Latest Developments and Applications in Coating Technologies

W.Kalss, Balzers Ltd, a unaxis company

1 Introduction

The keyword for manufacturers of cutting tools and coatings for cutting tools is productivity: a 30% reduction of tool costs, or a 50% increase in tool lifetime results only in a 1 % reduction of manufacturing costs. But an increase in cutting data by 20% reduces manufacturing costs by 15%. In order to achieve higher productivity different approaches – High Performance Cutting (HPC) and High Speed Cutting (HSC) *[1]* can be chosen.
Advances in manufacturing technologies (increased cutting speeds, dry machining, etc..) triggered the fast commercial growth of PVD coatings for cutting tools. On the other hand technological improvements in coating technologies (TiAlN, AlTiN, AlCrN and nanocomposite coatings) enabled these advances in manufacturing technologies.

2 Latest Trends in Coating Technology

25 years ago TiN started the success story of PVD coatings in cutting tool applications. TiN is charcterised by a broad application range, moderate hardness and good abrasive wear resistance. Substitution of nitrogen atoms by non metals like carbon yielded TiCN – a broad band coating with higher hardness and improved abrasive wear resistance. Introduction of aluminium in the cubic face centered TiN structure improved oxidation resistance of PVD coatings.
Recently a new generation of coatings were introduced, based on the Al-Cr-N system. This system is characterised by superior abrasive wear resistance and improved oxidation resistance – promising results in cutting tool application have been reported.

Speeding up innovation cycles is a must in times of fast changes and economic pressure. In order to speed up development of high performance coatings a new and improved approach has to be chosen – Design of Coatings: Based on a deep understanding of requirements of cutting processes and a detailled knowledge of coating properties, only a limited number of empiric steps are needed to obtain new high performance coatings.

2.1 Detailled understanding of coating properties

Important coating properties are shown in Figure 1. It is important to note that not the improvement of a single coating property (i.e. oxidation resistance) is sufficient to improve properties and performance of coatings. Only the improvement of a combination of coating properties leads to a better product.

Special focus of research is the measurement and the understanding of coating properties at elevated temperatures. As example below recent results in thermal conductivity of PVD coatings are shown.

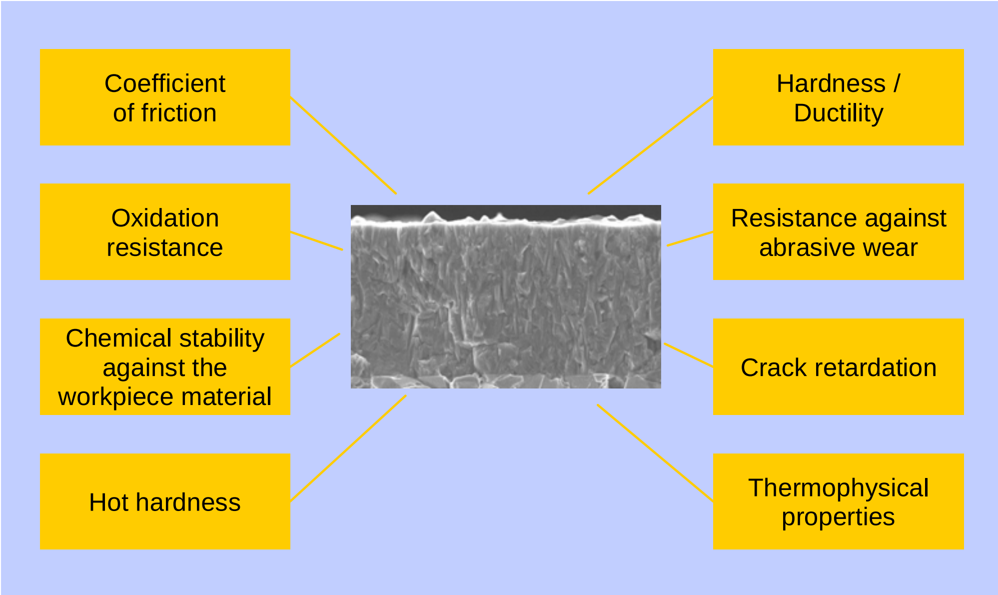


Figure 1 Important coating properties for cutting tool applications

In

Figure 2 the thermal conductivity of PVD coating is shown. This property defines (besides surface properties and coefficient of friction), which amount of heat goes into the tool and which amount of heat goes into the chips. As comparison thermal conductivity of cemented carbide is around 80 W/mK. Thermal conductivity is itself dependend on temperature. It is interesting to note that the thermal conductivity of AlCrN decreases above 250°C, whereas the thermal conductivity of AlTiN coatings increases with temperature.

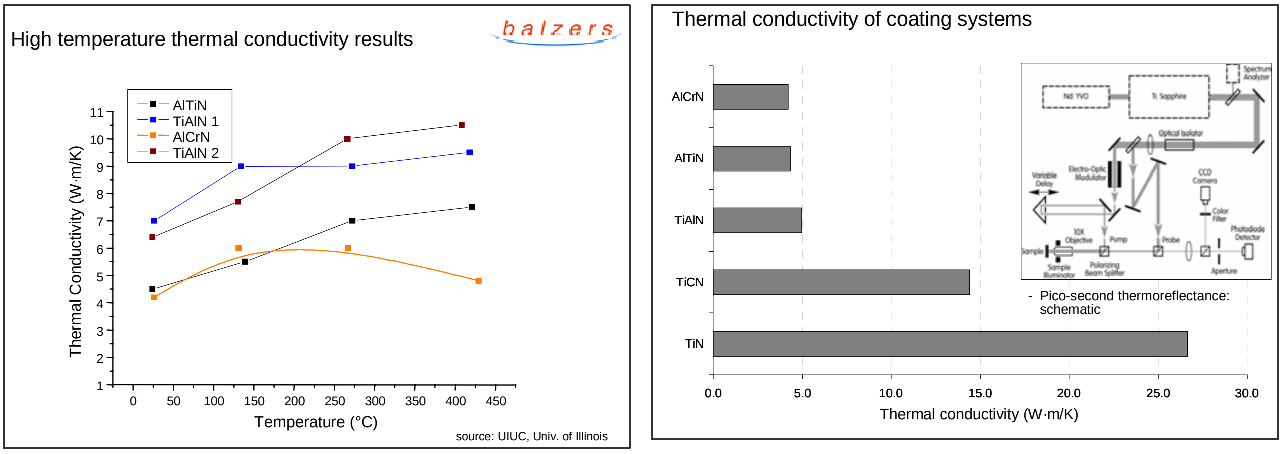


Figure 2 Thermal conductivity of coatings, determined by method „pico second thermal reflection” [2]

2.2 Al-Cr-N

From today's point of view in the system Ti-Al-N only minor improvements of coating properties and performance of cutting tool applications can be expected. In order to go a big step forward, totally new coating compositions have to be chosen. This lead to the development of a new coating generation based on Al-Cr-N.
Besides superior resistance against abrasive wear (Figure 3) also hot hardness and resistance against oxidation is improved (Figure 4) . It was shown by a wide range of cutting tests, that the Al-Cr-N coating system has a big potential at conventional cutting parameters, but also at High Performance and High Speed cutting conditions.

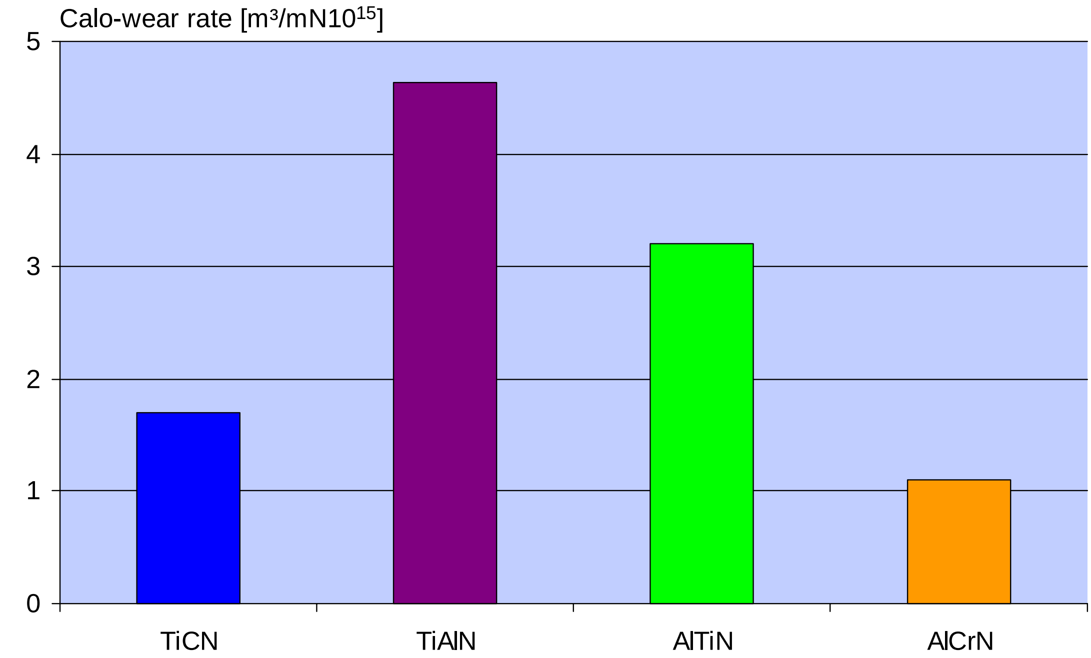


Figure 3 Resistance against abrasive wear, measured by calo wear test

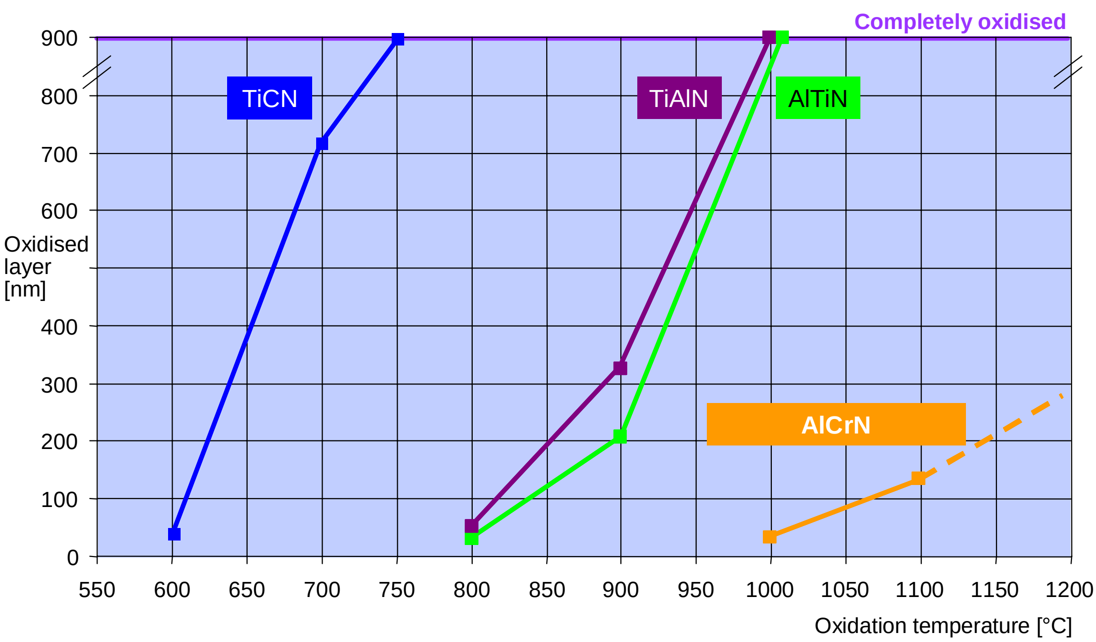
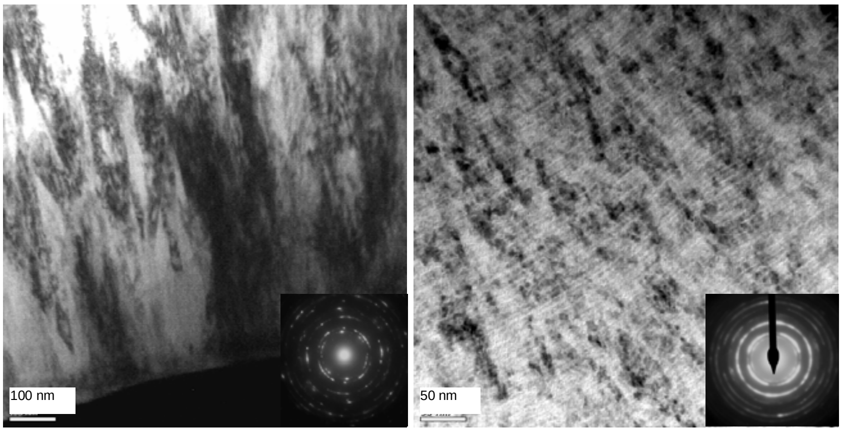


Figure 4 Oxidation resistance of PVD coatings, Al-Cr-N coatings show oxidation resistance until 1100°C

2.3 Nano composite coatings

Research in PVD coatings is also focussed in another area – nano composite and nano structured coatings. It was shown by Veprek [3], Holubar [4] and other researchers, that nano composite coatings show superior mechanical properties. Nano crystalline transition metal nitrides (metal = Ti, Zr, W, ..) are embedded in a amorphous or nano crystalline matrix of Si_3N_4. Due to that high hardness of coatings is achieved, and it was shown that also after a high temperature treatment (i.e. 1000°C) the high hardness does not decrease.



TiAlSiN single layer TiAlN/TiAlSiN multi layer

Figure 5 Example of nano composite coatings: TiAlSiN single layer, and TiAlN / TiAlSiN multilayer [5]

Crack retardation (the ability of coatings to react on high mechanical loads / cracks) is also an important property of PVD coatings. Escudeiro [5] has shown that crack propagation in PVD coatings can be influenced by multilayers of hard nanocomposite TiAlSiN and TiAlN. Figure 6 shows, that cracks are diverted parallel to the layered structure, and therefore the crack cannot propagate to the substrate. This is explained by the difference in compressive stresses of the single TiAlSiN and TiAlN layers .

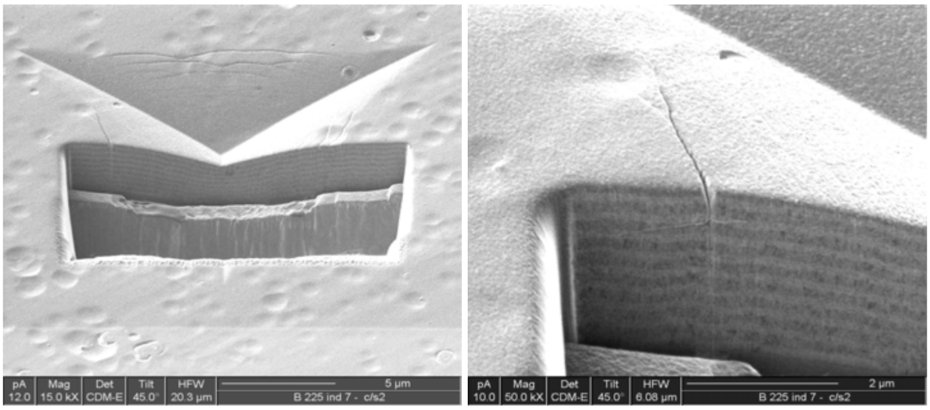


Figure 6 Crack propagation in nano crystalline multilayer coating [5]

2.4 Advances in Deposition Technologies

Smooth coatings with Arc Technology

Arc technology is the most important technology to deposit coatings for cutting tools. Main advantage of this technology is the high ionisation, the higher energy of ionised particles (leading to reliable adhesion), and the productive deposition rates. One drawback of this technology is that neutral clusters may evaporate from the sources, which lead to droplets on the coating surface. There are currently two technical solutions to overcome this drawback:

- Filtered Arc: neutral clusters are filtered out by an electromagnetic filter. This yields smoother coatings, but also a reduced deposition rate and lower energy of the ionised species are observed.
- Nano Dispersed Arc Jet (NDAJ): a special designed magnetic field enables the arc to cover the whole target surface at a higher speed. Therefore the average size of neutral particles is dramatically decreased – smoother coatings are achieved without loosing deposition rate [6].

Higher Ionistaion in sputtering

Concerning usage for cutting tools sputtering is the third important evaporation technology. Besides the wide range of materials which can be evaporated, also surface quality of coatings is good. One mayor drawback of sputtering is that only a minor fraction of evaporated material is ionized and leading to the formation of dense films. Pulsed sputtering is one approach to partly overcome this drawback.
Recently another promising approach was reported – High Power Pulsed Magnetron Sputtering, utilizing µs-pulses with an energy of megawatts, is used to boost ionisation. However generator technology is not fully developed and despite the high degree of ionisation deposition rate needs further improvement.

3 Applications

In gear cutting productivity and optimum usage of manufacturing equipment is the key. Therefore technological advances in tooling materials and coating technologies are introduced at a high speed.

In Figure 7 recent results with AlCrN based coatings are shown – tool life is increased by a factor of two. This is explained by the improved oxidation resistance, superior abrasive wear resistance and hot hardness, which are the key properties required for gear cutting applications. In practice the advances in coating technologies are used to increase cutting parameters and therefore decrease machining costs per piece.

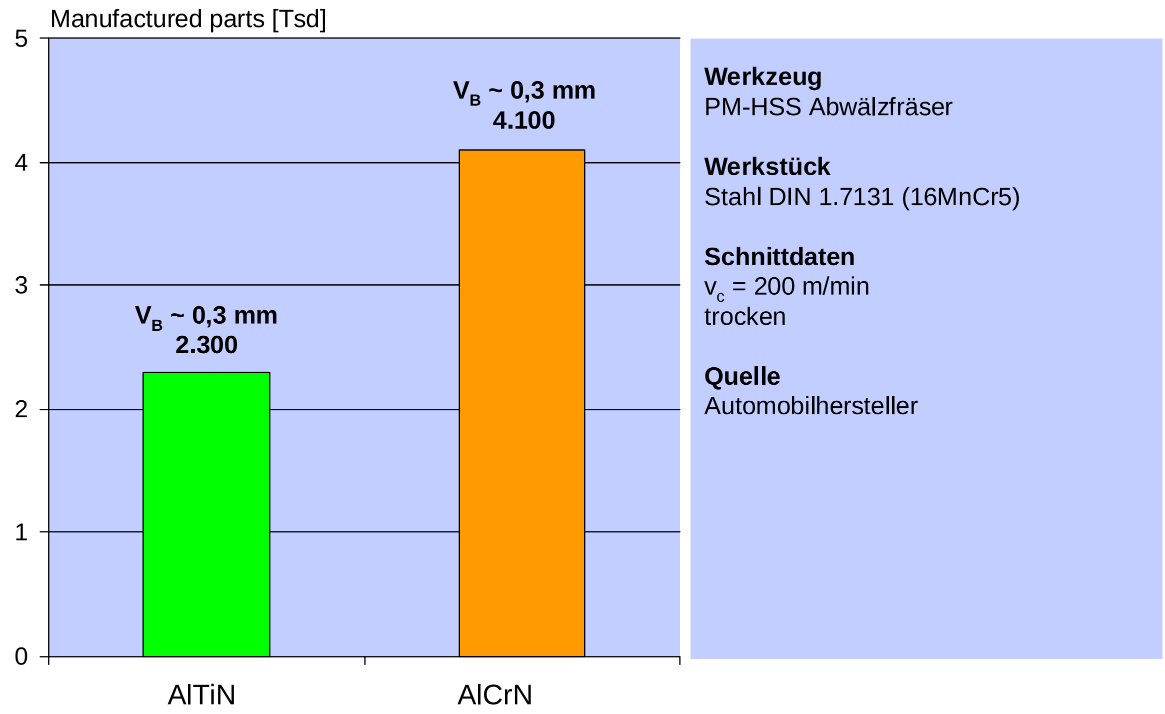


Figure 7 Comparison of tool life time in gear cutting (HSS PM hob, AlTiN and AlCrN coatings)

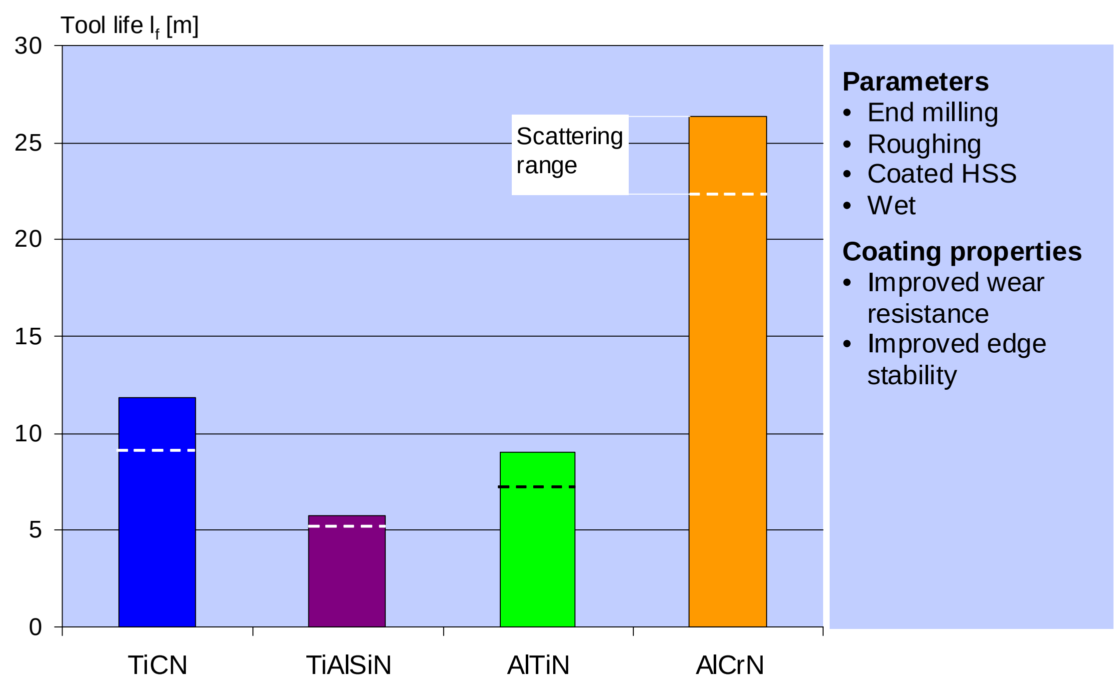


Figure 8 Milling of tool steel (1.2344, 1200 N/mm2) using HSS endmills

In Figure 8 milling of tool steel with HSS endmills is shown. AlCrN is compared with nanocomposite TiAlSiN, AlTiN and TiCN. Due to the low cutting speed oxidation resistance and hot hardness of coatings are not important. But abrasive wear resistance, crack resistance and the benefits of AlCrN on tough substrate materials lead to superior results of AlCrN.

The cutting tools for tapping used in industry have either untreated, vaporized or PVD coated surfaces [7, 8]. PVD TiN, TiCN are still the dominant PVD coatings, which is based on the fact that cutting speed is low and therefore abrasive wear resistance, coefficient of friction and adhesive wear properties are the dominant factors. To additionally increase the process stability and reliability, lubricant layers e.g. WC/C are put over hard coatings like TiAlN. [9]. Recently it was reported that AlCrN based coatings show promising results for blind hole tapping of austenitic steel [10], where adhesive properties and abrasive wear are the required coating properties.

4 Summary

The pressure for productivity increases triggers fast technological advances in coating and deposition technologies. Research is currently focussed on AlCrN based coatings and nanocomposite coatings.
A more detailled understanding of the correlation between requirements of cutting tool applications and coating properties will lead to shortened innovation cycles for high performance coatings.
In examples of gear cutting and milling modern PVD coatings were compared (TiAlN, AlTiN, AlCrN and nanocomposite TiAlSiN), where AlCrN showed superior results due to abrasive wear resistance, oxidation resistance and hot hardness.

5 Literatur

1 *Tönshoff, H.K., Friemuth, T., Andrae, P., Ben Amor, R.: High-Speed or High-Performance Cutting - A Comparison of New Machining Technologies, Production Engineering VIII/1 (2001), S. 5-8*
2 *Cahill, D. et al: Nanoscale thermal transport, Journal of Applied Physics, 93 (2003), S. 793-818*
3 *S.Veprek, P.Nesladek, A.Niederhofer, F.Glatz, M.Jilek, M.Sima, Surface and Coatings Technology 108-109 (1998) 138-147*
4 *P.Holubar, M.Jilek, M.Sima, surface and Coatings Technology 120-121 (1999) 184-188*
5 *A Escudeiro Santana, PhD thesis, EPFL Lausanne 2004*
6 *V.Derflinger et al., presented at ICMCTF 2004, San Diego, California*
7 *P. Müller, VDI-Z 145, 42-43 (2003), Nr. 5*
8 *S. Lux, Herstellung von Innengewinden, Verlag Moderne Industrie, 54-57 (2000)*
9 *V. Derflinger, Surf. Coat. Technol. 286-292 (1999)113*
10 *A.Reiter et al., presented at PSE 2004, Garmisch, Germany*