Scientific Society for Mechanical Engineering

TripleCoatings3® – New Generation of PVD-Coatings for Cutting Tools

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Received: 26th October 2008 | *Accepted*: 20th December 2008

The paper introduces a new generation of Physical Vapour Deposition (PVD) coatings. Triple Coatings3® has the advantages of conventional (TiN, CrN, TiAlN, AlTiN) coatings and of nanocomposite coatings (nc-TiAlN/a-SiN, nc-AlCrN/a-SiN, nc-AlTiCrN/a-SiN). TripleCoatings3® are applicable for general purpose use, but particularly for high performance cutting tools. They are best deposited in coating units with LARC®- and CERC®-Technology. TripleCoatings3® were developed by the systematic use of the most important add-on component materials (Ti, C, Al, Cr, Si) and with the help of simulation. TripleCoatings3® were introduced in the spring of 2007 and are already being widely used for cutting tools in manufacturing all over the world. From these applications this paper shows industrial results for turning, milling, drilling and hobbing.

Keywords: nanocomposite PVD coating, simulation in coating development, cutting tools, high performance cutting, tool life

1. Introduction: The significance of coating of cutting tools

The trend shows that first decade of the 3rd millennium may bring excellent business for the machining industry (*Figure 1*).

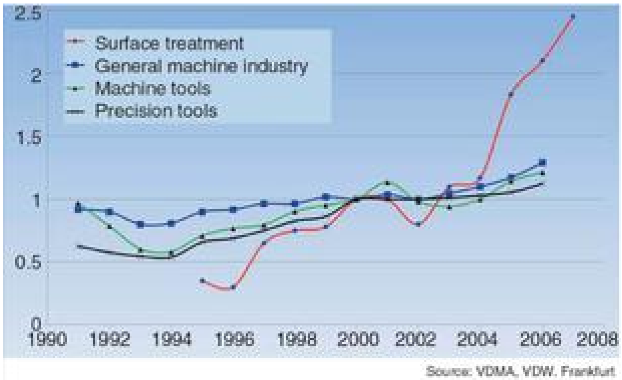

Fig. 1. Growth of production in the German machine industry

Compared to the statistical base year 2000 the growth is 21 per cent for machine manufacturers and 17 per cent for tool manufacturers respectively. The surface treatment industry has shown an increase of 110 per cent with the majority realised by thin film coating technologies, 72 per cent in Europe and 54 per cent in the USA.

Coating technology for cutting tools has developed rapidly (*Figure 2*). In 1980, only the TiN coating and until 1988 only TiCN and CrN were used. In 2000 14 standard coatings were available.

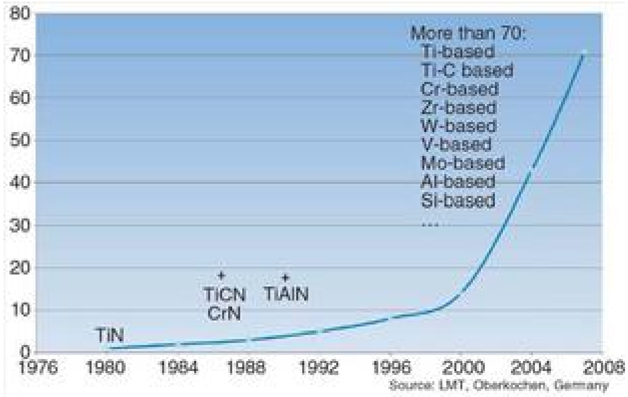

Fig. 2. Standard coatings developed in the last three decades

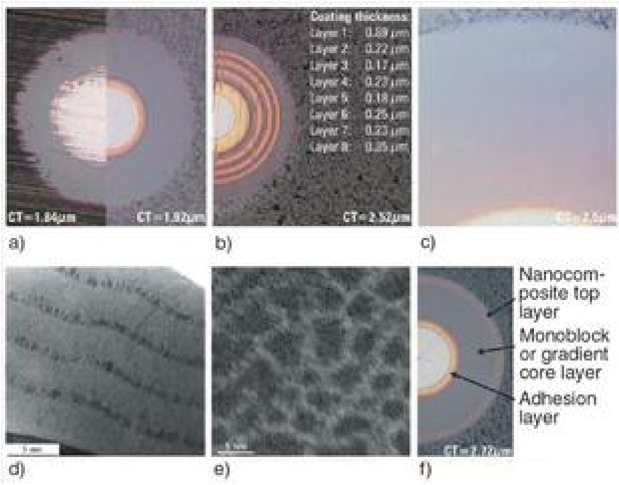

Fig. 3. Micro and nano-structures of PVD coatings for cutting tools: a) monoblock structure without and with adhesion layer; b) multilayer structure; c) gradient structure; d) nanolayer structure; e) nanocomposite structure; f) triple structure

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Considering the different stoichiometries and structures (*Figure 3*), it can be seen that several hundred different coatings are now available. In the case of coatings with different chemical compositions, there are 70 or so different coatings on the market.

2. Coating materials in today's PVD coatings

Figure 4 summarises the most important material components and their influence on the features of the coatings. Carbon strengthens the lattices of the basic coating TiN, increases the internal stress level and therefore the hardness, reduces the friction coefficient, but only up to 400°C. The TiCN coating is still the most popular coating for taps but is not adequate for dry and high-speed cutting.

Due to the excellent heat insulation between chips and tools, the TiAlN or AlTiN coatings are the most used coatings for modern high performance cutting. The latter is used when Al content is higher than 50 per cent. The market share of these coatings for cutting tools is around 40 per cent. However, with aluminium content in excess of 65–70 per cent the coatings lose hardness and wear resistance [1, 2]. Therefore other add-on materials had to be found to improve the performance of coatings.

The most important advantage of the Cr-doped coatings is their high resistance to abrasive wear. The high toughness and E-modulus is necessary for the Cr-doped HSS tools. The heat resistance is increased by Cr also but less than acceptable [3]. The depositing and use of Cr-doped coatings results in dangers for health and the environment. Vapour containing Cr can damage the human respiratory system. Additionally, the stripping of Cr-doped coating results in the generation of Cr6, which can cause skin cancer [4].

The excellent heat resistance and insulation of silicon is widely known. Coatings that contain Si as an alloying element in the metallic phase are sufficient for high speed cutting applications [5]. With the help of appropriate technology [6, 7] silicon also offers the possibility to create nanocomposites [8]. The nanocrystalline TiAlN-, AlCrN- or AlTiCrN-grains are embedded into the amorphous silicon nitride matrix (*Figure 3e*), which prevents grain growth and keeps the hardness level high, in excess of 50 GPa.

3. The aim of TripleCoatings$^{3®}$

When providing sufficient doping the 'dedicated' coating can be adapted to special applications and is able to greatly increase the coating performance in comparison to the universal coatings. In spite of these advantages many users would prefer the reduction of the current wide variety of coatings to a single universal all round coating. This is impossible, but the common use of the advantages of the most important add-on components (Ti, Al, Cr, Si) can work towards the development of a universal coating. This concept has led to the development of TripleCoatings$^{3®}$ [9].

The combination of the most important add-on materials (Ti, Cr, Al) brings relevant advantages in comparison to conventional coatings with only 2 metallic elements (*Figures 5, 6*) in increased tool life and consistency, as shown by the low scatter in *Figure 7*.

This important development has become possible with

Coating	+ Component	Grain fineness	Decreasing Internal stress	Hardness	Wear resistance (abrasive)	Wear resistance (oxidation)	Hot hardness	Heat insulation	Max. operating temperature	Possibility of thickness increase	Decreasing friction	Possibility of nanocomposites	Low target costs with alloyed targets	Low target costs with unalloyed targets LARC
Ti + N → basic coating: TiN	+ N	0	–	+	+	+	0	0	0	–	0	no	0	0
TiCN	+ C	0	– –	+ +	+ +	–	–	– –	–	– –	+ +	no	0	0
Typically TiAlCN with Al ~20–25%	+ Al	(+)	+	–	–	+	+	+	+	+	–	no	– –	0
Typically TiAlN	+ Al (– C)	+	–	+ if Al < X% – if Al > X%	+	+	+	+ +	+	–	–	no	–	+
Typocally AlTiCrN	+ Cr	–	+	+	+	+	+	+	(+)	+	–	no	– –	(–)
Typically AlCrN Cr ~30%	+ Cr (– Ti)	– –	+	(+)	+ +	(+)	+	+	(+)	+	(–)	no	– –	–
Typically TiAlN/SiN CrAlN/SiN or AlCrTiN/SiN	+ Si	+ +	(+)	+ +	+	+ +	+ +	+ +	+ +	0	0	yes	– –	+

+ means mainly positive change from the user's point of view
– means mainly negative change from user's point of view
+ or – changes in comparison to the coating in the row over X is probably around 65%

Fig. 4. Influence of the mostly used PVD coating materials and their features

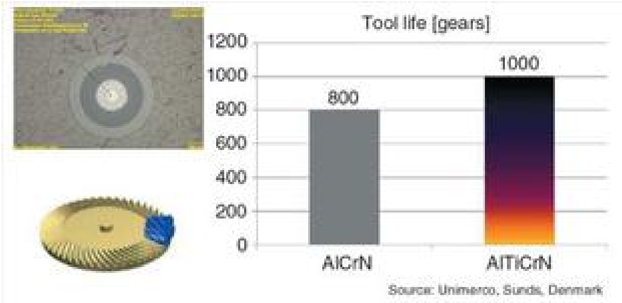


Fig. 5. Planetary gear cutting using AlTiCrN coated tool: material 212M, width of workpiece 63 mm, tools HSS, ø95×150 mm, roughing: $v_c = 120$ m/min, $f = 2.0$ mm, finishing: $v_c = 140$ m/min, $f = 1.5$ mm, criterion of tool life is 200 gears without profile failure with very tight tolerances.

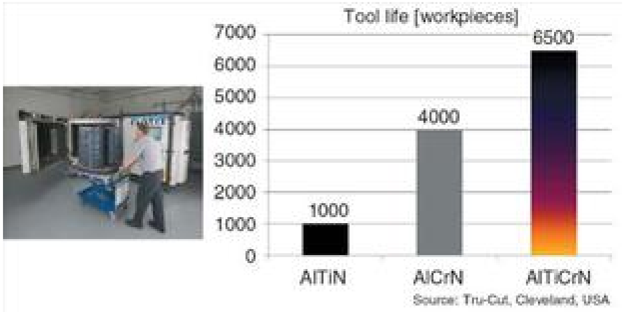


Fig. 6. Sawing with AlTiCrN coated tool: material, steel plates 4140, H13, S7, D2, A2, tools; carbide tipped saw blades 22"×70", $n = 42$/min, $v_c = 242$ m/min, emulsion.

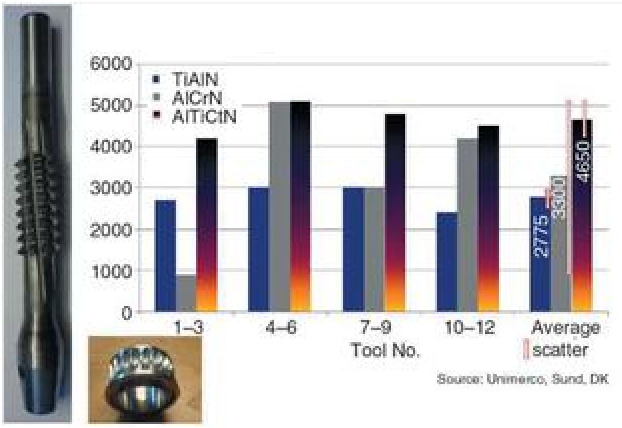


Fig. 7. Hobbing with AlTiCrN coated tool: material, 34CrNiMo6 (1.6582), $v_c = 45$ m/min, $f = 0.12$ mm, $n = 500$/min, cutting fluid, oil,

TripleCoatings3®, which also contain nanocomposite layers. Optimum adhesion can not be achieved by applying multi-component adhesion layers deposited from an alloy (e.g. TiAl or AlCr or TiSi) target. For optimum adhesion a 'start' layer of Ti-TiN or Cr-CrN should be applied.

TripleCoatings3® should be at least as universally used as the current generally used TiAlN-AlTiN with AlTiN as the core layer. The requirement of universality indicates that TripleCoatings3® should also be used as high performance coatings, which is provided by the nanocomposite top layer.

4. The structure of TripleCoatings3®

TripleCoatings3® can be preferentially deposited by the LARC-CERC-Technology [6, 10] working with rotating, mostly non alloyed targets (*Figure 8*). The basic configuration of the- coating unit π300 [9, 10] works with 3+1 cathodes. The three LARC®-cathodes (LAteral Rotating Cathodes) are located in the door of the vacuum chamber and the CERC®-cathode (CEntral Rotating Cathode) is in the centre of the vacuum chamber. The structure (mono, multi, gradient) and stoichiometry (material composition) of the coating are freely programmable.

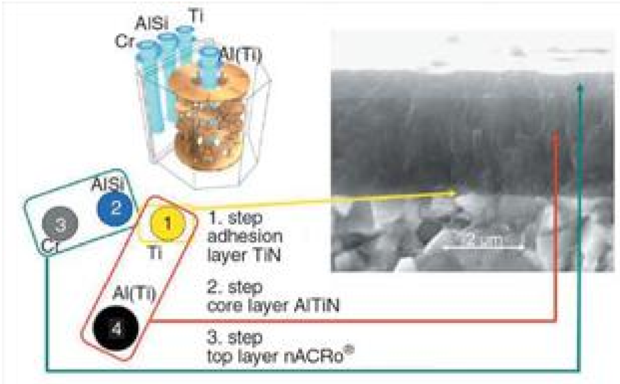
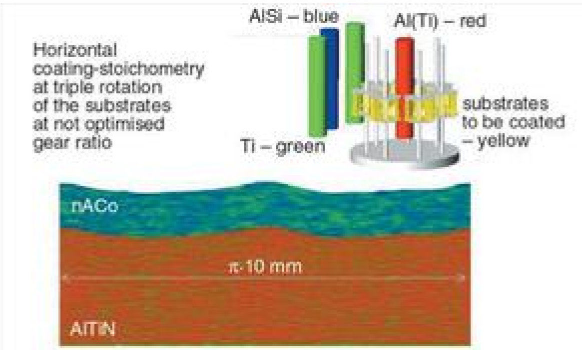


Fig. 8. Deposition of TripleCoatings3®-nACRo3® using the universal cathode configuration of the coating unit π300

The cathodes are linear and longer than the carousel holders of the substrates. Due to this design the coating thickness distribution is constant with very low scatter. The thin (~200 nm) adhesion layer is deposited from a pure Ti (or Cr) cathode. The tough core layer (TiAlN-AlTiN) is produced from the centre (Al(Ti)) and from the Ti-cathode on the side. The hard skin with high abrasive wear resistance is a CrAlN/SiN top coating (nACRo® [11]) in this example. It is extremely hard due to the nanocomposite structure and the high heat resistance of silicon.

5. Computer simulation for the design of coating stoichiometry

Computer simulation is and widely used for the design of machine tools and of cutting processes. Computer simulation can be an important aid in the design of the coating process regarding stoichiometry and elements to be used for the substrates. The simulation results of the deposition of nACo3® (*Figures 9–13*) gives the information before the process is started and any deposit is made.



coating	Al(Ti)-CERC	Ti-LARC-1	AlSi-LARC-2	Ti-LARC-1	axis	process time min	coating thickness µm	deposition rate µm/h
nACo		75	150	75	7×18	30	0.729	1.458
AlTiN	300	75		75	7×18	80	2.922	2.192
					Total	110	3.651	1.991

Fig. 9. Illustration of gear ratio problem of the substrate holder by simulating the deposition of TripleCoatings3®-nACo3®

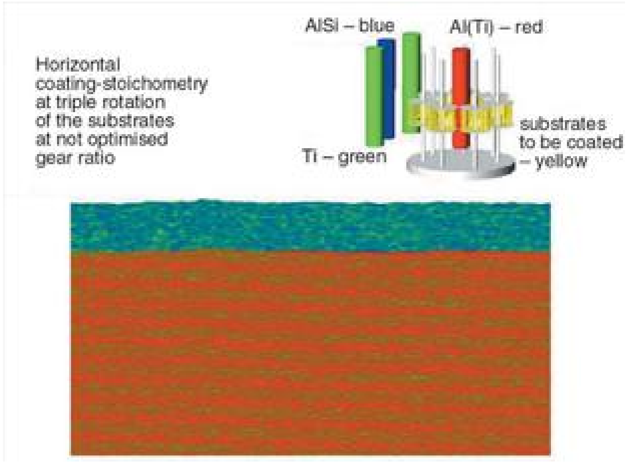


Fig. 10. Illustration of gear ratio problem (floating) of the substrate holder by simulating the deposition of TripleCoatings3®-nACo3®

There is an unusual and uneven horizontal thickness distribution around of the circumference of the tool, if a certain gear ratio of the substrate holders is chosen (*Figure 9*). A variation of the coating stoichiometry results in the creation of an unwanted 'multilayered' structure (*Figure 10*).

Optimisation of the gear ratios almost totally eliminates the occurrence of unevenness (*Figure 11*) without building expensive holders, privision of coating and conducting experiments.

The deposition rate for the substrates with triple rotation (e.g. shank tools) is 45 per

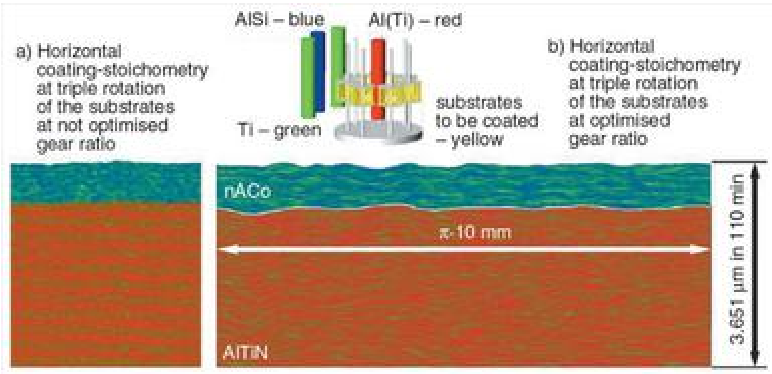
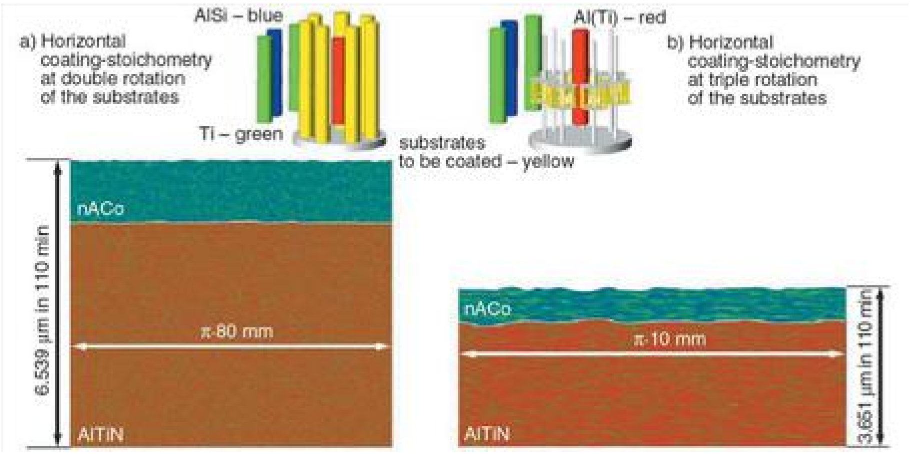


Fig. 11. Optimisation of the substrate holder gear ratio by simulating the deposition of TripleCoatings3®-nACo3®



coating	Al(Ti)-CERC	Ti-LARC-1	AlSi-LARC-2	Ti-LARC-1	axis	process time min	coating thickness µm	deposition rate µm/h
nACo		75	150	75	7×18	30	1.438	2.837
AlTiN	300	75		75	7×18	80	5.101	3.826
					Total	110	6.539	3.567

coating	Al(Ti)-CERC	Ti-LARC-1	AlSi-LARC-2	Ti-LARC-1	axis	process time min	coating thickness µm	deposition rate µm/h
nACo		75	150	75	7×18	30	0.729	1.458
AlTiN	300	75		75	7×18	80	2.922	2.192
					Total	110	3.651	1.991

Fig. 12. Comparison of thickness rates by simulating the deposition of TripleCoatings3®-nACo3®

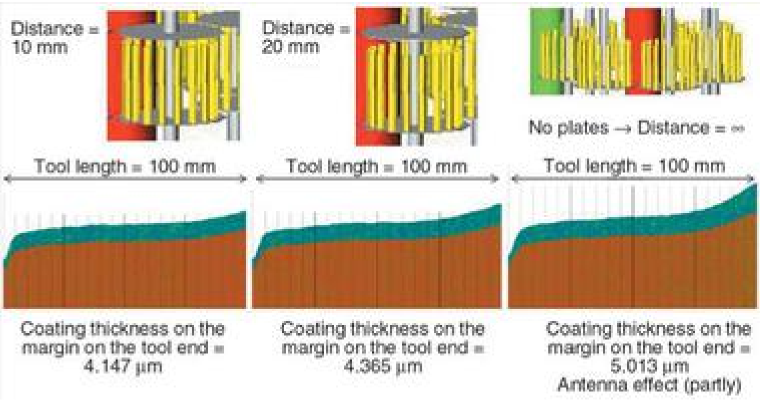


Fig. 13. The simulation of vertical deposition of TripleCoatings3®-nACo3® – Influence of the distance between tool top and cover plate

cent lower than that of the parts with triple rotation, e.g. hobs (*Figure 12*). The reason of this is the higher surface areas and the shadowing effect.

The simulation of the vertical coating distribution gives important information for the charging (loading) of the tools in the coating chamber (*Figure 13*). The excessive distance between the top end of the tool and the cover sheet increases the thickness of the margin of the tool and enforces the antenna effect.

The simulation of the vertical coating thickness distribution for a whole chamber (*Figure 14*) was used to design the position of the cathodes in a new (π313) machine (*Figure 15*).

6. The performance of TripleCoatings3® in industry

6.1. Turning

At traditional (low) cutting speeds the TripleCoatings3® nACo® shows similar results to the different versions of the AlTi-based coatings (*Figure 16*). At higher cutting speeds the traditional TiAl-based coatings are no longer usable. The TripleCoatings3® nACo3® shows an excellent results that outperforms the widely used CVD coating, even with Al_2O_3 layer (*Figure 17*).

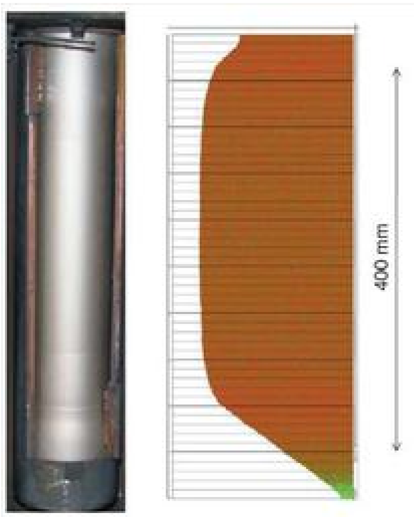


Fig. 14. The simulation of vertical deposition

Fig. 15. Outline of TripleCoatings3® machine

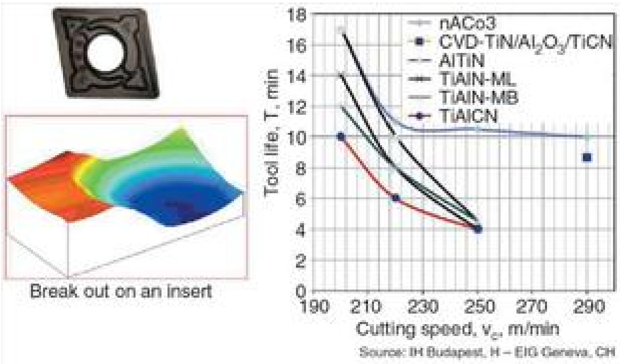


Fig. 16. Dry turning with nACo3®, material: C60 – 1.1221 – HB225, insert CNMG, a_p = 1.5 mm, f = 0.25 mm

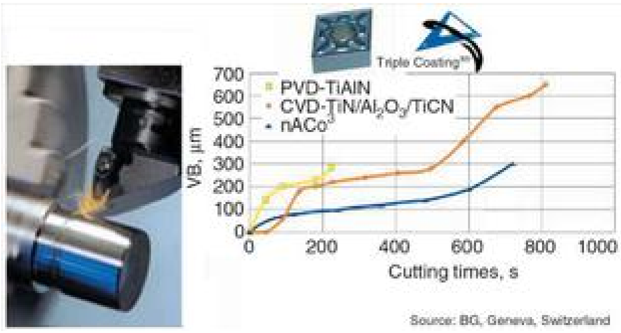


Fig. 17. Dry turning with nACo3® versus CVD coating, material: stainless steel AlSL 316L, inserts: Sandvik CNMG 12 04 08, v_c = 290 m/min, a_p = 0.8 mm, f = 0.24 mm, dry cutting, tool life criteria: $VB_{max} \leq 30$ µm, $KT_{max} \leq 130$ µm, N8 ($R_a < 3.2$ µm, $R_z < 12.5$ µm)

6.2. Milling

Cutting inserts with Cr-based coating are successful for milling (*Figure 18*) [13], because milling-cutter inserts are practically never de-coated, the possible disadvantages of Cr-based coating is insignificant. In *Figure 18* TripleCoatings[3®] became a 'quadro' coating, where the TiN top layer was necessary to add to meet the need to hide, unify and standardise the real coating colour. The widest range of different coating can be considered for end mills. It is a challenge for TripleCoatings[3®] to compete against the best coatings of the market leaders (AlCrN [14] and TiSiN [15]) but as *Figure 19* shows it is possible.

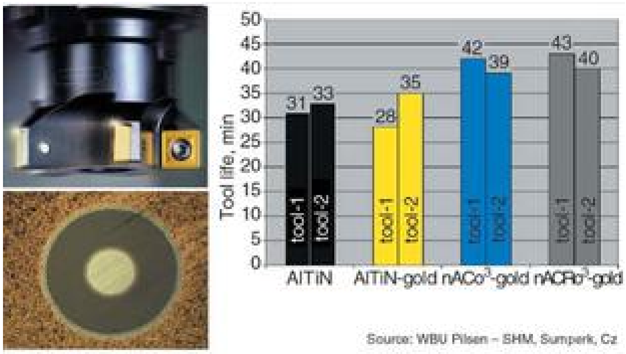


Fig. 18. Dry milling with inserts with nACo[3®] and nACRo[3®]: nACo[3]-gold = TiN + AlTiN + TiAlN/SiN + TiN, nACRo[3]-gold = CrN + AlTiN + CrAlN/SiN + TiN, insert: SPKN 1203 EDSR, material: Ck45, v_c = 276 m/min, a_p = 2 mm, f_z = 0.244 mm, a_e = 100 mm

6.3. Drilling

Drilling is the most successful field of application for TripleCoatings[3®] (*Figure 20*) [7]. There are clear advantages when compared with TiAlN, AlTiN, AlCrN and AlCrN/TiSiN. The triple structure makes greater thickness possible, which is extremely useful for drilling. Furthermore the low scatter of the results improves the reliability of the production.

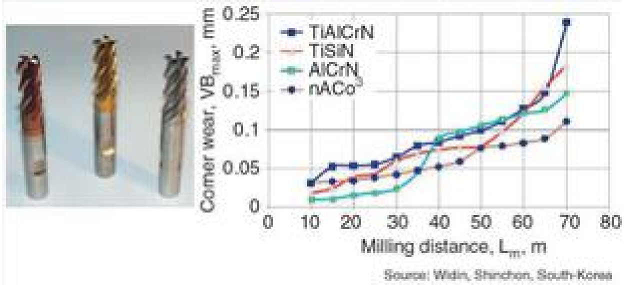


Fig. 19. Milling with nACo[3®] in heat treated steel, material: STC3 – HRC45, solid carbide end mills, d = 10 mm, v_c = 141 m/min, f = 0.18 mm.

6.4. Hobbing

Hobbing is probably the most difficult cutting process for coatings. The edge preparation of the hob, including deburring, edge rounding and teeth honing is very difficult due to the complex geometry and must be carried out consistently, [16, 17]. The large mass of hobs must be heated up fast and homogenously. The coat thickness must be the same on the top of the teeth and in the depth of the flutes. The most expensive hobs are normally re-ground, re-coated and re-used up to 15 times. Therefore de-coating is essential for hobs. To master the coating process the coaters must make simultaneous use of all advantages of all important coating components (Ti, Al, Cr, Si). However, as *Figure 21* shows, very good results can be obtained.

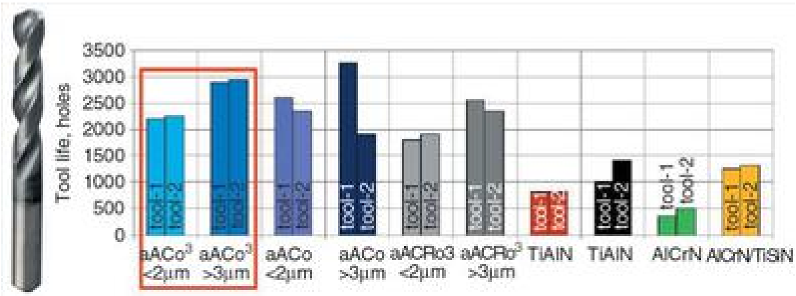


Fig. 20. Drilling with nACo[3®] in high alloyed steel, material: X155CrVMo12-1 – 1.2379, solid carbide drill, d = 5.2 mm, a_p = 15 mm, v_c = 74.5 m/min, f = 0.15 mm, internal cutting fluid, emulsion 7% – 30 bar

7. Summary

The new generation of PVD coatings TripleCoatings[3®] uses the advantages of conventional (TiN, CrN, TiAlN, AlTiN) and nanocomposite coatings (nc-TiAlN/a-SiN, nc-AlCrN/a-SiN, nc-AlTiCrN/a-SiN). TripleCoatings[3®] are applicable for general purposes but they achieve the best results in high-performance machining. The coating takes place in coating units using LARC®- and CERC®-Technology.

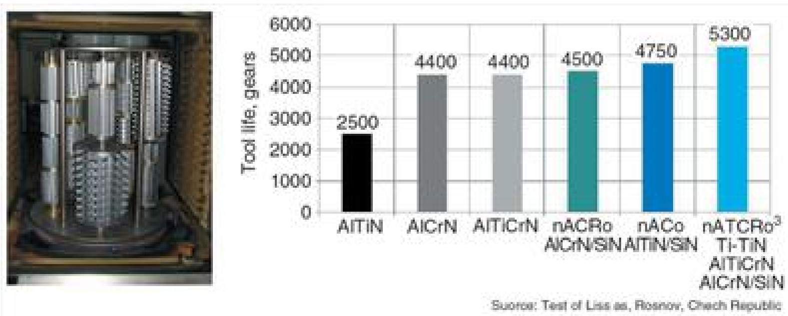


Fig. 21. Dry hobbing with nATCRo[3®], material: 100Cr6 – 800–900 N/mm², tools: HSS-PM4, module = 2.5, v_c = 150 m/min

The TripleCoatings^{3}® were introduced in the spring of 2007 and are widely being used extensively in the manufacturing industry all over the world.

References

[1] Paldey, S. et al.: Single and Multilayer Wear Resistant Coating of (Ti,Al)N; A Review Material Science and Engineering, Elsevier B.V., New York, A342/2003.

[2] Cselle, T.: Application of Coatings for Tooling – Quo Vadis 2005? VIP Vacuum's Best, Wiley, Weinheim, 2005

[3] Willmann, H. et al.: Thermal Stability and Age Hardening of Supersaturated AlCrN Hard Coatings – Heat Treatment and Surface Engineering, IHTSE Maney, London, 1/2007.

[4] Occupational Exposure to Hexavalent Chromium US-Occupational Safety & Health Administration Federal Register: Volume 71, Number 39, Rules and Regulations – 10099–10385, February 28, 2006.

[5] Tanaka, Y. et al.: Structure and Properties of Al–Ti–Si–N Coatings, Surface & Coatings Technology, Elsevier, 146–147, 21, 2001.

[6] Cselle, T. et al.: LARC: New Coating Technology for Industrial Use, Swiss Quality Production, Hanser, Zurich, May, 2003.

[7] Morstein, M. et al.: Rotating ARC PVD Cathodes – Five Years of Dependable High Performance ICTCMF, G7-6, San Diego, April, 2007.

[8] Veprek, S. et al.: Different Approaches to Superhard Coatings and Nanocomposites, Thin Solid Films, Elsevier, Amsterdam, 476, 1–29, 2005.

[9] TripleCoatings^{3}®, www.platit.com

[10] Cselle, T. et al.: 3+1 Cathodes – 30 Coatings – 300 Batches without Target Exchange, Swiss Quality Production, Hanser, Zürich, 8, 2007.

[11] Karvankova, P. et al.: Thermal Stability of nc-CrN/a-SiN Coatings, Material Research Society, Fall meeting, Boston, 2005.

[12] Jilek, M. et al.: New Machine Concept for TripleCoatings^{3}®, ICTCMF, G7-2-905, San Diego, April, 2008.

[13] Holubar, P.: Large-Scale Industrial Applications of Superhard Nanocomposites and Development of Advanced Coating Technology, Nanocoatings, Budapest, April, 2008.

[14] BALINIT® ALCRONA makes your tools fit for the ultimate in performance, www.oerlikonbalzerscoating.com

[15] Ishikawa, T. et al.: TiSiN based Ultra-hard Coating Materials, Hitachi Metals Technical Review, Tokyo, 59–64, 21, 2005.

[16] Cselle, T. et al.: Influence of Edge Preparation on the Performance of Coated Cutting Tools – ICMCTF, Invited lecture, San Diego, April, 2007.

[17] Lümkemann, A. et al.: Using the Full Potential of Nanocomposite Coatings on High Performance Tools – ICTCMF, San Diego, GP-11, April, 2008.