Nanostructured Coatings for High Performance Tools

LARC®: LAteral Rotating ARC-Cathodes

Reprint, Werkzeug Technik, No. 77, March/2003
Nanostructured Coatings for High Performance Tools

No doubt (Ti, Al)-based PVD coatings have conquered the market of high performance cutting tools in the last years. The actual top development trends, AlTiN-coatings and nanolayers will be supplemented or even replaced by nanocomposites.

Depending on which statistics you believe, the market shares of the (Ti, Al)-based PVD-coatings for coated high performance cutting tools amount to 25-55% (Fig. 2). The reasons for that are the outstanding features of the (Ti, Al)-based coatings:

- High hardness (~25-38 GPa) at relatively low residual stress (~ -3 to -5 GPa),
- High hot hardness, resulting in low hardness lost (~ 30-40%) up to temperatures of 800°C,
- High oxidation resistance (the same oxidation rate (~ 15-20 µg/cm²) at 800°C as for TiCN at 400°C and for TiN at 550°C),
- Low heat conductivity (up to 30% lower relative heat indentation coefficient than for TiN).

The coating industry is enormously innovative. There are a huge numbers of tests and solutions even to improve these outstanding features of the (Ti, Al)-coatings [1]-[17]. E.g.:

- Combination of ARC and sputtering,
- Filtering of ARC-droplets,
- Optimization of process parameters like ARC-current, BIAS-voltage, N₂-pressure etc.,
- Optimization of the crystalline structure to avoid the columnar structure and to improve the corrosion resistance,
- Deposition of multilayers to increase coating toughness and thickness,
- Addition of alloying components, such as chromium and yttrium to increase oxidation resistance,

Fig. 1: Nanocomposites structure (nc-T₁ₓAlₓN) / (α-Si₃N₄).

Fig. 2: Market shares of Coatings on Carbide Tools.

Fig. 3: Superlattice Nanolayer (Source: Southwestern University, Chicago).
zirconium, vanadium, boron and hafnium to improve wear resistance, or silicon to increase hardness and resistance against chemical reactions. The two most important development trends for (Ti, Al)-based coatings are actually the efforts to deposit nanolayers and to increase the aluminium content.

**Nanolayers effect**

They emerge from the refinement of the multilayer technique. At certain periods, i.e. at certain thicknesses of nanolayers significant hardness increases can be achieved. The high hardness is realized through the strongly different Young modulus of the sublayer materials. In the case of the nanolayers, which practically can’t be hold constantly for job coating and the maximal meaningful aluminium content of AlTiN-coatings can only be broken by physically new solutions like the nanocomposites [3], [7], [12], [13], [14], [17].

**Nanocomposite coatings**

In nanocomposite coatings different materials (e.g. Ti, Al, and Si) are deposited. They cannot be mixed. For example two different phases are emerged in the plasma, the nanocrystalline TiAlN will be embedded into the amorphous Si₃N₄-matrix (Fig. 1). This structure enables extremely high hardness (40-50 GPa) maintained to high temperatures (up to ~1100 °C, Fig. 6 [13], [14]), even at a lower Al content (e.g. 50%). It can be extremely important for dry high performance cutting. Further improvement is possible if the nanocomposite coating is deposited with a nanolayer basic structure (Fig. 7). The nanolayer period was calculated by FFT to 35Å.

To achieve this structure it is essential to build the cathodes close to each other. This could be realized with the help of the LARC®-Technology (LATERAL Rotating ARC-Cathodes), Fig. 8.

**LARC®-Technology**

To deposit nanocomposites on an industrial and economic scale, new coating equipment have to fulfil the following basic requirements:

- The cathodes must be built in very close to each other,
- A highly ionized plasma,
- Supported by a strong magnetic field is necessary,
- This requires a very fast motion of the ARC track.

Because the technologies, we know today, fulfil only partly these require-
ments, we developed a new procedure and new coating equipment. Both together implement the new LARC-Technology. Both water-cooled cathodes are in permanent rotation. The magnetic field is generated by coils and permanent magnets controlled both, vertically and radially. The most important advantages of the LARC-technology come from the rotating cathodes and their lateral position. Therefore they are called π-advantages (Fig. 9).

**The π Advantages**

1. **Optimal adhesion due to the VIRTUAL SHUTTER®**
   Optimal adhesion is the most important criterion for good coating. The lateral arrangement of the cylindrical cathodes makes VIRTUAL SHUTTER® possible, working without sensitive mechanical elements (Fig. 10). The magnetic field is turned by 180° and the ARC is ignited from the back. Due to this procedure it is possible to clean the targets before the coating process begins - and to deposit the initially large particles (droplets) against the wall. Meanwhile the substrates can be cleaned in intensive plasma. The ARC will be turned towards the tools without being distinguished. In effect, it is possible to shorten the time of ion etching and to deposit the adhesive coating with metallic clean targets.

2. **“Wide” targets with Long Working Life**
   The most trivial advantage of the rotating cylindrical cathodes is their width. With the same space requirement they are π-times wider than planar targets. A target can serve up to 200 batches without a change.

3. **Smooth layers by reduction of the ARC-droplets**
   With conventional ARC technology, most of the droplets are created at the beginning of the process. It starts during the ignition of the ARC, when the standing spot melts the largest baths. These large droplets are deposited to the back by VIRTUAL SHUTTER®.

   The size and number of the droplets depend during the deposition among others on the speed of the ARC-spot movement. It is created, respectively guided only by magnetic control for the planar targets with steered ARC.

   The spot movement is considerably faster and more regular with rotating cathodes. It is a result of the target rotation together with the vertical oscillation of the wide magnetic field.

   With the help of the Virtual Shutter® and the rapid ARC spot movement, the LARC®-technology can produce layers with significantly lower roughness (Fig. 11).

4. **Deposition nanocomposites**
   The lateral cylindrical targets on the side require minimum space. It is thus possible that several cathodes, requiring little space, deposit coatings with different metallic components even in small compact equipment.

   Due to the fast ARC-Spot low-cost target materials can be used even with low melting points (e.g. Al or AlSi). They can replace the expensive alloyed targets (e.g. Al25%/Ti75%, Al50%/Ti50%, Al67%/Ti33%, etc.).
A target consisting of pure silicon is not conceivable due to simple, mechanical reasons. The silicon is deposited from alloyed targets (AlSi, CrSi, TiSi etc.). After the deposition from the target, Al and Si must be segregated. Silicon is not solved into metallic phase, the nanocrystalline grains (TiAlN) are embedded into an amorphous Si$_3$N$_4$-matrix. For this highly ionized plasma, a highly intensive magnetic field is necessary. A fast ARC-spot movement will permit a high intensive magnetic field without “cutting through” the targets (which is a real danger with planar targets). The emergence of the nanocomposite structure shows no “space” between the nanocrystalline grains, keeps the crystal sizes small and the interface boundaries sharp, therefore giving a high hardness. An additional advantage is the stop of crack propagation at the grain boundaries.

5. Deposition nanogratings with Programmable Stochiometry

Due to the fast ARC-spot and the use of different “pure” targets (e.g., “pure” Ti, Al or AlSi) the coating sto-chiometry (composition) is freely programmable (continuously changeable = gradient) even during the processes. At the beginning of the gradient LARC®-coating (Fig. 10), the aluminium will be deposited later to the titanium, so that an optimum adhesion coating can emerge. Afterwards, during the deposition, the Al-content is continuously increased, so that the hardness, temperature stability and oxidation resistance of the coating improve. At the end, the aluminium content can be taken back, whereas the Ti content will be increased, and a beautiful, ilt surface will arise.

6. Deposition multi- respectively nanolayers

Multilayers (Fig. 13) are gradients with periodical changes. Increasing hardness leads to higher internal (residual) stress. With the help of the multilayer structure, the internal (residual) stress can be kept at the excellent values of ~ (-3 to -4 GPa) [7].

Size of the Coating Equipment

As you can see on the pictures, the first LARC®-coating units were designed to be compact – not of the size used by large tool manufacturers. Why?

- Coating should not be a privilege of the large coating centres and tool manufacturers. Small and medium-size enterprises should be able to deposit the most modern layers in their own workshops.
- The new coatings cannot detach TiAlN & Co. immediately. At the moment, the market does not yet require volume nanocomposite coating. The need of nanostructured coatings will increase continually within the next years, making utilization of larger coating units possible.
After having mastered the technology and production of cathodes in a minimize space requirement, the up-scaling will be easier. It is important that the cathodes are installed by pairs with small intermediate distances (Fig. 8). This ensures the deposition of nanocomposites with high productivity and without expensive alloyed targets (e.g. TiAl).

In small units it is not absolutely necessary to coat totally different substrates together for economical reasons. One can separate the substrates into groups according to the sizes or application and coat them in small dedicated batches. Therefore and because of the small distance between the cathodes the optimum nanolayer period can be deposited much easier even below 10 nm (Fig. 7).

Several small coating units are not less productive than a large one. In fact they are much more flexible and provide a reliability of service.

On a side note, making small coating units results in a smaller profit for the equipment manufacturers than large ones. Seen in a long term, it has always been worthwhile.

**Development Potential of the LARC-Technology**

By introducing new equipment, technologies or coatings, the commonly presented results pretend that the new product, compared with the competition, shows the highest achievement, with higher parameters and lower costs. From now on, let’s put this established custom aside. Instead of these Fig. 14, 15 and 16 clearly present the development potential of this innovative technology concerning cutting tools made from tungsten carbide. The presented improvements and cutting results can be achieved within the period of 2 months.

You also can see the importance of the dedicated coatings in these figures. For general milling operation the multilayer nanocomposite coating is clearly the best choice (Fig. 15). But for the special case of milling hardened steel the harder and thinner gradient coating outperformed the universal multilayers (Fig. 16).

**Conclusion**

The (Ti, Al)-based coatings are the market leader in the sphere of high performance cutting tools. Further development of the current top-coatings like nanolayers and AlTiN is limited, due to physical features. Nanocomposite-coatings break through these limits.

This article presents a fundamentally new development. The new LARC-technology works with rotating cylindrical cathodes in lateral positions. Considering this, the following so called π-advantages can be achieved:

- Optimal coating adhesion with the VIRTUAL SHUTTER®
- “Wide” targets with a longer working life
- Smooth coatings by reducing ARC-droplets
- Deposition of nanocomposites
- Deposition of nanogradients with programmable stochiometry
- Deposition of multi- and nanolayers.

Fig. 14 : Development Potential of LARC-Technology at Drilling. (Source: PLATIT AG, measured by iFT, Grenchen).
Nowadays, large and expensive coating equipment are no longer necessary to deposit competitive, simple or complicated coating structures dedicated for industrial application. On the contrary, with the help of the LARC®-technology medium sized enterprises can produce the newest nanostructured coatings by themselves and even generate their highly productive own brands.

Authors of this paper:
Dr. T. Cselle, Platit, CEO,
Dr. M. Morstein, Platit, Head R&D,
O. Coddet, Platit, R&D,
L. Geisser, Head Production,
Dr. P. Holubar, SHM, CEO,
M. Jilek, SHM, Head R&D,
M. Sima, SHM, R&D,
M. Janak, SHM, Head Production.

PLATIT (Grenchen, Switzerland) and SHM (Novy Malin, Czech Republic) established a joint venture company to develop and produce the LARC®-technology, coatings and equipment.

References
[16] Cselle, T.: Go into the New Economy, with High Performance Machining and Flexible Coating, Gorham Conference, Atlanta, May/2001,
Coating Properties

Nanocomposite Structure

Nanocrystalline grains are embedded into an amorphous matrix.

Surface Comparison

R \_ 0.07 \mu m \quad R \_ 0.02 \mu m

Nanolayer Structure of AITiN Coatings

Monolayer: for stable finishing and roughing
Multilayer: for interrupted cuts

Special high-performance PLATIT coating:
• very high aluminum content
• very high heat resistance
• for dry high speed machining
• especially at hard machining

Monolayer: for stable finishing and roughing
Multilayer: for interrupted cuts

Special high-performance PLATIT coating:
• very high aluminum content
• very high heat resistance
• finest coating surface
• highest edge stability
• especially for precision machining and tapping

Monolayer: for stable finishing and roughing
Multilayer: for interrupted cuts

Special high-performance PLATIT coating:
• extremely high nanohardness
• extremely high heat resistance
• for high performance and for normal machining conditions

Color | Nanohardness [GPa] | Thickness [\mu m] | Friction (fretting) coefficient | Max. usage temperature [°C] | Symbol color
---|---|---|---|---|---
TiN | gold | 24 | 1 - 7 | 0.55 | 600 |
TiAlN Monolayer | violet black | 35 | 1 - 4 | 0.5 | 800 |
TiAlN Multilayer | violet black | 28 | 1 - 4 | 0.6 | 700 |
TiCN-MP | red-copper | 32 | 1 - 4 | 0.2 | 400 |
TiCN | blue-grey | 37 | 1 - 4 | 0.2 | 400 |
MOVIC® | green-grey | - | 0.5 - 1.5 | 0.15 | 400 |
STARVIC© | green-grey | 32 | 1.5 - 5.5 | 0.15 | 400 |
GrN | metal-silver | 18 | 1 - 4 | 0.3 | 700 |
Ti, N | silver | 25 | 1 - 3 | 0.45 | 600 |
TiAlCN | burgundy-violet | 28 | 1 - 4 | 0.25 | 500 |
CROMVIC® | grey | 20 | 1.5 - 6 | 0.15 | 400 |
CBC (DLC) | grey | 20 | 0.5 - 4 | 0.15 | 400 |
GRADVIC® | grey | 28 | 1.5 - 6 | 0.15 | 400 |
AITiN | black | 38 | 1 - 4 | 0.7 | 800 |
µAITiN® | black | 38 | 1 - 2 | 0.3 | 800 |
AITiN/SiN | violet blue | 45 | 1 - 4 | 0.45 | 1100 |