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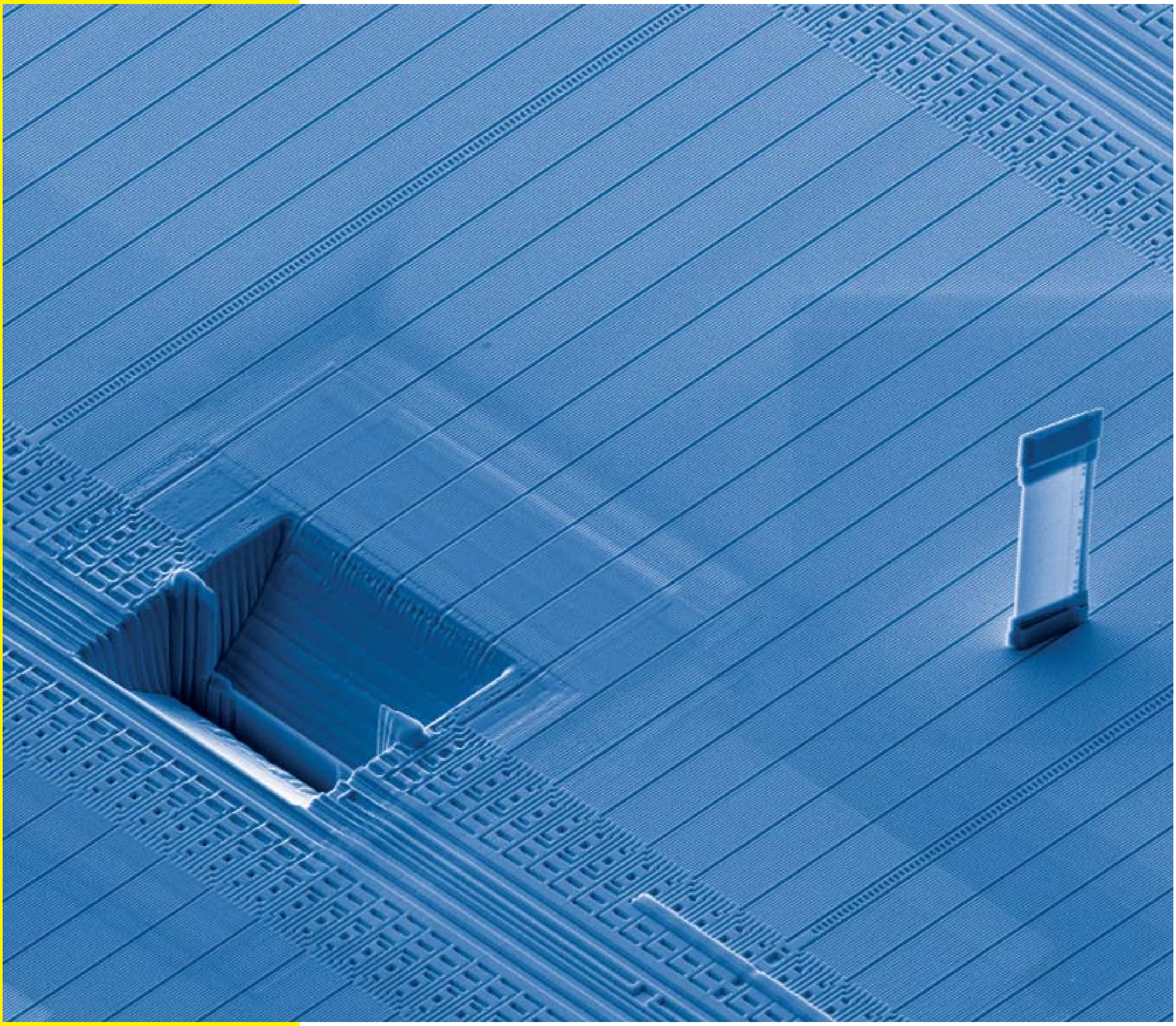

- Dry Vacuum Pumps
- Coatings
- Surface Radicals on Polymers
- Nanotechnology

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Application of Coatings for Tooling Quo Vadis 2005?

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Abstract

Every third patent registration in the area of cutting tools submits a principal claim concerning coating technology. But it is not only because of this that coating is one of the most important driving forces for the future of manufacturing engineering. It represents a major influence on tool performance and is improving it with giant steps [1], [14].

The following paper will not present the current state of today's coating-industry in the form of the common reviews. It is a short composition of important questions, problems and news in the practice of coating. Therefore the stressed-out user should find the time for answers to some of his important questions.

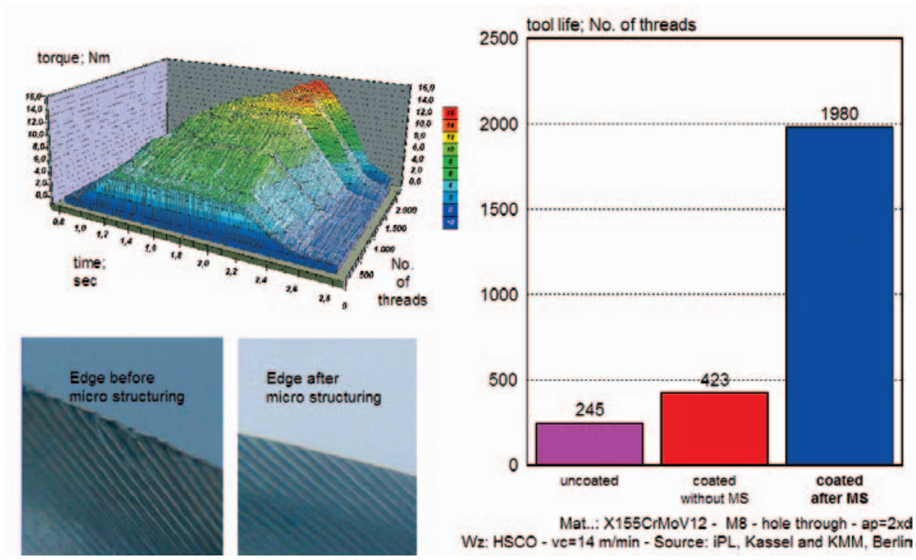

Fig. 1:
Tapping without and with Micro Structuring (MS) for Coating

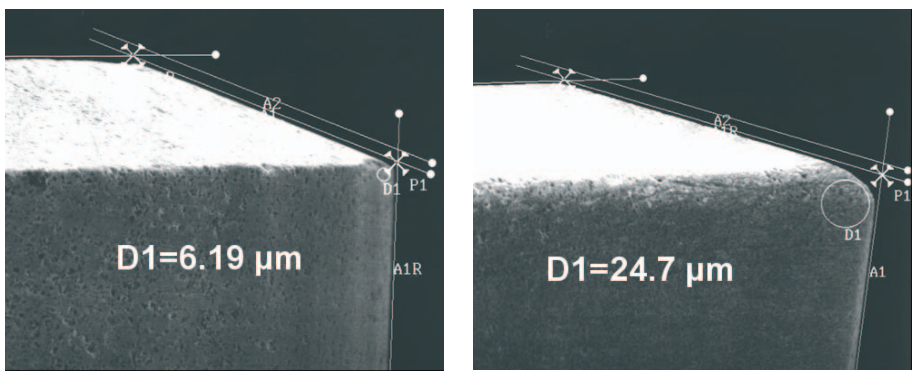

Fig. 2:
Micro Structuring of High Precision Tools. left: before Micro Structuring, right: after Micro Structuring

1 Do the cutting edges of precision tools need special pre-treatment before coating?

For HSS tools, even simple de-burring is of major importance (figure 1).

If coated without prior de-burring, the coated burr breaks on the first cut and the tool edge continues its work uncoated. This procedure yields only insignificantly better results.

If the sharp cutting edges made of carbide, cermet, ceramics and CBN (figure 2), which are often charged with small chips and gears, are not well micro structured, big outbursts of complete cutting parts are inevitable.

The prevailing opinion is that most of those cutting edges should be rounded with a defined small radius. Consequently, these tools will also be able to "bite" at fine finishing without outbursts.

The table in figure 3 summarizes the common micro structuring methods and their characteristics.

In addition to the micro structuring of cutting edges, some of these methods are also suitable for surface processing of cutting edge areas and flutes. For example, numerous well-known toolmakers brush or polish their high-performance thread formers both before and after the coating process:

Before coating irregularities in the flutes

Criteria / Features	Honing by Hand by Diamond File	Brushing	Polishing in walnut granulate with diamond paste	Micro blasting	Water beam	Treatment in magnetic powder
Quality	Best	Middle	Good	Middle	Good	Good
Constancy	Depending on person	Good	Good	Middle	Good	Good
Flexibility	Very high	Middle	Low	Low	Middle	Good
Productivity	Low	Middle	Middle	Good	High	Middle
Price	Only salary	Middle, standard machines available	Middle, standard machines available	Middle, standard machines available	Very high	High especially at automatic operation
Special features	Typical for small regrinders	Commonly used for end mills, difficult for taps	Also for flute polishing droplet removing difficult for small Ø	Also for flute polishing droplet removing dry and wet blasting	Only for large scale production, corrosion protection neccessary	Also for flute polishing droplet removing demagnetizing neccessary

Fig. 3:
Important Methodes for Micro Structuring (MS) for Coating

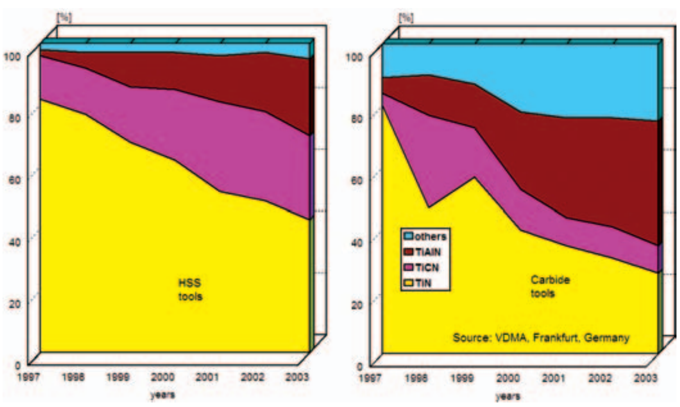

Fig. 4:
Marketshares of Coating on HSS and Carbide Tools

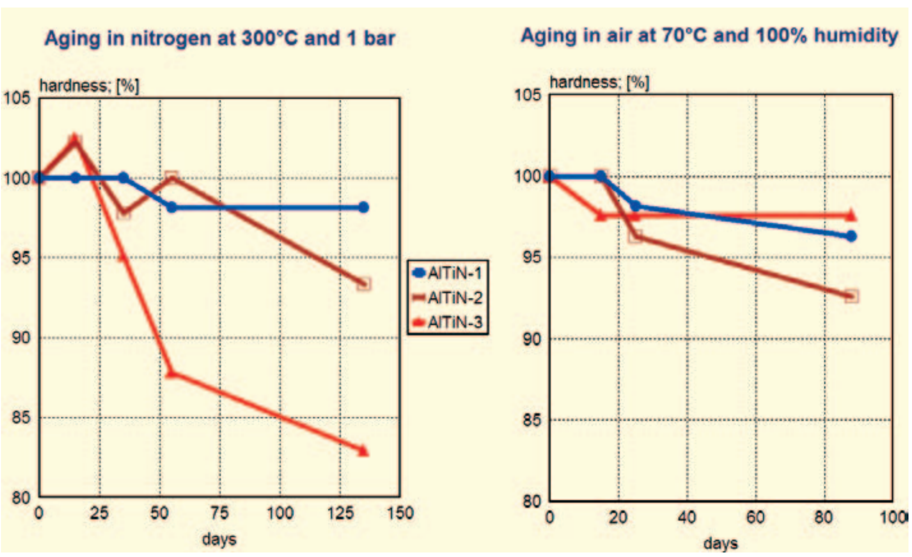

Fig. 5:
Hardness Change of aging of AlTiN-Coatings. left: aging in nitrogen at 300 °C and 1 bar; right: aging in air at 70 °C and 100 % humidity

and cutting edge areas that resulted from grinding are balanced. This allows them to sustain more pressure by the thread former. The former edges become uniformly rounder, which is an advantage for the non-cutting procedure.
After coating, droplets are removed, contributing to the better plastic flow of the formed work piece material.

2 Do AlTiN coatings lose hardness during storage?

Over the last few years, (Ti, Al) N-based coatings have achieved an increasingly larger market share (figure 4).
Logically, the gains are higher for carbide than HSS tools, because high strength is far more important at high temperatures and high cutting parameters.
In 2000 a publication from Japan [10] raised the suspicion that (Ti, Al) N-coatings would lose their hardness and strength even without outer impact at room temperature. The suspicion was not confirmed clearly, but doubts remained (figure 5).

3 How can we break through the limits of AlTiN-coatings?

It is a fact that the physical properties of AlTiN-coatings suddenly drop at an excessive elevation of the aluminum content (over about 70%, figure 6).
These physical limits can be overcome by

▷ Adding more warm-resistant alloy elements, such as chromium, yttrium, silicon, creating AlCrN, TiAlYN, TiAlSiN-coatings or

▷ By nanocomposite-structures, such as (TiN)/ (Si_3N_4), (TiAlN)/ (Si_3N_4) or (AlCrN)/ (Si_3N_4).

4 Will today's TiAlN-coatings be replaced by Ti-free coatings?

When it is not possible to increase the heat strength by adding more aluminum in a TiAlN-coating, another metal instead of titanium with a higher oxidation-resistance (like chromium) should be used. This is how AlCrN-coatings are created (figure 7 [2], [7], [11]).
Of course there are advantages and disadvantages:
Advantages:

▷ Chromium is more heat resistant than titanium.

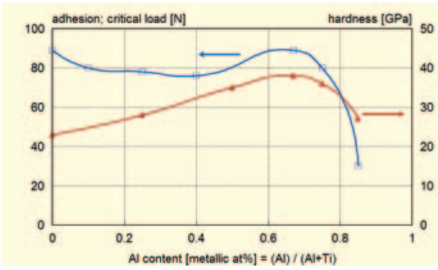

Fig. 6:
Features of (Ti,Al)-based Coatings Depending on Al-Contents

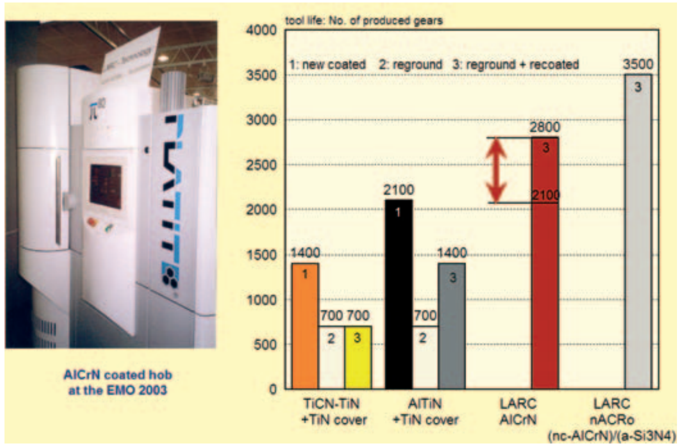

Fig. 7:
Application of AlCrN and (nc-AlCrN)/(a-SI_3N_4) for Hobs

▷ Cr based coatings normally have even better adhesion than Ti-based ones.
▷ With AlCrN, coating thickness can be higher than with AlTiN.
Disadvantages:
▷ The Cr-targets are much more expensive (up to 8 times) than Ti-targets
▷ With the same Al-content, AlCrN coatings are softer than AlTiN coatings
▷ Today, CrN can hardly be de-coated from carbides

A genuinely new alternative for the breakthrough of physical limits with AlTiN-coatings are nanocomposite coatings, which are more heat-resistant than CrAlN-coatings and can be produced more economically.

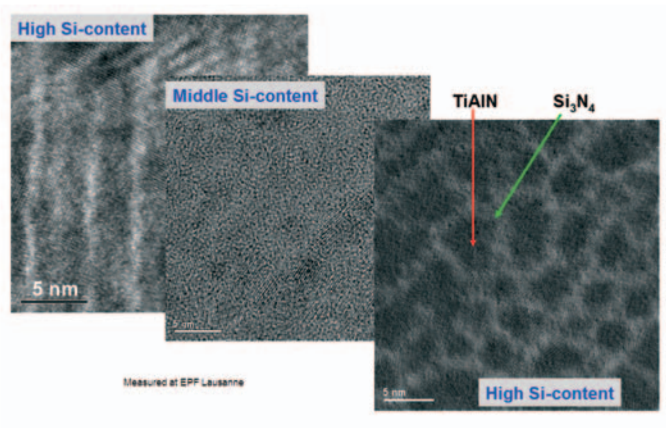

Fig. 8:
Nanocomposite Structures (nc-AlCrN)/(a-SI_3N_4) Coatings (nACO®) with different si-Content

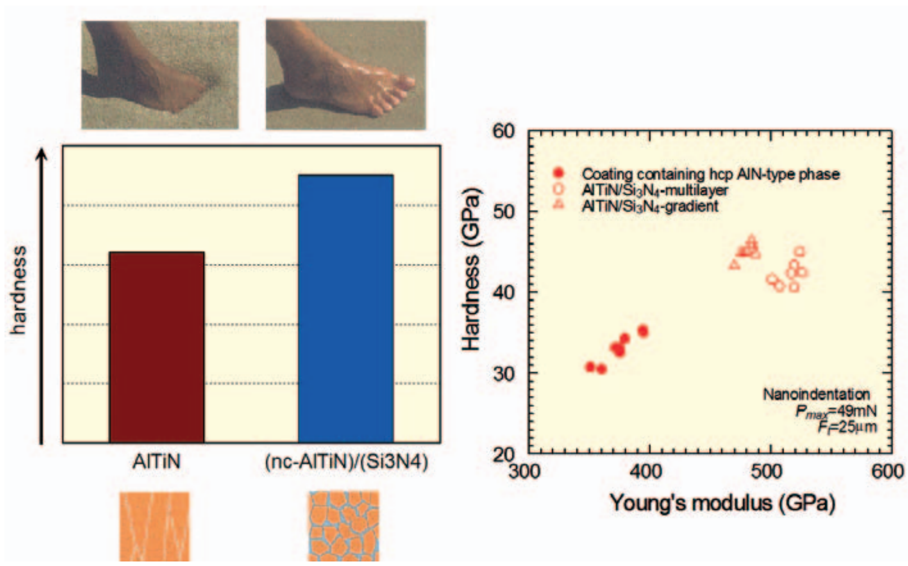

Fig. 9:
Hardness Increasing by Nanocomposite Structure

5 Why are nanocomposites the truly new kind of coatings?

By depositing very different kinds of materials, the components (like Ti, Cr, Al in the first group, and Si in the other) are not mixed completely, and 2 phases are created. The nanocrystalline TiAlN- or AlCrN-grains become embedded in an amorphous Si_3N_4-Matrix, which can best be noticed on the structure with higher silicon content (figure 8 [7]).

The beach analogy [8] of figure 9 offers a good illustration for the hardness increases made possible by nanocomposite-structures.

Usually, the foot sinks in dry sand. In wet sand, the foot does not sink or not as far, because the space between sand grains is filled with water. The surface has a higher resistance, so it is harder.

In addition to the higher hardness, nanocomposite coatings show their most important advantage in the enormous improvement of heat resistance. The spinodale segregation and the resulting loss of hardness tend to appear much later than with non-nanocomposites (figure 10 [12]):
▷ At about 200 – 300 °C later than with AlTiN-coatings and
▷ At about 100°C later than with AlCrN.

There are even indications that the hardness loss at 1200°C is caused by the cobalt diffusion of the carbide and not by the nanocomposite coating.

Thanks to the high hardness, the enormous heat-resistance and the toughness of the silicon "binder", coatings with a nanocomposite structure can stand their ground not only against PVD-coatings, but even against thick CVD-coatings (figure 11).

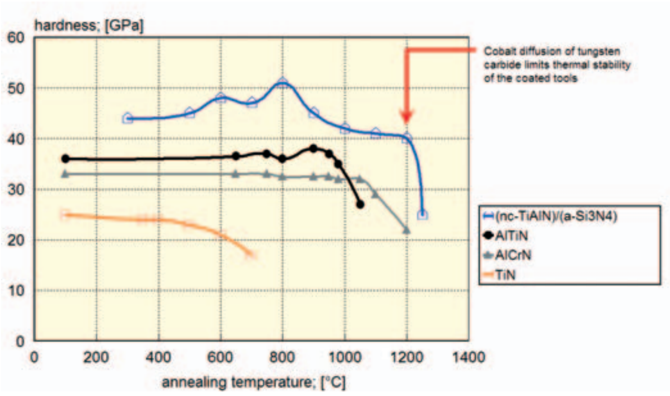

Fig. 10: Nanocomposite Structure shifts Spinodal Segregation to higher Temperatures

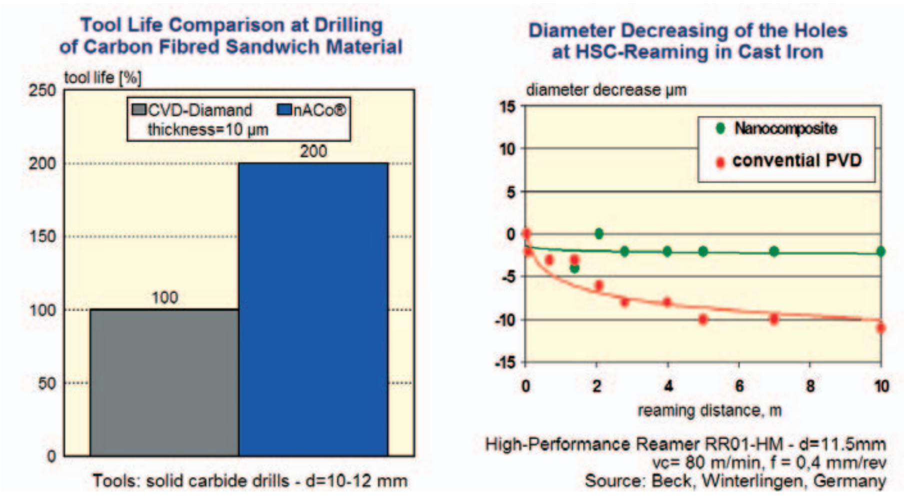

Fig. 11:
Nanocomposites in Comparsion with Conventional CVD- and PVD-Coatings; left: Tool life Comparsion Drilling of Carbon Fibred Sandwich Material; right: Diameter Degreasing of the Holes at HSC-Reaming in Cast Iron

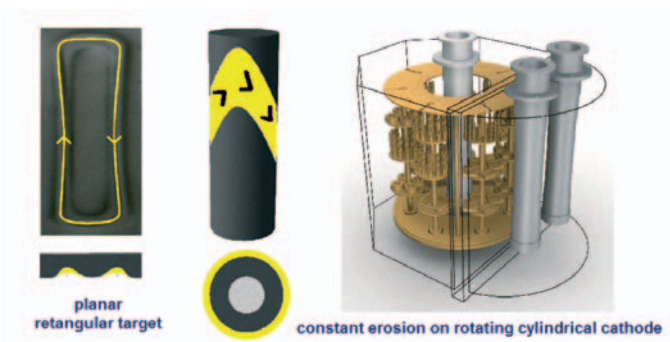

Fig. 12: ARC-Guiding and Target Erosion with Planar and Rotating Cylindrical Cathodes

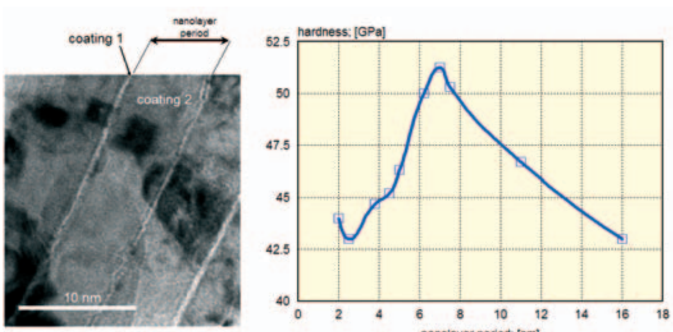

Fig. 13: Hardness of Nanocomposite (nc-TiAlN)/(a-SI_3N_4) with Nanolayer Structure

6 How can nanocomposites be deposited in an industrial and economical way?

▷ To avoid expensive alloyed targets (TiAl, AlCr) and to make segregation possible, much cheaper and "pure" cathodes (Ti, Cr, Al, AlSi) have to be installable next to each other.

▷ Highly ionized plasma with a high intensive magnetic field has to be built-in

▷ This requires a fast, moveable ARC-Spot.

▷ These requirements are met by the LARC®-method. (LARC®: LAteral Rotating ARC-Cathodes; figure 12 [3], [13]).

The water-cooled cathodes rotate. The magnetic field is created by permanent magnets and coils, and is steered vertically and radially. Because of the fast relative movement, low-melting target materials (like pure Al or AlSi) can be used instead of expensive alloys (like Al25%/Ti75%, Al50%/Ti50%, Al67%/Ti33%, Cr33%/Al67% etc.). After deposition from the target, Al and Si have to be separated ("segregation"). The silicon does not enter the metallic stage; instead, the nanocrystallines (like TiAlN or AlCrN) become embedded in the amorphous matrix (like Si3N4). The fast ARC-spot permits a highly intensive magnetic field, without burning the targets. (Whereas there is a high danger for planar targets.) The originating nanocomposite structure shows small crystalline sizes, no "gaps" between the nanocrystallines, sharp interface limits and therefore a high hardness. The generated comb structure stops cracks at grain boarders [7].

The constant erosion all around makes optimum use of the target material. Depending on the thicknesses and on the structures (mono-, gradient-, nano- or multilayer) of the required coatings, up to 200 batches can be deposited by one target pair. The cathodes should be longer than the coatable height, achieving an excellent coating thickness distribution in the chamber.

7 What are the most important advantages of rotating cathodes

a:
Industrial production of nanocomposites with non-alloyed, cost-effective targets.

b:
Optimal coating adhesion through VIRTUAL SHUTTER®
The magnetic field is rotated by 180° towards the back. The ARC is ignited at the back to clean the targets before the main coating process and to deposit any rough particles to the rear wall. After that, the ARC is turned towards the tools without switching off. In this way the duration of the ion etching is significantly shortened and the coating is deposited with pure metallic targets.

c:
"Wide" Targets with high durability
At equal space requirement, the rotating cylindrical cathode is π-times wider than a planar target.

d:
Smooth coatings through reduction of ARC-droplets
With rotating cathodes, the spot movement is fast and constant. It results from the addition of the target-rotation and the vertical oscillation of the wide magnetic field (figure 12). With the support of VIRTUAL SHUTTER® droplets from the beginning of the coating process are "sprayed" to the back wall, after which the fast ARC-spot movement is able to produce very smooth coatings.

e:
Ability to produce nanolayers due to the cathode pair with minimum distance, enabling exact control of the layer period (figure 13).

f:
Freely programmable coating stochiometry
With the use of non-alloyed cathodes, the ideal coating structure (figure 14) can be realized [7]:
▷ The adhesion layer is supposed to show a Young-Modulus comparable to the substrate's.
▷ The middle of the coating is supposed to build up the hardness like a spring, guarantee the suspension, and absorb cracks to make interrupted cutting possible.
▷ For the surface of the coating, the hardness, the wear resistance, and the oxidation resistance should be improved.
▷ A lubricating coating with a low friction-coefficient should prevent built-up edges.

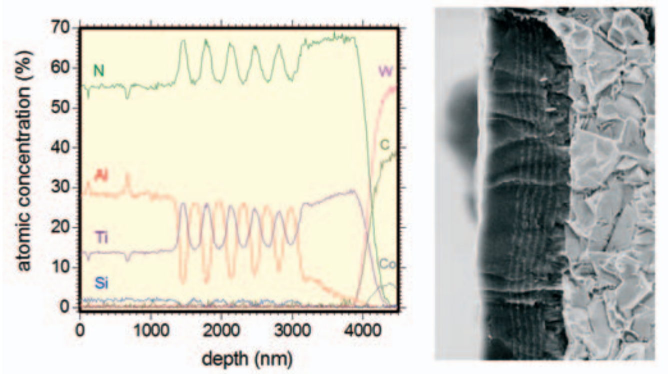

Fig. 14: Free Programable Stochiometry deposited with LARC®-Targets from Pure Ti and ALSi

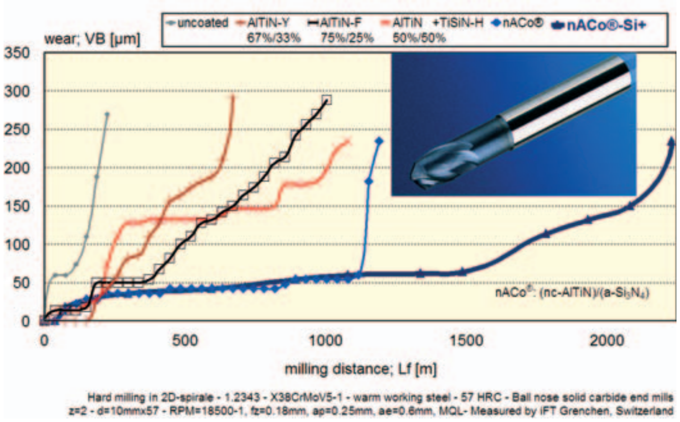

Fig. 15: Hard Milling with AlTiN- and Nanocomposite Coatings

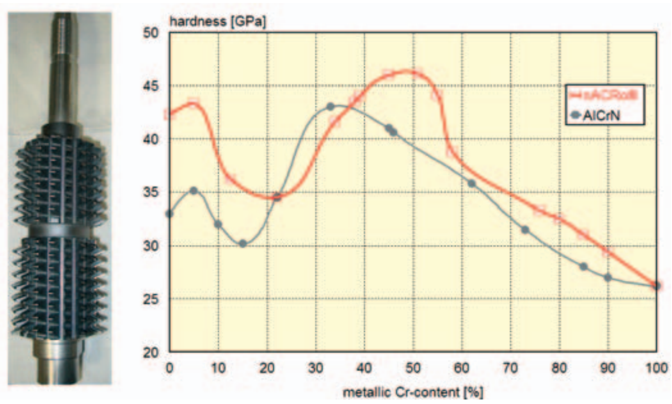

Fig. 16: Hardness of AlCr-based Coatings Depending on the Cr-Content

8 What alloy contents are optimal for nanocoatings?

At hard milling, nanocomposite coatings (TiAlN)/ (Si_3N_4) achieve clearly better results than conventional AlTiN layers at just 6% silicon. By increasing the silicon content to 10%, the tool life is increased nearly to double (fig. 15 [7], [11]).
By using pure (non-alloyed) targets, LARC® technology allows the deposition of freely programmable nanocomposite structures (currently with Ti, Al, Cr, Zr, and Si). The comparison of hardness tendencies between the nanocrystalline AlCrN and the nanocomposite (nc-AlCrN) / (a-Si_3N_4) proves again that nanocomposite structures show essential advantages against the conventional coating compositions (figure 16).

With the help of LARC®-technology, the disadvantages of the AlCrN-coating can be reduced:

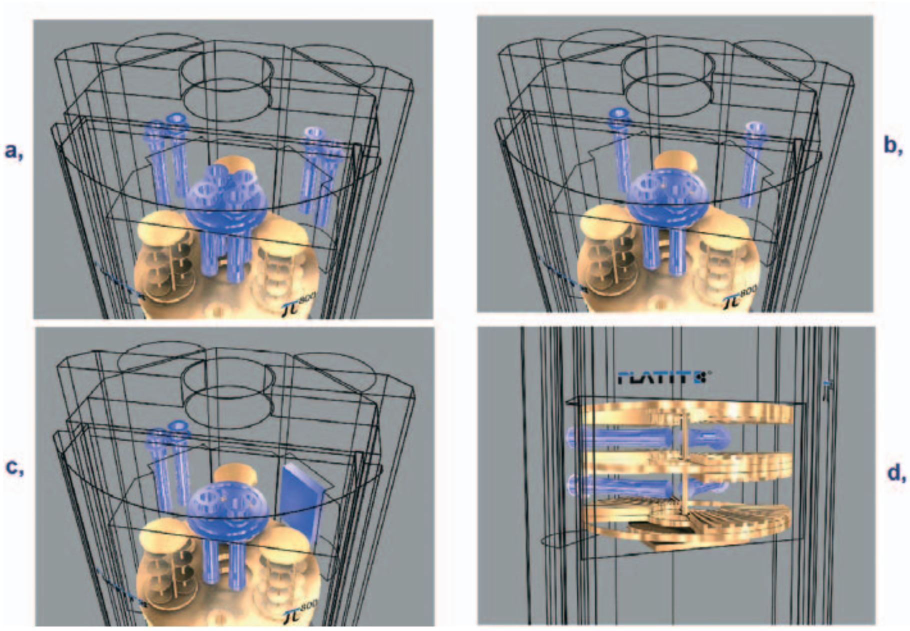

Fig. 17:
MoDeC®: Modular Dedicated Coating

The hardness is again over 40 GPa.
▷ Due to the low (5%) Cr content:
▷ the use of the expensive Cr-target can be minimized and
▷ The coating can be stripped from tungsten carbide.
▷ The deposition of thick layers (7, or even up to 10 μm) is possible with the help of the Cr content and therefore the AlCr-based coatings will be preferred for application on HSS hobs, mold and dies.

9 What is the right machine size?

Currently, “tailor-made coatings are almost exclusively produced for major clients” [2] in job coating. Therefore, modern coating units have to be constructed small enough so that this is also affordable for small and medium enterprises ("SMEs"). [14]. While this is not the only argument for small machines, it may easily be the most important:
▷ New coatings do not replace TiAlN and Co. immediately. The demand for nanostructured coatings will grow in the next couple of years, which makes it possible to use bigger machines.
▷ In smaller machines there is no need to coat completely different parts together. Smaller batches can also be performed in an economical way.
▷ Several small coating machines are not less productive than a big machine. They are much more flexible and make better delivery times possible.
▷ Once coaters have created the infrastructure for small-scale coating technology, scaling up gets much easier thanks to the rotating cathodes.
▷ The modular upgrading in width (not in height) is the correct way, because that way the same cathodes can be used modularly (figure 17):

a.
Central cathodes enhance separation by factor 3, to satisfy the requests of coating centers for an extremely productive coating of larger batches.
b.
Single cathodes at one side can take over special tasks, like deposition of a special adhesion layer or a DLC top coating. The central cathode pair produces the nanocomposite coating.
c.
In this configuration even the use of planar cathodes is suitable to produce simpler coatings.
d.
The horizontal usage possibilities show impressively the high flexibility of rotation-symmetrical cathodes. With this arrangement, it is possible to have a constant coating thickness for flat-lying parts like saw bands and forming-tools.

10 Job Coating or Integration into Own Production?

SMEs, e.g. mold and die makers, need dedicated high performance coatings for two critical production steps at least.
▷ for cutting tools (free form end mills, drills, taps etc.) to machine the hardened form pieces and
- for the moulds and dies themselves at their application for injection molding, pressing, punching, stamping.

The large coatings centers serve the SMEs more slowly than their large key costumers and normally with standard coatings only. Due to this the SMEs loose their two important advantages:
▷ the capability for fast delivery and
▷ the flexibility to offer dedicated solutions adapted to the application of the moulds even in small series.
The real solution to these handicaps for the SMEs can be the integration of the coating into their production line only.

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