig. 4 – The surface and fracture the sample no. 9 (Table 2), with of $\text{Al}_2\text{O}_3\text{-C}/\text{Al}_2\text{O}_3$ layer synthesized at 800°C (synthesis time: 25 min) and annealed at 1000°C (time: 15 min).

diagram of the apparatus used for the synthesis of the composite layers is shown in [5].

Selected samples were tested using scanning electron microscopy (SEM NANO NOVA 200 from FEI EUROPE Company, cooperating with the EDS analyzer from EDAX company).

Both cemented carbides covered with $\text{Al}_2\text{O}_3\text{-C}$ and $\text{Al}_2\text{O}_3\text{-C}/\text{Al}_2\text{O}_3$ composite layers, were chosen for cutting tests, in order to evaluate their wear resistance. Comparative tests were also performed using commercial tools covered with, among others, Al_2O_3 layers (Sadvik Baidonit) and commercial uncoated cemented carbides S30S (Sandvik Baidonit). Those tests were performed using C45 steel as a machined material.

3. Results and discussion

Presented results of SEM/EDS investigation relate to samples intended for tool life tests. Characteristics of these samples is shown in Table 2.

Fig. 1 shows surface and fracture of sample no. 10 (Table 2) with $\text{Al}_2\text{O}_3\text{-C}/\text{Al}_2\text{O}_3$ layer obtained by MOCVD. This composite layer (total thickness: about $1.11\ \mu\text{m}$, thickness of intermediate layer: about $70\ \text{nm}$) is dense and smooth. During the samples breaking, the layer broke away together with a fragment of the surface. It indicates good adhesion of the layer to the substrate.

Figs. 2 and 3 present point EDS analysis for selected points in Fig. 1 (layer and substrate).

Figs. 1–3 indicate that the surface of the substrate is covered with Al_2O_3 layer.

The surface and the fracture of the sample no. 9 (Table 2) are presented in Fig. 4. The layer is about $1.72\ \mu\text{m}$ thick. It is dense, smooth and well adherent to the substrate.

Presented in Fig. 4 composite layer synthesized by MOCVD method (sample no. 9, Table 2), similarly as in the case if

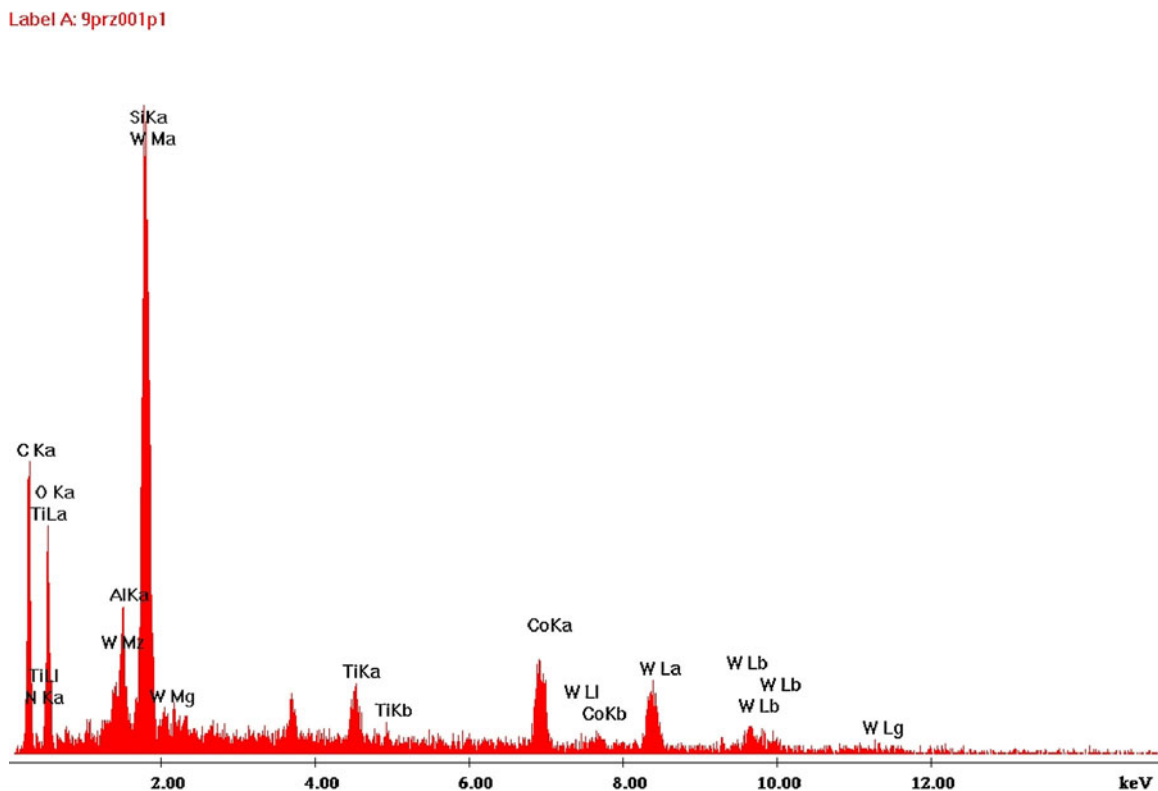


Fig. 5 – The EDS analysis results for point 1 in Fig. 4.

Label A: 9prz 001p2

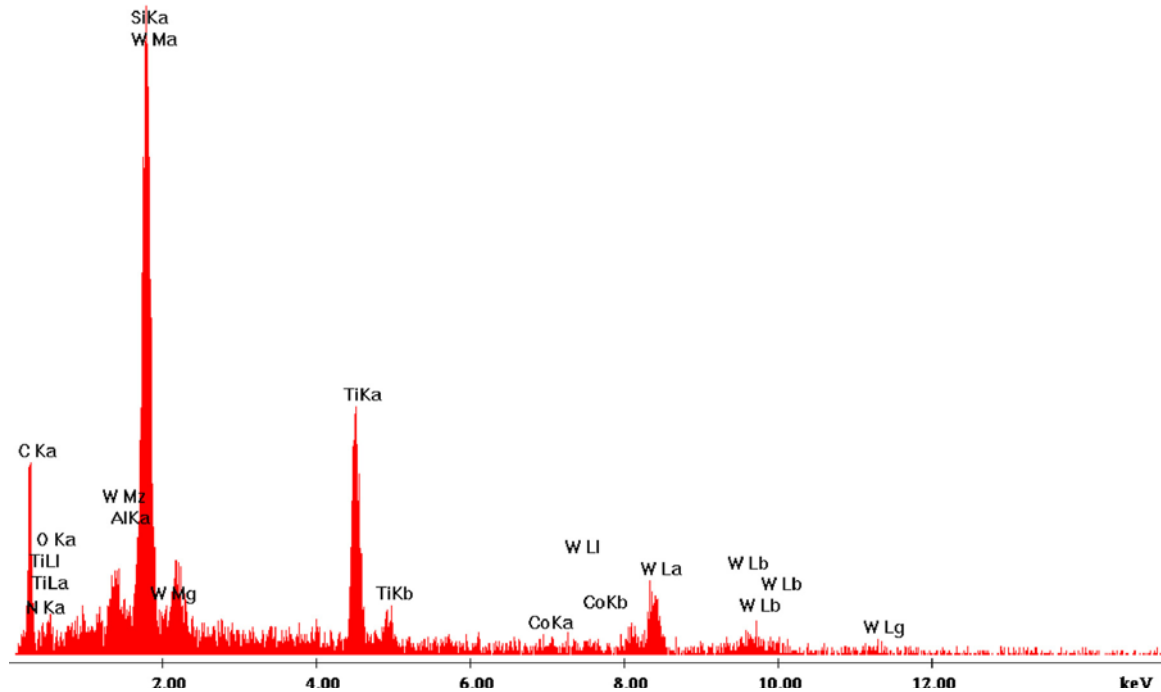


Fig. 6 – The EDS analysis results for point 2 in Fig. 4.

sample shown in Fig. 1 (sample no. 10, Table 2), is smooth, very dense and characterized by good adhesion to the substrate. Point EDS analyses (Fig. 5) indicate that the layer contains Al_2O_3 . Point EDS analyses for the substrate is shown in Fig. 6.

For comparison, the surface and fracture of the sample no. 6 (Table 2), with Al_2O_3 -C “intermediate” layer is shown in Fig. 7 and results of point EDS analysis for selected points of this sample are presented in Figs. 8 and 9. The layer thickness is about $0.6 \mu\text{m}$. The layer is very smooth, non-porous and contains Al_2O_3 .

Fig. 10 shows the surface of Al_2O_3 -C layer on the sample no. 1 (Table 2) after abrasion tests performed during the cutting tests. Before abrasion the layer thickness was about $0.77 \mu\text{m}$.

Figs. 11 and 12 indicate that after abrasion small amounts of Al_2O_3 remained on the sample surface. The sample surface is dense. The grains from the substrate are not evident yet. Darker areas (point 1, Fig. 11) indicate residues of smaller amounts of Al_2O_3 on the sample surface and in the brighter areas more aluminium oxide is remained.

Additionally, sample no. 5 (Table 2) intended for cutting tests, was subjected to SEM/EDS investigation. The sample surface was coated with thin TiN layer by CVD method at AGH UST (Fig. 13). TiN layer was deposited by reacting of TiCl_4 vapour and N_2 at temperature of 900°C . Synthesis time was 1 h. The layer thickness is about $4 \mu\text{m}$. The layer is non-porous.

Figs. 14 and 15 present the surface and the fracture of commercial material from Sandvik Baildonit (sample no. 3, Table 2). Cemented carbide surface is coated with the intermediate layer of Ti(C, N) (the layer thickness: about $7 \mu\text{m}$) and the outer Al_2O_3 layer (the layer thickness: about $4 \mu\text{m}$).

Figs. 14 and 15 indicate that both the outer Al_2O_3 layer and the intermediate Ti(C, N) layer are very porous. Results of EDS analysis of points marked in Fig. 15 are shown in Figs. 16–18. They confirm the presence of the Al_2O_3 and Ti(C, N) layers on the cemented carbide substrate.

An example of commercial Al_2O_3 layer, synthesized on intermediate Ti(C, N) layer on cemented carbide substrate in

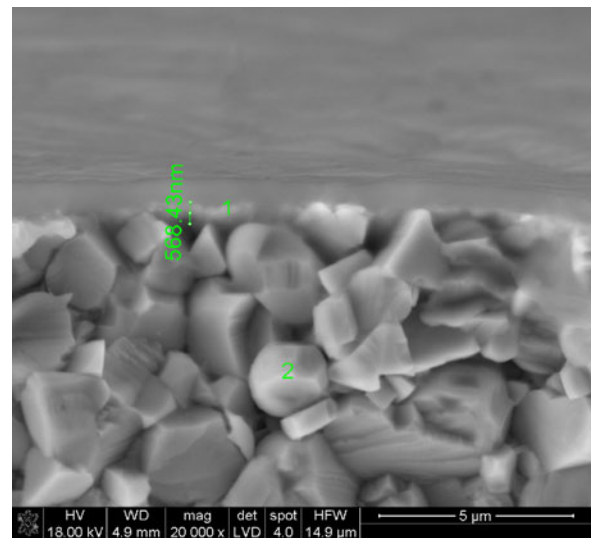


Fig. 7 – The surface and fracture of the sample no. 6 (Table 2), with Al_2O_3 -C layer synthesized at 1000°C (synthesis time: 12 min).

Label A: 6 prz 001p1

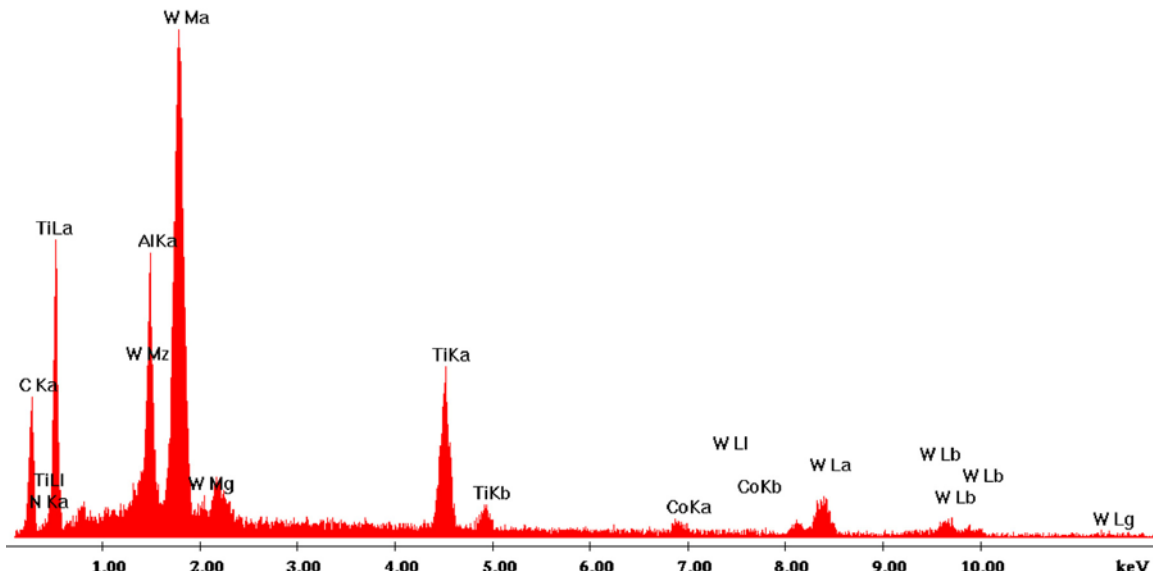


Fig. 8 – The EDS analysis results for point 1 in Fig. 7.

NMK-30/K30 grade (sample no. 4, Table 2), is illustrated in Fig. 19. The microstructure of presented Al_2O_3 layer is similar to one observed in the case of the sample no. 3 (Table 2).

The fracture of the sample no. 4 is shown in Fig. 20. Figs. 19 and 20 indicate that both Al_2O_3 layer (thickness: about $4\ \mu\text{m}$) and T(C, N) layer (thickness: about $7\ \mu\text{m}$) are also very porous.

Due to the fact that additional cutting tests were also planned for uncoated cemented carbide substrates and substrates coated with intermediate Ti(C, N) layer from

Sandvik Baildonit, their microstructure was also investigated with the use of SEM. Results of those studies are presented in Figs. 21–23.

The layer shown in Fig. 21 is porous and consists of two underlayers: more porous TiN (point 1) and less porous TiC (point 2). The microstructures of uncoated substrates are presented in Fig. 22 (S30S grade) and Fig. 23 (NMK-3/K30 grade).

Both S30S and NMK-30/K30 substrates are porous (Figs. 22 and 23). However, a porosity of NMK-30/K-30 substrate

Label A: 6 prz 001p2

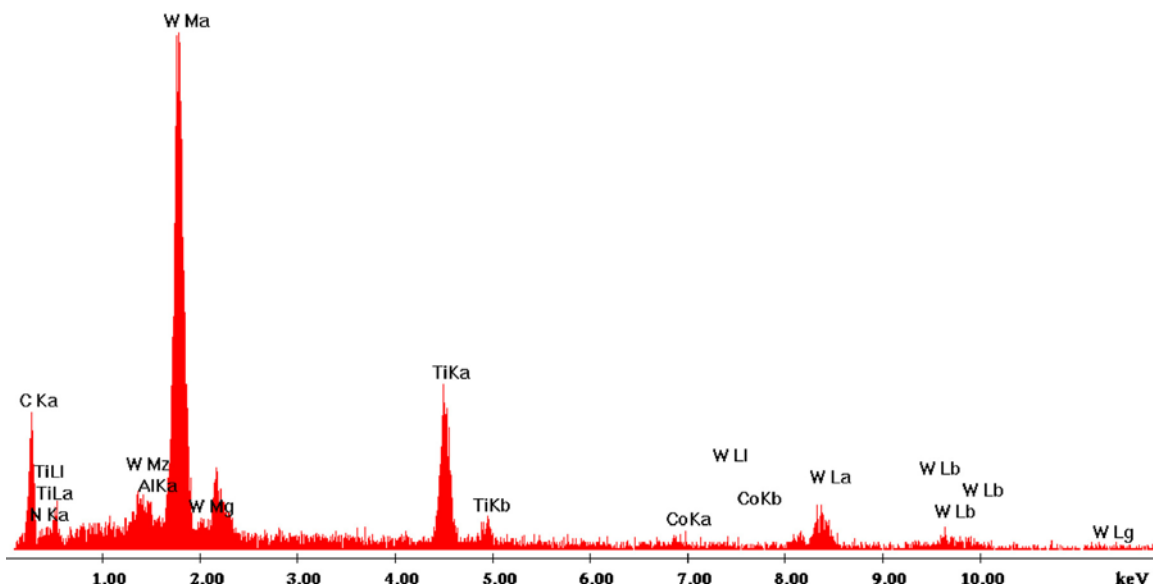


Fig. 9 – The EDS analysis results for point 2 in Fig. 7.

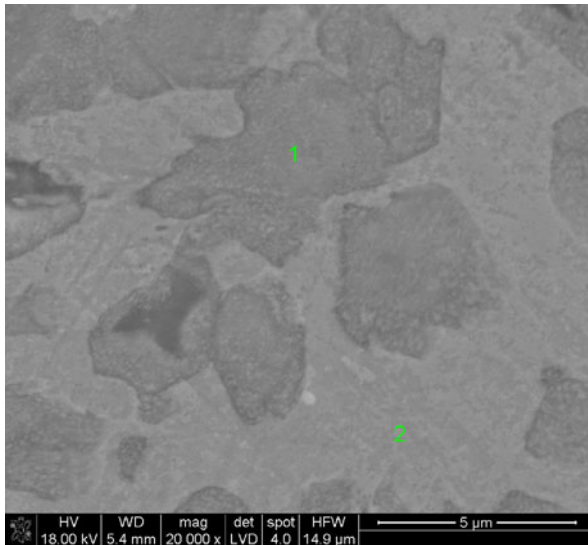


Fig. 10 – The surface of the sample no. 1 (Table 2) after abrasion tests performed during cutting tests. $\text{Al}_2\text{O}_3\text{-C}$ layer (thickness: $0.77\ \mu\text{m}$) synthesized at $800\ ^\circ\text{C}$ (synthesis time: 12 min) and additionally annealed at $1000\ ^\circ\text{C}$ (time: 15 min).

seems to be higher. Performed tool life tests confirm that S30S substrates are more durable (Fig. 24).

For the all samples presented in Table 2, the cutting tests were performed with the use of C45 steel rollers (60 mm in diameter) as a machined material. The first step of these tests included cutting the rollers to the diameter of 40 mm and the

second step, further machining to the diameter of 20 mm (without samples 2 and 7). Uncoated samples were machined only once, because of their high wear (higher wear was observed in the case of sample 2). The cutting parameters are shown in Table 3.

The measurements of the samples wear parameters after machining were performed by photogrammetric method. The samples were photographed before the test and after both steps of machining. The measurements were carried out with the use of “Struktura 1.0” image analysis software. The maximum width of the flank wear land VB_{Bmax} and the crater width KB were estimated. Results of these measurements are presented in Fig. 24.

As it was mentioned, for all samples covered with layers, cutting tests consisted of two steps. After the second step, the sample no. 9 turned out to be the best, when the VB_{Bmax} parameter is taken into consideration. The next samples were: 10, 1, 8, 4.3, 6 and 5. In the case of KB parameter, the best samples were following: 1, 3, 6 and 4. Similar wear was observed for samples: 5, 8, 9 and 10.

It seems that if $\text{Al}_2\text{O}_3\text{-C}/\text{Al}_2\text{O}_3$ or $\text{Al}_2\text{O}_3\text{-C}$ layers would be thicker, then their wear during machining would be significantly smaller, compared to commercial cutting tools covered with thick, but porous $\text{Ti}(\text{C}, \text{N}) + \text{Al}_2\text{O}_3$ layers from Sandvik Baildonit. On the basis of the results presented in Fig. 24, it can be concluded that the wear resistance of porous $\text{Ti}(\text{C}, \text{N}) + \text{Al}_2\text{O}_3$ layer, having total thickness of about $11\ \mu\text{m}$, is the same as in the case of non-porous $\text{Al}_2\text{O}_3\text{-C}/\text{Al}_2\text{O}_3$ layer, having total thickness of about $1\ \mu\text{m}$.

Therefore, obtained results of research in this work on microstructure and tools life of cemented carbides covered with non-porous nanocrystalline $\text{Al}_2\text{O}_3 + \text{C}/\text{Al}_2\text{O}_3$ layers by MOCVD method as well as porous cemented cutting tools

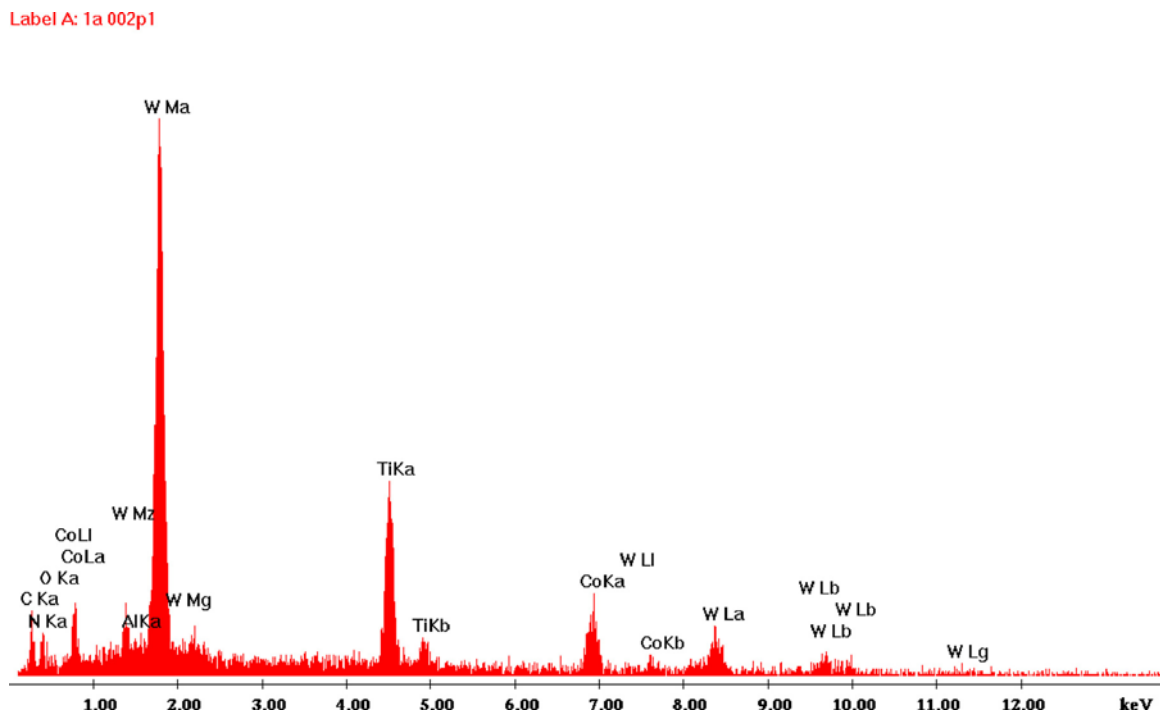


Fig. 11 – The EDS analysis results for point 1 in Fig. 10.

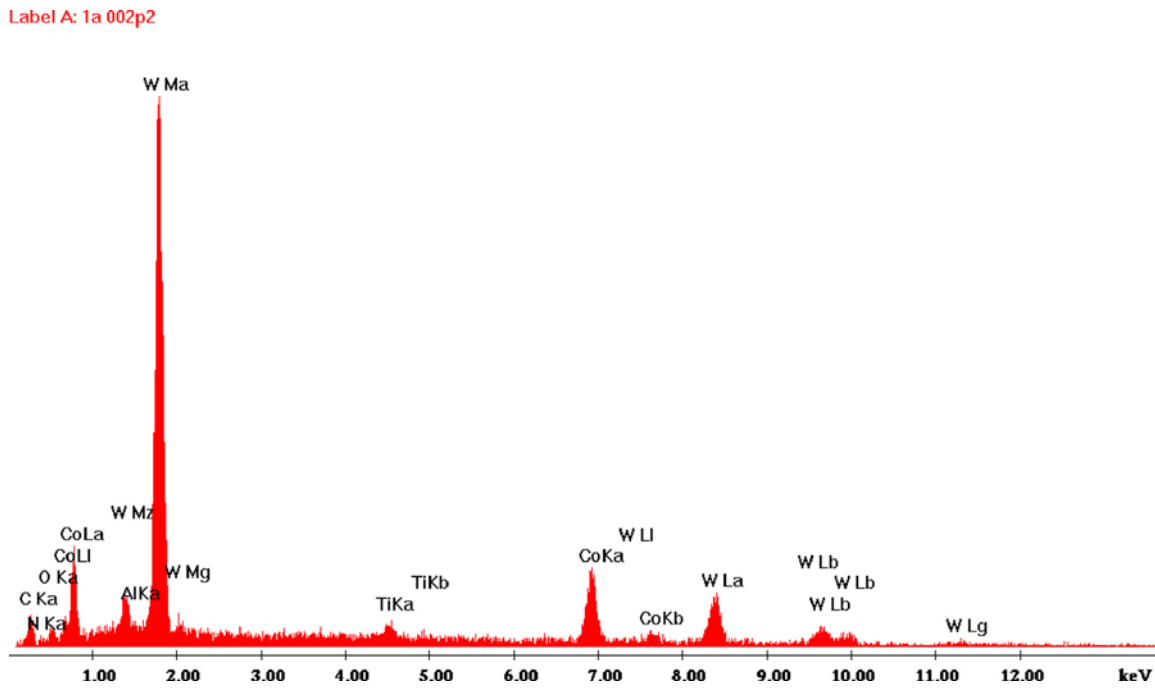


Fig. 12 – The EDS analysis results for point 2 in Fig. 10.

having large grain size produced by SANDVIK BAILONIT confirm rightness of theoretical considerations presented in the introduction of this work saying that pores as well as large grains can reduce mechanical strength of materials significantly. It should be noted that authors of this work do not know method of Ti(C, N) + Al₂O₃ layer synthesis used in SANDVIK in detail. It seems that, for example, Al₂O₃ layers were synthesized by known CVD method using AlCl₃ [6] (mentioned in the introduction of the work). Because of a low

reactivity of AlCl₃, synthesis of Al₂O₃ layers by this method requires using of high temperatures (above 1000 °C).

Such high temperatures of the synthesis process favour occurrence of homogeneous nucleation process and formation of porous powders in the gas phase as a result of this process. The composition of these powders is similar or the same as composition of synthesized layer. They settling on synthesized layer will cause its porosity, particularly in the case of materials having a large content of the covalent binding

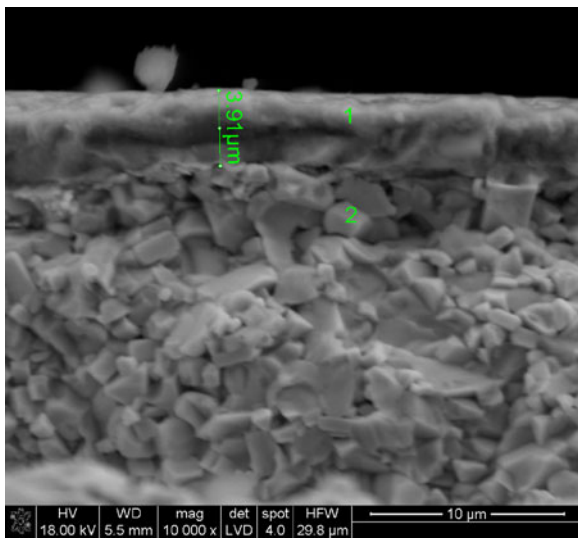


Fig. 13 – The fracture of the sample no. 5 (Table 2.) coated with dense TiN layer. The layer, about 4 μm in thickness, was deposited by CVD method.

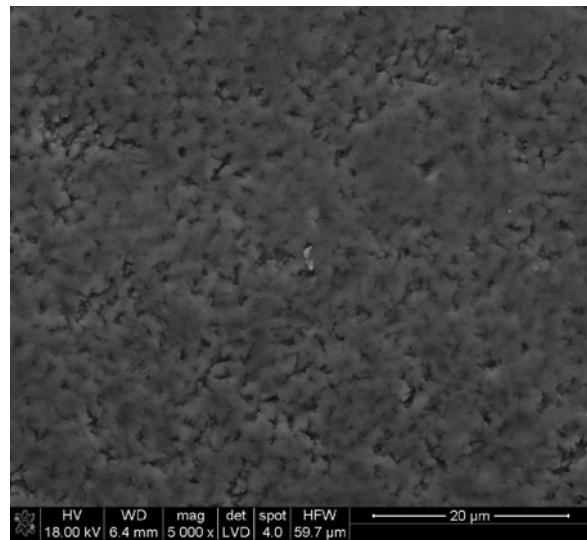


Fig. 14 – The surface of the sample no. 3 (Table 2), coated with Ti(C, N) + Al₂O₃ layers (Sandvik Baildonit). Substrate: cemented carbides, S30S grade.

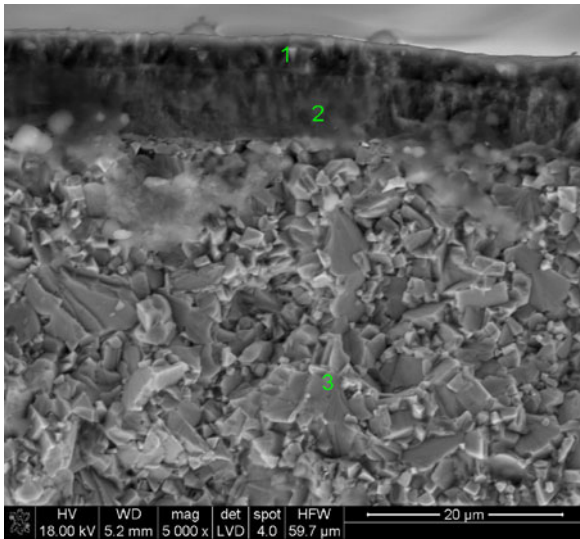


Fig. 15 – The fracture of the sample no. 3 (Table 2) presented in Fig. 14.

characterized by small surface and volume diffusion coefficients (Al_2O_3 belongs to this group of materials). Homogeneous nucleation process can easily occur when high reactant concentrations are used, their turbulent flow in the CVD reactor and high their temperature in the entire reactor volume take place. Therefore, for elimination of this process it is necessary to use of very low reactant concentrations and “cold wall” reactors. Reduction of reactant concentrations causes, however, decrease of the layer growth rate. Therefore, synthesis

time of the layer having predetermined thickness must be relatively long. High temperature and long annealing time of the layer during its synthesis favour its advanced recrystallization. The higher temperature and the longer synthesis time, the larger grains. It should be noted that such long lasting annealing of ceramic materials can cause secondary porosity in them, also in non-porous ceramics (the longer annealing time, the larger grains and the higher porosity of material). It is so called “burning of ceramics”.

In the case of $\text{Al}_2\text{O}_3 + \text{C}/\text{Al}_2\text{O}_3$ layers on cemented carbide cutting tools, first modelling investigation was carried out [12,13], what was mentioned in the introduction of this work. In this research quartz glass was used as a substrate. It was noted, that it is preferably to obtain the layer microstructure having uniform in size grains by preliminary synthesis of amorphous layers and then annealing of these layers controlled by the temperature as well as the time. In this way authors of these works synthesized amorphous Al_2O_3 layers by MOCVD method using aluminium acetylacetonate ($\text{Al}(\text{acac})_3$) as precursor at temperature of 800°C . Obtained layers were annealed at temperature of 950°C for a defined time. In this case uniform in size $\alpha\text{-Al}_2\text{O}_3$ grains were crystallized in the entire cross section of the layer, and their size and porosity depended on temperature and time. When the layer annealing time was shorter at this temperature then the grain size was “nano” what was easy to see using scanning microscopy. In the case of this work it is assumed that if the synthesis conditions of Al_2O_3 layers on cemented carbides would be similar as in the case of substrates of quartz glass then their microstructure would be also similar. Therefore it was expected to obtain “nano” grains of Al_2O_3 on cemented carbides. While during the direct layer synthesis it was observed the differentiation in the grain size in the layer

Label A: 3prz 001p1

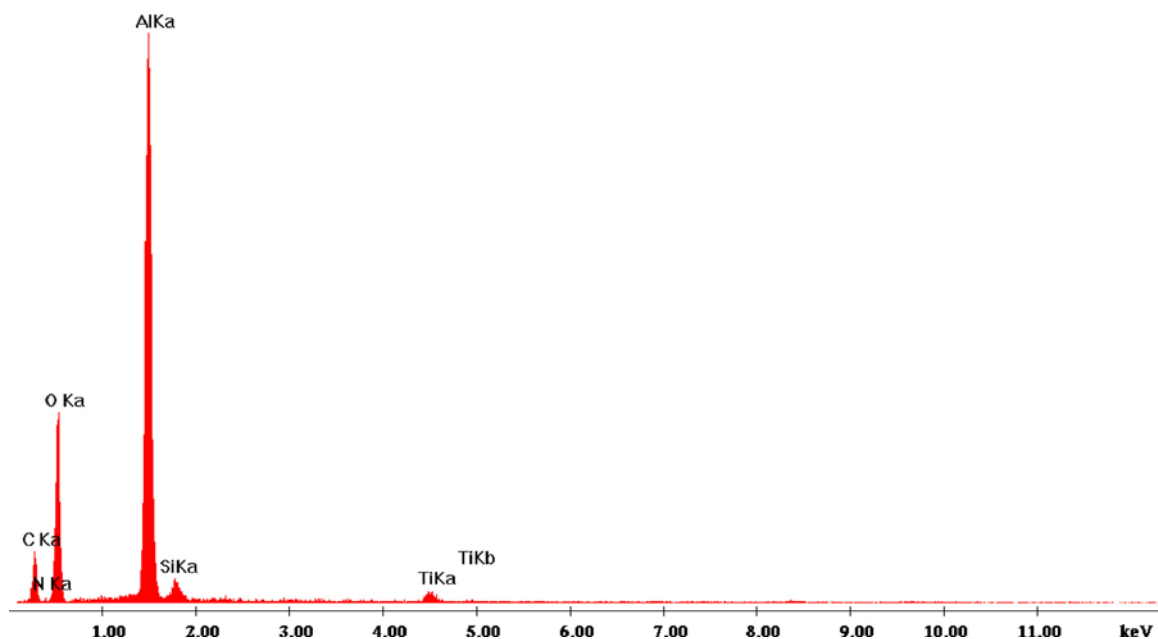


Fig. 16 – The EDS analysis results for point 1 in Fig. 15.

Label A: 3prz 001p2

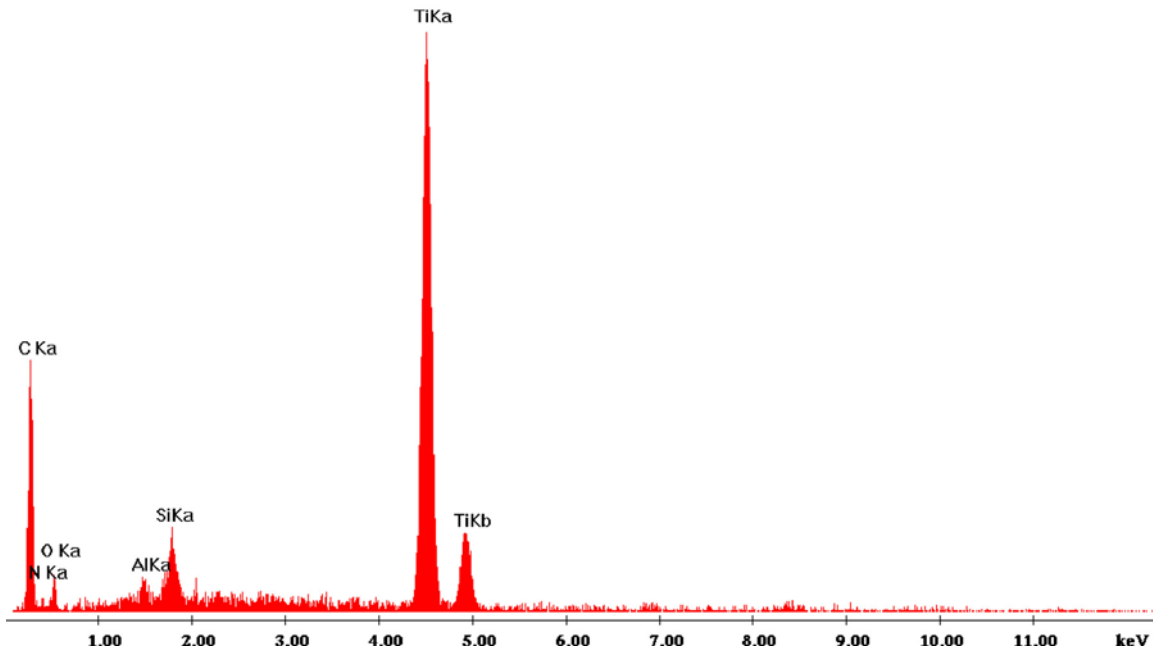


Fig. 17 – The EDS analysis results for point 2 in Fig. 15.

close to the substrate and at its surface was more than twice bigger when the synthesis temperature was 950 °C and the thickness of the layers synthesized directly and the layers annealed was similar.

In this work results of this research were used. First, amorphous layers were synthesized by the very short time.

Therefore they were non-porous and they had fine grains. Because of it, in spite they were thin, they were characterized by high durability.

The obtained results open a perspective for further detailed research on the Al_2O_3 composite layer synthesis by MOCVD method.

Label A: 3prz 001p3

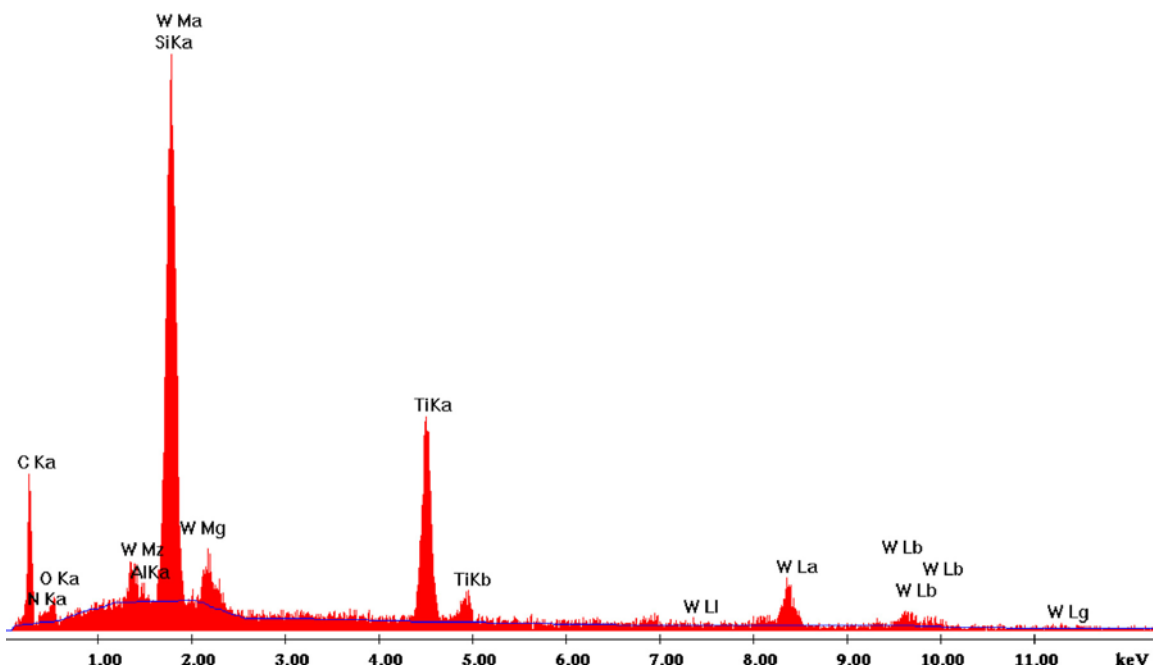


Fig. 18 – The EDS analysis results for point 3 in Fig. 15.

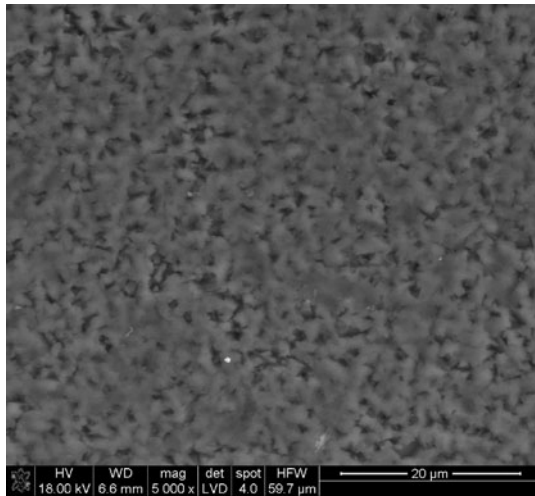


Fig. 19 – The surface of the sample no. 4 (Table 2) coated with Ti(C, N) + Al₂O₃ layers (Sandvik Baildonit). Substrate: cemented carbides, NMK-30/K30 grade.

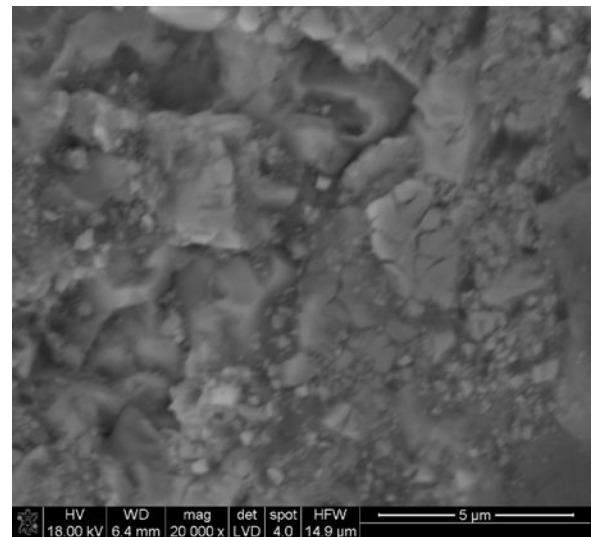


Fig. 22 – The surface of cemented carbide substrate, S30S grade, Sandvik Baildonit (sample no. 7, Table 2).

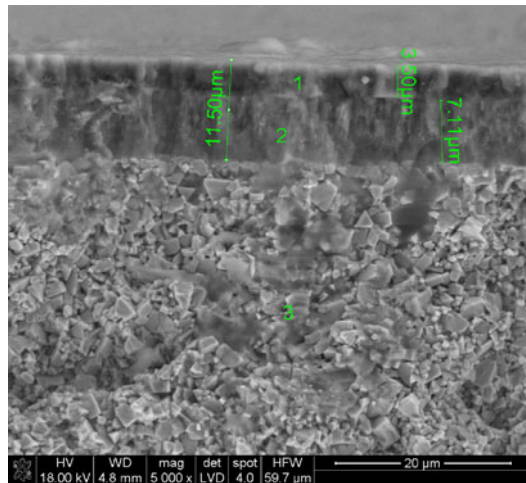


Fig. 20 – The fracture of the sample no. 4 (Table 2).

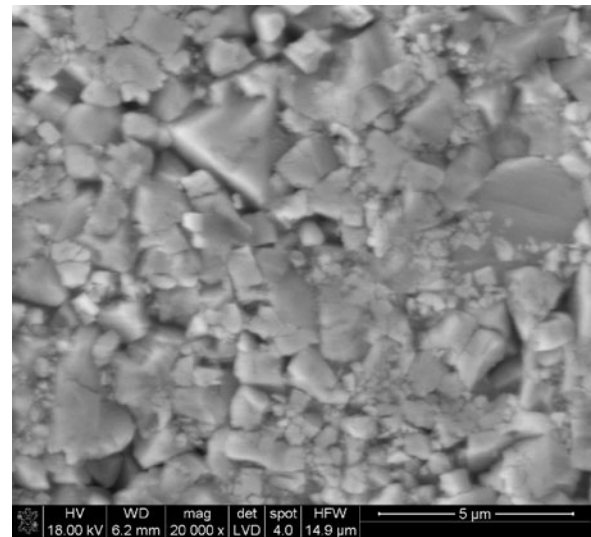


Fig. 23 – The surface of cemented carbide substrate, NMK-3-/K30 grade, Sandvik Baildonit (sample no. 2, Table 2).

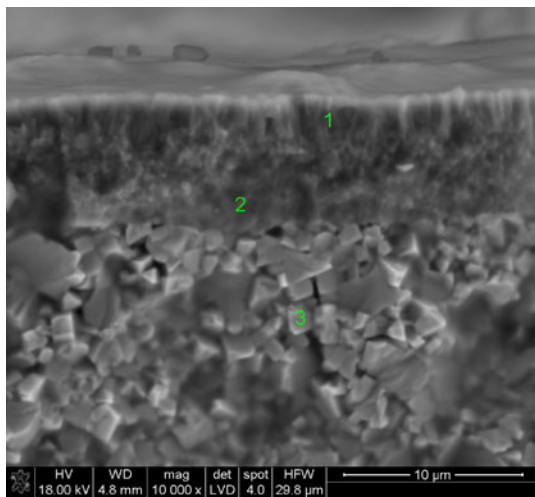


Fig. 21 – The fracture of the sample no. 8 (Table 2). Cemented carbide substrate (grade S30S) coated with Ti(C, N) layer about 7 μm thick (Sandvik Baildonit).

Table 3 – Machining test parameters for tool life estimation.

Cutting depth [mm]	2
Feed [mm/rotation]	0.1
Cutting rate [m/min]	
Step 1	180
Step 2	110

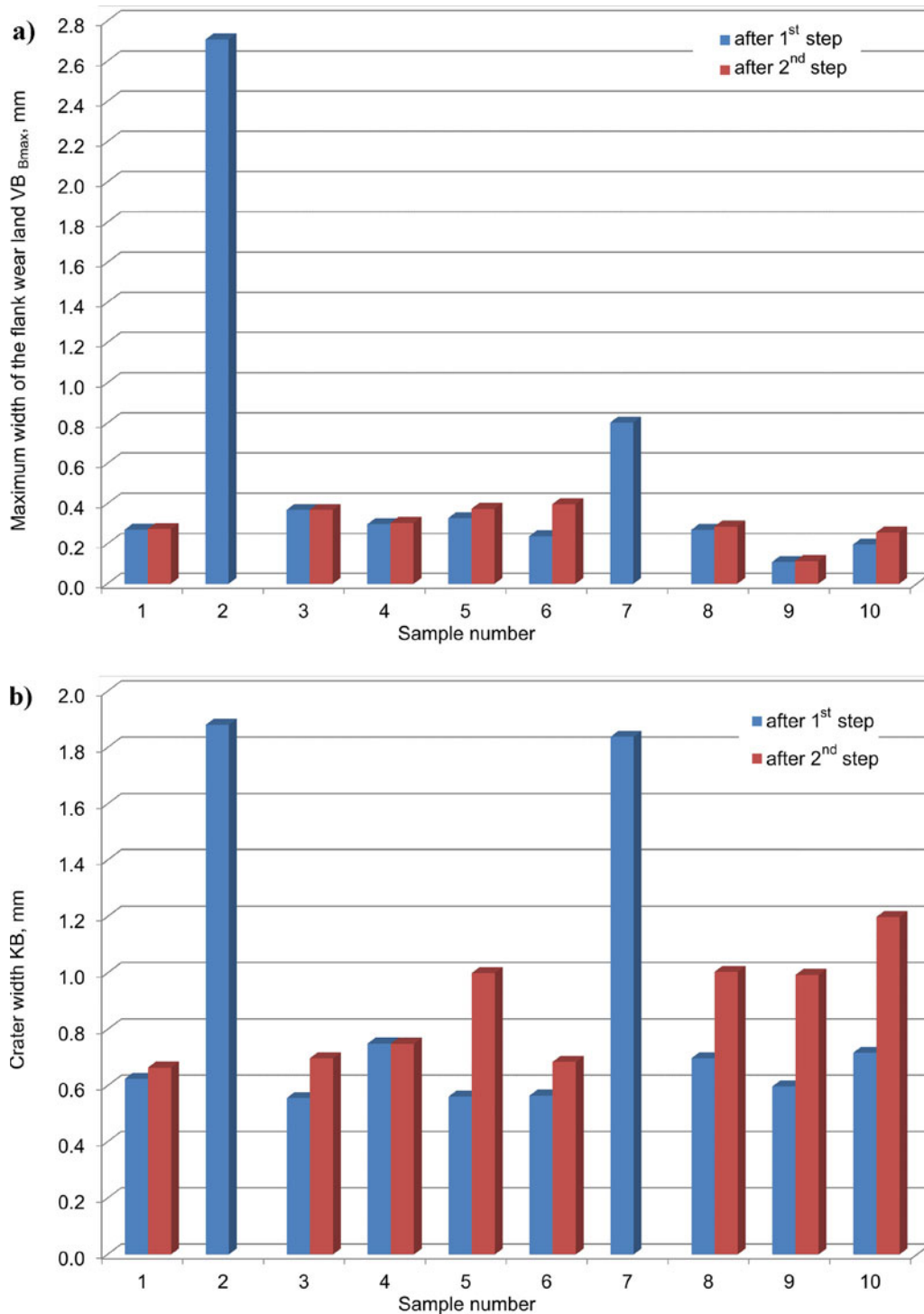


Fig. 24 – The wear parameters of samples after machining: (a) the maximum width of the flank wear land VB_{Bmax} , mm, (b) the crater width KB, mm.

4. Conclusions

The presented study indicates that proposed MOCVD method of Al_2O_3 layers synthesis is promising. Application of this method makes deposition of dense layers with controlled

microstructure possible. Fine grained layers (with grain size in order of nanometers) can be obtained. They may be also very thick. In a traditional CVD method nanocrystalline layers may be deposited, but only in the case of multilayers synthesis. Their main disadvantage is delamination process occurring during machining. It leads to a fast tool destruction. Therefore,

cutting tools with nanocrystalline monolayers should have longer tool life.

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