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Advanced tool materials for high-speed machining

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The growth of quality demands in high-speed machining (HSM) requires improved manufacturing solutions that provide the best performances at a reasonable cost. Increased performance has been recently achieved, through the exploitation of advances in new and improved tool materials and coatings. The objectives of this paper refer to the introduction of some advanced tool materials and hard coatings for machining with a geometrically defined cutting edge and a brief review of contemporary abrasives in high-speed grinding (HSG).

1. INTRODUCTION

In recent years, developments in the precision industry have caused a rapid increase in the use of brittle hard-machined materials such as sintered carbide, silicon, fine ceramics, etc. By using a suitable precision HSM method, shape accuracy within the micron range and high surface finish can be achieved. The selection of an appropriate procedure is dependent on machine tool concept, investigations with different tool specifications as well as a frame of process parameters manipulation [1].

Development in tool materials and abrasives is enabling the enforcement of HSM paradigms and simultaneously increasing the possibilities and extent of precision machining applications. In the areas of HSM and tooling PVD (Physical Vapour Deposition) hard coatings are indispensable and widely used to increase the life and productivity of tools and therefore reducing manufacturing costs. TiN based coatings evolved from single-layer to gradient multi-layer structures. CrN, TiAlN and CVD-diamond coatings have been predominantly used since the 90's. The number of coatings and their applications have been exponentially growing over the last decade. Contemporary super-hard coatings refer to multi-layer structures, nano-composite and nano-gradient coatings. Hard coatings are a prerequisite for HSM and dry machining [2].

Recent grinding technology has also considerably increased in performance with regards to productivity and precision. Modern tools with enhanced wear resistant super-abrasives and improved bond systems have contributed to this. In this way modern grinding tools, machine-tools and improved high-speed processes form the basis of future-oriented grinding technology [3].

2. CONTEMPORARY TRENDS IN THE FIELD OF CUTTING MATERIALS

The history of tool materials started in early 19^{th} century with the emergence of the first carbon based steels. The new millennium is characterized by the emergence of nano-structured hard coatings and PVDs. The contemporary research is focused on installations of new deposition systems for preparations of a new generation of hard coatings. New cutting tool materials and coatings enable the increase of the cutting speed (Figure 1).

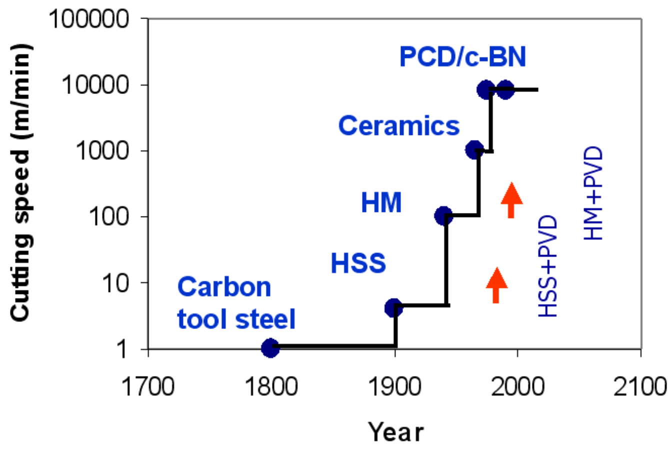


Figure 1. Cutting tool material evolution

Different tool materials are characterised by various failure and wear modes (Figure 2). PVD surface treatments applied on tools improve e.g. friction, corrosion and wear properties.

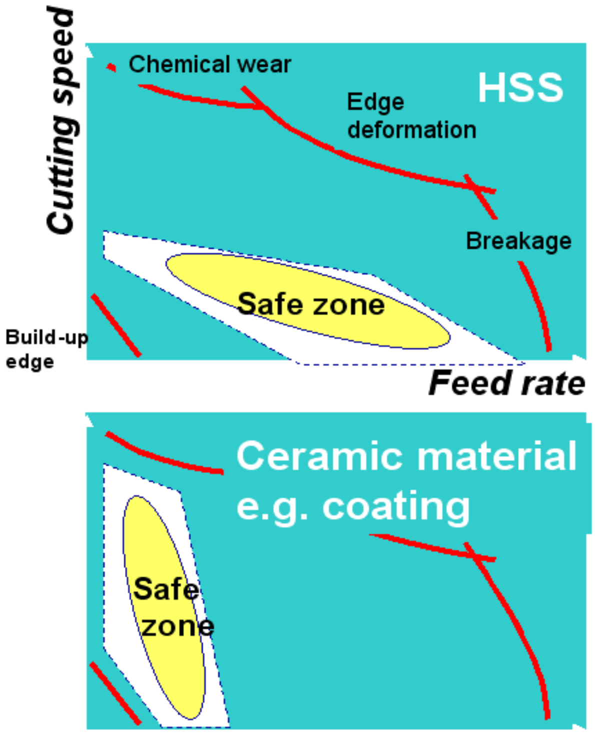


Figure 2. Failure mode for different tool materials

Hard PVD coatings expand the safe zone by minimising build-up edge and crater wear and improving fracture toughness of a cutting edge (Figure 3), whereby enabling HSM.

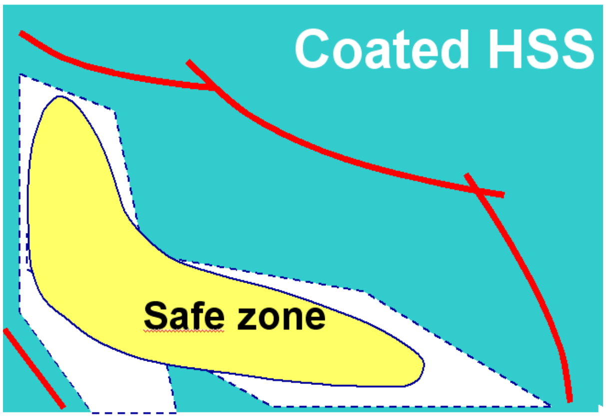


Figure 3. Coated HSS failure mode

Properties of hard coatings are characterised by the following requirements [4]:

- Good adhesion to tool substrate
- High microhardness at cutting temperature
- Chemical inertness relative to the workpiece
- Fine-grain, crystalline microstructure
- Compressive residual stress
- Crack-free and smooth surface morphology
- Low heat transfer coefficient

Adequate coating can optimise the relations of heat transfer. Due to the low heat transfer coefficient of TiAlN-coated tools, the heat flow into a tool is reduced (Figure 4).

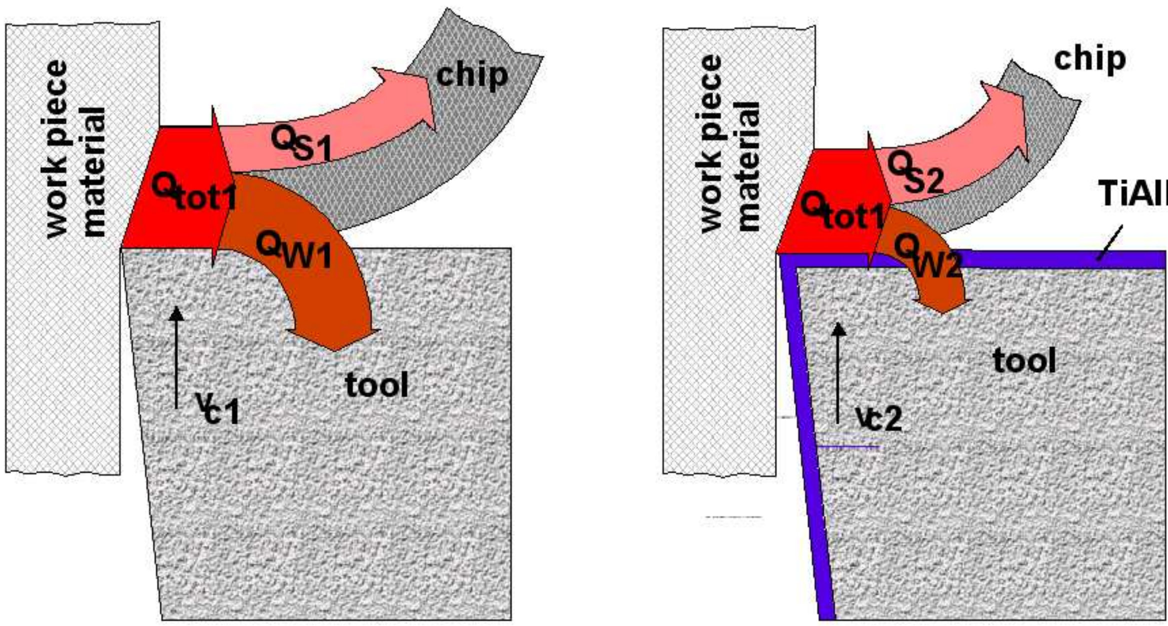


Figure 4. Optimal heat transfer

The properties of cutting tools can be further characterized by different microstructure coating designs (Figure 5).

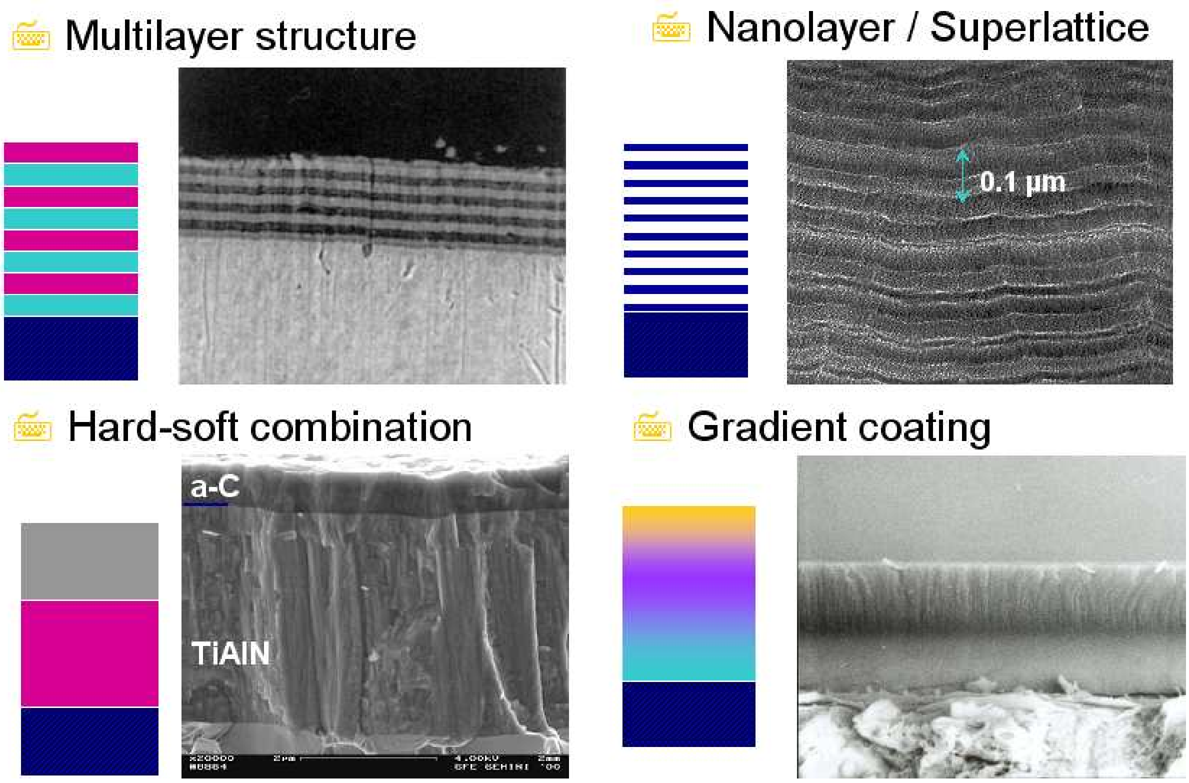


Figure 5. Microstructure coating designs

Contemporary trends show that the marketshares of TiAlN are increasing over the last couple of years (Figure 6).

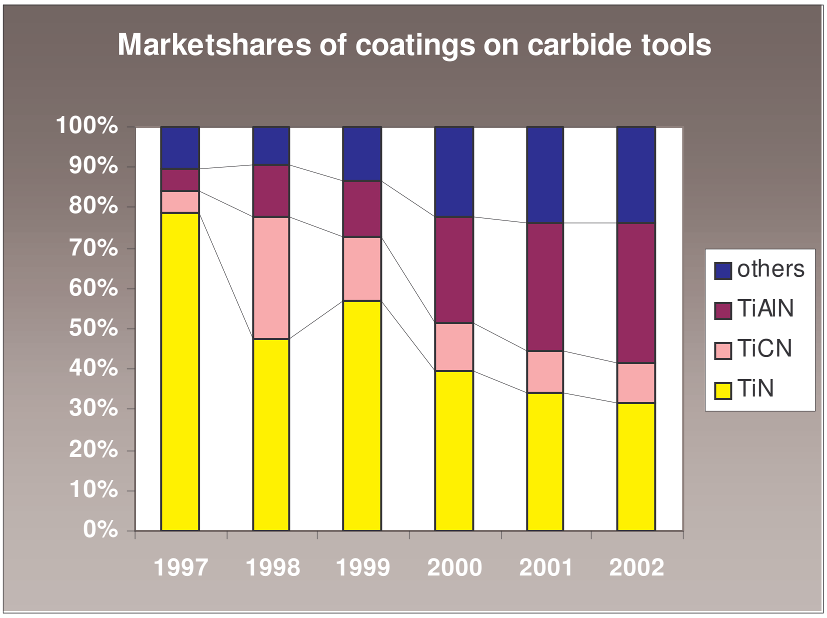


Figure 6. Marketshares of coatings on carbide tools

Current and future coatings and their applications are represented in the following figure (Figure 7).

Figure 7. Current and future coatings applications

Coatings are further characterised by their friction coefficient, which affects the various coatings' performance (Figure 8).

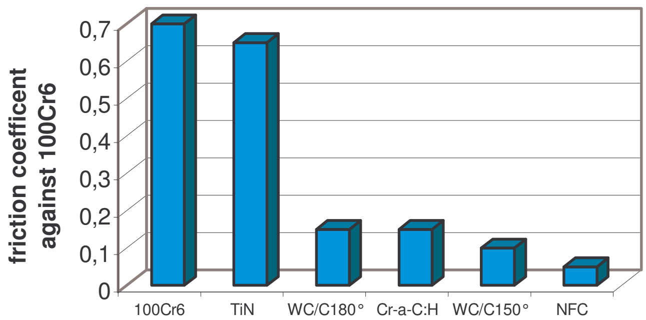


Figure 8. Coatings friction coefficient

Contemporary multilevel composite coatings are designed for the machining of soft substrate materials (Figure 9.)

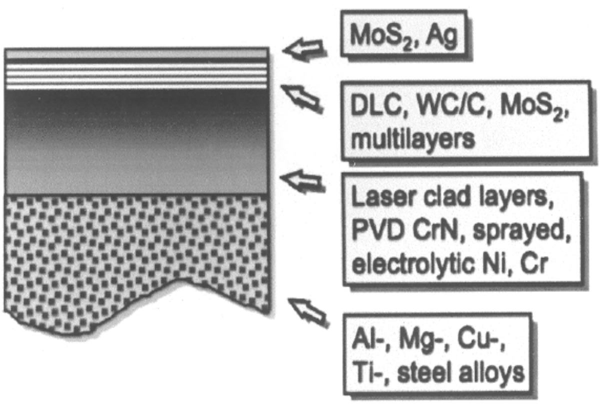


Figure 9. Structure and materials of a multilevel composite coating

2. HIGH-SPEED MACHINING AND CUTTING TOOLS

The performance and lifetime of cutting tools for HSM are determined by the surface and bulk material properties, where the solid surface determines:
Wear resistance
Corrosion resistance
Friction coefficient
Solderability
Conductivity
Refractive index
Wettability
Biocompatibility
Catalytical properties

HSM (Figure 10) of tempered steels is characterised by small chip thickness and high cutting temperature. Therefore, requirements for cutting tools and coatings refer to thermal and oxidation resistance, small thermal conductivity and the ability for chip heat removal.

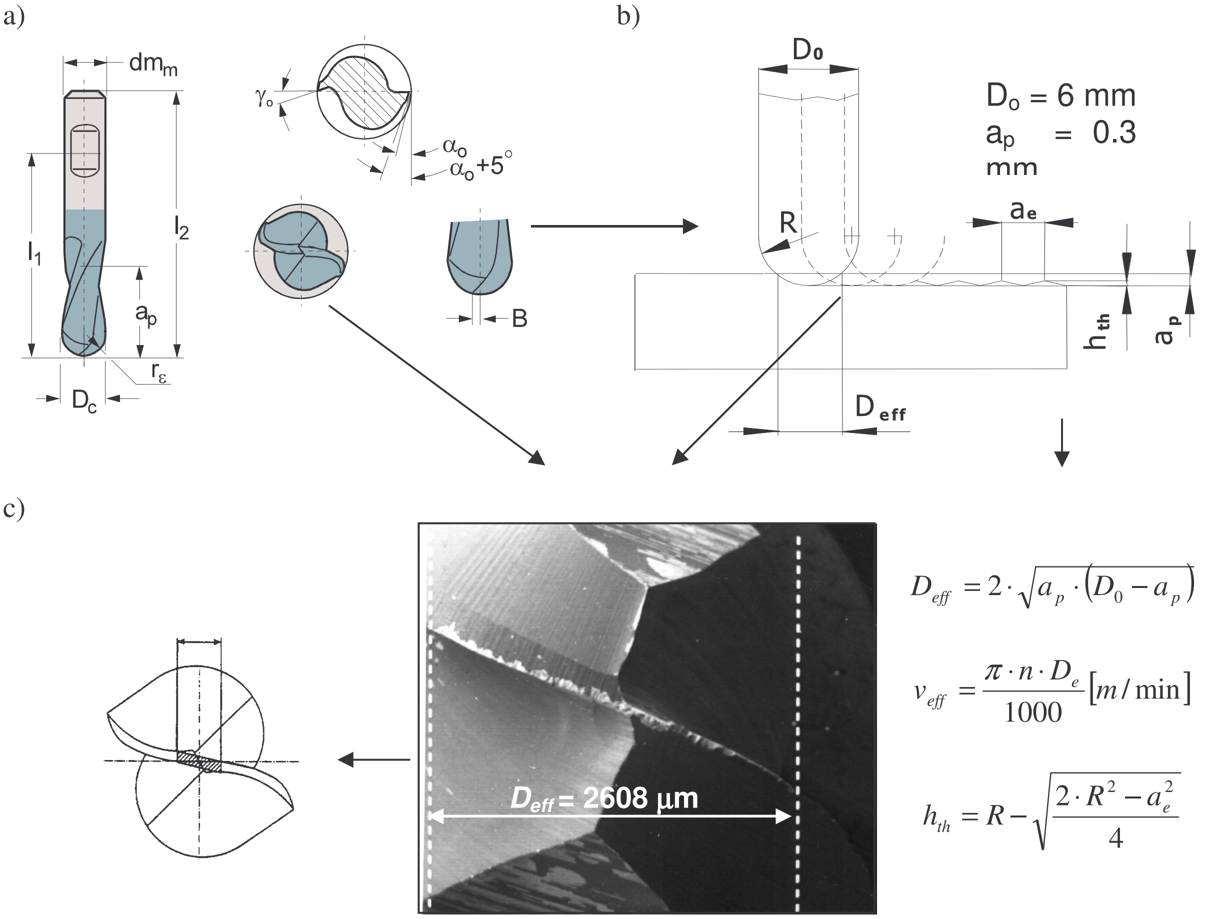


Figure 10. The geometry of typical two-flute solid carbide end mills (a), effective parameters of cutting in high-speed milling (b), SEM micrograph of worn cutting edge and position of central wear (c).

Table 1. Composition of coatings

Mnf.	Composition	Type
A	0.96 %Ti, 0.04 %Al	single-layer
B	0.55 %Ti, 0.45 %Al	single-layer
C	0.52 %Ti, 0.48 %Al+ WC/C	two-layers dry lubricating coating
D	0.36 %Ti, 0.64 %Al /TiN	multi-layers (nano layers system)

Figure 11. HSM of dies

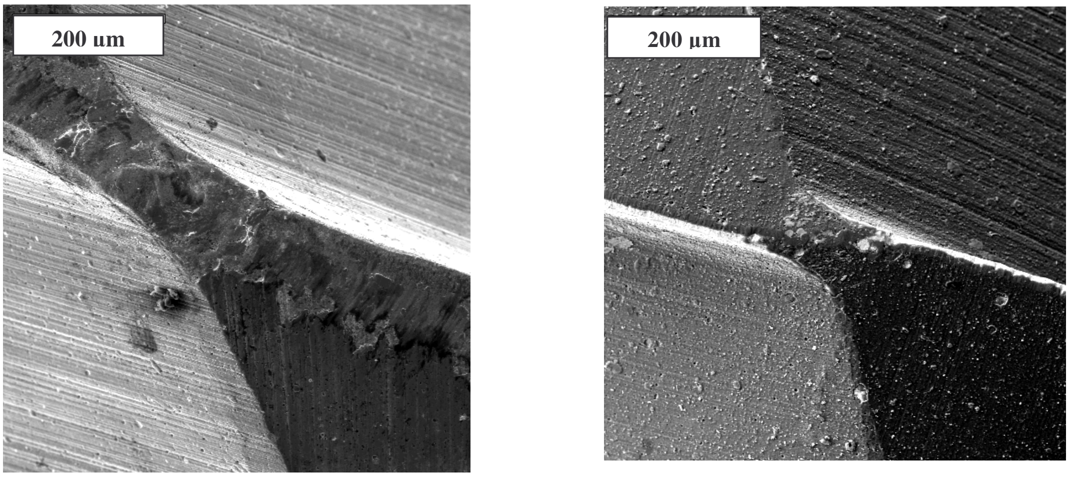


Figure 12. SEM micrographs of worn end mill cutters (manufacturers C and D) [4]

Dry lubricating coating of manufacturer C (TiAlN + WC/C) is not preferred for high-speed milling of alloyed tool steel; the strong central wear is distinctive (Figure 12-left). Both the flank and rake surfaces exhibited typical sliding wear features, comprising grooves and dispersed material transfer. The transferred material was predominantly high-temperature iron oxide hematite Fe_2O_3 as determined by SEM-EDS spectroscopy. On the other hand (Figure 12-right), it is clear that the TiAlN/TiN multi-layers nano-coating system (Producer D) has very high wear resistance.

Therefore, the combination of a hard multi-component (TiAlN) coating and a thin layer of hard lubricant (a-C) for dry machining also requires thermal resistant coating materials with high oxidation resistance and high resistance to abrasive wear.

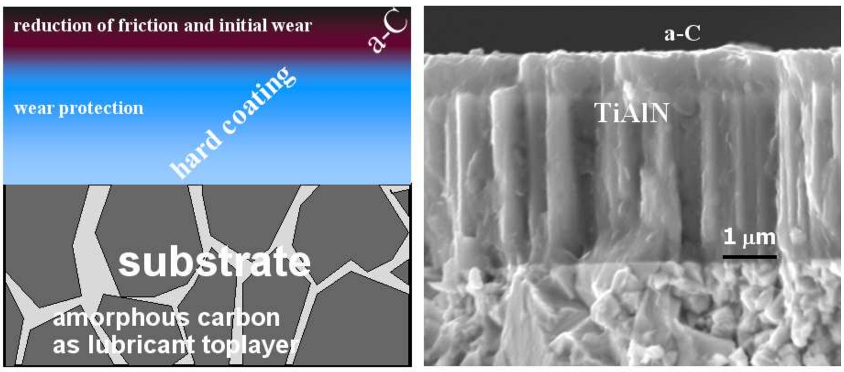


Figure 12. Combination of hard and lubricant coatings

The combination of hard and lubricant coatings also influence tool temperature (Figure 13). Hard coatings reduce heat fluctuation and prevent interface heat transfer.

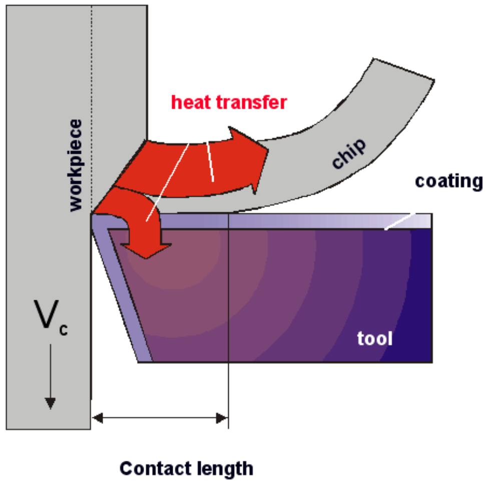


Figure 13. Heat transfer in combined coatings

Hard coating (TiAlN) is characterised by higher oxidation resistance than (TiN, TiCN). It forms an outer aluminium-oxide film and a thermal barrier. The hard lubricant (WC/C) induces less dynamic friction on the tool/chip interface and hence lowers cutting forces and heat generation [2].

HIGH-SPEED GRINDING (HSG) AND CONTEMPORARY ABRASIVES

Machining procedures with undefined cutting geometry are characterized by small chips, which can be measured only on the micro-scale and cannot be directly observed. Abrasives are subjected to special requirements referring to grain hardness and fracture toughness (Figure 14), heat resistance and chemical resistance.

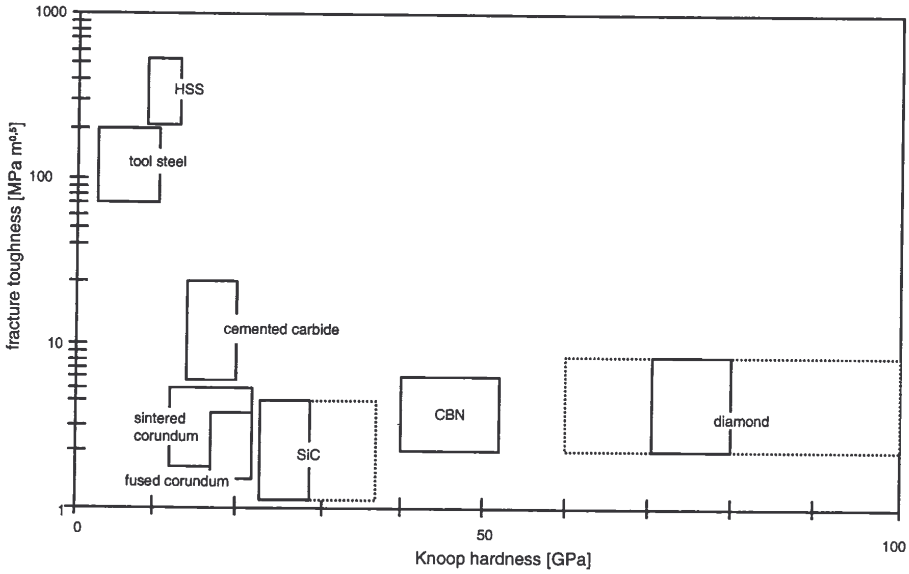
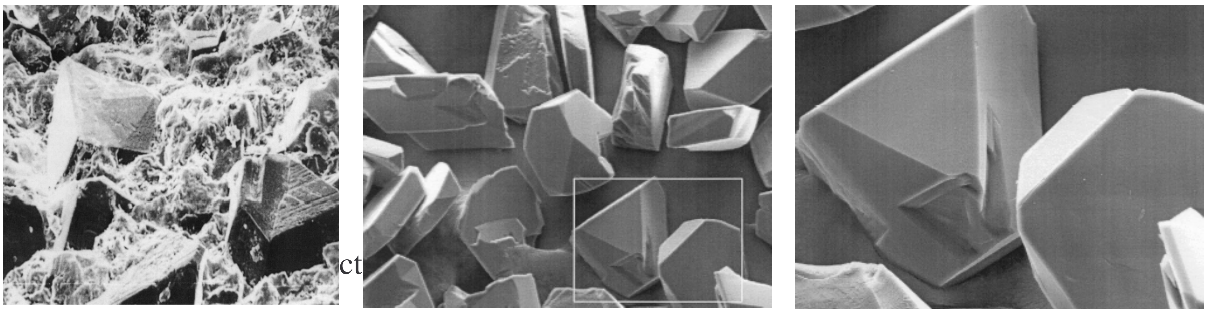


Figure 14. Abrasives hardness and toughness relations

Because of its high level of hardness, its thermal and chemical resistance, cubic boron nitride (CBN) is perfectly suited as a high-performance abrasive for HSG (Figure 16).



The latest HSG trends place emphasis upon the increased usage of seeded-gel (SG) microcrystalline ceramic aluminum oxide abrasive. SG combines the properties of the ceramic (K) and fused aluminium oxide (S) into vitrified grinding wheels.

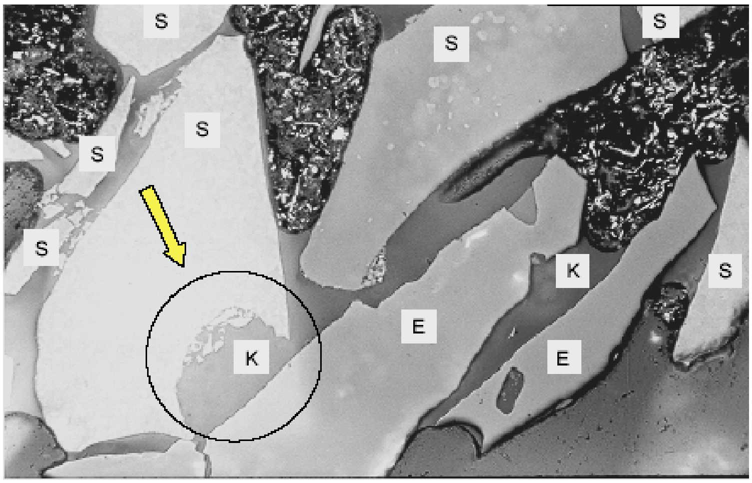


Figure 17. SG microstructure [3]

3. CONCLUSIONS

Discussed TiAlN coating is one of the most recently developed coating allowing the use of HSM. This multi-purpose coating is also suitable for working cast-iron and Al alloys and reduces friction and adhesion of plastics materials to the moulds. New applications are found on a daily basis.

The use of PVD hard coatings to improve tribological properties of tools is constantly increasing. During the last decade the number of new coating materials, structures and combinations increased significantly. We are witnessing only the very beginning of an evolution in the use of coatings. We are in a position to predict that the future of coatings will encompass virtually all mechanical components. PVD procedures further enable a wide spectrum of hard coatings, along with the promising nano-structured coatings and other super-hard coatings, e.g. diamond, CBN.

Other advantages of PVD coatings and to some extend CBN, SG abrasives include reducing of overall cycle times and downtime, due to tool replacement caused by excessive wear. Other aspects of advanced tool materials could refer to ecological machining. PVD coatings can be run dry or with very limited amount of fluid, which is therefore reduced. Cutting speeds and other production parameters can also be increased substantially, hence improving productivity and profit.

REFERENCES

1. J. Kopac, P. Krajnik, A. Sluga: Precision Grinding and Quality Control, ICPM 2003 Proceedings, Faculty of Mechanical Engineering, CTU in Prague, page 36-41, 2003.
2. P. Panjan: Novejsi razvoj PVD trdih zascitnih prevlek za zascito orodij in strojnih delov, Presezimo meje na nov nacin: dobavitelj - kupec - orodjar : zbornik posvetovanja, Fakulteta za strojnistvo, Univerza v Mariboru, page 111-115, 2003.
3. J. Kopac, P. Krajnik: Visokohitrostno brusenje - nov izziv za slovensko proizvodnjo , Presezimo meje na nov nacin: dobavitelj - kupec - orodjar : zbornik posvetovanja, Fakulteta za strojnistvo, Univerza v Mariboru, page 63-66, 2003.
4. M. Sokovic, J. Kopac, L.A. Dobrzanski, M. Adamiak, Wear of PVD-coated solid carbide end mills in dry high-speed cutting (HSC), Proceedings of the 10th Jubilee International Scientific Conference Achievements in Mechanical & Materials Engineering AMME'2001, Silesian University of Technology, Institute of Engineering Materials and Biomaterials, page 531-534, 2001.