19 Further refinement of the cutting materials

19.1 High-speed steels

The outstanding characteristics of high-speed steels are:

Great toughness,
Low-cost,
Sound machinability of the cutting material.

Even today, twist drills, taps, dies, gear cutting- and broaching tools are predominantly made of high-speed steel.

Significant improvements can be made through the coating of high-speed steels. The coating is performed with the physical vapour deposition (PVD method).

During the coating of high-speed steel, the coating temperature is approx. 500 °C. At this temperature, it is still possible to coat heat-treated tools without distortion. The materials used as hard deposits are

titanium nitride (TiN), titanium carbonitride (TiCN), titanium aluminium nitride (TiAlN) or titanium aluminium oxinitride (TiAlON),

which are coated at a thickness of 2 to 4 µm. Coated high-speed steels make possible an increase in power during machining due to longer tool life or higher cutting speeds:

tool life increase: 100 % to 500 %,
increase in cutting speed: 50 %

with the same tool life, in comparison to uncoated tools.

19.2 Cemented carbides

19.2.1 Uncoated cemented carbides

Cemented carbidesare cutting materials produced by powder metallurgy. The main components are tungsten carbide (TC), incorporating hardness, and cobalt (Co) as binder. For grades to machine steel, additional hard materials are added – mostly composite carbides based on titanium, tantalum and niobium – in lower percentages. The carbides are responsible for hardness and wear resistance, whereas the binder determines the toughness characteristics. Cemented carbides are naturally hard, which means that their characteristics cannot be altered like those of steel can be by means of heat treatment.

In comparison with high-speed steel, the most essential parameters of cemented carbides are their fundamentally greater hardness, on the one hand, and lower level of toughness, on the other hand:

Parameter	High-speed steels	Cemented carbides[1]
Hardness (HV 30)	700 … 900	1300 … 1800
Flexural strength (N/mm^2)	2500 … 3800	1000 … 2500
Heat resistance to	600 °C	> 1000 °C

1) Cemented carbide sorts for machining

Cemented carbide is available in many varieties with very different properties. Consequently, a suitable variant is available for almost all types of machining, from easy finishing to machining of hard work materials. In addition to this spectrum, varieties for all workpiece materials are available.

At present, the performance of cemented carbides is being significantly improved due to the use of finer and finer grain sizes. Traditional grades of cemented carbide grades for machining make use of medium grain sizes from 1 to 2 µm; today, for ultra-fine grains, grits of 0,2 to 0,4 µm are being used. The significance of this trend is the simultaneous and tremendous increase in the principal (and opposing) parameters “hardness – tool life“ and “toughness – reliability“.

19.2.2 Cermets

Cermets are cemented carbides, in which titanium carbonitride (TiCN) is used to provide the majority of the hardness instead of tungsten carbide, and a compound of nickel and cobalt serves as the binder. This difference in composition makes the cermets more heat resistant, on the one hand. On the other hand, it diminishes the material’s toughness.

Consequently, cermets are used for finishing and for operations with minimal requirements in terms of cutting edge toughness, preferentially for machining of steel.

19.2.3 Coated cemented carbides

An additional coating offers a significant increase in the performance of the cemented carbides, resulting in much higher tool life and/or increased cutting speeds.

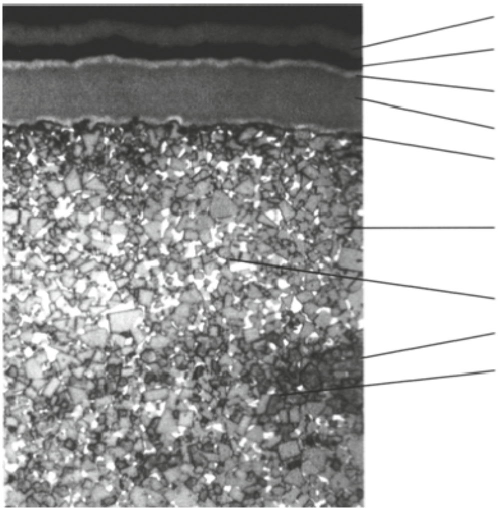

Figure 19.1
Micrograph of a multi-layer coating

Cemented carbides are preferentially coated by means of chemical vapour deposition (CVD). During this process, hard materials are made through chemical reactions in the coating furnace at temperatures from 850 to 1000 °C from gases that are fed in. These hard materials are deposited in a solid coat on the cemented carbide. Commonly used and proven hard materials are, for instance, titanium carbide (TiC), titanium carbonitride (TiCN), titanium nitride (TiN), aluminium oxide (Al_2O_3) and zircon carbonitride (ZrCN), of which multi-layer coats almost exclusively deposited (Figure 19.1). Total coat thickness may be up to 25 µm.

In certain cases, cemented carbides are also coated according to the PVD method. This stands for physical vapour deposition, whereby single coats of titanium nitride, titanium carbonitride, titanium aluminium nitride (TiAlN) or titanium aluminium oxinitride (TiAlON) are applied.

Coated cutting edges are typically characterised by their fillets, whose rounding radius is at least at the layer thickness level. In most CVD coats, this radius is substantially higher to avoid embrittlement of the cutting edge due to coating. For this purpose, radiuses from 20 to 100 µm – depending on the use of the cutting edge (roughing or finishing) – are common practice.

Coated cemented carbides are suitable to machine all steels and cast iron materials, as well as high-temperature alloys based on nickel or cobalt. In industrial production, for turning and drilling, coated indexable inserts are almost always used, and these inserts are also used in the majority of milling applications. Uncoated cutting edges are used for machining only on machines with low input power or if it is necessary to have very keen cutting edges.

Light- and non-ferrous metals are still machined with uncoated cemented carbide. The physical properties of the cutting materials are summarised in Table 19.1.

Table 19.1 Properties of the cutting materials

Properties		High-speed steel	Cemented carbide	Ceramic	Natural diamond
Density	g/cm^3	8,0 … 9,0	6,0 … 15,0	3,2 … 4,5	3,5
Vickers hardness (macro h.)	HV 30	700 … 900	850 … 1800	1400 … 2100	8000 … 10000
Compressive strength	N/mm^2	3000 … 4000	3000 … 6400	2500 … 5000	2000
Flexural strength	N/mm^2	2500 … 3800	1000 … 3400	400 … 900	400
Temperature stability	to K	870	> 1300	> 1800	970
Young's modulus 10^{-4}	N/mm^2	26 … 30	47 … 65	30 … 45	90 … 100
Reciprocal value of Young's modulus (dilation). (RT = 1,273°K)	$10^{-6}/K$	9 … 12	4,6 … 7,5	2,6 … 8,0	1,5 … 1,9
Thermal conductivity (RT)	$\frac{W}{Km}$	15 … 48	20 … 80	14 … 30	138

Figure 19.2 shows hardness and wear resistance as a function of flexural strength and toughness for the individual cutting materials.

The higher the hardness and wear resistance, the lower the toughness.

The ideal cutting material would be not only very hard, but also very tough. However, this kind of cutting material does not yet exist.

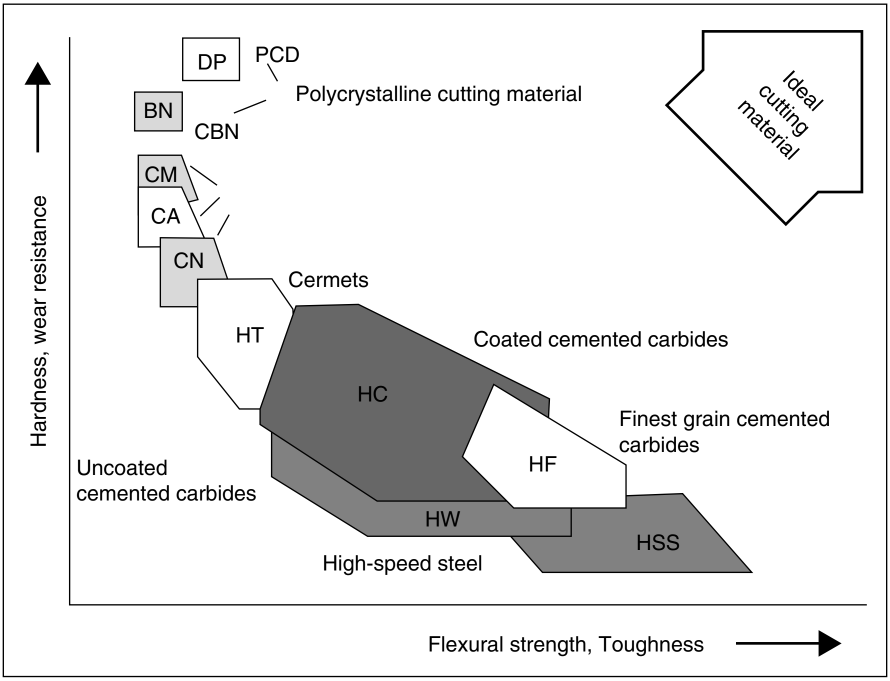

Figure 19.2
Hardness and toughness, assigned to different cutting materials

Table 19.2 Coated cemented carbides with recommended ranges of application (excerpt of a company documentation by Kennametal, Hertel, Fürth)

KC520M  TiAlN HM	**Composition:** Coated type of cemented carbide, with a 4 µm thick TiAlN coating (PVD) **Recommended use:** KC520M is a new sort of cemented carbide, which was specifically designed for medium machining (G) of spheroidal-graphite cast iron. KC520M can be used either with or without coolant.
KC525M  TiAlN HM	**Composition:** Coated cemented carbide type with a 4 µm thick TiAlN coating (PVD) **Recommended use:** New universal cemented carbide type for milling of steel, stainless steel and hard-working materials. KC525M can be used both with/without coolant. To be applied for light and medium machining (L and G)
KC715M  TiN TiCN TiN HM	**Composition:** KC715M is a new cemented carbide type, which is excellently suited to machining without coolant (dry machining). The wear-resistant substrate is highly resistant to thermal changes. **Recommended use:** The material is mainly used for light and medium machining (L, G range of steels, stainless steels and cast steel
KC725M  TiN TiCN TiN HM	**Composition:** Coated cemented carbide type with a 5 µm thick PVD multilayer coating (TiN/TiCN/TiN) **Recommended use:** KC725M is a high-performance type used to mill steel, stainless steel and spheroidal-graphite cast iron. Because of its high resistance to thermal shock, this type is excellently suited to machining with or without coolant. Major range of application is medium to hard machining (G, H)
KC735M  TiN HM	**Composition:** Coated cemented carbide type with a 4 µm thick PVD coating. This type is a special combination of high toughness and sound wear resistance. **Recommended use:** Even with the most demanding toughness requirements, KC735M achieves best results in the regions G and H. this type is suitable for milling with coolant.
KC915M  Al_2O_3 TiN HM	**Composition:** Coated cemented carbide type with a 7 µm thick CVD multilayer coating (TiN/Al_2O_3) **Recommended use:** KC915M is a multi-purpose type for milling of cast iron. This cutting material is the first choice for light and medium (L, G ranges) machining. KC915M is suitable for milling without coolant.
KC920M  Al_2O_3 TiN HM	**Composition:** Coated cemented carbide type with a 5 µm thick CVD multilayer coating (TiN/Al_2O_3) **Recommended use:** KC920M is a multi-purpose type used to mill cast iron. This cutting material is the first choice for light, medium and hard machining (L, G, H) . KC920M is suitable for milling either with or without coolant.
KC930M  TiN TiCN TiN HM	**Composition:** Coated cemented carbide type with an 8 µm thick CVD multilayer coating (TiN/TiCN/TiN) **Recommended use:** KC930M is a multi-region type used to mill steel and spheroidal-graphite cast iron. Ranges of application are light, medium and hard machining (L, G, H).

19.3 Ceramic

In ceramics, the following types are distinguished:

19.3.1 Oxide ceramic, white (clean ceramic)

The main constituent of the white oxide ceramic is Al_2O_3. To enhance toughness, low volumes of zirconium oxide ZrO_2 are added.

19.3.2 Oxide ceramic, black (mixed ceramic)

This is a mixed ceramic, which, in addition to aluminium oxide, consists of metallic hard materials, such as titanium carbide TiC and titanium carbonitride TiN. This way, compressive strength and abrasion resistance greater than those of white ceramic can be achieved.

19.3.3 Nitride ceramic

This type belongs to the non-oxidic cutting materials, based on Si_3N_4.

This ceramic is characterised by good fracture toughness and high thermal shock resistance. For this reason, it is suitable for roughing of grey cast iron.

19.3.4 Whisker ceramic

This is a kind of oxide ceramic with additionally interstratified fibres (whiskers), mostly of silicon carbide (SiC). Thus, the toughness properties are clearly enhanced.

19.3.5 Coated ceramic

In rare cases, ceramic is coated with materials based on silicon nitride to further increase the tool life characteristics.

Table 19.3 Ceramic cutting materials

Ceramics	Approximate composition	Ranges of application
Oxide ceramics, white	3–15 weight percentage ZrO_2 residual Al_2O_3	Grey cast iron, case-hardening- and tempering steels, suitable for: high v_C, lower feed values
Oxide ceramics, black	5–40 weight percentage TiC/TiN additionally up to 10 weight percentage ZrO_2 residual Al_2O_2	Chill casting, hardened steel suitable for: high v_C, low feed values
Nitride ceramic	0–7,5 weight per. Y_2O_3 } As sintering additives 0–17 weight per. Al_2O_3 } 0– 3 weight percentage MgO } Additionally up to 30 weight percentage TiC/TiN resiual Si_3N_4 (silicon nitride)	Grey cast iron; steels with high nickel content, suitable for: rough machining with medium v_c

19.4 Polycrystalline cutting materials

19.4.1 Polycrystalline diamond (PCD)

Polycrystalline (multi-grained) diamond is made synthetically of carbon under high pressure and at high temperature. PCD is – after the natural diamond – the hardest cutting material by far; for this reason, it provides unequaled wear resistance.

This diamond is used in series production to machine aluminium alloys with high silicon content (preferentially above 12%), which are extremely abrasive. Typical workpieces are crankcases and cylinder heads in the car industry. PCD is also used to machine fibre-reinforced plastics, because the keen cutting edges avoid delamination of the laminate. The material's hardness also results in long tool life in spite of very abrasive fibres. PCD may not be used to machine ferruginous workpiece materials.

19.4.2 Cubic boron nitride (CBN)

Polycrystalline (cubic) boron nitride is made of hexagonal ("standard") boron nitride using a procedure similar to PCD. The most important property of CBN is its high heat hardness. Consequently, CBN is outstandingly suited to machining of hardened steel- or cast workpieces, given that hardness values up to 68 HRC can be machined.

19.5 Marking of (hard) cutting materials

The hard cutting materials (these are all cutting materials, except for high-speed steels) differ greatly in composition and properties. However, they are nevertheless used for the same machining tasks, wherein cutting conditions and work results may be very different. Thus, for instance, to turn cast iron, one may use either uncoated or coated cemented carbide, white or black oxide ceramic, nitride ceramic or CBN. For these materials, the cutting speed values range from 60 to 1200 m/min as a function of the cutting material.

To better represent the hard cutting materials, the standard ISO 513 was reworked and is now valid in its extended version. In this version, the current "Classes of cutting application" according to ISO 513 are prefaced with letters to identify the cutting material group.

These are:

Table 19.4 Marking of hard materials according to ISO 513

Symbol	Cutting material group
HW	Uncoated cemented carbide, based on tungsten carbide
HF	Fine grain hard metal, grain size less than 1 µm
HT	Uncoated cemented carbide, based on titanium carbide or -nitride (cermet)
HC	Cemented carbides as aforementioned, but coated
CA	Oxide ceramic based on Al_2O_3, also with other oxides
CM	Oxide ceramic based on Al_2O_3 and other non-oxidic constituents
CN	Nitride ceramic based on Si_3N_4
CR	Fibre-reinforced ceramic based on Al_2O_3 (whisker ceramic)
CC	Ceramics as aforementioned, but coated
DP	Polycrystalline diamond (PCD)
DM	Monocrystalline (natural) diamond
BH	Polycrystalline boron nitride with high PCB content
BL	Polycrystalline boron nitride with low PCB content
BC	Polycrystalline boron nitride as aforementioned, but coated
In addition to the 3 machining main groups P, M and K, which have been commonly recognized up to now, the new standard ISO 513 will contain other main groups, with the following content:	
P	Unalloyed and alloyed steels (as before)
M	Rustproof austenitic steels (as before)
K	Unalloyed and alloyed cast iron (no other additional workpiece materials)
N	Non-ferrous metals and non-metals
S	Hard work alloys based on nickel or cobalt or titanium
H	Hardened iron materials (steel and cast materials)

Within each of these main groups, the individual cutting material grades are assigned according to their toughness- and hardness properties to different cutting classes (application classes), which are labeled with numbers.

Thus, the range of application of a cutting material type is indicated by specifying the cutting material recognition letter and the cutting class (application class), for instance HC-P25 or CA-K10 or BH-H05.