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CHIP FORMING PROCESS IN MACHINING OF THE DIFFERENT STRUCTURE STAINLESS STEEL WITH DIFFERENT TYPE OF NANOCOATED CUTTING TOOLS

SKAIDU VEIDOŠANAS PROCESS, APSTRĀDĀJOT DAŽĀDA TIPA STRUKTŪRAS NERŪSĒJOŠO TĒRAUDU AR DAŽĀDA TIPA NANOPĀRKLĀTIEM GRIEZĒJINSTRUMENTIEM

Keywords:
metal cutting, machining, stainless steel.

INTRODUCTION

In our days technologies such as high speed machining, dry machining and the development of difficult-to-machine workpiece materials will continue to put the pressure on cutting tool manufacturers for development of new products that can perform at higher speeds, provide longer tool life and withstand rigorous operating conditions. Some of the issues caused by these demands include increased temperatures in the cutting zone, where much of the energy applied to the cutting process is converted into heat. And, although the heat generated during the machining process can help make the cutting action easier by reducing the force needed for chip formation, it can also flow into the cutting edge to negatively impact tool life by causing plastic deformation of the tool. Every machinist is striving to achieve the optimal combination of productivity and tool life, which can become a complex task when cutting at high speeds in harder steels. For operators to take advantage of these machines high speed capabilities, they must have chemically stable, heat-resistant cutting tools. We are going to concentrate on the role of the insert coatings. The insert plays a critical role in chip formation the first step to good chip control, productivity, tool life and reliability.

In this paper one new turning insert coating which is called Duratomic TM4000 is chosen to study the 420 stainless steel machining process and also one more coating type TP2500 used to machine the 304 stainless steel. Stainless steels contain a high proportion of chromium, generally in excess of 13%. They are generally difficult to machine due to their high tensile strength, high ductility, high work hardening rate, low thermal conductivity, and abrasive character. This combination of properties often results in cutting forces, temperatures, and tool wear rates, as well as a susceptibility to notch wear, chip-breaking difficulties, BUE formation, and poor machined surface finish [1,2]. Alloying elements can be added to reduce some of these difficulties, however, resulting in freecutting grades with comparatively good machinability. Stainless steel is usually classified into four categories depending on their primary content of the matrix: ferritic, martensitic, austenitic, and duplex (combined ferritic/austenitic).

Ferritic stainless steels are alloyed primary with chromium, although molybdenum, titanium, or niobium may be added to some grades to improve corrosion resistance or as welded properties. Ferritic alloys are generally more machinable then other alloys. Their machinability generally decreases with increasing chromium content.

In addition to chromium, martensitic alloys may contain carbon, molybdenum, and nickel to increase strength. The machinability or martensitic stainless steels is influenced be hardness, carbon content, nickel content, and metallurgical structure [3]. As with most materials, increasing hardness typically reduces tool life and machinability. Increasing the carbon content increases the proportion of abrasive chromium carbides in the matrix and reduces tool life and machinability. The metallurgical factor which has the strongest influence on machinability is the proportion of free ferrite in the matrix: generally machinability increases with free ferrite content.

Austenitic stainless steels contain nitrogen, carbon, and nickel or manganese in addition to chromium. They exhibit high strength, ductility, and toughness, and are typically more difficult to machine than ferritic or martensitic stainless steel. Specific difficulties encountered when machining austenitic stainless steel include high wear rates due to high cutting forces and temperatures, BUE formation, chip control problems, poor surface integrity (hardened machined surfaces), and a tendency to chatter. Poor tool life is related to the annealed hardness, which increases with increasing nitrogen content. Increasing the carbon content increases the work-hardening rate and also decreases machinability. Abrasive carbon/nitrogen compounds may form in the matrix and reduce tool life; these can be controlled by adding titanium or niobium. As with other stainless steels, hardness increases and machinability decreases with increasing nickel content. Imparting moderate cold work to the material typically increases machinablity by reducing the tendency for BUE formation and improving the machined surface finish and integrity.

Main general guidelines for machining stainless steels include :use lower cutting speeds and metal removal rates than for carbon steels, use rigid tooling and fixturing to avoid chatter, maintain feed above a minimum level to avoid poor surface integrity, use sharp tools to avoid BUE formation, use proper cutting fluids with sufficient flow rates for heat removal, use more effective designed cutting tools with chip-breakers such as SECO MF4 and MF5 and coatings such as Duratomic – for machining stainless steel[4]. That is why it is necessary to learn more about new cutting tools and the machining process with some parameters combinations and how does they effect the cutting process and it's result. The experiment in turning of the 304 austenitic and 420 martensitic structure stainless steel on lathe 16K20 take place in RTU by G. Bunga, V. Gutakovskis and G. Pikurs.

MODERN CUTTING INSERT COATING DESCRIPTION

Coated carbide inserts have long dominated the majority of metal removal operations in job shops due to their wear resistance, chemical stability and high hardness. With the ability to remove large amounts of material across a range of applications while retaining a long tool-life, about 80% of inserts used in machining today are coated carbide grades. Coatings improve wear resistance, increase tool life, and can broaden the functionality of a particular grade as well as allowing for higher machining speeds. The coating is important, but the coating must also be applied to the appropriate substrate for the insert to achieve the desired characteristic. This multilayer coating technology means that each layer has its own function, be it toughness, wear-resistance, lubricity, etc. So, although the substrate is protected by the coating until there is significant tool wear, its properties have a significant impact on the way the tool and the coating perform. Within this realm, there is a variety of substrate and coating compositions and it's thickness in 1 μm to 10 μm. There are a numerous approaches to improving the performance of coated products. All these combinations are designed to improve quality, productivity or reduce cost.

Advancements in coatings technology have typically been incremental. The rare revolutionary change did come about with Seco Tools' unique Duratomic® methodology; a unique chemical vapor deposition (CVD) applied coating. Through extensive research and development, Seco learned how to control the crystallographic texture of the aluminum oxide (Al_2O_3) substrate layer. By modifying the coating deposition techniques, the individual crystals that make up the coating are "tilted" to bring a more favorable crystallographic direction into the cut. To use an analogy, think about how diamonds can be cleaved relatively easily in certain crystallographic directions, producing the facets that reflect and refract light and make gems so attractive. However, in other crystallographic directions diamond is very resistant to any form of breakage. Through this technique, Seco has learned how to control the alumina crystal growth. Essentially, this structural alteration creates a coating that offers improved mechanical and thermal properties in combination with better wear resistance and toughness.

Compared with conventionally produced Al_2O_3 the Duratomic coatings shows less crater wear, less deformation of the cutting edge, and longer tool life .When compared with titanium carbonitride Ti(C,N) coatings produced by MTCVD, or conventional Al_2O_3 coatings, the Duratomic developed grades consistently show increased flank wear resistance and improved toughness.

The optimized Duratomic coating structure is composed of two functional parts. The inner Ti(C,N) (thick-ness is 4 μm) base layer is responsible for excellent adhesion and the basic cutting edge strength while the top layer of Al_2O_3 (thickness is 3,5 μm) acts as an effective thermal barrier to permit higher cutting speeds (figure 1, 2).

Figure 1. Duratomic coating structure and its description.

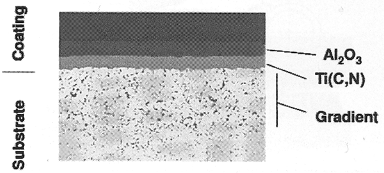


Table 1. Chosen duratomic coated TP2500 and TM4000 structure.

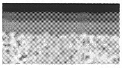
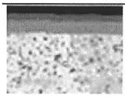
	TP2500 is intended for a wide range of turning applications in both steel and stainless steel and is also a good choice for cast iron. The wear resistance and edge strength together with the high versatility make the grade the first choice in a large number of applications. Ti(C,N) + Al2O3 DURATOMIC™
	TM4000 is intended for machining of stainless steel. The wear resistance and together with the superior edge toughness make the grade the first choice in stainless steel applications. Ti(C,N) + Al2O3 DURATOMIC™

Figure 2. Coating hardness depending on it's type and temperature.

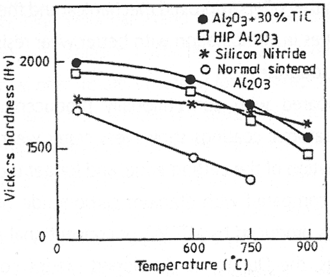


Figure 3. Machining operations type: a) 1 – Heavy/rough machining, 2 – different profile type machining, 3 – face machining; b) 1 – internal deep machining, 2 – internal rough/middle machining, 3 – internal different profile machining.

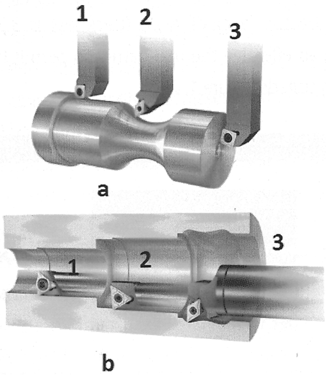


Figure 4. Chip forming process during machining on CNC lathe.

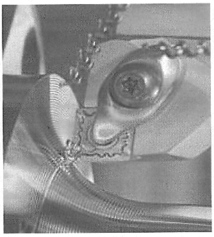
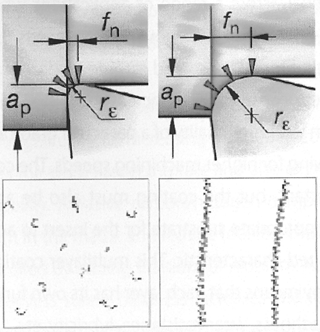


Figure 5. The dependence of the chip forming result on the cutting tool depth and cutting nose radius.



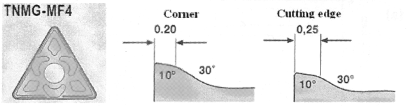
EXPERIMENTAL PARAMETERS AND CUTTING TOOL SELECTION

The aim of the experiment is to study the machining parameters and machined result, directly the surface roughness, cutting forces, chip forming process (Fig. 4,5.) and tool wear. The machining parameters are chosen to make the metal cutting process in middle/finish operation with different cutting speeds, different amount of the metal removal rate, but on the one cutting edge (Fig.3.). For our tree factor experiment was chosen the 420 and 304 stainless steel with high chromium content, modern Duratomic coated (figure 1, Table 1) turning insert TNMG 160412-MF4, TM4000 , TNMG 160408-MF5, TP2500 with cutting edge radius 1,2 mm and 0,8mm. Machining parameters combinations (table 2) are: feeding - 0,1 mm/Rpm and 0,35 mm/Rpm; cutting depth is 0,5mm; cutting speed 90 m/min., and 112 m/min. The chosen chipbreaker MF4 (Table 3), experimental rig is shown on the Figure 6,7, chip breaker MF5,for medium/finishing turning (table 3) with TM4000 and TP2500 coating , two holders with cutting angle φ = 90° and φ = 60° (figure 8) and recommendations from manufacturer (table .4).

Table 2. Machining process parametrs.

Parameter comb. Nr.	1	2	3	4	5	6	7	8
Feeding, mm/Rpm	0,1	0,35	0,1	0,35	0,1	0,35	0,1	0,35
Cutting depth, mm	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Cutting speed, m/mm	90	90	112	112	90	90	112	112
Cutting edge angle	60°	60°	60°	60°	90°	90°	90°	90°

Table 3. Chosen chip breaker and its description.



Chipbreaker intended for medium/finishing of stainless steels. Very open and highly positive geometry. Machining range: f (feeding) = 0.15 – 0.5 mm/rev, ap (depth of cut) = 0.5– 4 mm

Table 4. Recommended cutting parameters for TM4000 turning insert.

Seco material group No.	TM4000		
	Feed rate, f (mm/rev)		
	0,2	0,4	0,6
8	240	175	140
9	190	140	110
10	155	115	90
11	115	85	65

Figure 6. Experimental machine 16K20 with mounted dynamometer UDM-600 and digital microscope.

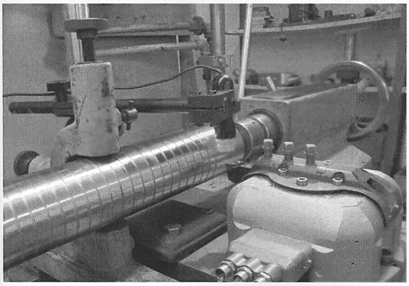


Figure 7. Experimental scheme: 1 – machining part, 2 – metal cutting tool , 3 – UDM-600, dynamometer, 4 – amplifier, 5 – voltmeter block.

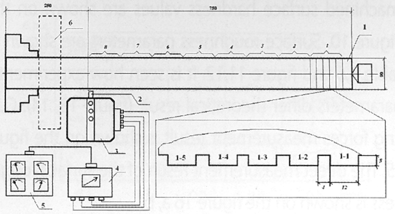


Figure 8. Turning insert holders for cutting angle φ = 60° (a) and φ = 90° (b).

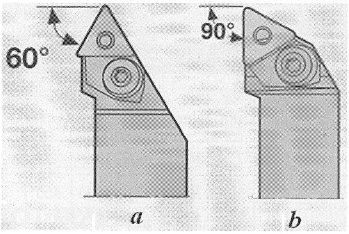
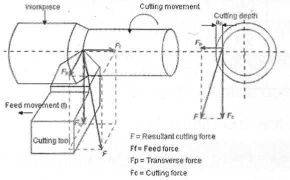


Figure 9. Cutting force in metal cutting Pz – main or resultant cutting force marked here as F_c.



EXPERIMENTAL RESULTS

The experiment was done using machining parameters combination of 8 variants with repeating five times each. Here are represented the part of the results directly for the dry- machining process of the 420 stainless steel with TM4000 coated cutting tool. The main idea was to study the machining parameters and machined result, directly the surface roughness, cutting forces, chip forming process and tool wear in machining process. There are measured surface roughness and hardness parameters: Ra- average roughness, arithmetic mean deviation of the profile; Rt - maximum height of the profile; The machined surface hardness values are shown on the Figure 10. Surface roughness parameters are shown in table 5,6 and figure 11,12. It is seen how experimental parameters differ theoretical result (figure 13, 14). Cutting forces measurement result is shown on the figure 15. The direct measurement result of the surface roughness is shown on the figure 16 a, b.

The results of the chip-forming process are shown on the figure 17. No significant cutting insert wear was noticed after this experiment (Figure 18).

Table 5. Experimental results.

Machining block number	Ra, µm	Rq, µm	Rt, µm	Rz, µm	Rc, µm	RSm, µm	Hardness, HB
1	5,92	7,34	44,82	34,05	19,89	404	262
2	4,57	5,64	29,41	20,1	12,51	466	275
3	5,04	6,3	39	30,3	16,8	372	272
4	5,72	7,14	40,88	31,89	15,07	375	264
5	5,56	6,86	47,2	33,6	18,07	362	250
6	3,46	4,22	21,55	18,24	9,79	334	273
7	5,4	6,68	41,7	32,5	16,3	351	277
8	3,68	5,55	35,4	26	12,56	324	278

Table 6. Best result comparison table.

Machining block number	Machining section number	Ra, µm	Rq, µm	Rt, µm	Rz, µm	Rc, µm	RSm, µm	Hardness, HB
2	2-1	5,44	6,67	35,02	28,35	13,99	474	282
	2-2	4,25	5,39	28,53	27,11	11,66	369	264
	2-3	5,16	6,31	28,99	25,6	16,41	756	276
	2-4	4,48	5,48	32,74	25,1	11,61	407	283
	2-5	3,52	4,38	21,76	19,02	8,91	328	270
6	6-1	3,29	3,93	17,83	16,5	9,51	320	258
	6-2	3,33	4,11	21,85	18,29	9,23	334	273
	6-3	3,1	3,84	18,15	16,64	8,68	334	280
	6-4	3,52	4,25	21,49	18,29	10,1	311	281
	6-5	4,06	4,98	28,44	21,49	11,43	372	276

Figure 10. Machined surface hardness.

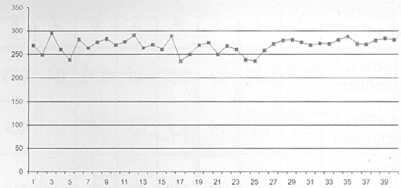


Figure 11. Ra result comparison: 1 – for cutting edge angle 60°; 2 – for cutting edge angle 90°.

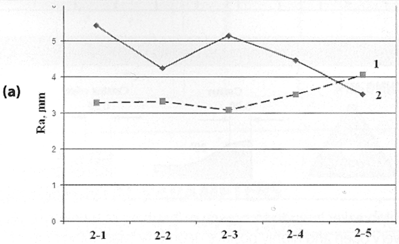


Figure 12. Rt result comparison: 1 – for cutting edge angle 60°; 2- for cutting edge angle 90°.

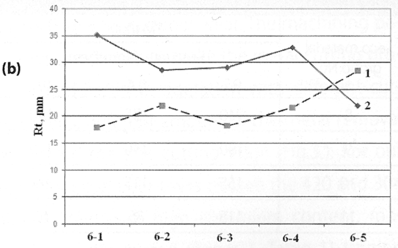


Figure 13. The dependence Ra- average roughness, arithmetic mean deviation of the profile.

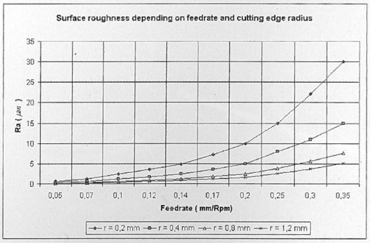


Figure 14. The dependence of the Rt- maximum total height of the profile.

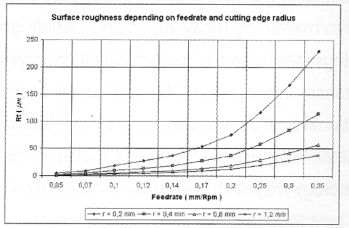


Figure 15. Cutting forces in machining process. Each machining parameter combination was repeated five times during the experiment.

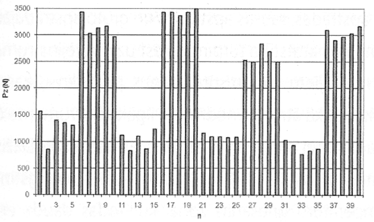
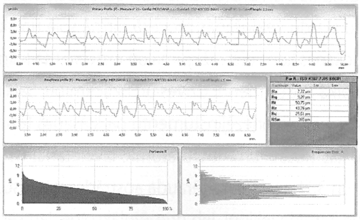


Figure 16. Surface roughness measurement results maximum (a) and minimum results (b).



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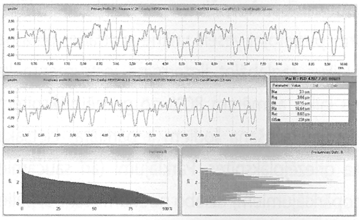


Figure 17. Chip forming result in different combinations of feed and depth of cut values. 1 – Recommended results, 2 – Received results.

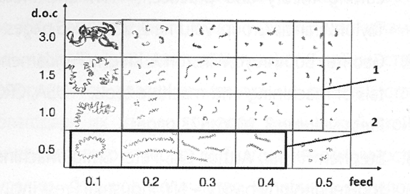
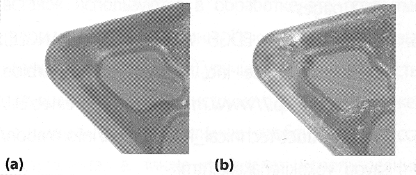


Figure 18. Cutting tool wear result before (a) and after (b) the experiment.



CONCLUSION

The experimental results show us how theoretical results differ the experimental results. During the experiment no critical tool wear took place, only a little flank wear and chipbreaker back face wear were seen, because of continuous chip flow contact with it. Main conclusion is that to get a better result it is necessary to change the cutting edge angle, but not increase cutting speed and decrease feeding, because of the high cutting forces which affect the cutting tool significantly and deform the previous machined area. The result of the surface roughness values are used to develop the mathematical model of the cutting process for the middle-finishing machining process using this selected cutting tool. As the cutting tools are systematized in the standards for the machining operation with some other manufacturers and their cutting tool grades and parameters, this model will be helpful for each manufacturer to get the direct roughness value, not performing the experiment and calculating the results once more.

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ABSTRACT

In our days technologies such as high speed machining, dry machining and the development of difficult- to-machine workpiece materials will continue to put the pressure on cutting tool manufacturers for development of new products that can perform at higher speeds, provide longer tool life and withstand rigorous operating conditions. Some of the issues caused by these demands include increased temperatures in the cutting zone, where much of the energy applied to the cutting process is converted into heat. The insert with different type and thickness combination plays a critical role in the chip formation first step to good chip control, productivity and tool life. In this paper one new turning insert coating technology, which is called Duratomic is chosen to study the 420 and 304 stainless steel machining process. Coated carbide inserts have long dominated the majority of metal removal operations in manufacturing plants due to their wear resistance, chemical stability and high hardness. With the ability to remove large amounts of material across a range of applications while retaining a long tool-life, about 80% of inserts used in machining today are coated carbide grades. Coatings (also called as nanocoatings) improve wear resistance, increase tool life, and can broaden the functionality of a particular grade as well as allowing for higher machining speeds. This multilayer coating technology means that each layer has its own function, be it toughness, wear-resistance, friction.

ABSTRAKTS

Mūsdienās tehnoloģijas attistība, piemēram, ātrgaitas apstrādes, sausas apstrādes un gruto apstrādajamo materiālu attitstība turpina spiest uz griezējinstrumentu ražotājiem, lai attīstītu jaunus produktus, kas var veikt lielākā ātrumā, nodrošina ilgāku instrumenta dzīvi un izturēt stingras ekspluatācijas apstākļos. Daži no jautājumiem, ko rada šīs prasības ietver paaugstinātu temperatūru griešanas zonā, kur rodas daudz enerģijas, kas rezultātā griešanās processā tiek pārvērsta siltumā. Mobilā griezejplāksnīte ar dažadiem nanopārklājumu tipu un biezumu kombināciju spēlē nozīmīgu lomu skaidu veidošanas procesā pirmā soļā un skaidu veidošanas kontrolē, ražigumā un instumenta kalpošanas laikā , instrumentu dzīves un uzticamību. Šajā rakstā viena jauna griezējinstumentu pārklāšanas tehnoloģija, kas nosaukumr ir Duratomic izvelēta lai isstudēt 420 un 304 nerūsējošā tērauda apstrādes procesu. Pārklātie karbīda ieliktņi, jeb griezējplāksnītes jau sen dominē vairums metāla atdalīšanas operāciju rūpniecībā, ņemot vērā to nodilumizturību, ķīmisko stabilitāti un augstu cietību. Ar spēju noņemt lielu materiāla daudzumi, pielietojot veselā vriknē apstrādes parametros, vienlaikus saglabājot ilgtermiņa instrumenta kalpošanas laiku, apmēram 80% no griezējplāksnītēm kas pielietojas ražošana šodiem ir pārklātas cietsakausējuma griezējplāksnītes. Pārklājumi (arī saucāmie pār nanopārklājumiem) uzlabo nodilumizturību, palielinot intrumenta kalpošanas laiku un var paplašināt funkcionalitāti noteiktā kategorijā, kā arī nodrošinot lielāku apstrādes ātrumu. Šo daudzslāņu pārklājumu tehnoloģija nozīmē, ka katram pārklājuma slānim ir savas funkcijas, vai tas būtu stingrība, nodilumizturība, berze.

АБСТРАКТ

В наши дни технологии, такие как высокоскоростной обработки, сухой обработки и развитие трудных для обработки материалов заготовки будут продолжать оказывать давление на производителей режущего инструмента для разработки новых продуктов, которые могут работать на более высоких скоростях, обеспечивают срок службы инструмента и выдерживать суровые условия эксплуатации. Некоторые из проблем, вызванных этим требованиям включают повышенную температуру в зоне резания, где большая часть энергии преобразуется в тепло. Стружколом с различным типом нанопокрытия и комбинаций толщины играют важную роль в первом шаге процесса формирования стружки и контроля стружкообразования, производительности и стойкость инструмента. В данной работе новая технология покрытия, которая называется Duratomic выбирана для изучения процесса обработки 420-й и 304-й нержавеющей стали. Покрытые вставками из карбида уже давно доминирует большинство операций по удаления металла на производстве благодаря их износостойкости, химической стойкости и высокой твердости. Благодаря возможности удалить большое количество материала в целом ряде комбинаций параметров обработки, сохраняя большой срок службы инструмента, около 80% вставок используются в обработке это покрытые твердосплавные пластины. Покрытия (также называемые нанопокрытием) улучшает износостойкость, повышает стойкость инструмента, а также может расширить функцио-нальные особенности класса инструмента, а также позволяет использование более высоких скоростей обработки. Это многослойная технология покрытия означает, что каждый слой имеет свою собственную функцию, будь то прочность, износостойкость, трение о поверхность.