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OVERVIEW OF CUTTING TOOL MATERIALS FOR FINISH MILLING

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ABSTRACT

Driven by the needs of the mechanical manufacturing industry, the late 19th century led to the rapid development of machine tools, cutting tools, and the emergence of new production methods. Cutting tools are a crucial element in any cutting operation. The material of the cutting tool determines its quality and has undergone many changes over the more than 100 years since the First Industrial Revolution. They have been continuously improved and developed, and in this process, the emergence of new cutting tool materials has created a need for changes in machine tool design trends to meet and fully utilize the cutting properties of these new materials, aiming for higher cutting productivity.

Generally, various types of cutting tool materials with diverse properties are currently used in industry. Although these cutting materials have different origins and mechanical properties, to assess the applicability of a particular cutting tool material to a specific application, several cutting performance evaluation measures are used to compare their suitability for the task. Common evaluation measures include determining hot hardness (thermal resistance), flexural strength, and wear resistance.

Keywords: Hot hardness (thermal strength), flexural strength, and wear resistance

1. INTRODUCTION

One of the revolutionary changes in the metal cutting industry is hard coating. The method of spray coating

cutting tools has expanded the application range of many types of cutting tool materials and significantly increased machining productivity. Currently, about 50% of high-speed steel cutting tools and about 85% of carbide cutting tools are coated. Advantages of coating: Increased surface hardness, thereby improving the wear resistance of the cutting tool. Increased wear resistance (various types of wear, abrasion, adhesion, etc.). Reduced coefficient of friction, thereby reducing cutting force, preventing adhesion wear at the contact area between the cutting tool face and the chip, reducing heat generation, etc. Reduced or prevented heat transfer to the cutting tool. Improved surface finish quality.

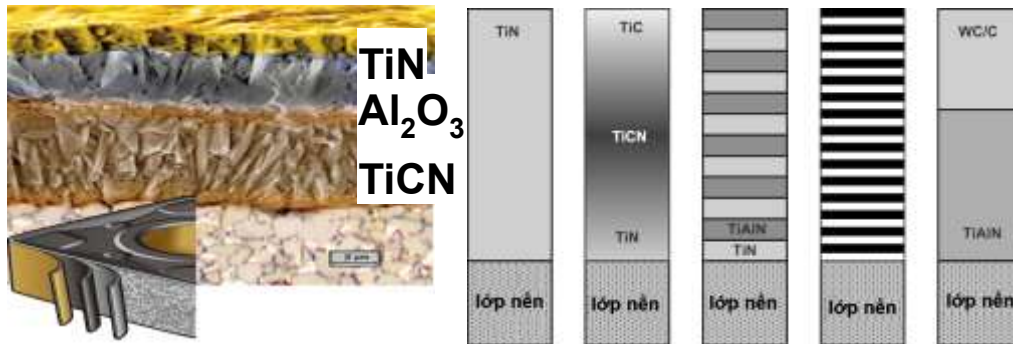


Figure 1. Single-layer and multi-layer coatings

The working performance of cutting tools can be improved by applying a coating to their surface. Various coating structures and materials can be combined to create cutting tools with high cutting performance. The coating not only extends the tool's lifespan but also provides wear resistance and prevents the adhesion of workpiece and chip material to the cutting surfaces. The durability of the coating depends on the material used, but recent studies have shown that multi-layer coating structures enhance coating hardness and increase wear resistance. Currently, combinations of various materials such as TiAlN/TiN, TiCN/TiSiN/TiAlN, etc., are being used for multi-layer coatings on cutting tool working surfaces. These multi-layer combinations create unique mechanical and surface properties for the cutting tool.

Changes in workpiece properties, manufacturing processes, and new government regulations in industrialized countries regarding green manufacturing have driven advancements in tool materials and cutting tools. For maximum productivity, machine tools need to operate at the fastest possible cutting speeds to minimize production costs. To achieve this goal, tool material manufacturers and cutting tool researchers have continuously sought the optimal blend of base materials, coatings, and coating layers; as well as the texture and geometric parameters of cutting tools.

During continuous cutting, the coating ensures optimal contact between the surfaces to reduce stress on the cutting wedge and maintain its shape stability. Additionally, the coating must withstand high compressive pressure during cutting. The coating must also adhere well to the cutting surface of the tool, increasing the tool's lifespan until the coating completely wears off on the substrate.

In general, cutting tool materials need three main properties: high hot hardness, good toughness, and chemical stability. It is almost impossible to find all three properties in a base material without a coating, and in fact, they are difficult to find in cutting tools with a single coating. Therefore, multilayer coatings are applied to overcome this limitation. Multilayer thin film coatings combine the desired properties of different materials to create cutting tool materials suitable for specific cutting conditions. For example, using surface bonding layers to enhance adhesion and a chemically inert thin coating on top of a wear-resistant coating. According to [unclear text], multilayer TiAlN thin films can be found in compounds such as TiAlN/TiAlCN, TiAlN/TiNbN, TiAlN/TiN, AlN/TiN/TiAlN, TiAlN/CrN, TiAlN/Mo, and W/TiAl.

The coatings were analyzed and measured according to several criteria to ensure the optimal application of coatings to reduce friction and wear, increase cutting tool life, and improve machining quality. Table 1 shows the mechanical properties for commonly used and commercially available coatings for cutting tools. Table 2 shows the functions of the coating materials.

Table 1. Some mechanical properties of coating materials.

Coating	Hardness HV (GPa)	Thickness (µm)	Coefficient of friction	Thermal stability (°C)
TiN	23,50	1 - 4	0.4	500
TiCN	27,50	1 - 4	0.2	450
CrN	21,00	1 - 4	0.6	700
TiAlN	33,00	1 - 4	0.5	600
TiAlCN	30,00	1 - 4	0.4	500

Table 2. Functions of coating materials

Coating material	Functions of coating materials
TiC	Increased resistance to abrasion and scratches.
TiN	Reduces the coefficient of friction, minimizes wear due to adhesion, and reduces the occurrence of tool burrs.
Ti(C,N)	Increased resistance to abrasion and tear strength.
TiAlN	High thermal hardness, ductility, and thermal shock resistance.
Al ₂ O ₃	Excellent thermal insulation and good oxidation resistance.
CrN	Excellent wear and corrosion resistance; low coefficient of friction and internal stress resistance.

2. METHOD

During the cutting process, the tool must operate in an extremely harsh environment: intense friction between the chip and the front surface, between the machined and finished surfaces and the back surface of the tool; very high cutting zone temperatures (the temperature of the cutting zone can reach thousands of degrees Celsius, or even higher); very high pressure, etc. Therefore, for the cutting tool to work stably under these conditions for a certain period of time (called the tool life), the material used to manufacture the tool must have suitable cutting properties. In addition, the tool material must also meet several requirements regarding economic and technological aspects. Specifically, we will study these requirements below.

2.1. Cutting feature

The mechanical properties, especially the hardness of the workpiece material, are being improved. Traditional chip-forming machining methods such as drilling, turning, and milling rely on a large difference in hardness between the cutting tool material and the material being cut. Cutting tools in some machining processes have low tool life due to hardness loss, increasing machining costs.

The development of cutting tools requires enhancing the mechanical properties of tool materials, especially in high-speed machining with long machining times. However, producing cutting tools in this direction faces many challenges. First, the material must meet the required mechanical properties. Second, the current conventional sintering method has many limitations, only suitable for certain materials and requiring a long sintering cycle, increasing the cost of the tool insert. In addition, the cutting tool material must be able to withstand harsh cutting conditions such as high temperatures and very high friction between the workpiece, chips, and the cutting surface and edge of the tool. Therefore, cutting tool materials need to possess many properties to meet the above requirements. These cutting properties are listed below:

2.2. Hardness

Hardness is a fundamental property of materials. The hardness of a material is generally understood as its ability to resist indentation at the point of impact by an external load applied through a harder object (called an indenter or probe). The more resistant a material is to indentation, the higher its hardness, and vice versa. Thus, determining hardness provides a preliminary assessment of the material's strength and ductility. Furthermore, materials with higher hardness have lower flexural strength and higher abrasion resistance and surface scratch resistance, and vice versa.

For the cutting process to occur, the hardness of the cutting tool must be higher than that of the workpiece. Typically, the hardness of the tool material should be 58 HRC or higher. When machining difficult-to-machine materials such as stainless steel, heat-resistant steels and alloys, etc., the tool material must have even higher hardness.

However, increasing hardness leads to increased brittleness and decreased mechanical strength, making

the cutting edge prone to chipping. Therefore, for different workpiece materials and different machining conditions (rough, finish, etc.), to determine the optimal hardness of the cutting tool material, the hardness ratio between the tool material and the workpiece material must be considered.

A characteristic that needs special attention when selecting cutting tool materials is hot hardness, or "hot hardness" or "thermal resistance," which determines the cutting ability of the tool at high temperatures.

2.3. Mechanical durability

During cutting, the tool is subjected to varying loads, impacts, forces, and shocks that can cause chipping of the cutting edge if it lacks sufficient mechanical strength. Therefore, tool materials need to combine high hardness with high mechanical strength, meaning they must have good tensile, compressive, and bending resistance, high impact toughness, and high elastic modulus, etc.

When selecting tool materials, the material's strength in the cutting temperature range must also be considered. At the cutting temperature, the mechanical properties of the material change significantly compared to normal temperatures.

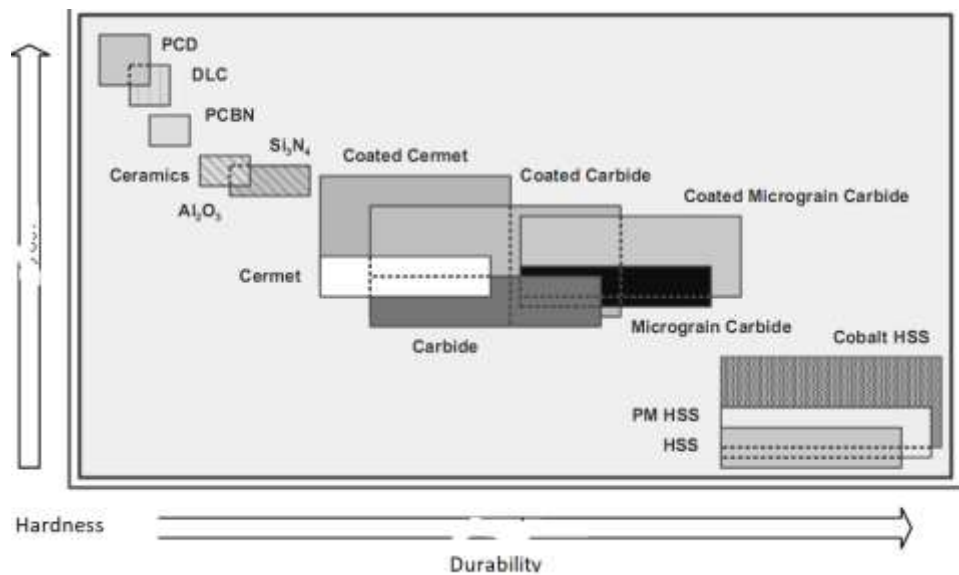


Figure 2. Relationship between stiffness and mechanical strength of some cutting tool materials.

2.4. Heat resistance

When working at high temperatures, the mechanical properties of materials change, especially the hardness, which significantly affects the work performance of the component. For cutting tools, which often operate at very high temperatures, thermal resistance is a crucial requirement.

Thermal resistance is also one of the factors limiting the cutting speed of the tool. Tools made from materials with low thermal resistance cannot operate in high temperature ranges, meaning they cannot operate at high cutting speeds, thus limiting productivity.

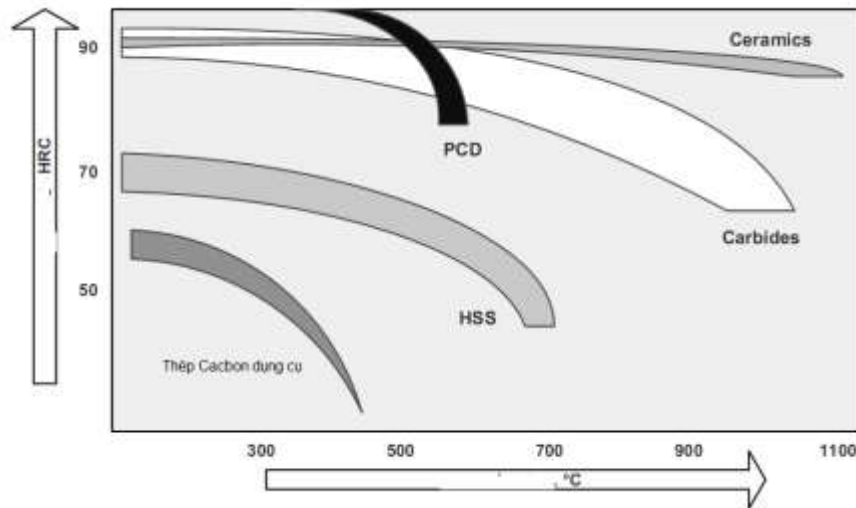


Figure 3. Relationship between temperature and material hardness

Generally, the hardness of materials is measured at room temperature. However, the term “thermal hardness” or “hot hardness” indicates that this is hardness at a specific temperature. According to the GOCT standard, “hot hardness” is defined as the temperature at which a tool material sample is continuously heated for 4 hours (240 minutes) and its room-temperature hardness is ≥ 59 HRC. We know that the hardness of a material decreases as its temperature increases. During metal cutting, heat is generated by the conversion of mechanical energy into thermal energy. Therefore, tool materials must be able to maintain their hardness and thus maintain wear resistance and strength at high temperatures, ranging from nearly 600°C to 1800°C . Figure 3 shows the change in hardness of different tool materials as the temperature increases.

2.5. Thermal conductivity

Thermal conductivity, characterized by its coefficient of thermal conductivity, is a physical quantity that describes a material's ability to conduct heat. In Fourier's law (an equation describing the phenomenon of heat conduction in materials), thermal conductivity appears as a coefficient characterizing the material. Thermal conductivity is defined as the amount of heat transferred through a unit area of material in a unit time, under a temperature gradient. The unit of measurement for the coefficient of thermal conductivity is W/m.K .

To improve the cutting performance of tool materials, an equally important requirement is to enhance their thermal conductivity. Cutting tools with high thermal conductivity allow for rapid heat transfer from the cutting zone to the outside, reducing cutting heat and increasing tool wear resistance, thereby enabling

higher cutting speeds.

2.6. Wear resistance

Wear resistance is the ability of a cutting tool to maintain its geometric shape and dimensional accuracy within acceptable limits after a certain period of operation (tool life). For a tool to function under such harsh conditions for a certain period, the tool material must have sufficient wear resistance. Wear resistance significantly impacts machining productivity, the quality of machined parts, and the quality of the cutting process.

Wear resistance (also known as abrasion resistance) is determined by measuring the degree of abrasion of cutting tool material particles when moving at a defined velocity, under a defined pressure, on a given moving surface. Wear resistance can be defined as the ability of a cutting material to maintain its volumetric integrity during a wear test and ultimately manifested in the tool life. A cutting tool material suitable for a particular application must exhibit a balanced combination of all the aforementioned features.

There are requirements that are compatible with each other; for example, materials with high hardness will have high wear resistance. However, in reality, it is not always possible to achieve all of these requirements simultaneously. For instance, increasing hardness will decrease bending strength. Therefore, depending on the specific machining conditions and requirements, the choice of tool material should primarily be based on certain requirements. For example, when rough machining surfaces with impacts and vibrations, the material should be chosen primarily based on mechanical strength to ensure the mechanical strength of the cutting part; when machining heat-resistant alloys, the cutting part material should be selected based on thermal resistance and thermal conductivity.

3. RESULTS

Table 3. Mechanical properties of PCD

Material symbol	Hardness HV (Gpa)	Density (g/cm ³)	Durability, GPa		Modul Young (Gpa)	Thermal conductivity (W/mK)	Heat resistance (K)	Coefficient of linear expansion (1/K).10 ⁻⁶
			Compress	flexural strengt h				
ASB	50 – 90	3,5 – 3,9	0,4 – 0,6	0,78	800 - 850	290 - 300	873 - 993	0,9 – 1,2
ASPK	80 - 100	3,5 – 4,0	0,4 – 0,8	0,5 – 1,0	900	-	1073 - 1173	0,9 – 1,2
SKM	60 -70	-	0,6 – 0,8	-	850	150 - 250	973 - 1073	-

ATP	46 - 82	-	-	-	-	-	-	-
SVBH	70 - 100	3,3 – 3,45	8,0 – 10,0	-	-	-	1073 - 1223	-
Karbonit	40 - 45	3,2 – 3,4	4,5 – 6,0	-	-	-	1473	-
Almet	94– 96 HRA	-	5,0 – 10,0	-	500 - 600	-	973	-
SV	65 - 100	-	5,0 – 10,0	-	850	-	1573 - 1623	-
DAP	72 - 80	-	4,8 – 5,3	-	-	-	-	-
Syndite 010	50	-	7,60	0,96	900	420 - 480	973	4,2
Syndite 025	49,8	-	7,61	0.9 – 1,1	841 - 925	550 - 640	973	4,5
Megadiamond	78	3,1 – 3,48	3,3 – 3,8	-	-	800 -900	1073 - 1473	-
DIARD 200	42 - 50	-	-	-	-	130	-	-
ompax	65 - 85	-	-	-	-	-	973	-

The technology of vapor deposition that creates a thin film on a substrate is generally classified into two types: chemical vapor deposition (CVD) and physical vapor deposition (PVD).

+ Physical vapor deposition (PVD) is a vacuum coating process in which the material used is separated from the source by vaporization or spraying. It is then transported by the vapor energy of the particles and condenses onto the material being coated, forming a thin film. Chemical compounds can be introduced into the coating chamber using the same source material. The process can also be achieved through reactive gases such as nitrogen, oxygen, or single-component hydrocarbons containing the desired reactive material, where these gases react with the metals on the substrate to be coated.

+ Chemical vapor deposition (CVD) is a thermally activated process in which a substrate material is heated and then reacts with a gaseous chemical compound. The main reactive vapors are metal halogens, metal carbonyls, hydride compounds, and organometallic compounds. To break down the metal compounds, the substrate material is typically heated to relatively high temperatures.

CVD coating technology was commercialized several decades ago in advanced industrial countries, but PVD coating technology is clearly having a strong impact on the market. PVD technology is successful because it allows the vapor deposition process to be carried out at lower temperatures, only around 450-550°C, compared to the CVD process, which is carried out at temperatures of 550-1100°C. The development of PVD technology facilitates the deposition of a thin film on sintered carbide tool materials because the deposition temperature is below the thermal resistance of high-speed steel. In addition, the

advantage of PVD is that it can precisely control the thickness of the coating, especially on the cutting edges of cutting tools. This allows for the production of a cutting tool with a sharper cutting edge. Compressive stress is created through the PVD process, a feature that can prevent the development of cracks in the cutting edge when subjected to strong cutting impacts.

Table 4. Mechanical properties of some cutting tool materials

Material	Elastic modulus E (GPa)	Hardness HV (GPa)	Compressive strength (MPa)	Thermal conductivity ($Wm^{-1}C^{-1}$)
WC	625 - 700	22 - 36	3.350 - 6.830	55 - 80
Kim cương	1.220	100	9.000	2.000
WC-C _o	400 - 650	7 – 22	3000 – 9.000	70 -120
Thép gió	150 - 200	2,40 – 4,0	250 – 1.760	15 - 65
SiC	400 - 460	23 – 26	1.000 – 4.500	80 -130
Al ₂ O ₃	343-390	12 – 20,6	500 – 2.700	2 - 38.5

The coatings were analyzed and measured according to several criteria to ensure the optimal application of coatings to reduce friction and wear, increase cutting tool life, and improve machining quality. Table 4 shows the mechanical properties for commonly used and commercially available coatings for cutting tools. Table 5 shows the functions of the coating materials.

Table 5. Some mechanical properties of coating materials

Coating materials	Hardness HV (GPa)	Thickness (μm)	Coefficient of friction	Thermal stability ($^{\circ}C$)
TiN	23,50	1 - 4	0.4	500
TiCN	27,50	1 - 4	0.2	450
CrN	21,00	1 - 4	0.6	700
TiAlN	33,00	1 - 4	0.5	600
TiAlCN	30,00	1 - 4	0.4	500

DISCUSSION

Previous studies, as shown in Table 6, have shown that the structure between the hard/soft layers and the hierarchy can create a strengthening mechanism, while also increasing wear resistance in the entire coating.

Influence of Hierarchical Coatings on Coating Properties

The effect of the hierarchical structure on the system properties can be demonstrated by the wear rate, as shown in Table 6. In microscopic and macroscopic experiments, the CAO structure showed the lowest wear rate due to its hierarchical structure. The CAO structure also has high wear resistance due to its high hardness. The hierarchical layer system in the CAO structure can distribute energy during crack propagation and avoid the formation of larger cracks. The hierarchical configuration can also design coatings in more specific applications by periodically changing the size of multiple layers with different mechanical properties.

Table 6. Degree of wear on test specimens.

Pattern	Degree of wear ($\text{mm}^3\text{N}^{-1}\text{m}^{-1}$)
HIGH hierarchy	$2,2 \times 10^{-4}$
LOW ranking	$4,5 \times 10^{-4}$
Single layer WCN	$1,1 \times 10^{-3}$
Background material	$3,1 \times 10^{-3}$

ACKNOWLEDGMENTS

In manufacturing and machining industries, cutting is a crucial process in producing quality products. Most cutting tools currently in use are made of sintered tungsten carbide. However, tungsten carbide has low wear resistance and short service life. Coatings are used to extend the service life of cutting tools and to improve the mechanical properties and material composition. The use of multilayer coatings for hierarchical structures is still very new and has not been extensively studied. Different materials and thicknesses of layers can be combined to achieve maximum cutting performance for the cutting tool. Depending on the materials and thicknesses of the layers, this hierarchical structure can improve the strength and hardness of the coating, reduce wear, and prevent crack propagation. Most research has focused on the materials and thicknesses of the multiple layers but has not emphasized the thickness of the individual layers. This is the direction of future development for spray-coated tools.

REFERENCES

- [1]. Kirsten B., 2016, "High-performance coatings for cutting tools", CIRP Journal of Manufacturing Science and Technology, 18, pp. 1-9.
- [2]. ISO 6506-1: 2014
Metallic materials - Brinell hardness test - Part 1: Test method.
- [3]. <https://www.emcotest.com/en/the-world-of-hardness-testing/hardness-know-how/theory-of-hardness-testing/rockwell/rockwell-test-procedure/>
- [4]. <https://www.emcotest.com/en/the-world-of-hardness-testing/hardness-know-how/theory-of-hardness-testing/rockwell-53/distinction-between-rockwell-and-super-rockwell-236/>
- [5]. Wentorf RH, Delai AJ. Cubic boron nitride compact and method for its production. US Patent

3233988, 1966.

[6]. Sergio Neves Monteiro et al. Cubic boron nitride competing with diamond as a superhard engineering material – an overview. © 2013 Brazilian Metallurgical, Materials and Mining Association. Published by Elsevier Editora Ltda.

[7]. Will G, Nover G, Von der Gonna J. New experimental results on the phase diagram of boron nitride. *J Solid State Chem.* 2000; 154:280-5.

[8]. Nakay N, Kono J. Compact for use in tool and the method for produce the same. US Patent 4389465, 1983

[9]. Sirota NN. Method for converting hexagonal boron nitride to a new structure. UK Patent 1317716, 1973. Corrigan FR. Method for producing large cubic boron nitride particles. UK Patent 2002333, 1978.

[10]. Bochko AV, Zaporozhets OI. Elastic constants and modulus of elasticity of cubic and wurzitic boron nitride (in Russian). *Powder Metall Met Ceram.* 1996;34(7-8):417-23.

[11]. Sato T, Hiraoka H, Endo T, Fukunaga O, Iwata M. Effect of oxygen on the growth of cubic boron nitride using Mg₃N, as catalyst. *J Mater Sci.* 1981;16:1829-34.

[12]. Guo W, Jia X, Guo WL, Xu HW, Shang J, Ma HA. Effects of additive LIF on the synthesis of cBN in the system Li₃N-hBN at HPHT. *Diamond and Related Mater.* 2010;19:1296-9.

[13]. Bobrovinichii GS, Skury ALD, Monteiro SN, Azevedo MG. Sintering of cubic boron nitride using titanium-based binder. *Mater Sci Forum.* 2012;727-728:446-9. Bobrovinichii GS, Skury ALD, Monteiro SN. Hard metal matrix composites reinforced with cubic boron nitride. *Mater Sci Forum.* 2012;727-728:310-3. Bobrovinichii GS, Skury ALD, Monteiro SN, Azevedo MG, Silva L. Boron nitride ceramic composite obtained by high pressure and high temperature sintering. *Mater Sci Forum.* 2012;727-728:736-9. Method of producing cubic boron nitride. UK Patent 1316045, 1982. Bundy FP. Method for converting hexagonal boron nitride to a new structure. US Patent 3212852

[14]. Bundy FO, Wentorf RH. Direct transformation of hexagonal boron nitride to denser forms. *J Chem Phys.* 1963;38:1144-9.

[15]. Wentorf RH, DeLai AJ. Produit compact formé par plusieurs cristaux de nitrure de bore cubique et procédé pour sa fabrication. France Patent 1302244, 1961.

[16]. Method of producing cubic boron nitride. UK Patent 1316045, 1982. [52] Bundy FP. Method for converting hexagonal boron nitride to a new structure. US Patent 3212852