CERATIZIT is a high-tech engineering group specialized in tooling and hard material technologies.

Tooling the Future

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Welcome to CERATIZIT USA’s Technical Reference Book:

Which parameters influence the properties of carbide? What is the rupture strength in relation to the cobalt content? On the following pages you will find the most important properties of carbide and how to apply them as well as information on the different specification parameters of our products.

In addition to this technical reference book, please be sure to check out our other catalogs; Solid Carbide Rods, Rods with Coolant Holes, our highly popular Rotary Tool Preforms, Carbide Grades.

We thank you for taking time to view this reference book, and we look forward to speaking with you in person to assist you in creating the best product ever.

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Carbide: Application and Composition

Carbide is a hard material with mechanical properties that can be adjusted within a very wide range, given its composition and microstructure. The hardness and toughness range of the CERATIZIT grades includes everything from wear-resistant tool steel to super-hard ceramic materials.

Criteria relevant for application
- Wear resistance, hardness
- Compressive strength
- Impact strength
- Transverse rupture strength
- Tribological properties
- Specific weight

<table>
<thead>
<tr>
<th>Natural diamond</th>
<th>PCD, diamond coated</th>
<th>CBN</th>
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<td>Ceramic (O)</td>
<td>Ceramic (N)</td>
<td>Cermet</td>
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<tr>
<td>Carbide</td>
<td>HSS</td>
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</tbody>
</table>

The hard material provides the necessary
- Hardness
- Wear resistance

The metallic binder provides
- Toughness
## Carbide: Grades
### Composition and Properties

<table>
<thead>
<tr>
<th>CERATIZIT grade code</th>
<th>ISO code</th>
<th>U.S. code</th>
<th>Binder [m %]</th>
<th>Density [g/cm³]</th>
<th>HV30</th>
<th>HRA [MPa]</th>
<th>Transverse rupture strength [MPa]</th>
<th>$K_{IC}$* (Shetty) [MPa*m½]</th>
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<tr>
<td><strong>Ultrafine grades</strong></td>
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### Grain size classification

<table>
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<tr>
<th>Average grain size [µm]</th>
<th>Classification</th>
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<td>&lt; 0.2</td>
<td>nano</td>
<td>N</td>
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<tr>
<td>0.2 – &lt; 0.5</td>
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<td>U</td>
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<tr>
<td>0.5 – &lt; 0.8</td>
<td>submicron</td>
<td>S</td>
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<tr>
<td>0.8 – &lt; 1.3</td>
<td>fine</td>
<td>F</td>
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<tr>
<td>1.3 – &lt; 2.5</td>
<td>medium</td>
<td>M</td>
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<tr>
<td>2.5 – &lt; 6.0</td>
<td>coarse</td>
<td>C</td>
</tr>
<tr>
<td>&gt; 6.0</td>
<td>extra-coarse</td>
<td>E</td>
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</table>

**Comment:**
1. The data in this table are typical material parameters. We reserve the right to modify the data due to technical progress or due to further development within our company.
2. $K_{IC}$*: The measured critical tension intensity factors ($K_{IC}$) depend to a high degree on the sample geometry and sample preparation. A direct comparison with parameters which have been determined by means of a different method is therefore not admissible.

The classification of carbides according to grain size corresponds to the recommendations of the Powder Metallurgy Association. The standard ISO codes for carbides which were developed for fine to medium grain sizes no longer correspond to today’s state of the art. In order to choose the correct grades, only the application data are relevant.

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Grade Description

Ultrafine grades

CTU08L: grade with a typical grain size of 0.2 μm for the machining of materials with a hardness > 65 HRC. Thanks to the high wear resistance also excellent suitability for abrasive fiber composite materials.

TSF22: grade for HSC machining of tempered steels with a hardness of > 60 HRC and abrasive aluminium alloys.

TSF44: grade for HSC machining of tempered steels up to 60 HRC, suitable for micro- and finishing tools and for a variety of materials.

Submicron grades

CTS12D: grade for machining aluminium alloys, fiber-reinforced plastics (carbon-fiber and glass-fiber reinforced), composite materials, graphite; particularly suitable for diamond coating.

CTS15D: grade for machining grey cast iron, tempered cast iron, non alloyed steel, non-ferrous metals and plastics.

CTS18D: grade for high-performance machining of steel, stainless steel and the machining of difficult to machine materials, for example titanium or Inconel.

CTS20D: grade for the universal machining of alloyed and non alloyed steels, titanium alloys and nickel-based alloys. Improved toughness ensures a reduced risk of ruptures on the cutting edges.

CTS25D: grade with high toughness for the machining of difficult materials and under unfavorable conditions.

CTS30D: grade with very high toughness for difficult machining conditions.

CTS20Z: grade for rotating solid carbide tools. For machining stainless steels, acid and heat-resistant steels, chromium alloyed steels, nickel & cobalt alloyed steels, titanium alloys, non ferrous metals, plastics.

CTS24Z: grade for for improved machining of titanium alloys and stainless steels as well as increased drilling performance in alloy steels.

Fine grain grades

CTF12E: grade for gun drills with an adapted relation between hardness and toughness. Suitable also for diamond-coated solid carbide tools.

CTF25E: grade for the production of PCD tools and tool shanks. The increased cobalt content and the coarser grain improve brazability while increasing fracture toughness.

CTF12A: fine grain grade for solid carbide tools with diamond coating. Excellent suitability for the machining of graphite and aluminum with a high silicon content.

Cermet

CTF28T: grade particularly for the finish machining of steel. Thanks to high oxidation resistance and low tendency to stick it is particularly suitable for the production of uncoated reamers.
Mechanical Properties of Carbide

Wear resistance
The most important property of carbide is wear resistance. This property – or, to be precise, this combination of properties – refers to the surface of the component. When two surfaces rub against each other, material is removed from both of them. Under low stress the material removed consists of single grains or particles. This phenomenon is called 'scoring'. In cases of high stress the material removed consists of grain clusters and is called 'abrasion'. The concept of wear is very complex and depends on many variables. Wear resistance is mainly tested using the ASTM B611-85 method. In this method a carbide piece is pressed onto a rotating steel disk using a lever. The rotating steel disk is the carrier for the abrasive material, which together with the material that is subject to analysis is transported from a tank below the container directly to the contact zone (see figure 1). The abrasive material consists of water and aluminium oxide (corundum). Wear resistance is determined by measuring the volume of material removed from the carbide piece while the revolution number, test time and the force applied at 90° on the steel disk are held at consistent levels. A gravimetric evaluation is carried out, with the volume removal indicated in mm³. As shown in figure 2, wear resistance increases the finer the grain and the lower the cobalt content.

Hardness
Hardness is a material's mechanical resistance to another, harder, material which penetrates it. The hardness is normally determined based on the Vickers hardness test according to ISO 3878. In this test a 136° pyramidal diamond indenter is pressed onto a work piece with a determined test force. The size of the indent is determined optically by measuring the two diagonals of the square indent produced by the applied force (F). The impression surface is calculated with formula #1 (see fig. 3). When introducing this test method the obsolete unit 'kilopond' was used for the test force. Therefore in the formula the factor 0.102 is used for conversion. The standardized indication of the Vickers hardness, for example, is as follows:

620 HV 30
Parameters:
▲ 620 = hardness
▲ HV = test procedure
▲ 30 = test force in kilopond

Figure 1: test assembly for the determination of wear resistance according to ASTM B611-85
Figure 2: wear resistance in relation to the cobalt content and grain size

Formula #1: calculation of the Vickers hardness (ISO 3878)

\[ HV = \frac{0.102 \times 2 \times F \times \sin^{136^\circ}}{d^2} = 0.1891 \times \frac{F}{d^2} \]
Another method for determining hardness is the Rockwell procedure (ISO 3738). It is similar to the Vickers procedure but uses a diamond braille indenter. Here, the depth of penetration is used as the degree of hardness. There is no theoretical basis for a conversion between the two procedures. In order to create a comparison a determinate test must be carried out. Like wear resistance, hardness also increases with a smaller grain size and lower cobalt content (see figure 4). As wear resistance and hardness show similar behaviour with regard to cobalt content and grain size, hardness is often used as a reference for wear resistance. Furthermore, the Vickers procedure is easier and quicker than ASTM B611-85. Nevertheless the relation of hardness and wear resistance is exponential and also depends on the grain size (see figure 5).

Figure 4: hardness in relation to the cobalt content and grain size

Figure 5: wear resistance in function of hardness with different grain sizes
Toughness
When a material is exposed to external static or dynamic stress, this leads to mechanical tensions. In many cases, particularly with impact loads, both the strength and ductility of the material have to be taken into account. These two properties represent the basis for the concept of toughness, which is defined as the capacity to resist fracture or rupture growth. Fracture in this context means the complete separation of the material into at least two parts. There are numerous possibilities to define or determine toughness, transverse rupture strength or fracture toughness. In the definition above, the integrated product of force and deformation until fracture occurs is used as the toughness value.

In the case of carbide, the Palmqvist method is frequently applied to determine the toughness as a critical tension intensity factor $K_{IC}$. For this purpose, the crack length of a Vickers hardness indent is used to deduce the fracture toughness (see figure 6). This is then converted into the tension intensity factor using formula #2. As can be seen in figure 7, toughness increases with the metal binder content and growing grain size. Compared to other metal materials, carbide can be found in the lower part of the toughness range, about the same as hardened steel.

$$K_{IC} = 0.15 \sqrt{\frac{HV30}{L}} \left[ \frac{MN}{m^2} \right]$$

Formula #2: calculation of the critical tension intensity factor $K_{IC}$

Figure 6: Palmqvist method for the determination of fracture toughness

Figure 7: fracture toughness in relation to the grain size and the cobalt content
By definition, carbide is to be considered a brittle material as there is basically no plastic deformation prior to fracture. This is confirmed by examination of surfaces where breakage occurred. Various carbides, however, show very big differences in terms of toughness which can be best explained by taking a look at the microstructure. Cracks inside the carbide grains may occur just like intergranular fractures and shear fractures in the binder metal. Generally the number of grain cracks rises with increasing grain size, and the number of shear fractures when raising the binder content. In terms of fracture energy, the main contribution to toughness comes from the length of the rupture in the metal binder (see figures 8 and 9).

Figure 8: rupture growth in large grain sizes; larger rupture growth – requires higher fracture energy – higher toughness

Figure 9: rupture growth in small grain sizes; direct, shorter rupture growth – requires lower fracture energy – lower toughness
Mechanical strength
Every material has defects such as inclusions and micro-ruptures. For brittle materials such as hardened steels or carbide the mechanical strength is limited by the number and size of these defects. In this context the mechanical strength depends on the volume, as with a growing material volume the probability of a large defect rises. Depending on the type of stress, various types of strength are distinguished.

Transverse rupture strength
Testing the transverse rupture strength is the easiest and most common procedure of analysing the mechanical strength of carbide. According to the standardized ISO 3327 procedure a test material of a certain length is placed on a surface and put under stress in the middle until it breaks (see figure 10). The transverse rupture strength (T.R.S.) is then the average value of several tests. The maximum value is achieved with a cobalt content of around 14% by weight and grain sizes of around 0.2 – 0.5μm.

The very low plastic deformation is normally not taken into account as it occurs only in the toughest carbides. Transverse rupture strength decreases with increasing temperature. Furthermore, the carbides show creep values when they are subjected to stress or to high temperatures for a long time. The transverse rupture strength is decisively influenced by the number and size of defects in the structure or on the surface. Fractures always occur at the weakest point of the structure, which is also where the largest defect is. A high number of defects therefore increases the probability that one of these defects causes a premature fracture on the point with the highest stress. As the quality demands in the field of carbide manufacturing are high, impurities or defects can be minimized and thus the risk of breakage reduced.

Tensile strength
When testing the tensile strength of brittle materials it is difficult to measure exact results. A precise result depends on both the perfect preparation of the test materials as well as on the additional stress present on the mounting fixtures. Applying the Weibull theory, however, the tensile strength can be deducted from the values of the transverse rupture strength.

Figure 10: illustration of a transverse rupture strength test

Figure 11: transverse rupture strength in relation to the grain size and the cobalt content
Compressive strength
One of the most remarkable properties of carbide is the extremely high compressive strength under uniaxial stress. This valuable property is used in virtually all application fields (cutting edges with high compressive strength in all machining processes, pressing and drawing dies, rolls, anvils and dies for the production of synthetic diamonds, etc.). The tension of this kind of stress doesn’t actually cause fracture due to pressure but due to tension: a shear fracture. A suitable procedure for determining compressive strength can be found in ISO 4506. To achieve precise values for carbide, the test piece's geometry must be changed so that the effects of the edges and contact, which occur in a simple cylindrical test piece, are eliminated. Elastic deformation is produced under initial load; however, before fracture a degree of plastic deformation results. Figure 12 shows the compressive strength of various grain sizes in relation to the cobalt content. The compressive strength increases when the metal binder content decreases and the grain size is reduced. A small grain carbide grade with a low metal binder content typically has a compressive strength of almost 7,000 N/mm². The compressive strength decreases when the temperature increases. The degree of plastic deformation increases notably with the temperature, so that the results are variable when temperatures are high.

Shear strength
The implementation of pure shear tests is very difficult. However, numerous things speak for the fact that the shear strength is somewhat higher than the compressive strength.

Fatigue strength
The fatigue strength of carbide is above 2 million pulsating compressive loads at around 65 to 85% of the static compressive strength. The compressive fatigue strength increases with a decreasing cobalt content and with decreasing grain size.
Modulus of elasticity, shear modulus, Poisson’s ratio
The modulus of elasticity indicates the resistance of a material against elastic deformation and is higher the more rigid a material is. In the case of carbide the modulus of elasticity is 2 to 3 times higher than in steel and increases linearly with decreasing metal binder content. See fig. 13: additives of γ-phase reduce the modulus of elasticity. An exact determination of the modulus of elasticity based on the tension-expansion diagram is difficult. Therefore, for reliable results resonance measurements of transverse and longitudinal waves are carried out according to ISO 3312. The shear module is determined in the same way with the help of torsional vibration. By determining the modulus of elasticity and the shear module the Poisson’s ratio can be calculated.

Influence of the grain size and the cobalt content on the most important properties
The most important mechanical properties of the carbide, such as hardness, transverse rupture strength and fracture toughness, are determined by the grain size of the tungsten carbide and cobalt content. Figure 14 shows the properties of CERATIZIT round rods and preforms. Sporadically it can be sustained that through smaller grain sizes higher hardness and transverse rupture strength can be achieved. At the same time, however, fracture toughness decreases. By increasing the cobalt content hardness is reduced, while the transverse rupture strength and fracture toughness are raised. Based on this fact a compromise between hardness and fracture toughness can be made. Figure 15 shows three different CERATIZIT grades and their hardness, fracture toughness and transverse rupture strength. 0% is the lowest value and 100% the highest value of all CERATIZIT grades.

Figure 13: modulus of elasticity of WC-Co carbides
<table>
<thead>
<tr>
<th>Property from to:</th>
<th>from:</th>
<th>to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness [HV30]</td>
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<td>2200</td>
</tr>
<tr>
<td>Transverse rupture strength [MPa]</td>
<td>2000</td>
<td>4600</td>
</tr>
<tr>
<td>Fracture toughness [MPa * m^{1/2}]</td>
<td>8.4</td>
<td>15</td>
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</table>

Figure 14: properties of CERATIZIT round rods and preforms

Figure 15: tension fields of three CERATIZIT grades, 0% – lowest value of all grades, 100% – highest value of all grades
Physical Properties of Carbide

Density
The density of carbide is determined according to ISO 3369 and varies strongly depending on the composition of the carbide grade. Grades with a very high WC content have the highest density. Grades with high titanium carbide content and a high binder content have the lowest density. Typically it can however be assumed that the density is around 50 to 100% higher than that of steel.

Thermal expansion
As tungsten carbide has a very low thermal expansion coefficient, the values for carbide compared to steel are very low. For carbide grades which contain titanium carbide the values are somewhat higher than for the pure WC-Co carbides. Figure 16 shows the thermal expansion in relation to the cobalt content can be seen.

Thermal conductivity
The thermal conductivity is of great significance for carbide applications, as it determines the temperature in the wear areas and has a large influence on the carbide’s thermal fatigue resistance and resistance to thermal fluctuations resistance. The thermal conductivity of WC-Co carbide is around twice that of unalloyed steels. It is only slightly influenced by the cobalt content and the grain size, while γ-phases like titanium carbide or tantalum carbide have an impact. Titanium carbide strongly reduces the thermal conductivity. Therefore, for milling grades tantalum carbide is mostly used as γ-phase (see figure 17).

Specific thermal capacity
The specific thermal capacity is the quantity of heat which is necessary to heat up 1 kg of a material by 1 °C. In application technology it is equally as important as thermal conductivity, because during the machining processes the heat has to be taken away from the cutting edge. Through a high thermal capacity the surrounding area is less hot as it can absorb more energy.

Specific electric resistance
WC-Co carbides have a low specific resistance of around 20μΩ cm and, as such, are good conductors of electricity. Carbides with γ-phases have a higher specific resistance.
Magnetic saturation & coercive field strength

Carbides with cobalt as a metal binder are ferromagnetic. If a ferromagnetic material is exposed to a magnetic field strength $H$, the magnetic flux density $B$ in this material increases (figure 18, blue line). The flux density decreases when the field strength rises, until maximum saturation is achieved. This maximum flux density is defined as magnetic saturation ($4\pi\sigma$).

When the external field strength is removed, the flux density in the material is reduced along the upper green line to a certain residual magnetism ($B_R$), the so called 'remanence'. The higher the remanence is, the better a material can be magnetised and the remanence can only be eliminated when the material is subjected to an inverse field. The inverse field strength $H_C$ which is necessary to reduce the magnetic flux density to zero, or to 'de-magnetize' the material, is defined as coercive field strength.

The finer the magnetic field lines of the metal binder phase in the carbide, the higher the coercive field strength. This means that the coercive field strength provides information about the state of the metal binder phase. The metal binder phase becomes finer with smaller tungsten carbide grains and lower binder content. As described under 1.1.2, the smaller the grains and the lower the metal binder content, the higher the hardness of the structure. In this way an accordant correlation between coercive field strength and hardness can be seen. In practical applications this represents a non-destructive measuring method for the hardness.

The magnetic saturation of carbide also depends on the content and the state of the cobalt binder. When one of these parameters is known, information can be given about the other parameters. In this context the carbon content of the carbide has a decisive influence on the magnetic state of the cobalt.

The magnetic saturation provides information about the carburization of the carbide. This measuring method represents an important tool for checking the production quality.

Permeability

Magnetic permeability means the penetrability of materials for magnetic fields. Although carbide is ferromagnetic, the magnetic permeability values are low. They increase equally along with the magnetic saturation and with the cobalt content and amount to around 5 H/m with 20 vol.%. Compared to this, vacuum has a magnetic permeability of 1 H/m and iron between 300 and 10,000 H/m.

Figure 18: hysteresis curve of a ferromagnetic material
Corrosion Resistance of Carbide

According to DIN EN ISO 8044 corrosion is a reaction of a metal material with its environment, which causes a measurable modification of the material and may lead to a reduced performance of the metal element or the entire system. In most cases the reaction is electrochemical in nature or in some cases chemical or metal-physical in nature. In carbides corrosion causes a reduction of the surface of the binder phase, thus on the surface there remains only a carbide 'skeleton'. The bond between carbide grains next to each other is very weak, so the rate of destruction increases correspondingly. When the metal binder content is low the carbide 'skeleton' is more pronounced. Consequently this type of carbide grade shows higher wear resistance and corrosion resistance than carbides with a higher metal binder content. In practical applications, however, this is not sufficient to significantly increase the service life. Due to their limited corrosion resistance pure WC-Co carbides are often not suitable for application fields with difficult corrosion conditions. Typically, it can be assumed that WC-Co carbides down to pH 7 are corrosion-resistant.

<table>
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<th>Resistance</th>
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<td>Ethanol</td>
<td>high resistance</td>
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<td>Sodium hydroxide</td>
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<td>Tap water</td>
<td>high resistance</td>
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<tr>
<td>Petroleum</td>
<td>high resistance</td>
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</tbody>
</table>

Figure 19: some chemical compounds and the corresponding resistance of carbide
## Specifications – Parameters

### Outside diameter
Measured outside diameter of the round rod.

### Length
Measured length of the round rod.

### Surface
The surface quality describes the state of the surface. For ground rods the surface value is indicated as maximum average roughness value Ra (DIN EN ISO 4287:1998).

### Straightness
Maximum deflection of a rotating rod which lies on two contact points, measured in the middle of the rod. The distance between the two contact points is 300 mm. When the rod is longer or shorter than 330 mm the contact width corresponds to the rod length minus 10 mm.

### Concentricity
Maximum deflection of a rod. Contact point A is 5 mm before the chamfer. Contact point B is in the middle of the rod. The measurement is carried out 2 mm from the end.

### Cylindricity
The cylindricity describes the tolerance field of an ideal cylinder inside which the skin surface of the rod should be.

### Roundness
Roundness is the radial distance of two concentric circles which include the circumference line of the round rod's section. (DIN ISO 1101).

### Pitch circle diameter
The pitch circle is defined as the circle which goes through two or three centre points of coolant holes.

### Hole diameter
The hole diameter is the diameter of the coolant holes inside the rod.

### Eccentricity
Eccentricity means the deviation of the pitch circle center point or, in case of a coolant hole, the deviation of the coolant hole center point from the center point of the rod.

### Helix angle
The helix angle is the angle between the longitudinal axis and the helix line.

### Torsion
Maximum difference of the angle of the two imaginary lines which go through the centre point of the coolant holes which are on the pitch circle.

### Pitch error
For rods with three helical coolant holes the section surface is divided into three circle sectors which go through the centre point of the coolant holes. The pitch error is the difference of the angles between the circle sectors.
Specifications – Pitch Classification

Definition of the helix angle
The helix angle indicates the torsion of the coolant holes in relation to the nominal diameter. In this context it has to be taken into account that the angle decreases depending on the diameter steps. For this reason, rods with 40° coolant holes are used for step drills in order to achieve an optimal spiral flute helix angle of 25 to 30°.

Definition of pitch
The pitch is the length of a complete 360° rotation of the coolant holes. This value is independent of the diameter or the diameter steps. The CERATIZIT designation system for coolant hole rods includes both the helix angle in degrees and the pitch of the helix in millimetres.

Conversion helix angle/pitch:

\[
\alpha = \tan^{-1} \left( \frac{d \cdot \pi}{Stg} \right)
\]

\[
Stg = \frac{d \cdot \pi}{\tan \alpha}
\]

Pitch classification
In order to guarantee the closest pitch tolerances, our carbide rods with helical coolant holes are divided into tolerance classes. For this purpose all rods are measured and assigned to the respective class, which is indicated on the product label.
Notes
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