GRINDING FOR TOOLMAKING

All about grinding cold-working, hot-working, high-speed and mold-making steels, including PM high-performance materials

MATERIALS FOR TOOLMAKING

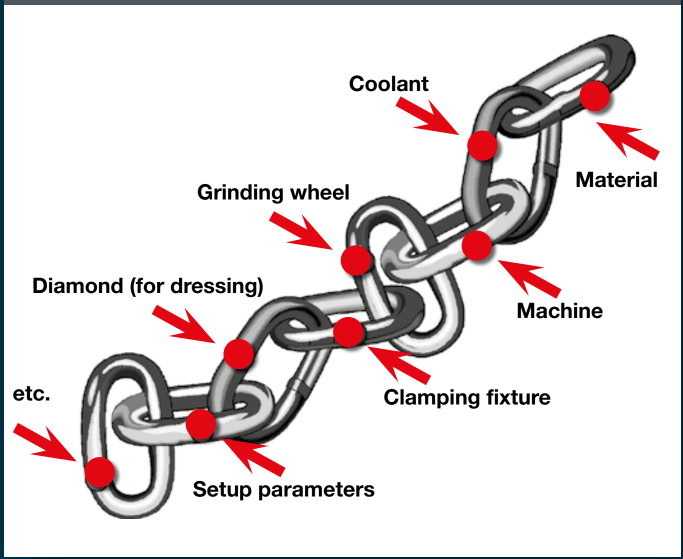
Contents

Introduction

The high alloy content of tool steels often makes them more difficult to grind than other steels, such as structural steels. For satisfactory results when grinding tool steels, the grinding wheel must be selected carefully. In order to select the right grinding wheel and grinding parameters, however, you need to know how grinding wheels work.

This brochure provides an overview of the structure of grinding wheels, how they work, and the parameters that determine the quality of grinding results. It also includes recommendations for suitable grinding wheels for conventional and powder-metallurgical BÖHLER tool and high-speed steels.

Figure 1: Some of the links in the grinding process –
THE WEAKEST LINK DEFINES THE PERFORMANCE LIMIT



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GRINDING CRACKS AND STRESSES

Tool steels (including HSS and PM)

The alloy components of tool steels greatly influence their grindability. The range of BÖHLER tool and high-speed steels extends from low-alloy steels such as K245 to very high-alloy steels such as S290 MICROCLEAN.

Grinding low-alloy tool steels seldom presents any difficulties. When grinding high-alloy tool and high-speed steels with high carbide content, however, problems can easily occur. For this reason, the grinding parameters must be selected carefully. The higher the wear resistance of a steel, the more difficult it is to grind. The wear resistance of a material is determined by the basic hardness of the steel and the hardness, size and proportion of the included carbides.

In order to increase the wear resistance of a tool steel, the steel is alloyed with carbide-forming elements, primarily tungsten, molybdenum and vanadium. The carbon content of the steel must also be relatively high in order to form carbides. Only boron nitride and diamond are harder than all of the carbides present in a tool steel. Diamond, however, is not suitable for grinding steel.

The number and size of the carbides in a steel greatly influence its grindability. The more carbides are present, and the larger they are, the more difficult grinding will be. For this reason, powder-metallurgical steels with smaller carbides are easier to grind than smelted steels of similar composition.

In order to obtain good performance when grinding high-alloy carbide tool steels, it is important to select the right grinding wheel. MICROCLEAN steels, for example, contain a great many tungsten, molybdenum and vanadium carbides. In order to cut through these carbides, an abrasive that is harder than corundum or silicon carbide is needed. For these steel sorts, therefore, boron nitride grinding wheels are mainly recommended. MICROCLEAN steels can nevertheless be ground using corundum or silicon carbide, but the steel matrix surrounding the carbides will be ground away while the carbides are torn out of the matrix. This causes high wear of the grinding wheel, along with a risk of poor grinding results.

Grinding cracks and stresses

Choosing the wrong grinding wheel or parameters creates a significant risk of crack formation in the workpiece. Grinding cracks are not normally as easy to see as in Figure 2. As a rule, the part needs to be inspected under a microscope or using a dye penetrant in order to see the cracks. Hot etching with 50% HCl at a temperature of 70°C and a soak time of 20 minutes can also be used to make grinding cracks visible.

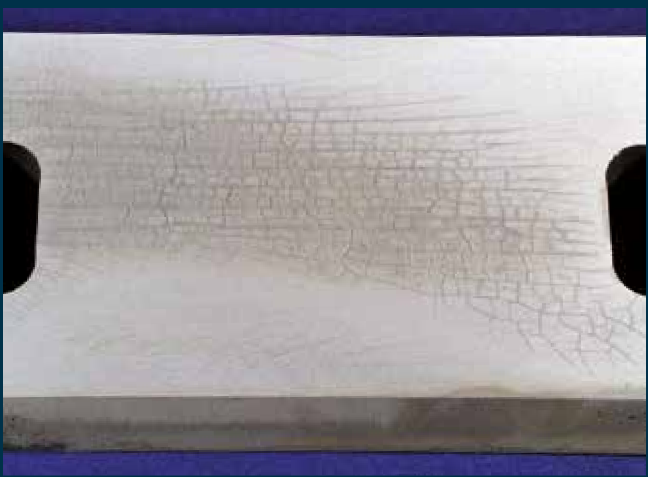


Figure 2: Grinding cracks

Grinding cracks typically form perpendicular to the direction of grinding and normally mean that the workpiece must be scrapped. Grinding cracks occur more easily in hardened tool steels than in non-hardened ones. A tool steel or high-speed steel that has been hardened but not tempered should never be ground. Hardened tool and high-speed steels must always be tempered before grinding.

The root cause of grinding cracks can be explained as follows:

Almost all of the energy expended for grinding is converted into heat, some due to friction and some due to deformation of the material. If the right grinding wheel has been selected, most of the energy is dissipated in the chips in the form of heat, and only a small amount warms the workpiece.

If a tool steel or high-speed steel that has been hardened and tempered is ground incorrectly, the ground surface can become so hot that the tempering temperature of the steel is exceeded. This reduces the surface hardness. If the temperature continues to increase, it may even reach the austenitization point and cause rehardening . This rehardened surface zone consists of non-tempered martensite and residual austenite, as shown in Figure 3. Very high stresses occur, leading to crack formation. Figure 4 shows the hardness profile in the surface zone of an improperly ground tool made of BÖHLER K110. Here improper grinding caused the rehardening described above. Due to the non-tempered martensite, the surface has high hardness. Directly beneath the surface is a region where the hardness is lower than the basic hardness of the tool steel because the tempering temperature was exceeded.

Improper grinding that leads to this transformed surface zone can very often be detected by discoloration (burns) burns on the ground surface. To prevent burns and grinding cracks, the temperature of the ground part must be kept low, for example by sufficient cooling. Properly dressed grinding wheels that cut the tool steel with sharp cutting edges must also be used, as otherwise excessive heat will be generated by friction.

The residual austenite content of a hardened and tempered tool steel or high-speed steel can have a substantial influence on grinding results. A high level of residual austenite increases the risk of crack formation during grinding. For most grinding processes, residual stresses arise in the ground surface zone.

These stresses are generally greatest just beneath the surface and can cause permanent deformation of the ground part, especially when grinding thin workpieces. The examples in Figures 4 and 5 show that the greatest risk of crack formation comes from improper grinding. Tensile stresses in the surface zone cause cracks in the material when they exceed the tensile strength of the steel. The risk of crack formation is lower with proper grinding – the surface stresses are compressive, which can increase the durability.

Grinding stresses can be reduced by repeated tempering after grinding. In this case, the tempering temperature should be about 30°C lower than the last tempering temperature in order to prevent loss of workpiece hardness. Another way to reduce grinding stresses is to peen the ground parts (see Figure 5.)

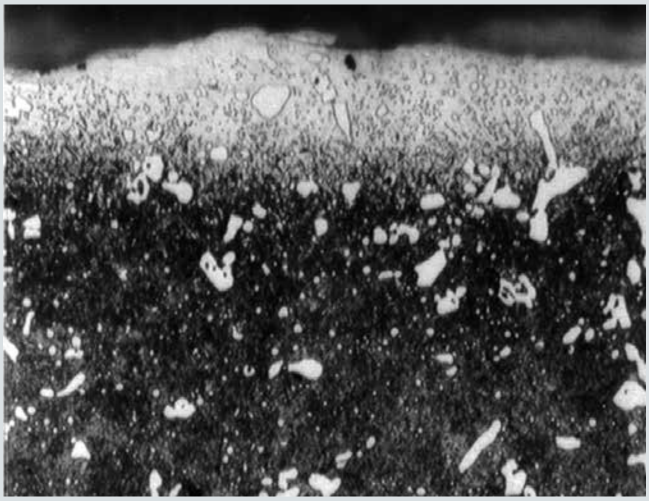


Figure 3: Rehardened surface zone

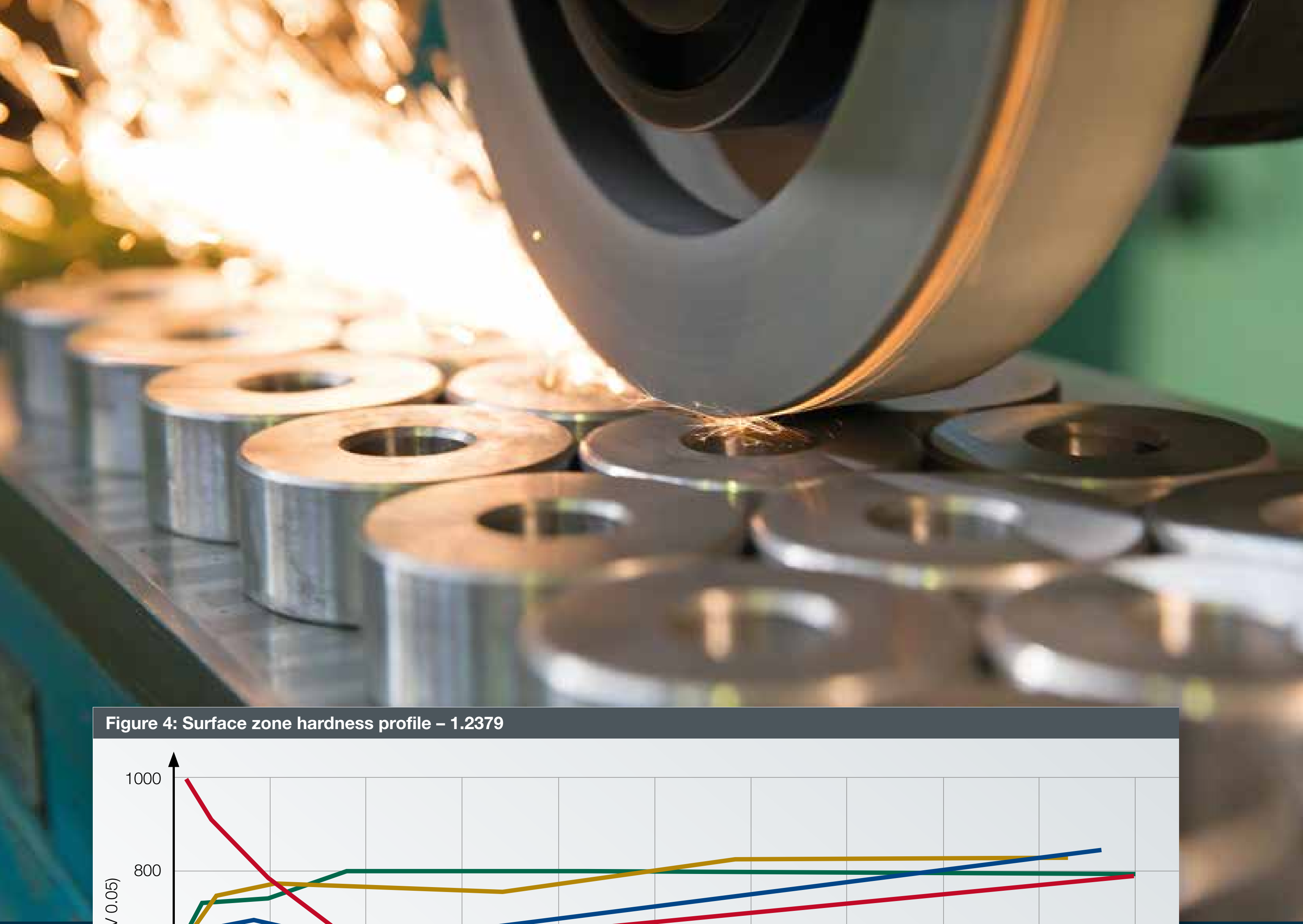
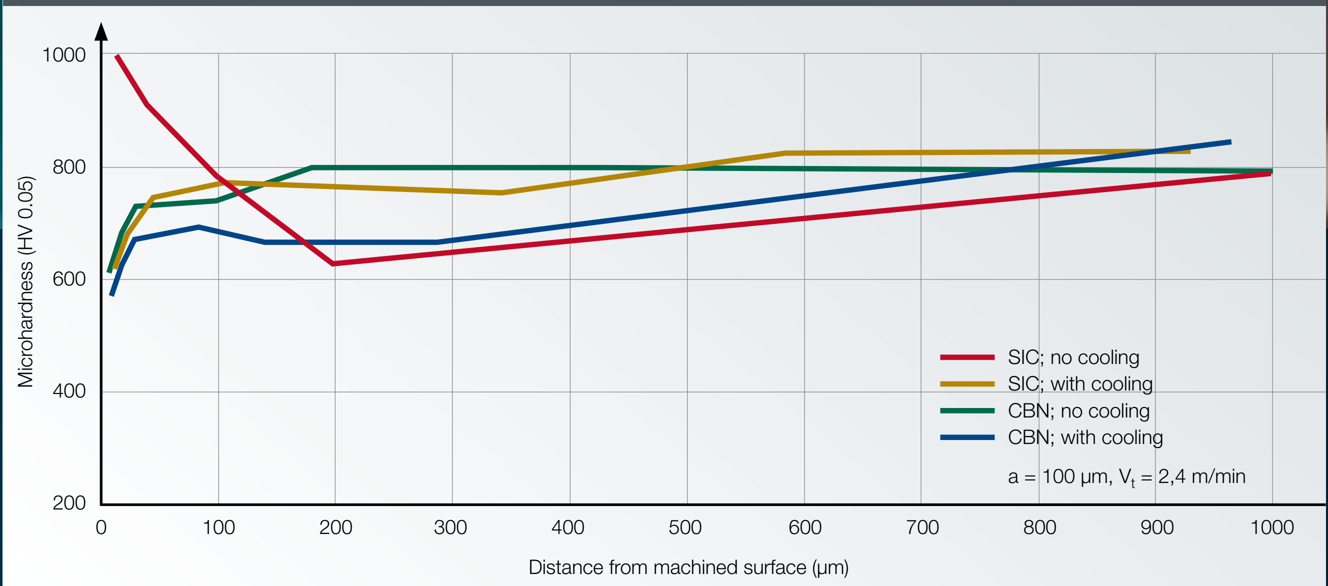
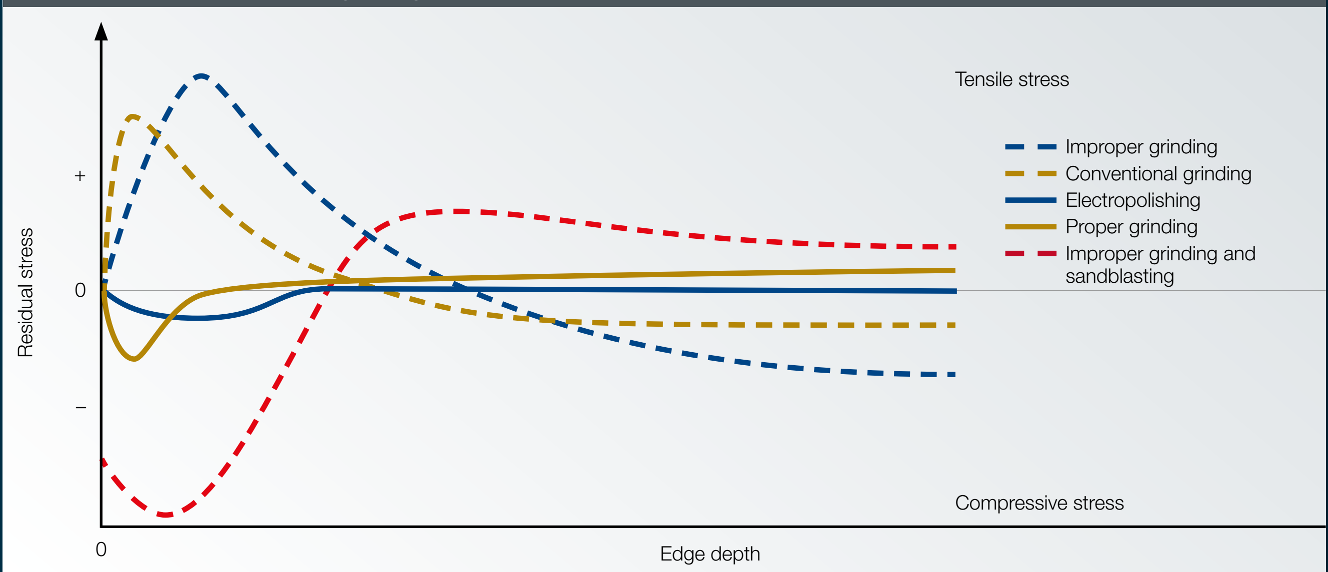


Figure 4: Surface zone hardness profile – 1.2379



Residual stresses after surface grinding of BÖHLER K110



GRINDING WHEEL COMPOSITION

Grinding wheel composition

In principal, a grinding wheel consists of:

- Abrasive
- Binder
- Pores

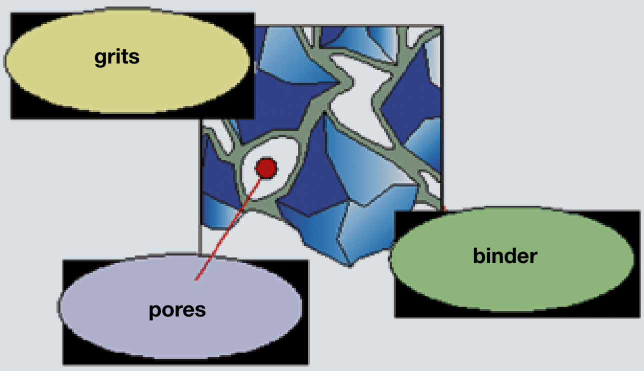


Figure 6: The arrangement and ratios of abrasive grits, pores and binder determine the action of a grinding wheel.

Certain specialty grinding wheels, such as those with metal-bonded diamonds, have no pores. The composition and ratio of the components listed above determine the grinding properties of a wheel. The composition of a grinding wheel is defined by a standardized designation approved by ISO. It consists a defined sequence of letters and digits that indicate the abrasive, the grit size, the hardness and the binder.

Example: A46 H V	
A	**Abrasive**
46	**Grit size**
H	**Hardness**
V	**Binder**

Abrasive

There are currently three basic types of abrasive used for grinding tool steels and HSS:

a) Corundum	Designation	A
b) Silicon carbide	Designation	C
c) Boron nitride	Designation	B

a) Corundum
Corundum is most often used as an abrasive for grinding iron and steel and is available in various forms. It can be alloyed with other oxides, most commonly with titanium oxide.

e.g. 31A – Mixture of normal, semifriable and fused white corundum
57A – Pink fused corundum
54A – White fused corundum with green binder

Unfortunately the color of the grinding wheel does not always indicate the type of abrasive, as some manufacturers dye their abrasives and binders. In recent years, sintered corundum (e.g. 93A), a new type of corundum with a fine crystalline structure has been developed. It gives the abrasive particularly good self-sharpening properties. The pressure created during grinding causes microsplintering, which continuously produces new, sharp cutting edges.

In order to take full advantage of the high performance potential of this abrasive, Winterthur has developed a perfectly tuned binder that fully exploits the self-sharpening properties of the abrasive.

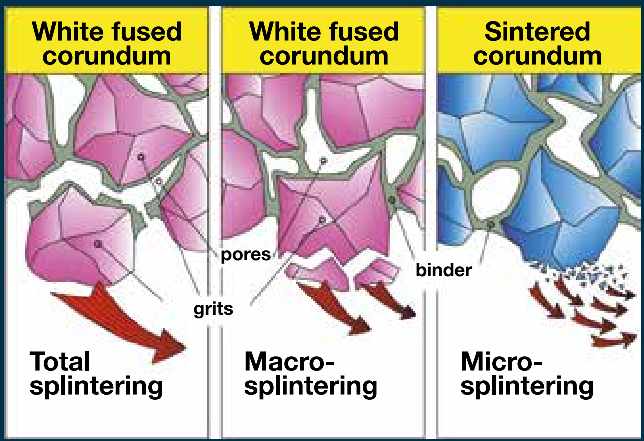


Figure 7: Comparison of fused white and sintered corundum (microcrystalline grit structure)

GRINDING WHEEL COMPOSITION

Properties of sintered corundum:

- High erosion rates, short cycle times
- Long wheel life
- Consistent grinding performance and low grinding forces
- Good dimensional stability
- Cooler grinding due to matched binder and structure
- Longer dressing intervals due to long service life

b) Silicon carbide (SiC)
Silicon carbide is most often used as an abrasive for grinding gray cast iron, carbides, plastic, glass, nonferrous metals and austenitic stainless steels, although it can also be used for hardened, high-alloy tool steels up to 65 HRc.

Two types of silicon carbide
There are two types of silicon carbide: black silicon carbide (designated C) and somewhat harder green silicon carbide (designated 11C), which is more brittle than the black type.

Winterthur nomenclature, conventional abrasive:								
54	**A**	**80**	**H**	**15**	**V**	**P**	**MF**	**604W**
11 31 54 93 etc.	A C S EA RA	coar- se 14 to 500 fine	soft A to Z hard	1 to 10 11 to 20	cera- mic binder	artificial porosity	L M H F G	bond type

Figure 8: Extended grade designation for grinding wheels:
porosity 1–10 = normal structure; greater than 11 = high porosity

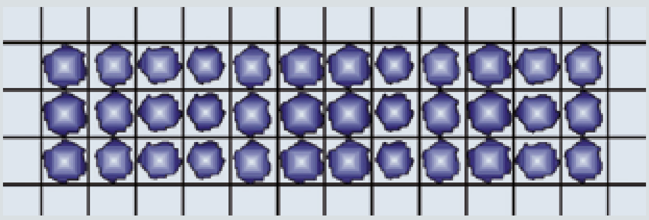


Figure 10: Image of F12 grit size

c) Cubic boron nitride (CBN)
Cubic boron nitride is produced similarly to synthetic diamonds. This abrasive is primarily used for grinding high carbide content tool steels and high-speed steels. One disadvantage of boron nitride is its high price, but its price-to-performance ratio compensates for this.

Winterthur offers easily profiled CBN with normal and porous structures. The exceptional thermal conductivity of CBN ensures cool grinding, greatly reducing potential surface zone damage. The tremendous wear resistance of CBN abrasive enables substantial increases in production and cost savings.

Winterthur nomenclature, cubic boron nitride:						
3B	**126**	**P**	**5**	**V**	**C**	**100**
3B 5B 32B etc.	coar- se 213 126 91 to 46 fine	soft N to S hard	1 to 18	ceramic binder	CBN concentration low 50 to 200 high	

Figure 9: Grade parameters for grinding wheels

Grit size

Abrasive grit size is of very important for selecting the correct grinding wheel. Grit sizes are classified by an international grit number (per FEPA.) Grit numbers F8 (coarse) through F1200 (superfine) correspond to the mesh count of a screen one inch on each side.

Coarse grits are used for high-throughput grinding (high rate of material removal), but this produces a rougher surface. Fine grits are used to produce a fine surface, for example when high edge stability is required.

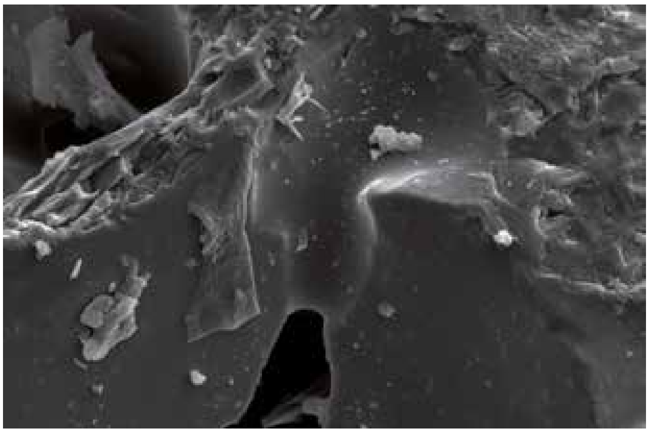


Figure 10a: Ideal ceramic binder bridge

The surface roughness of the ground workpiece is not solely dependent on the grit size of the grinding wheel. The sharpness of the wheel, the binder and the hardness of the wheel also affect the quality of the ground surface. For diamond and boron nitride grinding wheels, European manufacturers indicate the grit size by the grit in µm, in contrast to conventional abrasives.

Hardness

The term “grinding wheel hardness” does not refer to the grinding grit; rather, it indicates the resistance of the binder to break-out of the grinding grit. In a softer wheel the grinding grit can break loose more easily than in a harder wheel. The hardness is largely determined by the proportion of binder. The hardness of a grinding wheel is indicated by the letters A–Z, where A is the softest and Z the hardest.

Structure

Every grinding wheel has a natural porosity. At Winterthur this is expressed as a structure number in the range of 1 to 9, known as normal structure. The greater the structure number, the more porous the grinding wheel. The natural porosity of a wheel can be increase artificially by adding artificial pore generators to the mixture.

This artificially increased porosity is expressed by structure numbers from 11 to 19. Grinding wheels with structure numbers 10 and 20 (porous) are produced using a special casting process.

Binder

The grinding grits are held together by a binder. The following binders are used to securely bond the grits in the microstructure of the grinding wheel:

Ceramic	Designation	V
Synthetic resin	Designation	B

Ceramic binder

Modern ceramic binders at Winterthur largely consist of synthetic engineered glasses known as low-fired binders. They are immune to chemical effects and have unlimited shelf life. However, abrupt changes in temperature or impacts should be avoided.

Ceramic bonded grinding wheels are most often used for grinding tool steels. Synthetic resin is used as a binder for grinding wheels that run at high circumferential speeds.

11

HOW GRINDING WHEELS WORK

How grinding wheels work (grinding parameters)

Grinding is a cutting process in which the grinding grits form the cutting edges. The same principles apply to grinding as to other cutting processes, although certain factors make it necessary to consider the theory of grinding from a slightly different perspective.

These factors are:

- The cutting tool has an irregular cutting geometry – the arrangement of the grinding grits is irregular.
- The cutting geometry is variable – the action of an abrasive grinding tool includes a certain amount of self-sharpening, in which dull grits partially or completely break out to expose new grits.
- Negative cutting angle – the irregular and blunt shapes of the grinding grits mean that the cutting angle is often negative.
- A very large number of cutting edges
- Very high cutting speed – the typical cutting speed (35 m/sec = 2100 m/min) for precision grinding is well above the typical speed for other cutting processes.
- Very small chips. which means very small cutting depth for each cutting edge.
- Self-sharpening wheels – the pressure during grinding causes microsplintering, which continuously produces new, sharp cutting edges.

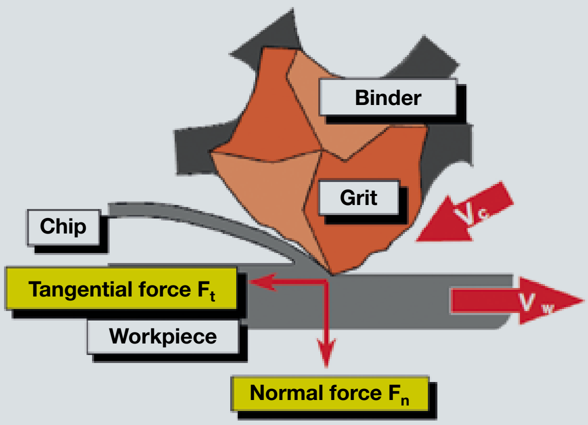


Figure 11: Chip formation during grinding (highly schematic). Cutting angles are normally negative.

Specific material removal rate Q_w’

The specific material removal rate, known by the abbreviation Q_w‘, describes the ability of a grinding wheel to remove material in mm^3 per mm of wheel width and per second. This allows direct comparison of various grinding processes in order to evaluate the actual removal rate. The parameter Q_w‘ is often used as the basis for calculating the infeed depth ae and advance feed rate V_W.

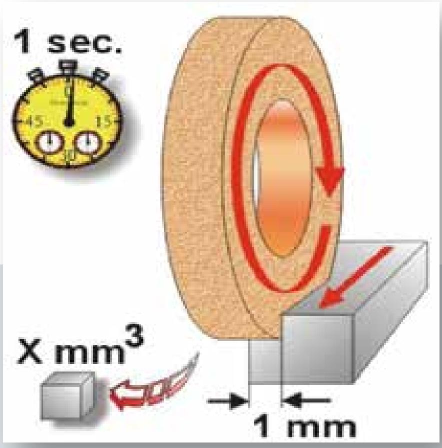


Figure 12: Graphic representation of Q_w

Typical values and applications

Reciprocal flat grinding:

- 1.5 mm^3/mm/s — Finishing
- 2.0 mm^3/mm/s — Hardened high-alloy steel
- 3.0 mm^3/mm/s — Good target value
- 5.0 mm^3/mm/s — High target value
- 10.0 mm^3/mm/s — High-performance process
- Material removal rates above 10 mm^3/mm/s are typically seen in deep grinding processes

Deep grinding:

- 7.0 mm^3/mm/s — Hardened high-alloy steel
- 10.0 mm^3/mm/s — Minimum target value
- 20.0 mm^3/mm/s — Good average value

CD deep grinding:

- 20.0 mm^3/mm/s — Minimum target value
- 50.0 mm^3/mm/s — High-performance process

Speed ratio q_s

The speed ratio qs is an important indicator of whether a grinding process is running optimally. This factor is the ratio of the circumferential speed of the grinding wheel to the workpiece speed.

$$q_s = \frac{\textbf{circumferential speed } V_c \textbf{ (m/s) x 1000 x 60}}{\textbf{workpiece speed } V_w \textbf{ (mm/min.)}}$$

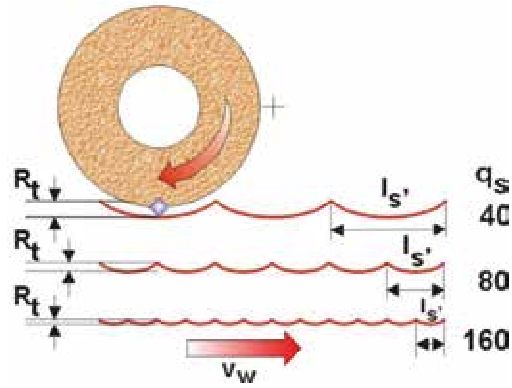


Figure 13: l_s' = Contact arc length of single grit
R_t = Surface roughness
V_c = Circumferential speed
V_w = Workpiece speed

Various speed ratio ranges:

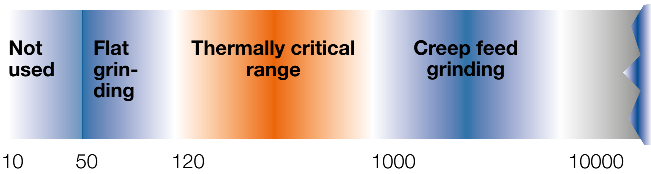


Figure 14: Graphic representation of the critical range

Applications:

Flat and external diameter grinding:
Roughing: 60 to 80
Finishing: 80 to 120

q_s < 50: risk of chatter marks
q_s > 120: risk of grinding burns

Creep feed grinding:
q_s > 1000 to 10 000
q_s < 1000: risk of grinding burns

The workpiece or bed speed V_W can easily be calculated by specifying the qs value and using the circumferential speed of the grinding wheel.

Wheel cutting speed V_c

The circumferential speed of a grinding wheel has a direct influence on the number of cutting edges engaged in chip cutting. For example, if the speed is doubled then twice as many grinding grits cut into the workpiece per unit time. This reduces the self-sharpening effect. so the grinding wheel ultimately acts harder and produces a finer surface finish, but it also carries the risk of surface burning.

By contrast, reducing the circumferential speed of a grinding wheel results in thicker chips, causing the grinding wheel to act softer. Generally, both the circumferential speed and the workpiece speed are increased in order to increase the material removal rate.

Increasing v_c:

- More cutting edges engaged per unit time
- Finer chips
- Lower loads on individual grits
- Less tendency for single grits to split

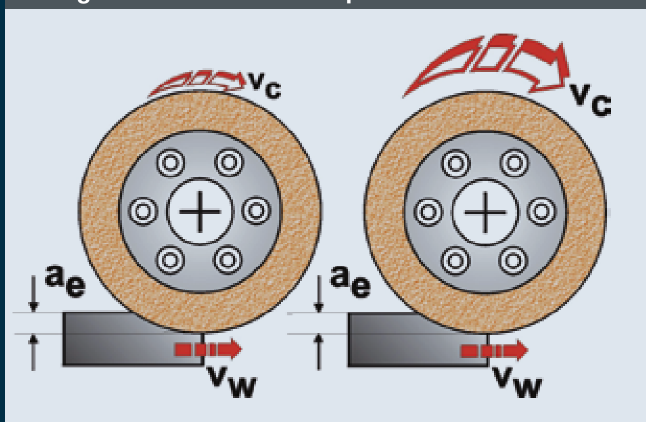
The wheel acts harder.

Reducing v_c:

- Fewer cutting edges engaged per unit time
- Coarser chips
- Higher loads on individual grits
- Greater tendency for single grits to split

The wheel acts softer.

Changes to circumferential speed



A typical safety limit for ceramic-bonded wheels is 40 m/s. Some grinding wheels, however, are approved for circumferential speeds up to 100 m/s. An appropriate circumferential speed for synthetic-resin-bonded boron nitride wheels is 35 to 40 m/s. For ceramic-bonded boron nitride wheels, a cutting speed of 45 to 63 m/s is often required.

Workpiece speed V_w

The grinding characteristics of a wheel can be altered by changing the workpiece speed. Increasing the workpiece speed makes the wheel act softer, and decreasing the speed makes the wheel act harder.

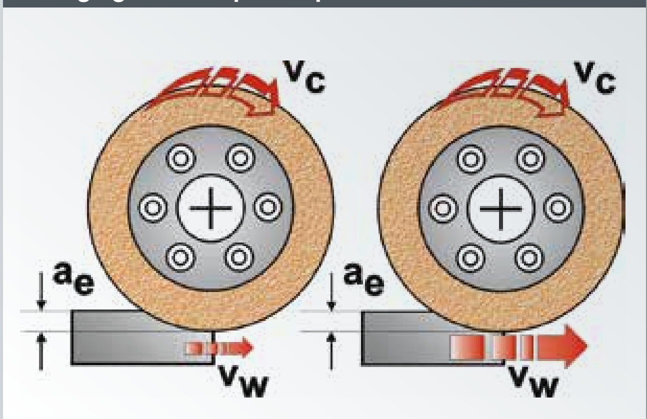
Grinding wheel infeed a_e

The grinding wheel infeed depends on the type of wheel, the stability of the machine, and/or how firmly the workpiece is clamped.

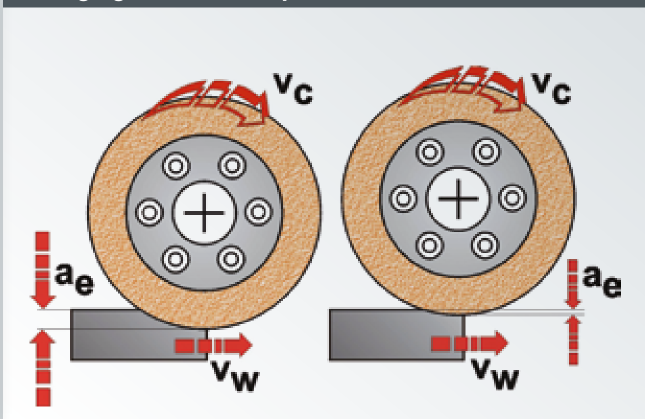
Guidelines for infeed using conventional wheels:
Rough grinding: ~ 0.05 mm/pass
Finish grinding: ~ 0.005 – 0.010 mm/pass

The infeed rate should be reduced when grinding with boron nitride wheels. If wheels with sintered corundum are used, the infeed should be set a little higher than the guidelines in order to increase the grinding pressure and obtain good self-sharpening.

Changing the workpiece speed



Changing the infeed depth



Increasing v_w:
- Increased material removal
- Coarser chips
- Higher loads on individual grits
- Greater tendency for single grits to split

The wheel acts softer.

Reducing v_w:
- Reduced material removal
- Finer chips
- Lower loads on individual grits
- Less tendency for single grits to split

The wheel acts harder.

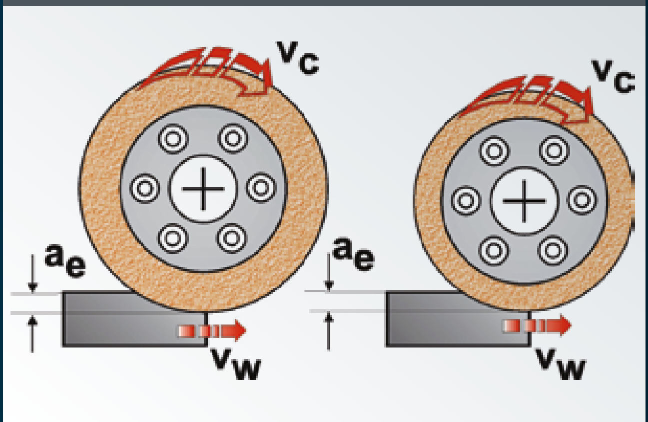
Increasing a_e:
- Increased material removal
- Coarser chips
- Higher loads on individual grits
- Greater tendency for single grits to split

The wheel acts softer.

Reducing a_e:
- Reduced material removal
- Finer chips
- Lower loads on individual grits
- Less tendency for single grits to split

The wheel acts harder.

Change in wheel diameter



Increasing d_s:
- Contact area Ak between wheel and workpiece increases
- Grinding forces remain practically unchanged
- Lower loads on individual grits
- Less tendency for single grits to split

The wheel acts harder.

Reducing d_s:
- Smaller contact area
- Grinding forces remain unchanged
- Higher loads on individual grits
- Greater tendency for single grits to split

The wheel acts softer.

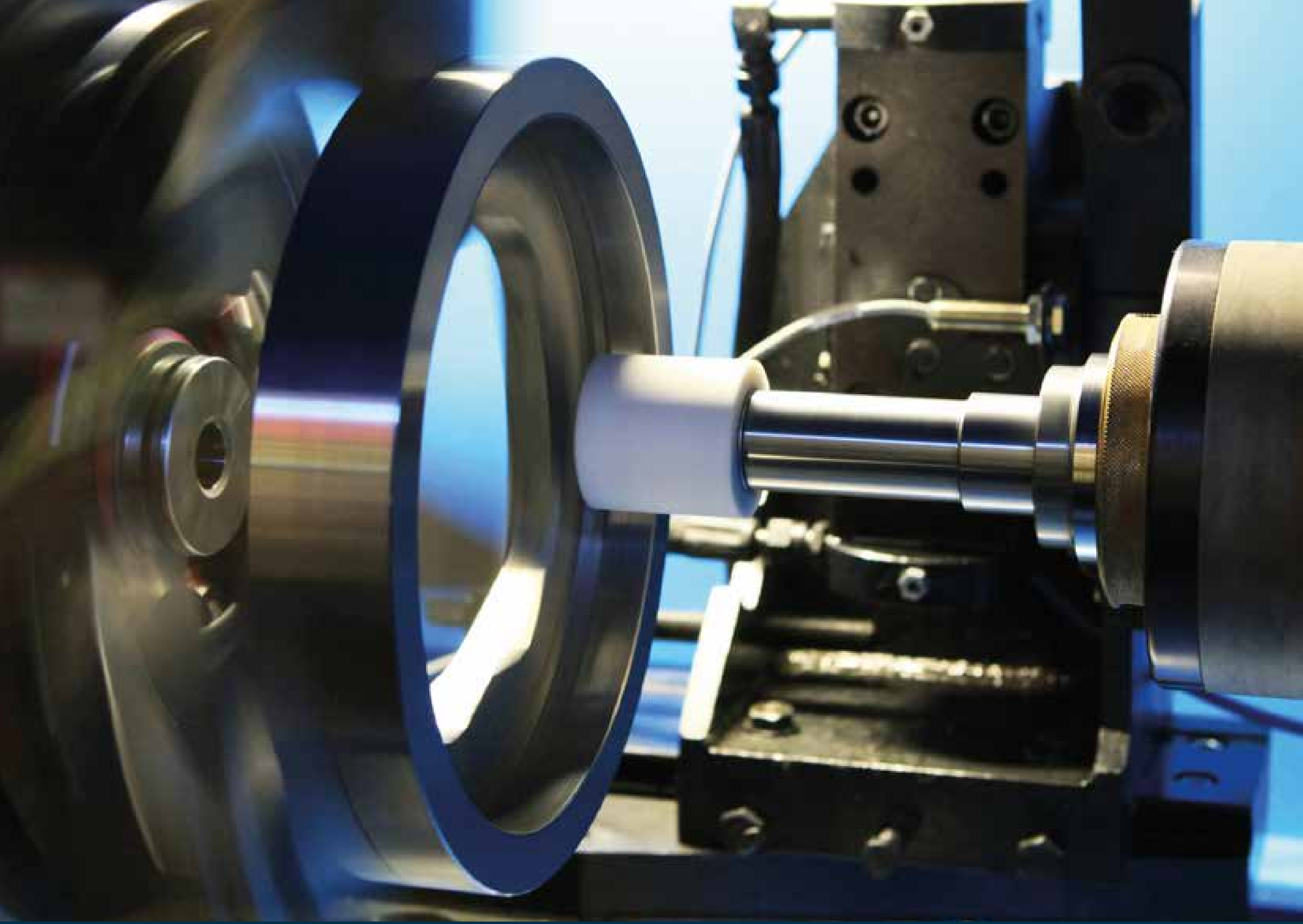
Contact area

The actual material removal takes place at the contact surface between the grinding wheel and the workpiece. With a greater contact area, a larger number of cutting edges are engaged in chip cutting. This makes the chips smaller and the specific forces lower. The opposite is true for a smaller contact area.

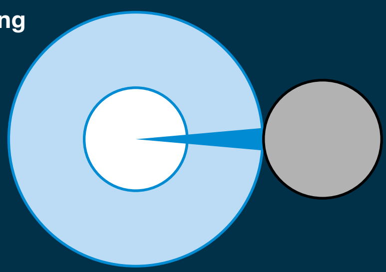
The contact length depends primarily on the grinding process. It also depends on the diameter of the grinding wheel, the cutting depth, and the workpiece dimensions. Differences in contact length are mainly significant when selecting a suitable wheel composition for a particular grinding process.

For example, if a grinding wheel with a diameter only a little smaller than the internal diameter of the workpiece is used for internal cylindrical grinding, the contact length is very long, leading to a low cutting force on the abrasive grit. For proper self-sharpening of the wheel, it must have a softer composition than for external cylindrical grinding of a similar workpiece. The contact width can be the width of the grinding wheel, for example with plunge grinding. If necessary, the contact width can be reduced by dressing the grinding wheel. This reduces the contact area and causes thicker chips and higher forces on the abrasive grits, so the wheel acts softer.

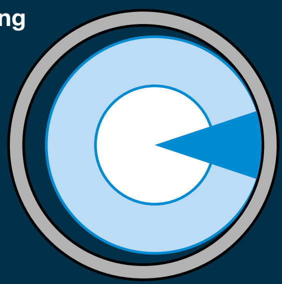
The number of cutting edges has a substantial effect on the grinding process. A larger number of cutting edges per unit area means that the cutting work is distributed over a larger number of abrasive grits, so the specific forces are lower. The grit size of the abrasive also influences the number of cutting edges at the contact surface, causing fine-grit grinding wheels to act harder.



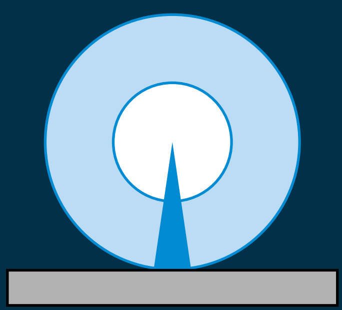
External cylindrical grinding (centerless grinding)



Internal cylindrical grinding



Flat grinding



Face grinding

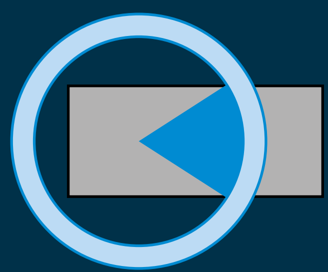


Figure 11: Contact lengths of various grinding processes

GRINDING PROBLEMS AND COUNTERMEASURES

If the grinding wheel acts too hard or too fine:

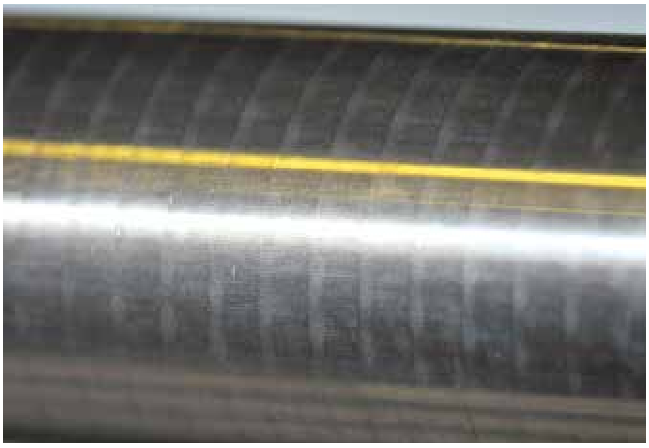
Indicator
- Wheel wears down quickly
- Too little bite
- Burning
- Tendency to chatter
- Wheel needs to be dressed often because it no longer cuts

Countermeasure
- Use a softer wheel or more open structure
- Select a coarser grit
- Reduce the wheel speed
- Increase the feed, infeed and/or workpiece speed

If the wheel acts too soft or too coarse:

Indicator
- Wheel loses its profile
- Wheel does not maintain its dimension
- Wheel needs to be dressed often because it no longer holds its shape
- Wheel consumption is too high

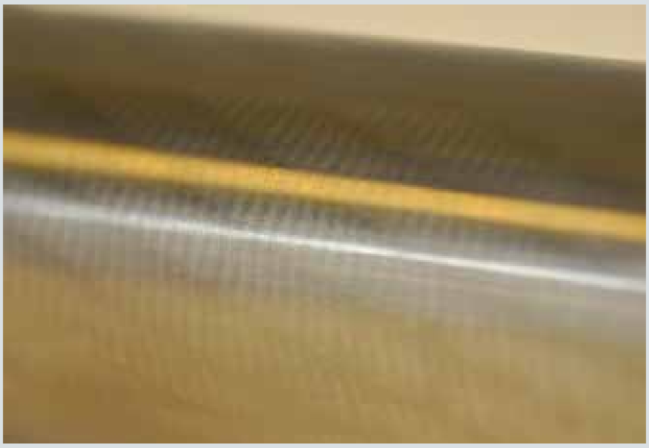
Countermeasure
- Select a harder wheel or tighter structure
- Select a finer grit
- Increase the wheel speed
- Reduce the feed, infeed and/or workpiece speed



The most common grinding problems and their countermeasures are:

a) Indicator: Thread pattern with pitch matching the table feed is visible on the surface of the workpiece

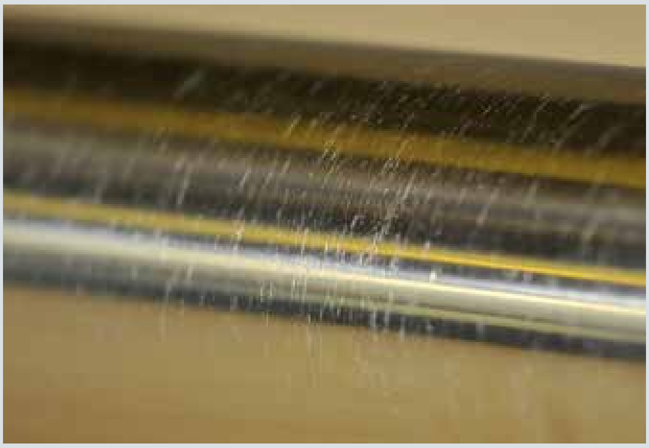
Correction
- The surface of the grinding wheel is not parallel to the motion of the bed (offset, thermal effect or dressing tool wear.)
- Monitor the dressing tool and thermal conditions



b) Indicator: Surface has **spirals, diagonal marks**, or a regular pattern

Cause
- Defective dressing process produces out-of-round wheel, which transfers the error to the workpiece

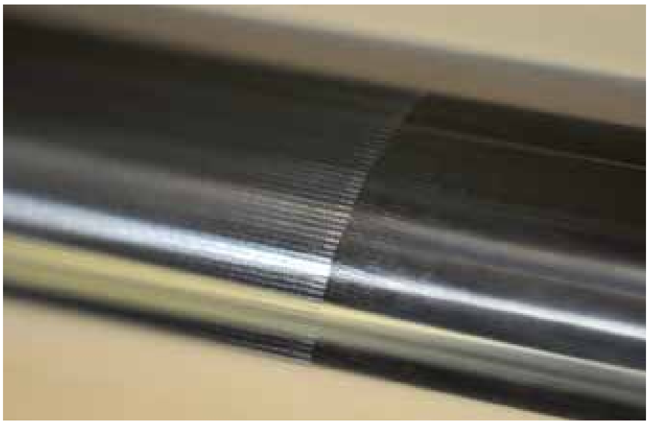
Correction
- Dress the wheel in one direction only; reduce dressing feed if necessary



c) Indicator: Workpiece surface shows irregularly distributed **short, comma-shaped scratches**

Cause
- Particles floating in the coolant or clogged wheel

Correction
- Clean the cover
- Check the filter
- Select a more open wheel structure



d) Indicator: Chatter marks parallel to the workpiece

Cause
- Grinding wheel imbalance
- Vibration of the workpiece or machine
- Wheel/workpiece speed ratio too low (qs < 60)

Correction
- Check workpiece fixturing
- Check wheel for imbalance or runout
- Never let coolant run across a wheel that is standing still
- Use a steady rest? (check) qs? (check)

e) Indicator: Spiral or localized yellow or brown **surface discoloration**

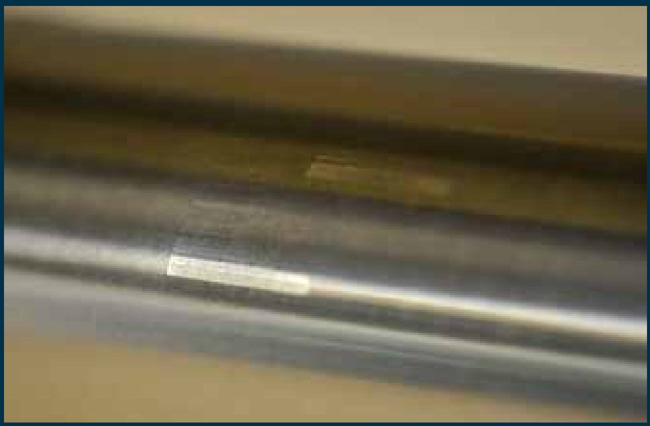
Cause
- Overheating in the grinding process Insufficient coolant flow? Speed ratio too high (qs >= 120)?
- Wheel dressed too finely?
- Wheel too hard

Correction
- Increase the dressing infeed, speed ratio < 120, increase coolant flow
- Use coolant with mineral oil content
- Select a softer wheel or more open structure

f) Indicator: Grinding with **dull wheel**, mirror finish or uneven areas from premachining remain intact

Cause
- Wheel dressed too finely, clogged, or grit too fine

Correction
- Increase dressing infeed
- Use new single-crystal diamond
- Use a more open (porous?) or coarser wheel



g) Indicator: Facets occur parallel to the workpiece axis (partial or over the entire circumference)

Cause
- Interference from inside or outside the machine (e.g. coolant pump, blower, forklift, punch presses, etc.)

Correction
- Eliminate the interference

GRINDER AND COOLANT

Grinder

The grinding process and the machine greatly influence the selection of the wheel composition.

A grinder should be as rigid as possible, so that it can work with high grinding pressure. This high grinding pressure is advantageous when using a sintered corundum, for example, as it is ideal for fostering the self-sharpening effect. The rigidity of the grinder and the type of fixturing also help to determine the selection of the grinding wheel.

If the machine is not rigid enough, then a softer wheel or smaller contact surface between the wheel and workpiece should be selected in order to ensure the required degree of self-sharpening. The spindle speed (spindle drive power) of the grinder also affects the wheel selection.

Coolant

Cutting fluid is used for grinding, just like all other cutting processes. This coolant is primarily needed to

- Cool the workpiece
- Act as a lubricant to reduce friction between the chips, the workpiece and the grinding wheel
- Prevent edge-zone effects on the workpiece
- Provide heat dissipation from the contact zone
- Flush out chips from the contact area
- Ensure consistent abrasive properties

Three types of cutting fluids are primarily used for grinding:

Water-based
These are fluids consisting of water with synthetic additives. They have good cooling capacity, but their lubrication properties are not as good.

Emulsions
These consist of water with 3–5% highly emulsified oil additive. Lower concentrations cause the pH value to drop, and odors or corrosion can occur. Emulsions with too high a concentration can cause wheel clogging during grinding and loss of material removal performance (reduced flushing effect). Foaming can also occur if the concentration is too high and the water hardness is too low. Emulsions are currently used for most grinding processes due to their low environmental impact and adequate performance.

Cutting oils
These are normally based on a mineral oil with additives. Cutting oils have very effective lubrication properties, but their cooling performance is not as good.

Dressing

Dressing the grinding wheel results in precise runout and the correct geometric shape. Dressing is also used to produce the desired effective roughness and to influence cutting capacity. Controlled changes to dressing conditions can change the topography of the wheel, which has a substantial influence on the grinding process and the desired result.

Dressing can be done in a stationary or rotating process. Fused red corundum, abrasive fabrics or mixed corundum can be used for stationary dressing. Rotating dressing wheels running in the same or opposite direction are used for rotational dressing. For detailed information on dressing parameters, please contact Rappold Winterthur Technologie.

Dressing terminology

ad = infeed depth of the diamond tool (mm)
bd = effective width of the diamond tool (mm)
ns = grinding wheel speed (rpm)
sd = diamond tool infeed per wheel revolution (mm/rev)
Ud = overlap (number)
Vd = diamond tool infeed rate (mm/min)

General:

- In general, the dressing tool infeed should be low (0.002 to 0.03 mm), as otherwise the microstructure will be damaged.
- To adjust the effective surface roughness, the dressing infeed rate vd should be varied (higher vd = greater roughness, and vice versa).

Important notes:

- Always use appropriate cooling when dressing. Diamonds are very sensitive to heat!
- NEVER traverse the wheel without infeed (ad = 0), because this will dull the wheel.

PRACTICAL EXAMPLE

WINTERTHUR
TECHNOLOGY GROUP

Determining the optimal abrasive for electroslag-remelted BÖHLER K340 ISODUR and powder-metallurgical BÖHLER K390 MICROCLEAN.

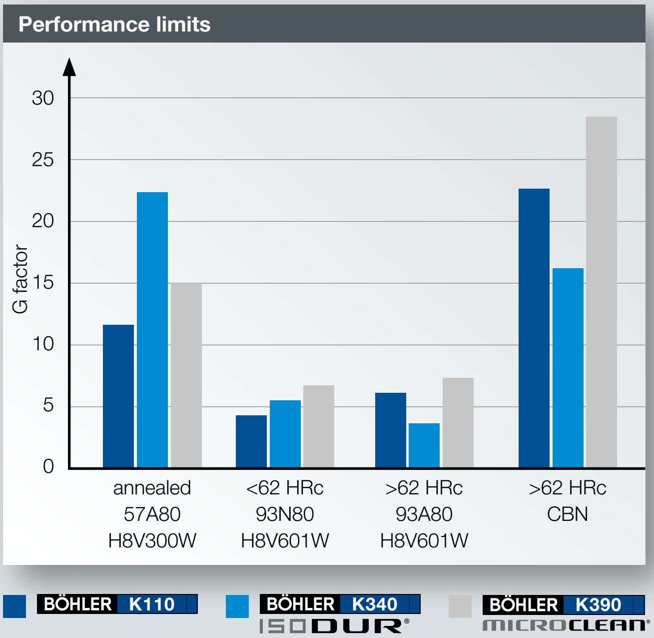
IIn a practical test, external cylindrical grinding was performed on BÖHLER K110 and BÖHLER K340 ISODUR (electroslag remelted 8% Cr cold-working steel with optimized toughness) and BÖHLER K390 MICROCLEAN (powder metallurgy)

The rods (Ø 80 mm, length 330 mm) were heat treated at BÖHLER, and all grades were ground after annealing to a hardness of less than 62 HRc and greater than 62 HRc. The abrasives were provided by Winterthur Technology. The grinding tests were performed in cooperation with the Institute for Manufacturing Engineering at the Technical University of Graz. The goal of the practical tests was to determine the optimal abrasive for the steel grades listed above (BÖHLER K110, BÖHLER K340 ISODUR and BÖHLER K390 MICROCLEAN).

The following grinding parameters were used:

Grinding process	External cylindrical grinding, reciprocal
Machine:	Kellenberger Kelvaria UR175/1000 (7,5 kW)
Hardness:	 Through-hardened (approximately 62 HRc)
Wheel designation:	57A80 H8V300W-50 m/s - Pink fused corundum 64A80 H8V300W-50 m/s - Mixture of pink fused and single-crystal corundum 93N80 H8V902W-50 m/s - NanoWin® (special corundum) 93A80 H8V601W-50 m/s - Mixture of white fused and sintered corundum 11C80 J15VPLF-50 m/s - Silicon carbide 32B126 O15CVPMFC75 - CBN
Parameters:	The same settings were used for each grinding wheel in the tests. • Same direction: yes • Wheel speed vc = 40 m/s • Workpiece speed nw = 200 rpm • Infeed ae = 0.008 mm on both sides • Addition = 1.0 mm on the diameter
Dressing:	With PKD nonwoven • Wheel speed vc = 40 m/s • Dressing speed vd = 200 mm/min • Dressing infeed ad = 0.02 mm on both sides
Coolant:	Blasocut Emulsion 3.5%, fully synthetic

The following diagram shows a summary of the results of the best grinding wheel grades for the different steel grades:



Cost effectiveness:

Cost effectiveness is evaluated as the least wheel wear relative to the maximum material removal rate (G factor) for each steel grade and hardness.

- In the annealed state (~56 HRc), pink fused corundum (57A) is best
- With material hardness below 62 HRc, the 93N material (NanoWin®) was the most suitable universal wheel, closely followed by the sintered corundum variant 93A80 H8V601W
- The harder the material, the more cost effective the CBN wheel becomes. The CBN wheel is by far the best option for full hardness (> 62 HRc) with respect to the G factor, but is several times more expensive than conventional ceramics.

The following tables contain details for grinding tools, molds and dies made from BÖHLER hot-working, mold-making, cold-working and high-speed steels. These recommendations were developed jointly by BÖHLER Edelstahl and Rappold Winterthur Technologie.

Grinding powder-metallurgical materials
BÖHLER has continued to refine the manufacturing process for powder-metallurgical high-speed steels and tool steels. With the world's most modern system in Kapfenberg, the third generation of MICROCLEAN materials is being produced with even better performance characteristics.

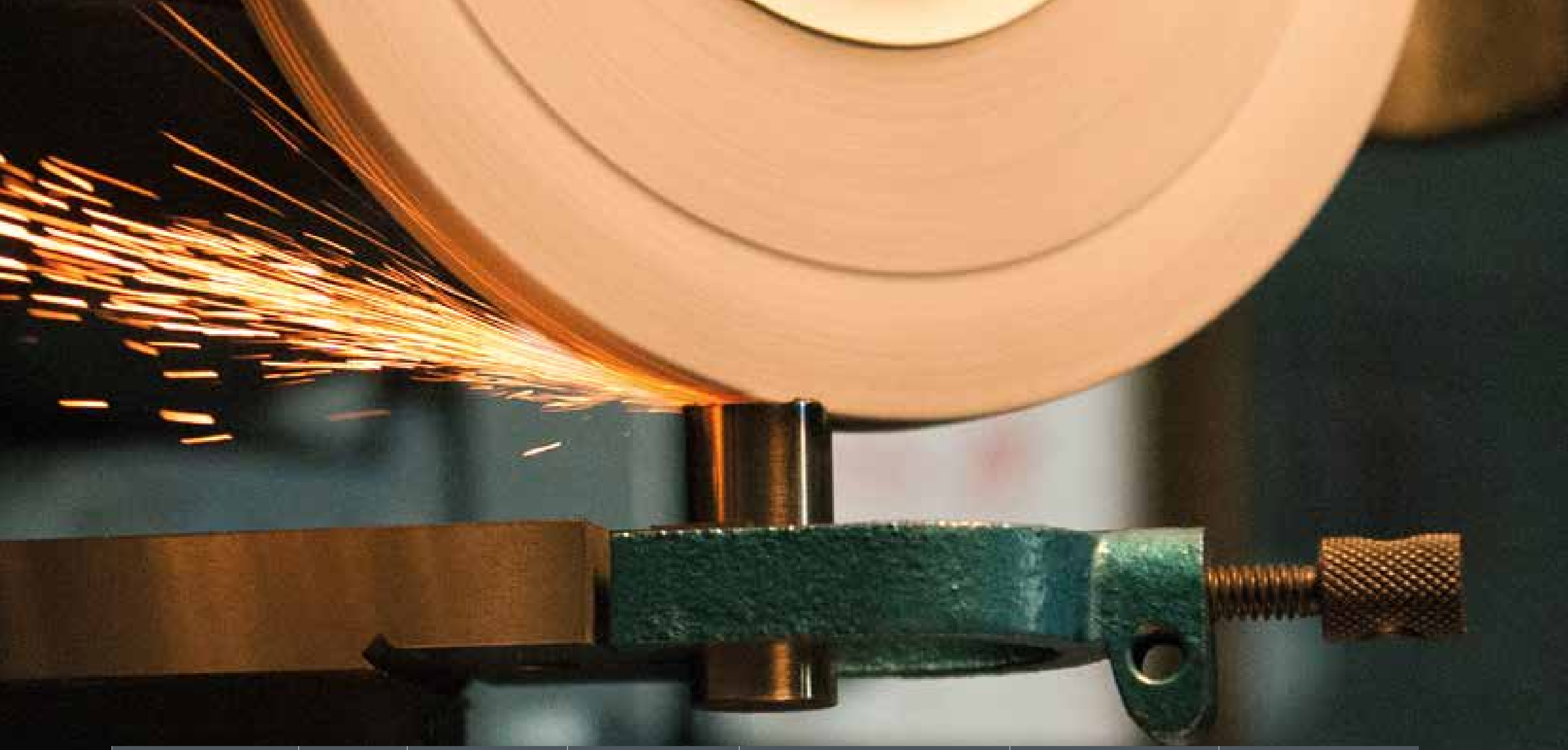
The BÖHLER MICROCLEAN steels set new standards for high performance in terms of **toughness, wear resistance, compressive strength** and **corrosion resistance**.

An extensive range of cold-working, mold-making and high-speed steels gives our customers a clear competitive advantage.

Grinding recommendations are also provided for powder-metallurgical BÖHLER steels, which are more difficult to grind because of their high alloy content.

RECOMMENDATIONS FOR GRINDING BÖHLER TOOL STEELS AND HIGH-SPEED STEELS

BÖHLER grade	Condition	External cylindrical grinding	Internal cylindrical grinding	Centerless grinding		Flat grinding	Profile and creep grinding
Medium alloy steel							
BÖHLER K245 BÖHLER K455 BÖHLER K460 BÖHLER K510 BÖHLER K600 BÖHLER K605 BÖHLER K720 BÖHLER W300 BÖHLER W302 BÖHLER W303 BÖHLER W320 BÖHLER W321 BÖHLER W350 ISOBLOC® BÖHLER W360 ISOBLOC® BÖHLER W400 VMR® BÖHLER W403 VMR® BÖHLER W600 ISOBLOC®	annealed	57A80 J7V300W 57A60 K5V300W	54A80 H9V904W	Throughfeed Plunge	31A80 L6V301W 31A120 L6V301W	64A60 H15VP300W	54A80 H15VPMF904W
	hardened	54A60 J7V904W 54A80 H8V904W	93A80 H13VP601	Throughfeed Plunge	54A80 L6V604W 93A80 L6V601W 54A180 L6V604W 93A120 L6V601W	93A60 F15VPH601W	93A80 F15VPH601W
BÖHLER M200 BÖHLER M238 BÖHLER M261 BÖHLER M268 VMR® BÖHLER M300 ISOPLAST® BÖHLER M303 EXTRA BÖHLER M314 EXTRA BÖHLER M315 EXTRA	prehardened	54A60 J7V904W	54A80 H15VPMF904W	Throughfeed Plunge	31A80 L6V301W 31A120 L6V301W	54A60 H15VPMF904W	54A80 H15VPMF904W
	hardened	54A80 H8V904W 93A80 H8V601W	32B91 P8CV600C100 ev. 93A80 H13VP601	Throughfeed Plunge	54A80 L6V604W 54A180 L6V604W	54A60 F15VPH904W	54A80 F15VPH904W



BÖHLER grade	Condition	External cylindrical grinding	Internal cylindrical grinding	Centerless grinding		Flat grinding	Profile and creep grinding
High alloy steel							
BÖHLER K100 BÖHLER K110 BÖHLER K305 BÖHLER K306 BÖHLER K353 BÖHLER K340 ISODUR® BÖHLER K360 ISODUR® BÖHLER S400 BÖHLER S500 BÖHLER S600 BÖHLER S700 BÖHLER S404 BÖHLER S607 BÖHLER S630 BÖHLER S705 BÖHLER M310 ISOPLAST® BÖHLER M333 ISOPLAST® BÖHLER M340 ISOPLAST®	annealed	57A80 J7V300W 64A80 H8V300W	64A80 H8V300W 54A80 H15VPMF904W	Throughfeed Plunge	31A80 L6V301W 31A120 L6V301W	54A60 H15VPMF904W	54A80 H15VPMF904W
	hardened < 62HRc	93A80 H8V601W 93N80 H8V902W	93A80 H13VP601 11C60 H15VP	Throughfeed Plunge	93A80 J7V601W 93A120 J7V601W ev. 11C120 K4V	64A60 H15VP300W	93A80 F15VPH601W 54A80 F15VPH904W
	hardened > 62HRc	32B91 P5V600C100 ev. 93A80 H8V601W	32B91 P8CV600C100 ev. 93A80 H13VP601	Throughfeed Plunge	32B91 P8CV600C100 32B126 N5CV800C100	93A60 F15VPH601W 32B126 Q15CVPMF600C75	93A80 F15VPH601W
PM grades							
BÖHLER S290 MICROCLEAN® BÖHLER S390 MICROCLEAN® BÖHLER S590 MICROCLEAN® BÖHLER S690 MICROCLEAN® BÖHLER S790 MICROCLEAN® BÖHLER K390 MICROCLEAN® BÖHLER K490 MICROCLEAN® BÖHLER K890 MICROCLEAN® BÖHLER M368 MICROCLEAN® BÖHLER M390 MICROCLEAN®	annealed	57A80 H8V300W	54A80 H15VPMF904W	Throughfeed Plunge	54A80 J7V904W 54A120 J7V904W	54A60 H15VPMF904W	54A80 H15VPMF904W
	hardened < 62HRc	93N80 H8V601W	93A80 H13VP601	Throughfeed Plunge	93A80 J7V601W 93A120 J7V601W	64A60 H15VP300W	93A80 F15VPH601W 54A80 F15VPH904W
	hardened > 62HRc	32B91 P5V600C100 ev. 93A80 H8V601W	32B91 P8CV600C100	Throughfeed Plunge	32B126 P8CV600C100 32B126 N5CV800C100	93A60 F15VPH601W 32B126 Q15CVPMF600C75	93A80 F15VPH601W

Wheel grades:
31A... Mixture of normal, semifriable, fused white corundum
93A... Mixture of sintered corundum and white fused corundum
11C... Green SiC
32B... Cubic boron nitride (CBN)
93N... NanoWin, suitable for soft alloy components
54A... Fused white corundum with recrystallized binder system
57A... Pink fused corundum, grit somewhat tougher than
64A... Mixture of single-crystal and fused pink corundum

BÖHLER

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