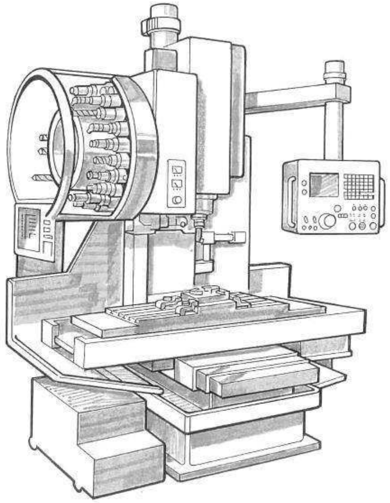
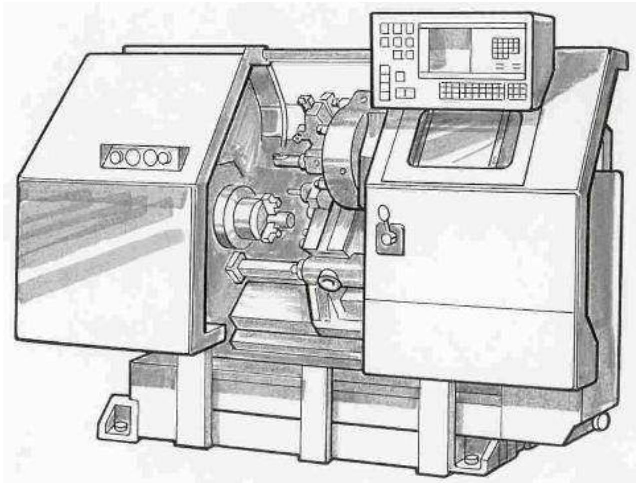
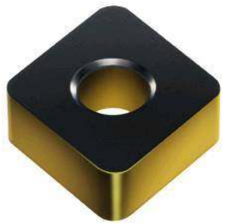


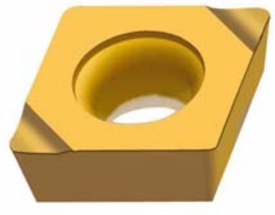


P
M
K
N
S
H

HSS
Hard metal
Cermet
Si_3N_4
CBN
PCD

Cutting materials



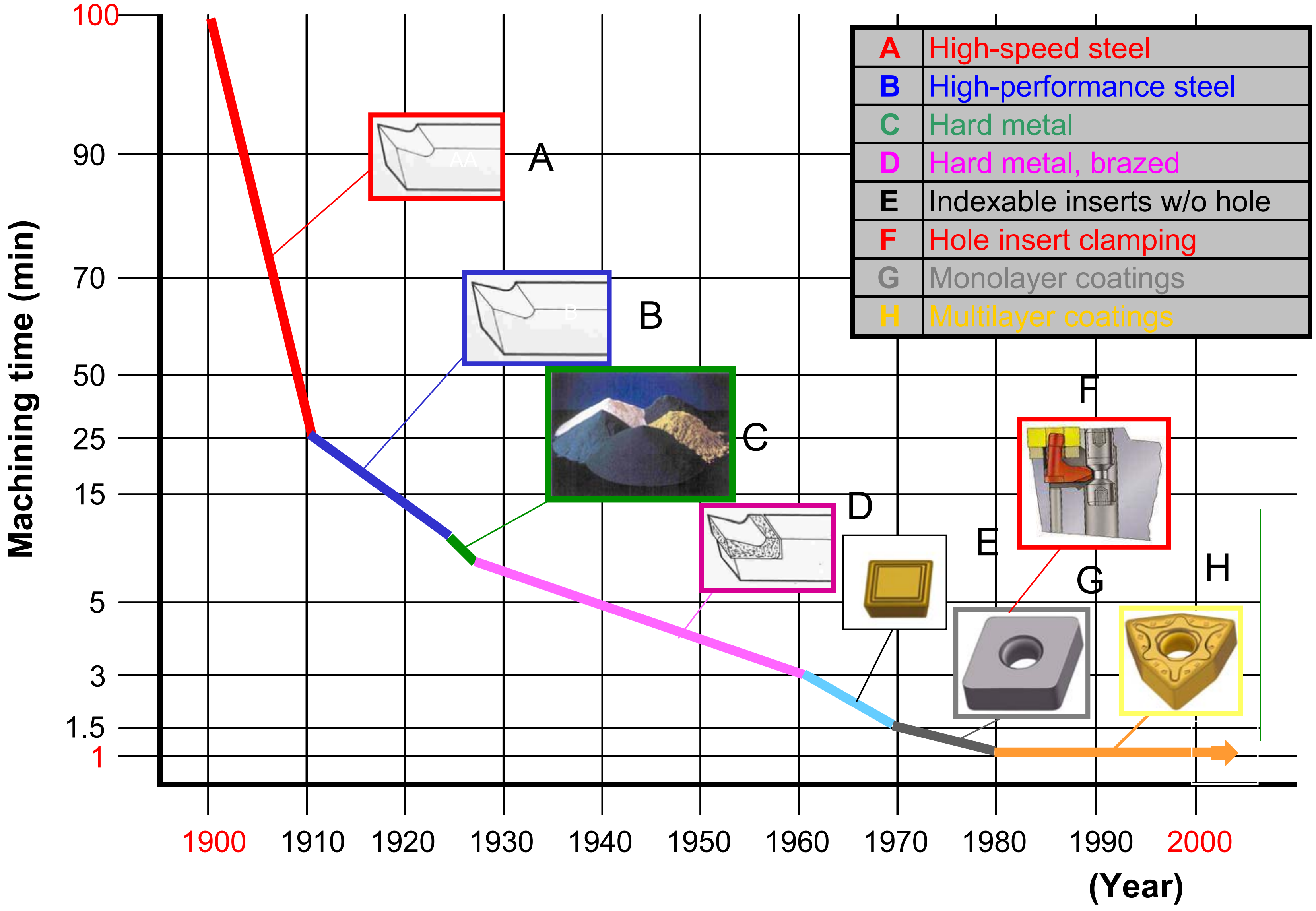


Foreword

Metal cutting today is a dynamic cutting technology which encompasses a number of scientific fields.
On the one hand it is subject to an on-going process of transformation with the changing strategies applied in the science of metal cutting and the processing industries as new workpiece materials are developed. At the same time, continuous further developments in the cutting material sector are also instrumental in triggering change.

Cutting materials are developed in order to maximize performance in the field of metal cutting by permitting high cutting speeds and greater feed rates coupled with enhanced process reliability, and so help reduce metal cutting costs.
Cutting materials are also developed for dry machining, a process which is gaining in popularity.
Today, there are cutting materials available in the machining market capable of optimizing every conceivable metal cutting operation in fields ranging from mechanical, automotive and aeronautical engineering, to the energy industry, aerospace engineering and many more.

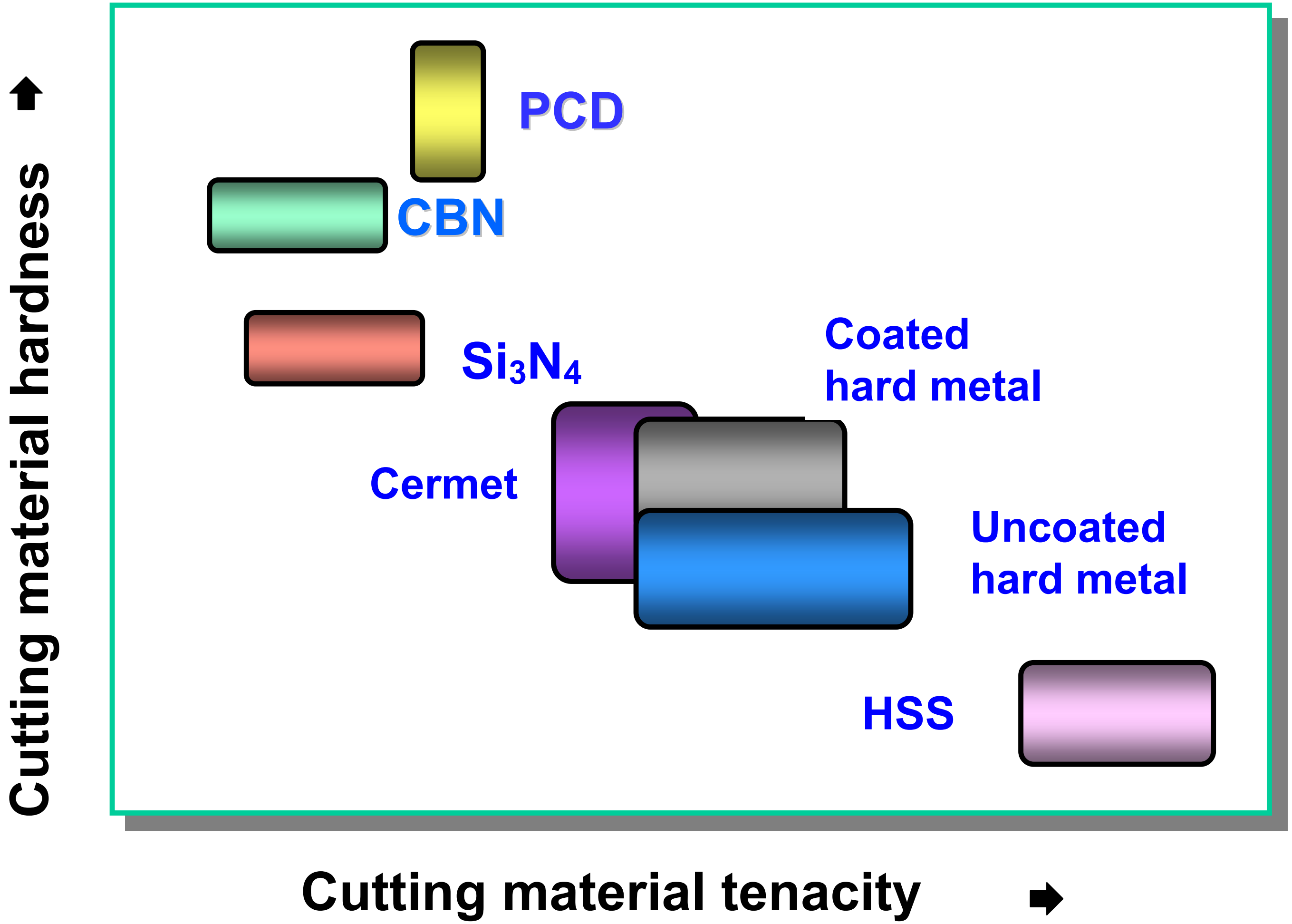
Development of cutting materials using the example of "Turning"



1. Cutting materials

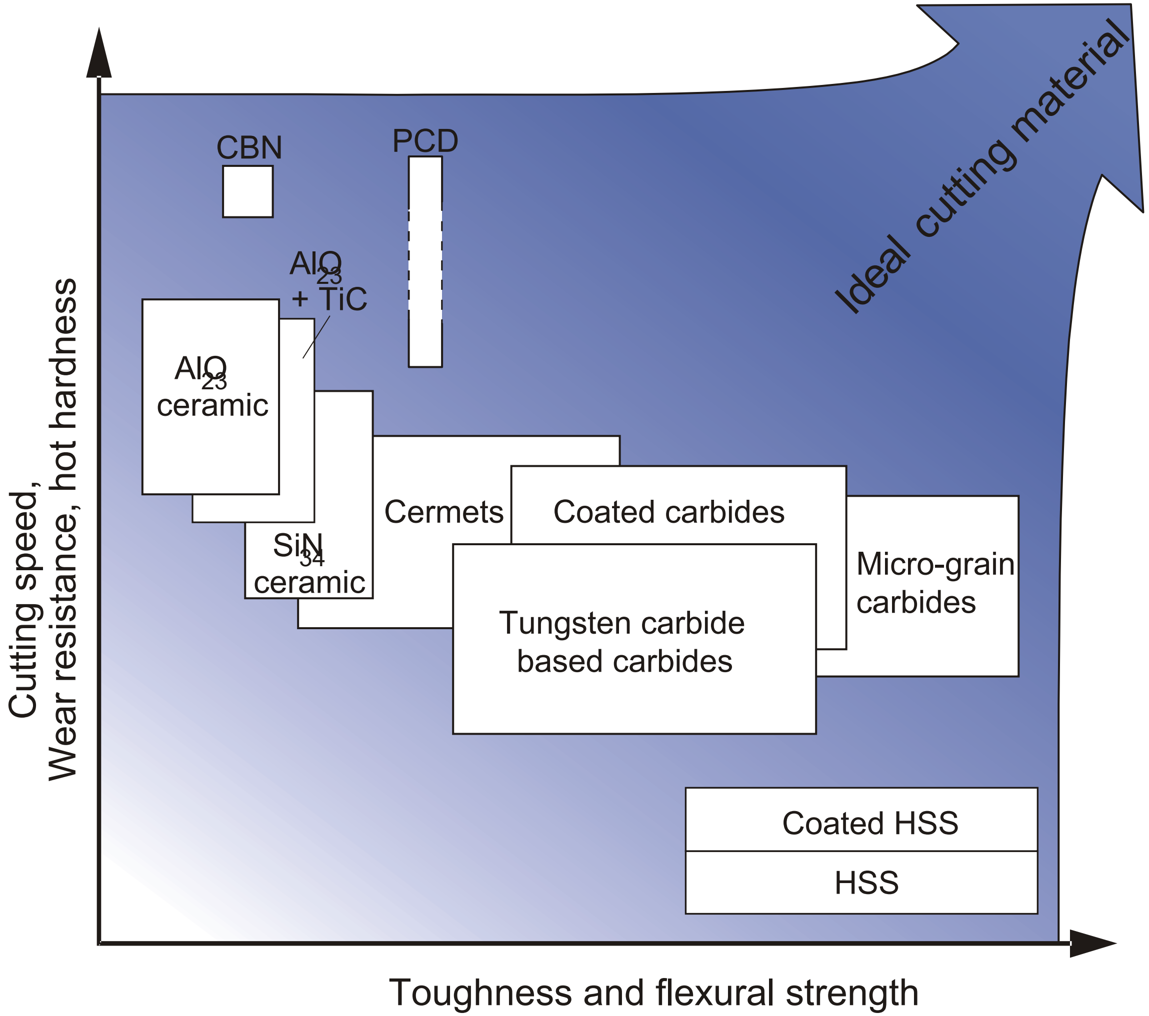
The start of cutting material development coincided with the beginning of the industrial revolution in the 18th and 19th centuries, and began to accelerate rapidly with the advent of the 20th century. Up until the 19th century, the field of metalworking remained restricted to the work of the smith before mechanically powered machines became available.
Machine tools developed rapidly in step with newly developed types of cutting materials. At the start of the 20th Century, metal cutting was still a laborious affair. Alloyed and unalloyed carbon steel qualities were the best cutting materials available at the time. Further development in the field of metallurgy culminated in the emergence of high-performance high-speed steel with a hot hardness of up to 600℃. The nine teen-thirties saw the advent of the family of hard metals. Cutting assignments which used to take 25 minutes could now be completed in just five minutes. The first types of hard metal to be developed were pure tungsten carbide-cobalt compounds (K types). Further developments resulted in steel types of hard metal based on tungsten carbide in a first phase and other complex carbides and the bonding metal cobolt as a third phase.
Hard metal coating, an important step in the development of cutting materials, was initiated at the end of the sixties. These coatings represented a milestone in the development of cutting materials which were both wearproof and simultaneously tenacious. Today, almost 90% of all hard metals used for drilling, turning and milling operations are coated.

Cutting materials for metal cutting



EZA9912D

Trends in the development of cutting materials



1. Cutting materials

1.1 What is required of modern metal cutting materials:

The material used to produce the cutting edge used for metal stock removal is known as **cutting material.**
The cutting material used is subject to high **mechanical, thermal, chemical** and **abrasive stresses** during the metal cutting process.

To ensure that the cutting materials used are able to withstand these levels of stress, they must possess the following main properties:

- The capability to resist wear **(wear resistance)**,
- Extreme flexural strength **(tenacity)**,
- The capability not to lose hardness and chemical resistance at high cutting temperatures (turning max.1100℃) **(hot hardness).**

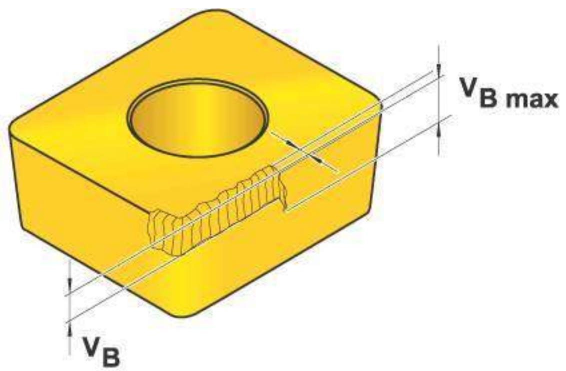
High-performance high-speed steel (HSS), hard metal, cermet, cutting ceramic, cubic boron nitride (CBN) and polycrystalline diamond (PCD) are available as cutting materials offering one or more of these properties.

Cutting material properties

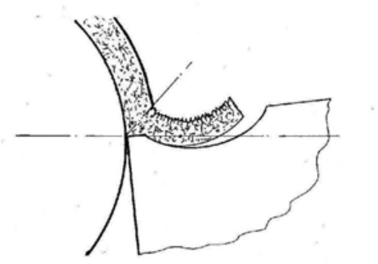
Cutting materials are subjected during use to high levels of mechanical, thermal and chemical stress.

The following properties are a requirement:

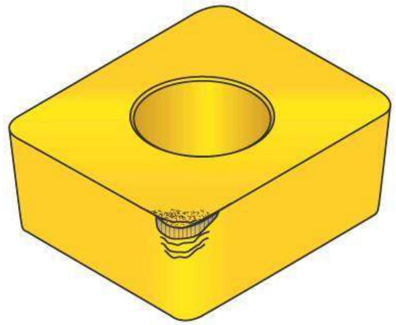
High abrasion resistance



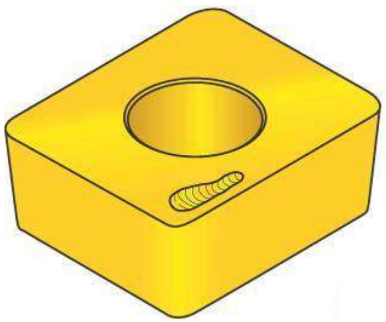
High flexural strength



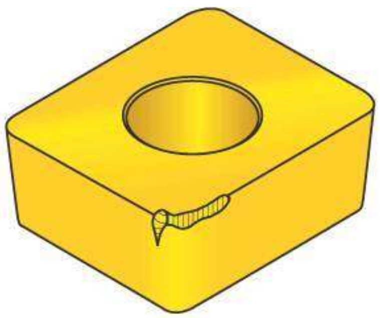
Good hot hardness, hardness and compression strength



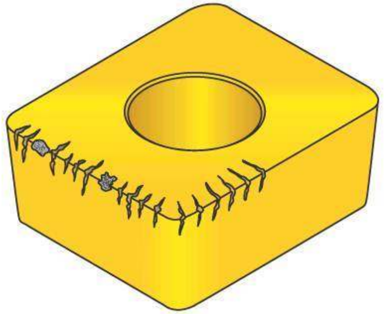
Resistance to diffusion



Resistance to oxidation



Resistance to thermal interaction



1. Cutting materials

1.2 Cutting material properties

During their application, cutting materials are exposed to high levels of mechanical and thermal stress. As cutting temperatures rise, the thermally-related causes of wear, diffusion and oxidation, assume greater importance.

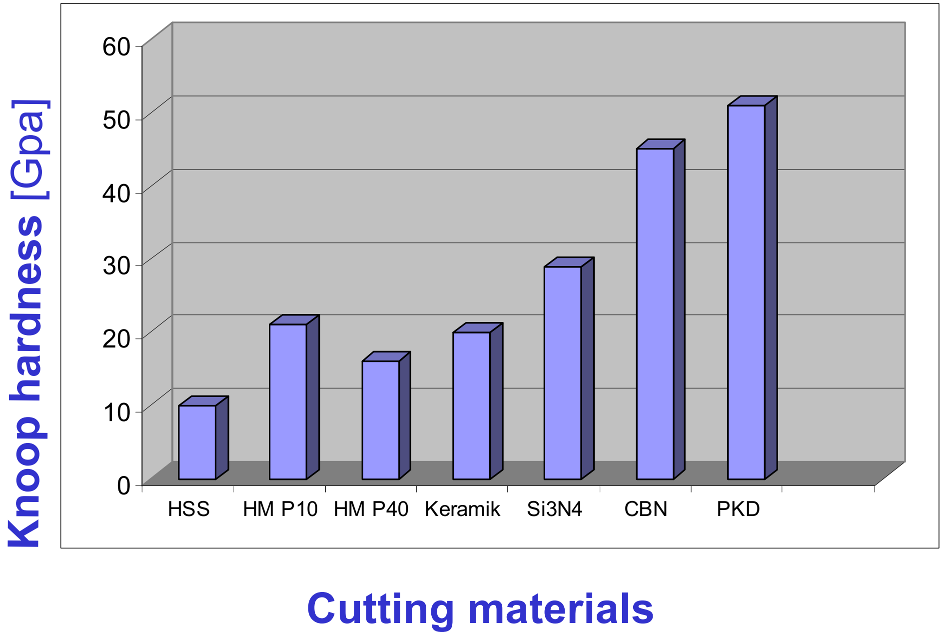
The ideal cutting material should have the following properties:

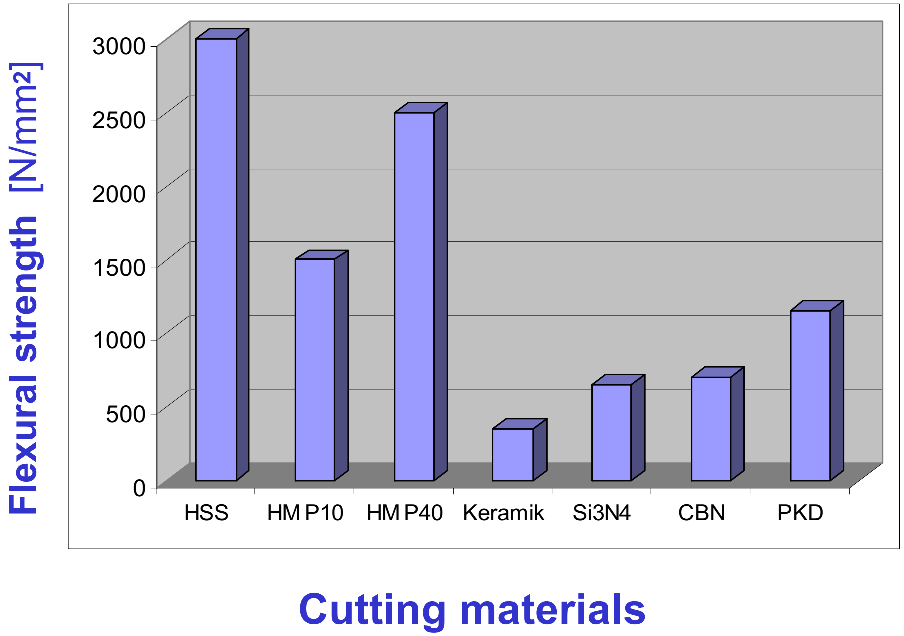
- **Good hot hardness,** permitting resistance to flank wear and plastic deformation
- **Good tenacity,** as a protection against cutting edge fracture
- **Chemical stability,** in order to resist oxidation and diffusion
- **Chemically neutral response to the workpiece material**
- **Good resistance to thermal interaction**

Alloying Elements

Alloying elements	Abbreviation	Cutting force	Chipbreaking	Wear	Machining	Typical workpiece matrials
Aluminium	**Al**	normal	poor	Built-up cutting edge Flank wear	negative	Nitrided steel
Chromium	**Cr**	high	poor	Flank wear Oxidation Plastic deformation	negative	Stainless steel
Cobalt	**Co**	high	poor	Flank wear Plastic deformation	negative	HSS
Manganese	**Mn**	high	poor	Flank wear Plastic deformation	negative	Heat-treatable steel
Molybdenum	**Mo**	high	poor	Flank wear	negative	Hot work tool steel
Nickel	**Ni**	normal	normal	Built-up cutting edge Notches	negative	austenitic stainless steel
Vanadium	**V**	high	poor	Flank wear Notches	negative	Cold work tool steel
Tungsten	**W**	high	poor	Notches Flank wear Oxidation	negative	HSS

Hardness and flexural strength of cutting materials





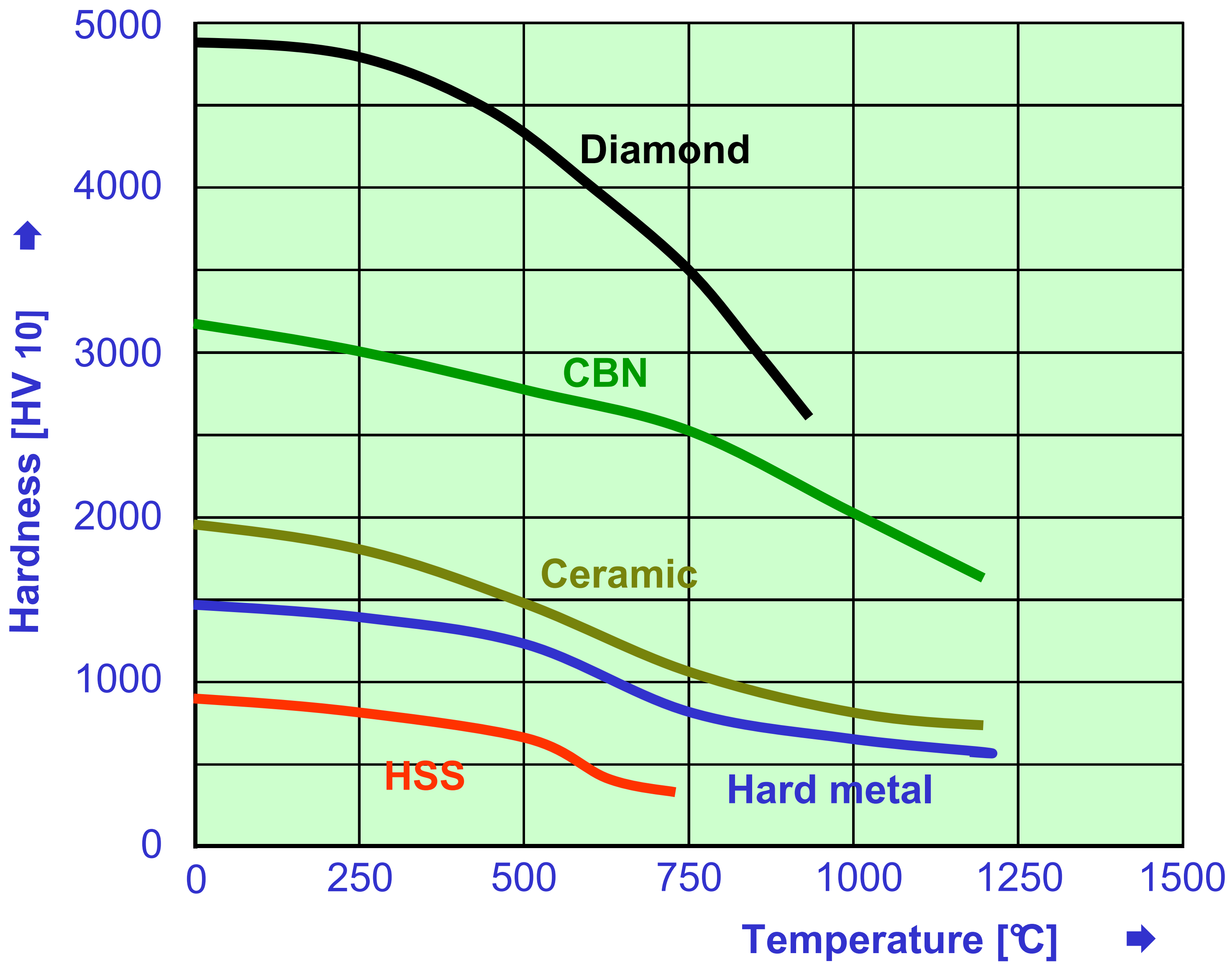
1. Cutting materials

1.3 Hardness and flexural strength of cutting materials

For the correct selection and deployment of cutting materials, the factors hardness and/or flexural strength play an instrumental role, depending on the machining operation in question. However, other conditions can also impede or even prevent the use of a certain cutting material:

- The action limit of **HSS** is reached when the metal cutting temperature exceeds 600℃.
- When machining hardened steel, **CBN** requires a minimum workpiece material hardness of 48HRc.
- **Cerme**t is suitable for metal cutting only at low feed rates (f < 0.2 mm), low cutting depths (max. 2 mm) and when the material permits homogenous stock removal.
- **Si_3N_4** has an action limit when machining nodular cast iron above a strength of 600 N/mm^2.
- Due to its affinity to iron, **PCD** cannot be used for machining steel materials and cast iron.
- **Ceramic cutting materials**, used on short-chipping cast materials, ensure maximum productivity. However, their use is subject to stability in both the workpiece and the machine.

Hot hardness of cutting materials (mean values)



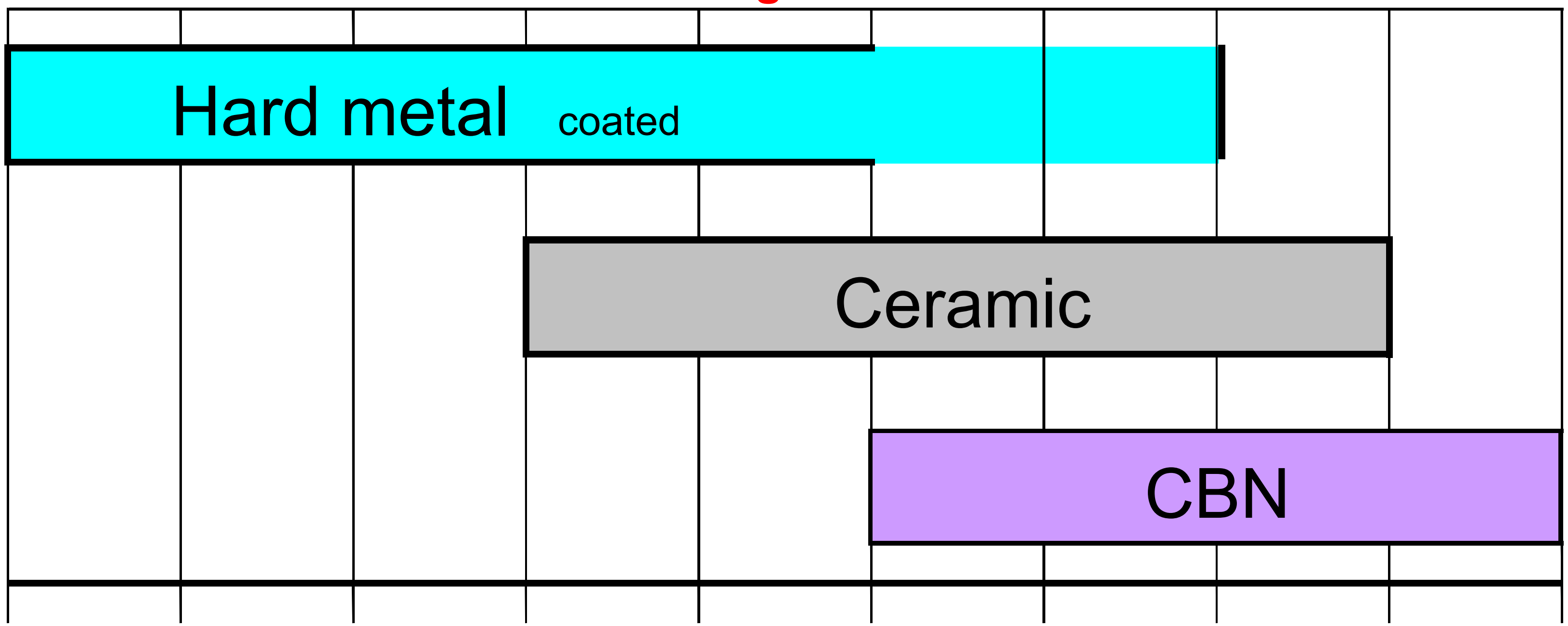
1. Cutting materials

1.4 Hot hardness of cutting materials

High cutting speeds and feed ranges as well as relatively hard workpiece materials result in a high level of heat generation and pressure (**hot hardness**) during the machining process.
For the cutting material, which is required to be resistant to this stress and not demonstrate plastic deformation, hot hardness is the decisive factor.
Typical deformation of the cutting edge results in geometric alteration of the cutting wedge, higher temperatures, chip flow alterations, and can very quickly reach a critical stage which can lead to **total fracture of the cutting edge**.

Cutting materials relative to workpiece hardness

Cutting material



Material hardness

25	30	35	40	45	50	55	60	65	70	HRc
250	285	325	380	420	485	560	HB			
860	970	1100	1290	1430	1670	2000	N/mm^2			

1. Cutting materials

1.5 Cutting materials relative to workpiece hardnesses

The issue of which cutting material to use for which workpiece material arises where both the hardness or strength of the workpiece material are close to the feasibility limits. The need to still achieve “economical metal cutting” is often a factor here, while in many cases the economy of a metal cutting process has been sacrificed in the search for a compromise solution.

For the field of **long-chipping steel materials**, the most commonly used cutting material is **hard metal (coated)**.

Ceramic cutting materials are used almost as an equivalent to hard metal for **short-chipping cast materials**.

The field of application for **cubic boron nitride (CBN)** encompasses **short-chipping cast workpiece materials and hard steel workpiece materials above 48HRc.**

Selection factors for cutting materials

Machine tool

- Thermal stability
- Stat. and dyn. rigidity
- Geom. and kinetic precision
- Performance

Process

- TURNING
- TURNING with interrupted cut
- MILLING
- DRILLING

Tool

- Geometry
- Cutting material
- Coatings

Workpiece material

- Chemical composition
- Microstructure
- Hardness

Metal cutting process

- Chip breaking
- Service life
- Cutting force
- Surface quality of the workpiece

Cutting conditions

- Cutting speed
- Cutting depth
- Feed
- Cooling lubricant

1. Cutting materials

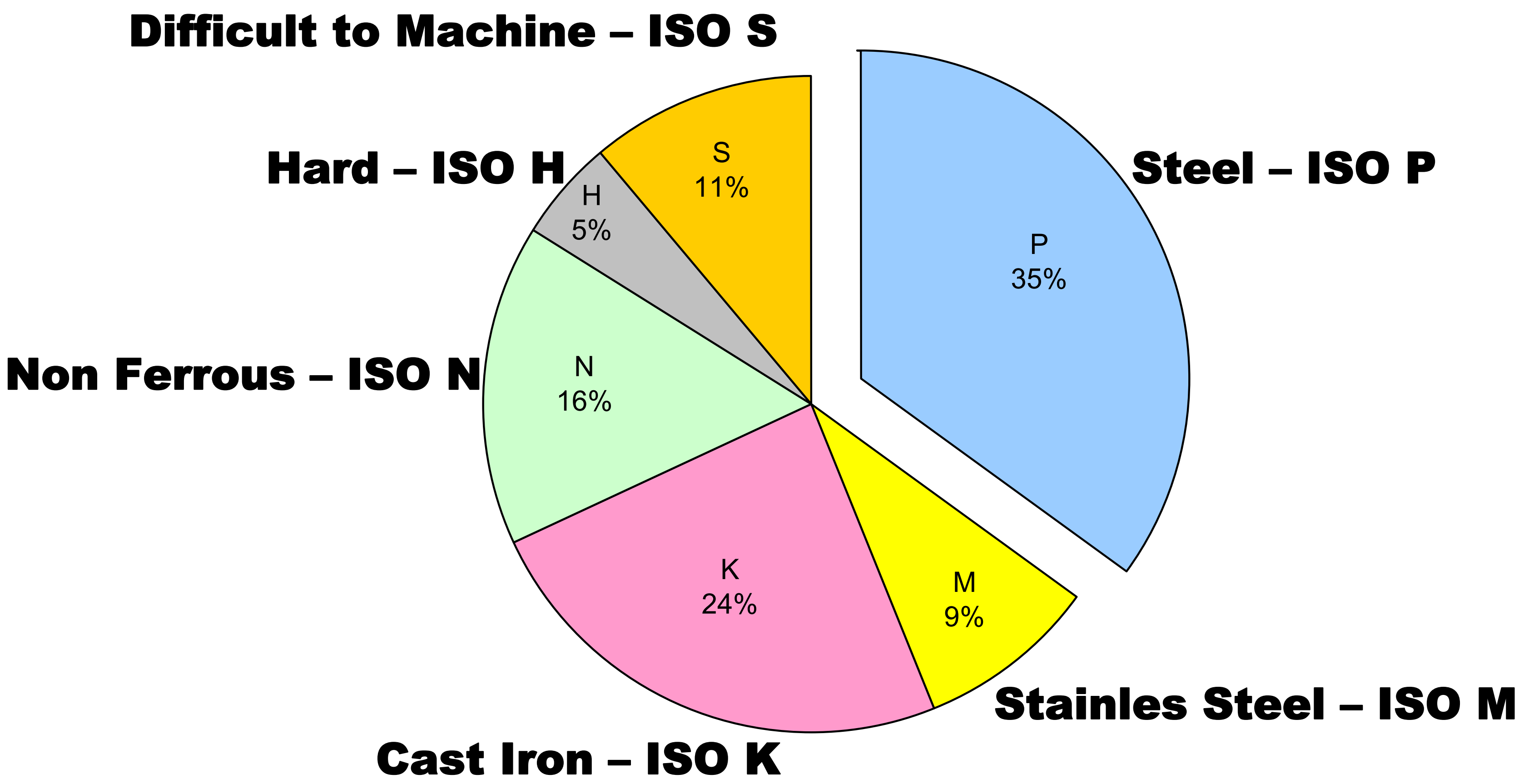
1.6 Selection factors for cutting materials

The right selection of cutting material exerts an enormous influence on the achievable life of tools and so on the produced piece numbers and tooling costs.
The must **suitable tool** for a machining operation **must be a combination of geometry and cutting material**, which must be selected and adapted with consideration to the following basic factors:

- The cutting method (drilling, turning, milling)
- The characteristics of the workpiece material being cut and the shape of the workpiece
- The condition of the workpiece blank (forged, cast etc.)
- The thermal, chemical and mechanical resilience of the cutting material
- The machining parameters (cutting speed, feed rate, cutting depth etc.) depending on the cutting material.
- Machine tool related factors such as output, stability etc.
- The type of workpiece clamping.

If there are **several cutting materials technically suitable** for any particular metal cutting operation, **then the one offering economic benefits is given preference.** Cost and feasibility calculations therefore represent a priority issue in the choice of cutting material.

Material to machine World Wide



1.7 Overview of cutting materials worldwide

Today, hard metals account for around half of the total consumption of cutting materials, and have consequently assumed the role occupied by HSS in the nineties.
There has been speculation over recent years about where hard metal will reach the limits of its usefulness as a cutting material, and where the effects of coatings will be exhausted.
It is frequently predicted that ceramic materials, cermets and new HSS developments will take over many of the application fields currently dominated by hard metals. However, in the meanwhile developments in the field of cutting materials have shown that hard metals still continue to make continuous advances as a cutting material.
The reason for this is the constant endeavour to achieve improved performance for coated hard metal types and to improve wear resistance of the coatings used relative to the tenacity of the substrate.
The introduction of wide-ranging different new coated hard metal types in line with the ISO classification system for workpiece material applications has also served to extend the field of application for carbides.
These objectives can only be achieved through specific research and development activities.

High speed steel (HSS)

Steels

Structural steel

Application for:
Mechanical and automotive engineering, steel construction, equipment engineering

Subdivided into:

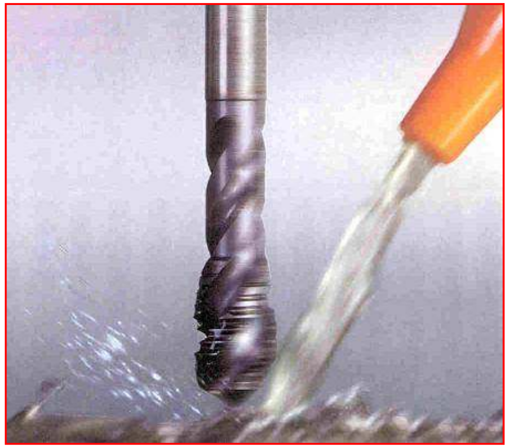
Unalloyed struct. steel	Creep-resistant steel
Fine grain struct. steel	Highly creep-resistant steel
Free cutting steel	Heat resistant steel
Case-hardened steel	Stainless steel
Heat-treated steel	Austenitic steel
Nitriding steel	
Spring steel	

Tool steel

Application for:
Cutting tools, press dies, injection moulding dies
Manual and machine tools

Subdivided into:

Cold work tool steel
Hot work tool steel
High-speed steel (HSS)



2. High speed steel (HSS)

The application of high speed steels (HSS), which are classified into four different alloy and performance groups, is determined by their composition.
HSS is a high-alloy tool steel with an alloy content of up to appr. 35%.
The **martensite** age-hardened in the basic microstructure and the **interstitial carbides** (in particular molybdenum tungsten double carbide, chrome carbide and vanadium carbide) **determine** the **hardness** and the **wear resistance. Alloying chrome** promotes the **formation of carbide** and **through hardening**.

The **action limits of HSS** are reached when the machining temperature reaches a range from **550°- 600℃** . From this range, high-speed steel tends to demonstrate **thermal** overloading and the cutting edge becomes plastified.
This limits the **cutting speed range of HSS for steel machining to a maximum of 40 m/min.**

High speed steel HSS and HSS- C

2. High speed steel (HSS)

2.1 High speed steel HSS and HSS- C

The benefits of thin carbide layers of the type used since the end of the sixties in coating hard metal can also be used to improve the wear properties of high-speed steel. The basic coating method used is that of **PVD** (**p**hysical **v**apour **d**eposition).

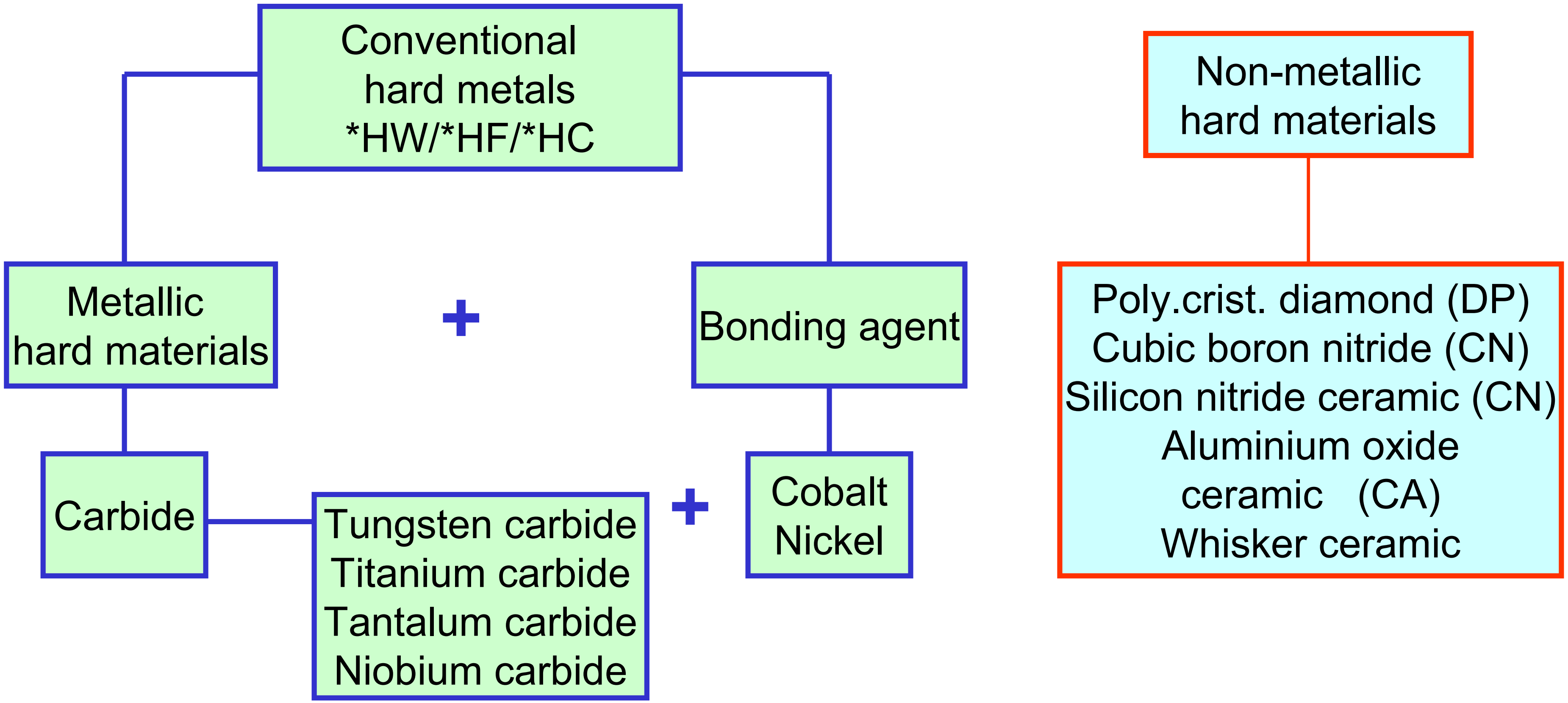
PVD is a low-temperature process performed at appr. 500℃. Coating serves to reduce **wear, friction** and consequently **heating, oxidation and diffusion**.

The fields of application for coated HSS are the same as those for uncoated HSS.

However, HSS is capable of closing the cutting speed gap between appr. **40 m/min** and **80 m/min** left by uncoated HSS and hard metal.

Concentric tools form the main field of application for HSS-C, for example helical drills, thread taps, milling cutters, countersinks etc., i.e. metal cutting tools with a highly positive cutting wedge and sharp cutting edges.

Metallic hard materials



*HW = Uncoated hard metal
*HF = Fine grained hard metal
*HC = Coated hard metal

3. Metallic hard materials

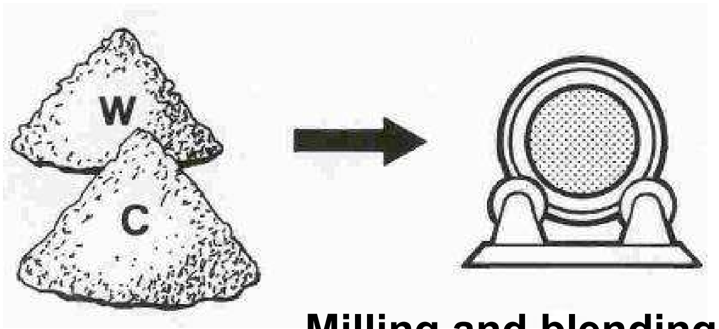
The term **"HARD MATERIALS"** encompasses materials with a Vickers hardness of over 1000HV.

The **main components** of the cutting material **hard metal** are metallic hard materials (carbide, nitride, silicide and boride).
These are represented in the following chemical compounds:

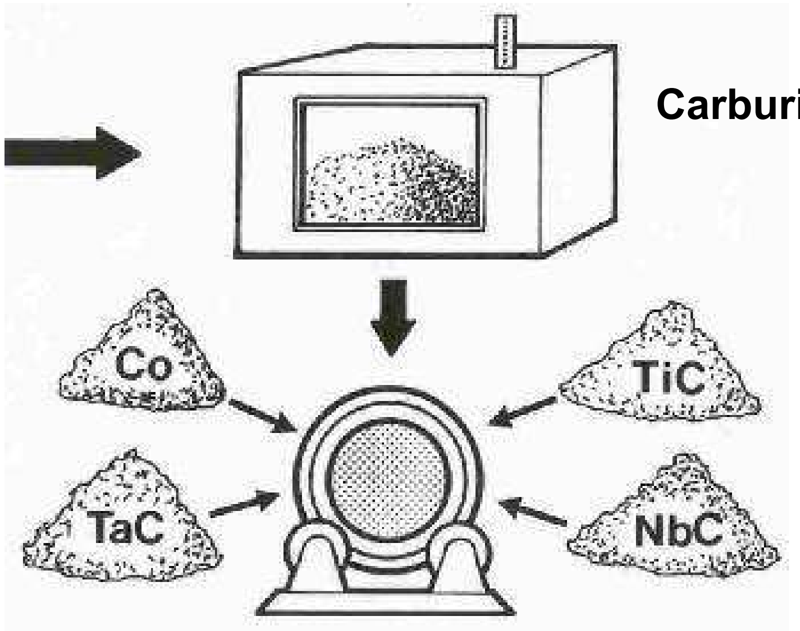
Titanium carbide	**TiC)**
Titanium nitride	**(TiN)**
Titanium diboride	**(TiB_2)**
Circonium carbide	**(ZrC)**
Circonium diboride	**(ZrB_2)**
Niobium carbide	**(NbC)**
Tantalum carbide	**(TaC)**
Chromium carbide	**(Cr_3C_2)**
Chromium boride	**(CrB_2)**
Molybdenum silicide	**($MoSi_2$)**
Tungsten carbide	**(WC)**

Of **particular importance** for the field of hard metal technology are the **carbides.**

Metallic hard material: Hard metal



Milling and blending



Carburization

Mixing to a powder

HARD material + METAL bond = Hard metal

Mixing carbides

WC= Tungsten carbide
TiC= Titanium carbide
TaC= Tantalum carbide
NbC= Niobium carbide

Bonding agent

Co= Cobalt

3. Metallic hard materials

3.1 Metallic hard material: hard metal

Hard metal is a cutting material made up of carbide particles held together by a bonding agent.

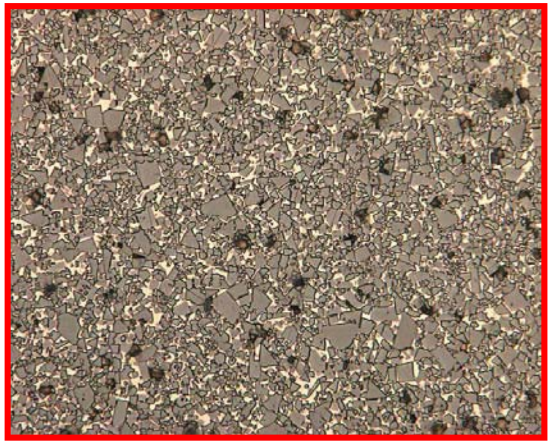
These **carbides** are extremely hard. The most important of them are:

Tungsten carbide	**(WC)**
Titanium carbide	**(TiC)**
Tantalum carbide	**(TaC)**
Niobium carbide	**(NbC)**

The **bonding agent** used is predominantly

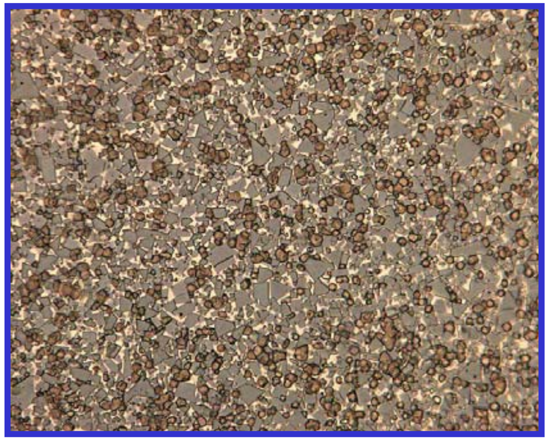
Cobalt (Co)

Structures of hard metal



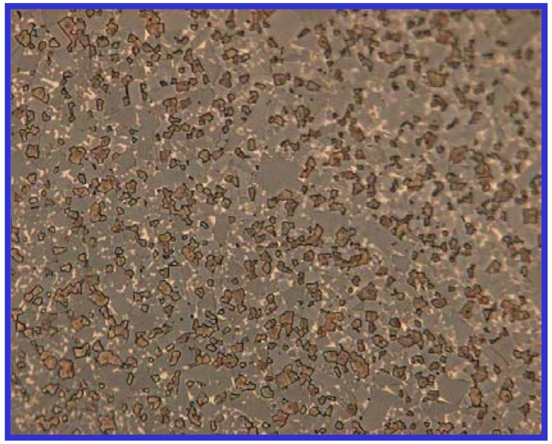
K type,
high amount of bonding agent

Fine grained type



P type,
high amount of bonding agent

K type,
low amount of bonding agent



P type,
low amount of bonding agent

3. Metallic hard materials

3.1.1 Structures of hard metal

Pure WC-Co hard metals, so-called **K types**, were available right from the early days of hard metal development, and were used predominantly for **machining short-chipping cast materials**. This is a two-phase hard metal with a hard tungsten carbide phase (α phase) and that of the highly tenacious cobalt binding metal (β phase).

By mixing in other carbides such as titanium carbide, tantalum carbide and niobium, hard metals with greater wear resistance **– P types** – were developed specifically for **machining long-chipping steel workpiece** materials.
Three-phase hard metals were developed with an additional phase in titanium, tantalum and niobium carbides (γ phase).
By varying the **grain size and the bonding agent, it is possible combine hardness and tenacity,** whereby large grit sizes and a higher proportion of bonding agents increase the tenacity of hard metals, while file grit sizes (fine-grained hard metals) and a low proportion of bonding agent lend hard metals a relatively high degree of hardness.
In this way, different hard metal compositions and structures can address differing metal cutting conditions.

Hard metal properties

	Increasing **WC** content	Increasing **Co** content	Increasing **TiC** content	Increasing **TaC** content	Increasing **grain size**
Hardness	+	-	++	+	-
Compressive strength	+	-	o	o	-
Abrasion resistance	++	--	+	+	-
Hot hardness	+	-	++	+	-
Flexural strength	-	++	-	-	+
Diffusion inertia	o	o	+	+	o
Oxidation resistance	-	o	++	+	o
Thermal cycling resistance	o	+	-	+	-
Edge strength	o	o	-	+	-
Modulus of elasticity	++	-	+	+	o
Abrasion resistance	+	-	+	+	-
Tenacity	-	+	-	+	+

++ Marked influence

- - Marked influence

+ - Influence

O No perceptible influence

3. Metallic hard materials

3.1.2 Hard metal characteristics

Characteristics of alloying elements:

Tungsten carbide (WC)
WC provides a high degree of hardness and wear resistance. Linking WC with cobalt at sintering temperature brings about good cohesion and a pore-free microstructure.

Titanium carbide (TiC)
Possesses a high degree of hardness and low diffusion tendency. TiC increases diffusion resistance, but demonstrates a reduced inner bond strength (tenacity) of the cutting material.

Tantalum carbide (TaC), niobium carbide (NbC)
Increases diffusion resistance. Tenacity, wear resistance and hot hardness are improved.

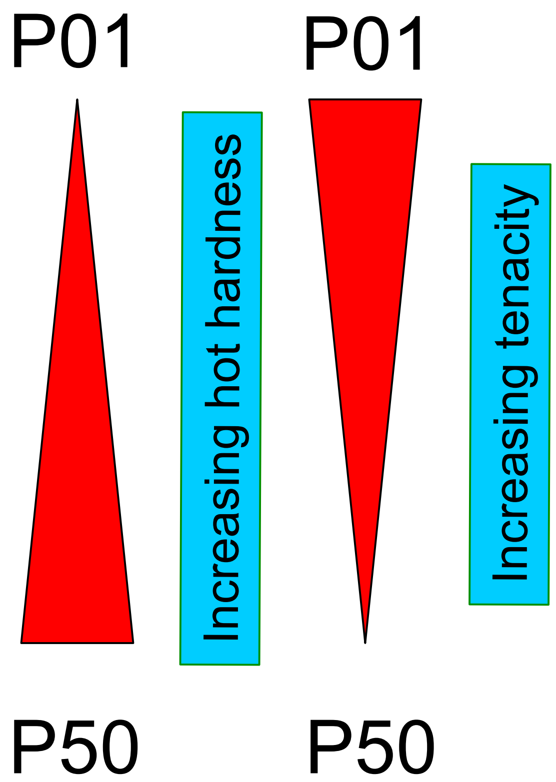
Cobalt (Co)
The cobalt content largely determines the tenacity of the hard metal.

ISO classification of hard metal (1)

Blue P
- denotes the machining of long-chipping materials such as steel, cast steel and stainless steel.

Yellow M
- denotes the machining of austenitic stainless steel and heat resistant materials.

Red K
- denotes the machining of short-chipping materials such as grey cast iron, malleable cast iron, nodular cast iron and vermicular cast iron

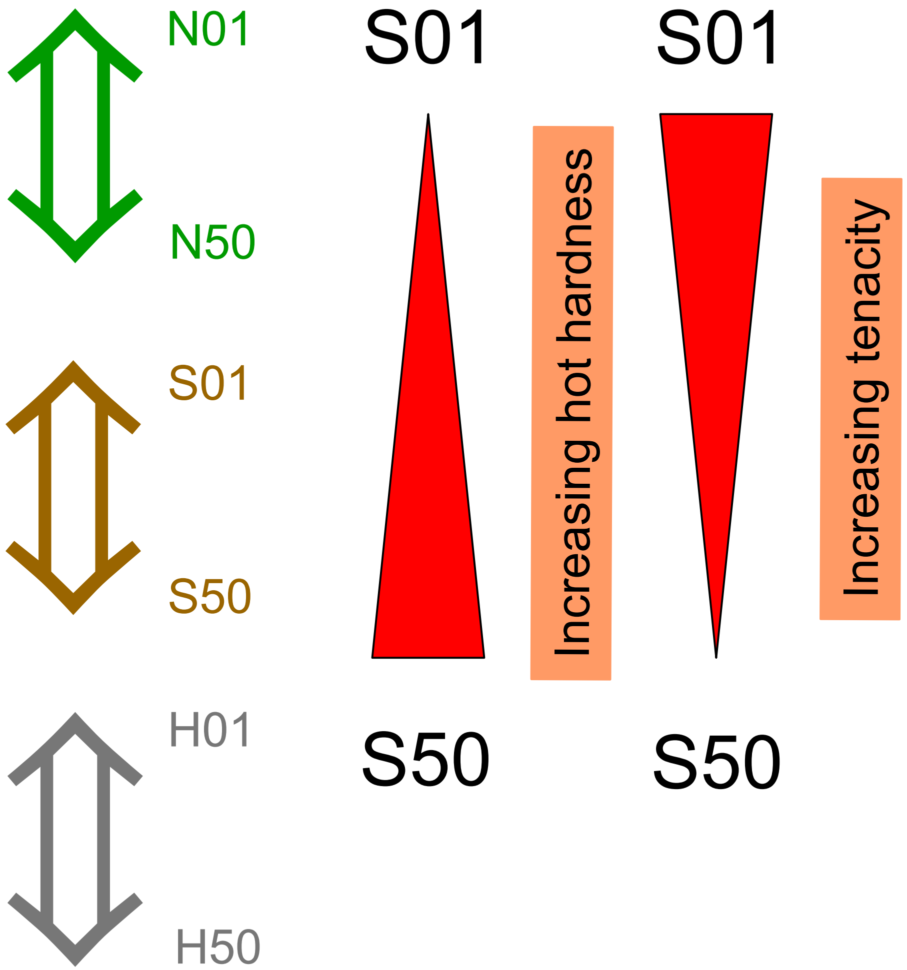


ISO classification of hard metal (2)

Green N
- denotes the machining of aluminium and other non-ferrous metals, non-metal materials.

Orange S
- denotes the machining of high-temperature resistant nickel and cobalt alloys as well as titanium and titanium alloys.

White H
- denotes the machining of hardened steel, hardened cast iron materials as well as mould castings and manganese steel.



3. Metallic hard materials

3.1.3 ISO classification of hard metal (1)

Hard metals are subdivided by ISO (ISO standard 513) into six groupings (P, M, K, N, S, H) in order to create a clearer overview and guarantee the identification of hard metals in operation.

Blue **P** denotes the machining of long-chipping materials such as steel, cast steel and stainless steel.

Yellow **M** denotes the machining of austenitic, stainless steel and heat-resistant materials.

Red **K** denotes the machining of short-chipping materials such as grey cast iron, malleable cast iron, nodular cast iron and vermicular-graphite cast iron.

Green **N** denotes the machining of aluminium and other non-ferrous metals, as well as non-metallic materials.

Orange **S** denotes the machining of high-temperature resistant nickel and cobalt alloys as well as titanium and titanium alloys.

White **H** denotes the machining of hardened steel, hardened cast iron materials as well as mould castings and manganese steel.

3. Metallic hard materials

3.1.4 ISO classification of hard metal (2)

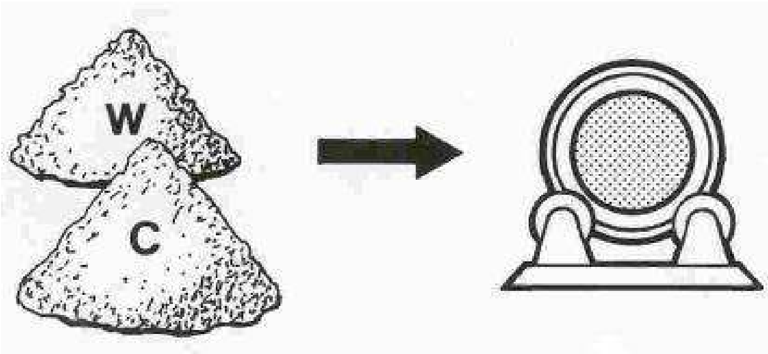
The International Standards Organisation (ISO) has created a **classification system for certain application fields**. Here, workpiece materials to be machined are placed in opposition to the characteristics of hard metal. The P group, for instance, encompasses long-chipping steel materials.
Each group is subdivided into **sub-groups from 01 - 50**, whereby greater tenacity is required of the cutting edge as the numbers rise, while in descending numerical order greater wear resistance is required of the cutting edge.

Starting with **Group 01**, which includes materials for finishing work with high cutting speeds and low feed rates; **Group 25** encompasses cutting speeds and feed rates for medium metal cutting, and so on upward to **Group 40 / 50** for rough machining at low cutting speeds, with large removal cross-sections and changing machining conditions.

The subgroups of the ISO classification refer exclusively to the cutting material hard metal and do not include ceramic, CBN or PCD cutting materials.

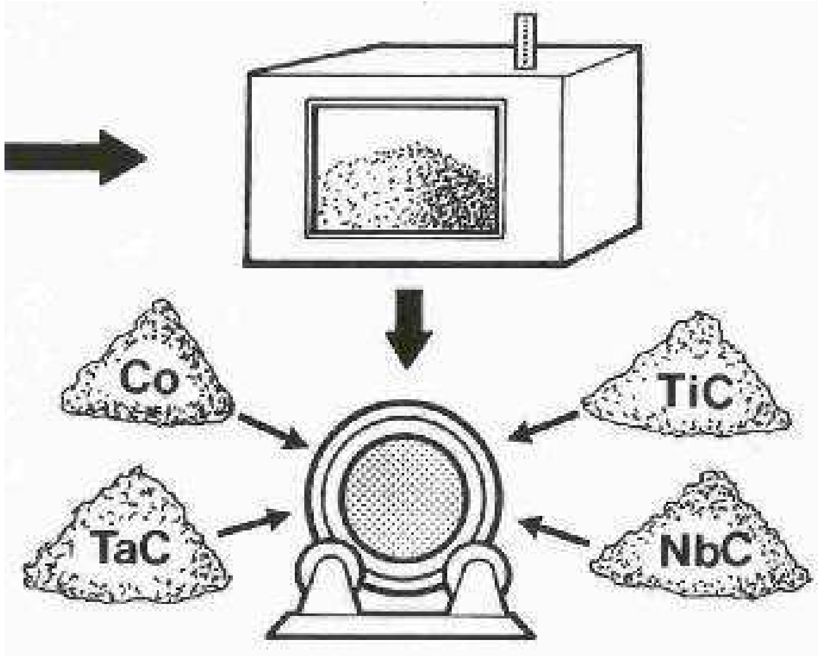
This classification is standardized in DIN/ISO 513.

Composition of press-ready powder



Mixing
Carburization
1500-1800℃

Tungsten carbide (WC)
Grain size
0.6 - 6µm



The proportion of mixing carbides is between 0% and 25%, of metal binding agent between 3% and 15%.

Pressing agent = 1 - 2% paraffin

3.1.5 Composition of press-ready powders

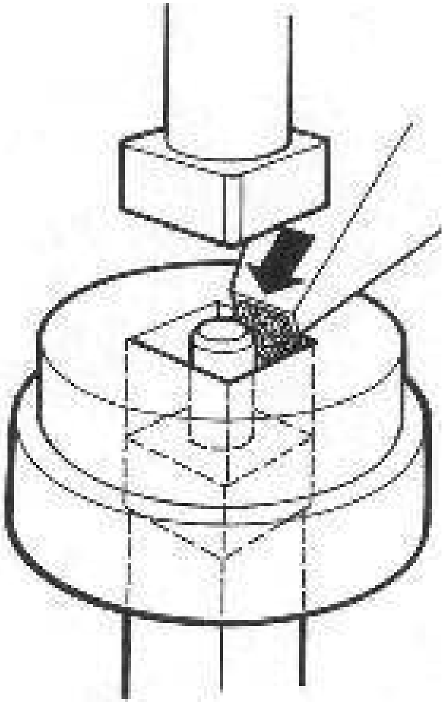
Hard metal can only be manufactured by means of powder metallurgy.

The sourcing of raw materials and the energy-intensive processing methods help to make hard metal raw materials relatively expensive. Some hard metal manufacturers start their production process with tungsten carbide powder in different grit sizes, others prefer to produce not only the carbide but also the metal from chemically pure tungsten compounds. Depending on the required hard metal type, the necessary quantities of tungsten carbide with a defined grit size characteristic, complex carbides of a defined composition and cobalt are precisely weighed and prepared for milling.

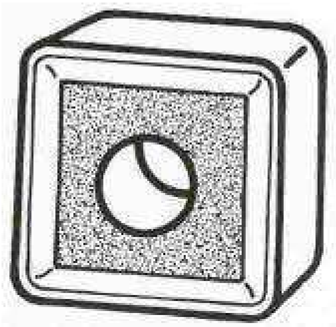
The wet milling method used exclusively today serves to transform the powder constituents into an ultra-finely dispersed conglomerate. After the milling process, the wet sludge is passed through a sieve and the milling fluid and powder separated. As filling the press mould when using automatic pressing processes calls for particularly **good pourability** in the powder, the dried powder must subsequently be transformed into granulate. The **pressing agent** (e.g. 1-2% paraffin wax) is generally added during the course of drying.

Pressing of (hard metal) powder

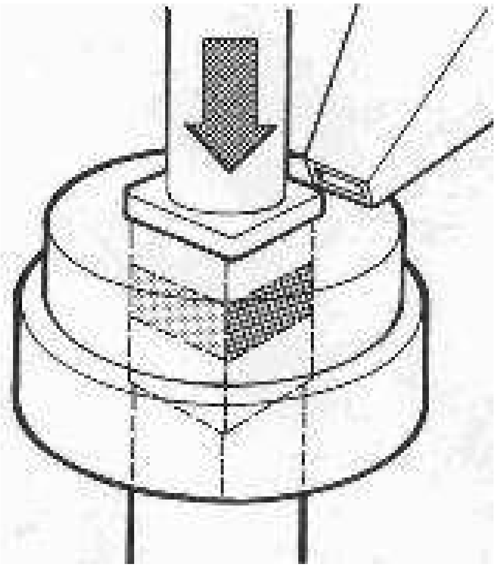
Filling



Pressed microstructure



Pressing



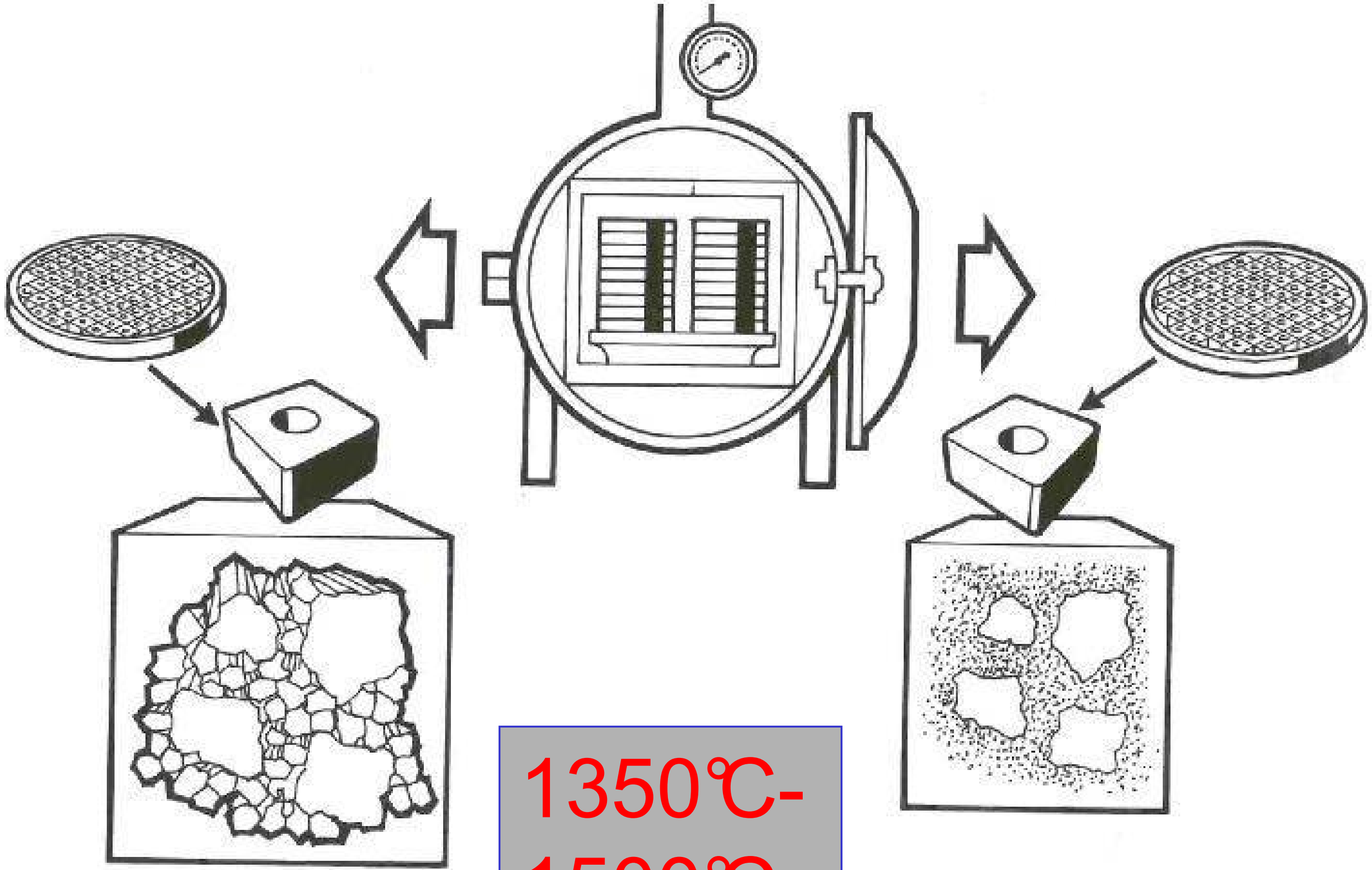
Porosity= 50%
Shrinkage factor= 17%-20%

3. Metallic hard materials

3.1.6 Pressing of (hard metal) powder

The manufacture of indexable inserts for metal cutting or other moulded parts made of hard metal begins with moulding by hand (hand forming) or moulding using pressing dies.
The **efficient method of moulding** is **direct pressing** in pressing dies in high-speed automatic mechanical or hydraulic presses.
The filling of press moulds naturally calls for powders with particularly good **pouring properties**.
As a result of pressing in single or double-sided automatic presses, the blank is given its basic shape, but not the measurements it is required to demonstrate in its sintered state. This type of “**compact**” has a **porosity (shrinkage) of appr. 50 % by volume, which disappears completely after the sintering process. The linear shrinkage factor for the width, height and length dimension is between 17 and 20%.**
These dimensions must be taken into consideration as early as the design of the press dies (male and female die).
As the carbides used (WC, Ti, Ta, Nb) do not have plastic deformation capability, the pressing forces are between 1.5 – 1.8 tons per cm^2 (150 – 180 MPa). The benefit of the pressing method for producing hard metals is the ability for direct moulding and also the achievable piece numbers at between 15 and 20 strokes per minute. Alternative methods are: Injection moulding, extrusion pressing, cold isostatic pressing.

Hard metal sintering



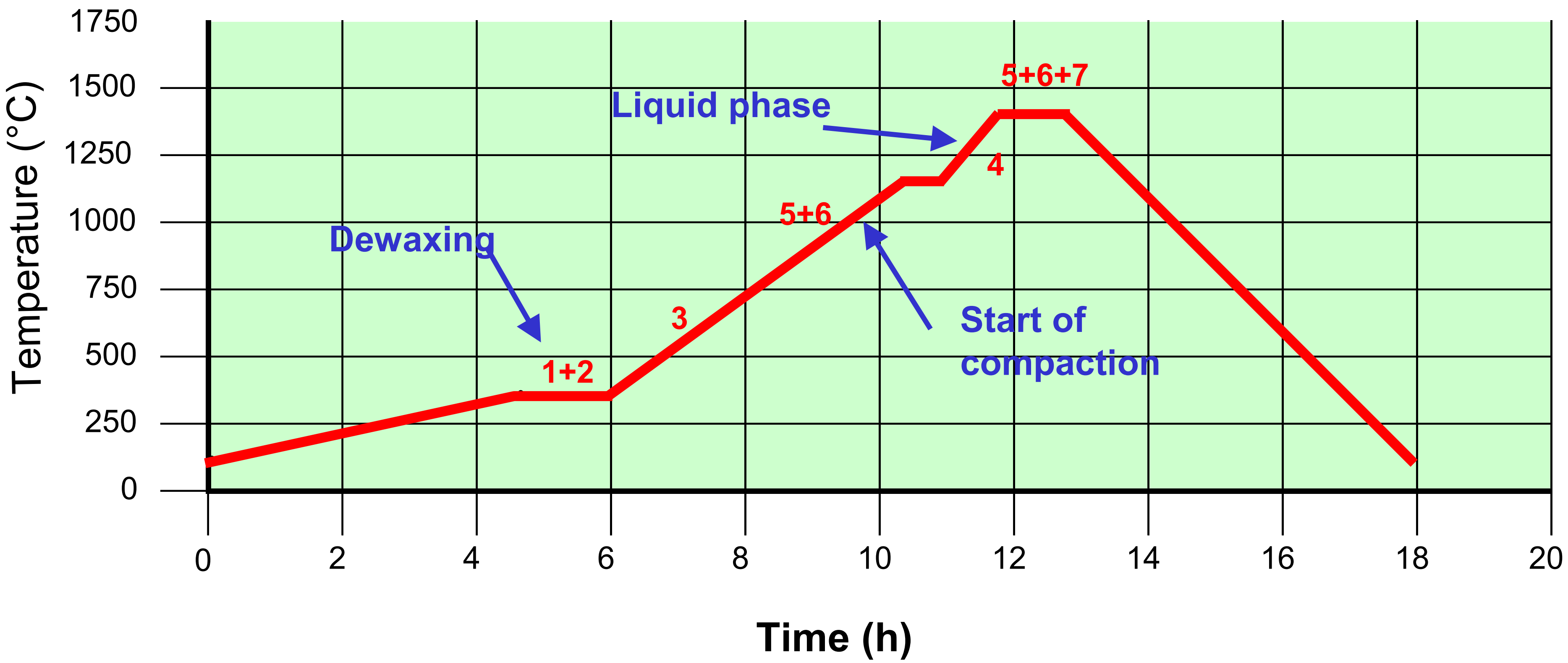
1350℃-
1500℃

3. Metallic hard materials

3.1.7 Hard metal sintering

Sintering requires first and foremost precise temperature regulation, process sequence times and a suitable atmospheric environment in order to complete the enormous transformation from a porous powder compact to a dense hard metal blank and so to the best possible cutting material available.
The compacts prepared ready for sintering on graphite plates are placed in the sintering oven. Initially during the heating-up process, the compacts reach the critical range at which the pressing aid (paraffin) is expelled.
The sintering process must be precisely temperature and time controlled in order to ensure that the produced carbide demonstrates the required characteristics.
During the sintering process, a reaction occurs which is called **liquid phase sintering**, meaning that on reaching the relevant prescribed sintering temperature of 1350 to 1500℃, the bondin g agent (cobalt) is melted and a not insignificant quantity of carbide has dissolved.
The capillary forces which occur during sintering cause the pores to close, while the powder grains join primarily as a result of diffusion.

Temperature – time progression during sintering



3. Metallic hard materials

3.1.8 Temperature-time progression during sintering

1. Dewaxing phase
2. Homogenization
3. Dissolution of carbides in the binding phase
4. Formation of the liquid phase (binder metal); new arrangement of carbide grains
5. Compaction, shrinkage
6. Grain growth process
7. Degradation of interfacial energy due to re-arrangement process of individual grains

3. Metallic hard materials

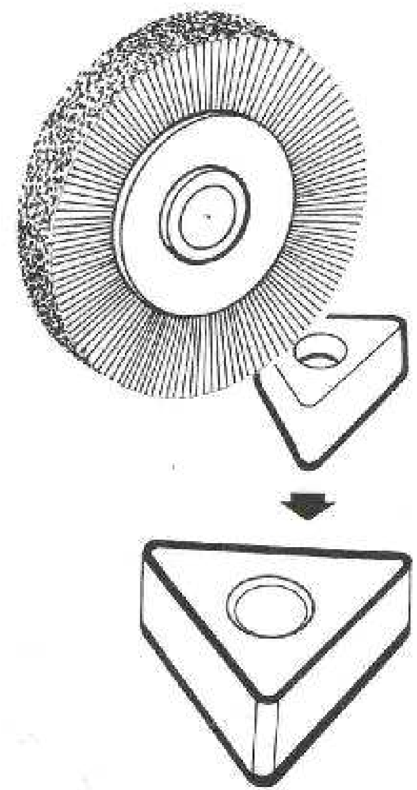
3.1.9 Grinding the contact surfaces

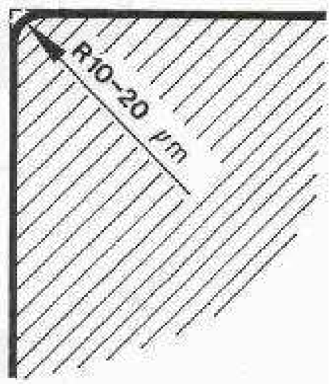
Special grinding machines are generally used to grind the contact surfaces **(face grinding**) of indexable inserts. On these machines, the two face surfaces are ground between two diamond grinding wheels inclined slightly towards each other, whereby the indexable inserts are embedded in steel cages.

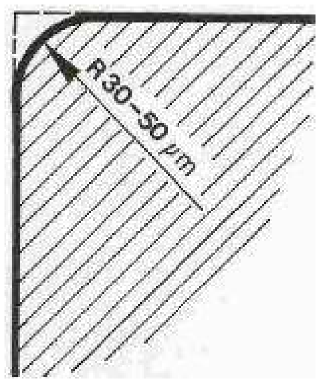
The **contact surfaces** of the indexable inserts, which can be a one or two-sided version, **are ground** firstly **in order to guarantee the precision of the tool (centre height**) and **more importantly to ensure improved heat dissipation during the metal cutting process.**

Hard metal is a poor conductor of heat, i.e. the entire metal cutting energy (heat) is stored primarily in the hard metal. During the metal cutting process turning, for example, when working with the parameters of an HC- P10 type, metal cutting temperature levels of 1000℃ are reached close to the cutting edge radius.
In most clamping systems used for turning, bilaterally ground carbide underlays are integrated in order to improve the dissipation of heat.

Rounding the cutting edges







3. Metallic hard materials

3.2.1 Rounding the cutting edges

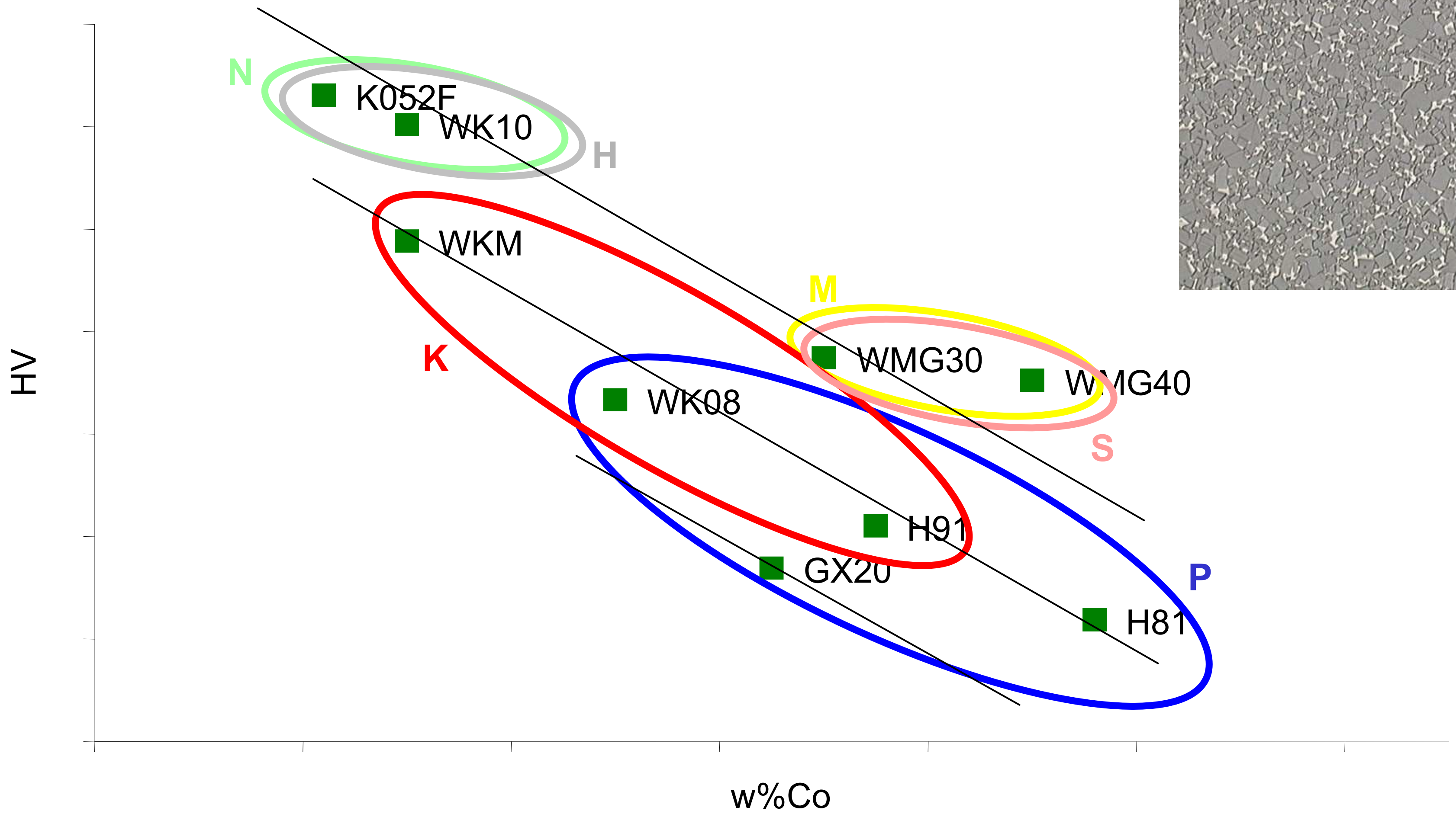
By pressing and sintering in the press mould, a precision-sintered hard metal blank has been created in its basic shape and with its finish-sintered cutting edges and corner radii.

However, due to the manufacturing process, at the **precision sintered cutting edges** there is a slight burr formation which is dangerous for the subsequent metal cutting process.

The cutting edges should be protected for the metal cutting process. **Chamfering or rounding in order to stabilize the cutting edges** was a customary practice as far back as soldered hard metal tools.
Most indexable inserts have corner-rounded cutting edges. This treatment of the sintered blank by means of brushing or blasting produces a rounding effect and stabilizes the cutting edge.

Depending on the size of the indexable insert, the cutting edge radius, hard metal sort and application conditions during metal cutting, **the rounding effect is between 10 µm and 100 µm.**

The right Substrate



3. Metallic hard materials

3.2.2 Base hard metals and substrates

Base hard metals (classical hard metals):

Uncoated hard metals are **an established cutting material for all applications where extreme cutting edge sharpness** (K10/ N10) **or tenacity** (P40/ K40) are paramount. The proportion of "classical hard metals" (base hard metals) is no more than 10% for drilling, turning and milling operations. The size of the carbide is around 1 – 3 µm.

Ultra-fine grained hard metals:

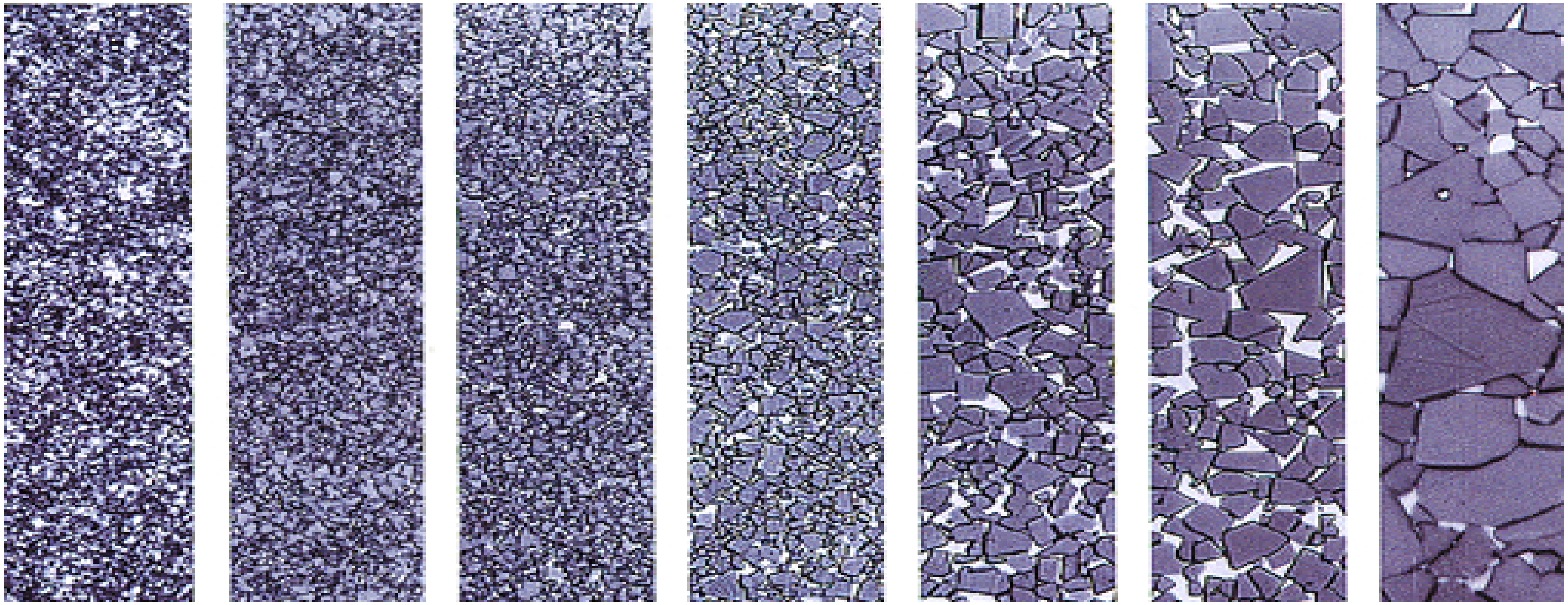
Ultra-fine grained hard metals are superior to conventional hard metals in terms of their hardness, edge strength and flexural strength, but quickly display plastic deformation tendencies under thermal stress. **Ultra-fine grained hard metals are used predominantly for solid carbide drills, indexable inserts for thread tapping and for machining high temperature resistant workpiece materials.**

Hard metal substrates:

Impact resistance and bending strength call for a high cobalt or binding metal content. However, this can exert an unfavourable effect on compressive strength and high temperature resistance.
Today, the combination of substrate and coating provides us with the basis for hard metal types adjusted in line with their specific application. Most substrates belong to ISO application groups P05 - P30, M10 - M30, K10 - K20 for turning and drilling, and P25 – P45 for milling.

Carbide substrates – Grain sizes

Ultra fine	Extra fine	Fine	Medium	Medium coarse	Coarse	Extra coarse

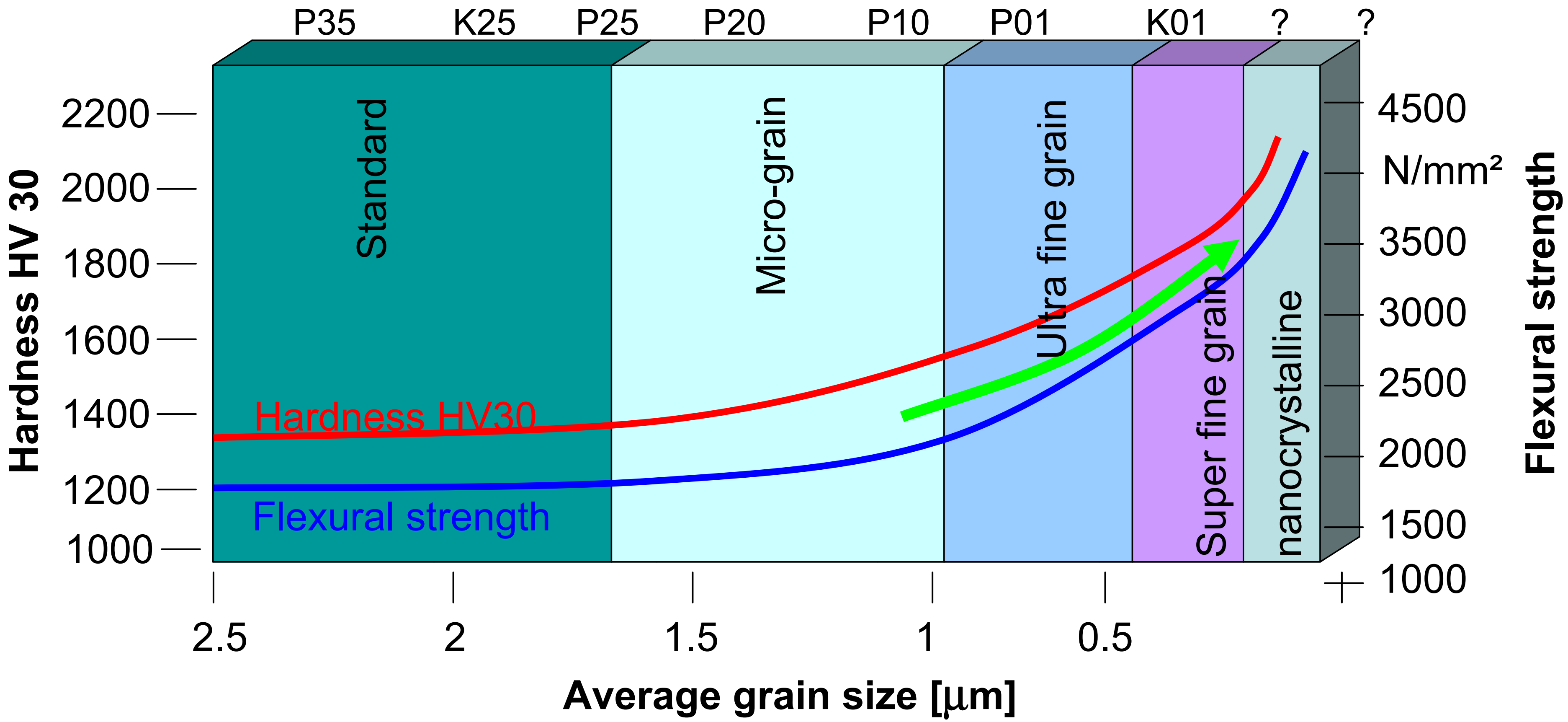


0.3-0.5 µm	0.5-0.9 µm	1.0-1.3 µm	1.4-2.0 µm	2.1-3.4 µm	3.5-5.0 µm	5.0-8.0 µm

Micro-grain

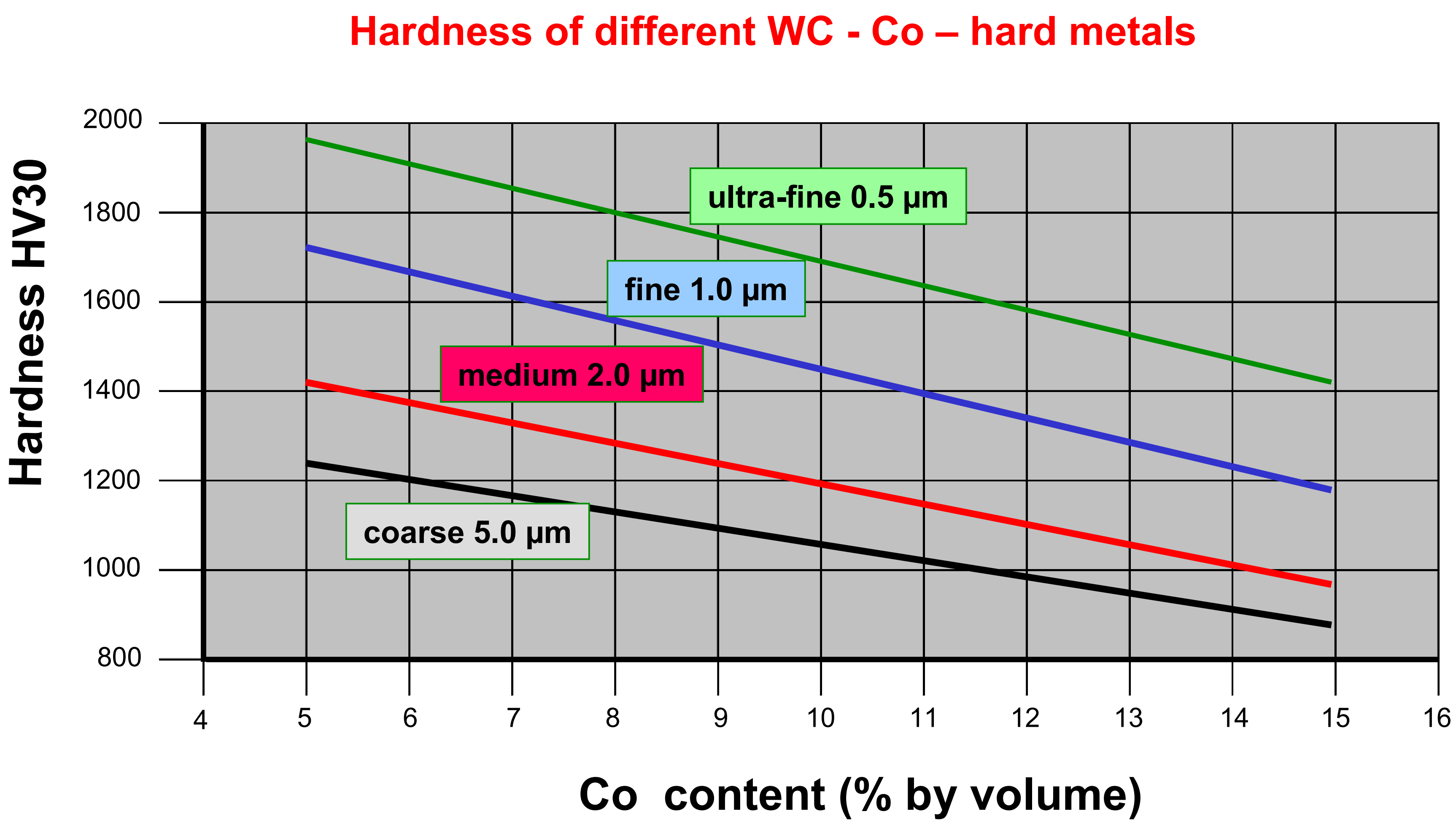
Source: Walter

Carbide – Properties

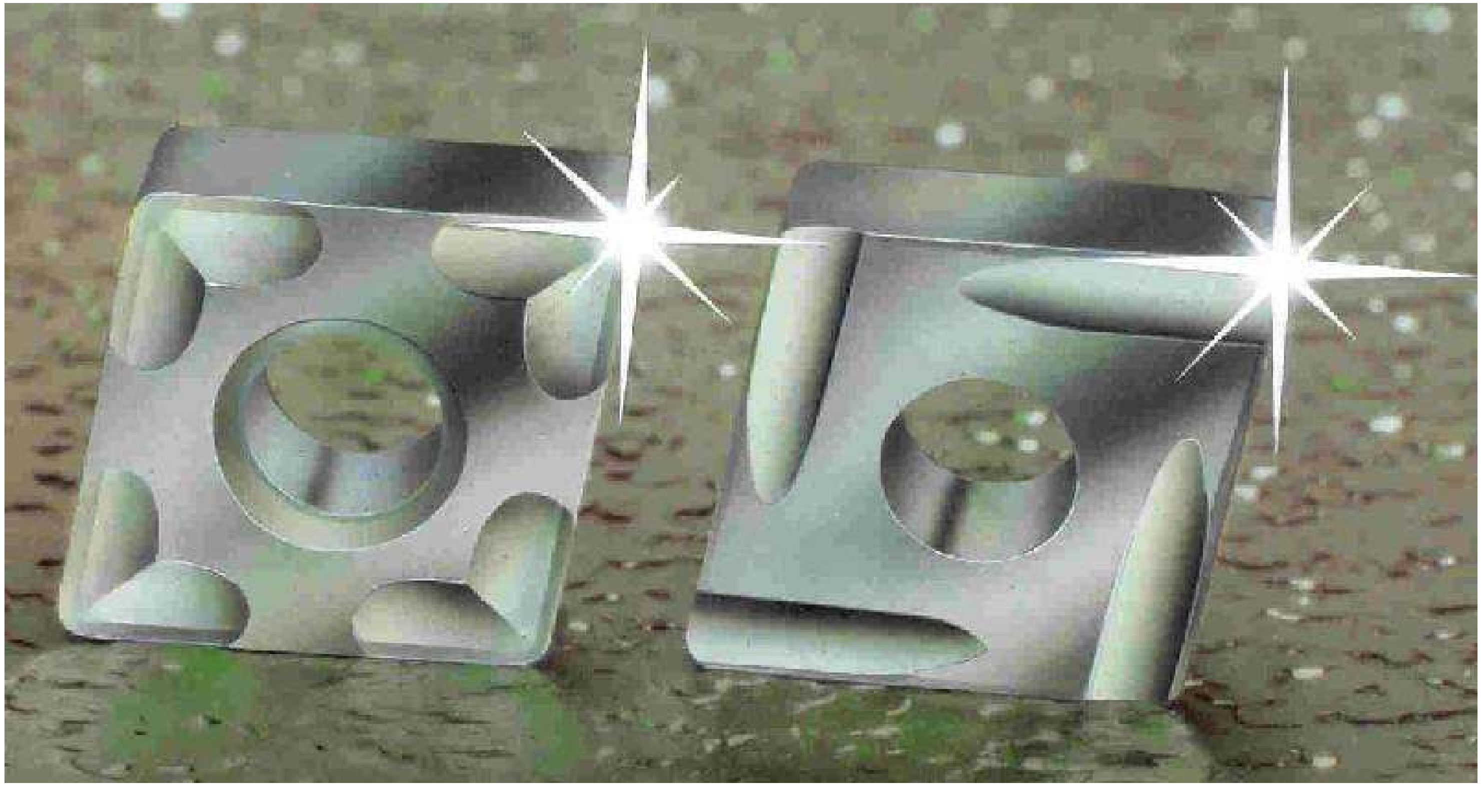


Source: Walter

Base hard metals and substrates



Cermet



3. Metallic hard materials

3.5 Cermet

Cermets are a special form of hard metal. In contrast to conventional hard metals, they are made of titanium carbide and titanium nitride, and the binding metal nickel. The name **Cermet** is derived from the words “ceramic” and “metal”.

Cermets unite the benefits offered by both these materials in terms of their metal cutting capability.

Discovered as long ago as the 1930s, these materials were consistently further developed and used with a good degree of economic success, particularly in Japan.

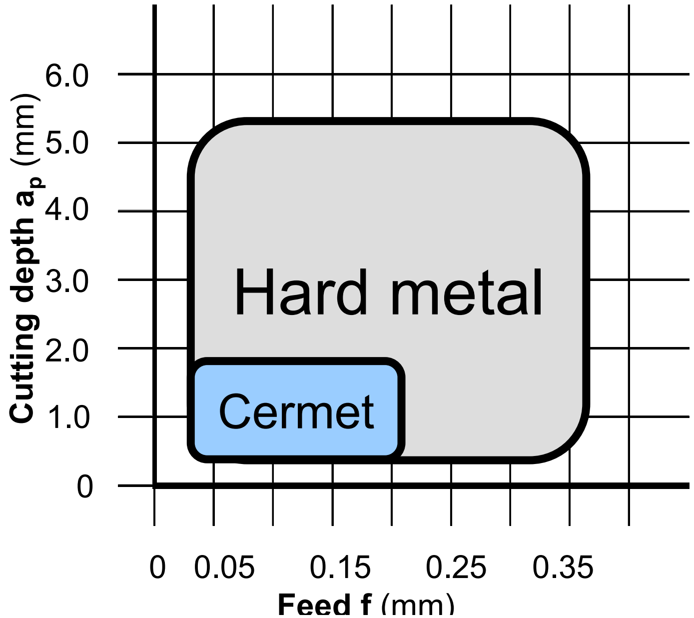
The cermets of the modern generation are characterized by their **hot strength,** their **high resistance to abrasive wear** and **low coefficients of friction.** Their **minimal tendency to oxidation** means that practically no oxidation wear (notching) occurs. They also permit stock removal at low cutting speeds (< 100 m/min).

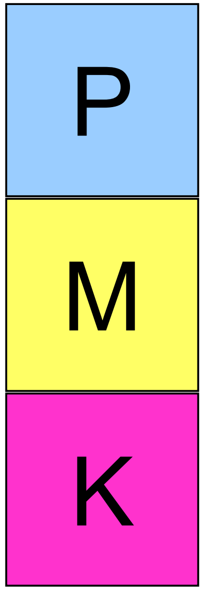
Improvements in their resistance to thermal shock have made cermets also suitable for individual milling operations.

For optimum results, machining conditions should ideally be stable and the removal cross section low.

Cermet (fields of application)

!!  !!





3. Metallic hard materials

3.5 Cermet (fields of application)

Typical fields of application which draw economic gain from the benefits of cermets are:

- Finish turning and precision drilling of long-chipping steel materials as well as stainless and austenitic steels using a constant, uninterrupted cut
- With minimal casting and forging skins
- Wherever **small removal cross sections** are involved, such as

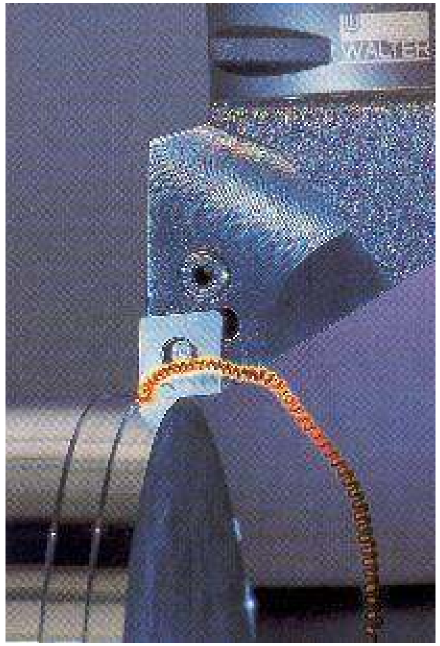
  Cutting depth max. 2.00 mm

  Feed max. 0.20 mm
- Wherever oxidation notching occurs in coated hard metals.

As far as milling is concerned, cermets play an important role both for finishing operations and also for general applications on steel materials:

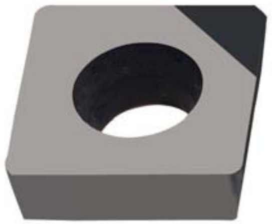
- As for fine thread cutting, drilling and turning at high cutting speeds, moderate feed rates, but for milling work relatively high but even cutting depths.
- Only minimal casting or forging skins where possible.
- High-tenacity cermets for milling permit metal cutting of stainless and austenitic steels.

Non-metallic hard materials



Si_3N_4

Al_2O_3



PCD

CBN

4. Non-metallic hard materials

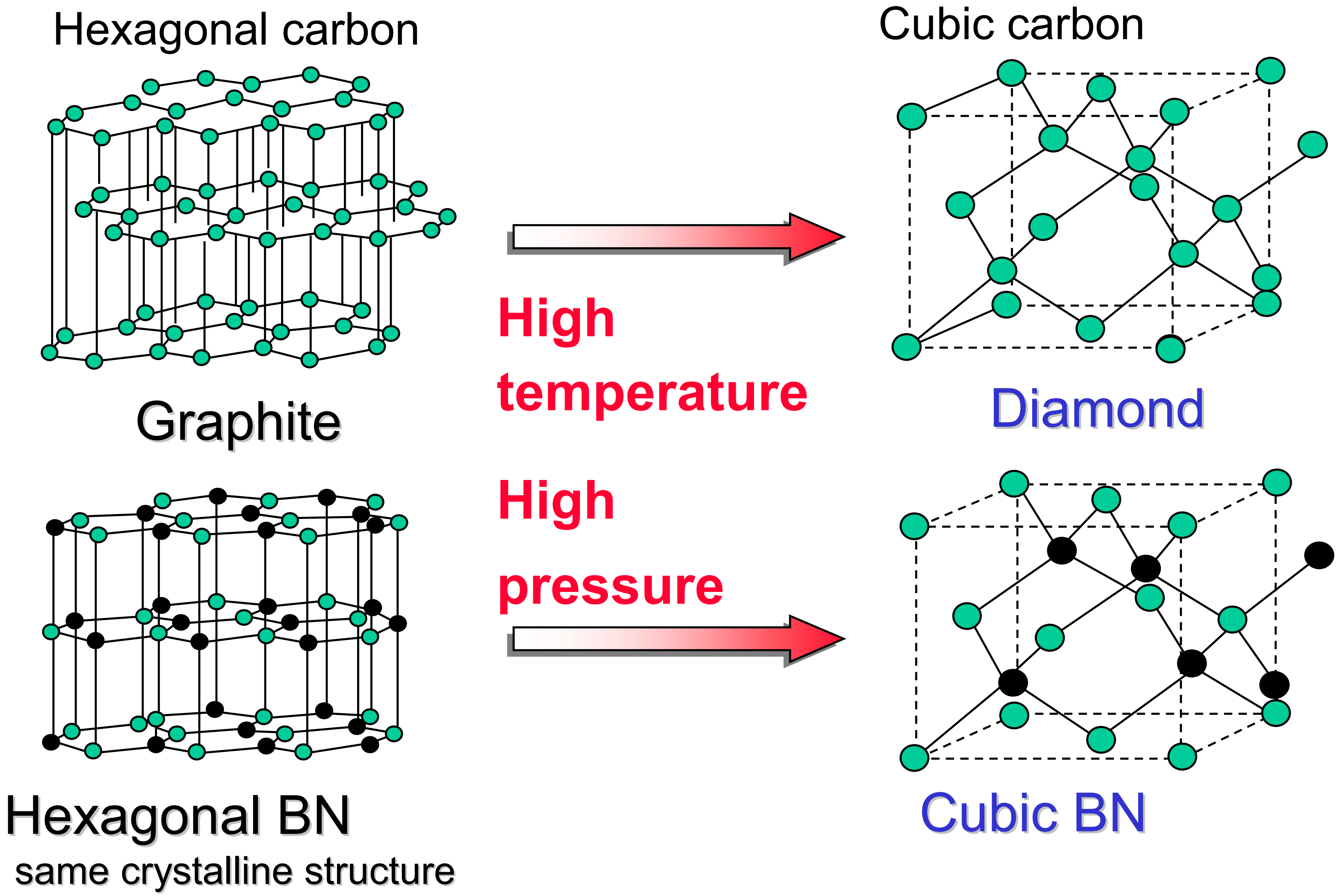
Boron carbide (B_4C), **diamond**, **cubic boron nitride (CBN)**, **aluminium oxide (Al_2O_3)** and **silicon carbide (SiC)** are the best known of the non-metallic hard materials.
Silicon nitride (Si_3N_4), **aluminium nitride (AlN)** and **sialon**, hard compounds of the elements **Si**, **Al**, **O and N**, are meeting with a growing degree of interest in the field of metal cutting.
The most important non-metallic hard materials in use today are discussed in the following:

Silicon nitride ceramic (Si_3N_4)
Aluminium oxide ceramic (Al_2O_3)
Cubic boron nitride (CBN)
Polycrystalline diamond (PCD)

The successful application of non-metallic hard materials depends heavily on the machining conditions:

- General stability of the clamping fixture and machine,
- precisely adapted cutting data and cutting allocation, possibly involving starting cut technology,
- this includes also cutting edges adapted to the machining operation, protective chamfers and cutting wedge angles.

Polycrystalline diamond (PCD) and cubic boron nitride (CBN)

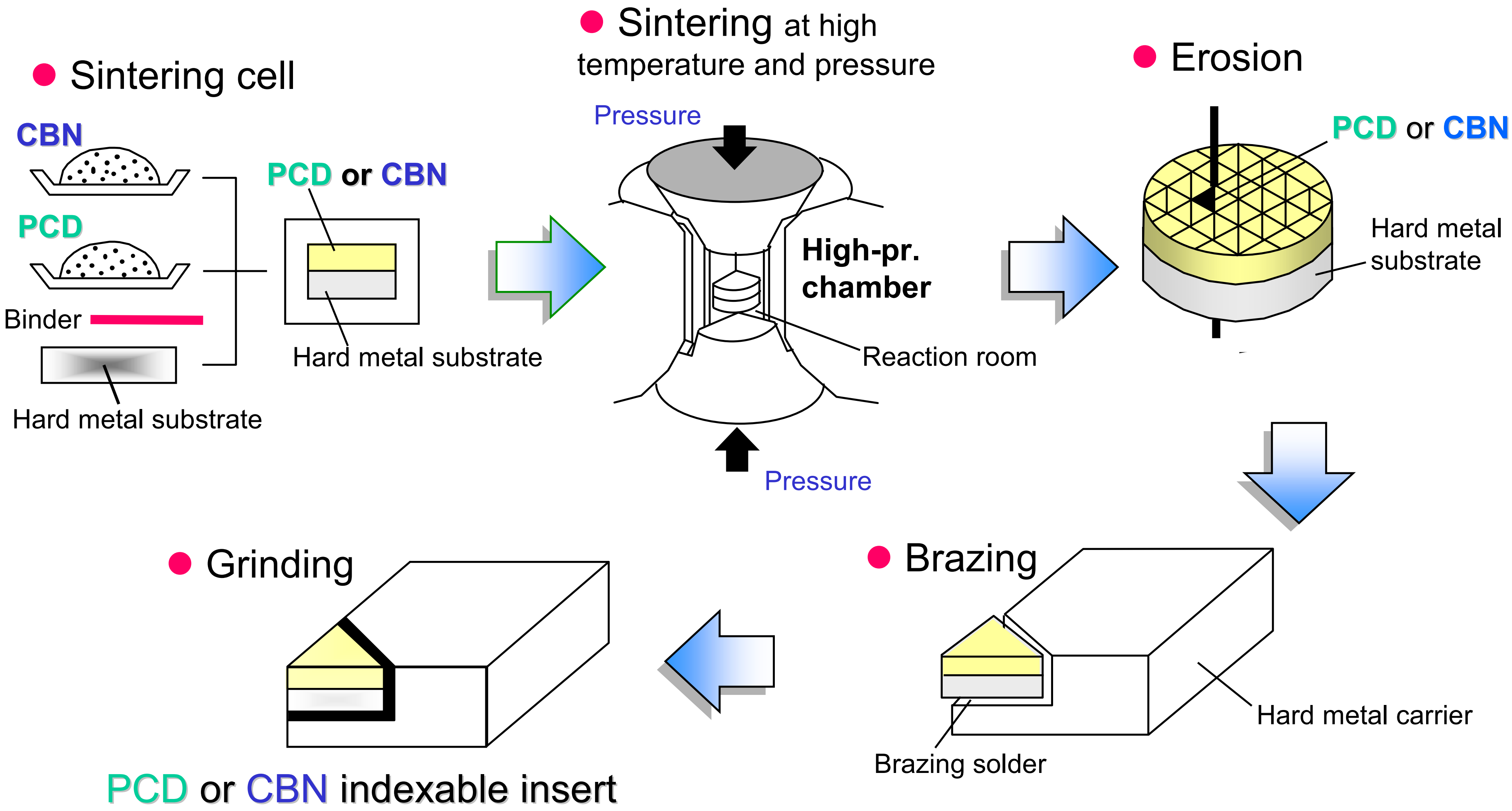


4. Non-metallic hard materials

4.1 Polycrystalline diamond (PCD) and cubic boron nitride (CBN)

Carbon as an element occurs in nature in two modifications: Once in the form of soft **graphite**, and also as cubic crystallizing **diamond.**
This monocrystalline diamond, which almost attains the same hardness level as polycrystalline diamond (PCD) occurs in primary deposits in the host rock kimberlite, from which it is mined. The diamond is also extracted from secondary deposits, for example in petrified river sediment, by means of elutriation.
The quality of the raw stones is assessed according to size, crystal shape, colour and purity.
The production of synthetic diamonds has been in progress since 1955.
Ultra high-pressure technology developed for **diamond synthesis**, which also permitted the manufacture of cubic boron nitride, is used to manufacture polycrystalline diamonds. Preferred applications for **PCD** today are **milling, turning and (thread cutting) of abrasive hypereutectic aluminium-silicon alloys.**
Due to its low affinity to iron, **CBN** is used in preference for the **machining of hard cast iron and steel materials.**

Manufacture of PCD and CBN cutting materials



4. Non-metallic hard materials

4.1.1 Manufacture of PCD and CBN cutting materials

The manufacture of polycrystalline inserts made of diamond and cubic boron nitride involves the fusing of fine diamond or cubic boron nitride crystals under **internal pressure** with the addition of small quantities of binding materials such as titanium carbide (TiC). The conditions are the same or similar to those used for diamond synthesis.
Depending on the type, different grain sizes are used.
Diamond synthesis generally takes place using a cylindrical high-pressure chamber. The actual reaction area contains the graphite and reaction metals arranged in alternation, and is heated up to the required temperature.
For the predominantly produced **grain sizes of 0.01 - 0.1 mm,** production takes place at **temperatures of around 1500℃** and in a **pressure range of around 60 000 bar**.
The blank which is produced is then separated into smaller pieces and shapes depending on the field of application and intended use, and brazed during a subsequent production process onto a **substrate** such as a hard metal.
The poor heat conductivity of polycrystalline diamond and cubic boron nitride ensure the durability of the brazing joint.
The cutting edge is further processed by means of grinding and lapping.

CBN (Fields of application)

Higher boron nitride content:

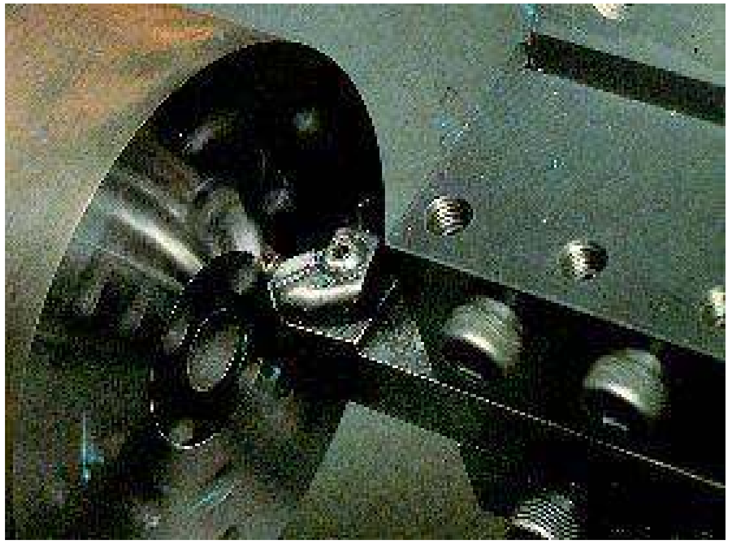
Perlitic / ferritic grey cast iron
Martensitic grey cast iron (HRc 39 - 45)
Nodular cast iron (> 600 N/mm^2)
Malleable cast iron

Low proportion of boron nitride:

Machining of steel with a constant cut

Higher proportion of boron nitride:

Machining of steel with an interrupted cut



4. Non-metallic hard materials

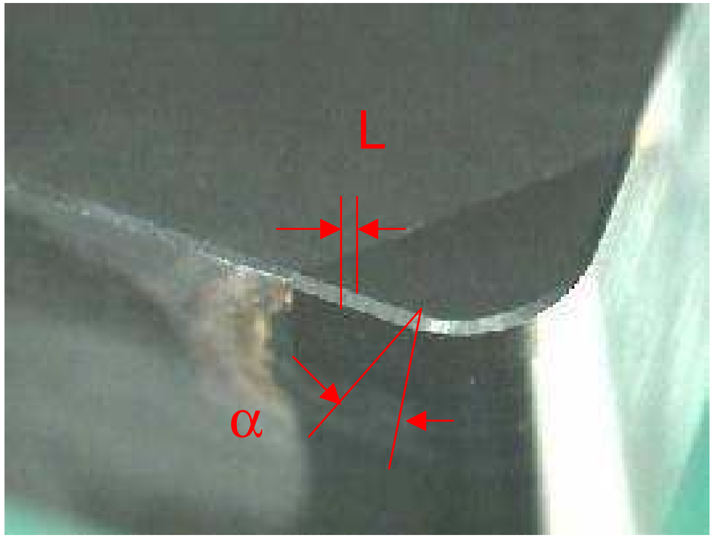
4.1.2 CBN (fields of application)

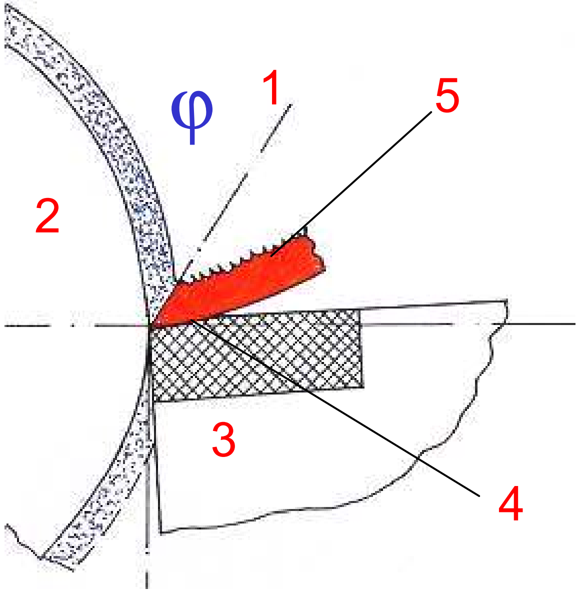
CBN has outstanding performance characteristics due to its **high level of hot hardness** up to extreme temperatures (1800℃), and its genera lly **good chemical stability** during the metal cutting process.
The characteristics of a CBN cutting material can be varied by changing the crystal size, the content and type of binder used to manufacture different types.

Low boron nitride content:
In combination with a ceramic binder, a **greater degree of wear resistance and chemical stability** is created. This combination is therefore particularly suited for the machining of hard steel workpieces (required minimum hardness = **50 HRc**) using a **constant cut**.

Higher boron nitride content:
With a higher boron nitride content, the **flexural strength** of the CBN increases.
This combination is suitable for machining hard steel workpieces using an **interrupted cut, perlitic/ferritic grey cast iron, martensitic grey cast iron** (HRc 39 - 45), **nodular cast iron** (> 600 N/mm^2) **and malleable cast iron.**

Hard machining with CBN





Material	High % CBN		Low % CBN	
	Roughing	Finishing	Roughing	Finishing
Hardened steel, constant cut				20°x 0.1 - 0.15mm
Hardened steel, under cut	20°x 0.1 - 0.15mm	20°x 0.1 - 0.15mm		
Perlitic / ferritic grey cast iron	20°x 0.1 - 0.15mm			
Gr.cast iron, (martensitic) HRC 39-45	20°x 0.1 - 0.15 mm			
Nodular grey cast iron >600N/mm2	20°x 0.1 - 0.15mm			
Chilled iron, hardness HV 570-900	20°x 0.1 - 0.15mm			

1 = Shearing plane 4 = Rake face
2 = Workpiece 5 = Chip
3 = Cutting edge

4. Non-metallic hard materials

4.1.3 Hard machining with CBN

Hard machining is defined as **hard milling** or **hard turning**, i.e. a machining process with a defined cutting edge which takes place after a workpiece has been heat treated.
Cutting speeds achievable during hard machining are between **80** and **250 m/min**, at feed rates of **0.02** to **0.3 mm** and chip depths of up to **0.5 mm**.
The **machining process** is generally a **dry one.**
The high cutting speeds generate a high degree of heat. As CBN is a ceramic cutting material, it remains cool. The **heat is dissipated with the chips** but also enters the workpiece, heating it up in the shearing zone. This heat softens the shearing zone and plastifies the workpiece material, facilitating the chipping process.
Hard workpiece materials with their martensitic microstructure do not permit plastic deformation at normal cutting temperatures and pressures.
For hard milling, it is generally advisable to aim at a dry milling operation in counter-rotation.

PCD application fields

4. Non-metallic hard materials

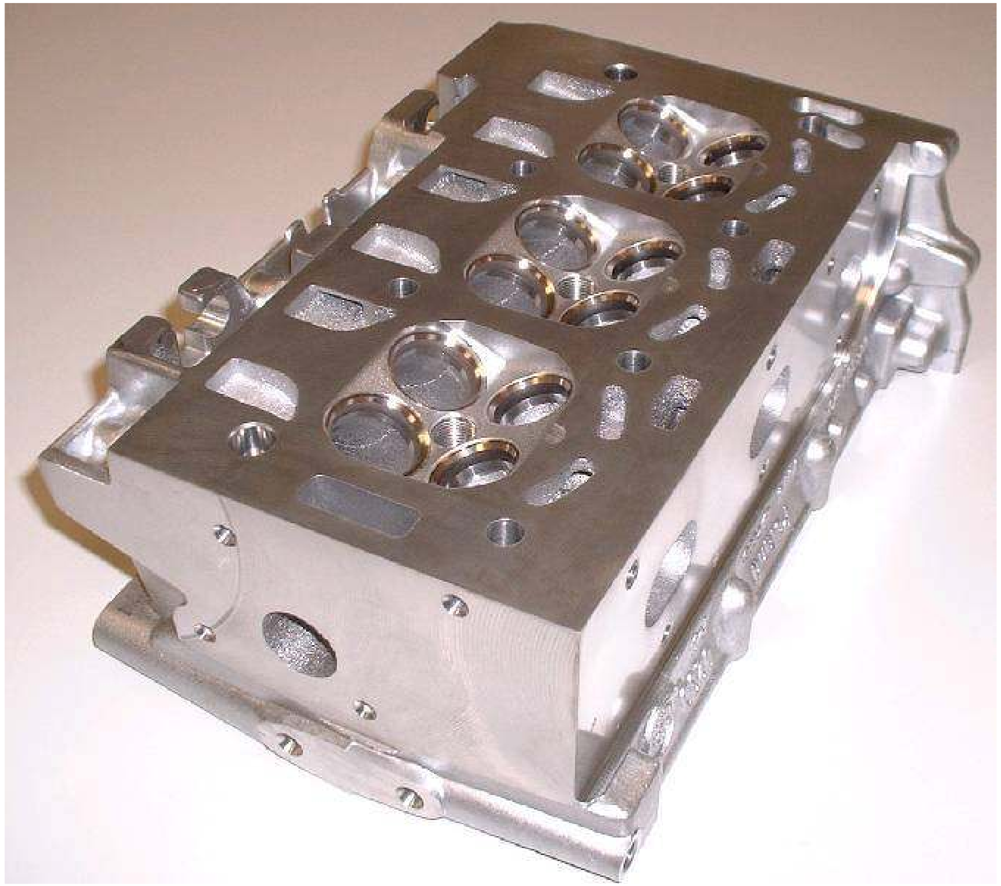
4.1.4 PCD application fields

Most machining operations on metal exclude the deployment of PCD in practical application.
Used correctly, PCD is an excellent cutting material particularly for **abrasive non-ferrous and non-metal workpiece materials** which demand accuracy and a high standard of surface quality.
Sharp cutting edges and positive clearance and rake angles, resulting in minimal but highly stable wedge angles, and positive radial and axial angles in the tool, are of benefit.
In general, cooling lubricants can be used.

The limitations of this cutting material:

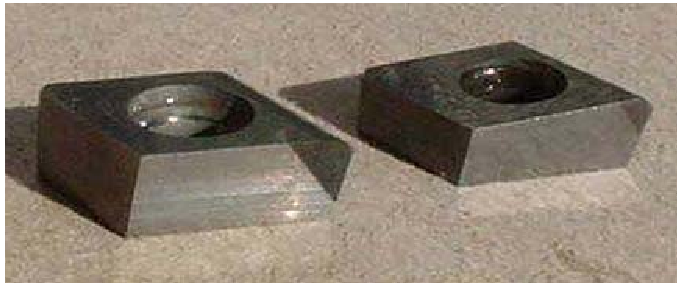
- It is only suitable for pre-finishing and finishing turning and drilling (thread cutting) operations
- Usable for finishing and wide finishing milling operations
- The metal cutting temperature must not exceed 600°C
- Due to its affinity to iron, it cannot be used for machining iron materials
- Neither is it suitable for high temperature resistant alloys

PCD application fields, materials



Material: Aluminium alloy

Mill with PCD cutting edges

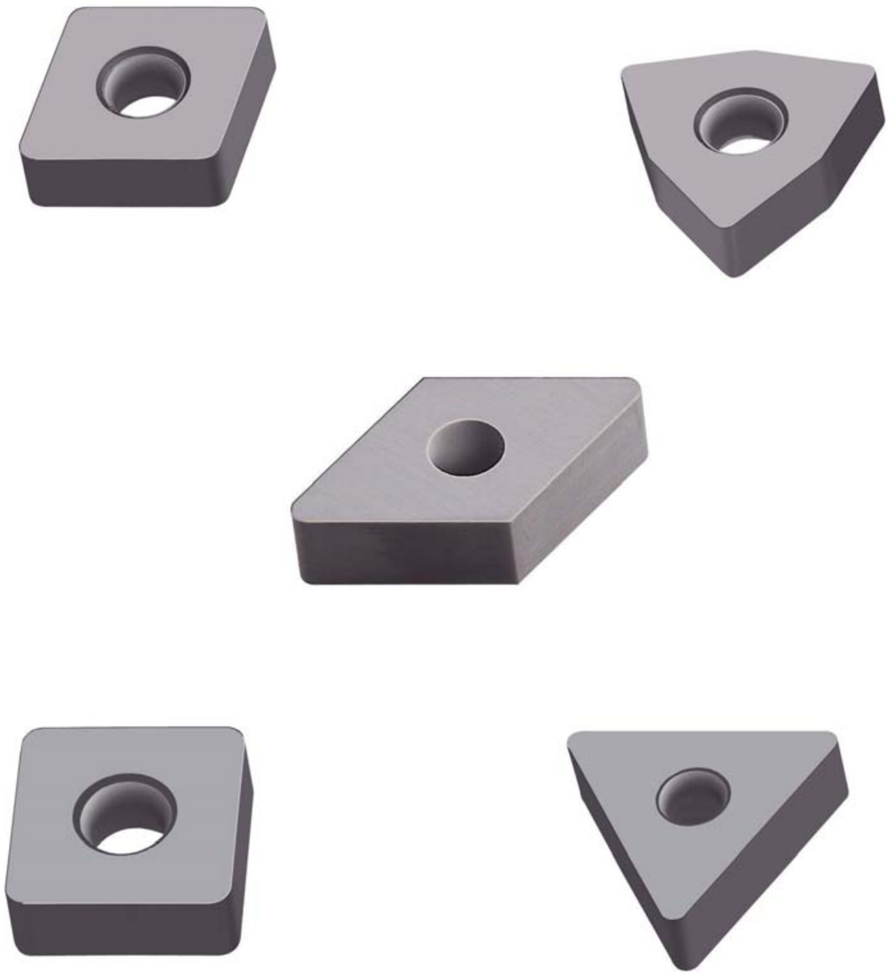


PCD cutting edges

4.1.5 PCD application fields, materials

Preferred applications for PCD are turning (thread cutting) and milling of **abrasive eutectoid and hypereutectoid aluminium alloys.**
Aluminium alloys have excellent machining characteristics. Their working temperatures are usually low and they are capable of withstanding high cutting temperatures.
However, large hard silicon particles result in an excessively fast increase in flank wear at the tool cutting edge. The **chip thickness** is an important factor in the milling of aluminium alloys. If **low tooth feed rates** occur as a result of **high cutting speeds** during milling operations, a rubbing or chafing process results rather than cutting. The cutting zone overheats, resulting in **reduced tool service life.**
Other important points in the machining of aluminium alloys are **chip formation** and **chip control**. Where the removal cross section is not adjusted to the metal cutting operation, as is the case for example when turning, some chips do not break easily and demonstrate a tendency to curl and tangle.
PCD is also used for the machining of other **abrasive non-metallic materials** such as for example **composite materials, synthetic resins, rubber, plastic, graphite etc.**. Due to its high degree of brittleness, PCD calls for **stable conditions, rigid tools and machines** as well as **high cutting speeds.** Because of the minimal adhesion tendency of PCD compared to aluminium, built-up edge formation is reduced.

Ceramic cutting materials



4. Non-metallic hard materials

4.2 Ceramic cutting materials

Ceramic cutting materials have a **high level of hot hardness** and do **not react with the workpiece material.**
We differentiate between two basic ceramic types:

aluminium oxide-based (Al_2O_3)
silicon nitride-based (Si_3N_4)

Aluminium oxide-based ceramic can be subdivided into three groups:

- Ceramic based on **pure oxide** with low strength and minimal heat conductivity, which is little suited for metal cutting. The colour of pure ceramic is **white when cold pressed, grey when warm pressed.**
- With its high heat conductivity, **aluminium oxide-based** mixed ceramic enjoys a relatively wide application range in the field of metal cutting.
- **Whisker-reinforced** ceramic, derived from individual crystal fibres known as whiskers, possesses enormous tenacity, tensile strength and good thermal shock resistance as a result of its reinforcement. It is used preferably for high temperature resistant alloys, hardened steel, grey cast iron and generally for cutting operations involving interruptions.
  Silicone nitride-based ceramic is superior in terms of shock behaviour and tenacity to aluminium oxide-based ceramic.

Silicone nitride based ceramic Si3N4