Metal Cutting

Summary – *After a description of the metal cutting process and a review of the wear and failure modes, these notes will look at how cutting tool materials and coatings have been developed specifically for metal cutting.*

1. The cutting process

Domestic forms of cutting such as slicing bread, chopping vegetables, or using a craft knife are all characterised by a thin, narrow angled wedge blade being driven into the material with force. Metal cutting is not like that, the material is much too hard for such a process to work.

Metal cutting is more similar to "cutting" butter or ice cream straight from the refrigerator or freezer. The blade is placed into the body of the material to a shallow depth and then moved laterally across the surface to remove material and create a new surface below the cutting edge. The cutting occurs along the length of the submerged edge. This cutting is a continuous shearing action and the material removed is fully plastically deformed. The deformed material removed is called the **swarf or chip.**

The cutting tool is much thicker and stronger than a normal blade and has two faces. The **rake face** of the blade which is in contact with the material. The **clearance or flank face** which is below the cutting edge provides a minimal clearance with work material.

The tool **rake angle α** is the angle of the rake face to a plane normal to the work surface. Zero rake is nominally perpendicular to the work surface, positive rake angle gives an angle of less than 90° between the rake face and work surface, and a negative rake tool has an angle of greater the than 90°. The tool **clearance angle** is the angle between the tool flank and the newly exposed work material surface.

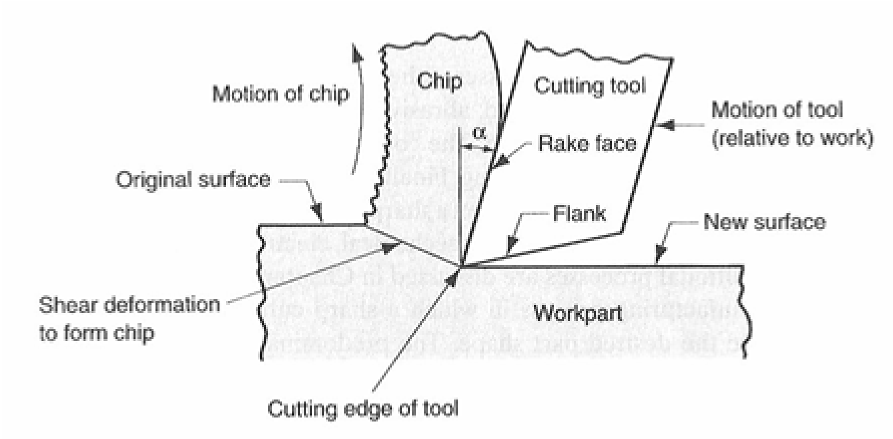

Figure 1. The cutting tool interaction

1.1 Seizure and Flow zones

The comparison between spreading cold butter and cutting metal ends with the visual analogy, the metal cutting process is more complex at the

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microscopic level. The impression that the swarf is sheared away from the main body of material and then slides across the rake face of the cutting tool is simplistic interpretation of what actually happens.

Studies have shown that as the swarf passes over the rake face of the cutting tool, a process of molecular bonding occurs between the swarf and the tool material. The two surfaces are effectively seized. The conditions are perfect for solid phase welding; newly formed surfaces free from contaminants and oxides.

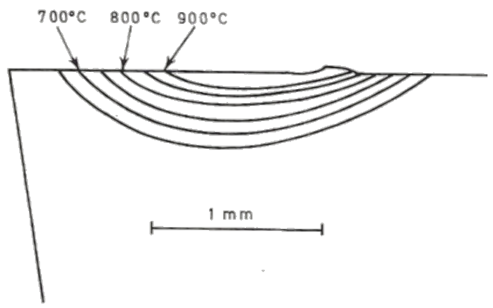
The level of seizure we are considering is different to the common perception of something that is locked solid like a seized bearing or mechanism. Here we considering a model where the seizure is minor, random and local. The shearing forces are greater than the adhesive bond, overcoming the seizure and the motion of the swarf is effectively continuous.

The condition of seizure is most concentrated on the rake face closest to the cutting edge and along the clearance flank, where the two surfaces make contact as the tool wears.

However this does not fully describe the behaviour of the swarf as it passes over the rake surface. Micro-photographs of the swarf also suggest that the material behaves like a viscous fluid as it passes over the rake face. It has a flow zone with a velocity gradient across it, the velocity approaching zero at the rake face where the seizure is occurring. An appreciation of these conditions is important to help understand the wear modes later in these notes.

1.2 Heat generation

There is a considerable amount of heat generated during the plastic deformation of the swarf. In an elastic deformation the energy applied is stored as strain energy and little heat is produced. When a material is deformed plastically, as with the creation of the swarf in cutting, all the energy applied is converted to heat.



The major heat source is from the created swarf and the maximum temperatures are experienced just behind the cutting edge in the area of seizure.

Figure 2 The temperature profile across the rake face of a cutting tool.

Some heat is produced due to the friction between the workpiece and the tool flank but this is less significant, even for a worn tool. The heat generated increases with the cutting speed and feed rate.

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1.3 Coolant

The area of contact between workpiece and tool does provide some thermal conductivity, and heat is lost along the cutting edge to the workpiece material, but the majority of machining operations use a coolant both to control the temperature of the cutting tool, and to remove the swarf from the area.

It is very important to be able to control the temperature of the cutting to extend the tool life and improve the surface finish of the machined surface.

Coolant is applied in a variety of ways:

Flood coolant, in which large volumes of coolant is applied from multiple, low pressure nozzles to quench the working area.

Mist coolant, is a high pressure application which uses less coolant but must operate within a sealed space to condense and reclaim the coolant.

Through-tool coolant, requires the machine tool and cutting tool to be specially designed to allow coolant to flow though the machine spindle or tool post, and then out through the cutting tool directly into the cutting area.

Most coolants are milky white or blue in appearance and are an emulsion of soluble mineral or synthetic oil mixed with water in a concentration of between 1:10 & 1:60. A more recent development is the use of high pressure CO^2 (Carbon Dioxide) or compressed air applied using through–tool technology. The gas expands freely as it leaves the tool and in doing so draws in the generated heat, away from the tool.

There are operating cost associated with the use of coolant in respect to the cost, storage and handling of the coolant. It does have an effective life and must be routinely emptied and replaced. This incurs additional cost in lost production and the cost of disposal.

The ability to cut “dry”, without coolant is an important and desirable economic feature of modern coated cutting tools.

2. Metal cutting variables

For most metal cutting the tool/workpiece cutting interaction is between a rotating object and a fixed object. In turning, the workpiece is rotating and the cutting tool is fixed, in milling & drilling the opposite is true, the workpiece is fixed and the cutting tool is rotating. These cutting process are described by 3 cutting variables:

The **depth of cut** a_p is the length of the submerged cutting edge in contact with the material. In Figure 3. the depth of cut for turning is the reduction in

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radius of the cylinder, for milling the thickness removed and for drilling it is the radius of the drill. What is the depth of cut for a saw blade?

The **cutting speed** v_c is the relative motion between cutting edge and workpiece it is a tangential speed of the rotational motion and is expressed in m/min. The motion is usually associated with a rotating workpiece or tool and where the diameter and rotational speed are given:

$$V_c = d_m \times \pi \times n_w$$

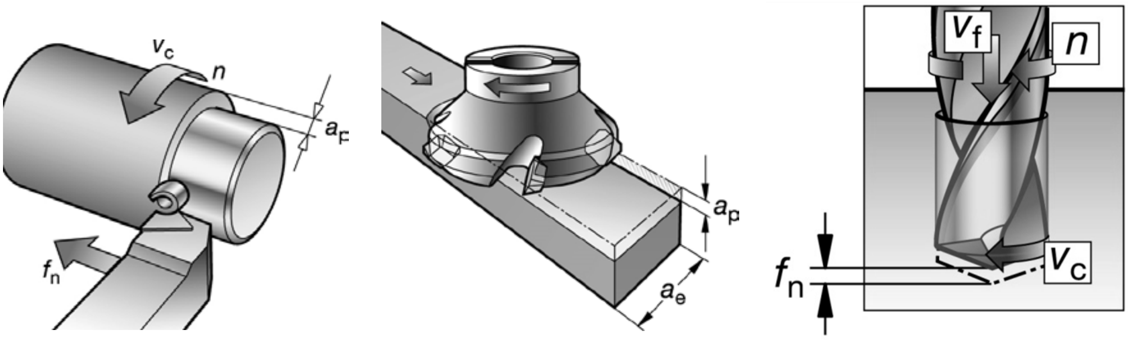
V_c in metres/min
d_m diameter in metres
n_w rotational speed in RPM

For drilling and some milling operations, the cutting speed varies from a maximum at the outside edge to effectively zero at the centre of the cutter. The specified cutting speed is the maximum speed.

The **feed rate** f_n is how fast the cutting edge is pushed into the material during cutting. It is often specified as mm per revolution or per edge, depending upon whether it is a single or multi-edge tool. Feed rate is then converted into linear speed of metres per min by use of the cutting speed.

For a conventional drill there are 2 cutting edges. If the feed rate is 0.05 mm per edge, then the feed rate is 0.1 mm per revolution. If the drill is turning at 600 RPM, the feed rate is 60 mm/min, or 0.06 m/min.

The **material removal rate**, MRR, is the amount of material removed per unit of time and is specified in mm^3 per min. It is determined by the cutting area x feed rate. Take care when calculating MRR to work in the correct units as the feed rate must be converted and expressed as a function of the cutting speed. Some examples are shown below in Figure 3.



MRR = $\pi \times \frac{D_o^2 - D_i^2}{4} \times f_n$

MRR = $a_e \times a_p \times f_n$

MRR = $\frac{\pi D^2}{4} \times f_n$

Figure 3. The 3 cutting variables & MRR for Turning, Face Milling & Drilling.

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Examples

1.a. Consider a 3 flute[1] 12 mm diameter end mill running at 300 RPM taking a 3mm cut at a feed rate of 0.08 mm per edge per rev.

Area of cut = 12 x 3 = 36 mm^2

Feed rate per min = 3 x 300 x 0.08 = 72 mm/min

MRR = 36 x 72 = 2590 mm^3/min

1.b. Consider turning a bar down from 60mm to 50mm diameter in a single cut at a feed rate of 0.2mm/rev and a cutting speed of 150m/min.

Area of cut = $\pi \times \frac{(60^2 - 50^2)}{4}$ = 863 mm^2

Chuck speed = $\frac{150 \times 10^3}{55 \times \pi}$ = 868 RPM

Feed rate per min = 868 x 0.2 = 173 mm/min

MRR = 863 x 173 = 150 x 10^3 mm^3/min

3. Cutter wear & failure modes

All cutting tools, no matter how hard, will wear and eventually fail. The important criterion for the production engineer is that it wears in a controlled and predictable manner and there are no catastrophic failures. Tool wear and effective tool life can be predicted under steady state conditions using the Taylor Tool Life equation:

$VT^{\eta}=C$ where T is Tool Life in minutes
V is cutting speed in metres/min
C & η are constants depending upon cutting conditions
(Tool & Workpiece materials, Depth of cut, coolant, feed)

What is noticeable is that tooling wear is most affected by the cutting speed, depth of cut and feed rate have little effect. Below are explanations of the wear mechanisms and failure modes of the cutting tool during metal cutting.

We will see how the wear mechanisms are predominately affected by the temperature of the cutting, and the failure modes by the mechanical properties of the cutting tool.

[1] Flutes are cutting edges on a drill or milling cutter, hence 3 flute = 3 edges

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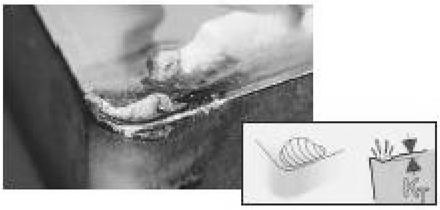
3.1 Diffusion & Crater Wear

Diffusion is the transfer of atoms from one body to another, and is the major contributor to tooling wear.



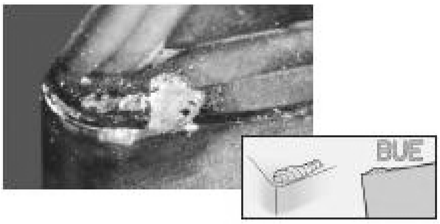
The diffusion wear is noticeable as a crater which appears on the rake face, behind the cutting edge, in the area of the hottest part of the cutting tool. It also coincides with the area of maximum seizure in the cutting process.

The rate of diffusion increases as the temperature of the cutting increases, and is proportional to the cutting speed and feed rate. Rapid cratering is a limiting factor on material removal rates because of its sensitivity to cutting speed and feed rate.

However speeds and feeds are not the only considerations in the rate of diffusion wear. Diffusion and Solution[2] wear is also dependent upon the compatibility properties of the two materials in contact; the workpiece and the cutting tool.

3.2 Attrition & Built Up Edge

After diffusion, attrition is the second most dominant form of wear of cutting tools. It is noticeable at lower cutting speeds and lower tool temperatures out of the flow zone and occurs when the cutting conditions cause a build-up of swarf on the rake face of the tool.



The built up layer, or built up edge BUE, is when the plastically deformed swarf adheres to the cutting edge of the tool, work hardens and covers the cutting edge. It grows layer upon layer to an extent where pieces will fracture away.

Attrition wear occurs when the pieces of BUE fracture and are taken away. They are so strongly bonded to the rake face they also rip out and remove microscopic pieces of the cutting tool material. The wear pattern is characterised by the irregular surface left behind, where the relatively large pieces of tooling material have been pulled from the surface, diffusion wear leaves a very smooth surface to the crater.

An increase in cutting speed and hence cutting temperature will create a flow zone sees the end of BUE and attrition wear.

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[2] Chemical solution wear,

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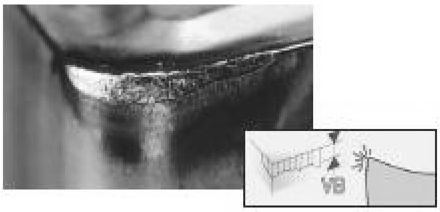
3.3 Abrasion or Flank wear

Abrasion is caused by the action of materials harder than the cutting tool.



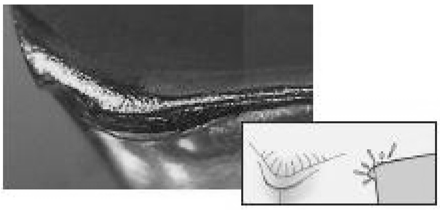
Abrasive wear is seen on the clearance face and is what you want to see. This means you are running under good conditions with no cratering or BUE.

This scenario occurs in processed metals which contain carbides or nitrides or more frequently when machining castings where there are occlusions of silicates from the sand or shell casting process.

The other occurrence is in combination with attrition wear when entrapped pieces of fragmented tooling material trapped within the swarf act as an abrasive on the cutting tool.

3.4 Plastic deformation failure

Plastic deformation is the most common mode of failure of cutting edges, until now we have been discussing wear modes.



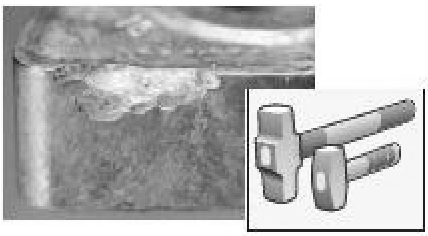
Excessive heat generated during cutting softens the tool edge to a point where the edge is plastically deformed either inwards, away from the workpiece, or downwards causing the flank to swell.

The result is commonly a distortion of the cutting edge and an increase in friction and more heat, which leads to further deformation etc. etc.

As the deformation develops, either cracking will appear in the tool material leading to eventual fracture and loss of the cutting edge, or in some cases a complete melting of the tool.

3.5 Edge fracture (chipping) failure

Edge fracture or “chipping” along the cutting edge occurs when the cutting forces exceed the tensile strength of the tool.



The tool is simply not strong enough to cope with the forces acting upon it.
The forces make be an impact or due to excessive depth of cut or feed rate.
Edge fracture can also be caused by vibration or a poorly mounted tool.

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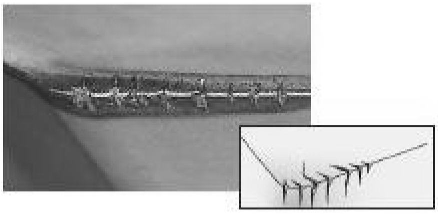
3.6 Thermal cracking failure

During interrupted cutting (milling) the tool edges experience rapid and frequent changes in temperature.



These conditions can lead to micro-cracking and failure due to the thermal cycling effect.

3.7 Summary

At lower cutting speeds and feed rates there is insufficient heat generated for the swarf to flow and built up edge is a problem. As speeds and feeds are increased and the temperature increases and the BUE disappears as a flow zone is created.

If the cutting speed is increased further, the temperature rises to a level where diffusion wear starts to operate and "cratering" occurs. The crater position coincides with the area of highest temperature, away from the cutting edge.

If the speeds and feeds are increased further, there is additional heat generated a risk of plastic deformation of the cutting tool if the tool gets too hot.

The best performance in the cutting process occurs in the flow zone region, where the optimum cutting temperature is achieved above the BUE area and below that leading to cratering.

4. Cutting Tool requirements

Metal cutting can be broken down into two different requirements:

4.1 Roughing – the bulk removal on material reduce the workpiece size down to a "near net" shape close to the required final size. Imagine starting to produce a part for a billet or block, you need to remove a lot of material as quickly and as cheaply as possible.

The process will be exerting high contact forces as you operate with high feed rates of up to 0.5mm/edge and large depths of cuts of up to 6mm. You are limited only by the strength and rigidity of the cutting tool and the available power of the machine tool.

When you are close to the final size your requirements change.

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4.2 Finishing – the final cut, or cuts, to finish the components must achieve the specified dimensional tolerance and surface finish, and any fine detailed features such as grooves or sharp corner radii.

The process requirements completely change from roughing. The cutting tools will be much finer with small radii, the cutting speeds are higher, the feed rates are reduced and the depths of cut are much less, no greater than 1mm. The forces are much lower but the tool rigidity is very important to achieve any tight tolerances.

The nature of the metal cutting is also influenced by the workpiece material and the cutting conditions. Metal cutting is also divided into continuous and interrupted

4.3 Continuous - where the edge of the tool is in continuous contact during cutting, the tool experiences steady state condition cutting forces. This occurs during turning of round bar materials and in the drilling.

4.4 Interrupted or Discontinuous – where the edge of the tool experiences repetitive and cyclical loading, as it periodically engages and releases during cutting. Interrupted cutting is experienced by the side edges of milling cutters, or when turning castings or forging which are not round or making parts from square or hexagonal materials.

It is always good practice to avoid such events. For example if manufacturing a shaft with a keyway, hole, spline or flat feature, always complete the turning first and then produce the milled or drilled features.

The tool requirements for each combination of requirement and application are very different. A continuous, finishing cutting tool requires completely different mechanical properties to that for an interrupted roughing tool. The continuous finishing tool will experience low and steady state cutting forces and so is suited to a very hard material with high wear resistance. The same tool used for roughing would fracture and fail. The roughing tool needs greater strength at the sacrifice of wear resistance.

Ideally all tools would be extremely hard wearing but the nature of such materials is that they are also very brittle with poor toughness. Higher strength materials achieve their toughness at the sacrifice of hardness. A range of cutting tool materials are needed which possess a range of the mutually opposite properties of:

Hot hardness – the ability to retain design geometry and high hardness at the elevated temperatures experienced in cutting.

Toughness – mechanical strength to resist impacts, cyclical loading during interrupted machining and high cutting forces.

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5. Cutting tool materials

Below is a selection of the materials currently used in metal cutting with the year of their introduction.

1912 High Speed Steels (HSS) are alloyed and heat treated High Carbon steels.

1930 Cemented carbides (Cermets) are produced by a sintering process using carbon and tungsten, with a cobalt binder.

1960 Ceramics made from Al. oxide and Silicon Nitride.

1978 Cubic Boron Nitride (CBN) is a man-material not found in nature. Boron Nitride crystals are hexagonal, with a face-centre cubic structure.

1983 Poly Crystalline Diamond (PCD) diamond crystals in a metallic matrix.

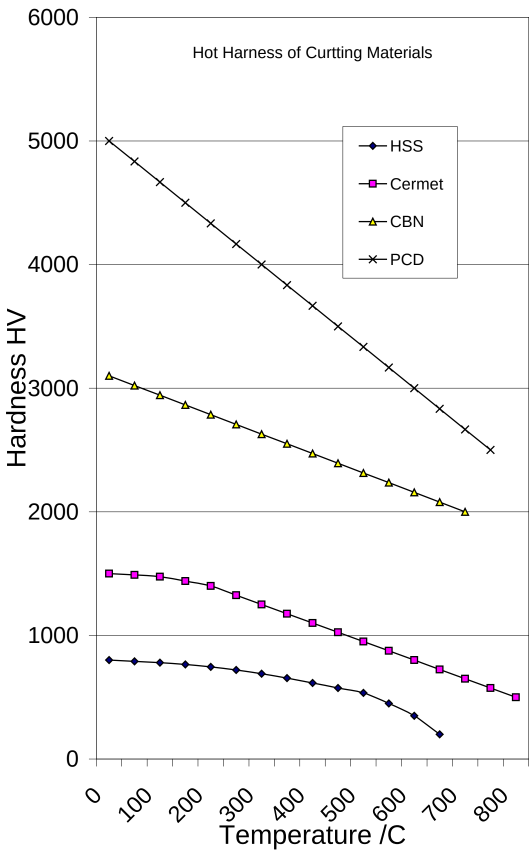

Figure 4. Hardness vs Temperature for cutting materials

6. Cemented Carbides (Cermets)

Cemented carbides have made such an impact on metal cutting over the past 80 years it is worth discussing the subject in isolation. In the 1900s, tungsten carbides and similar materials were recognised as suitable for cutting tools. They possessed extreme hardness with high melting points. The problem was they were very brittle and difficult to process into useful forms. They could only be produced by casting and were poor quality.

In 1920, Osram experimented with powder technology mixing tungsten (W) powder with carbon (C) and using cobalt (Co) as a binder. The mixture was then sintered at below the melting point of the WC compound and a fully dense material was produced in a single cycle. This new production method triggered the development of alloys of WC with varying quantities of cobalt as a major new cutting tool material.

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The new materials were termed cemented carbides and later “cermets” as they demonstrated the mixed properties of a ceramic and metal. One important characteristic, which was in contradiction to their “ceramic” status, was their ability to deform plastically without fracture under compressive loads.

The various Cermet alloys used for metal cutting have a cobalt content of between 4% and 12%, and a carbide grain size of 0.5 µm to 10 µm, and as a rule:

- Material Hardness is inversely proportional to grain size & cobalt content.
- Plastic yield limit is proportional to cobalt content.

Depending upon the machining application, different tooling material alloys and different combinations of grain size and cobalt content each have their own distinct advantages.

Whilst proving very effective in cutting cast iron and non-ferrous materials at higher speeds and feed rates, the new WC-Co Cermet grades did not provide any benefits for cutting steel. The WC-Co tools exhibited greater crater wear at high speed and were no better than the existing HSS tools.

Process developments using titanium and tantalum as alternatives to tungsten did provide the benefits required. The TiC-Co and TaC-Co Cermet grades:

- were more resistant to the crater wear at higher speeds and feeds than HSS, which enabled cutting speeds to be increased by a factor of 3.
- offered superior compressive strength compared to the WC-Co grades.

7. Coatings

To further improve the cutting performance, multiple coatings of ceramic and metal alloys are applied to the surface of cutting tools in layers only a few microns thick. These very hard, fine grain materials can extend tool life by up to 3 times, although more usefully they enable a 25% - 50% increase in cutting speed with no reduction in tool life.

Vapour deposition techniques have evolved to apply single or multiple coatings down to sub-micron level. It is common now for cutters to have 3, 4 or 5 layers of coatings.

Typical coating materials are titanium carbides (TiC), nitrides (TiN) and carbo-nitrides (TiCN), and alumina (AlO).

- TiN coatings are particularly resistant to diffusion wear in the area of seizing, demonstrated by a reduction in crater wear.
- TiC coatings are more resistant to abrasive flank wear

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Another simple advantage of these coatings is the introduction of a colour to assist with easy recognition between the many different material grades.

There is a problem with using coated tooling for interrupted cutting as the coatings can chip or de-laminate. The vapour deposition coating techniques have improved the adherence to the carbide substrate, but it can still be a source of failure.

8. ISO 513 – Classification & Application for cutting materials

All these new Cermet materials using different alloys, grain sizes, binder levels and then coatings has led to multiple options in cutting tools. Standard ISO 513 was written to assist in the selection of the most suitable cutter material grade from all the materials available for a specific machining application.

Two identification letters specify the material from which the cutter is made.

For the Cermet group of alloys:

HW Uncoated carbide, main content tungsten carbide (WC) with grain size of greater than 1 micron

HF Uncoated carbide, main content tungsten carbide (WC) with grain size of less than 1 micron

HT Uncoated carbide, main content TiC or TiN or both.

HC All coated Carbides.

Further combinations exists for Ceramic (C*), Diamond (D*) and CBN (B*) cutter tool materials, both coated and uncoated.

All workpiece materials are divided up into 6 categories and given an indication letter.

For cutting steel (P), we use Titanium and Tantalum carbides & nitrides, for cutting cast iron (K) use Tungsten carbides and for stainless steel (M) use a combination of all three materials. In practice cutting tool manufacturers offer products which are less specific, and are suitable for a variety of materials.

Within each workpiece material category, there is further two-digit numerical sub-division code which characterises the hardness or toughness of the cutting material.

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Main groups of application			Groups of application			
Identification letter	Identification colour	Materials to be machined	Hard cutting materials			
P	blue	**Steel:** All kinds of steel and cast steel except stainless steel with an austenitic structure.	P01 P10 P20 P30 P40 P50	P05 P15 P25 P35 P45	↑ [a]	↓ [b]
M	yellow	**Stainless steel:** Stainless austenitic and austenitic/ferritic steel and cast steel.	M01 M10 M20 M30 M40	M05 M15 M25 M35	↑ [a]	↓ [b]
K	red	**Cast iron:** Grey cast iron, cast iron with spheroidal graphite, malleable cast iron.	K01 K10 K20 K30 K40	K05 K15 K25 K35	↑ [a]	↓ [b]
N	green	**Non-ferrous metals:** Aluminium and other non-ferrous metals, non-metallic materials.	N01 N10 N20 N30	N05 N15 N25	↑ [a]	↓ [b]
S	brown	**Superalloys and titanium:** Heat-resistant special alloys based on iron, nickel and cobalt, titanium and titanium alloys.	S01 S10 S20 S30	S05 S15 S25	↑ [a]	↓ [b]
H	grey	**Hard materials:** Hardened steel, hardened cast iron materials, chilled cast iron.	H01 H10 H20 H30	H05 H15 H25	↑ [a]	↓ [b]

[a] Increasing speed, increasing wear resistance of cutting material.

[b] Increasing feed, increasing toughness of cutting material.

Figure 5. Extract from ISO 513

The lower the number, the finer the carbide grain-size and lower the cobalt content, resulting in a higher wear resistance grades. These can be run at high cutting speeds and high temperatures. These grades are naturally brittle and prone to cracking and edge damage and are suitable for continuous finishing cutting.

The higher the number, the larger the carbide grain-size and higher the cobalt content. These grades are much less hard wearing but much tougher and more impact resistant. They are suitable interrupted roughing cutting. The coarser grains are much more susceptible to attrition wear than the fine grain grades.

The ISO standard is purely empirical and the grades are relative for each cutting tool manufacturer. They are however very useful in production engineering when solving machining problems. It is possible to make quick and valid decision on suitable grades and then adjust up or down the sub-divisions depending upon the performance of the tool, usually working on the performance and from visual inspection of the cutting edge.

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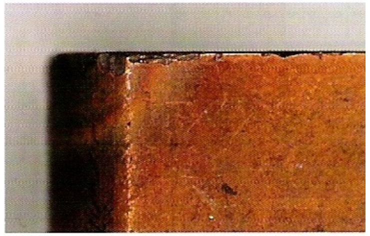
9. Selection of grade and coating

As already said, cutting tool manufacturers do not offer a specific material grade for every combination but optimised products which can be used for a selection of cutting conditions. Below is an extract from Sandvik Coromant for turning applications

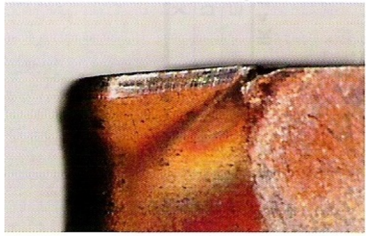
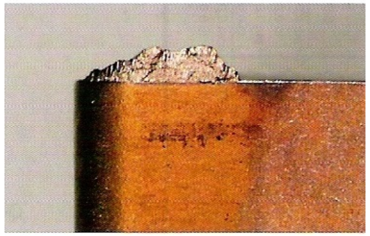
Grade	ISO area applications						Cutting material	Cemented carbide type	Coating procedure and composition	
	P	M	K	N	S	H				
GC1005		M15		N10	S15		HC		PVD	(Ti,Al)N+TiN
GC1025	P25	M15			S15		HC		PVD	(Ti,Al)N+TiN
GC1105		M15			S15		HC		PVD	(Ti,Al)N
GC1115		M15		N15	S20		HC		PVD	Oxide
GC1125	P25	M25		N25	S25		HC		PVD	Oxide
GC1515	P25	M20	K25				HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC2015	P25	M15					HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC2025	P35	M25					HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC2035		M35					HC		PVD	(Ti,Al)N+TiN
GC235	P45	M40					HC		CVD	Ti(C,N)+TiN
GC3005	P10		K10				HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC3205			K05				HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC3210			K05				HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC3215			K05				HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC4205	P05		K10			H15	HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC4215	P15		K15			H15	HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC4225	P25	M15					HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
GC4235	P35	M25					HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
S05F					S05		HC		CVD	MT-Ti(C,N)+Al_2O_3+TiN
H10				N15			HW			
H10A					S10		HW			
H10F					S15		HW			
H13A			K20	N15	S15	H20	HW			
GC1525	P15	M10					CT		PVD	Ti(C,N)
CT5015	P10		K05				HT			

Reference to this chart, together with an examination of the wear or failure mode of the cutting tool and consideration of the machining conditions, different tooling grade selections may be tried to improve MRR and/or tool life.

Metal Cutting Process Tutorial

Observation	Application & Conditions / Current Grade / Coolant	Diagnosis	Suggestions
Flank wear 	Finish turning of steel bar.		
	GC 3005		
	Flood Coolant		
Edge chipping 	Rough turning of cast iron pipes.		
	GC 3005		
	Dry Cutting		
Cratering 	Drilling of stainless steel bores.		
	GC 2035		
	Through Tool Coolant		

Metal Cutting Process Tutorial

Observation	Application & Conditions	Current Grade	Coolant	Diagnosis	Suggestions
Plastic deformation 	Heavy roughing turning of steel bar.	GC 2025	Flood Coolant		
Built-up edges 	Drilling of Aluminium blocks.	GC 2035	Through Tool Coolant		
Insert breakage 	Milling of steel forgings.	GC4215	Flood Coolant		

Graphic by courtesy of WNT Tooling