International Journal of Scientific & Engineering Research, Volume 6, Issue 5, May-2015 1256
ISSN 2229-5518

Physicochemical properties of materials for single flute end mill cutters

Veselina Dimitrova [1], Ventsislav Dimitrov [2]

Abstract— This article is designed as a set of three interconnected elements. Here are presented the conditions for the formation and removal of of the chip at milling with single flute end mill cutters, examined is instrumental wear, analyzed are the types of materials for the manufacturing of tools, as is paid especially attention to zirconium two - and three - component structures ZrN, ZrC and ZrCN.

Index Terms— cutting tools, single flute end mill cutters, high-speed machining, cutting tools materials, coatings, zirconium structures

1 Introduction

The single flute end mill cutters tools are functioning in conditions of quasi–dry machining, characterized by intensive cutting conditions reaching levels of around of - Vc = 300-1000 [m/min] cutting speed, minute feed fm = 60÷90 [m/min] and acceleration 1-3 G (10÷30 m/s2). Emulsion agents from natural or mostly synthetic origin, mixed with air are introduced into the cutting zone by direct injection technology. It prevents the formation of the built-up edge along the tool surface in the area of the secondary deformation, and provides thermal stabilization of the process system, which is achieved by compensating the deformation of the workpiece changes, accompanying the cutting process [3],[4].

Single flute end mill cutters are established on advanced CNC machines, main CNC machining centers, providing mainly optimized tools interpolation trajectory, generated in assembled geometric complex profile models. The milling strategies create the base capabilities of the integrated or parallel functioning, associative, hybrid and parametric CAD/ CAM CAE software package, serving machine.

2 Part I – Cutting conditions, tool-chip forming and wear

2.1 Introduction in part I

Regimes in operating tools requirements to materials used in their construction, both operational and technological and economic factors [2],[38]. Economic requirements to the material used are the need to minimize the cost of the tool is designed to produce per unit of output. The performance shall be borne by the characteristics necessary for the proper operation of the tools during their operation. These include requirements such as high stiffness of blade, which determines the workpiece without significant tool wear, durability of the instruments, toughness and strength of the material, good thermal performance - heat resistance, thermal conductivity, coefficient of thermal expansion, chemical inertness, etc.

The choice of tools material is a complex iterative optimization process depending on the type of workpiece material, its physical and mechanical properties, structural elements and geometric parameters of the tool, cutting conditions under which it will operate, the presence or absence of the grinding compound and its type, the type of technology equipment – tools machines and equipment, etc. [31],[32],[33].

2.2 Models of the chip formation in high-speed milling

Milling of plastic aluminum alloy is characterized by a significant degree of deformability of the grains of the material in secondary deformation (share) zone and increased friction between the chip and the tool face. Metallographic studies on the flank of the chip, show a strong curvature of the lines of texture in both tools contact shear zones [2].

On the zone of plastic contact, where friction is internal, there is a prevailing adhesive interaction at the expense of the weakened cohesive connections. Closest to the front surface tools slow movement and upon reaching the critical level of the coefficient of friction stop building a solid structure - built-up edge. The process is multiplicated in the presence of roughness on the tool face. Physical construction of the built-up edge is not identical to the chip and the workpiece material. Its hardness is 2-3 times greater than the hardness of the workpiece material. The built-up edge is destroyed in moment in which strength and become insufficient to withstand the load of the chip and it is destroyed. Implantation of high-imposing elements of the ruined built-up edge in tools area causes abrasion resistance and wears [1], [2], [38].

In the zone of elastic contact, characterized mainly with external friction, presumed deformation should be less. In plastic materials, however, such as aluminium alloys and hardened the connecting polymeric structures in bimaterial composites HPL, observed deformation comparable to those congestive zone, deformation is observed in commensurate with the secondary deformation (share) zone. This is explained with the property of these materials, to increase their strength in the presence of plastic deformation and according to the tendency such materials to form priority

- [1] *Veselina Dimitrova is Author name is students at Doctor Degree in material science in Technical University of Sofia, Sliven Engineering-Pedagogical Faculty, Bulgaria, European Union, E-mail: vkdd@abv.bg*
- [2] *Ventsislav Dimitrov is Assistant Profesor of Manufacturing Technology in Technical University of Sofia, Sliven Engineering-Pedagogical Faculty, Bulgaria, European Union, E-mail: vpdd@abv.bg*

ISSN 2229-5518

flowing chip. Her contact with the tools face is larger, and the coefficient of friction, higher.

2.3 Cutting tools wear

The wide contact area, high coefficient of friction and a significant degree in milling of aluminium alloys suggest strongly tools wear surfaces. Consequently, to the modification of the geometrical parameters of the cutting tools wedge and this affects the cutting resistance, coefficient of friction on the anterior surface, dynamic parameters, the temperature of the cutting and etc. Elastic recovery rear surfaces, reduces static rear corners and further increases force load on cutting. Impair the quality of the machined surface, which in certain areas become strong, emerging in her cold-work hardening.

Intensification of cutting conditions at high-speed (HSM) and high-precision milling (HPM) to a certain extent eliminates the negative conditions. In this case cutting conditions is intensifying and apply quasi–dry machining. Apparition of built-up edge decreased, but not disappeared, contrariwise high cutting speeds increase cycles per forming and destruction, that hit loaded the cutting wedge and causes brittle destruction of the cutting part. Advantage is the use of single flute end mill cutters, chip formation is reduced.

In summary it can be said that the machining of plastic materials, in particular aluminum alloys, technological requirements for tools geared primarily to ensure their durability and reliability indicators. Fastness formed optimal cutting conditions, infallibility - flows from failures and maintainability ability to recover properties of cutting tools after reaching the technical resource (mean time between failures). High levels of performance tooling hardness and heat resistance in the case are of such significance as in high-speed milling of other groups cultivated material, as here hardness and melting point exceeding respectively HB100 and T<600÷800°C, i.e. they are below the maximum levels for tools of this type and there are no prerequisites for the emergence of diffusion wear.

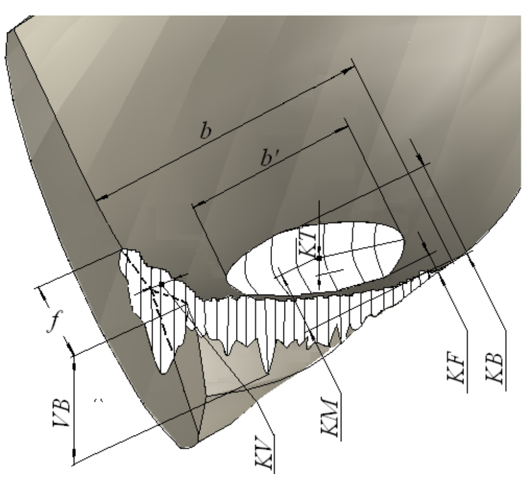

Fig. 1. Scheme of the wear for single flute end mill cutters [1], [2].

Typical for single flute end mill cutters functioning in high-speed milling condition is the wear simultaneously on major flank Aα and tool face Aγ. Here continuous friction of the flowing chip in face formed crater, which gradually expands and increases your depth, while the major flank appears playground with α0 = 0 ° fig. 1 [1], [2]. On Aα wear expressed about with dimensions b*VB, gradually passes and Aα', where the dimensions of are approximately f *VB.

The parameters characterizing wear are:

- width of crater KB,
- depth of crater KT[mm],
- distance to the centre of concave KM[mm],
- width of threshold KF[mm],
- width of wear VB[mm],
- dimensionally wear KV[mm].

2.4 Conclusion of part I

2.4.1 The iterative optimization process in the selection of instrumental material is consistent with the complex operational, technological and economic conditions.

2.4.2 When the machining of aluminum alloys in conditions of high-speed milling are observed predominantly adhesive in the area of plastic contact and relatively high coefficient of friction in the zone of elastic contact, due to the large area of the chip flowing by the tool face.

2.4.3 The wide contact area, high coefficient of friction and the significant degree of plastic deformation, form by single flute end mill cutters, conditions for occurrence wear simultaneously on major flank Aα and tool face Aγ.

3 Part II – Materials for manufacturing of tools

3.1 Introduction in part II

Tools materials for single flute end mill cutters are classified according to applicability, operational environment, constructional and geometrical parameters. It is necessary to have regard to economic considerations when choosing and defined by the tool and seriality of manufacturing.

3.2 Tool steels for monolithic mills

3.2.1 High-speed steel HSS

According to the classification of single flute end mill cutters presented in the first section of the development, for monolithic tools using two categories of tool steels - high-speed steel and sintered cermets. High speed steel in comparison with other types is characterized by the greatest stability, absence of internal tensions, but with the greatest consumption of tolls materials in the formation of the cutting part. High-speed steel [38], indicated in the marking of the tools with the HSS, contain large amounts of elements forming hard carbides (tungsten, titanium, vanadium, etc.), significantly increasing the heat resistance and strength of materials. After heat treatment structure includes martensite, carbides and double carbides of alloying elements.

More rarely for manufacturing of single flute end mill cutters are used and high-speed steel HSS-Co5% (M35). Famous names Co5%, S 6-5-2-5, 1.3243, Z 90 WDCV 06-05-04-02, HS 6-5-2-5, BM 35. She approaches the steel BS EN ISO 4957 - HS6-5-2-5 (R6M5K5) [29], [30]. Distinguished with a major amount of tungsten in the composition, but in contrast, has a lower content of cobalt and therefore performance and features in terms of the cutting speed are lower than those of the HSS Co8 (M42) - table 1.

TABLE 1
CHEMICAL COPMOSITION AND TECHNOLOGY CHARACTERISTICS OF HSS [11],[27]

Chemical composition	HSS Co8 (M42)	HSS Co5 (M35)
Carbon (C)	1,05%÷1,15%	0,92%÷0,95%
Tungsten (Wolfram) (W)	1,15%÷1,85%	6,4%
Manganese (Mn)	0,15%÷0,4%	————
Silicon (Si)	0,15%÷0,65%	0,35%
Molybdenum (Mo)	9,00%÷10,00%	4,85%÷5,00%
Vanadium (V)	0,95%÷1,35%	1,8%
Chromium (Cr)	3,5%÷4,25%	4,3%
Nickel (Ni)	max 0,3%	————
Cobalt (Co)	7,75%÷8,75%	4,8%

Thermal processing	HSS Co8 (M42)	HSS Co5 (M35)
HARDENING Temperature of preheating Temperature of hardening Time for hardening	 733°C÷843°C 1163°C÷1191°C (2÷5)min	 820°C÷870°C 1050°C÷1250°C (3÷7)min
TEMPERING Temperature of tempering	733°C÷843°C	510°C÷620°C

Physical - mechanical properties	HSS Co8 (M42)	HSS Co5 (M35)
Hardness HRc/HV Wear resistance Strength	65÷70/ 840÷1000 High Average	60÷67/ 700÷920 High Average

For the manufacturing of single flute end mill cutters are used and powder-metallurgical (Powder Metallurgy) and obtained by injection (Spray Forming) speed steel. They are characterized with fine grain carbide and high uniformity in combination with high isotropy. Possess a higher hardness than conventional high-speed steel [6].

Despite its undoubted economic, technological and operational environment positives however, high-speed steel have some significant drawbacks. Among them in the first place is their relatively low in cutting with other tolls categories durability.

Often at high pressures at the contact surfaces of the cutting wedge create a plastic barrier layer facilitates continuous bonding of the chip with the tools face, wherein the particles are removed from the surface of the cutting wedge and the concern of the chip. Observe, etc. adhesive wear.

3.2.2 Sintered cermets

The sintered cermet mainly tungsten carbides (WC) and less titanium, tantalum, associated with cobalt, iron and their alloys. [38] They have a significantly higher heat resistance and rigidity, allowing higher cutting speeds. They are used for tools with a diameter up to 10-12mm.

Technological properties in this group of materials are characterized by high-speed steel in that in tools manufacturing of them do not apply machining, plastic deformation, welding and hardening, and is shaping through sintering of hybrid pre-alloyed metal powders. Fuel of tools materials is low, and also reduced prime cost.

The technology for forming a tool required [21], [22]:

- mixing the starting powders,
- compaction (most compression),
- sintering - a process in which metallic powders are converted into a coherent solid part at temperatures below the melting point,
- additional processing (calibration, impregnation, TM, surface compaction),
- providing tools geometry by grinding with diamond discs.

More often for single flute end mill cutters is preferred over metal ceramics of high-speed steel, the most used cutting material. Sintered cermet tools occupy about 50% of the market share for all categories tools materials. Metal ceramic is used as in the form of monolithic tools and as carbide replaceable tip.

The main material of the ceramics is tungsten carbide in combination with a binder of cobalt (Co). Unlike speed steel here the percentage content of Cobalt is lower on account of any other refractory materials such as Ti, B and Zr, increasing hardness and wear resistance [35], [36].

The chemical composition, physical properties, thermochemystri properties and operational environment of the most common type of sintered cermets WC-Co are shown in table 2 [27], [34], [35].

3.3 Tool steels with coating

Improvement of operational environment and technological indicators of tool steels - durability, strength by cyclic and temperature loads, increased resistance of chemically active or abrasive environments, lack of influence on the output cutting tool geometry, etc. be carried out through application on the monolayer and multilayer nanostructural coatings [36], [37]. The use of appropriate coating increases the durability with 4-5 times, in some cases up to 10 times, and the accuracy and smoothness of the machined surface is improved. The coatings are deposited as the tools of high-speed steel and sintered cermet.

The properties that should have given coverage are divided into two groups [5] [8], [13], [19]:

- the physico-mechanical properties of classification criteria - strength, micro hardness, thermal resistance, impact strength, residual stresses in the cover and the base, coefficient of friction, thickness, number of layers and adhesion with the base and the machined material, heat conductivity.

- chemical indicators with classification criteria - material and number of elements of the coating, chemical and corrosion resistance.

TABLE 2
CHEMICAL COPMOSITION AND TECHNOLOGY CHARACTERISTICS OF WC-CO [9], [16].

Chemical composition	WC-Co
Tungsten (W)	82%÷86%
Carbon (C)	6,08%÷6,25%
Cobalt (Co)	6%÷8%
Iron (Fe)	≤0,05%
Cromium (Cr)	≤1,00%
Molybdenum (Mo)	≤0,02%
Vanadium (V)	≤1,00%
Physical properties	**WC-Co**
Hardness HRc/HV	1700÷2400
Strength	1620 MPa
Density	15.63 g/cm3
Temperature of melting	2870°C
Temperature of boiling	6000°C
Young's modulus	550 GPa
Coefficient of friction	0,22÷0,28
Thermochemistry properties	**WC-Co**
Specific heat capacity	33,49 J/mol.K
Std molar entropy	32,1 J/mol.K

On single flute end mill cutters are used mainly multielement multicomponent composite structures - systems titan - nitride TiN, titanium aluminum nitride TiAlN, carbonitrides (TiCN), borides TiB_2. Coatings with high chemical, corrosion resistance and cost, aluminum - titanium nitride AlTiN and titan- chromium nitride TiCrN in the case not be applied due to lack of aggressive environments [7], [8].

The low hardness of the machine material prevents appearance of crack, i.e. it is not necessary to make coatings with high and particularly high cohesion resistance. However, it is necessary to ensure micro hardness expressing the resistance of the coating against abrasion, here mainly find application in coatings micro hardness over 3000 HV. These criteria meet again titanium aluminum nitride TiAlN, and aluminum-chromium nitride AlCrN.

It is necessary the coatings have low levels of residual stresses, leading to increased adhesion to the substrate, essentially they provide and the low coefficient of friction for faster removal of the chip from cutting zone. These criterion coatings classify those with low and particularly low coefficient of friction. Those with particularly low friction coefficient are with and without the presence of a special anti-friction layer. Without a special layer of coating is mainly TiAlN. Specific anti-friction layers are molybdenum disulphide MoS_2, VS_2 vanadium disulfide, molybdenum-vanadium disulfide $MoVS_2$, a compound of molybdenum with selenium $MoSe_2$, titanium carbide plus titanium boride TiC + TiB2, as well as tungsten carbide - carbon WC - C [5], [19].

The high adhesion is realized with the transitional boundary tool coatings such as TiN and TiCN, boron nitride BN, boron carbonitrides BCN, titanium-nitride TiBN. The absence of adhesion with the material of the tool prevents the formation of bedding and the accumulation of chips in the tools channel. Characteristic type of coverage is TiAlN [5], [12], [19].

Table 3 shows comparative data on physical and mechanical properties, chemical composition and operational environment of multielement structures.

TABLE 3
PERFORMANCES OF MULTILAYER COATINGS [5], [18],[19]

Coating name	Coating color	Hardness, HV	Coating thickness, µm	Coefficient of friction	Coating temp., °C	Method for coating
TiN	Gold	2300÷2500	IS2,3÷3,2µm max ≈ 8 µm	0,4÷0,65	700°C / 600 °C	PVD
TiAlN	Dark gray	2900÷3100	IS1,8÷3,2µm max ≈ 5 µm	0,35÷ 0,65	800°C / 700 °C	PVD
TiCN	Rose	2800÷3200	IS2,5÷3,5µm max ≈ 8 µm	0,2÷0,3	800°C / 400 °C	CVD
AlTiN	Dark gray/ black	3000÷3400	IS1,8÷3,2µm max ≈ 5 µm	0,35÷0,7	800°C / 700 °C	PVD
TiAlSiN	Gray	3200÷3500	IS1,8÷3,2µm max ≈ 5 µm	0,35÷0,7	850°C / 750 °C	PVD
CrN	Silver	1800÷2100	IS2,2÷3,8µm max ≈ 7 µm	0,3÷0,45	700°C / 550 °C	PVD
AlCrN	Blue - gray	3000÷3200	IS1,8÷3,2µm max ≈ 5 µm	0,35÷0,5	900°C / 800 °C	CVD

The coatings are formed by physical vapor deposition PVD and chemical vapor deposition CVD. These are a low temperature process, which determines the low appearance of crack. Connections between atoms are shorter, tensile stresses low and cohesion resistance - high. Application of finishing operations reduces roughness and removed the cracks existed in the process of applying the coating.

The low temperature method of natural coating, referred to as PVD method is implemented in 400÷ 600°C [28].

It is used in coating thin layer is characterized by:

- advantages - can be applied to the sharp edges, have compressive residual stresses;

- disadvantages - the weak adhesion with the base and irregular thickness.

CVD method is implemented at 800÷ 1000°C.

It is used in a large and an average thickness of a coated and characterized by:

- advantages - better adhesion to the substrate, may be formed thicker wear resistant coatings that are of uniform thickness;
- disadvantages - it can be applied successfully over sharp edges, the coating is characterized by a tensile residual stresses.

In recent years, are used nanocomposite structures characterized by high levels of hardness and wear resistance inflicted by physical vapor deposition with side rotating cathodes PVD LARC (Lateral rotating cathodes) - Al-TiN/ Si3N4 (nACo), AlCrN / Si3N4 (nACRo) and nACVI. Characterizing them strength, heat resistance and corrosion resistance are comparable to those generated by cutting mineral-ceramic hard alloys - Table 4.

TABLE 4
PERFORMANCES OF NANOCOMPOSITE STRUCTURES

Coating name	Coating color	Hardness, HV	Coating thickness, μm	Coefficient of friction	Coating temp., °C	Method for coating
nACo (AlTiN/Si3N4)	Violet - blue	4000÷4500	IS1,5÷2,2μm max ≈ 4 μm	0,45÷ 0,65	1400°C / 1200 °C	PVD (LARC)
nACRo (AlCrN/Si3N4)	Dark gray	3800÷4000	IS2,7÷3,2μm max ≈ 7 μm	0,35÷ 0,55	1400°C / 1100 °C	PVD (LARC)
nACVI	Light gray	2500÷3700	IS2,5÷3,5μm max ≈ 6 μm	0,25÷ 0,35	1250°C / 1000 °C	PVD/CVD

3.4 Conclusion of part II

3.4.1 A major disadvantages of high-speed steel is their relatively low, compared to other tools, mater durability.

3.4.2 Among the HSS is the preferred brand molybdenum HSS Co8 (M42) hardness 63-68HRC.

3.4.3 Carbide-containing hard alloys are the most common materials for making of single flute end mill cutters, therefore, in that they do not apply mechanical methods for processing plastic deformation, welding and hardening, but speciation through sintering of hybrid pre-alloy metallurgy ceramic powders.

3.4.4 The geometric parameter of the tools of sintered cermets is provided by fine grinding with diamond shaped discs.

3.4.5 The tools with single and multilayer coatings are characterized by increased operational environment and technological parameters – hardness, durability, strength by cyclic and temperature loads, increased resistance of chemically active or abrasive environments.

3.4.6 Mainly used two- and three component composite structures based on titanium - TiN and titanium aluminium nitride TiAlN.

3.4.7 The coatings are applied mainly by CVD and PVD methods.

4 PART III – ZIRCONIUM METAL- CERAMIC STRUCTURES

4.1 Introduction in part III

In addition to established in practice coatings TiN, TiAlN and TiCN, whose characteristics are studied, rarely apply innovative multi-component metal-based structures of zirconium - ZrN [7], [15]; ZrC [14] and ZrCN [10], [13]. They belong to the group of cermet and provide good physico-mechanical properties, high wear resistance, high micro hardness and thermal stability, low levels of residual stresses in the coating, as well as a significantly lower coefficient of friction. There is less strength compared to other coatings but in contrast, do not contain rare chemical elements. In the literature there are no data on the cutting regimes that operate in single flute end mill cutters covered with them. Data for themselves coatings and modes in which they are applied are also scarce.

4.2 Composition and properties of zirconium coating

Studied to date materials coatings ZrN, ZrC and ZrCN [17] provide the highest levels of corrosion resistance combined with high biological agents relative passivity. This allows the tools on which they are made to function in a healthcare environment. When machining aluminum sheets and composite panels, these properties do not have essential but the machining of HPL boards with entirely organic composition, passivation of biological agents introduced into the cutting area is a significant positive for these group tools coatings. On the other hand ZrN, ZrC and ZrCN do not have physical uniformity of aluminium alloys such as titanium-aluminium nitride TiAlN, aluminium-titanium nitride AlTiN, titanium-aluminium-silicon nitride TiAlSiN and aluminium-chromium nitride AlCrN. Inertness of zirconium allows coatings to aluminium used at high-speed (HSM) and high-precision machining (HPM) with single flute end mill cutters of aluminium sheet and aluminium composite panel.

Coatings of ZrN and ZrCN be applied by means physical vapor deposition PVD [20] and those of ZrC with chemical vapor deposition CVD [23], [24]. For ZrC coatings applied to tools with sharp cutting edges such as single flute end mill cutters is possible and use of physical vapour deposition.

Zirconium nitride ZrN, zirconium carbide ZrC and zirconium carbonitrides ZrCN are refractory high temperature ceramic material [25], [26]. In natural state they are in a state of metal powders with cubic ionic crystal lattice made of zirconium cations filling octahedral inter-watermelons and nitrogen, carbon and carbonitrides anions. Structural zirconium nitride and zirconium carbo-nitride ZrCN are identical. Characterizing them lattice is face-centered cubic - cF8 type B1 - fig.2,a, while zirconium carbide it is body-centered cubic tetrahedral - cF8 type B3 - fig.2,b. Multivariate tensor describing array of bars according to the symbolism of the Hermann-Mauguin is denoted by Fm3m for ZrN, respectively ZrCN and F-43m for ZrC.

Crystal panels consisting Miller index have indications for ZrCN 1,1,1 (parallel-plate our axes X, Y and Z) - fig.3,a, ZrN 1,0,0 (parallel-plate only of axe X) – fig.3,b and ZrC 326. (based panel-bone crosses coordinate axes at a distance less than one) - fig.3.c

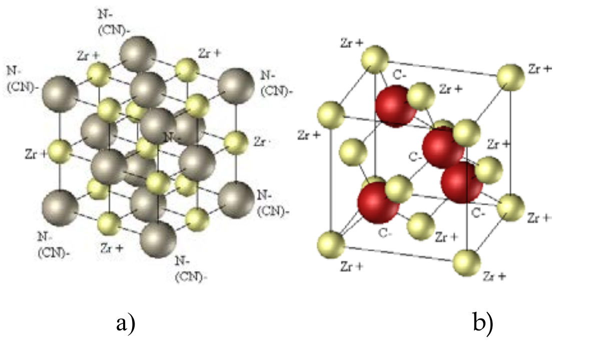

Fig. 2. Cubic ionic crystal lattice [39]:
a) face-centered cubic – cF8 тип B1 на ZrN (ZrCN), б) body-centered cubic tetrahedral - cF8 тип B3 на ZrC

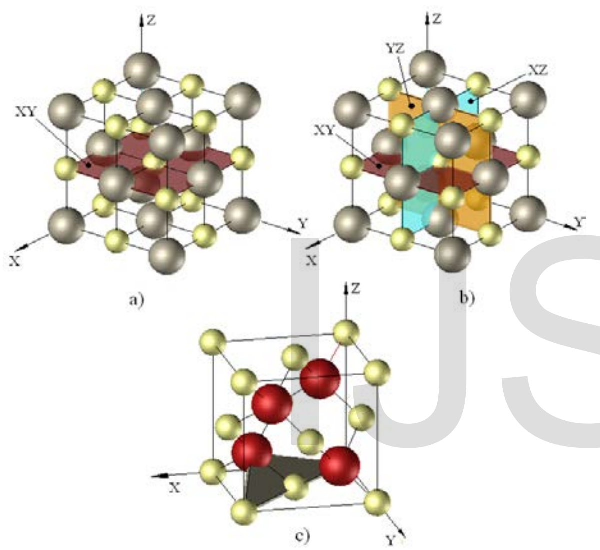

Fig. 3. Crystal panels - Miller index [40]:
a) ZrCN) - 1,1,1; б) ZrN – 1,0,0; б) ZrC - 326

The chemical composition of the coatings depend on the method of preparation, the temperature of extraction and saturation levels of the base elements N and C in them. There are many brands applied as in powdered material and shaped as targets for PVD and CVD shows the averaged data on the chemical composition, physical and thermochemical properties of coatings, derived based on the composition of widespread brands ZrN, ZrC and ZrCN - table 5.

In specific characteristics required percentage composition of these elements will be changed.

Operational environment of the two types coatings are presented in Table 6.

4.3 Conclusion of part III

The chemical composition, physical, thermochemical properties and operational environment characteristics of the

TABLE 5
CHEMICAL COPMOSITION AND TECHNOLOGY CHARACTERISTICS OF ZRN, ZRC AND ZRCN [26],[28],[30]

Chemical composition	ZrN	ZrC	ZrCN
Zirconium (Zr)	85%÷87%	88%÷89%	34%÷36%
Nitrogen (N)	13%÷15%	0,05%	17%÷40%
Carbon (C)	0,2%÷0,35%	11%÷12%	15%÷40%
Oxygen (O)	0,35%÷0,55%	0,65%	2%÷4%
Impurities			
Aluminium (Al)	0,1%÷0,15%	0,005%	0,25%÷0,35%
Iron (Fe)	0,05%	0,06%	0,06%
Natrium (Na)	0,01%	0,005%	0,005%
Phosphorus (P)	≤0,003%	≤0,003%	≤0,003%
Sulphur (S)	≤0,003%	≤0,003%	≤0,003%

Thermal processing	ZrN	ZrC	ZrCN
Temperature of melting	2952ºC	3532ºC÷3540ºC	3864ºC÷3922ºC
Temperature of boiling		5100ºC	
Density	7,09 kg/m³	6,73 kg/m³	7,67 kg/m³
Young's modulus	450 GPa	383 GPa	346 GPa
Molar mass	105,23 g.mol^{-1}	103,23 g.mol^{-1}	

Physical - mechanical properties	ZrN	ZrC	ZrCN
Specific heat capacity	40,442 J/mol.K	37,442 J/mol.K	
Std molar entropy	38,83 J/mol.K	33.14 J/mol.K	29,8 J/mol.K
Std enthalpy of formation	-365 kJ/mol	-197kJ/mol	-170,5kJ/mol

three types of coatings give reason to do some basic conclusions regarding their applicability on single flute end mill cutters for high-speed milling (HSM) and high-precision machining (HPM) of aluminium sheets, profiles, composite panels and high pressure laminate (HPL) panels.

TABLE 6
PERFORMANCES OF ZRN, ZRC and ZrCN

Coating name	Coating color	Hardness, HV	Coating thickness, μm	Coefficient of friction	Coating temp., °C	Method for coating
ZrN	Gold	2300÷2500	IS2,2÷3,8μm max ≈ 4 μm	0,25÷ 0,35	600ºC / 550 ºC	PVD
ZrC	Light gray	2440÷2650	IS3,5÷4,6μm max ≈ 8 μm	0,2 ÷ 0,3	750ºC / 600 ºC	CVD/PVD
ZrCN	Brownish - silver	2600÷3200	IS1,5÷3,5μm max ≈ 4 μm	0,35÷ 0,5	600ºC / 1100 ºC	PVD

4.3.1 The three types of coatings provide lower levels of the friction coefficient, and hence higher wear resistance compared to standard coatings employed. Commensurate with them are only TiCN and nanocomposite structure nACVI.

4.3.2 Concerning the two component structures ZrC is the material with the higher melting point, in densities of the same order of ZrN, it is depositional at higher temperature, which determines the use of chemicals vacuum methods. Application in use of physical vapor deposition in the case requires reaching maximum temperature levels for method.

4.3.3 ZrC referred to ZrN is material with higher hardness and a lower modulus of elasticity, which suggests feasibility in terms of pure and fine milling with high cutting speeds, at a shallow depth and low dynamic performance.

4.3.4 From turn ZrCN comparable with other two materials, having two component structures, has a threemetal-ceramic structure. It has the highest hardness, but also the highest coefficient of friction. However, its corrosion resistant and thermal stability superior to those of ZrC and especially of the ZrN, allowing it to hold more higher levels of the elements of the cutting conditions.

4.3.5 Coordination numbers are close, but still ZrCN is the material with the highest density of the crystal lattice, followed by ZrN and lastly ZrC. Therefore, its performance and thermo mechanical higher.

GENRAL CONCLUSION

1. Research and illustrated the conditions of formation and removal of the chip and wear of single flute end mill cutters.
2. Analized in detail are chemical composition and technological-operational environment parameters of single flute end mill cutters.
3. Indicated the advantages and disadvantages of zirconium metal-ceramic structures.

REFERENCES

[1] Ангелов Н., Обработване на материалите и инструментална екипировка, Издателство на ТУ-София, 2007.
[2] Колев Ив., Рязане на материалите, Печатна база на РУ, Русе, 2009.
[3] Николчева Г., Г.Попов, Инструменти за високоскоростна (HSM) и високопрецизна обработка (HPM), „Сп. Инженеринг ревю“,8, 2014,
[4] Угринов Пл., Ст. Калчевски, П.Кънчев, Екологично чиста суха обработка- класификация на методите за охлаждане и мазане, XXI МНТК „АДП-2012”,
[5] Угринов Пл., Класификация на покритията на инструменти за високоскоростна суха и квазисуха обработка по физико-механични и химични признаци, XVII ННТК с международно участие „АДП-2008”
[6] A. G. Leatham, A. J. W. Ogilvy, P. F. Chesney. The production of Advanced Materials by means of the Osprey Process. MDPM Jurnal, Vol.18-21, 1988.
[7] Arrieta M., Low Temperature CVD of Zirconium Nitride a Fluidized Bed, Texas A&M University, August 2012,
[8] Audy J., A Study of dry machining performance of the TiN, Ti(Al,N) and Ti(C,N) coatings and a M35 HSS type tool substrate material assessed through basic cutting quantities generated when orthogonal turning a bisalloy 360 grade steel work-piece material, Journal of engineering, TOME VI, 2008
[9] Bonny K., P. De Baets, EDM machinability and dry sliding friction of WC-Co cemented carbides, Int. J. Manufacturing Research, Vol. 4, No. 4, 2009 ,
[10] Braic M., V. Braic, M. Balaceanu, C.N. Zoita, A. Kiss, A. Vladescu, A. Popescu, R. Ripeanu, Structure and properties of Zr/ZrCN coatings deposited by cathodic arc method, MC&P, Volume 126, Issue 3, 15 April 2011, P.p 818-825
[11] Davis, Joseph R., ASM International. Handbook Committee, Tool materials. ASM International. p. 289. ISBN 978-0-87170-545-7,1995,
[12] González L. G., and team,A Study ot TiAlN coatings prepared by RF Co-Sputering, Brazilian Journal of Chemical Engineering, Vol. 24, No. 02, pp. 249 - 257, June, 2007
[13] Grigore E. Zirconium carbonitride films deposited by combined magnetron sputtering and ion implantation // SCT, 2010, № 204., 1892.
[14] Hwang C. S., Kim H.J. Deposition of Pb(Zr,Ti)C>3 thin films by metal-organic chemical vapor deposition using P-diketonate precursors at low temperatures // Journal of the American Ceramic Society. 1995. - Vol. 78. - 2. - P. 329-336.
[15] Kanoun M. B., S. Goumri-Said, Effect of alloying on elastic properties of ZrN based transition metal nitride alloys, Elsevier - Surface & Coatings Technology 255, pp. 140 –145, 2014
[16] Kurlov, Alexey S.; Gusev, Alexsandr I. (2013). WC Structure, Properties and Application in Hardmetals, Springer Science+Business Media, 2013
[17] Larijani M. M. , M. B. Zanjanbar, M. Alijannejad, A. Majdabadi, The effect of carbon fraction in Zr(C, N) films on the nano-structural properties and hardness, Iranian Physical Journal, 2-3, 18-21,2008.
[18] Luo Quanshun, G. Robinson, M. Pittman, M.Howarth,SIM.W.,M. Staylley, H.Leitner, R. Ebner, D. Caliscanoglu, P. Hovsepian, Performance of nanostructured multilayer PVD coating TiAlN/VN in dry high speed milling of aerospace aluminium 7010-T7651, SCT Jurnal, 200, 123-127., 2005
[19] Mishev G., Heisel U., Trendz for improving the tribological properties of details and assemblies of machine tools, Journal of the TU at Plovdiv "Fundamental Sciences and Applications", Vol. 13(6), 2006
[20] Igartua1 A., X. Fernandez1 , B. Zabala1 , M. Conte1 , U. Ruiz de Gopegui1. Tribological behaviour of ZrCN PVD and other DLC coatings for engine components, 40th Leeds-Lyon Symposium on Tribology, 2013.
[21] Jüri Pirso J., S.Letunovitš, M. Viljus, Friction and wear behaviour of cemented carbides, Elsevier, Jurnal Wear 257 (2004) 257–265
[22] Prabhudev K.H., Handbook of Heat Treatment of Steels, Tata McGraw-Hill Education, 1988
[23] S.E. Landwehr, G.E. Hilmas, W.G. Fahrenholtz; Processing of ZrC–Mo Cermets for HighTemperature Applications, Part I: Chemical Interactions in the ZrC–Mo System; J. Am. Ceram. Soc., 90 (2007) 1998–2002.
[24] S.E. Landwehr, G.E. Hilmas, W.G. Fahrenholtz; Processing of ZrC–Mo Cermets for High Temperature Applications, Part II: Pressureless Sintering and Mechanical Properties; J. Am. Ceram. Soc., 91 (2008) 873–878.
[25] Seshan Kr., Handbook of Thin Film Deposition, Third Edition, William Andrew, Elsevier Inc, Waltham USA, 2012
[26] Silva E., M. R. Figueiredo R.Franz , R. Escobar Galindo,C. Palacio, A. Espinosa, S. Calderon,S.Carvalho, Structure–property relations in ZrCN coatings for tribological applications, Elsevier – SCT, 205, pp.2134–2141, 2010
[27] Tracton A.A., CMS, Taylor & Francis Group, NW, 2007
[28] T. Peniashki, Types of coatings and methods for their deposition on the machine tools some guidelines for selecting suitable materials and methods for coating, National Conference BULTRIB, 2011, pp.257-285
[29] Velchev St., Bulgarian-english dictionary-reference book of metal cutting, Ruse,2009
[30] Yalamanchili P. K., ZrN based Nanostructured Hard Coatings Structure-Property Relationship, Linköping University Sweden, ISSN: 0280-7971, 2014
[31] http://www.datron.com
[32] http://www.harveytool.com
[33] http://www.astech-tools.com
[34] http://www.jaiganeshsteel.com/
[35] http://www.rudolfsteel.com/
[36] http://www.jnm.co.jp/
[37] http://www.ctia.com.cn/
[38] http://epubl.tugab.bg/documents/cat_view/41
[39] http://www.geocities.jp/ohba_lab_ob_page/structure6.html
[40] http://chemistry.bd.psu.edu/jircitano/Miller.html