TECHNICAL DATA

TROUBLE SHOOTING FOR TURNING

Solutions / Factors / Trouble — Cutting Conditions and Style and Design of the Tool: Up ↗ Down ↘

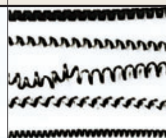
Trouble		Factors	Insert Grade Selection: Select a Harder Grade	Insert Grade Selection: Select a Tougher Grade	Insert Grade Selection: Select a Grade with Better Thermal Shock Resistance	Insert Grade Selection: Select a Grade with Better Adhesion Resistance	Cutting Conditions: Cutting Speed	Cutting Conditions: Feed Rate	Cutting Conditions: Depth of Cut	Cutting Fluids: Do Not Use Water-soluble Cutting Fluid	Cutting Fluids: Determine Dry or Wet Cutting	Style and Design of the Tool: Select Chip Breaker	Style and Design of the Tool: Rake Angle	Style and Design of the Tool: Corner Radius	Style and Design of the Tool: Lead Angle	Style and Design of the Tool: Honing Strengthens the Cutting Edge	Style and Design of the Tool: Class of Insert (Unground-Ground)	Style and Design of the Tool: Improve Tool Holder Rigidity	Machine and Installation of Tool: Installation of the Tool and Workpiece	Machine and Installation of Tool: Toolholder Overhang	Machine and Installation of Tool: Machine with Inadequate Horsepower and Rigidity
Short Tool Life	Rapid insert wear	Improper tool grade	●																		
		Improper cutting edge geometry										●	● ↗	● ↗	● ↗	● ↘					
		Improper cutting conditions					● ↘	● ↗			● Wet										
	Chipping and fracturing of cutting edge	Improper tool grade		●																	
		Improper cutting conditions						● ↘	● ↘												
		Lack of cutting edge strength										●		● ↗		● ↗					
		Thermal cracking			●		● ↘	● ↘	● ↘	●	● Dry										
		Built-up edge				●	● ↗	● ↗		●	● Wet										
		Lack of rigidity																●	●	●	●
Worsening Dimensional Accuracy	Dimensional unevenness during machining	Improper insert tolerance															●				
		Large cutting resistance and cutting edge flank										●	●	● ↘	● ↘	● ↘		●	●	●	●
	Machining accuracy not maintained adjustment is necessary each time	Improper tool grade	●																		
		Improper cutting conditions					● ↘	● ↗													
Poor Surface Finish	Worsening surface roughness	Welding occurs					● ↗			●	● Wet										
		Improper cutting edge geometry										●		● ↗							
		Vibration occurs					● ↘	● ↘	● ↘									●	●	●	●
Heat Generation	Cutting heat creates deterioration in machining accuracy and tool life	Improper cutting conditions					● ↘	● ↘	● ↘												
		Improper cutting edge geometry										●	● ↗			● ↘					

Trouble		Factors \ Solutions	Insert Grade Selection: Select a Harder Grade	Insert Grade Selection: Select a Tougher Grade	Insert Grade Selection: Select a Grade with Better Thermal Shock Resistance	Insert Grade Selection: Select a Grade with Better Adhesion Resistance	Cutting Conditions: Cutting Speed	Cutting Conditions: Feed Rate	Cutting Conditions: Depth of Cut	Cutting Conditions: Cutting Fluids: Do Not Use Water-soluble Cutting Fluid	Cutting Conditions: Cutting Fluids: Determine Dry or Wet Cutting	Style and Design of the Tool: Select Chip Breaker	Style and Design of the Tool: Rake Angle	Style and Design of the Tool: Corner Radius	Style and Design of the Tool: Lead Angle	Style and Design of the Tool: Honing Strengthens the Cutting Edge	Style and Design of the Tool: Class of Insert (Unground-Ground)	Style and Design of the Tool: Improve Tool Holder Rigidity	Machine and Installation of Tool: Installation of the Tool and Workpiece	Machine and Installation of Tool: Toolholder Overhang	Machine and Installation of Tool: Machine with Inadequate Horsepower and Rigidity
Burr / Chipping / Roughness	Burr (Steel, Aluminum alloy)	Notch wear occurs	●																		
		Improper cutting conditions					● ↘	↗ ●			● Wet										
		Improper cutting edge geometry										●	↗ ●	● ↘	● ↘	● ↘					
	Chipping (Cast iron)	Improper cutting conditions						● ↘	● ↘												
		Improper cutting edge geometry										●	↗ ●	↗ ●	↗ ●	● ↘					
		Vibration occurs																●	●	●	●
	Roughness (Mild steel)	Improper tool grade				●															
		Improper cutting conditions					↗ ●			●	● Wet										
		Improper cutting edge geometry										●	↗ ●			● ↘					
		Vibration occurs																●	●	●	●
Chip Control	Uncontrolled, continuous / tangled	Improper cutting conditions					● ↘	↗ ●	↗ ●		● Wet										
		Wide chip control range										●									
		Improper cutting edge geometry												● ↘	● ↘						
	Broken into short lengths and scatter	Improper cutting conditions						● ↘	● ↘		● Dry										
		Small chip control range										●									
		Improper cutting edge geometry												↗ ●	↗ ●						

Up ↗ Down ↘

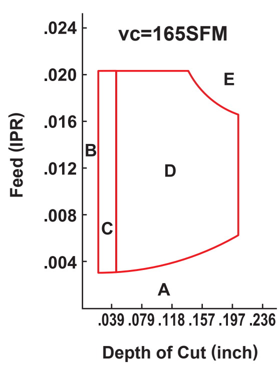
CHIP CONTROL FOR TURNING

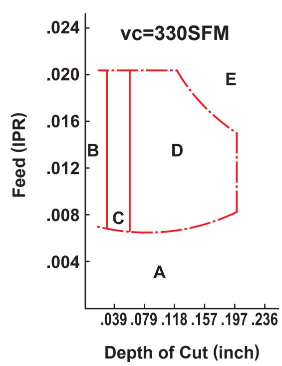
CHIP BREAKING CONDITIONS IN STEEL TURNING

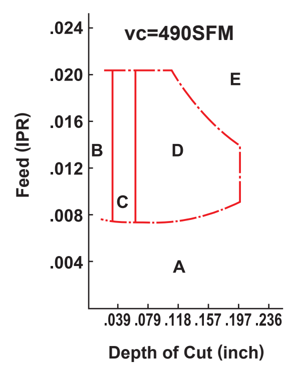
Type	A Type	B Type	C Type	D Type	E Type
Small Depth of Cut d <.276"					
Large Depth of Cut d=.276"—.591"					
Curl Length l	Curless	l≥2inch	l≤2inch 1—5 Curl	≒ 1 Curl	1 curl—half curl
Note	●Irregular continuous shape ●Tangle about tool and workpiece	●Regular continuous shape ●Long chips	Good	Good	●Chip scattering ●Chattering ●Poor finished surface ●Maximum

Cutting Speed and Chip Control Range of Chip Breaker

In general, when cutting speed increases, the chip control range tends to become narrower.





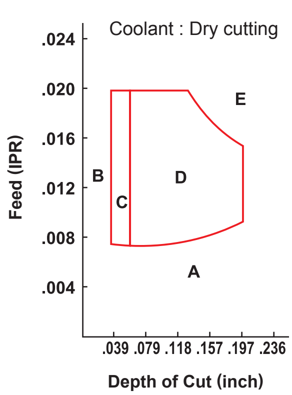


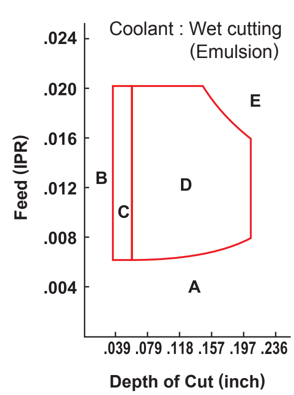
Workpiece : **AISI 1045 (180HB)**
Insert : **TNMG332**
Grade : **P10**Grade

Tool : **MTJNR2525M16N**
Dry Cutting

Effects of Coolant on the Chip Control Range of a Chip Breaker

If the cutting speed is the same, the range of chip control differs according to whether coolant is used or not.





Workpiece : **AISI 1045**
Cutting Condition : **vc=330SFM**

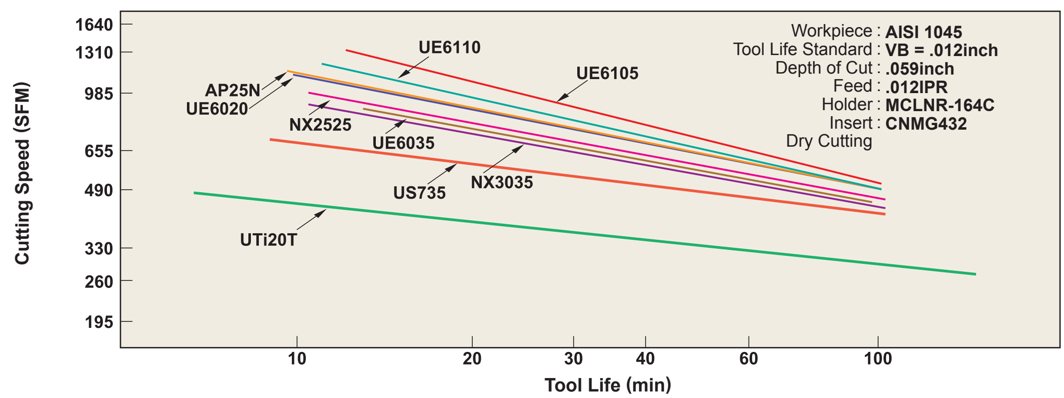
EFFECTS OF CUTTING CONDITIONS FOR TURNING

EFFECTS OF CUTTING CONDITIONS

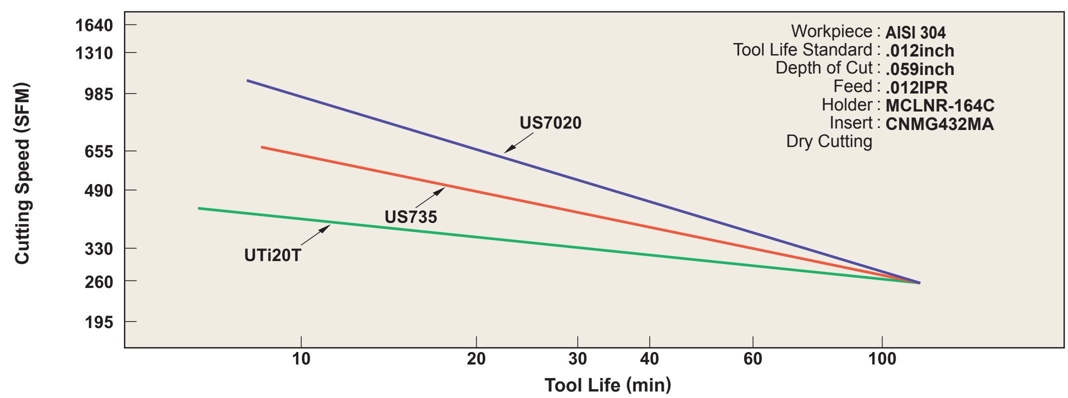
Ideal conditions for cutting are short cutting time, long tool life, and high cutting accuracy. In order to obtain these conditions, selection of efficient cutting conditions and tool, based on work material, hardness, shape and machine capability is necessary.

CUTTING SPEED

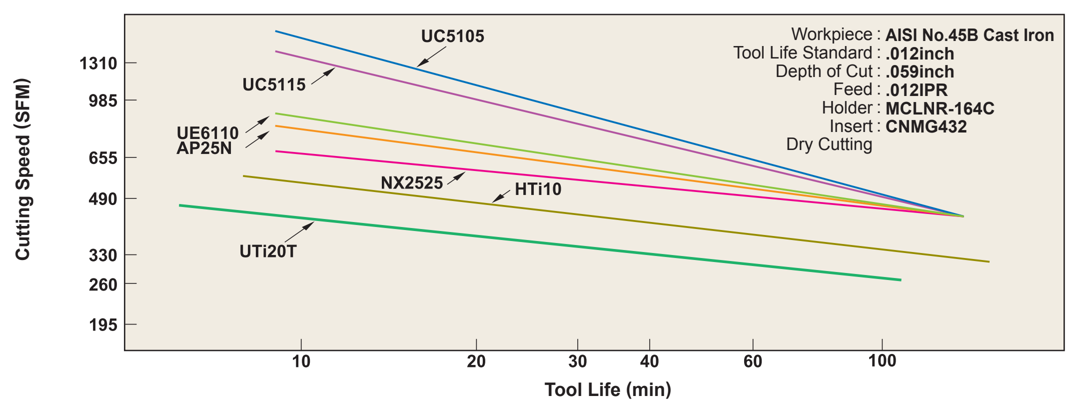
Cutting speed effects tool life greatly. Increasing cutting speed increases cutting temperature and results in shortening tool life. Cutting speed varies depending on the type and hardness of the work material. Selecting a tool grade suitable for the cutting speed is necessary.



P Class Grade Tool Life



M Class Grade Tool Life



K Class Grade Tool Life

Effects of Cutting Speed

1. Increasing cutting speed by 20% decreases tool life to 1/2. Increasing cutting speed by 50% decreases tool life to 1/5.
2. Cutting at low cutting speed (65—130 SFM) tends to cause chattering. Thus, tool life is shortened.

TECHNICAL DATA

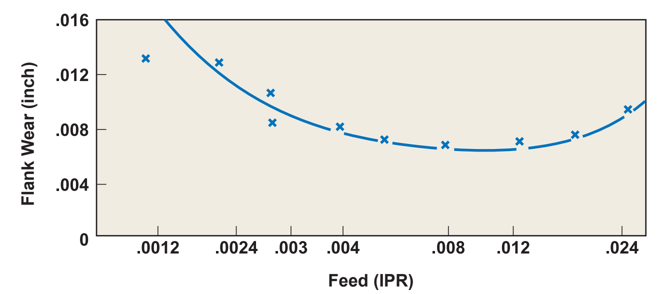
EFFECTS OF CUTTING CONDITIONS FOR TURNING

FEED

In cutting with a general holder, feed is the distance a holder moves per workpiece revolution. In milling, feed is the distance a machine table moves per cutter revolution divided by number of inserts. Thus, it is indicated as feed per tooth. Feed rate relates to finished surface roughness.

Effects of Feed

1. Decreasing feed rate results in flank wear and shortens tool life.
2. Increasing feed rate increases cutting temperature and flank wear. However, effects on the tool life is minimal compared to cutting speed.
3. Increasing feed rate improves machining efficiency.



Cutting Conditions Workpiece : AISI 4340 Grade : STi10T
Depth of Cut ap=.040(inch) Cutting Speed vc=660(SFM)
Cutting Time Tc=10min

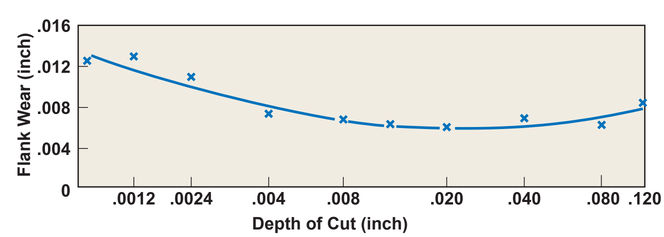
Feed and Flank Wear Relationship in Steel Turning

DEPTH OF CUT

Depth of cut is determined according to the required stock removal, shape of workpiece, power and rigidity of the machine and tool rigidity.

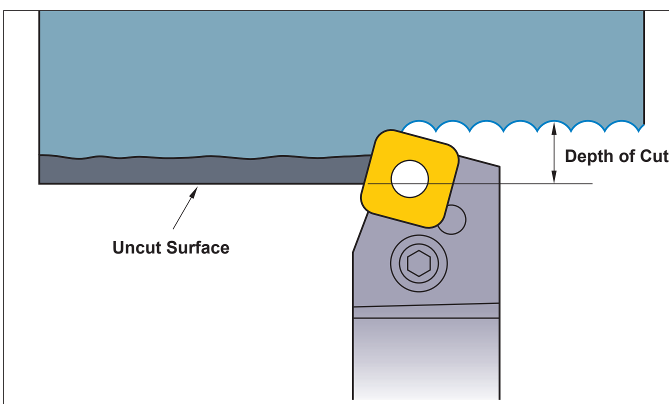
Effects of Depth of Cut

1. Changing depth of cut doesn't effect tool life greatly.
2. Small depths of cut result in friction when cutting the hardened layer of a workpiece. Thus tool life is shortened.
3. When cutting uncut or cast iron surfaces, the depth of cut needs to be increased as much as the machine power allows to avoid cutting impure hard layer with the tip of cutting edge which prevents chipping and abnormal wear.



Cutting Conditions Workpiece : AISI 4340 Grade : STi10T
Feed f=.008(IPR) Cutting Speed vc=660(SFM)
Cutting Time Tc=10min

Depth of Cut and Flank Wear Relationship in Steel Turning

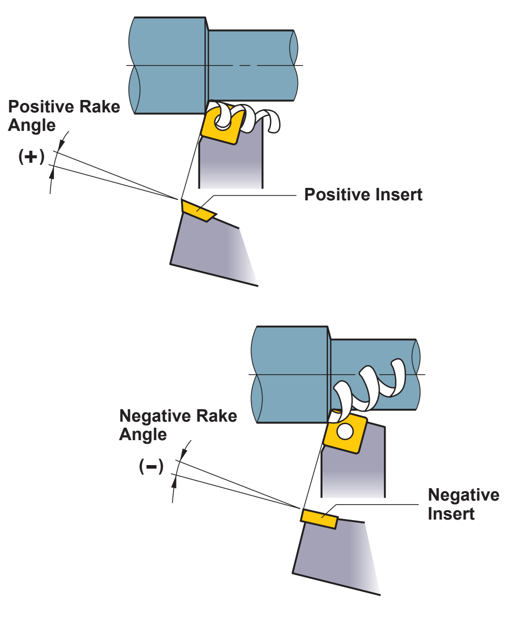


Roughing of Surface Layer that Includes Uncut Surface

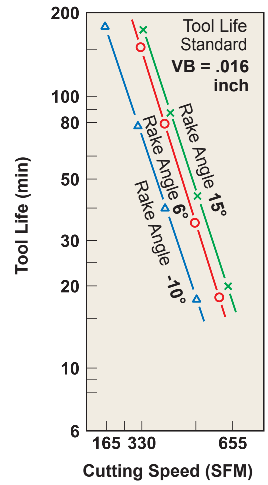
FUNCTION OF TOOL FEATURES FOR TURNING

RAKE ANGLE

Rake angle is a cutting edge angle that has large effects on cutting resistance, chip disposal, cutting temperature and tool life.

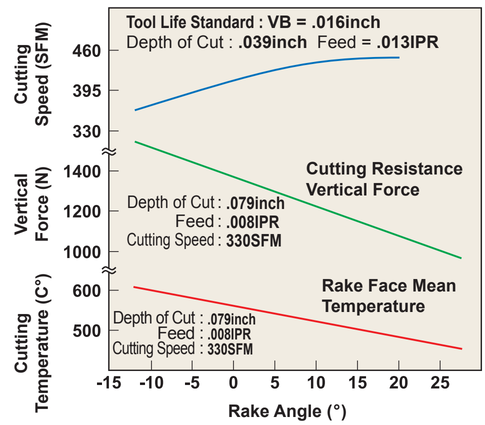


Chip Disposal and Rake Angle



Cutting Conditions
Grade : **STi10**
Depth of Cut : **.039inch**
Feed : **.013IPR**
Workpiece : **Alloy steel**

Rake Angle and Tool Life



Cutting Conditions
Workpiece : **Alloy steel** Grade : **STi10T**
Dry Cutting

Effects of Rake Angle on Cutting Speed, Vertical Force, and Cutting Temperature

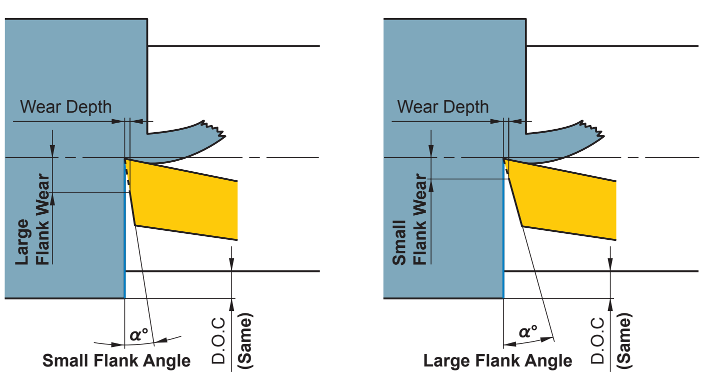
Effects of Rake Angle

1. Increasing rake angle in the positive (+) direction improves sharpness.
2. Increasing rake angle by 1° in the positive (+) direction decreases cutting power by about 1%.
3. Increasing rake angle in the positive (+) direction lowers cutting edge strength and in the negative (-) direction increases cutting resistance.

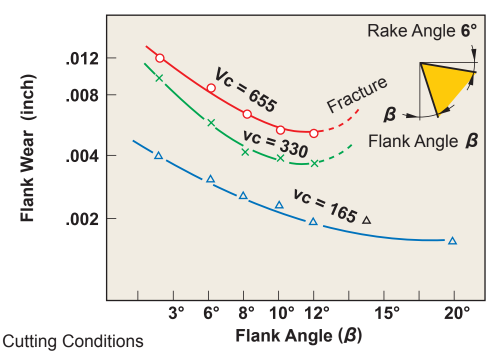
When to Increase Rake Angle in the Negative (-) Direction	When to Increase Rake Angle in the Positive (+) Direction
◯ Hard workpiece. ◯ When cutting edge strength is required such as in interrupted cutting and uncut surface cutting.	◯ Soft workpiece. ◯ Workpiece is easily machined. ◯ When workpiece or the machine have poor rigidity.

FLANK ANGLE

Flank angle prevents friction between flank face and workpiece resulting in smooth feed.



Flank angle creates a space between tool and workpiece.
Flank angle relates to flank wear.



Cutting Conditions
Workpiece : **Alloy steel (200HB)** Feed : **.013IPR**
Grade : **STi20** Cutting Time : **20min**
Depth of Cut : **.039inch**

Flank Angle and Flank Wear Relationship

Effects of Flank Angle

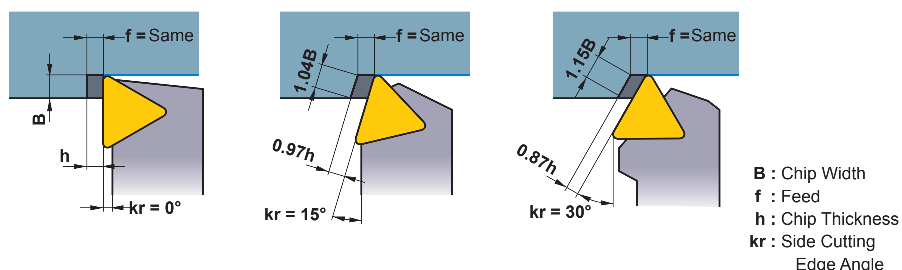
1. Increasing flank angle decreases flank wear occurrence.
2. Increasing flank angle lowers cutting edge strength.

When to Decrease Flank Angle	When to Increase Flank Angle
◯ Hard workpieces. ◯ When cutting edge strength is required.	◯ Soft workpieces. ◯ Workpieces suffer from work hardening easily.

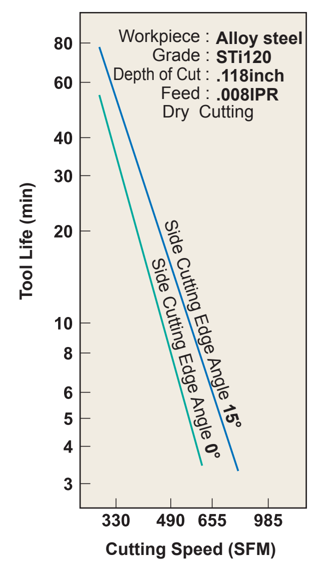
FUNCTION OF TOOL FEATURES FOR TURNING

SIDE CUTTING EDGE ANGLE (LEAD ANGLE)

Side cutting edge angle lower impact load and effect feed force, back force, and chip thickness.



Side Cutting Edge Angle and Chip Thickness

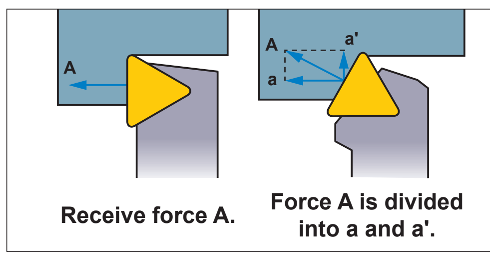


Side Cutting Edge and Tool Life

Effects of Side Cutting Edge Angle (Lead Angle)

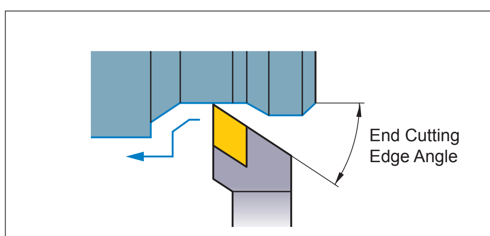
1. At the same feed rate, increasing the side cutting edge angle increases the chip contact length and decreases chip thickness. As a result, the cutting force is dispersed on a longer cutting edge and tool life is prolonged. (Refer to the chart.)
2. Increasing the side cutting edge angle increases force a'. Thus, thin, long workpieces suffer from bending in some cases.
3. Increasing the side cutting edge angle decreases chip control.
4. Increasing the side cutting edge angle decreases the chip thickness and increases chip width. Thus, breaking chips is difficult.

When to Decrease Lead Angle	When to Increase Lead Angle
○ Finishing with small depth of cut.	○ Hard workpieces which produce high cutting temperature.
○ Thin, long workpieces.	○ When roughing a large diameter workpiece.
○ When the machine has poor rigidity.	○ When the machine has high rigidity.



END CUTTING EDGE ANGLE

End cutting edge angle prevents wear on tool and workpiece surface and is usually 5°– 15°.

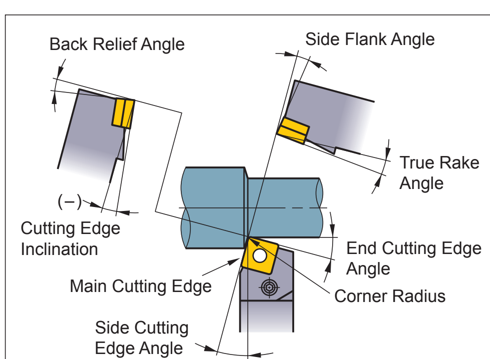


Effects of End Cutting Edge Angle

1. Decreasing the end cutting edge angle increases cutting edge strength, but it also increases cutting edge temperature.
2. Decreasing the end cutting edge angle increases the back force and can result in chattering and vibration while machining.
3. Small end cutting edge angle in roughing and large angle in finishing are recommended.

CUTTING EDGE INCLINATION

Cutting edge inclination indicates inclination of the rake face. In heavy cutting, the cutting edge receives extremely large shock at the beginning of cutting. Cutting edge inclination keeps the cutting edge from receiving this shock and prevents fracturing. 3°– 5° in turning and 10°– 15° in milling are recommended.

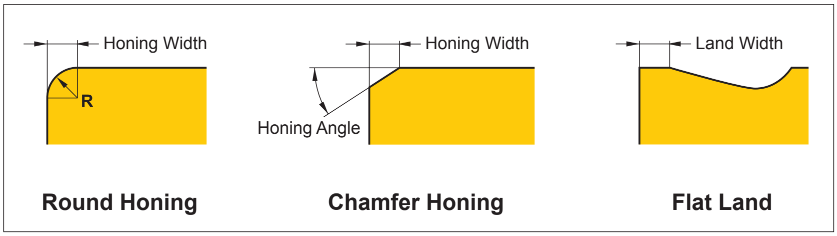


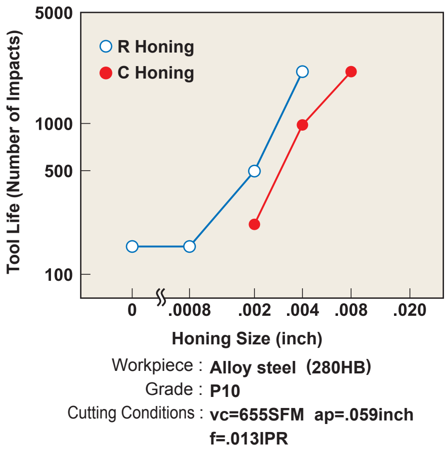
Effects of Cutting Edge Inclination

1. Negative (-) cutting edge inclination disposes chips in the workpiece direction, and positive (+) disposes chips in the opposite direction.
2. Negative (-) cutting edge inclination increases cutting edge strength, but it also increases back force of cutting resistance. Thus, chattering easily occurs.

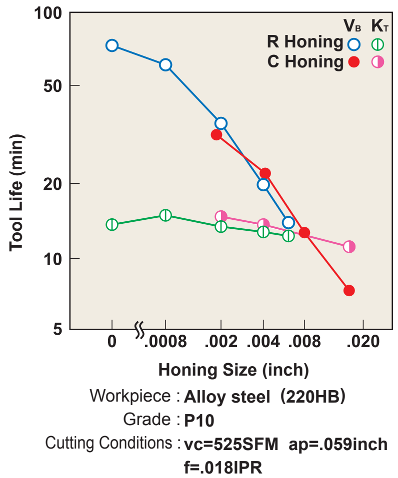
HONING AND LAND

Honing and land are cutting edge shapes that maintain cutting edge strength.
Honing can be round or chamfer type. The optimal honing or / and land width is approximately 1/2 of the feed.
Land is the narrow flat area on the rake or flank face.

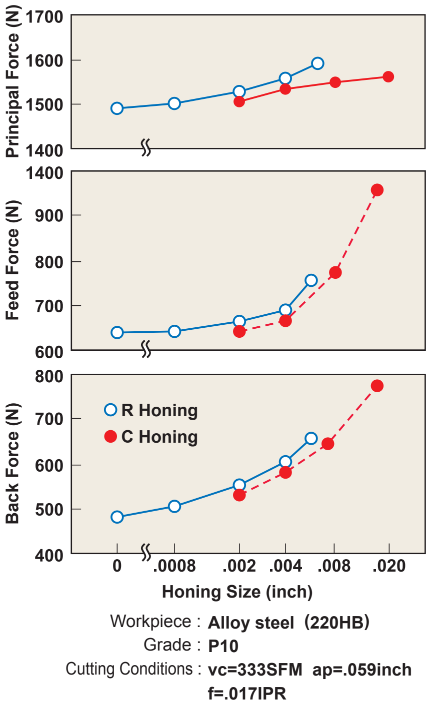




Honing Size and Tool Life
Due to Fracturing



Honing Size and Tool Life
Due to Wear



Honing Size and Cutting Resistance

Effects of Honing

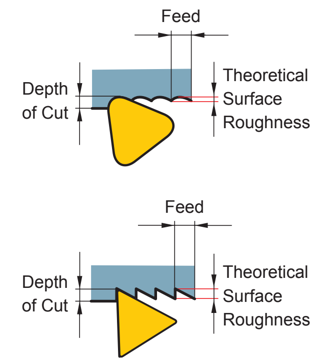
1.Enlarging the honing increases cutting edge strength, and reduces fracturing.
2.Enlarging the honing increases flank wear occurrence. Honing size doesn't affect rake wear.
3.Enlarging the honing increases cutting resistance and chattering.

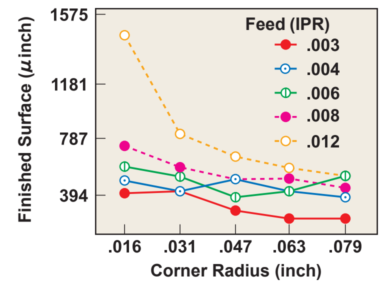
When to Decrease Honing Size	When to Increase Honing Size
○ When finishing with small depth of cut and small feed. ○ Soft workpieces. ○ When the workpiece and the machine have poor rigidity.	○ Hard workpieces. ○ When the cutting edge strength is required such as for uncut surface cutting and interrupted cutting. ○ When the machine has high rigidity.

FUNCTION OF TOOL FEATURES FOR TURNING

CORNER RADIUS

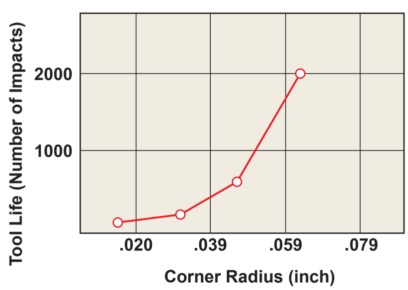
Corner radius effects the cutting edge strength and finished surface. In general, a corner radius 2 – 3 times the feed is recommended.





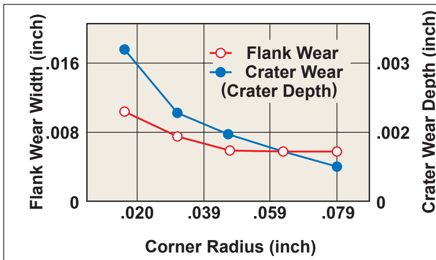
Workpiece : Alloy steel (200HB)
Grade : P20
Cutting Speed : vc=395SFM ap=.020inch

Corner Radius and Finished Surface



Workpiece : Alloy steel (280HB)
Grade : P10
Cutting Conditions : vc=330SFM ap=.079inch f=.013IPR

Corner Radius Size and Tool Life Due to Fracturing



Workpiece : Alloy steel (200HB)
Grade : P10
Cutting Conditions : vc=460SFM ap=.079inch f=.008IPR Tc=10min

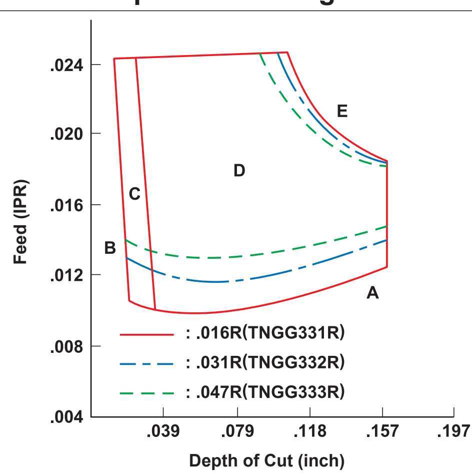
Corner Radius Size and Tool Wear

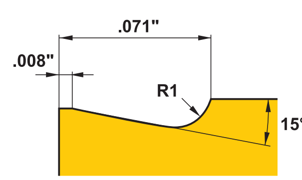
Effects of Corner Radius

1. Increasing the corner radius improves the surface finish.
2. Increasing the corner radius improves cutting edge strength.
3. Increasing the corner radius too much increases the cutting resistance and causes chattering.
4. Increasing the corner radius decreases flank and rake wear.
5. Increasing the corner radius too much results in poor chip control.

When to Decrease Corner Radius	When to Increase Corner Radius
○Finishing with small depth of cut. ○Thin, long workpieces. ○When the machine has poor rigidity.	○When the cutting edge strength is required such as in interrupted cutting and uncut surface cutting. ○When roughing a workpiece with large diameter. ○When the machine has high rigidity.

Corner Radius and Chip Control Range





Workpiece : AISI 1045 (180HB)
Insert : TNGG331R
TNGG332R
TNGG333R
(STi10T)
(Side Cutting Edge angle 3°)
Cutting Speed : vc=330SFM
Dry Cutting

(Note) Please refer to page F004 for chip shapes (A, B, C, D, E).

FORMULAS FOR CUTTING

CUTTING SPEED (vc)

$$vc = \frac{\pi \cdot Dm \cdot n}{12} \text{(SFM)}$$

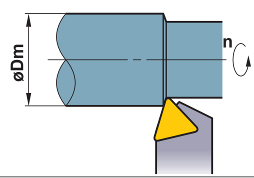
vc (SFM) : Cutting Speed
Dm (inch) : Workpiece Diameter
π (3.14) : Pi
n (min^{-1}) : Main Axis Spindle Speed

(Problem) What is the cutting speed when the main axis spindle speed is 700 min^{-1} and external diameter is ϕ2" ?

(Answer) Substitute π=3.14, Dm=2, n=700 into the formula.

$$vc = \frac{\pi \cdot Dm \cdot n}{12} = \frac{3.14 \times 2 \times 700}{12} = 365\text{SFM}$$

Cutting speed is 365SFM.



FEED (f)

$$f = \frac{l}{n} \text{(IPR)}$$

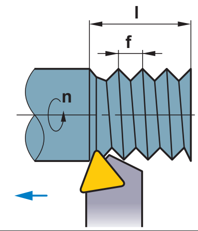
f (IPR) : Feed per Revolution
l (inch/min) : Cutting Length per Min.
n (min^{-1}) : Main Axis Spindle Speed

(Problem) What is the feed per revolution when the main axis spindle speed is 500min^{-1} and cutting length per minute is 4.72 inch/min ?

(Answer) Substitute n=500, l=4.72 into the formula.

$$f = \frac{l}{n} = \frac{4.72}{500} = .009\text{IPR}$$

The answer is .009IPR.



CUTTING TIME (Tc)

$$Tc = \frac{Im}{l} \text{(min)}$$

Tc (min) : Cutting Time
Im (inch) : Workpiece Length
l (inch/min) : Cutting Length per Min.

(Problem) What is the cutting time when 4 inch workpiece is machined at 1000min^{-1} with feed= .008IPR ?

(Answer) First, calculate the cutting length per min. from the feed and spindle speed.

$$l = f \times n = .008 \times 1000 = 8\text{inch/min}$$

Substitute the answer above into the formula.

$$Tc = \frac{Im}{l} = \frac{4}{8} = 0.5\text{min}$$

0.5×60=30 (sec.) The answer is 30 sec.

THEORETICAL FINISHED SURFACE ROUGHNESS (h)

$$h = \frac{f^2}{8Re} \times 1000^2 (\mu\text{inch})$$

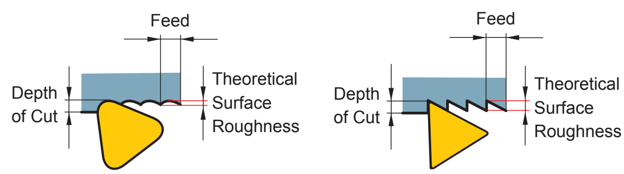
h (μinch) : Finished Surface Roughness
f (IPR) : Feed per Revolution
Re (inch) : Insert Corner Radius

(Problem) What is the theoretical finished surface roughness when the insert corner radius is .031inch and feed is .008IPR ?

(Answer) Substitute f= .008 IPR, R= .031 into the formula.

$$h = \frac{(.008)^2}{8 \times .031} \times 1000^2 = 258\ \mu\text{inch}$$

The theoretical finished surface roughness is 258μinch.



TECHNICAL DATA

TROUBLE SHOOTING FOR MILLING

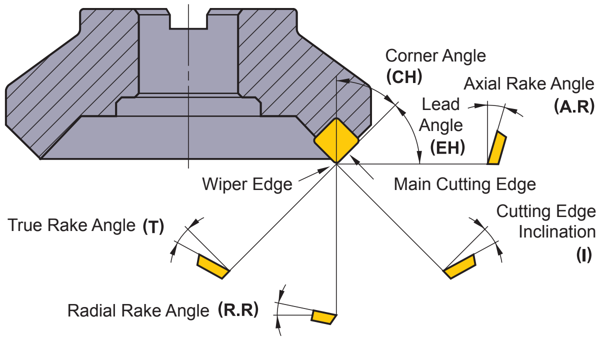
Up ↗ Down ↘

Trouble		Factors	Insert Grade Selection: Select a Harder Grade	Insert Grade Selection: Select a Tougher Grade	Insert Grade Selection: Select a Grade with Better Thermal Shock Resistance	Insert Grade Selection: Select a Grade with Better Adhesion Resistance	Cutting Conditions: Cutting Speed	Cutting Conditions: Feed Rate	Cutting Conditions: Depth of Cut	Cutting Conditions: Engage Angle ↗ Up	Cutting Fluids: Do Not Use Water-soluble Cutting Fluid	Cutting Fluids: Determine Dry or Wet Cutting	Style and Design of the Tool: Rake Angle	Style and Design of the Tool: Corner Angle	Style and Design of the Tool: Honing Strengthens the Cutting Edge	Style and Design of the Tool: Cutter Diameter	Style and Design of the Tool: Decrease the Number of Teeth	Style and Design of the Tool: Wider Chip Pocket	Style and Design of the Tool: Use of a Wiper Insert	Style and Design of the Tool: Run-out Accuracy	Style and Design of the Tool: Improve Cutter Rigidity	Machine and Installation of Tool: Installation of the Tool and Workpiece	Machine and Installation of Tool: Shorten Tool Overhang	Machine and Installation of Tool: Machine with Inadequate Horsepower and Rigidity
Short Tool Life	Rapid insert wear	Improper tool grade	●																					
		Improper cutting edge geometry											↗●	↗●	●↘					●				
		Improper cutting conditions					●↘					● Wet												
	Chipping and fracturing of cutting edge	Improper tool grade		●																				
		Improper cutting conditions						●↘	●↘															
		Lack of cutting edge strength													↗●									
		Thermal cracking occurs			●		●↘	●↘	●↘		●	● Dry												
		Built-up edge occurs				●	↗●	↗●			●	● Wet												
		Lack of rigidity																			●	●	●	●
Poor Surface Finish	Worsening surface roughness	Improper cutting conditions	●				●↘	●↘	●↘															
		Welding occurs				●	↗●				●	● Wet	↗●		●↘									
		Poor run-out accuracy																	●	●				
		Vibration occurs					●↘	●↘	●↘	↗●			↗●		●↘		●				●	●	●	●
	Not parallel or irregular surface	Workpiece bending						●↘	●↘				↗●	●↘	●↘		●					●		
		Tool clearance																			●	●	●	●
		Large back force											↗●	●↘	●↘		●							
Burr / Chipping	Burr	Chip thickness is too large					↗●	●↘	●↘															
		Cutter diameter is too large								↗●						●↘								
		Poor sharpness											↗●		●↘									
		A large corner angle												●↘										
	Chipping	Improper cutting conditions						●↘	●↘															
		Poor sharpness											↗●		●↘									
		Corner angle is too small												↗●										
		Vibration occurs					●↘	●↘	●↘	↗●			↗●		●↘		●				●	●	●	●
Chip Control	Poor chip disposal, chip jamming and chip packing	Welding occurs					↗●																	
		Chip thickness is too thin					↗●	↗●																
		Cutter diameter is too small														●↘								
		Poor chip disposal									●	● Wet					●	●						

TECHNICAL DATA

FUNCTION OF TOOL FEATURES FOR FACE MILLING

FUNCTION OF EACH CUTTING EDGE ANGLE IN FACE MILLING

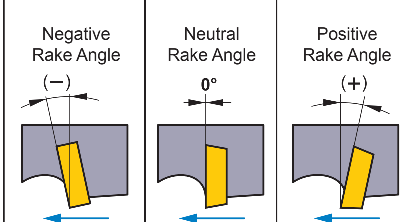


Each Cutting Edge Angle in Face Milling

Type of Angle	Symbol	Function	Effect
Axial Rake Angle	A.R	Determines chip disposal direction.	**Positive** : Excellent machinability.
Radial Rake Angle	R.R	Determines sharpness.	**Negative** : Excellent chip disposal.
Corner Angle	CH	Determines chip thickness.	**Large** : Thin chips and small cutting impact. Large back force.
True Rake Angle	T	Determines actual sharpness.	**Positive(large)** : Excellent machinability. Minimal welding. **Negative(large)** : Poor machinability. Strong cutting edge.
Cutting Edge Inclination	I	Determines chip disposal direction.	**Positive (large)** : Excellent chip disposal. Low cutting edge strength.

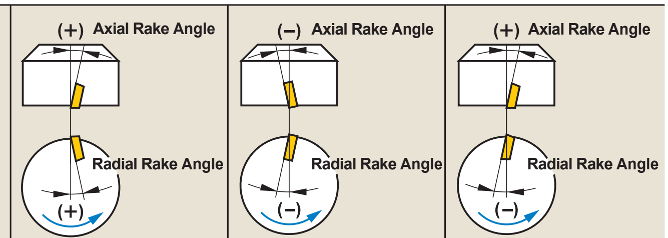
STANDARD INSERTS

Positive and Negative Rake Angle



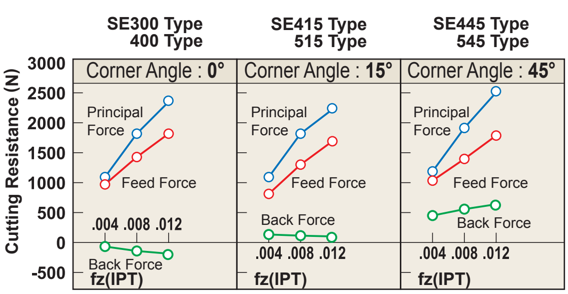
- Insert shape whose cutting edge precedes is a positive rake angle.
- Insert shape whose cutting edge follows is a negative rake angle.

Standard Cutting Edge Shape



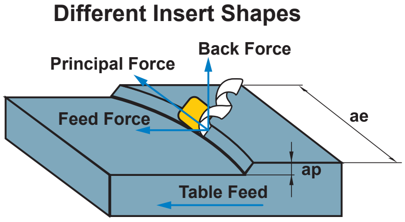
Standard Cutting Edge Combinations		Double Positive (DP Edge Type)	Double Negative (DN Edge Type)	Negative/Positive (NP Edge Type)
Axial Rake Angle (A.R.)		Positive (+)	Negative (–)	Positive (+)
Radial Rake Angel (R.R.)		Positive (+)	Negative (–)	Negative (–)
Insert Used		Positive Insert (One Sided Use)	Negative Insert (Double Sided Use)	Positive Insert (One Sided Use)
Work Material	Steel	●	–	●
	Cast Iron	–	●	●
	Aluminum Alloy	●	–	–
	Difficult-to-Cut Material	●	–	●

CORNER ANGLE (CH) AND CUTTING RESISTANCE



Workpiece : Alloy Steel (281HB)
Tool : ø4" Single Insert
Cutting Conditions : vc=410SFM ap=.157inch ae=4.33inch

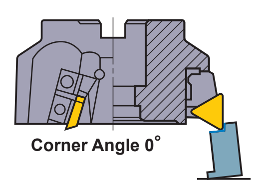
Cutting Resistance Comparison between Different Insert Shapes



Three Cutting Resistance Forces in Milling

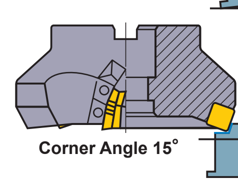
Corner Angle 0°

Back force is in the minus direction. Lifts the workpiece when workpiece clamp rigidity is low.



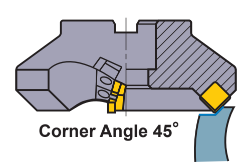
Corner Angle 15°

Corner angle 15° is recommended for face milling of workpieces with low rigidity such as thin workpieces.



Corner Angle 45°

The largest back force. Bends thin workpieces and lowers cutting accuracy.
* Prevents workpiece edge chipping in cast iron cutting.



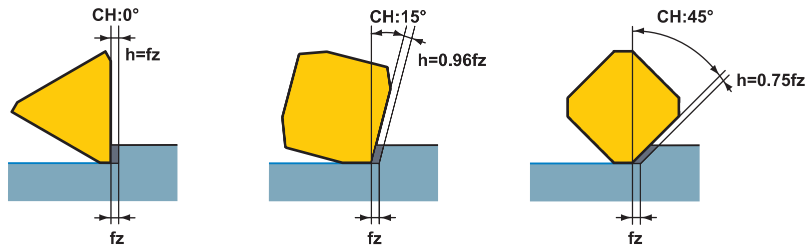
* Principal force: Force is in the opposite direction of face milling rotation.
* Back force: Force that pushes in the axial direction.
* Feed Force: Force is in the feed direction and is caused by table feed.

FUNCTION OF TOOL FEATURES FOR FACE MILLING

CORNER ANGLE AND TOOL LIFE

Corner Angle and Chip Thickness

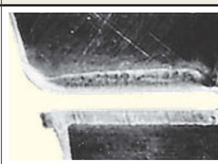
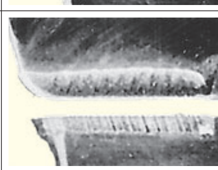
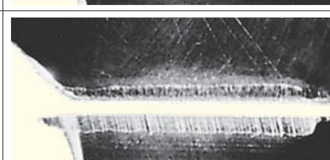
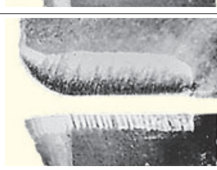
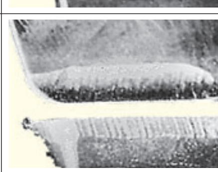
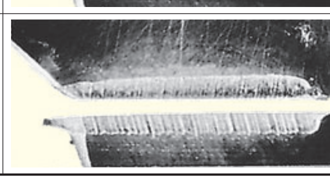
When the depth of cut and feed per tooth, fz, are fixed, the larger the corner angle (CH) is, then the thinner the chip thickness (h) becomes (for a 45° CH, it is approx. 75% that of a 0° CH). This can be seen in below. Therefore as the CH increases, the cutting resistance decreases resulting in longer tool life. Note however, if the chip thickness is too large then the cutting resistance can increase leading to vibrations and shortened tool life.



Effects on chip thickness due to the variation of corner angles

Corner Angle and Crater Wear

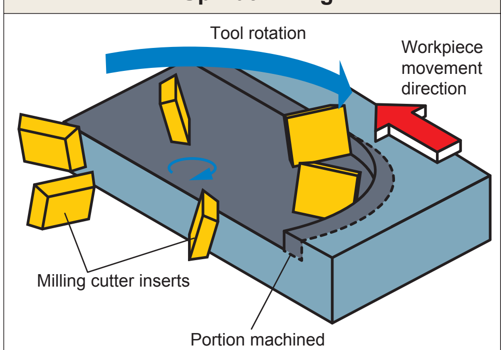
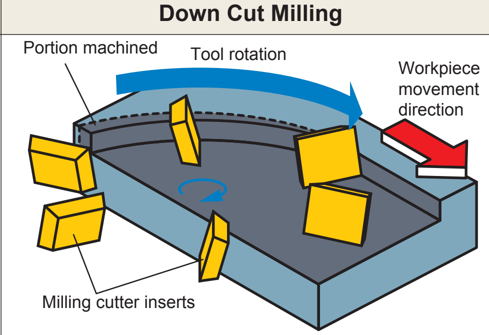
Below shows wear patterns for different corner angles. When comparing crater wear for 0° and 45° corner angles, it can be clearly seen that the crater wear for 0° corner angle is larger. This is because if the chip thickness is relatively large, the cutting resistance increases and so promotes crater wear. As the crater wear develops then cutting edge strength will reduce and lead to fracturing.

	0° Corner Angle	**15°** Corner Angle	**45°** Corner Angle
vc=330SFM Tc=69min			
vc=410SFM Tc=55min			
vc=525SFM Tc=31min			

Workpiece : **AISI 4340 (287HB)**
Tool : **D1=4.92inch**
Insert : **M20**
Cutting Conditions : **ap=.118inch**
ae=4.33inch
fz=.008IPT
Coolant : Dry Cutting

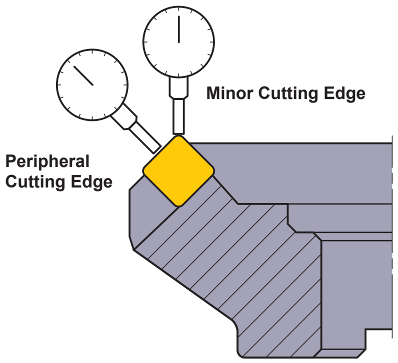
UP CUT AND DOWN CUT MILLING

Which method to be used will depend on the machine and the face mill cutter that has been selected. Generally down cut machining offers longer tool life than up cut milling.

Up Cut Milling	**Down Cut Milling**
	

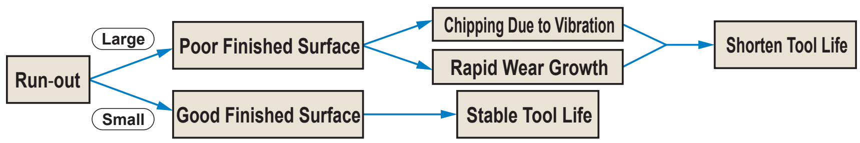
FINISHED SURFACE

Cutting Edge Run-out Accuracy

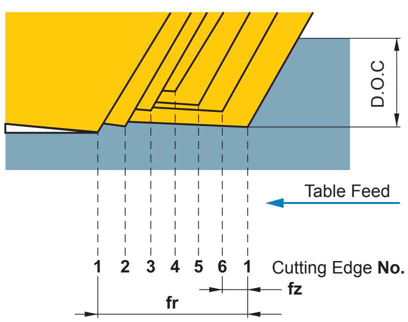


Cutting Edge Run-out and Accuracy in Face Milling

Cutting edge run-out accuracy of indexable inserts on the cutter body greatly affects the surface finish and tool life.



Improve Finished Surface Roughness



fz : Feed per Tooth
fr : Feed per Revolution

Sub Cutting Edge Run-out and Finished Surface

Mitsubishi Materials' normal minor cutting edge wiper flat width is .055 inch. Usually the minor cutting edges are set parallel to the face of a milling cutter and theoretically the finished surface accuracy should be maintained, even if run-out accuracy is poor.

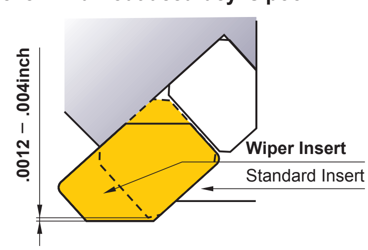
Actual Problems

· Cutting edge run-out.
· Minor cutting edge inclination.
· Cutter body accuracy.
· Spare parts accuracy.
· Welding, vibration, chattering.

Countermeasure

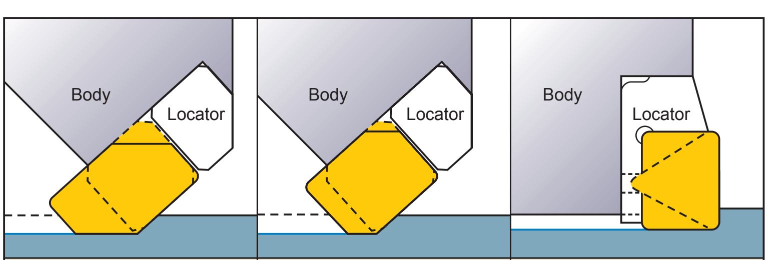
Wiper Insert

*Machine a surface that has already been machined by normal insert in order to produce smooth finished surface.



· Replace one normal insert with wiper insert.
· Wiper inserts are set to protrude by .0012 — .004 inch from the standard inserts.

How to Set a Wiper Insert



(a) **One Corner Type**	(b) **Two Corner Type**	(c) **Two Corner Type**
Replace normal insert.	**Replace normal insert.**	**Use locator for wiper insert.**

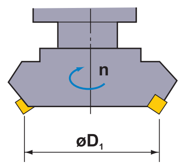
· Minor cutting edge length has to be larger than the feed per revolution.
*But, too long minor cutting edge can also cause chattering.
· When the cutter diameter is large and feed per revolution is longer than the minor cutting edge of the wiper insert, the use of two or three wiper inserts is possible.
· When using more than 1 wiper inserts, eliminate run-out of wiper inserts.
· Use a high hardness grade (high wear resistance) for wiper inserts.

FORMULAS FOR MILLING

CUTTING SPEED (vc)

$$vc = \frac{\pi \cdot D_1 \cdot n}{12} \text{ (SFM)}$$

vc (SFM)	: Cutting Speed	D_1 (inch)	: Cutter Diameter
π (3.14)	: Pi	n (min^{-1})	: Main Axis Spindle Speed



(Problem) What is the cutting speed when main axis spindle speed is $350min^{-1}$ and cutter diameter is ϕ5" ?

(Answer) Substitute π 3.14, D=5", n=350 into the formula.

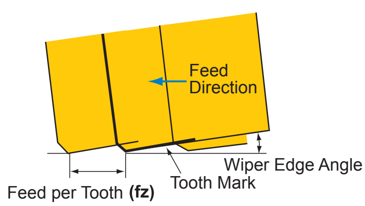
$$vc = \frac{\pi \cdot D \cdot n}{12} = \frac{3.14 \times 5" \times 350}{12} = 457.9 \text{ SFM}$$

The cutting speed is 457.9SFM.

FEED PER TOOTH (fz)

$$fz = \frac{vf}{z \cdot n} \text{ (IPT)}$$

fz (IPT)	: Feed per Tooth	z : Insert Number
vf (inch/min)	: Table Feed per Min.	
n (min^{-1})	: Main Axis Spindle Speed (Feed per Revolution fr=z x fz)	



(Problem) What is the feed per tooth when the main axis spindle speed is $500min^{-1}$, insert number is 10, and table feed is 20inch/min ?

(Answer) Substitute the above figures into the formula.

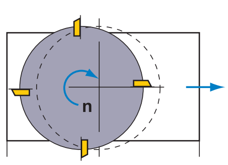
$$fz = \frac{Vf}{z \times n} = \frac{20}{10 \times 500} = .004 \text{ IPT}$$

The answer is .004IPT.

TABLE FEED (vf)

$$vf = fz \cdot z \cdot n \text{ (inch/min)}$$

vf (inch/min)	: Table Feed per Min.	
fz (IPT)	: Feed per Tooth	z : Insert Number
n (min^{-1})	: Main Axis Spindle Speed	



(Problem) What is the table feed when feed per tooth is .004IPT, with 10 inserts and main axis spindle speed is $500min^{-1}$?

(Answer) Substitute the above figures into the formula.

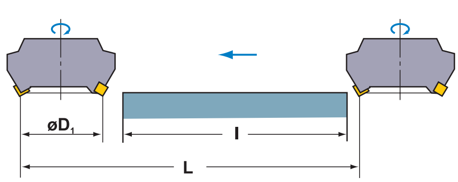
vf = fz x z x n = .004IPT x 10 x 500 = 20inch/min

The table feed is 20inch/min.

CUTTING TIME (Tc)

$$Tc = \frac{L}{vf} \text{ (min)}$$

Tc (min)	: Cutting Time
vf (inch/min)	: Table Feed per Min.
L (inch)	: Total Table Feed Length (Workpiece Length(l)+Cutter Diameter(D_1))



(Problem) What is the cutting time required for finishing 4" width and 12" length surface of a cast iron (GG20) block when cutter diameter is ϕ8", the number of inserts is 16, the cutting speed is 410SFM, and feed per tooth is .01". (spindle speed is $200min^{-1}$)

(Answer) Calculate table feed per min vf=.01 x 16 x 200=32inch/min

Calculate total table feed length. L=12+8=20inch

Substitute the above answers into the formula.

$$Tc = \frac{20}{32} = 0.625 \text{ (min)}$$

0.625 x 60 = 37.5 (sec.)

The answer is 37.5 sec.

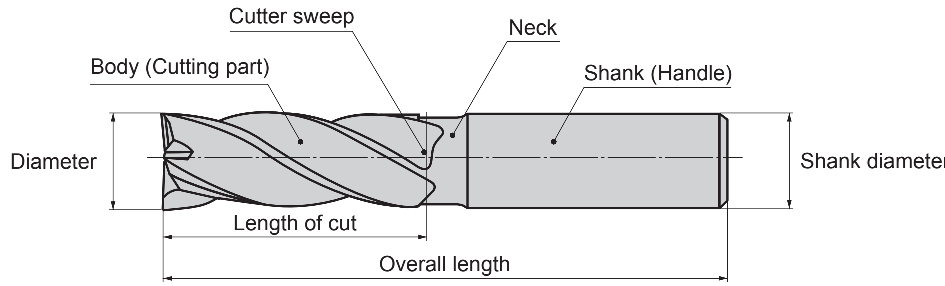
TROUBLE SHOOTING FOR END MILLING

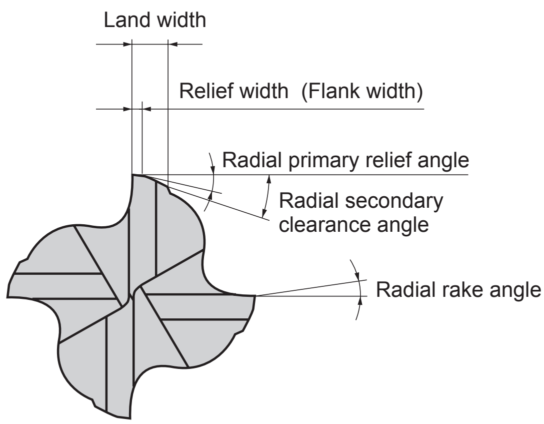
Markers: ● with ↗ = Up; ● with ↘ = Down.

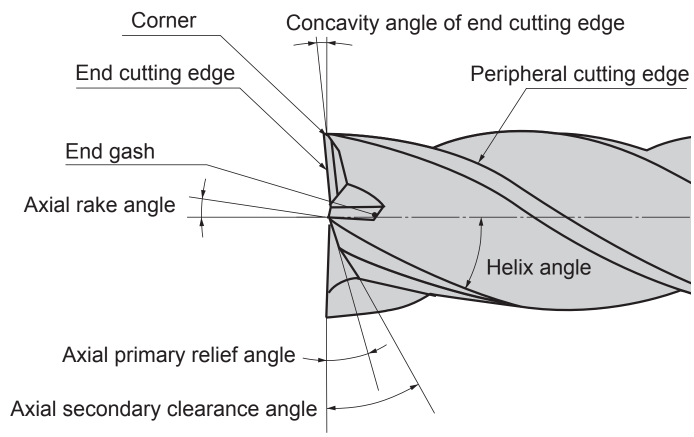
Trouble		Factors \ Solutions	Insert Grade Selection	Cutting Conditions									Style and Design of the Tool						Machine and Installation of Tool					
			Coated Tool	Cutting Speed (Up ↗ / Down ↘)	Feed Rate (Up ↗ / Down ↘)	Depth of Cut (Up ↗ / Down ↘)	Decrease Pick Feed Rate	Down Cut	Air Blow	Cutting Fluids: Increase Coolant Quantity	Cutting Fluids: Do Not Use Water-soluble Cutting Fluid	Cutting Fluids: Determine Dry or Wet Cutting	Helix Angle (Up ↗ / Down ↘)	Number of Flutes (Up ↗ / Down ↘)	Concavity Angle of End Cutting Edge (Up ↗ / Down ↘)	Tool Diameter (Up ↗ / Down ↘)	Improve End Mill Rigidity	Wider Chip Pocket	Shorten Tool Overhang	Tool Installation Accuracy	Spindle Collet Run-out Accuracy	Collet Inspection and Exchange	Increase Chuck Clamping Power	Machine Stability, Rigidity
Short Tool Life	Large wear at the peripheral cutting edge	Non-coated insert is used	●																					
		Not enough flutes												●↗										
		Improper cutting conditions		●↘							●													
		Up cut milling						Down Cut																
	Chipping	Improper cutting conditions																						
		Fragile cutting edge															●							
		Insufficient clamping force																				●	●	
		Poor clamping rigidity																	●	●	●	●	●	●
	Breakage during cutting	Improper cutting conditions				●↘																		
		Poor end mill rigidity														●↗	●							
		Overhang longer than necessary				●↘													●					
		Chip packing								●								●						
Poor Surface Finish	Vibration during cutting	Improper cutting conditions		●↘	●↘																			
		Poor end mill rigidity											●↗	●↗		●↗	●							
		Poor clamping rigidity																	●	●	●	●	●	●
	Poor wall surface roughness	Large cutting edge wear	●																					
		Improper cutting conditions		●↘		●↘																		
		Chip jamming							●	●		● Wet												
	Poor bottom surface roughness	The end cutting edge does not have a concave angle			●↘	●↘									●↗									
		Large pick feed					●																	
	Out of vertical	Large cutting edge wear	●																					
		Improper cutting conditions			●↘	●↘																		
		Poor end mill rigidity											●↗	●↗		●↗	●							
	Poor surface finish accuracy	Improper cutting conditions		●↘	●↘	●↘																		
		Poor clamping rigidity																	●	●	●	●	●	●
Burr / Chipping / Burrs	Burr, workpiece chipping	Improper cutting conditions			●↘	●↘																		
		Large helix angle											●↘											
	Quick burr formation	Notch wear occurs	●																					
		Improper cutting conditions		●↘	●↗																			
Chip Control	Chip packing	Metal removal too large			●↘	●↘																		
		Lack of flute chip space												●↘				●						

END MILL FEATURES AND SPECIFICATION

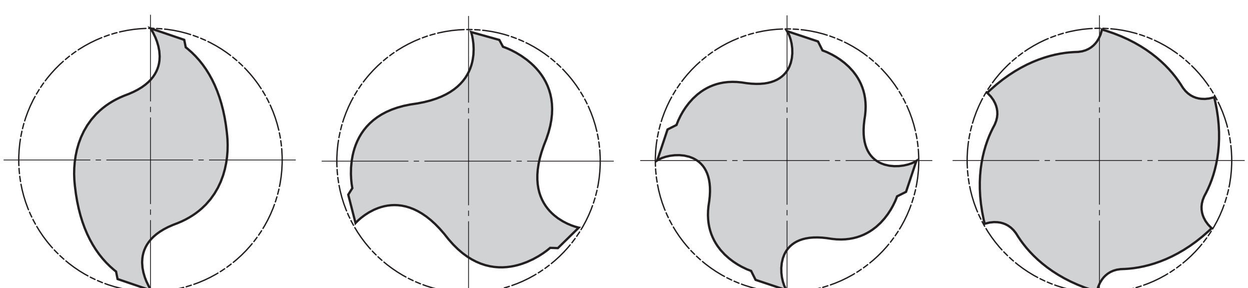
NOMENCLATURE







COMPARISON OF SECTIONAL AREA OF CHIP POCKET



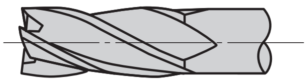
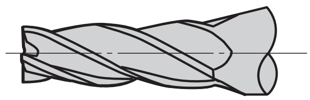
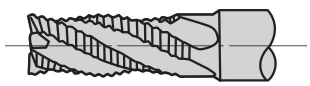
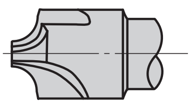
2-flutes 50% | 3-flutes 45% | 4-flutes 40% | 6-flutes 20%

CHARACTERISTICS AND APPLICATIONS OF DIFFERENT-NUMBER-OF-FLUTE END MILLS

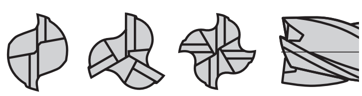
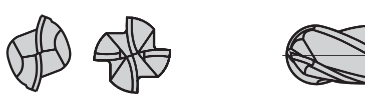
		2-flutes	3-flutes	4-flutes	6-flutes
Feature	Advantage	Effective chip disposal. Horizontal feed milling possible.	Effective chip disposal. Horizontal feed milling possible.	High rigidity.	High rigidity. Superior cutting edge durability.
Feature	Fault	Low rigidity.	Diameter is not measured easily.	Chip disposal is poor.	Chip disposal is poor.
Usage		Various cutting modes including slotting, shoulder milling and drilling.	Slotting, shoulder milling Heavy cutting, finishing	Shallow slotting, shoulder milling Finishing	Machining hardened steels. Shallow slotting, shoulder milling.

END MILL TYPE AND GEOMETRY

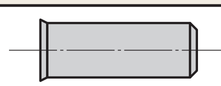
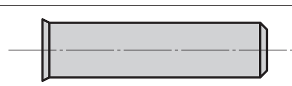
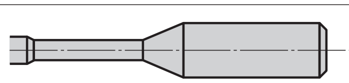
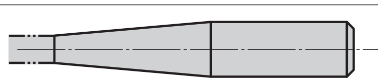
PERIPHERAL CUTTING EDGE

Type	Shape	Feature
Ordinary Flute		Regular flute geometry as shown is most commonly used for roughing and finishing of side milling, slotting and shoulder milling.
Tapered Flute		A tapered flute geometry is used for special applications such as mould drafts and for applying taper angles after conventional straight edged milling.
Roughing Flute		Roughing type geometry has a wave like edge form and breaks the material into small chips. Additionally the cutting resistance is low enabling high feed rates when roughing. The inside face of the flute is suitable for regrinding.
Formed Flute		Special form geometry as shown is used for producing corner radii on components. There are an infinite number of different geometry's that can be manufactured using such style of cutters.

END CUTTING EDGE

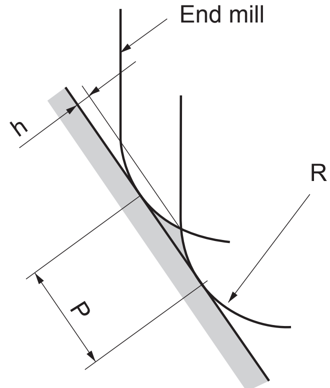
Type	Shape	Feature
Square End (With Center Hole)		Generally used for side milling, slotting and shoulder milling. Plunge cutting is not possible due to the center hole that is used to ensure accurate grinding and regrinding of the tool.
Square End (Center Cut)		Generally used for side milling, slotting and shoulder milling. Plunge cutting is possible and greater plunge cutting efficiency is obtained when using fewer flutes. Regrinding on the flank face can be done.
Ball End		Geometry completely suited for curved surface milling. At the extreme end point the chip pocket is very small leading to inefficient chip evacuation.
Corner Radius End		Used for radius profiling and corner radius milling. When pick feed milling an end mill with a large diameter and small corner radius can be efficiently used.

SHANK AND NECK PARTS

Type	Shape	Feature
Standard (Straight Shank)		Most widely used type.
Long Shank		Long shank type for deep pocket and shoulder applications.
Long Neck		Long neck geometry can be used for deep slotting and is also suitable for boring.
Taper Neck		Long taper neck features are best utilized on deep slotting and mould draft applications.

PITCH SELECTION OF PICK FEED

PICK FEED MILLING (CONTOURING) WITH BALL NOSE END MILLS, END MILLS WITH CORNER RADIUS



$$h=R \cdot \left[1-\cos\left\{\sin^{-1}\left(\frac{P}{2R}\right)\right\}\right]$$

R : Radius of Ball Nose, Corner Radius

P : Pick Feed

h : Cusp Height

CORNER R OF END MILLS AND CUSP HEIGHT BY PICK FEED

Unit : inch

R \ P	Pitch of Pick Feed (P)									
	.004	.008	.012	.016	.020	.024	.028	.031	.035	.039
0.5	.0001	.0004	.0009	.0017	.0026	.0039	—	—	—	—
1	.00004	.0002	.0004	.0008	.0016	.0018	.0025	.0033	.0042	—
1.5	.00004	.0001	.0003	.0005	.0008	.0012	.0016	.0021	.0027	.0034
2	.00004	.0001	.0002	.0004	.0006	.0009	.0012	.0016	.0020	.0025
2.5	.00004	.00007	.0002	.0003	.0005	.0007	.0010	.0013	.0016	.0020
3		.00007	.0002	.0003	.0004	.0006	.0008	.0011	.0013	.0017
4		.00004	.0001	.0002	.0003	.0004	.0006	.0008	.0010	.0012
5		.00004	.00007	.0002	.0002	.0004	.0005	.0006	.0008	.0010
6		.00004	.00007	.0001	.0002	.0003	.0004	.0005	.0007	.0008
8			.00004	.0001	.0002	.0002	.0003	.0004	.0005	.0006
10			.00004	.00007	.0001	.0002	.0002	.0003	.0004	.0005
12.5			.00004	.00007	.0001	.0002	.0002	.0002	.0003	.0004

R \ P	Pitch of Pick Feed (P)									
	.043	.047	.051	.055	.059	.063	.067	.071	.075	.079
0.5	—	—	—	—	—	—	—	—	—	—
1	—	—	—	—	—	—	—	—	—	—
1.5	.0041	—	—	—	—	—	—	—	—	—
2	.0030	.0036	.0043	—	—	—	—	—	—	—
2.5	.0024	.0029	.0034	.0039	—	—	—	—	—	—
3	.0020	.0024	.0028	.0033	.0037	.0043	—	—	—	—
4	.0015	.0018	.0021	.0024	.0028	.0032	.0036	.0041	—	—
5	.0012	.0014	.0017	.0019	.0022	.0025	.0029	.0032	.0036	.0040
6	.0010	.0012	.0014	.0016	.0019	.0021	.0024	.0027	.0030	.0033
8	.0007	.0009	.0010	.0012	.0014	.0016	.0018	.0020	.0022	.0025
10	.0006	.0007	.0008	.0010	.0011	.0013	.0014	.0016	.0018	.0020
12.5	.0005	.0006	.0007	.0008	.0009	.0010	.0011	.0013	.0014	.0016

TROUBLE SHOOTING FOR DRILLING

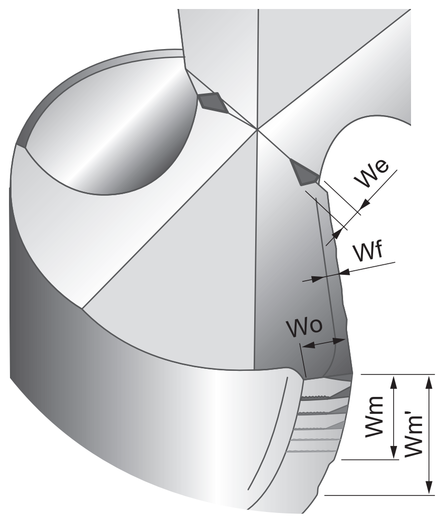
Trouble		Factors \ Solutions	Cutting Conditions									Style and Design of the Tool							Machine and Installation of Tool				
			Cutting Speed	Feed Rate	Lower the Feed at Initial Entry	Lower the Feed when Exiting	Step Feed	Increase the Accuracy and the Depth of the Pre-hole	Cutting Fluids: Increase Oil Ratio	Cutting Fluids: Increase Volume	Cutting Fluids: Increase Coolant Pressure	Chisel Width	Honing Width	Core Thickness	Shorten the Flute Length	Decrease the Lip Height	Use a Drill with Coolant Holes	Change to a Drill with X Type Thinning	Tool Installation Accuracy	Shorten Tool Overhang	Flatten the Workpiece Face	Workpiece Installation Accuracy	Machine Stability, Rigidity
			Up ↗ / Down ↘	Up ↗ / Down ↘								Large ↗ / Small ↘	Large ↗ / Small ↘	Large ↗ / Small ↘									
Short Tool Life	Drill breakage	Lack of drill rigidity												● ↗	●								
		Improper cutting conditions		● ↘																			
		Large deflection of the tool holder																	●				●
		Workpiece face is inclined																			●		
	Large wear at the peripheral cutting edge	Improper cutting conditions	● ↘																				
		Increase in tem. at cutting point							●	●							●						
		Poor run-out accuracy																	●				
	Chipping of the peripheral cutting edge	Improper cutting conditions		● ↘			●																
		Large deflection of the tool holder																	●				●
		Chattering, vibration											● ↘							●		●	●
	Chisel edge chipping	The chisel edge width is too large										● ↘											
		Poor entry			●																		
		Chattering, vibration											● ↘							●		●	●
Poor Hole Accuracy	Hole diameter increases	Lack of drill rigidity												● ↗	●								
		Improper drill geometry														●							
	Hole diameter becomes smaller	Increase in tem. at cutting point							●	●							●						
		Improper cutting conditions	● ↘																				
		Improper drill geometry														●							
	Poor straightness	Lack of drill rigidity												● ↗	●								
		Large deflection of the tool holder																	●				●
		Poor guiding properties						●															
	Poor hole positioning accuracy, roundness and surface finish	Lack of drill rigidity												● ↗	●								
		Poor entry																●					
		Improper cutting conditions			●																		
		Large deflection of the tool holder																	●				●
Burr	Burrs at the hole exit	Improper drill geometry											● ↘										
		Improper cutting conditions				●																	
Chip Control	Long chips	Improper cutting conditions		● ↗				●															
		Poor chip disposal								●	●			● ↘			●						
	Chip packing	Improper cutting conditions	● ↘	● ↘				●															
		Poor chip disposal								●	●			● ↘			●						

TECHNICAL DATA

DRILL WEAR CONDITION AND CUTTING EDGE DAMAGE

DRILL WEAR CONDITION

The diagram below shows a simple drawing depicting the wear of a drill's cutting edge. The generation and the amount of wear differ according to the workpiece materials and cutting conditions used. But generally, the peripheral wear is largest and determines a drill tool life. When regrinding, the flank wear at the point needs to be ground away completely. Therefore, if there is large wear more material needs to be ground away to renew the cutting edge.



We : Chisel edge wear width

Wf : Flank wear width (The middle of the cutting edge)

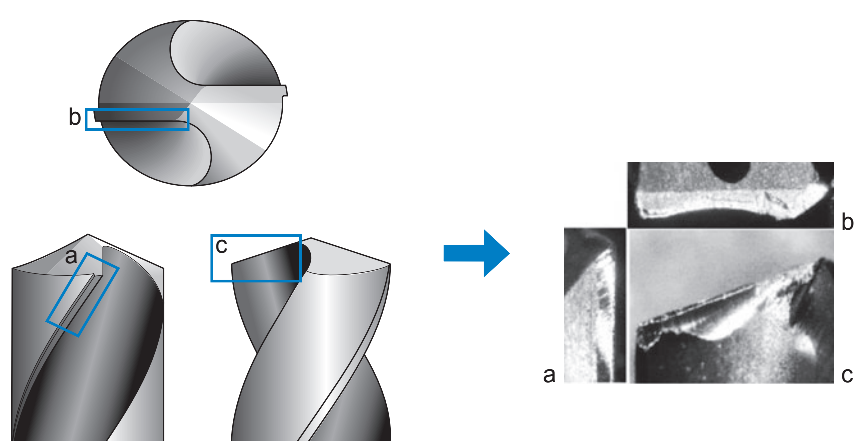
Wo : Outer corner wear width

Wm : Margin wear width

Wm' : Margin wear width (Leading edge)

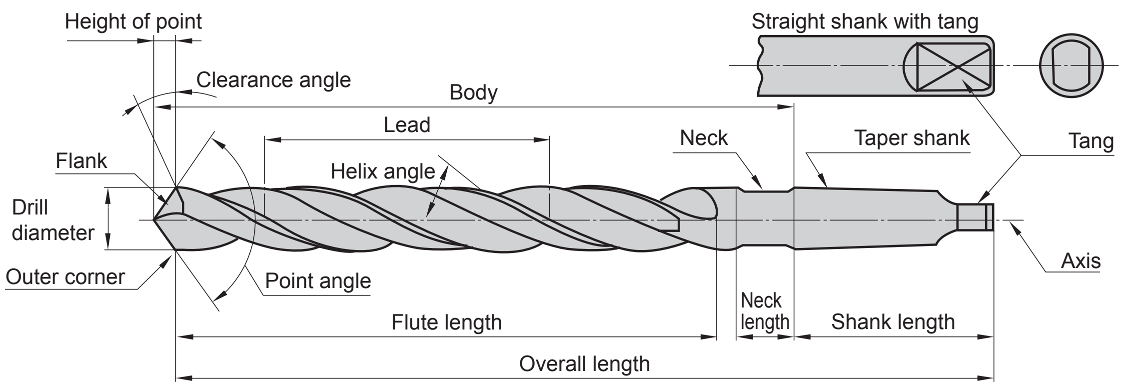
CUTTING EDGE DAMAGE

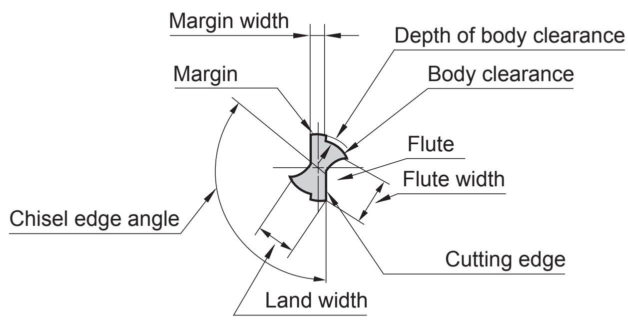
When drilling, the cutting edge of the drill can suffer from chipping, fracture and abnormal damage. In such cases it is important to take a closer look at the damage, investigate the cause and take countermeasures.



DRILL TERMINOLOGY AND CUTTING CHARACTERISTICS

NAMES OF EACH PART OF A DRILL





SHAPE SPECIFICATION AND CUTTING CHARACTERISTICS

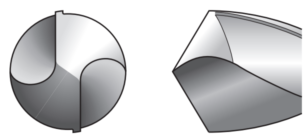
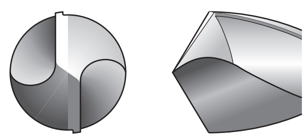
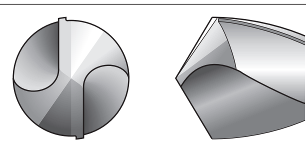
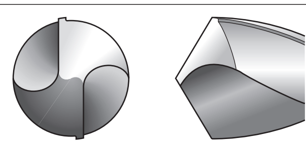
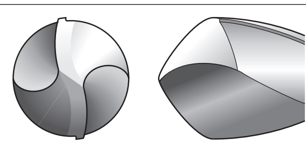
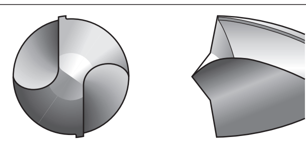
Helix Angle	Is the inclination of the flute with respect to the axial direction of a drill, which corresponds to the rake angle. The rake angle of a drill differs according to the position along the cutting edge. The rake angle is largest at the periphery and smallest towards the center of the cutting edge. The chisel edge has a negative rake angle, crushing the work. **High-hardness material** **Small ◀·· Rake Angle ··▶ Large** **Soft material** (Aluminum, etc.)
Flute Length	It is determined by depth of hole, guide bush length, and regrinding allowance. Since the influence on the tool life is great, it is necessary to minimize it as much as possible.
Point Angle	In general, the angle is 118° for high speed steel drills and 130—140° for carbide drills. **Soft material with good machinability** **Small ◀·· Point angle ··▶ Large** **For hard material and high-efficiency machining**
Web Thickness	It is an important element that determines the rigidity and chip disposal performance of a drill. The web thickness is set according to applications. Low cutting resistance, Low rigidity, Good chip disposal performance, Machinable material } **Thin ◀·· Web thickness ··▶ Thick** { Large cutting resistance, High rigidity, Poor chip disposal, High-hardness material, cross hole drilling, etc.
Margin	The margin determines the drill diameter and functions as a drill guide during drilling. The margin width is decided taking into consideration the friction with in the hole to be drilled. **Poor guiding performance** **Small ◀·· Margin width ··▶ Large** **Good guiding performance**
Diameter Back Taper	To reduce friction with the inside of the drilled hole, the portion from the point to the shank is tapered slightly. The degree is usually represented by the quantity of reduction in the diameter with respect to the flute length, which is approx. .0016"—.016"/4".

DRILL TERMINOLOGY AND CUTTING CHARACTERISTICS

CUTTING EDGE GEOMETRY AND ITS INFLUENCE

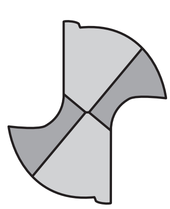
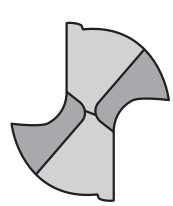
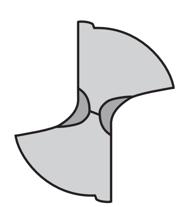
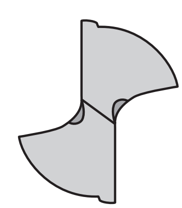
As shown in table below, it is possible to select the most suitable cutting edge geometry for different applications. If the most suitable cutting edge geometry is selected then higher machining efficiency and higher hole accuracy can be obtained.

Typical Cutting Edge Geometries

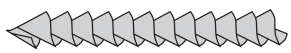
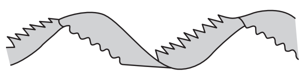
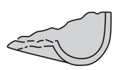
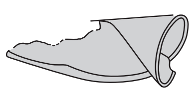
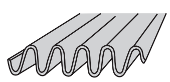
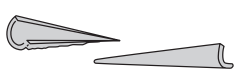
Grinding Name	Geometry	Features and Effect	Use
Conical		• The flank is conical and the clearance angle increases toward the center of the drill.	• For general use.
Flat		• The flank is flat and facilitates cutting.	• Mainly for small diameter drills.
Three Rake Angles		• As there is no chisel edge, the results are high centripetal force and small hole oversize. • Requires a special grinding machine. • Requires grinding of three sides.	• For drilling operations that require high hole accuracy and positioning accuracy.
Spiral Point		• To increase the clearance angle near the center of the drill, conical grinding combined with irregular helix. • S type chisel edge with high centripetal force and machining accuracy.	• For drilling that requires high accuracy.
Radial Lip		• The cutting edge is ground radial with the aim of dispersing load. • High machining accuracy and finished surface roughness. • For through holes, small burrs on the base. • Requires a special grinding machine.	• For cast iron and light alloy. • For cast iron plates. • Steel
Center Point Drill		• This geometry has two-stage point angle for better concentricity and a reduction in shock when exiting the workpiece.	• For thin sheet drilling.

WEB THINNING

The rake angle of the cutting edge of a drill reduces toward the center, and it changes into a negative angle at the chisel edge. During drilling, the center of a drill crushes the work, generating 50—70% of the cutting resistance. Web thinning is very effective for reduction in the cutting resistance of a drill, early removal of cut chips at the chisel edge, and better initial bite.

Geometry	 **X type**	 **XR type**	 **S type**	 **N type**
Features	The thrust load substantially reduces, and the bite performance improves. This is effective when the web is thick.	The initial performance is slightly inferior to that of the X type, but the cutting edge is tough and the applicable range of workpiece materials is wide.	Popular design, easy cutting type.	Effective when the web is comparatively thick.
Major Applications	General drilling and deep hole drilling.	General drilling and stainless steel drilling.	General drilling for steel, cast iron, and non-ferrous metal.	Deep hole drilling.

DRILLING CHIPS

Types of Chips	Geometry	Features and Ease of Raking
Conical Spiral		Fan-shaped chips cut by the cutting edge are curved by the flute. Chips of this type are produced when the feeding rate of ductile material is small. If the chip breaks after several turns, the chip raking performance is satisfactory.
Long Pitch		Long pitch chips exit without coiling and will coil around the drill.
Fan		This is a chip broken by the restraint caused by the drill flute and the wall of a drilled hole. It is generated when the feed rate is high.
Segment		A conical spiral chip that is broken before the chip grows into the long-pitch shape by the restraint caused by the wall of the drilled hole due to the insufficiency of ductility. Excellent chip disposal and chip discharge.
Zigzag		A chip that is buckled and folded because of the shape of flute and the characteristics of the material. It easily causes chip packing in the flute.
Needle		Chips broken by vibration or broken when brittle material is curled with a small radius. The raking performance is satisfactory, but these chips can become closely packed jams.

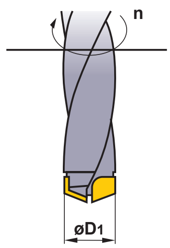
FORMULAS FOR DRILLING

CUTTING SPEED (vc)

$$vc = \frac{\pi \cdot D_1 \cdot n}{12} \quad (SFM)$$

vc (SFM)	: Cutting Speed	**D1(inch)**	: Drill Diameter
π (3.14)	: Circular Constant	**n (min^{-1})**	: Rotational Speed of the Main Spindle

*Unit transformation (from "mm" to "m")



(Problem) What is the cutting speed when main axis spindle speed is 1350min^{-1} and drill diameter is .500inch ?

(Answer) Substitute π=3.14, D1=.500inch, n=1350 into the formula

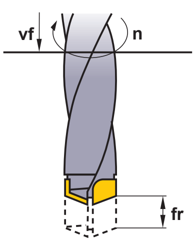
$$vc = \frac{\pi \cdot D_1 \cdot n}{12} = \frac{3.14 \times .500 \times 1350}{12} = 176.6SFM$$

The cutting speed is 176.6SFM

FEED OF THE MAIN SPINDLE (vf)

$$vf = fr \cdot n \quad (inch/min)$$

vf (inch/min)	: Feed Speed of the Main Spindle (Z axis)
fr (IPR)	: Feed per Revolution
n (min^{-1})	: Rotational Speed of the Main Spindle



(Problem) What is the spindle feed (vf) when feed per revolution is .008IPR and main axis spindle speed is 1350min^{-1}?

(Answer) Substitute fr=.008, n=1350 into the formula

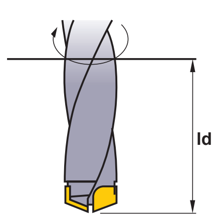
vf = fr×n = .008×1350 = 10.8inch/min

The spindle feed is 10.8inch/min.

DRILLING TIME (Tc)

$$Tc = \frac{Id \cdot i}{n \cdot fr}$$

Tc	**(min)**	: Drilling Time
n	**(min^{-1})**	: Spindle Speed
Id	**(inch)**	: Hole Depth
fr	**(IPR)**	: Feed per Revolution
i		: Number of Holes



(Problem) What is the drilling time required for drilling a 1.2inch length hole in alloy steel at a cutting speed of 165SFM and feed .006IPR ?

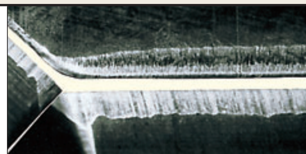
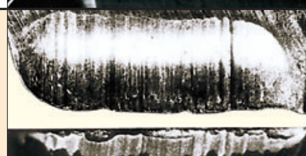
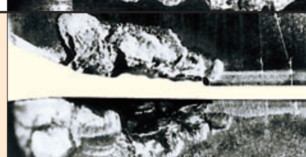
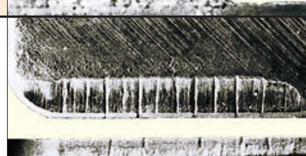
(Answer) Spindle Speed $n = \frac{165 \times 12}{.59 \times 3.14} = 1068.8min^{-1}$

$$Tc = \frac{1.2 \times 1}{1068.8 \times .006} = .187$$

$$= .187 \times 60 \fallingdotseq 11.2 \text{ sec}$$

TOOL WEAR AND DAMAGE

CAUSES AND COUNTERMEASURES

Tool Damage Form		Cause	Countermeasure
Flank Wear		· Tool grade is too soft. · Cutting speed is too high. · Flank angle is too small. · Feed rate is extremely low.	· Tool grade with high wear resistance. · Lower cutting speed. · Increase flank angle. · Increase feed rate.
Crater Wear		· Tool grade is too soft. · Cutting speed is too high. · Feed rate is too high.	· Tool grade with high wear resistance. · Lower cutting speed. · Lower feed rate.
Chipping		· Tool grade is too hard. · Feed rate is too high. · Lack of cutting edge strength. · Lack of shank or holder rigidity.	· Tool grade with high toughness. · Lower feed rate. · Increase honing. (Round honing is to be changed to chamfer honing.) · Use large shank size.
Fracture		· Tool grade is too hard. · Feed rate is too high. · Lack of cutting edge strength. · Lack of shank or holder rigidity.	· Tool grade with high toughness. · Lower feed rate. · Increase honing. (Round honing is to be changed to chamfer honing.) · Use large shank size.
Plastic Deformation		· Tool grade is too soft. · Cutting speed is too high. · Depth of cut and feed rate are too large. · Cutting temperature is high.	· Tool grade with high wear resistance. · Lower cutting speed. · Decrease depth of cut and feed rate. · Tool grade with high thermal conductivity.
Welding		· Cutting speed is low. · Poor sharpness. · Unsuitable grade.	· Increase cutting speed. (For ANSI 1045, cutting speed 260 SFM.) · Increase rake angle. · Tool grade with low affinity. (Coated grade, cermet grade)
Thermal Cracks		· Expansion or shrinkage due to cutting heat. · Tool grade is too hard. *Especially in milling.	· Dry cutting. (For wet cutting, flood workpiece with cutting fluid) · Tool grade with high toughness.
Notching		· Hard surfaces such as uncut surface, chilled parts and machining hardened layer. · Friction caused by jagged shape chips. (Caused by small vibration)	· Tool grade with high wear resistance. · Increase rake angle to improve sharpness.
Flaking		· Cutting edge welding and adhesion. · Poor chip disposal.	· Increase rake angle to improve sharpness. · Enlarge chip pocket.
Flank Wear Fracture *Damage for polycrystallines		· Damage due to the lack of strength of a curved cutting edge.	· Increase honing. · Tool grade with high toughness.
Crater Wear Fracture *Damage for polycrystallines		· Tool grade is too soft. · Cutting resistance is too high and causes high cutting heat.	· Decrease honing. · Tool grade with high wear resistance.

MATERIAL CROSS REFERENCE LIST

CARBON STEEL

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	JIS	W.-nr.	DIN	BS	EN	AFNOR	UNI	UNE	SS	GB
A570.36	STKM 12A STKM 12C	1.0038	RSt.37-2	4360 40 C	–	E 24-2 Ne	–	–	1311	15
1015	–	1.0401	C15	080M15	–	CC12	C15, C16	F.111	1350	15
1020	–	1.0402	C22	050A20	2C	CC20	C20, C21	F.112	1450	20
1213	SUM22	1.0715	9SMn28	230M07	1A	S250	CF9SMn28	F.2111 11SMn28	1912	Y15
12L13	SUM22L	1.0718	9SMnPb28	–	–	S250Pb	CF9SMnPb28	11SMnPb28	1914	–
–	–	1.0722	10SPb20	–	–	10PbF2	CF10Pb20	10SPb20	–	–
1215	–	1.0736	9SMn36	240M07	1B	S300	CF9SMn36	12SMn35	–	Y13
12L14	–	1.0737	9SMnPb36	–	–	S300Pb	CF9SMnPb36	12SMnP35	1926	–
1015	S15C	1.1141	Ck15	080M15	32C	XC12	C16	C15K	1370	15
1025	S25C	1.1158	Ck25	–	–	–	–	–	–	25
A572-60	–	1.8900	StE380	4360 55 E	–	–	FeE390KG	–	2145	–
1035	–	1.0501	C35	060A35	–	CC35	C35	F.113	1550	35
1045	–	1.0503	C45	080M46	–	CC45	C45	F.114	1650	45
1140	–	1.0726	35S20	212M36	8M	35MF4	–	F210G	1957	–
1039	–	1.1157	40Mn4	150M36	15	35M5	–	–	–	40Mn
1335	SMn438(H)	1.1167	36Mn5	–	–	40M5	–	36Mn5	2120	35Mn2
1330	SCMn1	1.1170	28Mn6	150M28	14A	20M5	C28Mn	–	–	30Mn
1035	S35C	1.1183	Cf35	060A35	–	XC38TS	C36	–	1572	35Mn
1045	S45C	1.1191	Ck45	080M46	–	XC42	C45	C45K	1672	Ck45
1050	S50C	1.1213	Cf53	060A52	–	XC48TS	C53	–	1674	50
1055	–	1.0535	C55	070M55	9	–	C55	–	1655	55
1060	–	1.0601	C60	080A62	43D	CC55	C60	–	–	60
1055	S55C	1.1203	Ck55	070M55	–	XC55	C50	C55K	–	55
1060	S58C	1.1221	Ck60	080A62	43D	XC60	C60	–	1678	60Mn
1095	–	1.1274	Ck101	060A96	–	XC100	–	F.5117	1870	–
W1	SK3	1.1545	C105W1	BW1A	–	Y105	C36KU	F.5118	1880	–
W210	SUP4	1.1545	C105W1	BW2	–	Y120	C120KU	F.515	2900	–

ALLOY STEEL

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	JIS	W.-nr.	DIN	BS	EN	AFNOR	UNI	UNE	SS	GB
A573-81	SM400A, SM400B SM400C	1.0144	St.44.2	4360 43 C	–	E28-3	–	–	1412	–
–	SM490A, SM490B SM490C	1.0570	St52-3	4360 50 B	–	E36-3	Fe52BFN Fe52CFN	–	2132	–
5120	–	1.0841	St52-3	150M19	–	20MC5	Fe52	F.431	2172	–
9255	–	1.0904	55Si7	250A53	45	55S7	55Si8	56Si7	2085	55Si2Mn
9262	–	1.0961	60SiCr7	–	–	60SC7	60SiCr8	60SiCr8	–	–
ASTM 52100	SUJ2	1.3505	100Cr6	534A99	31	100C6	100Cr6	F.131	2258	Gr15, 45G
ASTM A204Gr.A	–	1.5415	15Mo3	1501-240	–	15D3	16Mo3KW	16Mo3	2912	–
4520	–	1.5423	16Mo5	1503-245-420	–	–	16Mo5	16Mo5	–	–
ASTM A350LF5	–	1.5622	14Ni6	–	–	16N6	14Ni6	15Ni6	–	–
ASTM A353	–	1.5662	X8Ni9	1501-509-510	–	–	X10Ni9	XBNi09	–	–
3135	SNC236	1.5710	36NiCr6	640A35	111A	35NC6	–	–	–	–
3415	SNC415(H)	1.5732	14NiCr10	–	–	14NC11	16NiCr11	15NiCr11	–	–
3415, 3310	SNC815(H)	1.5752	14NiCr14	655M13	36A	12NC15	–	–	–	–
8620	SNCM220(H)	1.6523	21NiCrMo2	805M20	362	20NCD2	20NiCrMo2	20NiCrMo2	2506	–
8740	SNCM240	1.6546	40NiCrMo22	311-Type 7	–	–	40NiCrMo2(KB)	40NiCrMo2	–	–
–	–	1.6587	17CrNiMo6	820A16	–	18NCD6	–	14NiCrMo13	–	–
5015	SCr415(H)	1.7015	15Cr3	523M15	–	12C3	–	–	–	15Cr

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	JIS	W.-nr.	DIN	BS	EN	AFNOR	UNI	UNE	SS	GB
5140	SCr440	1.7045	42Cr4	–	–	–	–	42Cr4	2245	40Cr
5155	SUP9(A)	1.7176	55Cr3	527A60	48	55C3	–	–	–	20CrMn
–	SCM415(H)	1.7262	15CrMo5	–	–	12CD4	–	12CrMo4	2216	–
ASTM A182 F11, F12	–	1.7335	13CrMo4 4	1501-620Gr27	–	15CD3.5 15CD4.5	14CrMo45	14CrMo45	–	–
ASTM A182 F.22	–	1.7380	10CrMo910	1501-622 Gr31, 45	–	12CD9 12CD10	12CrMo9 12CrMo10	TU.H	2218	–
–	–	1.7715	14MoV63	1503-660-440	–	–	–	13MoCrV6	–	–
–	–	1.8523	39CrMoV13 9	897M39	40C	–	36CrMoV12	–	–	–
9840	–	1.6511	36CrNiMo4	816M40	110	40NCD3	38NiCrMo4(KB)	35NiCrMo4	–	–
4340	–	1.6582	34CrNiMo6	817M40	24	35NCD6	35NiCrMo6(KB)	–	2541	40CrNiMoA
5132	SCr430(H)	1.7033	34Cr4	530A32	18B	32C4	34Cr4(KB)	35Cr4	–	35Cr
5140	SCr440(H)	1.7035	41Cr4	530M40	18	42C4	41Cr4	42Cr4	–	40Cr
5115	–	1.7131	16MnCr5	(527M20)	–	16MC5	16MnCr5	16MnCr5	2511	18CrMn
4130	SCM420 SCM430	1.7218	25CrMo4	1717CDS110 708M20	–	25CD4	25CrMo4(KB)	55Cr3	2225	30CrMn
4137 4135	SCM432 SCCRM3	1.7220	34CrMo4	708A37	19B	35CD4	35CrMo4	34CrMo4	2234	35CrMo
4140 4142	SCM 440	1.7223	41CrMo4	708M40	19A	42CD4TS	41CrMo4	42CrMo4	2244	40CrMoA
4140	SCM440(H)	1.7225	42CrMo4	708M40	19A	42CD4	42CrMo4	42CrMo4	2244	42CrMo 42CrMnMo
–	–	1.7361	32CrMo12	722M24	40B	30CD12	32CrMo12	F.124.A	2240	–
6150	SUP10	1.8159	50CrV4	735A50	47	50CV4	50CrV4	51CrV4	2230	50CrVA
–	–	1.8509	41CrAlMo7	905M39	41B	40CAD6 40CAD2	41CrAlMo7	41CrAlMo7	2940	–
L3	–	1.2067	100Cr6	BL3	–	Y100C6	–	100Cr6	–	CrV, 9SiCr
–	SKS31 SKS2, SKS3	1.2419	105WCr6	–	–	105WC13	100WCr6 107WCr5KU	105WCr5	2140	CrWMo
L6	SKT4	1.2713	55NiCrMoV6	BH224/5	–	55NCDV7	–	F.520.S	–	5CrNiMo
ASTM A353	–	1.5662	X8Ni9	1501-509	–	–	X10Ni9	XBNi09	–	–
2515	–	1.5680	12Ni19	–	–	Z18N5	–	–	–	–
–	–	1.6657	14NiCrMo134	832M13	36C	–	15NiCrMo13	14NiCrMo131	–	–
D3 ASTM D3	SKD1	1.2080	X210Cr12	BD3	–	Z200C12	X210Cr13KU X250Cr12KU	X210Cr12	–	Cr12
H13 ASTM H13	SKD61	1.2344	X40CrMoV51 X40CrMoV51	BH13	–	Z40CDV5	X35CrMoV05KU X40CrMoV51KU	X40CrMoV5	2242	40CrMoV5
A2	SKD12	1.2363	X100CrMoV51	BA2	–	Z100CDV5	X100CrMoV51KU	X100CrMoV5	2260	100CrMoV5
–	SKD2	1.2436	X210CrW12	–	–	–	X215CrW121KU	X210CrW12	2312	–
S1	–	1.2542	45WCrV7	BS1	–	–	45WCrV8KU	45WCrSi8	2710	–
H21	SKD5	1.2581	X30WCrV93	BH21	–	Z30WCV9	X28W09KU	X30WCrV9	–	30WCrV9
–	–	1.2601	X165CrMoV12	–	–	–	X165CrMoW12KU	X160CrMoV12	2310	–
W210	SKS43	1.2833	100V1	BW2	–	Y1105V	–	–	–	V
T4	SKH3	1.3255	S 18-1-2-5	BT4	–	Z80WKCV	X78WCo1805KU	HS18-1-1-5	–	W18Cr4VCo5
T1	SKH2	1.3355	S 18-0-1	BT1	–	Z80WCV	X75W18KU	HS18-0-1	–	–
–	SCMnH/1	1.3401	G-X120Mn12	Z120M12	–	Z120M12	XG120Mn12	X120MN12	–	–
HW3	SUH1	1.4718	X45CrSi93	401S45	52	Z45CS9	X45CrSi8	F.322	–	X45CrSi93
D3	SUH3	1.3343	S6-5-2	4959BA2	–	Z40CSD10	15NiCrMo13	–	2715	–
M2	SKH9, SKH51	1.3343	S6/5/2	BM2	–	Z85WDCV	HS6-5-2-2	F.5603	2722	–
M7	–	1.3348	S 2-9-2	–	–	–	HS2-9-2	HS2-9-2	2782	–
M35	SKH55	1.3243	S6/5/2/5	BM35	–	6-5-2-5	HS6-5-2-5	F.5613	2723	–

MATERIAL CROSS REFERENCE LIST

STAINLESS STEEL (FERRITIC, MARTENSITIC)

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	JIS	W.-nr.	DIN	BS	EN	AFNOR	UNI	UNE	SS	GB
403	SUS403	1.4000	X7Cr13	403S17	–	Z6C13	X6Cr13	F.3110	2301	OCr13 1Cr12
–	–	1.4001	X7Cr14	–	–	–	–	F.8401	–	–
416	SUS416	1.4005	X12CrS13	416S21	–	Z11CF13	X12CrS13	F.3411	2380	–
410	SUS410	1.4006	X10Cr13	410S21	56A	Z10C14	X12Cr13	F.3401	2302	1Cr13
430	SUS430	1.4016	X8Cr17	430S15	60	Z8C17	X8Cr17	F.3113	2320	1Cr17
–	SCS2	1.4027	G-X20Cr14	420C29	56B	Z20C13M	–	–	–	–
–	SUS420J2	1.4034	X46Cr13	420S45	56D	Z40CM Z38C13M	X40Cr14	F.3405	2304	4Cr13
405	–	1.4003	–	405S17	–	Z8CA12	X6CrAl13	–	–	–
420	–	1.4021	–	420S37	–	Z8CA12	X20Cr13	–	2303	–
431	SUS431	1.4057	X22CrNi17	431S29	57	Z15CNi6.02	X16CrNi16	F.3427	2321	1Cr17Ni2
430F	SUS430F	1.4104	X12CrMoS17	–	–	Z10CF17	X10CrS17	F.3117	2383	Y1Cr17
434	SUS434	1.4113	X6CrMo17	434S17	–	Z8CD17.01	X8CrMo17	–	2325	1Cr17Mo
CA6-NM	SCS5	1.4313	X5CrNi134	425C11	–	Z4CND13.4M	(G)X6CrNi304	–	2385	–
405	SUS405	1.4724	X10CrA113	403S17	–	Z10C13	X10CrA112	F.311	–	OCr13Al
430	SUS430	1.4742	X10CrA118	430S15	60	Z10CAS18	X8Cr17	F.3113	–	Cr17
HNV6	SUH4	1.4747	X80CrNiSi20	443S65	59	Z80CSN20.02	X80CrSiNi20	F.320B	–	–
446	SUH446	1.4762	X10CrA124	–	–	Z10CAS24	X16Cr26	–	2322	2Cr25N
EV8	SUH35	1.4871	X53CrMnNiN219	349S54	–	Z52CMN21.09	X53CrMnNiN219	–	–	5Cr2Mn9Ni4N
S44400	–	1.4521	X1CrMoTi182	–	–	–	–	–	2326	–
–	–	1.4922	X20CrMoV12-1	–	–	–	X20CrMoNi1201	–	2317	–
630	–	1.4542	–	–	–	Z7CNU17-04	–	–	–	–

STAINLESS STEEL (AUSTENITIC)

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	JIS	W.-nr.	DIN	BS	EN	AFNOR	UNI	UNE	SS	GB
304L	SUS304L	1.4306	X2CrNi1911	304S11	–	Z2CN18.10	X2CrNi18.11	–	2352	OCr19Ni10
304	SUS304	1.4350	X5CrNi189	304S11	58E	Z6CN18.09	X5CrNi1810	F.3551 F.3541 F.3504	2332	OCr18Ni9
303	SUS303	1.4305	X12CrNiS188	303S21	58M	Z10CNF18.09	X10CrNiS18.09	F.3508	2346	1Cr18Ni9MoZr
–	SUS304L	–	–	304C12	–	Z3CN19.10	–	–	2333	–
304L	SCS19	1.4306	X2CrNi189	304S12	–	Z2CrNi1810	X2CrNi18.11	F.3503	2352	–
301	SUS301	1.4310	X12CrNi177	–	–	Z12CN17.07	X12CrNi1707	F.3517	2331	Cr17Ni7
304LN	SUS304LN	1.4311	X2CrNiN1810	304S62	–	Z2CN18.10	–	–	2371	–
316	SUS316	1.4401	X5CrNiMo1810	316S16	58J	Z6CND17.11	X5CrNiMo1712	F.3543	2347	0Cr17Ni11Mo2
–	SCS13	1.4308	G-X6CrNi189	304C15	–	Z6CN18.10M	–	–	–	–
–	SCS14	1.4408	G-X6CrNiMo1810	316C16	–	–	–	F.8414	–	–
–	SCS22	1.4581	G-X5CrNiMoNb1810	318C17	–	Z4CNDNb1812M	XG8CrNiMo1811	–	–	–
316LN	SUS316LN	1.4429	X2CrNiMoN1813	–	–	Z2CND17.13	–	–	2375	OCr17Ni13Mo
316L	–	1.4404	–	316S13	–	Z2CND17.12	X2CrNiMo1712	–	2348	–
316L	SCS16 SUS316L	1.4435	X2CrNiMo1812	316S13	–	Z2CND17.12	X2CrNiMo1712	–	2353	OCr27Ni12Mo3
316	–	1.4436	–	316S13	–	Z6CND18-12-03	X8CrNiMo1713	–	2343, 2347	–
317L	SUS317L	1.4438	X2CrNiMo1816	317S12	–	Z2CND19.15	X2CrNiMo1816	–	2367	OOCr19Ni13Mo
UNS V 0890A	–	1.4539	X1NiCrMo	–	–	Z6CNT18.10	–	–	2562	–
321	SUS321	1.4541	X10CrNiTi189	321S12	58B	Z6CNT18.10	X6CrNiTi1811	F.3553 F.3523	2337	1Cr18NI9Ti
347	SUS347	1.4550	X10CrNiNb189	347S17	58F	Z6CNNb18.10	X6CrNiNb1811	F.3552 F.3524	2338	1Cr18Ni11Nb
316Ti	–	1.4571	X10CrNiMoTi1810	320S17	58J	Z6CNDT17.12	X6CrNiMoTi1712	F.3535	2350	Cr18Ni12Mo2T
318	–	1.4583	X10CrNiMoNb1812	–	–	Z6CNDNb1713B	X6CrNiMoNb1713	–	–	Cr17Ni12Mo3Mb

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	**JIS**	**W.-nr.**	**DIN**	**BS**	**EN**	**AFNOR**	**UNI**	**UNE**	**SS**	**GB**
309	SUH309	1.4828	X15CrNiSi2012	309S24	–	Z15CNS20.12	X6CrNi2520	–	–	1Cr23Ni13
310S	SUH310	1.4845	X12CrNi2521	310S24	–	Z12CN2520	X6CrNi2520	F.331	2361	OCr25Ni20
308	SCS17	1.4406	X10CrNi18.08	–	58C	Z1NCDU25.20	–	F.8414	2370	–
–	–	1.4418	X4CrNiMo165	–	–	Z6CND16-04-01	–	–	–	–
17-7PH	–	1.4568 1.4504	–	316S111	–	Z8CNA17-07	X2CrNiMo1712	–	–	–
NO8028 S31254	–	1.4563	–	–	–	Z1NCDU31-27-03 Z1CNDU20-18-06AZ	–	–	2584 2378	–
321	SUS321	1.4878	X12CrNiTi189	321S32	58B, 58C	Z6CNT18.12B	X6CrNiTi18 11	F.3523	–	1Cr18Ni9Ti

HEAT RESISTANT STEELS

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	**JIS**	**W.-nr.**	**DIN**	**BS**	**EN**	**AFNOR**	**UNI**	**UNE**	**SS**	**GB**
330	SUH330	1.4864	X12NiCrSi3616	–	–	Z12NCS35.16	–	–	–	–
HT, HT 50	SCH15	1.4865	G-X40NiCrSi3818	330C11	–	–	XG50NiCr3919	–	–	–

GRAY CAST IRON

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	**JIS**	**W.-nr.**	**DIN**	**BS**	**EN**	**AFNOR**	**UNI**	**UNE**	**SS**	**GB**
–	–	–	–	–	–	–	–	–	0100	–
No 20 B	FC100	–	GG 10	–	–	Ft 10 D	–	–	0110	–
No 25 B	FC150	0.6015	GG 15	Grade 150	–	Ft 15 D	G15	FG15	0115	HT150
No 30 B	FC200	0.6020	GG 20	Grade 220	–	Ft 20 D	G20	–	0120	HT200
No 35 B	FC250	0.6025	GG 25	Grade 260	–	Ft 25 D	G25	FG25	0125	HT250
No 40 B	–	–	–	–	–	–	–	–	–	–
No 45 B	FC300	0.6030	GG 30	Grade 300	–	Ft 30 D	G30	FG30	0130	HT300
No 50 B	FC350	0.6035	GG 35	Grade 350	–	Ft 35 D	G35	FG35	0135	HT350
No 55 B	–	0.6040	GG 40	Grade 400	–	Ft 40 D	–	–	0140	HT400
A436 Type 2	–	0.6660	GGL NiCr202	L-NiCuCr202	–	L-NC 202	–	–	0523	–

DUCTILE CAST IRON

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	**JIS**	**W.-nr.**	**DIN**	**BS**	**EN**	**AFNOR**	**UNI**	**UNE**	**SS**	**GB**
60-40-18	FCD400	0.7040	GGG 40	SNG 420/12	–	FCS 400-12	GS 370-17	FGE 38-17	07 17-02	QT400-18
–	–	–	GGG 40.3	SNG 370/17	–	FGS 370-17	–	–	07 17-12	–
–	–	0.7033	GGG 35.3	–	–	–	–	–	07 17-15	–
80-55-06	FCD500	0.7050	GGG 50	SNG 500/7	–	FGS 500-7	GS 500	FGE 50-7	07 27-02	QT500-7
A43D2	–	0.7660	GGG NiCr202	Grade S6	–	S-NC202	–	–	07 76	–
–	–	–	GGG NiMn137	L-NiMn 137	–	L-MN 137	–	–	07 72	–
–	FCD600	–	GGG 60	SNG 600/3	–	FGS 600-3	–	–	07 32-03	QT600-3
100-70-03	FCD700	0.7070	GGG 70	SNG 700/2	–	FGS 700-2	GS 700-2	FGS 70-2	07 37-01	QT700-18

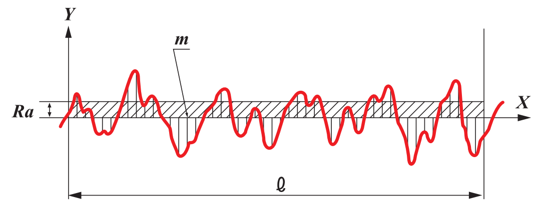
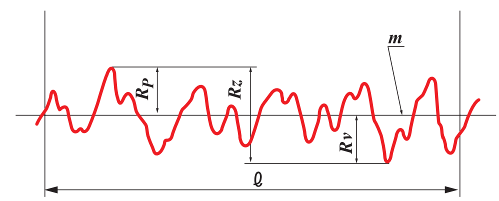
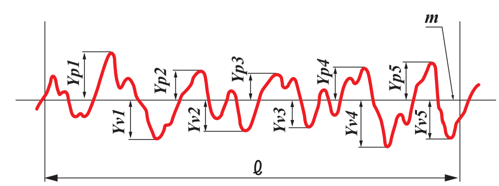
MALLEABLE CAST IRON

USA	Japan	Germany		U. K.		France	Italy	Spain	Sweden	China
AISI/SAE	**JIS**	**W.-nr.**	**DIN**	**BS**	**EN**	**AFNOR**	**UNI**	**UNE**	**SS**	**GB**
–	FCMB310	–	–	8 290/6	–	MN 32-8	–	–	08 14	–
32510	FCMW330	–	GTS-35	B 340/12	–	MN 35-10	–	–	08 15	–
40010	FCMW370	0.8145	GTS-45	P 440/7	–	Mn 450	GMN45	–	08 52	–
50005	FCMP490	0.8155	GTS-55	P 510/4	–	MP 50-5	GMN55	–	08 54	–
70003	FCMP540	–	GTS-65	P 570/3	–	MP 60-3	–	–	08 58	–
A220-70003	FCMP590	0.8165	GTS-65-02	P 570/3	–	Mn 650-3	GMN 65	–	08 56	–
A 220-80002	FCMP690	–	GTS-70-02	P 690/2	–	Mn 700-2	GMN 70	–	08 62	–

SURFACE ROUGHNESS

SURFACE ROUGHNESS

(From JIS B 0601-1994)

Type	Code	Determination	Determination Example (Figure)
Arithmetical Mean Roughness	Ra	**Ra means the value obtained by the following formula and expressed in micrometer (µm) when sampling only the reference length from the roughness curve in the direction of the mean line, taking X-axis in the direction of mean line and Y-axis in the direction of longitudinal magnification of this sampled part and the roughness curve is expressed by y=f(x):** $Ra=\frac{1}{\ell}\int_0^{\ell}\{f(x)\}dx$ (µm)	
Maximum Height	Rz	**Rz shall be that only when the reference length is sampled from the roughness curve in the direction of the mean line, the distance between the top profile peak line and the bottom profile valley line on this sampled portion is measured in the longitudinal magnification direction of roughness curve and the obtained value is expressed in micrometer (µm).** **(Note) When finding Rz, a portion without an exceptionally high peak or low valley, which may be regarded as a flaw, is selected as the sampling length.** $Rz=R_P+R_V$ (µm)	
Ten-Point Mean Roughness	RzJIS	**RzJIS shall be that only when the reference length is sampled from the roughness curve in the direction of its mean line, the sum of the average value of absolute values of the heights of five highest profile peaks (Yp) and the depths of five deepest profile valleys (Yv) measured in the vertical magnification direction from the mean line of this sampled portion and this sum is expressed in micrometer (µm).** $Rz_{JIS}=\frac{(Y_{p1}+Y_{p2}+Y_{p3}+Y_{p4}+Y_{p5})+(Y_{v1}+Y_{v2}+Y_{v3}+Y_{v4}+Y_{v5})}{5}$ (µm)	 $Y_{p1},Y_{p2},Y_{p3},Y_{p4},Y_{p5}$:altitudes of the five highest profile peaks of the sampled portion corresponding to the reference length l. $Y_{v1},Y_{v2},Y_{v3},Y_{v4},Y_{v5}$:altitudes of the five deepest profile valleys of the sampled portion corresponding to the reference length l.

RELATIONSHIP BETWEEN ARITHMETICAL MEAN (Ra) AND CONVENTIONAL DESIGNATION (REFERENCE DATA)

Arithmetical Mean Roughness Ra		Max. Height Rz	Ten-Point Mean Roughness RzJIS	Sampling Length for Rz • RzJIS l (mm)	Conventional Finish Mark
Standard Series	Cutoff Value λc (mm)	Standard Series			
0.012 a	0.08	0.05s	0.05z	0.08	▽▽▽▽
0.025 a	0.25	0.1 s	0.1 z		
0.05 a		0.2 s	0.2 z	0.25	
0.1 a	0.8	0.4 s	0.4 z		
0.2 a		0.8 s	0.8 z	0.8	
0.4 a		1.6 s	1.6 z		▽▽▽
0.8 a		3.2 s	3.2 z		
1.6 a		6.3 s	6.3 z		
3.2 a	2.5	12.5 s	12.5 z	2.5	▽▽
6.3 a		25 s	25 z		
12.5 a	8	50 s	50 z		▽
25 a		100 s	100 z	8	
50 a		200 s	200 z		–
100 a	–	400 s	400 z	–	

*The correlation among the three is shown for convenience and is not exact.
*Ra : The evaluation length of Rz and RzJIS is the cutoff value and sampling length multiplied by 5, respectively.

HARDNESS COMPARISON TABLE

HARDNESS CONVERSION NUMBERS OF STEEL

Brinell Hardness (**HB**), 10mm Ball, Load: 3,000kgf		Vickers Hardness (**HV**)	Rockwell Hardness (3)				Shore Hardness (**HS**)	Tensile Strength (Approx.)
Standard Ball	Tungsten Carbide Ball		A Scale, Load: 60kgf, Diamond Point (**HRA**)	B Scale, Load: 100kgf, 1/16" Ball (**HRB**)	C Scale, Load: 150kgf, Diamond Point (**HRC**)	D Scale, Load: 100kgf, Diamond Point (**HRD**)		MPa (2)
—	—	940	85.6	—	68.0	76.9	97	—
—	—	920	85.3	—	67.5	76.5	96	—
—	—	900	85.0	—	67.0	76.1	95	—
—	(767)	880	84.7	—	66.4	75.7	93	—
—	(757)	860	84.4	—	65.9	75.3	92	—
—	(745)	840	84.1	—	65.3	74.8	91	—
—	(733)	820	83.8	—	64.7	74.3	90	—
—	(722)	800	83.4	—	64.0	73.8	88	—
—	(712)	—	—	—	—	—	—	—
—	(710)	780	83.0	—	63.3	73.3	87	—
—	(698)	760	82.6	—	62.5	72.6	86	—
—	(684)	740	82.2	—	61.8	72.1	—	—
—	(682)	737	82.2	—	61.7	72.0	84	—
—	(670)	720	81.8	—	61.0	71.5	83	—
—	(656)	700	81.3	—	60.1	70.8	—	—
—	(653)	697	81.2	—	60.0	70.7	81	—
—	(647)	690	81.1	—	59.7	70.5	—	—
—	(638)	680	80.8	—	59.2	70.1	80	—
—	630	670	80.6	—	58.8	69.8	—	—
—	627	667	80.5	—	58.7	69.7	79	—
—	—	677	80.7	—	59.1	70.0	—	—
—	601	640	79.8	—	57.3	68.7	77	—
—	—	640	79.8	—	57.3	68.7	—	—
—	578	615	79.1	—	56.0	67.7	75	—
—	—	607	78.8	—	55.6	67.4	—	—
—	555	591	78.4	—	54.7	66.7	73	2055
—	—	579	78.0	—	54.0	66.1	—	2015
—	534	569	77.8	—	53.5	65.8	71	1985
—	—	533	77.1	—	52.5	65.0	—	1915
—	514	547	76.9	—	52.1	64.7	70	1890
(495)	—	539	76.7	—	51.6	64.3	—	1855
—	—	530	76.4	—	51.1	63.9	—	1825
	495	528	76.3	—	51.0	63.8	68	1820
(477)	—	516	75.9	—	50.3	63.2	—	1780
—	—	508	75.6	—	49.6	62.7	—	1740
	477	508	75.6	—	49.6	62.7	66	1740
(461)	—	495	75.1	—	48.8	61.9	—	1680
—	—	491	74.9	—	48.5	61.7	—	1670
	461	491	74.9	—	48.5	61.7	65	1670
444	—	474	74.3	—	47.2	61.0	—	1595
—	—	472	74.2	—	47.1	60.8	—	1585
—	444	472	74.2	—	47.1	60.8	63	1585
429	429	455	73.4	—	45.7	59.7	61	1510
415	415	440	72.8	—	44.5	58.8	59	1460
401	401	425	72.0	—	43.1	57.8	58	1390
388	388	410	71.4	—	41.8	56.8	56	1330
375	375	396	70.6	—	40.4	55.7	54	1270
363	363	383	70.0	—	39.1	54.6	52	1220
352	352	372	69.3	(110.0)	37.9	53.8	51	1180
341	341	360	68.7	(109.0)	36.6	52.8	50	1130
331	331	350	68.1	(108.5)	35.5	51.9	48	1095
321	321	339	67.5	(108.0)	34.3	51.0	47	1060
311	311	328	66.9	(107.5)	33.1	50.0	46	1025
302	302	319	66.3	(107.0)	32.1	49.3	45	1005
293	293	309	65.7	(106.0)	30.9	48.3	43	970
285	285	301	65.3	(105.5)	29.9	47.6	—	950
277	277	292	64.6	(104.5)	28.8	46.7	41	925
269	269	284	64.1	(104.0)	27.6	45.9	40	895
262	262	276	63.6	(103.0)	26.6	45.0	39	875
255	255	269	63.0	(102.0)	25.4	44.2	38	850
248	248	261	62.5	(101.0)	24.2	43.2	37	825
241	241	253	61.8	100	22.8	42.0	36	800
235	235	247	61.4	99.0	21.7	41.4	35	785
229	229	241	60.8	98.2	20.5	40.5	34	765
223	223	234	—	97.3	(18.8)	—	—	—
217	217	228	—	96.4	(17.5)	—	33	725
212	212	222	—	95.5	(16.0)	—	—	705
207	207	218	—	94.6	(15.2)	—	32	690
201	201	212	—	93.8	(13.8)	—	31	675
197	197	207	—	92.8	(12.7)	—	30	655
192	192	202	—	91.9	(11.5)	—	29	640
187	187	196	—	90.7	(10.0)	—	—	620
183	183	192	—	90.0	(9.0)	—	28	615
179	179	188	—	89.0	(8.0)	—	27	600
174	174	182	—	87.8	(6.4)	—	—	585
170	170	178	—	86.8	(5.4)	—	26	570
167	167	175	—	86.0	(4.4)	—	—	560
163	163	171	—	85.0	(3.3)	—	25	545
156	156	163	—	82.9	(0.9)	—	—	525
149	149	156	—	80.8	—	—	23	505
143	143	150	—	78.7	—	—	22	490
137	137	143	—	76.4	—	—	21	460
131	131	137	—	74.0	—	—	—	450
126	126	132	—	72.0	—	—	20	435
121	121	127	—	69.8	—	—	19	415
116	116	122	—	67.6	—	—	18	400
111	111	117	—	65.7	—	—	15	385

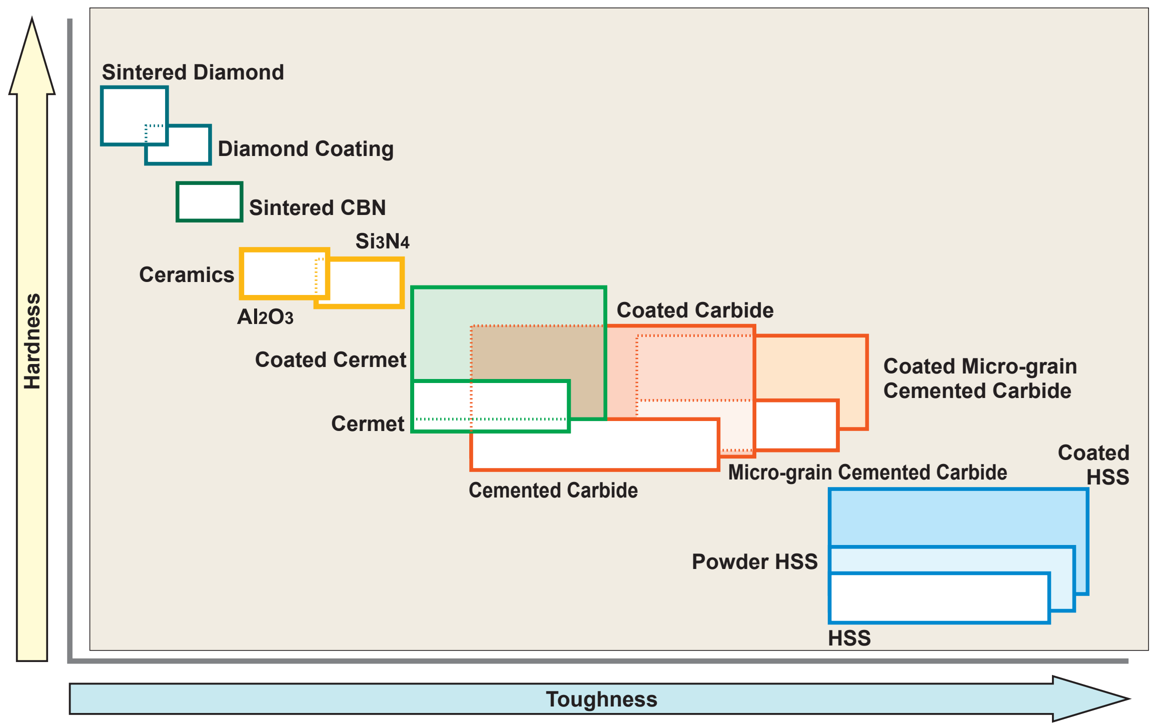
(Note 1) The above list is the same as that of AMS Metals Hand book with tensile strength in approximate metric value and Brinell hardness over a recommended range.

(Note 2) 1MPa=1N/mm^2

(Note 3) Figures in ( ) are rarely used and are included for reference. This list has been taken from JIS Handbook Steel I.

CUTTING TOOL MATERIALS

The chart below shows the relationship between various tool materials, in relation with hardness on a vertical axis and toughness on a horizontal axis.
Today, cemented carbide, coated carbide and TiC-TiN-based cermet are key tool materials in the market. As they offer a high balance of hardness and toughness.



GRADE CHARACTERISTICS

Hard Materials	Hardness (HV)	Energy Formation (kcal/g · atom)	Solubility in Iron (%.1250℃)	Thermal Conductivity (W/m·k)	Thermal * Expansion (x 10^{-6}/k)	Tool Material
Diamond	>9000	–	Highly Soluble	2100	3.1	Sintered Diamond
CBN	>4500	–	–	1300	4.7	Sintered CBN
Si_3N_4	1600	–	–	100	3.4	Ceramics
Al_2O_3	2100	-100	≒0	29	7.8	Ceramics Cemented Carbide
TiC	3200	-35	< 0.5	21	7.4	Cermet Coated Carbide
TiN	2500	-50	–	29	9.4	Cermet Coated Carbide
TaC	1800	-40	0.5	21	6.3	Cemented Carbide
WC	2100	-10	7	121	5.2	Cemented Carbide

* 1W/m • K=2.39×10^{-3}cal/cm • sec • ℃

GRADE CHAIN

For Cutting Tools

Tool Material	Work Material	Grades
Cemented Carbide	P Steel	UTi20T
	M Stainless Steel	UTi20T
	K Cast Iron	HTi05T, HTi10, UTi20T
	N Non-Ferrous	HTi10
	S Heat Resistant Alloy Ti Alloy	RT9005, RT9010, TF15
Coated Carbide	P Steel	UE6105, UE6110, UE6020, UE6035, F7010, F7030, VP10MF (PVD), VP20MF (PVD), VP15TF (PVD), VP30RT (PVD)
	M Stainless Steel	US7020, US735, F7010, F7030, VP10MF (PVD), VP20MF (PVD), VP15TF (PVD), VP30RT (PVD), UP20M
	K Cast Iron	UC5105, UC5115, MC5020, VP15TF (PVD)
	N Non-Ferrous	LC15TF
	S Heat Resistant Alloy Ti Alloy	US905, VP05RT (PVD), VP10RT (PVD), VP15TF (PVD), MP9030 (PVD)
	H Hardened Materials	MP8010 (PVD) [NEW], VP15TF (PVD)
Cermet	P Steel	NX2525, NX55, NX3035, NX4545
	M Stainless Steel	NX2525, NX4545
	K Cast Iron	NX2525
Coated Cermet	P Steel	AP25N (PVD), VP25N (PVD), VP45N (PVD)
	M Stainless Steel	AP25N (PVD)
	K Cast Iron	AP25N (PVD), VP25N (PVD)
Polycrystallines	Non-Ferrous Non-Metal (Sintered Diamond)	MD220
	Sintered Alloy	MB4020
	K Cast Iron (Sintered CBN)	MB710, MB5015 [NEW], MB730, MB5140, BC5030
	H Hardened Materials (Sintered CBN)	MBC010, MBC020, BC8020 [NEW], MB810, MB8025, MB825, MB835
Micro-Grain Cemented Carbide	Steel Cast Iron	SF10, MF07, MF10, TF15, MF20, MF30

GRADE COMPARISON TABLE

CEMENTED CARBIDE

	ISO Classification	ISO Symbol	Mitsubishi	Kennametal	Sandvik	Seco Tools	Iscar	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi Tool
Turning	P	P01										
		P10		P10	S1P		IC70	ST10P	TX10S		SRT	WS10
		P20	UTi20T	K125M TTM	SMA		IC70 IC50M	ST20E	TX20 TX25		SRT DX30	EX35
		P30	UTi20T	GK K600 TTR	SM30		IC50M IC54	A30 A30N	TX30 UX30	PW30	SR30 DX30	EX35 EX40
		P40		G13	S6		IC54	ST40E	TX40		SR30 DX35	EX45
	M	M10		K313	H10A	890		EH510 U10E	TU10		UMN	WA10B
		M20	UTi20T	K68 KMF K125M TTM	H13A	HX 883	IC08	EH520 U2	TU20 UX30		DX25 UMS	EX35
		M30	UTi20T	K600 TTR	H10F SM30		IC08 IC28	A30 A30N	UX30		DX25 UMS	EX40 EX45
		M40		G13	S6		IC128		TU40		UM40	EX45
	K	K01	HTi05T	K605	H1P			H1 H2	TH03 KS05F		KG03	WH01 WH05
		K10	HTi10	K313 K110M THM THM-U	H1P H10 HM	890	IC20	EH10 EH510	G1F TH10	KW10	KG10 KT9	WH10
		K20	UTi20T	K715 KMF K600	H13A	890 HX 883	IC20	G10E EH20 EH520	G2F, KS15F G2, KS20	GW25	CR1 KG20	WH20
		K30	UTi20T	THR		883		G10E	G3		KG30	
	N	N01		K605	H10 H13A			H1 H2	KS05F	KW10		
		N10	HTi10	K313 K110M THM THM-U		890 H15	IC20	EH10 EH510	TH10 H10T	KW10 GW15	KT9	WH10
		N20		K715 KMF K600		HX KX 883 H15 H25	IC20	G10E EH20 EH520	KS15F		CR1	WH20
		N30		G13 THR		H25 883						
	S	S01	RT9005								KG03	
		S10	RT9005 RT9010	K10 K313 THM	H10 H10A H10F H13A	890	IC07 IC08	EH10 EH510	KS05F TH10	KW10	FZ05 KG10	
		S20	RT9010 TF15	K715 KMF		890 883 HX H25	IC07 IC08	EH20 EH520	KS15F KS20	KW10	FZ15 KG20	
		S30	TF15	G13 K600 THR							KG30	
Milling	P	P10			S1P						SRT	
		P20	UTi20T	K125			IC50M IC28	A30N	TX25		SRT DX30	EX35
		P30	UTi20T	GX K600			IC50M IC28	A30N	UX30	PW30	SR30 DX30	EX35 EX40
		P40					IC28		UX40	PW30	SR30	EX45
	M	M10		K110M							UMN	
		M20	UTi20T	K313			IC20	A30N	TX25		DX25 UMS	EX35
		M30	UTi20T	KFM K600			IC28	A30N	UX30		DX25 UMS	EX40 EX45
		M40					IC28		TU40			EX45
	K	K01	HTi05T								KG03	
		K10	HTi10	K110M K313	H1P		IC20	G10E	TH10	KW10 GW25	KG10	WH10
		K20	UTi20T	KFM		HX	IC20	G10E		GW25	KT9 CR1 KG20	WH20
		K30	UTi20T								KG30	

(Note) The above table is selected from a publication. We have not obtained approval from each company.

MICRO GRAIN

	ISO Classification	ISO Symbol	Mitsubishi	Kennametal	Sandvik	Seco Tools	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi Tool
Cutting Tools	Z	Z01	**SF10 MF07 MF10**		6UF 8UF PN90		F0	F MD08F MD1508		FZ05 FB05 FB10	NM08
		Z10	**HTi10 MF20**		H3F H6F H6FF	890	XF1 F1 AFU	M MD10 MD05F MD07F	FW30	FZ10 FZ15 FB15	NM15
		Z20	**TF15 MF30**		H10F	890 883	AF0 SF2 AF1	MD20 BM10		FZ15 FB15 FB20	BRM20 EF20N
		Z30			H15F	883	A1 CC	UM		FZ20 FB20	NM25

CERMET

	ISO Classification	ISO Symbol	Mitsubishi	Kennametal	Sandvik	Seco Tools	Iscar	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi Tool
Turning	P	P01	**AP25N**				IC20N IC520N	T110A T2000Z	NS520 AT520 GT520 GT720	TN30 PV30	LN10 CX50	
		P10	**AP25N NX2525**	KT125 KT315	CT5015 GC1525	CM CMP	IC20N IC520N IC530N	T1200A T2000Z T1500A	NS520 AT530 GT720 GT730	TN60 TN6010 PV60 PV7010	CX50 CX75 PX75	CZ25
		P20	**AP25N NX2525 NX3035**	KT5020 KT325 KT1120	GC1525		IC20N IC75T IC30N IC520N IC530N	T1200A T2000Z T3000Z T1500A	NS530 GT530 GT730 NS730	TN90 TN6020 PV90 PV7020 PV7025	CX75 PX75 PX90	CH550
		P30	**VP45N**				IC75T IC30N	T3000Z	NS530 NS730	TN90 PV90	PX90	
	M	M10	**NX2525 AP25N**	KT125	GC1525	CM CMP		T110A T2000Z	NS520 AT530 GT530 GT720	TN60 TN6020 PV60 PV7020	LN10 CX50	
		M20	**NX2525 AP25N NX3035**					T1200A T2000Z	NS530 GT730 NS730	TN90 TN6020 PV90 PV7020 PV7025	CX50 CX75	CH550
		M30						T3000Z				
	K	K01	**AP25N NX2525**					T110A T2000Z	NS710 NS520 AT520 GT520 GT720	TN30 PV30 PV7005	LN10	
		K10	**AP25N NX2525**	KT125 KT325	CT5015			T1200A T2000Z	NS520 GT530 GT730 NS730	TN60 TN6020 PV60 PV7020 PV7025	LN10	
		K20	**AP25N NX2525**					T3000Z			CX75	
Milling	P	P10	**NX2525**			C15M	IC30N			TN60	CX75	
		P20	**NX2525**	KT530M HT7 KT605M	CT530	C15M	IC30N		NS530	TN100M	CX75 CX90	CH550 CH7030 MZ1000 MZ2000
		P30	**NX4545**				IC30N	T250A	NS530 NS540 NS740		CX90 CX99	MZ3000 CH7035
	M	M10	**NX2525**				IC30N			TN60		
		M20	**NX2525**	KT530M HT7 KT605M	CT530	C15M	IC30N		NS530	TN100M	CX75	CH550 CH7030 MZ1000 MZ2000
		M30	**NX4545**					T250A	NS540 NS740		CX90 CX99	MZ3000 CH7035
	K	K01										
		K10	**NX2525**						NS530	TN60		
		K20	**NX2525**	KT530M HT7							CX75	

(Note) The above table is selected from a publication. We have not obtained approval from each company.

GRADE COMPARISON TABLE

CVD COATED GRADE

	ISO Classification	ISO Symbol	Mitsubishi	Kennametal	Sandvik	Seco Tools	Iscar	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi Tool
Turning	P	P01	UE6105	KCP05 KC9105	GC4205 GC4005	TP0500 TP1500	IC9150 IC8150 IC428	AC810P AC700G	T9005	CA5505	JC110V	HG8010
		P10	UE6105 UE6110	KCP10 KCP25 KC9110	GC4215 GC4015	TP1500 TP2500	IC9150 IC9015 IC8150 IC8250	AC810P AC700G AC2000 AC820P	T9005 T9115	CA5505 CA5515	JC110V JC215V	HG8010 HG8025 GM8020
		P20	UE6110 UE6020	KCP25 KC9125	GC4215 GC4225 GC4015 GC4025	TP2500	IC9015 IC8250 IC9025 IC9250 IC8350	AC2000 AC820P AC830P	T9115 T9125	CA5515 CA5525 CR9025	JC110V JC215V	HG8025 GM8020 GM25
		P30	UE6020 UE6035 UH6400 US735	KCP30 KCP40 KC8050	GC4225 GC4235 GC4025 GC4035	TP3500 TP3000	IC8350 IC9250 IC9350	AC830P AC630M	T9125 T9035	CA5525 CA5535 CR9025	JC215V JC325V	GM25 GM8035
		P40	UE6035 UH6400 US735	KCP30 KCP40 KC9140 KC9040 KC9240 KC9245	GC4235 GC4035	TP3500 TP3000	IC9350	AC630M	T9035	CA5535	JC325V JC450V	GM8035 GX30
	M	M10	US7020	KCM15	GC2015	TM2000	IC9250 IC8250	AC610M	T9115	CA6515	JC110V	
		M20	US7020	KCM15 KC9225	GC2015	TM2000	IC9250 IC9025 IC656	AC610M AC630M	T6020 T9125	CA6515 CA6525	JC110V	HG8025 GM25
		M30	US735	KCM25 KC9230	GC2025	TM4000	IC9350 IC635	AC630M	T6030	CA6525		GM8035 GX30
		M40	US735	KCM35 KC9240 KC9245	GC2025	TM4000	IC9350	AC630M				GX30
	K	K01	UC5105	KCK05	GC3205 GC3210	TH1500 TK1000	IC5005 IC9007	AC410K	T5105	CA4505 CA4010	JC050W JC105V	HG3305
		K10	UC5115	KCK15 KCK20 KC9315	GC3205 GC3210 GC3215	TK1000 TK2000	IC5005 IC5010 IC9150 IC428 IC4028	AC410K AC420K AC700G	T5115	CA4515 CA4010 CA4115	JC050W JC105V JC110V	HG3315 HG8010
		K20	UC5115 UE6110	KCK20 KC9110 KC9325	GC3215	TK2000	IC5010 IC8150 IC9150 IC9015 IC418	AC420K AC700G AC820P	T5115 T5125	CA4515 CA4115 CA4120	JC110V JC215V	HG8025 GM8020
		K30	UE6110	KC9125 KC9325			IC9015 IC418	AC820P	T5125		JC215	HG8025 GM8020
	S	S01	US905		S05F							
Milling	P	P10				MP1500	IC9080 IC4100 IC9015				JC730U	
		P20	FH7020 F7030		GC4220	MP1500 MP2500	IC5100 IC520M	ACP100	T3130		JC730U	GX2030
		P30	F7030	KC930M	GC4230	MP2500	IC4050	ACP100	T3130			GX2030
		P40		KC935M	GC4240							GX2030 GX30 GF30
	M	M10					IC9250					
		M20	F7030	KC925M		MP2500	IC520M IC9350	ACP100	T3130		JC730U	
		M30	F7030	KC930M	GC2040	MP2500	IC9350 IC4050	ACP100	T3130			GF30 GX30
		M40		KC930M KC935M			IC635					GF30 GX30
	K	K01									JC600	
		K10	MC5020 F5010					ACK100	T1115 T1015		JC600	
		K20	MC5020 F5020	KC915M	GC3220 K20W	MK1500	IC5100 IC9150	ACK200	T1115 T1015		JC610	
		K30		KC920M KC925M KC930M KC935M	GC3040	MK3000	IC4100 IC4050 IC520M				JC610	GX2030 GX30

(Note) The above table is selected from a publication. We have not obtained approval from each company.

PVD COATED GRADE

	ISO Classification	ISO Symbol	Mitsubishi	Kennametal	Sandvik	Seco Tools	Iscar	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi Tool
Turning	P	P01								PR915 PR1005		
		P10	VP10MF	KC5010 KC5510 KU10T	GC1525 GC1025	CP200 TS2000	IC250 IC350 IC507 IC570 IC807 IC907 IC908		AH710	PR915 PR1005 PR930 PR1025 PR1115 PR1225		
		P20	VP10RT VP20RT VP15TF VP20MF	KC5025 KC5525 KC7215 KC7315 KU25T	GC1525 GC1025 GC1125	CP250 TS2500	IC228 IC250 IC308 IC328 IC350 IC354 IC507 IC528 IC570 IC807 IC808 IC907 IC908 IC928 IC1008 IC1028 IC3028		AH710 AH725 AH120 SH730 GH730 GH130	PR930 PR1025 PR1115 PR1225		IP2000
		P30	VP10RT VP20RT VP15TF VP20MF	KC7015 KC7020 KU25T KC7235	GC1025 GC1125	CP500	IC228 IC250 IC328 IC330 IC354 IC528 IC1008 IC1028 IC3028		AH725 AH120 SH730 GH730 GH130 AH740 J740			IP3000
		P40		KC7040 KC7140 KC7030		CP500	IC228 IC328 IC330 IC528 IC1008 IC1028 IC3028		AH740 J740			
	M	M01										
		M10	VP10MF	KC5010 KC5510 KC6005 KC6015	GC1005 GC1025 GC1125 GC1105	CP200 TS2000	IC330 IC354 IC507 IC520 IC570 IC807 IC907 IC3028	AC510U	AH710	PR915 PR1025 PR1225	JC5003 JC8015	IP050S
		M20	VP10RT VP20RT VP15TF VP20MF	KC5025 KC5525 KC7020 KC7025	GC1005 GC1025 GC1125 GC1105	CP250 TS2500 CP500	IC250 IC330 IC354 IC808 IC908 IC1008 IC1028 IC3028	AC520U	AH710 AH725 AH120 SH730 GH730 GH130 GH330	PR1025 PR1125 PR1225 PR915 PR930	JC5003 JC5015 JC8015	IP100S
		M30	VP10RT VP20RT VP15TF VP20MF	KC7030 KC7225	GC1125 GC2035	CP500	IC228 IC250 IC328 IC330 IC1008 IC1028 IC3028	AC520U AC530U	GH330 AH725 AH120 SH730 GH730 GH130 J740	PR1125	JC5015 JC8015	
		M40			GC2035		IC328 IC928 IC1008 IC1028 IC3028	AC530U	J740			
	K	K01										
		K10		KC5010 KC7210		CP200 TS2000	IC350 IC1008		GH110 AH110 AH710	PR905		
		K20	VP10RT VP20RT VP15TF	KC7015 KC7215 KC7315		CP200 CP250 TS2000 TS2500	IC228 IC350 IC808 IC908 IC1008		GH110 AH110 AH710 AH725 AH120 GH730 GH130	PR905		
		K30	VP10RT VP20RT VP15TF	KC7225		CP500	IC228 IC350 IC808 IC908 IC1008		AH725 AH120 GH730 GH130			
	S	S01	VP05RT				IC507 IC907		AH905		JC5003 JC8015	
		S10	VP05RT VP10RT VP20RT	KC5010 KC5410 KC5510	GC1105 GC1005 GC1025	CP200 CP250 TS2000 TS2500	IC507 IC903	AC510U	AH905 SH730 AH110 AH120		JC5003 JC5015 JC8015	
		S20	VP10RT VP20RT VP15TF	KC5025 KC5525	GC1025 GC1125	CP250 TS2500 CP500	IC300 IC808 IC908 IC928 IC3028	AC510U AC520U	AH120 AH725	PR1125	JC5015 JC8015	
		S30	VP15TF		GC1125			AC520U	AH725	PR1125		
Milling	P	P01									JC5003	ATH80D PTH08M PCA08M PCS08M
		P10		KC715M	GC1010 GC1025		IC250 IC350 IC808 IC810 IC900 IC903 IC908 IC910 IC950	ACP100 ACP200		PR730 PR830 PR1025 PR1225	JC5003 JC5030 JC8015 JC5015 JC5118	ACS05E CY9020 JX1005 JX1020 PC20M JP4020 PCA12M
		P20	VP15TF	KC522M KC525M	GC1025 GC1010 GC2030	F25M MP3000	IC250 IC300 IC328 IC330 IC350 IC528 IC808 IC810 IC830 IC900 IC908 IC910 IC928 IC950 IC1008	ACP200	AH725 AH120 GH330 AH330	PR730 PR830 PR1025 PR1225 PR1230	JC5015 JC5030 JC5040 JC8015 JC5118	CY150 CY15 JX1015

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GRADE COMPARISON TABLE

	ISO Classification	ISO Symbol	Mitsubishi	Kennametal	Sandvik	Seco Tools	Iscar	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi Tool
Milling	P	P30	**VP15TF VP30RT**	KC725M KC530M	GC1010 GC1030 GC2030	F25M MP3000 F30M	IC250 IC300 IC328 IC330 IC350 IC528 IC830 IC900 IC928 IC950 IC1008	ACP200 ACP300	AH725 AH120 AH130 AH140 GH130 AH730	PR660 PR1230	JC5015 JC5040 JC8015 JC5118	JS4060 CY250 CY25 HC844 JX1045 PTH30E
		P40	**VP30RT**	KC735M	GC1030	F40M T60M		ACP300	AH140		JC5040 JC5118	JS4060 PTH40H JX1060 GF30 GX30
	M	M01										PCS08M
		M10		KC715M	GC1025 GC1030		IC903	ACP200		PR730 PR1025 PR1225	JC5118	CY9020 JX1020
		M20	**VP15TF VP20RT**	KC730 KC522M KC525M	GC1025 GC1030 GC1040 GC2030	F25M MP3000	IC250 IC300 IC808 IC830 IC900 IC908 IC928 IC1008	ACP200 ACP300	AH725 AH120 GH330 AH330 GH110	PR730 PR660 PR1025 PR1225	JC5015 JC5040 JC5118 JC8015	CY150 CY15 JX1015
		M30	**VP15TF VP20RT VP30RT**	KC725M KC735M	GC1040 GC2030	F30M F40M MP3000	IC250 IC300 IC328 IC330 IC830 IC928 IC1008	ACP300	AH120 AH725 AH130 AH140 GH130 AH730 GH340	PR660	JC5015 JC8015 JC8050 JC5118	CY250 CY25 HC844 JX1045
		M40	**VP30RT**			F40M		ACP300	AH140		JC5015 JC5118 JC8050	JX1060 GF30 GX30
	K	K01							AH110 GH110 AH330		JC5003	ATH80D PTH08M PCA08M PCS08M
		K10		KC510M	GC1010		IC350 IC810 IC830 IC900 IC910 IC928 IC950 IC1008		AH110 GH110 AH725 AH120 GH130 AH330	PR1210 PR905	JC5003 JC8015	ASC05E JX1005 JX1020 CY9020 CY100H CY10H
		K20	**VP15TF VP20RT**	KC520M KC525M	GC1010 GC1020	MK2000	IC350 IC808 IC810 IC830 IC900 IC908 IC910 IC928 IC950 IC1008	ACK300	GH130	PR1210 PR905	JC5015 JC5080 JC8015	CY150 CY15 PTH13S JX1015
		K30	**VP15TF VP20RT**	KC725M KC735M	GC1020		IC350 IC808 IC830 IC908 IC928 IC950 IC1008	ACK300			JC5015 JC8015 JC5080	CY250 GX2030 GX30 CY25 PTH40H PTH30E JX1045
	S	S01								PR905	JC5003 JC8015 JC5118	
		S10	**VP15TF**	KC510M	C1025		IC903	EH520Z EH20Z		PR905	JC5003 JC5015 JC8015 JC5118	PCS08M PTH13S JS1025
		S20	**VP15TF MP9030**	KC522M KC525M	GC1025 GC2030		IC300 IC908 IC808 IC900 IC830 IC928 IC328 IC330	EH520Z EH20Z ACK300		PR905	JC8015 JC5015 JC8050 JC5118	CY100H CY10H
		S30		KC725M	GC2030 S30T	F40M	IC830 IC928	ACK300			JC8050 JC5118	
	H	H01	**MP8010**				IC903				JC8003 JC8008	
		H10	**VP15TF**	KC635M	GC1010 GC1030	MH1000 F15M	IC900				JC8003 JC8008 JC8015 JC5118	BH200 BH250
		H20	**VP15TF**	KC635M	GC1010 GC1030	F15M	IC900 IC808 IC908 IC1008				JC8015 JC5118	ATH80D PTH08M PCA08M JX1005
		H30		KC530M		MP3000 F30M	IC808 IC908 IC1008					

(Note) The above table is selected from a publication. We have not obtained approval from each company.

TECHNICAL DATA

CBN

	ISO Classification	ISO Symbol	Mitsubishi	Sandvik	Seco Tools	Element Six	Sumitomo	Tungaloy	Kyocera	Dijet
Turning	H	H01	**MBC010** **MB810**		CBN050C	DBC50	BNC100 BNX10	BXM10 BXC30 BX310	KBN05M KBN10M KBN10C KBN510	
		H10	**MBC020** **BC8020** **MB8025**	CB7015 CB20	CBN10 CBN100 CBN100P CBN150	DCC500	BNC160 BNX20 BN2000	BXM20 BXA30 BX330	KBN25M KBN25C KBN525	JBN300
		H20	**BC8020** **MB8025** **MB825**	CB7025 CB7050 CB50	CBN150 CBN200 CBN300 CBN300P	DCN450	BNC200 BNX25 BN2000 BN250	BXM20 BXA40 BX360	KBN30M	JBN245
		H30	**BC8020** **MB835**		CBN350	DCX650	BNC300 BN350	BXC50 BX380	KBN35M	
	S	S01	**MB730**				BN700	BX450 BX950 BX480		
		S10								
		S20								
		S30								
	K	K01	**MB710** **MB5015**	CB50 CB7050			BN500	BX930	KBN60M	JBN795
		K10	**MB710** **MB5015** **MB730**		CBN300 CBN300P	DBA80	BN700	BX950	KBN60M KBN900	JBN330
		K20	**MB730** **MBS140** **BC5030**		CBN200	DBW85 DBS900 AMB90	BN700 BNS800	BXC90 BX90S	KBN900	
		K30	**MBS140** **BC5030**		CBN350		BNS800	BXC90 BX90S		
	Sintered Alloy		**MB4020** **MB835**		CBN200	DBW85 DBS900	BN7500 BN700	BX470 BX480	KBN65B KBN65M KBN70M	

PCD

	ISO Classification	ISO Symbol	Mitsubishi	Sandvik	DIAMOND INNOVATIONS	Element Six	Sumitomo	Tungaloy	Kyocera	Dijet
Turning	N	N01	**MD205**	CD10	1800	CTH025	DA90	DX180 DX160	KPD001	JDA30 JDA735
		N10	**MD205** **MD220**		1500	CTB010	DA150	DX140	KPD001 KPD010	JDA40 JDA745
		N20	**MD220** **MD230**		1300	CTB002	DA2200	DX120	KPD230	JDA10 JDA715
		N30	**MD230**		1600		DA1000	DX110		

(Note) The above table is selected from a publication. We have not obtained approval from each company.

INSERT CHIP BREAKER COMPARISION TABLE

NEGATIVE INSERT TYPE

ISO Classifi-cation	Cutting Mode	Mitsubishi	Kennametal	Sandvik	Seco	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi
P	Finish	PK* FH FY	UF, FF	QF	FF1	FA FL	01* TF ZF	DP* GP, VF XP, XP-T		FE
	Light	C SA SH	LF, FN	PF MF	MF2	SU LU SX, SE	NS, 27 TSF, TS	HQ, CQ	PF UR UA, UT	BE BH, CE
	Light (Mild Steel)	SY					17	XQ, XS		
	Light (With Wiper)	SW	FW	WP, WF	W-MF2	LUW, SEW	AFW, ASW	WP, WQ		
	Medium	MP MA MH	MG, MN	PM QM, 61 SM	MF3 MF5, M3 M5	GU UG GE, UX	NM, ZM, AS TM DM, 37	CJ, GS PS, HS PT, CS	PG UB	CT, AB AH AY, AE
	Medium (With Wiper)	MW	MW	WMX, WM	W-M3 W-MF5	GUW				
	Medium -Heavy	GH	RN	PR, HM Std.	MR6, MR7	MU MX, ME	TH	PH GT, HT	UD, GG	AR, RE
	Heavy	HZ HX HV	MR RM, RH	QR, PR HR	R4, R5, R6 57, RR6, R7 R8, RR9	MP HG, HP	57 65, TU	PX HX	UC	TE, UE HX HE, H
M	Finish Light	SH	K, FP	MF		SU	SS	MQ, GU		MP, SE
	Medium	MS ES	P, MP	MM	MF4	EX, UP	SA, SM S	MS, MU SU, HU ST	SF SG	PV, DE
	Heavy	GH HZ	RP	MR MR	M5, MR7 56, R6	MP			SZ	
K	Finish Light	MA	FN	KF	M4	UZ	CF	Std.		VA
	Medium	Std.	Std., UN	KM		GZ, UX	CM, 33, Std.	C, ZS, GC		V
	Heavy	Flat Top		KR		Flat Top	CH, Flat Top	Flat Top		
S	Finish	FJ*	FS, K	SF	MF1					
	Light	MJ, MJ*		SGF*		SU*		TK		
	Medium	MS	◌NGP*	◌NGP* 23, SM	M1		SA, HMM			
	Heavy	GJ	MS	SR, SMR	M5, MR3					

* Peripheral ground type insert.

(Note) Above charts are based on published data and not authorized by each manufacturer.

7° POSITIVE INSERT TYPE

ISO Classifi-cation	Cutting Mode	Mitsubishi	Kennametal	Sandvik	Seco	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi
P	Finish	SMG*	LF*	UM*		FC*, SC*	JS*, 01*	CF*, CK* GQ*, GF*		
	Finish Light	FV SV	11, UF LF	UF, PF	FF1 F1	FP, LU SU, SK	PF, PSF PS, PSS	GP XP, VF		JQ
	Light (With Wiper)	SW	FW	WK* WF, WP	W-F1	LUW				
	Medium	MV Std.	MF	UM, PM	F2	MU	23 PM, 24	HQ XQ, GK	FT	JE
	Medium (With Wiper)	MW	MW	WM	W-F2					
M	Finish–Light	SV		MF			SS*			MP
	Medium	Std.		MM						
K	Medium	Flat Top		KF, KM, KR		Flat Top*	Flat Top CM	Flat Top*	FT	
N	Medium	AZ*	HP*	AL*	AL*	AG*, AW*	AL*	AH*	ASF* ALU* ACB*	
S	Finish Light	FJ*	LF* HP*			SC*				

* Peripheral ground type insert.
(Note) Above charts are based on published data and not authorized by each manufacturer.

11° POSITIVE INSERT TYPE

ISO Classifi-cation	Cutting Mode	Mitsubishi	Kennametal	Sandvik	Seco	Sumitomo	Tungaloy	Kyocera	Dijet	Hitachi
P	Finish Light	FV, SMG* SV	UF LF	PF		FK LU SU	01* PF, PSF PS, PSS	GP, CF* GF*, XP		JQ
	Medium	MV	MF	PM		MU	PM 23 24	HQ XQ		JE
M	Finish–Light	SV		MF			SS*			MP
	Medium	MV		MM						

* Peripheral ground type insert.
(Note) Above charts are based on published data and not authorized by each manufacturer.

TECHNICAL DATA