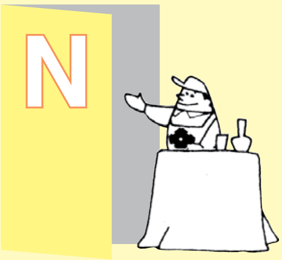
Technical Guidance References

N9 to N39

N



Technical Guidance

References

Calculating Cutting Speed

(1) Calculating rotation speed from cutting speed

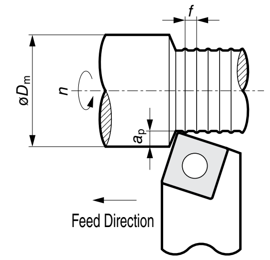
$n = \frac{1{,}000 \times v_c}{\pi \times D_m}$	n : Spindle speed (min^{-1}) v_c : Cutting speed (m/min) D_m : Diameter of work piece (mm) π : ≒3.14

(Ex.) v_c=150m/min, D_m=100mm

$$n = \frac{1{,}000 \times 150}{3.14 \times 100} = 478\ (\text{min}^{-1})$$

(2) Calculating cutting speed from rotational speed

$v_c = \frac{\pi \times D_m \times n}{1{,}000}$	Refer to the above table



- · n : Spindle speed (min^{-1})
- · v_c : Cutting speed (m/min)
- · f : Feed rate (mm/rev)
- · a_p : Depth of cut (mm)
- · D_m : Diameter of work piece (mm)

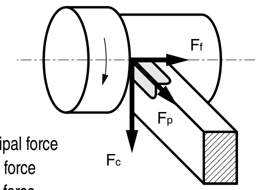
Calculating Power Requirement

$P_c = \frac{v_c \times f \times a_p \times k_c}{60 \times 10^3 \times \eta}$ $H = \frac{P_c}{0.75}$	P_c : Net power requirement (KW) V_c : Cutting speed (m/min) f : Feed rate (mm/rev) a_p : Depth of cut (mm) k_c : Specific cutting force (MPa) H : Required horsepower (HP) η : Machine efficiency (0.70 to 0.85)

● RoughValue of Kc

Aluminium: 800MPa
General Steel: 2,500 to 3,000MPa
Cast Iron: 1,500MPa

Cutting Force

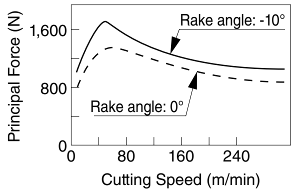


F_c: Principal force
F_f: Feed force
F_p: Back force

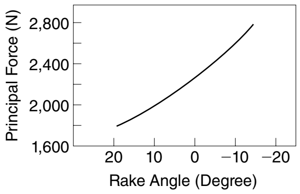
● Calculating Cutting Force

$P = \frac{k_c \times q}{1{,}000}$ $= \frac{k_c \times a_p \times f}{1{,}000}$	P : Cutting force (kN) k_c : Specific cutting force (MPa) q : Chip area (mm^2) a_p : Depth of Cut (mm) f : Feed Rate (mm/rev)

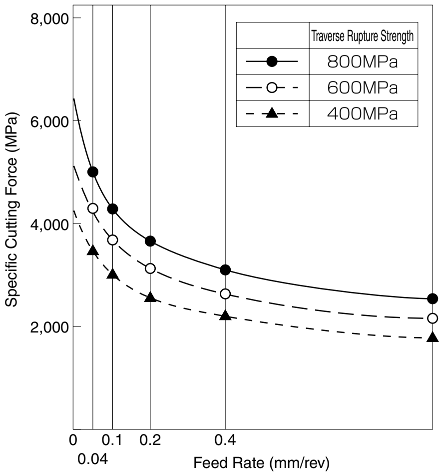
Relation Between Cutting Speed and Cutting Force



Relation Between Rake Angle and Cutting Force



Relation Between Feed Rate and Specific Cutting Force (For Carbon Steel)

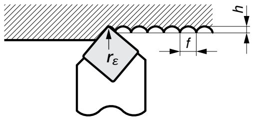


When feed rate decreases, specific cutting force increases.

Roughness

● Theoretical Surface Finish

$h = \frac{f^2}{8 \times r\varepsilon} \times 10^3$	h : Theoretical surface roughness (μm) f : Feed rate (mm/rev) $r\varepsilon$: Nose radius (mm)



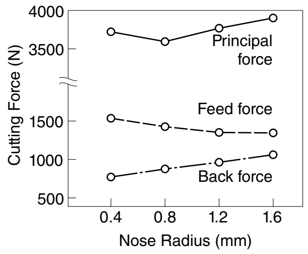
● Actual Surface Roughness

Steel:
Theoretical surface finish x 1.5 to 3
Cast iron:
Theoretical surface finish x 3 to 5

● Ways to Improve Finishing Surface Roughness

(1) Use an insert with a larger nose radius.
(2) Optimise the cutting speed and feed rate so that built-up edge does not occur.
(3) Select an appropriate insert grade.
(4) Use wiper insert

Relation Between Nose Radius and Cutting Force

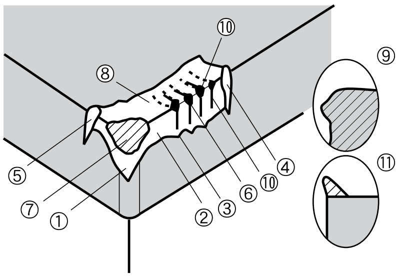


Large nose radius increases back force.

Work : SCM440(38HS)
Inserts : TNGA2204 SS
Holder : PTGNR2525-43
Cutting Conditions : v_c=100m/min
a_p=4mm
f =0.45mm/rev

Tool Failures and Tool Life

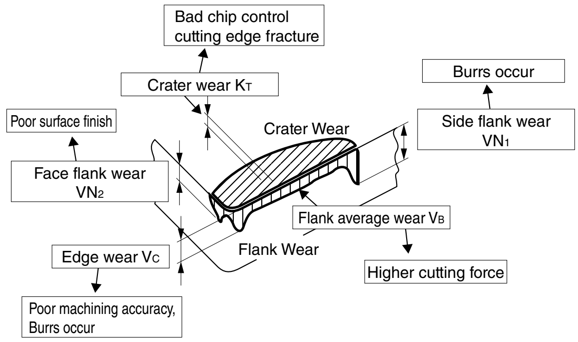
■ Forms of Tool Failures

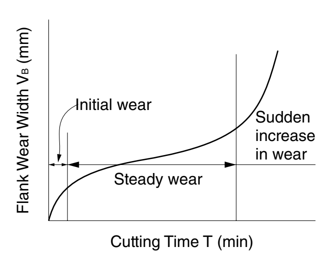
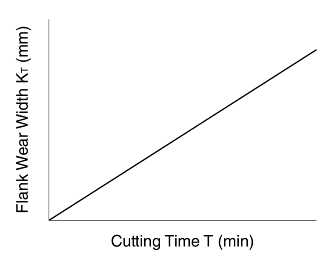


Cat.	No.	Name of Failure	Cause of Failure
Resulting from Mechanical Causes	(1) to (5)	Flank Wear	Due to the scratching effect of hard grains contained in the work material.
	(6)	Chipping	Fine breakages caused by high cutting loads or chattering.
	(7)	Fracture	Coarse breakage caused by the impact of an excessive mechanical force acting on the cutting edge.
Resulting from Chemical Reactions	(8)	Crater Wear	Swaft chips removing tool material as it flow over the top face at high temperatures.
	(9)	Plastic Deformation	Cutting edge is depressed due to softening at high temperatures.
	(10)	Thermal Crack	Fatigue from rapid, repeated heating and cooling cycles during machining.
	(11)	Built-up Edge	Adhesion or accumulation of extremely-hard alteration product of work material on the cutting edge.

■ Tool Wear

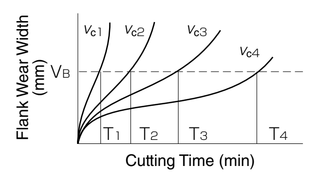
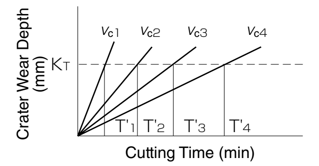
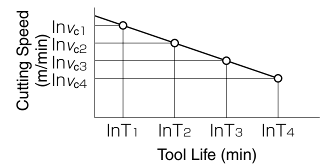
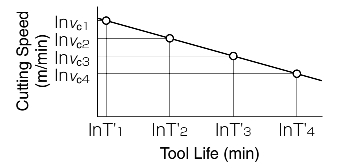
Forms of Tool Wear



Flank Wear	Crater Wear
	
· Wear increases rapidly right after starting cutting, then moderately and proportionally, and rapidly again after a certain value.	· Wear increases in proportion to the cutting time.

■ Tool Life (V-T)

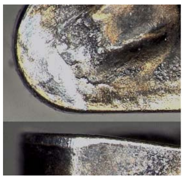
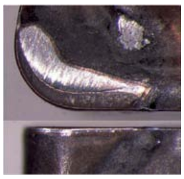
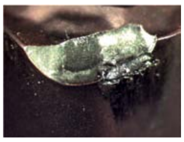
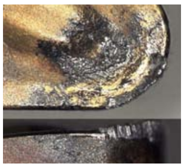
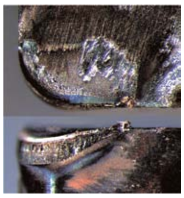
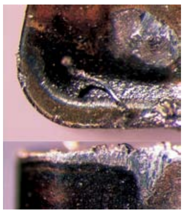
· This double logarithm graph shows the relative tool life of the specified wear over a range of cutting speeds on the X-axis, and the cutting speed along the Y-axis.

	Flank Wear	Crater Wear
Tool Wear		
Tool Life		

Tool Failure and Remedies

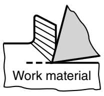
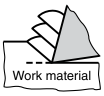
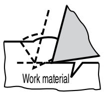
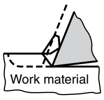
Turning Edition

Insert Failure and Countermeasures

Type of Insert Failure	Cause	Countermeasures
Flank Wear 	· Grade lacks wear resistance. · Cutting speed is too fast. · Feed rate is far too slow.	· Select a more wear-resistant grade. P30 → P20 → P10 K20 → K10 → K01 · Use an insert with a larger rake angle. · Decrease the cutting speed · Increase feed rates.
Crater Wear 	· Grade lacks crater wear resistance. · Rake angle is too small. · Cutting speed is too fast. · Feed rate and depth of cut are too large.	· Select a more crater-wear-resistant grade. · Use an insert with a larger rake angle. · Change the chipbreaker. · Decrease the cutting speed · Reduce feed rates and depth of cut.
Chipping 	· Grade lacks toughness. · Insert falls off due to chip build-up. · Cutting edge lacks toughness. · Feed rate and depth of cut are too large.	· Select a tougher grade. P10 → P20 → P30 K01 → K10 → K20 · Increase amount of honing on cutting edge. · Reduce rake angle. · Reduce feed rates and depth of cut.
Fracture 	· Grade lacks toughness. · Cutting edge lacks toughness. · Holder lacks toughness. · Feed rate is too fast. · Depth of cut is too large.	· Select a tougher grade. P10 → P20 → P30 K01 → K10 → K20 · Select a chipbreaker with a strong cutting edge. · Select a holder with a larger approach angle. · Select a holder with a larger shank size. · Reduce feed rates and depth of cut.
Welding of Built-up Edge 	· Inappropriate grade selection. · Dull cutting edge. · Cutting speed is too slow. · Feed rate is too slow.	· Select a grade with less affinity to the work material. Coated carbide or cermet grades. · Select a grade with a smooth coating. · Use an insert with a larger rake angle. · Reduce amount of honing. · Increase cutting speeds. · Increase feed rates.
Plastic Deformation 	· Grade lacks thermal resistance. · Cutting speed is too fast. · Feed rate is too fast. · Depth of cut is too large. · Not enough cutting fluid.	· Select a more crater-wear-resistant grade. · Use an insert with a larger rake angle. · Decrease the cutting speed · Reduce feed rates and depth of cut. · Supply a sufficient amount of coolant.
Notch Wear 	· Grade lacks wear resistance. · Rake angle is too small. · Cutting speed is too fast.	· Select a wear-resistant grade. P30 → P20 → P10 K20 → K10 → K01 · Use an insert with a larger rake angle. · Alter depth of cut to shift the notch location.

Chip Control

Type of Chip Generation

	Spiralling	Shearing	Tearing	Cracking
Shape				
Condition	Continuous chips with good surface finish.	Chip is sheared and separated by the shear angle.	Chips appear to be torn from the surface.	Chips crack before reaching the cutting point.
Application	Steel, Stainless steel	Steel, Stainless steel (Low speed)	Steel, Cast iron (very low speed, very small feed rate)	Cast iron, Carbon
Influence Factor	Easy ← Work deformation → Difficult Large ← Rake angle → Small Small ← D.O.C. → Large Fast ← Cutting speed → Slow			

Type of Chip Control

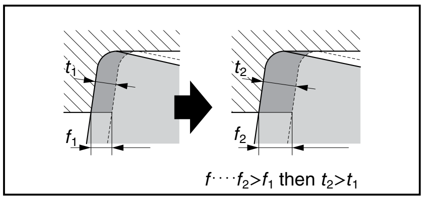
	Depth	A	B	C	D	E
Chip Types	Large					
	Small					
Evaluation	NC Lathe (For Automation)	×	×	○	○	△
	General Lathe (For Safety)	×	○	○	○～△	×

Good: C type, D type

Poor
- A type: Twines around the tool or workpiece, damages the machined surface and affects safety.
- B type: Causes problems in the automatic chip conveyor and chipping occurs easily.
- E type: Causes spraying of chips, poor machined surface due to chattering, chipping, large cutting force and high temperatures.

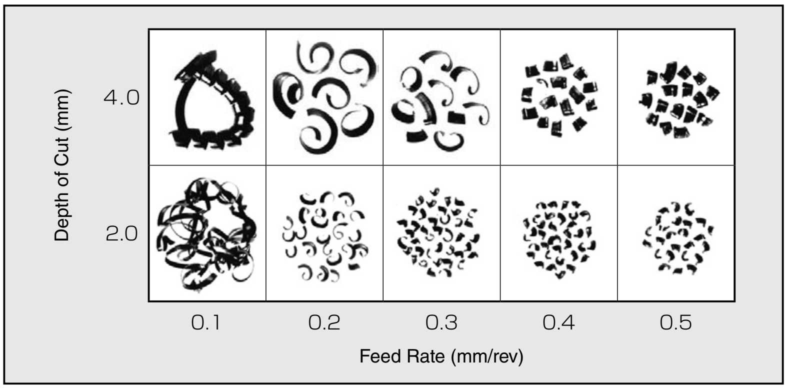
Factor of Improvement Chip Control

(1) Increase Feed Rate (f)

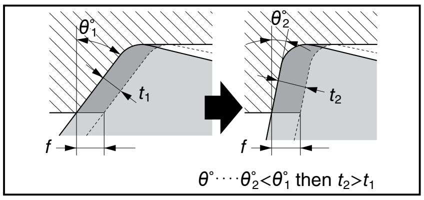


$f \cdots f_2 > f_1$ then $t_2 > t_1$

When feed rate increases, chips become thick and chip control improves.

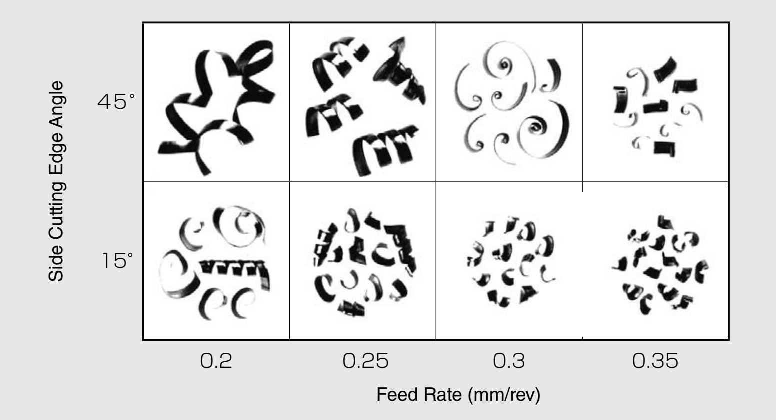


(2) Decrease Side Cutting Edge (θ)

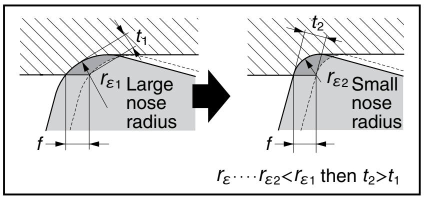


$\theta^\circ \cdots \theta_2^\circ < \theta_1^\circ$ then $t_2 > t_1$

Even if feed rate is the same, smaller side cutting edge angle makes chips thick and chip control improves.



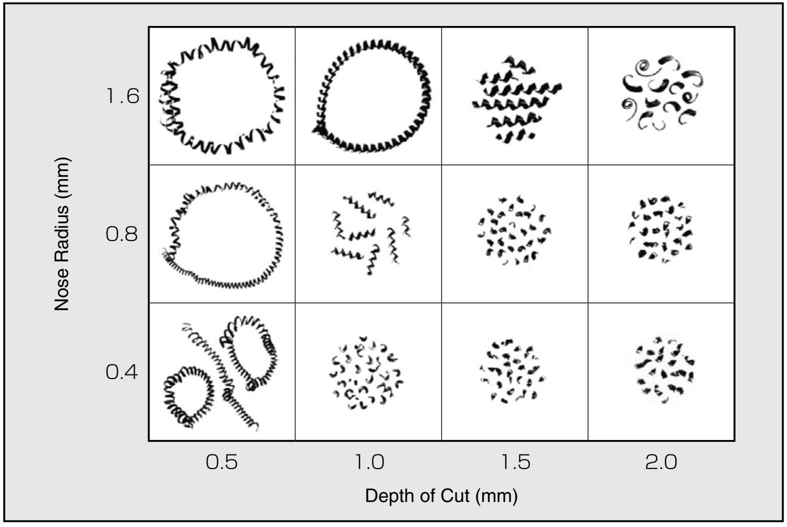
(3) Decrease Nose Radius ($r\varepsilon$)



$r\varepsilon \cdots r\varepsilon_2 < r\varepsilon_1$ then $t_2 > t_1$

Even if feed rate is the same, a smaller nose radius makes chip thick and chip control improves.

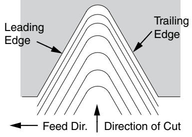
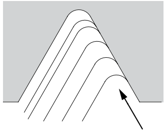
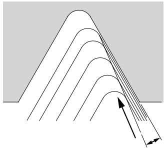
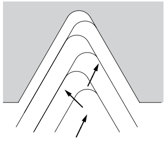
* Cutting force increases in proportion with the length of the contact surface. Therefore, a larger nose radius increases back force which induces chattering. With the same feed rate, a smaller nose radius produces a rougher surface finish.



Basics of Threading

Turning Edition

Cutting Methods in Threading

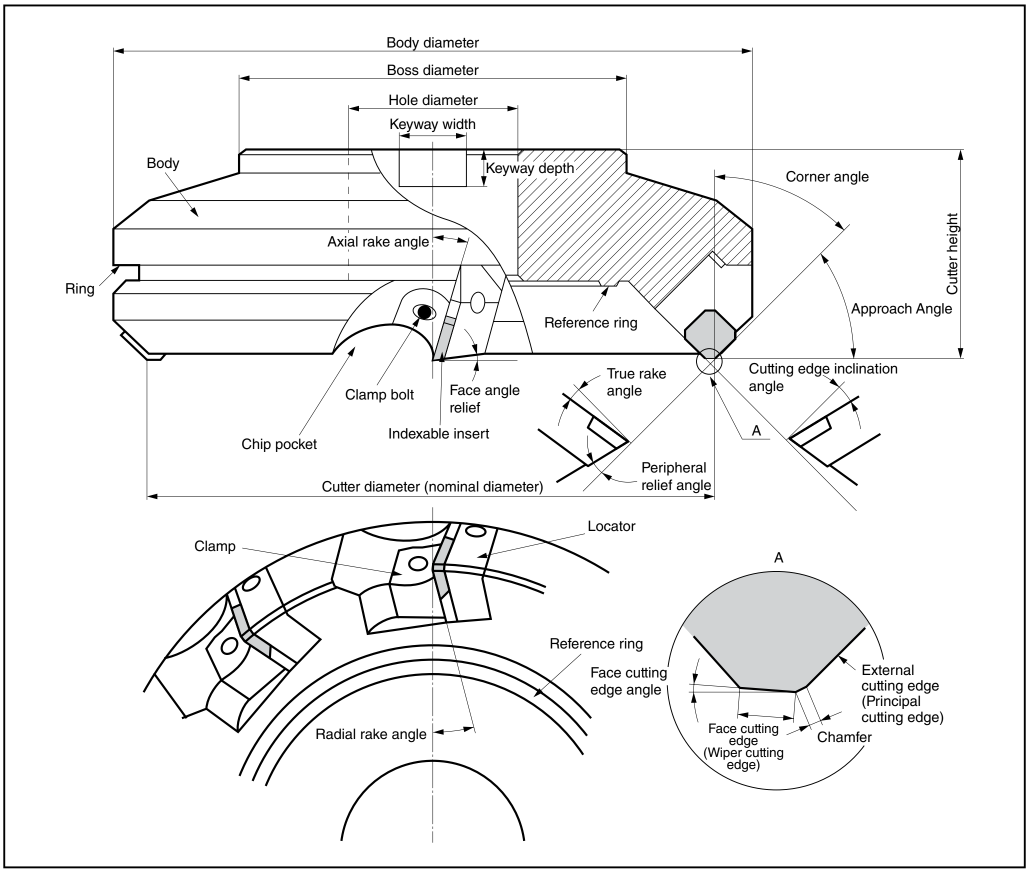
Cutting Method	Characteristics
Radian Infeed 	· Most common threading technique, used mainly for small pitch threads. · Easy to change cutting conditions such as depth of cut, etc. · Longer contact points lead to more chatter. · Difficult to control chip evacuation. · Damage on the trailing edge gets larger faster.
Flank Infeed 	· Effective for large pitch threads and blemish-prone work material surfaces. · Chips evacuate from one side for good chip control. · The trailing edge side is worn, and therefore the flank is easily worn.
Corrected Flank Infeed 	· Effective for large pitch threads and blemish-prone work material surfaces. · Chips evacuate from one side for good chip control. · Reduces flank wear on trailing edge side.
Alternating Flank Infeed 	· Effective for large pitch threads and blemish-prone work material surfaces. · Wears evenly on right and left cut edges. · Since both edges are used alternatively, chip control is sometimes difficult.

Troubleshooting for Threading

Failure		Cause	Countermeasures
Cutting Edge Failure	Excessive Cutting Edge Wear	· Tool material	· Select a more wear-resistant grade
		· Cutting condition	· Decrease the cutting speed · Optimise coolant flow and density · Change the number of passes.
	Uneven Wear on Right and Left Sides	· Insert attachment	· Check whether the cutting edge inclination angle is appropriate for the screw lead angle. · Check whether the tool is mounted properly.
		· Cutting condition	· Change to corrected flank infeed or alternating flank infeed
	Chipping	· Cutting condition	· If caused by a built-up edge, increase cutting speed
	Breakage	· Packing of chips	· Supply enough amount of coolant to the cutting edge.
		· Cutting condition	· Increase the number of passes while decreasing the depth of cut per pass. · Use different tools for roughing and finishing applications.
Shape and Accuracy	Poor Surface Roughness	· Cutting condition	· If blemished due to low-speed machining, increase the cutting speed. · If chattering occurs, decrease the cutting speed. · If the depth of cut of the final pass is small, make it larger.
		· Tool material	· Select a more wear-resistant grade
		· Inappropriate cutting edge inclination angle	· Select a correct shim to secure relief on the side of the insert.
	Inappropriate Thread Shape	· Insert attachment	· Check whether the tool is mounted properly.
	Shallow Thread Depth	· Small depth of cut	· Check cutting depth
		· Tool weara	· Check damage to the cutting edge.

Technical Guidance
Basics of Milling

■ Parts of a Milling Cutter



■ Milling Calculation Formulas

● Calculating Cutting Speed

$$v_c = \frac{\pi \times D_c \times n}{1{,}000}$$

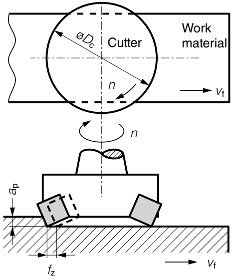
$$n = \frac{1{,}000 \times v_c}{\pi \times D_c}$$

● Calculating Feed Rate

$$v_f = f_z \times z \times n$$

$$f_z = \frac{v_f}{z \times n}$$

v_c : Cutting speed (m/min)
π : ≈ 3.14
D_c: Cutter diameter (mm)
n : Rotational speed (min^{-1})
v_f : Feed rate per minute (mm/min)
f_z : Feed rate per tooth (mm/t)
z : Number of teeth



● Power Requirement

$$P_c = \frac{a_e \times a_p \times v_f \times k_c}{60 \times 10^6 \times \eta} = \frac{Q \times k_c}{60 \times 10^3 \times \eta}$$

● Horsepower Requirement

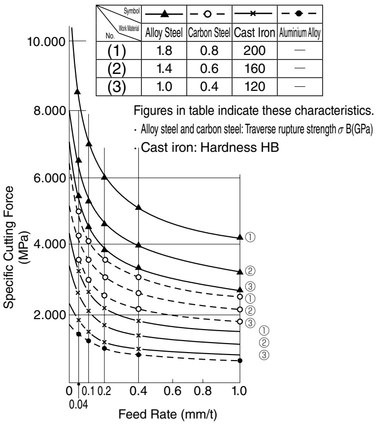
$$H = \frac{P_c}{0.75}$$

● Chip Removal Amount

$$Q = \frac{a_e \times a_p \times v_f}{1{,}000}$$

P_c: Power requirement (kw)
H : Required horsepower (HP)
Q : Chip removal amount (cm^3/min)
a_e: Cutting width (mm)
v_f : Feed rate (mm/min)
a_p: Depth of cut (mm)
k_c: Specific cutting force (MPa)
Rough value: Steel: 2,500 to 3,000MPa
Cast iron: 1,500MPa
Aluminium: 800MPa
η : Machine efficiency (about 0.75)

● Relation Between Feed Rate, Work Material, Specific Cutting Force



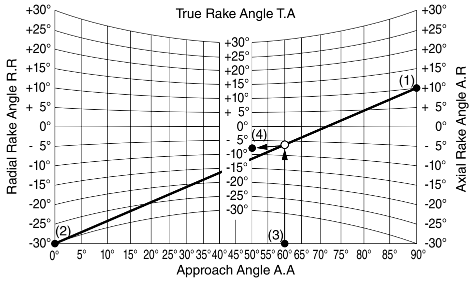
No. \ Work Material (Symbol)	Alloy Steel (—▲—)	Carbon Steel (- ○ -)	Cast Iron (—×—)	Aluminium Alloy (- ● -)
(1)	1.8	0.8	200	—
(2)	1.4	0.6	160	—
(3)	1.0	0.4	120	—

Figures in table indicate these characteristics.
· Alloy steel and carbon steel: Traverse rupture strength σ B(GPa)
· Cast iron: Hardness HB

Functions of the Various Cutting Angles

	Description	Symbol	Function	効 果
(1) (2)	Axial rake angle Radial rake angle	A.R. R.R.	Determines chip removal direction, built-up edge, cutting force	Available in positive to negative (large to small) rake angles; Typical combinations: Positive and Negative, Positive and Positive, Negative and Negative
(3)	Approach angle	A.A.	Determines chip thickness, chip removal direction	Large: Thin chips and small cutting force
(4)	True rake angle	T.A.	Effective rake angle	Positive (Large): Excellent machinability Low cutting edge strength. Negative (Small): Strong cutting edge and easy chip adhesion.
(5)	Cutting edge inclination angle	I .A.	Determines chip control direction	Positive (Large): Excellent chip control and small cutting force. Low cutting edge strength.
(6)	Face cutting edge angle	F.A.	Determines surface roughness	Small: Improved surface roughness.
(7)	Relief angle		Determines edge strength, tool life, chattering	

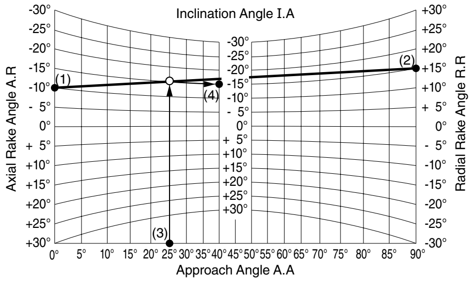
True Rake Angle Chart (T.A)



(Ex.) (1) A.R (Axial rake angle) = +10°
(2) R.R (Radial rake angle) = –30°
(3) A.A (Approach angle) = 60°
-> T.A. (True rake angle) = –8° (4)

<Formula> $\tan T.A=\tan R.R \cdot \cos A.A + \tan A.R \cdot \sin A.A$

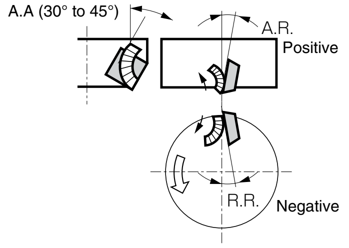
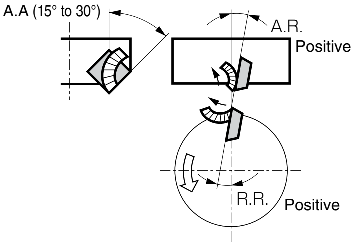
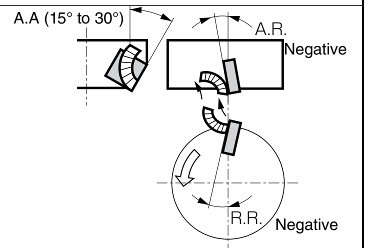
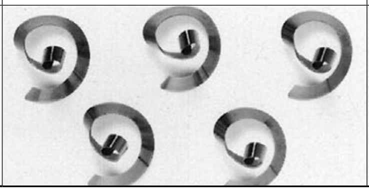
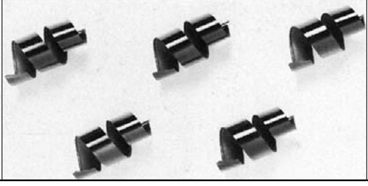
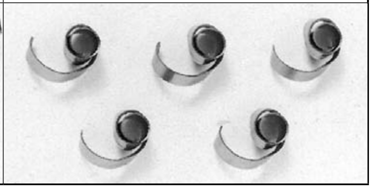
Inclination Angle (I.A) Chart



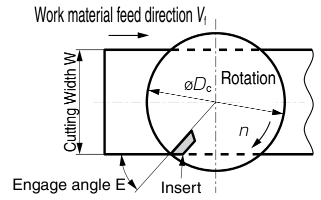
(Ex.) (1) A.R (Axial rake angle) =–10°
(2) R.R (Radial rake angle) =+15°
(3) A.A (Approach angle) = 25°
-> I (Inclination angle) =–15° (4)

<Formula> $\tan I.R=\tan A.R \cdot \cos A.A - \tan R.R \cdot \sin A.A$

Rake Angle Combination

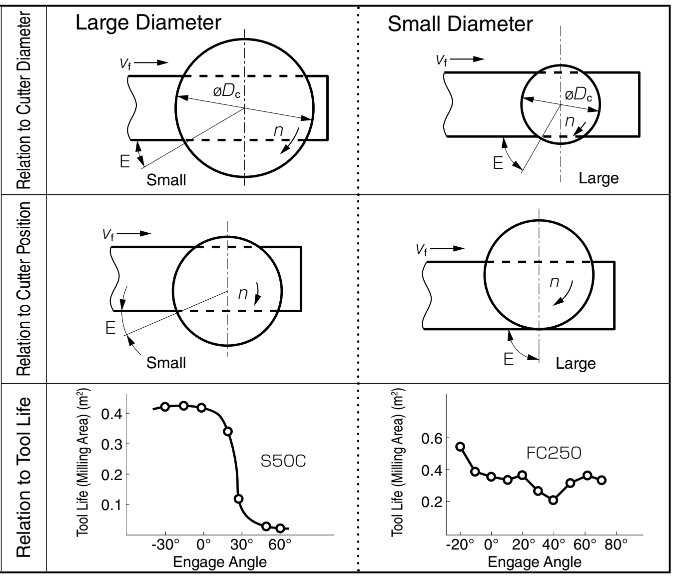
	Negative - Positive Type	Double Positive Type	Double Negative Type
Edge Combination and Chip Removal A.R: Axial rake angle R.R: Radial rake angle A.A: Approach angle : Chip and removal direction : Rotation			
Advantages	Excellent chip removal and cutting action	Good cutting action	Double-sided inserts can be used and higher cutting edge strength
Disadvantages	Only single-sided inserts can be used	Lower cutting edge strength and only single-sided inserts can be used	Dull cutting action
Application	For Steel, Cast iron, Stainless steel, Alloy steel	For general milling of steel and low rigidity work piece	For light milling of cast iron and steel
Series	WGC Type, UFO Type	DPG Type	DNX Type, DGC Type, DNF Type
Chips (Ex.) · Work material: SCM435 · v_c=130m/min f_z=0.23mm/t a_p=3mm			

Relation Between Engage Angle and Tool Life

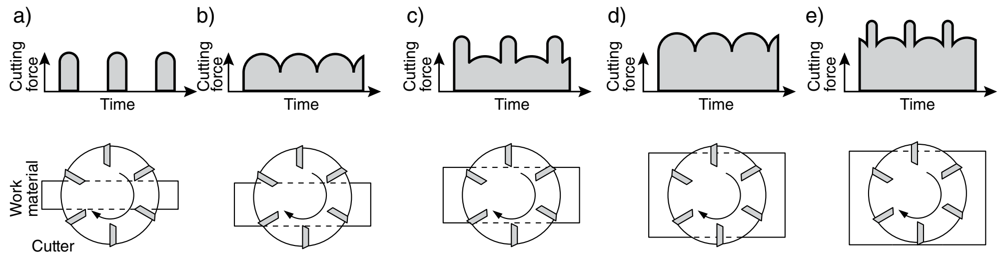


The engage angle denotes the angle at which the full length of the cutting edge comes in contact with the work material, with reference to the feed direction.

- The larger E is, the shorter the tool life.
- To change the value of E:
  1) Increase the cutter size.
  2) Shift the position of the cutter.



● Relation between the number of simultaneously engaged cutting edges and cutting force: Normally, cutting width is considered to be appropriate with 70 to 80% of the cutter diameter engaged as shown in example d). However, this may not apply due to the actual rigidity of the machine or work piece, and machine horsepower.



a) · 0 or 1 edge in contact at same time.

b) · Only 1 edge in contact at any time.

c) · 1 or 2 edges in contact.

d) · 2 edge in contact at any time.

e) · 2 to 3 edges in contact.

To Improve Surface Roughness

(1) Inserts with wiper flat

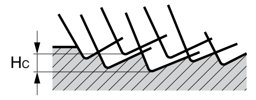
When all the cutting edges have wiper flats, a few teeth are intentionally elevated to play the role of a wiper insert.

- · Insert equipped with straight wiper flat (Face angle: 15' - 1°)
- · Insert equipped with curved wiper flat (Curvature ≈ R500 (example))

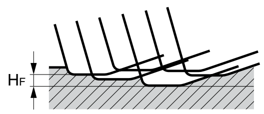
(2) Wiper insert assembling system

A system to protrude one or two inserts (wiper inserts) with a smooth curved edge just a little beyond the other teeth to wipe the milled surface. (Applies to WGC, RF types, etc.)

● Surface roughness without wiper flat

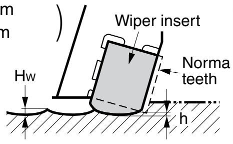


● Surface roughness with straight wiper flat

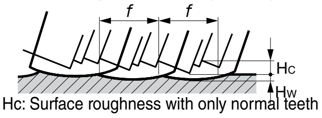


h: Projection value of wiper insert

(Fc: 0.05mm
Al: 0.03mm)

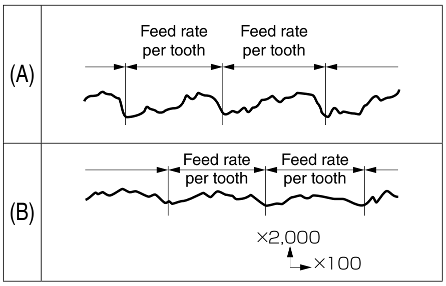


f : Feed rate per revolution (mm/rev)



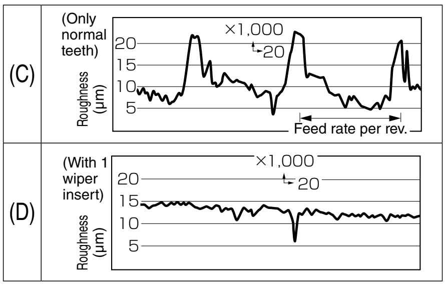
Hc: Surface roughness with only normal teeth
Hw: Surface roughness with wiper insert

● Influence of different face angles on surface finish



- · Work : SCM435
- · Cutter: DPG5160R (Single tooth)
- · v_c = 154m/min
  f_z = 0.234mm/t
  a_p = 2mm
- · Face Cutting Edge Angle
  (A): 28'
  (B): 6'

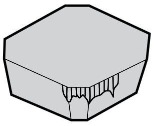
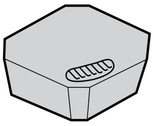
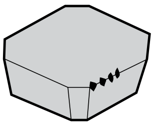
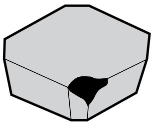
● Effects of having wiper insert (example)



- · Work : FC250
- · Cutter: DPG4100R
- · Insert : SPCH42R
- · Face run-out : 0.015mm
- · Radial run-out: 0.04mm
- · v_c = 105m/min
  f_z = 0.29mm/t
  (1.45 mm/rev)
- (C) : Only normal teeth
- (D) : With 1 wiper insert

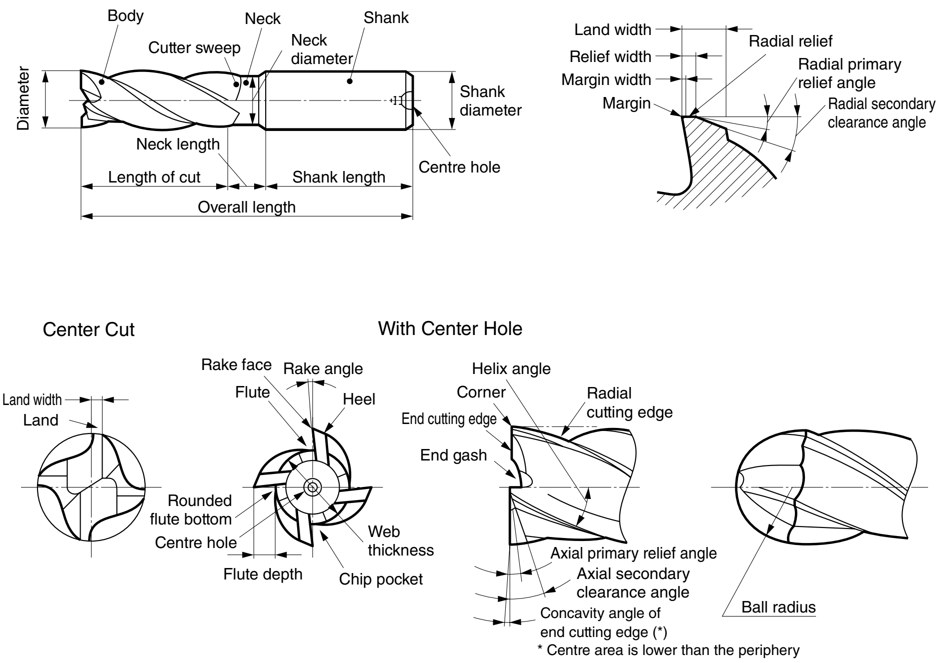
Troubleshooting for Milling

■ Tool Failure and Remedies

<table>
<tr><th colspan="2">Failure</th><th colspan="2">Basic Remedies</th><th>Remedy Examples</th></tr>
<tr><td rowspan="11">Cutting Edge Failure</td><td rowspan="2">Excessive Flank Wear
</td><td>Tool Material</td><td>· Select a more wear resistant grade.
Carbide (P30 → P20 / K20 → K10) → { Coated / Cermet</td><td rowspan="2">· Recommended insert grades
<table>
<tr><th></th><th>Steel</th><th>Cast Iron</th><th>Non-Ferrous Alloy</th></tr>
<tr><td>Finishing</td><td>T250A (Cermet)</td><td>ACK200 (Coated Carbide)
BN700 (SUMIBORON)</td><td>DA1000 (SUMIDIA)</td></tr>
<tr><td>Roughing</td><td>ACP100 (Coated Carbide)</td><td>ACK200 (Coated Carbide)</td><td>DL1000 (Coated Carbide)</td></tr>
</table></td></tr>
<tr><td>Cutting Conditions</td><td>· Reduce cutting speeds. Increase feed rate.</td></tr>
<tr><td rowspan="2">Excessive Crater Wear
</td><td>Tool Material</td><td>· Select a crater-resistant grade.</td><td rowspan="2">· Recommended insert grades
<table>
<tr><th></th><th>Steel</th><th>Cast Iron</th><th>Non-Ferrous Alloy</th></tr>
<tr><td>Finishing</td><td>T250A (Cermet)</td><td>ACK200 (Coated Carbide)</td><td>DA1000 (SUMIDIA)</td></tr>
<tr><td>Roughing</td><td>ACP100 (Coated Carbide)</td><td>ACK200 (Coated Carbide)</td><td>DL1000 (Coated Carbide)</td></tr>
</table></td></tr>
<tr><td>Cutting Conditions</td><td>· Reduce cutting speeds. Reduce depth-of-cut and feed rate.</td></tr>
<tr><td rowspan="3">Chipping
</td><td>Tool Material</td><td>· Change to tougher grades.
P10 → P20 → P30
K01 → K10 → K20</td><td rowspan="3">· Recommended insert grades
<table>
<tr><th></th><th>Steel</th><th>Cast Iron</th></tr>
<tr><td>Finishing</td><td>ACP200 (Coated Carbide)</td><td>ACK200 (Coated Carbide)</td></tr>
<tr><td>Roughing</td><td>ACP300 (Coated Carbide)</td><td>ACK300 (Coated Carbide)</td></tr>
</table>
· Recommended cutter: SEC-WaveMill WGX Type
· Cutting conditions: Refer to H22</td></tr>
<tr><td>Tool Design</td><td>· Select a negative-positive cutter configuration with a large peripheral cutting edge angle (a small approach angle).
· Reinforce the cutting edge (Honing).
· Select a strong edge insert (G → H).</td></tr>
<tr><td>Cutting Conditions</td><td>· Reduce feed rates.</td></tr>
<tr><td rowspan="3">Breakage
</td><td>Tool Material</td><td>· If it is due to excessive low speeds or very low feed rates, select an adhesion resistant grade.
· If it is due to thermal cracking, select a thermal impact resistant grade.</td><td rowspan="3">· Recommended insert grades
<table>
<tr><th></th><th>Steel</th><th>Cast Iron</th></tr>
<tr><td>Roughing</td><td>ACP300 (Coated Carbide)</td><td>ACK300 (Coated Carbide)</td></tr>
</table>
· Recommended cutter: SEC-WaveMill WGX Type
· Insert thickness: 3.18 → 4.76mm
· Insert type: Standard → Strong edge type
· Cutting conditions: Refer to H22</td></tr>
<tr><td>Tool Design</td><td>· Select a negative-positive (or negative) cutter configuration with a large peripheral cutting edge angle (a small approach angle).
· Reinforce the cutting edge (Honing).
· Select a stronger chipbreaker (G → H)
· Increase insert size (Thickness in particular).</td></tr>
<tr><td>Cutting Conditions</td><td>· Select appropriate conditions with regards to the particular application.</td></tr>
<tr><td rowspan="9">Others</td><td rowspan="3">Unsatisfactory Machined Surface Finish</td><td>Tool Material</td><td>· Select an adhesion resistant grade.
Carbide → Cermet</td><td rowspan="3">· Recommended insert grades
<table>
<tr><th colspan="2"></th><th>Steel</th><th>Cast Iron</th><th>Non-Ferrous Alloy</th></tr>
<tr><td>General Purpose</td><td>Cutter
Insert</td><td>WGX type*
ACP200
(Coated Carbide)</td><td>DGC type
ACK200
(Coated Carbide)</td><td>RF type*
H1 (Carbide)
DL1000 (Coated Carbide)</td></tr>
<tr><td>Finishing</td><td>Cutter
Insert</td><td>WGX type
T250A (Cermet)</td><td>FMU type
BN700 (SUMIBORON)</td><td>RF type
DA1000 (SUMIDIA)</td></tr>
</table>
* marked cutters can be fitted with wiper inserts.</td></tr>
<tr><td>Tool Design</td><td>· Improve axial runout of cutting edges.
(Use a cutter with less runout / Attach correct inserts.)
· Use wiper inserts.
· Use special purpose cutters designed for finishing.</td></tr>
<tr><td>Cutting Conditions</td><td>· Increase cutting speeds</td></tr>
<tr><td rowspan="3">Chattering</td><td>Tool Design</td><td>· Select a cutter with sharp cutting edges.
· Use an irregular pitched cutter.</td><td rowspan="3">· Recommended cutter
For Steel: SEC-WaveMill WGX Type
For Cast Iron: SEC-DNX Type
For Non-Ferrous Alloy: High Speed cutter for Aluminium RF type</td></tr>
<tr><td>Cutting Conditions</td><td>· Reduce feed rates.</td></tr>
<tr><td>Others</td><td>· Improve workpiece and cutter clamp rigidity.</td></tr>
<tr><td>Unsatisfactory Chip Control</td><td>Tool Design</td><td>· Select cutter with good chip removal features.
· Reduce number of teeth.
· Enlarge chip pocket.</td><td>· Recommended cutter: SEC-WaveMill WGX Type</td></tr>
<tr><td rowspan="2">Edge Chipping On Workpiece</td><td>Tool Design</td><td>· Increase the peripheral cutting edge angle (decrease the approach angle).
· Select a stronger chipbreaker (G → L).</td><td rowspan="2">· Recommended cutter: SEC-WaveMill WGX Type</td></tr>
<tr><td>Cutting Conditions</td><td>· Reduce feed rates.</td></tr>
<tr><td>Burr On Workpiece</td><td>Tool Design
Cutting Conditions</td><td>· Select a cutter with sharp cutting edges.
· Increase feed rates.
· Select a low-burr insert.</td><td>· Recommended cutter: SEC-WaveMill WGX Type + FG Breaker
DGC Type + FG Breaker</td></tr>
</table>

Technical Guidance
Basics of Endmilling

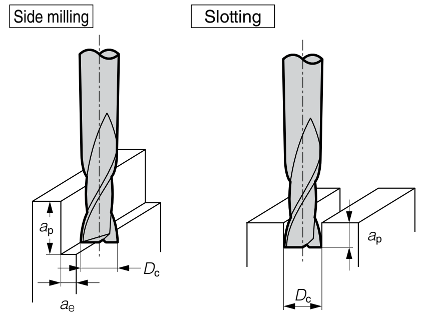
Parts of an Endmill



Calculating Cutting Conditions (Square Endmill)

● Calculating Cutting Speed

$$v_c = \frac{\pi \times D_c \times n}{1,000} \qquad n = \frac{1,000 \times v_c}{\pi \times D_c}$$



● Calculating Feed Rate Per Revolution and Per Tooth

$$v_f = n \times f \qquad f = \frac{v_f}{n}$$

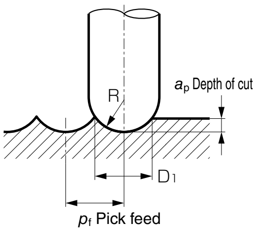
$$v_f = n \times f_z \times z \qquad f_z = \frac{f}{z} = \frac{v_f}{n \times z}$$

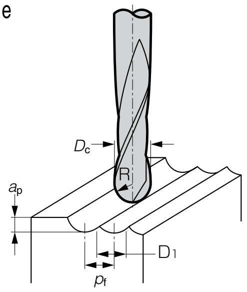
(Ball Endmill)

● Calculating Notch Width (D_1)

$$D_1 = 2 \times \sqrt{2 \times R \times a_p - a_p^2}$$

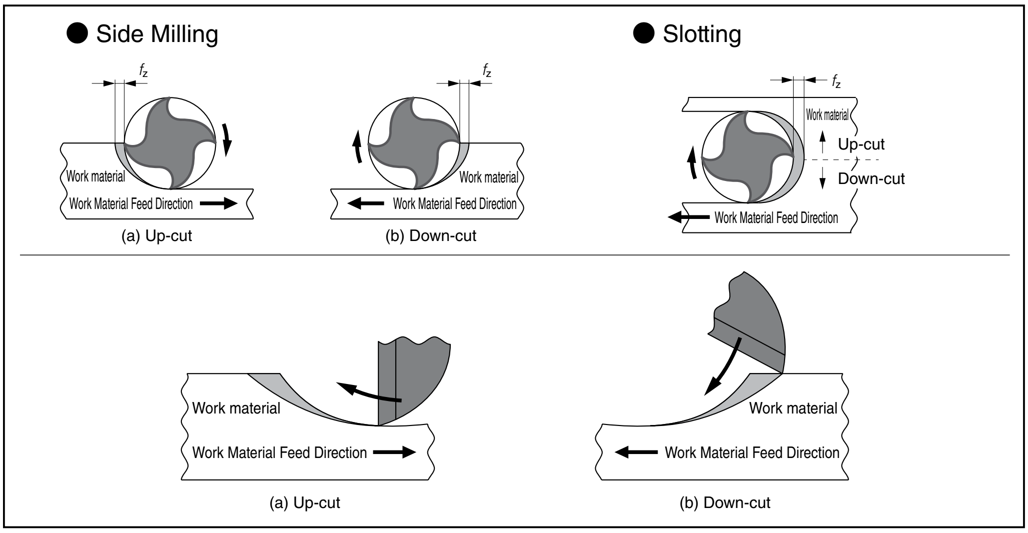
● Cutting speed and feed rate (per revolution and per tooth) are calculated using the same formula as square endmill.



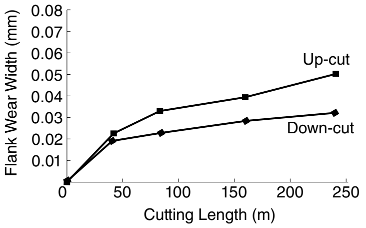


v_c : Cutting speed (m/min)
π : ≈ 3.14
D_c : Endmill diameter (mm)
n : Spindle speed (min^{-1})
v_f : Feed rate (mm/min)
f : Feed rate per revolution (mm/rev)
f_z : Feed rate per tooth (mm/t)
z : Number of teeth
a_p : Axial Depth of Cut (mm)
a_e : Radial Depth of Cut (mm)
R : Ballnose Radius

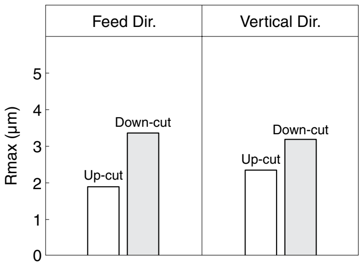
Up-cut and Down-cut



Wear Amount



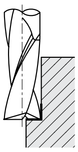
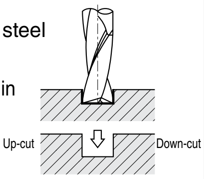
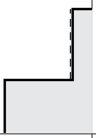
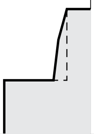
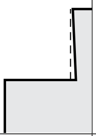
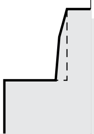
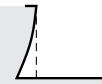
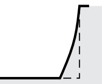
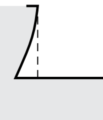
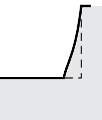
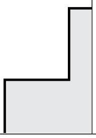
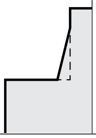
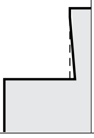
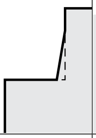
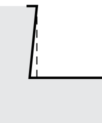
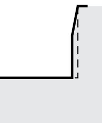
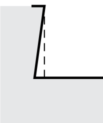
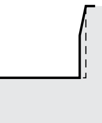
Surface Roughness

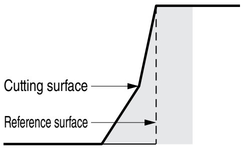


Condition

Work: S50C
Endmill: GSX21000C-2D
(ø10mm, 2 teeth)
Cutting Conditions: v_c=88m/min
(N=2800min^{-1})
v_f=530mm/min
(f_z=0.1mm/t)
a_p=15mm
a_e=0.5mm
Side Milling
Dry,Air

Relation Between Cutting Condition and Deflection

Endmill Specifications			Side Milling				Slotting			
			Work: Pre-hardened steel (40HRC) Cutting Conditions: v_c=25m/min a_p=12mm a_e=0.8mm 				Work: Pre-hardened steel (40HRC) Cutting Conditions: v_c=25m/min a_p=8mm a_e=8mm 			
Cat. No.	Number of Teeth	Helix Angle	Feed rate		Feed rate		Feed rate		Feed rate	
			0.16mm/rev		0.11mm/rev		0.05mm/rev		0.03mm/rev	
			Style		Style		Style		Style	
			Up-cut	Down-cut	Up-cut	Down-cut	Up-cut	Down-cut	Up-cut	Down-cut
GSX20800S-2D	2	30°								
GSX40800S-2D	4	30°								
Results			· The tool tip tends to back off with the down-cut. · 4 teeth offers more rigidity and less backing off.				· The side of the slot tends to cut into the up-cut side toward the bottom of the slot. · 4 teeth offers higher rigidity and less deflection.			



Technical Guidance
Troubleshooting for Endmilling

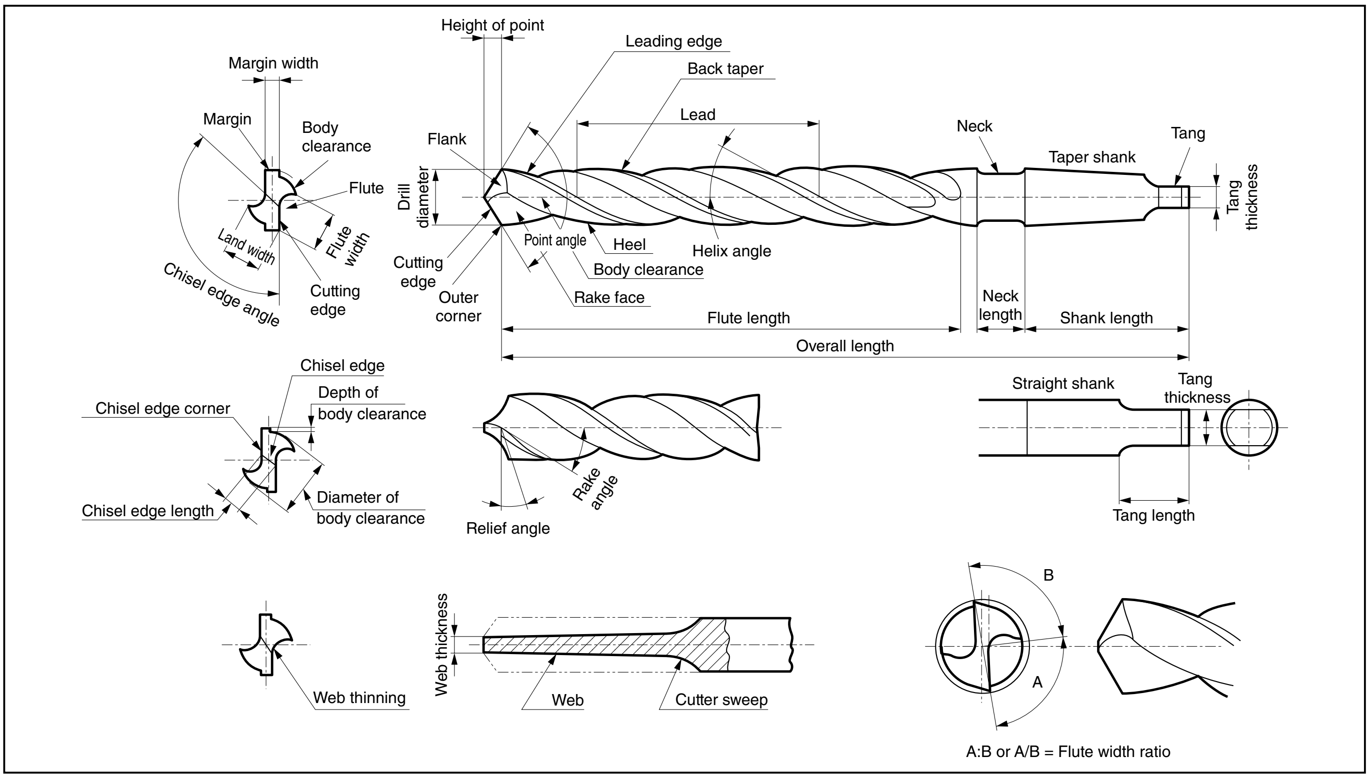
■ Troubleshooting for Endmilling

Failure		Cause		Remedies
Cutting Edge Failure	Excessive Wear	Cutting Conditions	· Cutting speed is too fast · Feed rate is too fast	· Decrease cutting speed and feed rate.
		Tool Shape	· The flank relief angle is too small	· Change to an appropriate flank relief angle
		Tool Material	· Insufficient wear resistance	· Select a substrate with more wear resistance · Use a coated tool
	Chipping	Cutting Conditions	· Feed rate is too fast · Cutting depth is too deep · Tool overhang is too long	· Decrease cutting speed. · Reduce depth of cut · Adjust tool overhang for correct length
		Machine Area	· Work clamps are weak · Tool is not firmly attached	· Clamp the work piece firmly · Make sure the tool is seated in the chuck properly
	Tool Fracture	Cutting Conditions	· Feed rate is too fast · Cutting depth is too deep · Tool overhang is too long · Cutting edge is too long	· Decrease cutting speed. · Reduce depth of cut · Reduce tool overhang as much as possible · Select a tool with a shorter cutting edge
		Tool Shape	· Web thickness is too small	· Change to more appropriate web thickness
Others	Shoulder Deflection	Cutting Conditions	· Feed rate is too fast · Cutting depth is too deep · Tool overhang is too long · Cutting on the down-cut	· Decrease cutting speed. · Reduce depth of cut · Adjust tool overhang for correct length · Change directions to up-cut
		Tool Shape	· Helix angle is large · Web thickness is too thin	· Use a tool with a smaller helix angle · Use a tool with the appropriate web thickness
	Unsatisfactory Machined Surface Finish	Cutting Conditions	· Feed rate is too fast · Packing of chips	· Decrease cutting speed. · Use air blow · Use an insert with a larger relief pocket.
	Chattering	Cutting Conditions	· Cutting speed is too fast · Cutting on the up-cut · Tool overhang is too long	· Decrease the cutting speed · Change directions to down-cut · Adjust tool overhang for correct length
		Tool Shape	· Rake angle is large	· Use a tool with an appropriate rake angle
		Machine Area	· Work clamps are weak · Tool is not firmly attached	· Clamp the work piece firmly · Make sure the tool is seated in the chuck properly
	Packing of Chips	Cutting Conditions	· Feed rate is too fast · Cutting depth is too deep	· Decrease cutting speed. · Reduce depth of cut
		Tool Shape	· Too many teeth · Packing of chips	· Reduce number of teeth · Use air blow

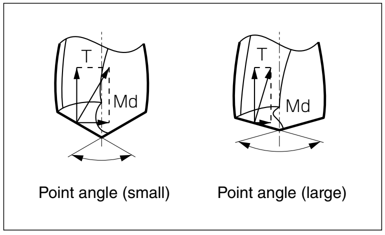
Technical Guidance
Basics of Drilling

Drilling Edition

■ Parts of a Drill

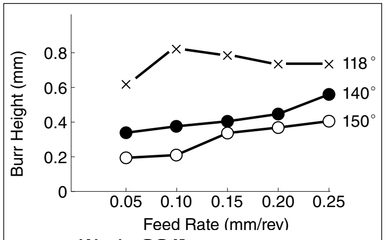


● Point Angle and Force



When point angle is large, thrust becomes large but torque becomes small.

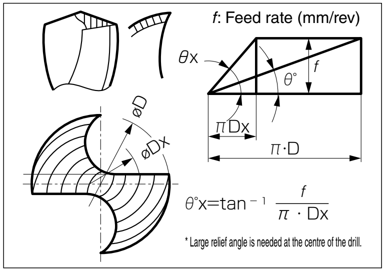
● Point Angle and Burr



Work: SS41
Cutting Speed v_c=50m/min

When point angle is large, burr height becomes low.

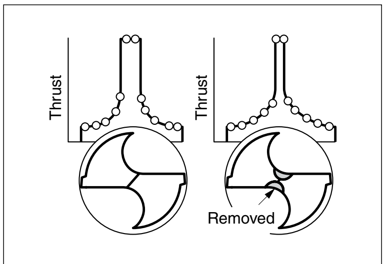
● Minimum Requirement Relief Angle



$$\theta°x = \tan^{-1}\frac{f}{\pi \cdot Dx}$$

* Large relief angle is needed at the centre of the drill.

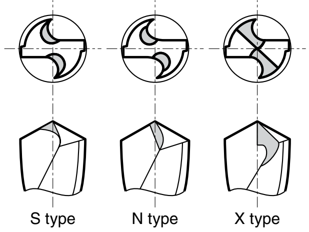
● Web Thickness and Thrust



Web thinning decreases the thrust concentrated at the chisel edge, makes the drill edge sharp, and improves chip control.

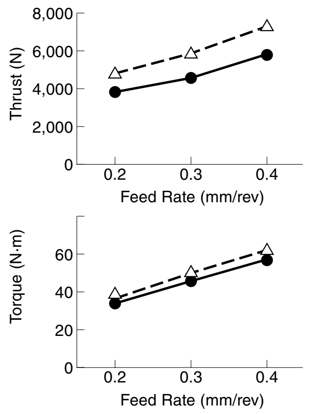
● Decrease Chisel Width by Thinning

Typical types of thinning



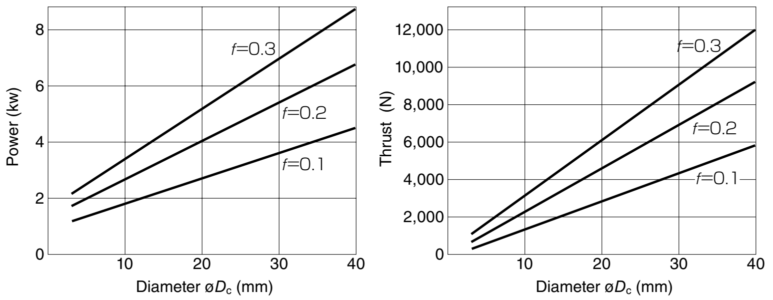
S type: Standard type used generally.
N type: Suitable for thin web drills.
X type: For hard-to-cut material or deep hole drilling. Drill starts easier.

● Relation Between Edge Treatment and Cutting Force



Drill : Multi-drill KDS215MAK
Width : ● → 0.15mm △ → 0.23mm
Work : S50C (230HB)
Cutting Conditions : v_c=50m/min, Wet

Reference of Power Requirement and Thrust



f: Feed rate (mm/rev)

Work material: S48C (220HB)

Cutting Condition Selection

- Control Cutting Force for Low Rigid Machine

The following table shows the relation between edge treatment width and cutting force. If a problem caused by cutting force occurs, reduce either the feed rate or the edge treatment width.

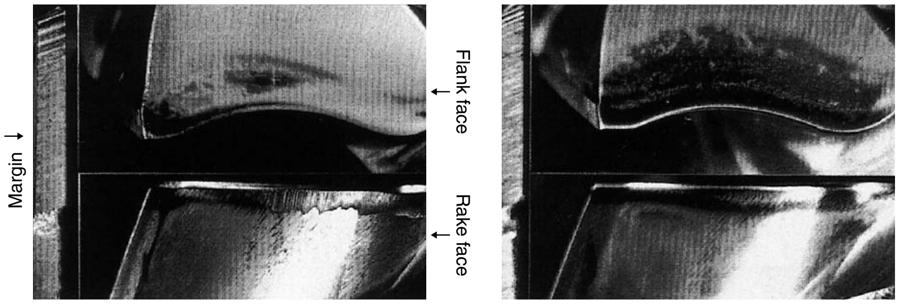
Cutting Conditions		Edge Treatment Width			
		0.15mm		0.05mm	
v_c(m/min)	*f*(mm/rev)	Torque (N·m)	Thrust (N)	Torque (N·m)	Thrust (N)
40	0.38	12.8	2,820	12.0	2,520
50	0.30	10.8	2,520	9.4	1,920
60	0.25	9.2	2,320	7.6	1,640
60	0.15	6.4	1,640	5.2	1,100

Drill : ø10mm
Work : S50C 230HB

- High Speed Machining Recommendation

If there is surplus capacity with enough machine power and rigidity under normal cutting conditions, you can ensure sufficient tool life even with high-speed machining. In high-speed machining, however, a sufficient amount of coolant must be supplied.

Wear Example

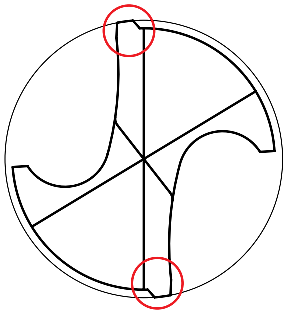


v_c=60m/min　　v_c=120m/min

Work : S50C (230HB)
Cond.: *f* = 0.3mm/rev
H = 50mm
Life : 600holes (Cutting length: 30m)

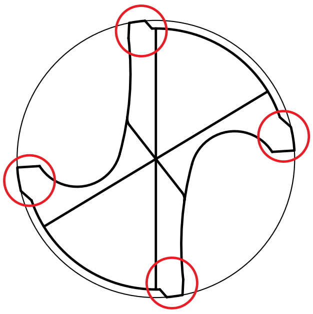
Explanation of Margins (Difference between single and double margins)

- Single Margin (2 guides: circled parts)



- Shape used on most drills

- Double Margin (4 guides: circled parts)



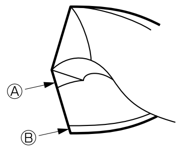
- 4-point guiding reduces hole bending and undulation for improved stability and accuracy during deep hole drilling.

Technical Guidance
Basics of Drilling

Drilling Edition

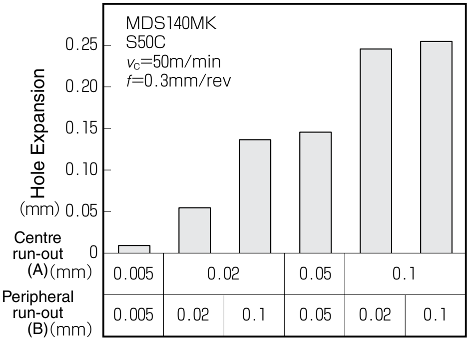
Run-out Accuracy

For the run-out accuracy of web-thinned drills, not only the difference in lip height (B) but also the run-out after thinning (A) is important.



(A): The run-out accuracy of thinning point
(B): The difference of the lip height

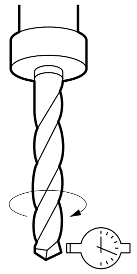
(Units: mm)



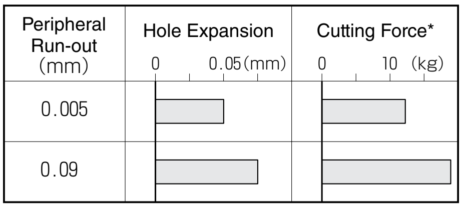
Peripheral Run-out Accuracy when Tool Rotates

● When the tool rotates

The peripheral run-out accuracy of the drill mounted on the spindle should be controlled within 0.03mm. If the run-out exceeds the limit, the drilled hole will also become large causing an increase in the horizontal cutting force, which may result in drill breakage.



Run-out: within 0.03mm



* Horizontal cutting force.

Drill: MDS120MK Work material: S50C (230HB)

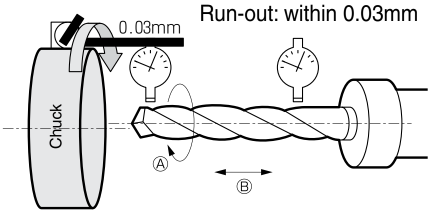
Cutting Conditions: v_c=50m/min, f=0.3mm/rev, H=38mm

Water soluble coolant

● When the work material rotates

Not only the peripheral run-out at the drill edge (A) but also the concentricity at (B) should be controlled within 0.03mm.

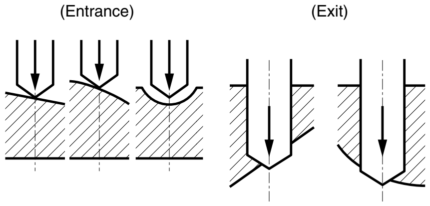
Run-out: within 0.03mm



Influence of Work Material Surface

● Work material with slanted or uneven surface

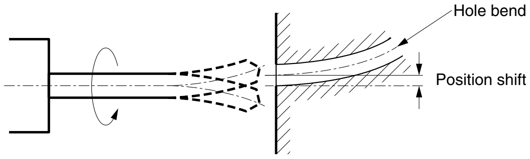
If the surface of the hole entrance or exit is slanted or uneven, decrease the feed rate to 1/3 to 1/2 of the recommended cutting condition.



How to Use a Long Drill

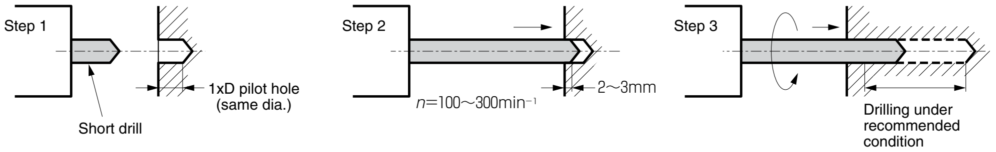
● Problem

When using a long drill (e.g. XHGS type and XHT type), DAK type drill, or SMDH-D type drill at high rotation speeds, the run-out of the drill tip may cause a deviation of the entry point as shown on the right, bending the drill hole and resulting in drill breakage.

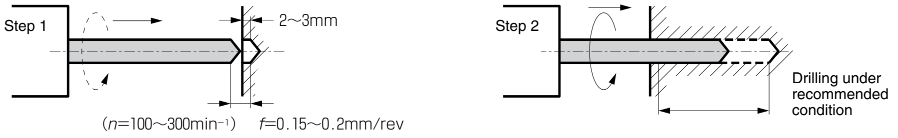


● Remedies

Method 1



Method 2 * Low rotational speed minimises centrifugal forces and prevents drill bending.



Technical Guidance
MultiDrill Usage Guidance

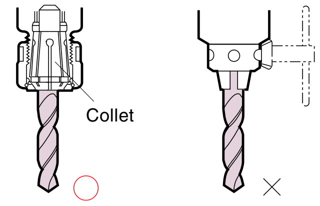
Drill Maintenance

(1) Collet Selection and Maintenance

- Ensure proper chucking of drills to prevent vibration. Collet chucks (thrust bearing type) provide strong and secure grip force.

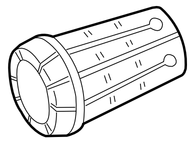
(Drill chucks and keyless chucks are not suitable for MultiDrills as they have a weaker grip force.)

- When replacing drills, regularly remove cutting debris inside the collet by cleaning the collet and the spindle with oil. Repair marks with an oilstone.



Collet Chuck

Drill Chuck

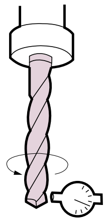


If there are marks, repair with an oilstone or change to a new one.

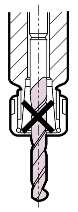
(2) Drill Installation

- The peripheral run-out of the drill mounted on the spindle should be controlled within 0.03mm.
- Do not chuck on the drill flute.

(If drill flute inside the holder, chip removal will be obstructed thus causing damage to the drills.)



Edge run-out to be within 0.03mm.



Do not grip on the drill flute.

Using Cutting Oil

(1) Choosing of Cutting Oil

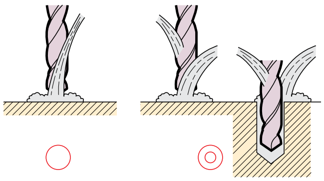
- If cutting speed is more than 40m/min, cutting oil JISW1 type 2 is recommended for its good cooling effect & chip removal ability as it is highly soluble.
- If cutting speed is below 40m/min and longer tool life is a priority, non-water cutting oil JISA1 type 2, an activated sulphuric chloride oil, is recommended for its lubricity.

* Non-water soluble oil may be flammable. To prevent fire, a substantial amount of oil should be used to cool the component so that smoke or heat will not be generated.

(2) Supply of Coolant

- If using an external supply of coolant, fill a substantial amount from the inlet. Oil pressure range: 0.3 to 0.5 MPa, oil level range: 3 to 10 /min.
- If using an internal supply of coolant (Ex: HK Type) for holes For holes ø4 or smaller, the oil pressure must be at least 1.5MPa to ensure a sufficient supply of coolant.
  holes ø6 or larger: 0.5 to 1.0 MPa for hole depths below 3 times the drill diameter, and 1 to 2 MPa or more for hole depths more than 3 times the diameter.

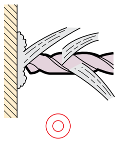
- External supply of coolant
  - Vertical drilling



Use high pressure at entrance

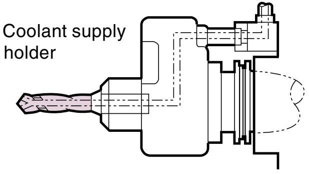
Easy usage

- Horizontal drilling

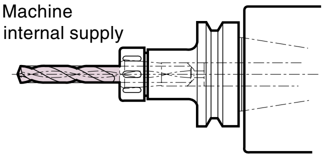


Use high pressure at entrance

- Internal supply of coolant
  - Coolant supply holder



- Machine internal supply

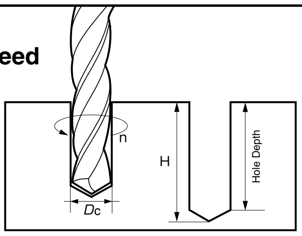


Calculation of Power Consumption and Thrust

● Calculating Cutting Speed

$$v_c = \frac{\pi \text{ x } D_c \text{ x } n}{1{,}000}$$

$$n = \frac{1{,}000 \text{ x } v_c}{\pi \text{ x } D_c}$$



● Calculating Feed Rate Per Revolution and Per Tooth

$$v_f = n \text{ x } f \qquad f = \frac{v_f}{n}$$

● Calculation of Cutting Time

$$T = \frac{H}{V_f}$$

v_c : Cutting Speed (m/min)
π : Circular Constant ≈ 3.14
D_c : Drill Diameter (mm)
n : Spindle Speeds (min^{-1})
v_f : Feed Rate (mm/min)
f : Feed Rate per Revolution (mm/rev)
H : Drilling Depth (mm)
T : Cutting Time (min)
HB : Brinell Hardness

● Calculation of Power Consumption and Thrust

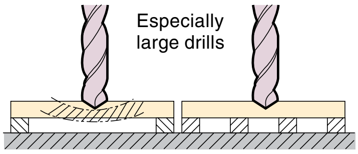
$$\text{Power Consumption (kW)} = \text{HB} \times D_c^{0.68} \times v_c^{1.27} \times f^{0.59} / 36{,}000$$

$$\text{Thrust (N)} = 0.24 \times \text{HB} \times D_c^{0.95} \times f^{0.61} \times 9.8$$

* When designing the machine, an allowance of 1.6 x Power Consumption and 1.4 x Thrust should be given.

Work Clamping

High thrust forces occur during high-efficiency drilling. Therefore, the workpiece must be supported to prevent fracture caused by bending. Also, large torques and horizontal cutting forces occur. Therefore, the workpiece must be clamped firmly enough to withstand them.



Bending ×

Fracture ○

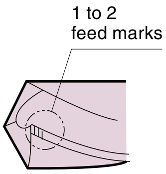
Drill Regrinding

- When to regrind
  When one or two feed marks (lines) appear on the margin, when corner wear reaches the margin width, or when small chipping occurs, it indicates that the drill needs to be sent for regrinding.

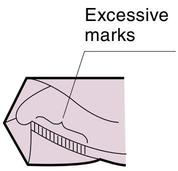
- How and where to regrind
  We recommend applying regrinding and recoating. Recoating is recommended to prevent shortening of tool life. Note, ask us or an approved vendor to recoat with our proprietary coating.

- Regrinding on your own
  Customers regrinding their own drills can obtain MultiDrill Regrinding Instructions from us directly or your vendor.

- Tool life determinant



○ Appropriate tool life



× Over-used

Technical Guidance
Tool Failure and Remedies
Drilling Edition

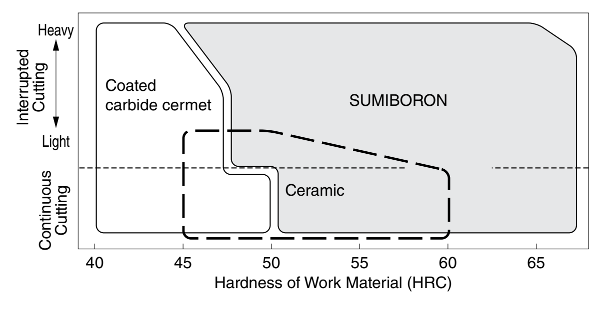
■ Troubleshooting for Drilling

Failure		Cause	Basic Remedies	Remedy Examples
Drill Failure	Excessive Wear on Cutting Edge	· Inappropriate cutting conditions.	· Use higher cutting speeds.	· Refer to the upper limit of the recommended conditions listed the Igetalloy Cutting Tools Catalogue.
			· Increase feed rates.	· Refer to the upper limit of the recommended conditions listed the Igetalloy Cutting Tools Catalogue.
		· Unsuitable cutting fluid.	· Reduce pressure if using internal coolant.	· 1.5 MPa or below (external coolant if hole depth is L/D = 2 or less).
			· Use cutting fluid with more lubricity.	· Use JIS A1 grade No. 1 or its equivalent.
	Chisel Point Chipping	· Off-centre starts.	· Reduce feed rate at entry point.	· f=0.08 to 0.12mm/rev
			· Pre-processing to ensure flat contact surface.	· Use endmill to produce flat surface.
		· Equipment and/or work material lacks rigidity.	· Change cutting conditions to reduce resistance.	· Increase v_c and decrease f (reduce thrust).
			· Improve work material clamp rigidity.	
		· Cutting edge is too weak.	· Increase size of chisel width.	· Set chisel width from 0.1 to 0.2 mm.
			· Increase amount of honing on cutting edge.	· Make thinning section of central area 1.5x current width.
	Chipping On Peripheral Cutting Edge	· Inappropriate drilling conditions.	· Decrease the cutting speed.	· Refer to the lower limit of recommended conditions listed in the Igetalloy Cutting Tools Catalogue.
			· Reduce feed rate.	· Refer to the lower limit of recommended conditions listed in the Igetalloy Cutting Tools Catalogue.
		· Unsuitable cutting fluid.	· Use cutting fluid with more lubricity.	· Use JIS A1 grade No. 1 or its equivalent.
		· Equipment and/or work material lacks rigidity.	· Improve work material clamp rigidity.	
		· Cutting edge is too weak.	· Increase amount of honing on cutting edge.	· Make peripheral cutting edge 1.5x current width.
			· Reduce the amount of front flank angle.	· Reduce the amount of front flank angle by 2° to 3°.
		· Peripheral cutting edge starts cutting first	· Increase margin width (W margin).	· Increase margin width by 2 to 3x current width.
		· Cutting interrupted when drilling through workpiece.	· Reduce feed rate.	· Refer to the lower limit of recommended conditions listed in the Igetalloy Cutting Tools Catalogue.
			· Increase amount of honing on cutting edge.	· Make peripheral cutting edge 1.5x current width.
			· Reduce the amount of front flank angle.	· Reduce the amount of front flank angle by 2° to 3°.
	Margin Wear	· Inappropriate drilling conditions.	· Decrease the cutting speed.	· Refer to the lower limit of recommended conditions listed in the Igetalloy Cutting Tools Catalogue.
		· Unsuitable cutting fluid.	· Use cutting fluid with more lubricity.	· Use JIS A1 grade No. 1 or its equivalent.
			· Increase coolant supply.	· If using external coolant, change to internal coolant supply.
		· Latent margin wear.	· Early regrind to ensure adequate back taper.	· Regrind margin damage to 1 mm or less.
		· Unsuitable tool design.	· Increase amount of back taper.	· Make back taper 0.5/100.
			· Reduce margin width.	· Decrease margin width to two-thirds of current width.
	Drill Breakage	· Chip build-up.	· Use optimal cutting conditions and tools.	· Refer to the table of recommended conditions in the Igetalloy Cutting Tools Catalogue.
			· Increase coolant supply.	· If using external coolant, change to internal coolant supply.
		· Collet clamp lacks strength.	· Use collet with strong grip force.	· Replace collet chuck if damaged. · Use collet holder one size bigger.
		· Equipment and/or work material lacks rigidity.	· Improve work material clamp rigidity.	
Unsatisfactory Hole Accuracy	Oversized Holes	· Off-centre starts.	· Reduce feed rate at entry point.	· f=0.08 to 0.12mm/rev
			· Decrease the cutting speed.	· Refer to the lower limit of recommended conditions listed in the Igetalloy Cutting Tools Catalogue.
			· Pre-processing to ensure flat contact surface.	· Use endmill to produce flat surface.
		· Drill bit lacks rigidity.	· Use optimal drill type for hole depth.	· Refer to the Igetalloy Cutting Tools Catalogue.
			· Improve overall rigidity of drill.	· Large web with comparatively small flute.
		· Drill bit has run-out	· Improve drill clamp precision.	· Replace collet chuck if damaged.
			· Improve drill clamp rigidity.	· Use collet holder one size bigger.
		· Equipment and/or work material lacks rigidity.	· Improve work material clamp rigidity.	
	Poor Surface Finish	· Inappropriate cutting conditions.	· Increase cutting speeds.	· Refer to the upper limit of the recommended conditions listed the Igetalloy Cutting Tools Catalogue.
			· Reduce feed rate.	· Refer to the lower limit of recommended conditions listed in the Igetalloy Cutting Tools Catalogue.
		· Unsuitable cutting fluid.	· Use cutting fluid with more lubricity.	· Use JIS A1 grade No. 1 or its equivalent.
	Holes Are Not Straight	· Off-centre starts.	· Increase feed rates.	· Refer to the upper limit of the recommended conditions listed the Igetalloy Cutting Tools Catalogue.
		· Drill is not mounted properly.	· Improve drill clamp precision.	· Replace collet chuck if damaged.
			· Improve drill clamp rigidity.	· Use collet holder one size bigger.
		· Equipment and/or work material lacks rigidity.	· Improve work material clamp rigidity.	
			· Select a double margin tool.	· Refer to the Igetalloy Cutting Tools Catalogue.
Unsatisfactory Chip Control	Packing Of Chips	· Inappropriate drilling conditions.	· Increase cutting speeds.	· Refer to the upper limit of the recommended conditions listed the Igetalloy Cutting Tools Catalogue.
			· Increase feed rates.	· Refer to the upper limit of the recommended conditions listed the Igetalloy Cutting Tools Catalogue.
		· Poor chip evacuation.	· Increase the amount or pressure of coolant applied if using internal coolant.	
	Long Stringy Chips	· Inappropriate drilling conditions.	· Increase feed rates.	· Refer to the upper limit of the recommended conditions listed the Igetalloy Cutting Tools Catalogue.
			· Increase cutting speeds.	· Refer to the upper limit of the recommended conditions listed the Igetalloy Cutting Tools Catalogue.
		· Cooling effect is too strong.	· Reduce pressure if using internal coolant.	· Keep pressure 1.5 MPa or lower if using internal coolant.
		· Dull cutting edge.	· Reduce amount of edge honing.	· Reduce to around two-thirds of current width.

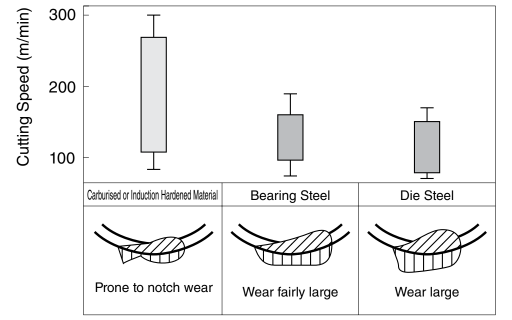
Technical Guidance

Hardened Steel Machining with SUMIBORON

■ Application Map of the Various Tool Materials

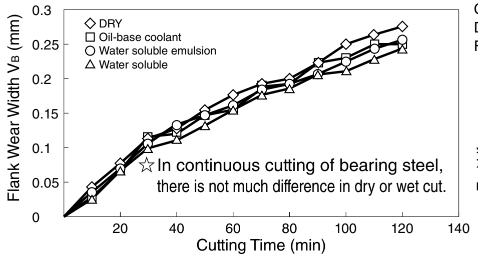


■ Work Materials and their Cutting Speed Recommendations



■ Influence of Coolant on Tool Life

● Continuous Cutting

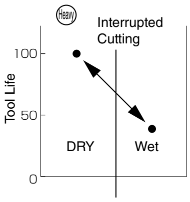


☆In continuous cutting of bearing steel, there is not much difference in dry or wet cut.

Work: SUJ2(58 to 62HRC)
Condition: TPGN160304
v_c=100m/min a_p=0.15mm f =0.1mm/rev Continuous cutting

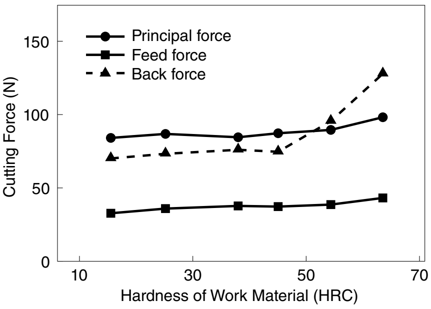
● Interrupted Cutting

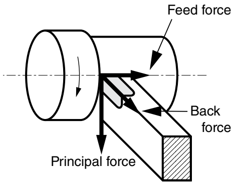
SKD11–4U Slotting
Cutting speed v_c=100m/min.
D.O.C a_p=0.2mm
Feed rate f =0.1mm/rev



For continuous cutting, the influence of coolant on tool life is minimal. However, for interrupted cutting, coolant will shorten the tool life because of thermal cracking.

■ Relation Between Work Material Hardness and Cutting Force

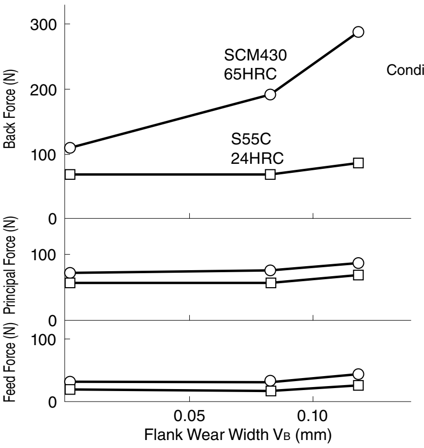




Work : SK 3
Conditions: C/speed v_c=120m/min.
D.O.C a_p=0.2mm.
Feed rate f =0.1mm/rev

Back force increases substantially for harder work materials.

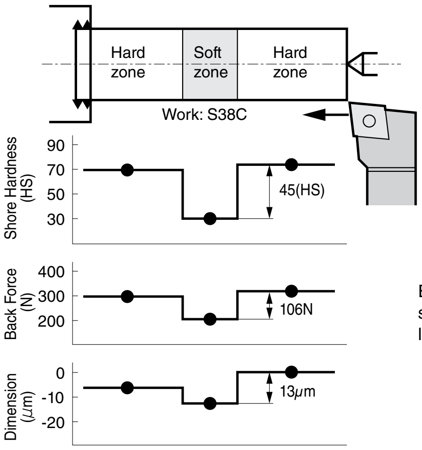
■ Relation Between Flank Wear and Cutting Force



Condition: C/speed v_c=80m/min
D.O.C a_p=0.15mm
Feed rate f =0.1mm/rev

For hardened steel machining, back force increases substantially due to the expansion of flank wear.

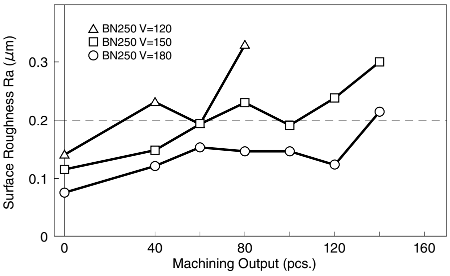
■ Influence of Work Material Hardness on Cutting Force and Accuracy



Cutting Speed : v_c=120m/min
Depth of Cut : a_p=0.5mm
Feed rate : f =0.3mm/rev Dry

External dimension at the soft zone is smaller due to lower cutting forces.

■ Relation Between Cutting Speed and Surface Roughness

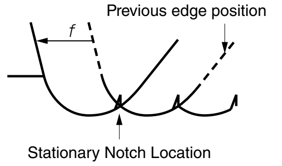
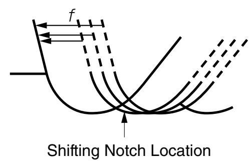
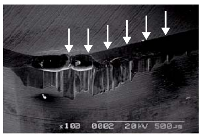


Work: SCM420H
58 to 62HRC
Holder: MTXNR2525
Insert: NU–TNMA160408

Conditions:
v_c= 120, 150, 180 m/min
f = 0.045mm/rev
a_p= 0.15mm
Wet

At high cutting speeds, surface roughness is more stable.

■ Improvement of Surface Roughness by Altering the Feed Rate

Constant Feed Rate	Variable Feed Rate
Previous edge position  f Stationary Notch Location	 f Shifting Notch Location
	

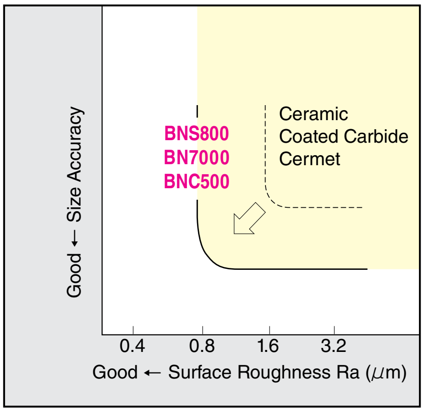
☆ Varying the feed rate spreads the notch location over a larger area.
→ Surface finish improves and notch wear decreases.

Technical Guidance

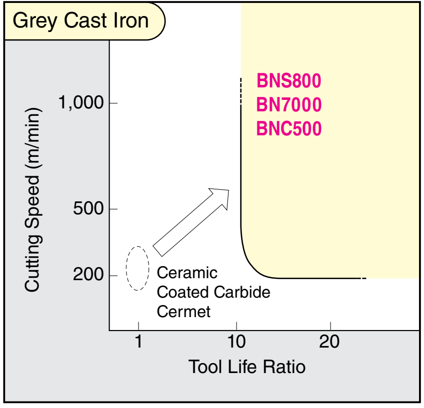
High Speed Machining of Cast Iron withs SUMIBORON

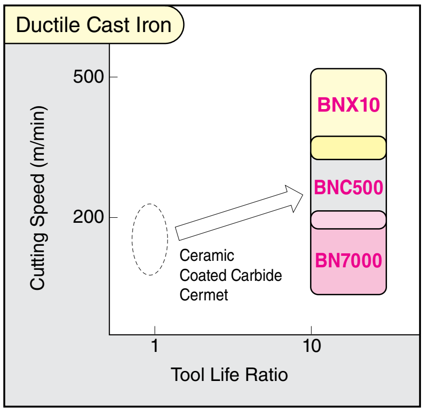
■ Advantages of Using SUMIBORON for Cast Iron Machining

● Higher Accuracy



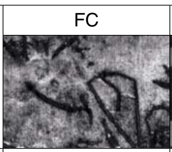
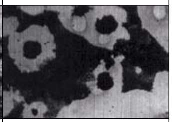
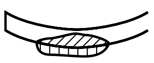
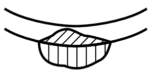
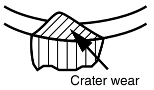
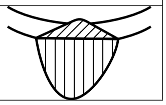
● Longer Tool Life at Higher Cutting Speeds



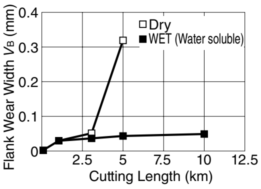


■ Turning

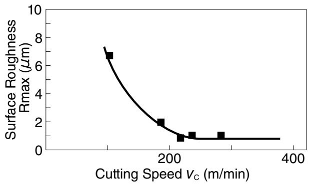
● Cast Iron Structure and Wear Shape Examples

		FC	FCD
Structure			
	Matrix	Pearlite	Pearlite + Ferrite
Tool Wear Shape	Wet		
	Dry	 Crater wear	

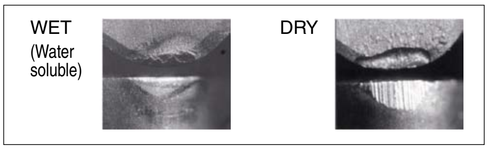
(v_c = 200 to 500m/min)



Work : FC250 Continuous cutting
Tool material : BN500
Tool Shape : SNGN120408
Conditions : v_c=450m/min
a_p=0.25mm
f =0.15mm/rev
Dry&Wet
(water soluble)



Machine : N/C lathe
Work : FC250 200HB
Holder : MTJNP2525
Tool material : BN500
Tool Shape : TNMA160408
Conditions : v_c=110 to 280m/min
f =0.1mm/rev
a_p=0.1mm
Wet

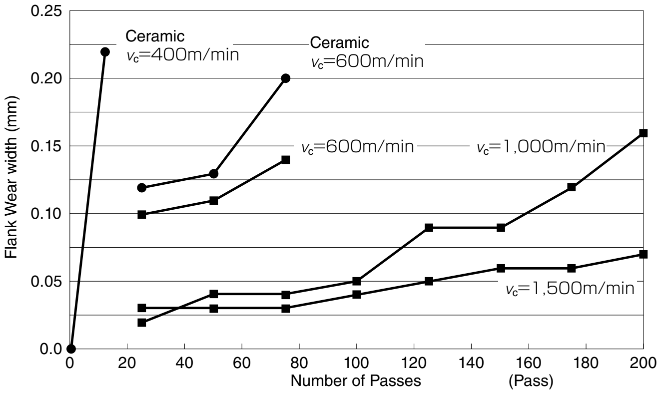


For machining cast iron with SUMIBORON, cutting speeds (v_c) should be 200m/min and above. WET cutting is recommended.

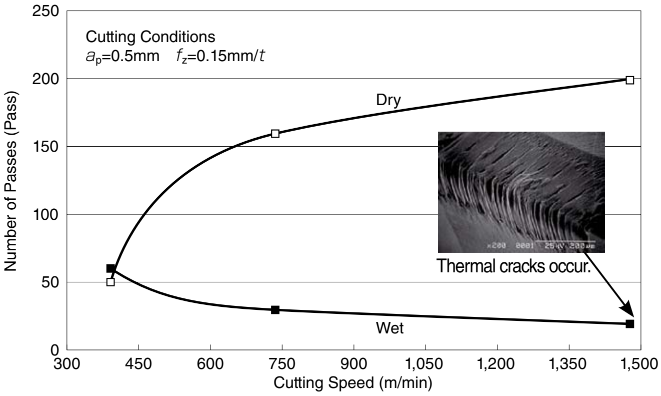
■ Milling

SUMIBORON BN Finish Mill EASY

- High speed machining v_c=2,000m/min
- Surface Roughness 3.2Rz (1.0Ra)
- Running cost is reduced because of economical insert.
- Easy insert setting with the aid of a setting gauge.
- Employs safe, anti-centrifugal force construction for high-speed conditions.



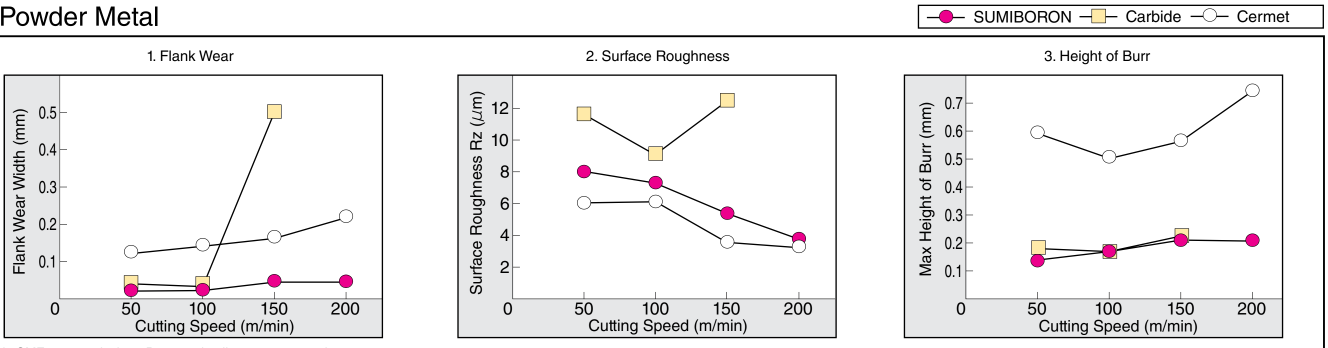
(Conditions)
· Work: FC250 · Condition: a_p =0.5mm f_z =0.1mm/t Dry
· Tool material: BN7000



Dry cutting is recommended for high speed milling of cast iron with SUMIBORON.

Technical Guidance
Machining Hard-to-cut Materials with SUMIBORON

Powder Metal



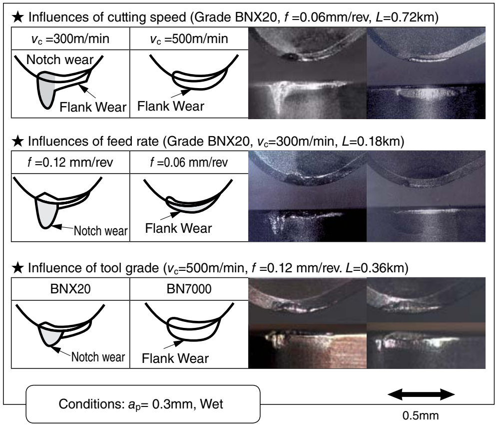
Work: SMF4040 equivalent, Process details: ø80-ø100mm heavy interrupted facing with grooves and drilled holes. (After 40 passes)
Cutting Conditions: f=0.1mm/rev, a_p=0.1mm, Wet
Insert: TNGA160404

For general powder metal components, carbide and cermet grades can perform up to v_c=100m/min. However, around v_c=120m/min SUMIBORON, on the other hand, exhibits stability and superior wear resistance, burr prevention and surface roughness especially at high speeds.

Heat Resistive Alloy

Ni Based Alloy

Typical tool damage of CBN tool when cutting Inconel 718

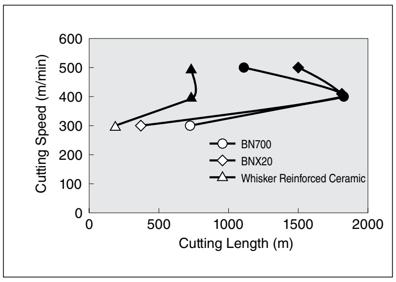

★ Influences of cutting speed (Grade BNX20, f =0.06mm/rev, L=0.72km)

★ Influences of feed rate (Grade BNX20, v_c=300m/min, L=0.18km)

★ Influence of tool grade (v_c=500m/min, f =0.12 mm/rev. L=0.36km)

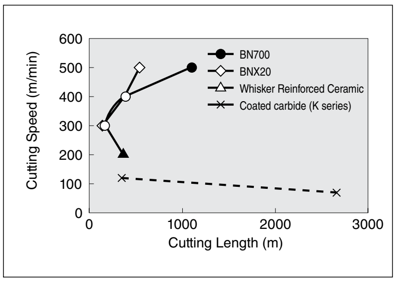
Conditions: a_p= 0.3mm, Wet

Conditions: f=0.06mm/rev, a_p=0.3mm, Wet



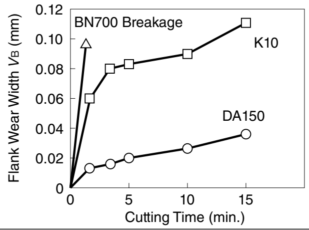
Tool life criteria
Notch wear = 0.25mm (○)
Or flank wear = 0.25mm
BNX20 is recommended for high speed and low feed rates
BN700 is recommended for cutting speeds below v_c=240m/min.

Conditions: f=0.12mm/rev, a_p=0.3mm, Wet

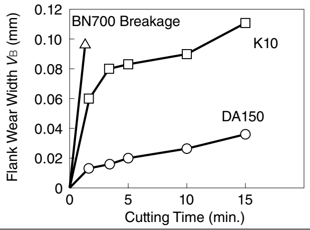


Tool life criteria
Notch wear = 0.25mm (○)
Or flank wear = 0.25mm
BN700 is recommended for cutting at high feed rates.
(Over f =0.1mm/rev)

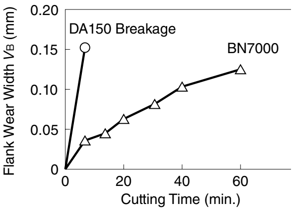
Ti Based Alloy



Work: Ti–6A–4V
Insert: NF–DNMX120404
Cutting Conditions: v_c =100m/min. a_p =0.1mm f =0.05mm/rev Wet
☆ SUMIDIA positive type inserts are extremely good for Ti Alloy, due to high cutting edge strength and high wear resistance.



Work: Ti–6A–4V
Insert: NF–DNMX120404
Cutting Conditions: v_c =100m/min. a_p =0.1mm f =0.05mm/rev Wet
☆ SUMIDIA positive type inserts are extremely good for Ti alloy, due to high cutting edge strength and high wear resistance.

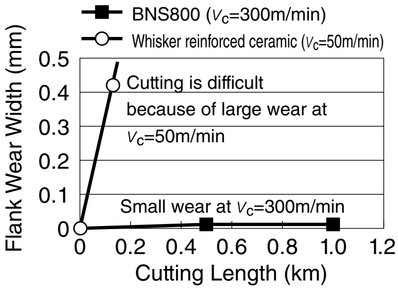


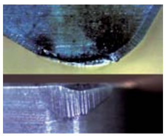
Work: Ti–6Al–4V
Tool: DNMA150412
Cutting Conditions: v_c =120m/min. a_p =0.3mm f =0.25mm/rev Wet
☆ Highly fracture resistant BN7000 negative insert is suitable for high-efficiency machining with a large depth-of-cut and a high feed rate.

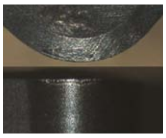
Hard Facing Alloys

Work: Colmonoy No.6
(NiCr-based self-fluxing alloy)

Insert : SNGN0 90308
Cutting Conditions : v_c = 50,300m/min
f = 0.1mm/rev
a_p = 0.2mm
Dry

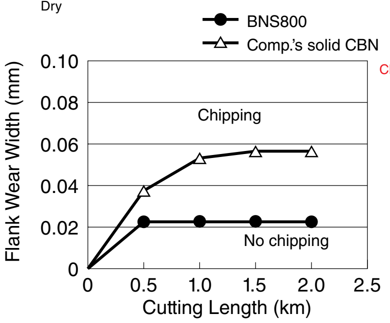


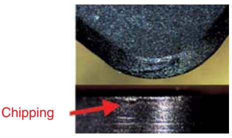

Whisker Reinforced Ceramic
(v_c =50m/min, After 10m of cutting)


BNS800
(v_c =300m/min, After 2km of cutting)

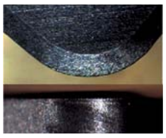
Work: Stellite SF-20
(Co-based self-fluxing alloy)

Insert : SNGN090308
Cutting Conditions : v_c = 50m/min
f = 0.1mm/rev
a_p = 0.2mm
Dry





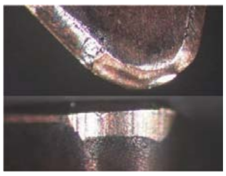
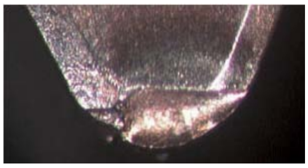
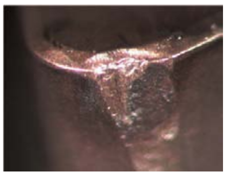
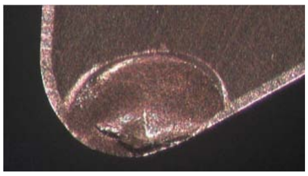
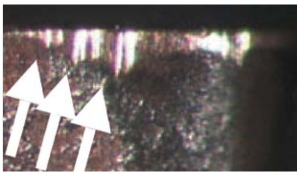
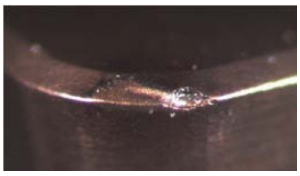
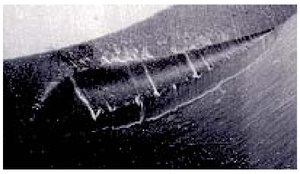
Comp.'s solid CBN
(After 2km of cutting)


BNS800
(After 2km of cutting)

Technical Guidance

Tool Failure and Remedies

SUMIBORON Edition

Type of Insert Failure	Cause	Countermeasures
Flank Wear 	· Grade lacks wear resistance. · Cutting speed is too fast.	· Select a more wear resistant grade.（BNC2010,BN1000,BN2000） · Decrease the cutting speed. Reduce the cutting speed to less than v_c=200m/min. (Higher feed rate reduces the overall tool-to-work contact time.) · Use an insert with a larger relief angle.
Crater wear 	· Grade lacks wear resistance. · Cutting speed is too fast.	· Change to a high efficiency grade.（BNC2010,BNX25,BNX20） · Reduce cutting speed and increase feed rate (low-speed, high-feed cutting). Reduce the cutting speed to less than v_c=200m/min. (Higher feed rate reduces the overall tool-to-work contact time.)
Breakage At Bottom of Crater 		
Flaking 	· Grade lacks toughness. · Back force is too high.	· Select a tougher grade (e.g. BNC2020 and BN2000). · Select an insert with a stronger cutting edge (Increase negative land angle and hone) · If the grade has enough toughness, improve the cutting edge sharpness.
Notch Wear 	· High boundary stress.	· Change to a grade with a higher boundary wear resistance (e.g. BNC2010 and BN2000). · Increase the cutting speed (150m/min or more). · Change to "Variable Feed Rate" method, which alters the feed rate every fixed number of outputs. · Increase negative land angle and hone.
Chipping at Forward Notch Position 	· Impact to front cutting edge is too large or too often applied.	· Change to a fine-grained grade with a higher fracture resistance (e.g. BNC300 and BN350). · Increase feed rates (Higher feed rates are recommended to reduce chipping.) · Select an insert with a stronger cutting edge (Increase negative land angle and hone)
Chipping at Side Notch Position 	· Impact to side cutting edge is too large or too often applied.	· Select a tougher grade.（BN350,BNC300） · Reduce feed rate. Increase the side cutting angle · Increase the work radius · Select an insert with a stronger cutting edge (Increase negative land angle and hone)
Thermal Crack 	· Thermal shock is too severe.	· Completely dry condition is recommended. · Select a grade with better thermal conductivity. · Decrease cutting speed, depth of cut, feed rate.

■ SI Basic Unit

● Quantity as a Reference of SI Unit

Quantity	Name	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Current	Ampere	A
Temperature	Kelvin	K
Quantity of Substance	Mol	mol
Luminous Intensity	Candela	cd

● Basic Unit Provided with Unique Name and Symbol (Extracted)

Quantity	Name	Symbol
Frequency	Hertz	Hz
Force	Newton	N
Pressure and Stress	Pascal	Pa
Energy, Work, and Calorie	Joule	J
Power and Efficiency	Watt	W
Voltage	Volt	V
Resistance	Ohm	Ω

■ SI Prefix

● Prefix Showing Integral Power of 10 Combined with SI Unit

Coefficient	Name	Symbol	Coefficient	Name	Symbol	Coefficient	Name	Symbol
10^{24}	Yota	Y	10^{3}	Kilo	k	10^{-9}	Nano	n
10^{21}	Zeta	Z	10^{2}	Hecto	h	10^{-12}	Pico	p
10^{18}	Exa	E	10^{1}	Deca	da	10^{-15}	Femto	f
10^{15}	Peta	P	10^{-1}	Deci	d	10^{-18}	Atto	a
10^{12}	Tera	T	10^{-2}	Centi	c	10^{-21}	Zepto	z
10^{9}	Giga	G	10^{-3}	Milli	m	10^{-24}	Yocto	y
10^{6}	Mega	M	10^{-6}	Micro	μ			

■ Principal SI Unit Conversion List (□ coloured portions are SI units)

● Force

N	kgf
1	1.01972×10^{-1}
9.80665	1

● Stress

Pa (N/m^2)	MPa (N/mm^2)	kgf/mm^2	kgf/cm^2	kgf/m^2
1	1×10^{-6}	1.01972×10^{-7}	1.01972×10^{-5}	1.01972×10^{-1}
1×10^{6}	1	1.01972×10^{-1}	1.01972×10	1.01972×10^{5}
9.80665×10^{6}	9.80665	1	1×10^{2}	1×10^{6}
9.80665×10^{4}	9.80665×10^{-2}	1×10^{-2}	1	1×10^{4}
9.80665	9.80665×10^{-6}	1×10^{-6}	1×10^{-4}	1

$1Pa = 1N/m^2$, $1MPa = 1N/mm^2$

● Pressure

Pa (N/m^2)	kPa	MPa	GPa	bar	kgf/cm^2	mmHg または Torr
1	1×10^{-3}	1×10^{-6}	1×10^{-9}	1×10^{-5}	1.01972×10^{-5}	7.50062×10^{-3}
1×10^{3}	1	1×10^{-3}	1×10^{-6}	1×10^{-2}	1.01972×10^{-2}	7.50062
1×10^{6}	1×10^{3}	1	1×10^{-3}	1×10	1.01972×10	7.50062×10^{3}
1×10^{9}	1×10^{6}	1×10^{3}	1	1×10^{4}	1.01972×10^{4}	7.50062×10^{6}
1×10^{5}	1×10^{2}	1×10^{-1}	1×10^{-4}	1	1.01972	7.50062×10^{2}
9.80665×10^{4}	9.80665×10	9.80665×10^{-2}	9.80665×10^{-5}	9.80665×10^{-1}	1	7.35559×10^{2}
1.33322×10^{2}	1.33322×10^{-1}	1.33322×10^{-4}	1.33322×10^{-7}	1.33322×10^{-3}	1.35951×10^{-3}	1

$1Pa = 1N/m^2$

● Work / Energy / Calorie

J	kW · h	kgf · m	kcal
1	2.77778×10^{-7}	1.01972×10^{-1}	2.38889×10^{-4}
3.60000×10^{6}	1	3.67098×10^{5}	8.60000×10^{2}
9.80665	2.72407×10^{-6}	1	2.34270×10^{-3}
4.18605×10^{3}	1.16279×10^{-3}	4.26858×10^{2}	1

1J = 1W・s,1J = 1N・m

● Power (Efficiency and Motive Energy) / Thermal Flow

W	kgf・m/s	PS	kcal/h
1	1.01972×10^{-1}	1.35962×10^{-3}	8.60000×10^{-1}
1×10^{3}	1.01972×10^{2}	1.35962	8.60000×10^{2}
9.80665	1	1.33333×10^{-2}	8.43371
7.355×10^{2}	7.5×10	1	6.32529×10^{2}
1.16279	1.18572×10^{-1}	1.58095×10^{-3}	1

1W = 1J/s, PS : Horsepower

● Specific Heat

J/(kg・K)	1kcal (kg · ˚C)cal/ (g · ˚C)
1	2.38889×10^{-4}
4.18605×10^{3}	1

● Thermal Conductivity

W/(m・K)	kcal/(h・m・˚C)
1	8.60000×10^{-1}
1.16279	1

● Rotating Speed

min^{-1}	rpm
1	1

$1min^{-1} = 1rpm$

References

Steel and Non-Ferrous Metal Symbols Chart

Carbon Steels

JIS	AISI	DIN
S10C	1010	C10
S15C	1015	C15
S20C	1020	C22
S25C	1025	C25
S30C	1030	C30
S35C	1035	C35
S40C	1040	C40
S45C	1045	C45
S50C	1049	C50
S55C	1055	C55

Ni-Cr-Mo Steels

SNCM220	8620	21NiCrMo2
SNCM240	8640	—
SNCM415	—	—
SNCM420	4320	—
SNCM439	4340	—
SNCM447	—	—

Cr Steels

SCr415	—	—
SCr420	5120	—
SCr430	5130	34Cr4
SCr435	5132	37Cr4
SCr440	5140	41Cr4
SCr445	5147	—

Cr-Mo Steels

SCM415	—	—
SCM420	—	—
SCM430	4131	—
SCM435	4137	34CrMo4
SCM440	4140	42CrMo4
SCM445	4145	—

Mn Steels and Mn-Cr Steels for Structurer Use

SMn420	1522	—
SMn433	1534	—
SMn438	1541	—
SMn443	1541	—
SMnC420	—	—
SMnC443	—	—

Carbon Tool Steels

SK1	—	—
SK2	W1-11 $^{1}/_{2}$	—
SK3	W1-10	C105W1
SK4	W1-9	—
SK5	W1-8	C80W1
SK6	—	C80W1
SK7	—	C70W2

High Seed Steels

JIS	AISI	DIN
SKH2	T1	—
SKH3	T4	S18-1-2-5
SKH10	T15	S12-1-4-5
SKH51	M2	S6-5-2
SKH52	M3–1	—
SKH53	M3–2	S6-5-3
SKH54	M4	—
SKH56	M36	—

Alloy Tool Steels

SKS11	F2	—
SKS51	L6	—
SKS43	W2-9 $^{1}/_{2}$	—
SKS44	W2-8	—
SKD1	D3	X210Cr12
SKD11	D2	—

Grey Cast Iron

FC100	No 20B	GG-10
FC150	No 25B	GG-15
FC200	No 30B	GG-20
FC250	No 35B	GG-25
FC300	No 45B	GG-30
FC350	No 50B	GG-35

Nodular Cast Iron

FCD400	60-40-18	GGG-40
FCD450	—	GGG-40.3
FCD500	80-55-06	GGG-50
FCD600	—	GGG-60
FCD700	100-70-03	GGG-70

Ferritic Stainless Steels

SUS405	405	X10CrAl13
SUS429	429	—
SUS430	430	X6Cr17
SUS430F	430F	X7CrMo18
SUS434	434	X6CrMo17 1

Martensitic Stainless Steels

SUS403	403	—
SUS410	410	X10Cr13
SUS416	416	—
SUS420JI	420	X20Cr13
SUS420F	420F	—
SUS431	431	X20CrNi17 2
SUS440A	440A	—
SUS440B	440B	—
SUS440C	440C	—

Austenitic Stainless Steels

JIS	AISI	DIN
SUS201	201	—
SUS202	202	—
SUS301	301	X12CrNi17 7
SUS302	302	—
SUS302B	302B	—
SUS303	303	X10CrNiS18 9
SUS303Se	303Se	—
SUS304	304	X5CrNiS18 10
SUS304L	304L	X2CrNi19 11
SUS304NI	304N	—
SUS305	305	X5CrNi18 12
SUS308	308	—
SUS309S	309S	—
SUS310S	310S	—
SUS316	316	X5CrMo17 12 2
SUS316L	316L	X2CrNiMo17 13 2
SUS316N	316N	—
SUS317	317	—
SUS317L	317L	X2CrNiMo18 16 4
SUS321	321	X6CrNiTi18 10
SUS347	347	X6CrNiNb18 10
SUS384	384	—

Heat Resisting Steels

SUH31	—	—
SUH35	—	—
SUH36	—	X53CrMnNi21 9
SUH37	—	—
SUH38	—	—
SUH309	309	—
SUH310	310	CrNi2520
SUH330	N08330	—

Ferritic Heat Resisting Steels

SUH21	—	CrAl1205
SUH409	409	X6CrTi12
SUH446	446	—

Martensitic Heat Resisting Steels

SUH1	—	X45CrSi9 3
SUH3	—	—
SUH4	—	—
SUH11	—	—
SUH600	—	—

Steel and Non-Ferrous Metal Symbols Chart

Classifications and Symbols of Steels

Class	Material	Symbol	Code Description
Structural Steels	Rolled Steels for welded structures	SM	"M" for "Marine"-Usually used in welded marine structures
	Re-rolled Steels	SRB	"R" for "Re-rolled" and "B" for "Bar"
	Rolled Steels for general structures	SS	S for "Steel" and for "Structure"
	Light gauge sections for general structures	SSC	C for "Cold"
Steel Sheets	Hot rolled mild steel sheets / plates in coil form	SPH	P for "Plate" and "H" for "Hot"
Steel Tubes	Carbon steel tubes for piping	SGP	"GP" for "Gas Pipe"
	Carbon steel tubes for boiler and heat exchangers	STB	"T" for "Tube" and "B" for "Boiler"
	Seamless steel tubes for high pressure gas cylinders	STH	"H" for "High Pressure"
	Carbon steel tubes for general structures	STK	"K" for "Kozo"-Japanese word meaning "structure"
	Carbon steel tubes for machine structural uses	STKM	"M" for "Machine"
	Alloy steel tubes for structures	STKS	"S" for "Special"
	Alloy steel tubes for piping	STPA	"P" for "Piping" and "A" for "Alloy"
	Carbon steel tubes for pressure piping	STPG	"G" for "General"
	Carbon steel tubes for high temperature piping	STPT	"T" for "Temperatures"
	Carbon steel tubes for high pressure piping	STS	"S" after "SP" is abbreviation for "Special"
	Stainless steel tubes for piping	SUS-TP	"T" for "Tube" and "P" for "Piping"
Steel for Machine Structures	Carbon steels for machine structural uses	SxxC	"C" for "Carbon"
	Aluminium Chromium Molybdenum steels	SACM	"A" for "Al", "C" for "Cr" and "M" for "Mo"
	Chromium Molybdenum steels	SCM	"C" for "Cr" and "M" for "Mo"
	Chromium steels	SCr	"Cr" for "Chromium"
	Nickel Chromium steels	SNC	"N" for "Nickel" and "C"for "Chromium"
	Nickel Chromium Molybdenum steels	SNCM	"M" for "Molybdenum"
	Manganese steels for structural use Manganese Chromium steels	SMn SMnC	"Mn" for "Manganese" "C" for "Chromium"
Special Steels Tool Steels	Carbon tool steels	SK	"K" for "Kogu"-Japanese word meaning "tool"
	Hollow drill steels	SKC	"C" for "Chisel"
	Alloy tool steel	SKS SKD SKT	S for "Special" D for "Die" T for "Tanzo"-Japanese word for "forging"
	High speed tool steels	SKH	"H" for "High speed"
Stainless Steels	Free cutting sulphuric steels	SUM	"M" for "Machinability"
	High Carbon Chromium bearing steels	SUJ	"J" for "Jikuuke"-Japanese word meaning "bearing"
	Spring steels	SUP	"P" for "Spring"
	Stainless Steels	SUS	"S" after "SU" is abbreviation for "Stainless"
Heat-resistant Steels	Heat-resistant steels	SUH	"U" for "Special Usage" and "H" for "Heat"
	Heat-resistant steel bars	SUH-B	"B" for "Bar"
	Heat-resistant steels sheets	SUHP	"P" for "Plate"
Forged Steels	Carbon steel forgings for general use	SF	"F" for "Forging"
	Carbon steel booms and billets for forgings	SFB	"B" for "Billet"
	Chromium Molybdenum steel forgings	SFCM	"C" for "Chromium" and "M" for "Molybdenum"
	Nickel Chromium Molybdenum steel forgings	SFNCM	"N" for "Nickel"
Cast Irons	Grey cast irons	FC	"F" for "Ferrous" and "C" for "Casting"
	Spherical graphite / Ductile cast irons	FCD	"D" for "Ductile"
	Blackheart malleable cast irons	FCMB	"M" for "Malleable" and "B" for "Black"
	Whiteheart malleable cast irons	FCMW	"W" for "White"
	Pearlite malleable cast irons	FCMP	"P" for "Pearlite"
Cast Steels	Carbon cast steels	SC	"C" for "Casting"
	Stainless cast steels	SCS	"S" for "Stainless"
	Heat-resistant cast steels	SCH	"H" for "Heat"
	High Manganese cast steels	SCMnH	"Mn" for "Manganese" and "H" for "High"

Non-Ferrous Metals

Class	Material	Symbol
Copper and Copper Alloys	Copper and Copper alloys - Sheets, plates and strips	CxxxxP
		CxxxxPP
		CxxxxR
	Copper and Copper alloys - Welded pipes and tubes	CxxxxBD
		CxxxxBDS
		CxxxxBE
		CxxxxBF
Aluminium and Aluminium Alloys	Aluminium and Al alloys - Sheets, plates and strips	AxxxxP
		AxxxxPC
	Aluminium and Al alloys -Rods, bars, and wires	AxxxxBE
		AxxxxBD
		AxxxxW
	Aluminium and Al alloys-Extruded shapes	AxxxxS
	Aluminium and Al alloys forgings	AxxxxFD
		AxxxxFH
Magnesium Alloys	Magnesium alloy sheets and plates	MP
Nickel Alloys	Nickel-copper alloy sheets and plates	NCuP
	Nickel-copper alloy rods and bars	NCuB
Wrought Titanium	Titanium rods and bars	TB
Castings	Brass castings	YBsCx
	High strength Brass castings	HBsCx
	Bronze castings	BCx
	Phosphorus Bronze castings	PBCx
	Aluminium Bronze castings	AlBCx
	Aluminium alloy castings	AC
	Magnesium alloy castings	MC
	Zinc alloy die castings	ZDCx
	Aluminium alloy die castings	ADC
	Magnesium alloy die castings	MDC
	White metals	WJ
	Aluminium alloy castings for bearings	AJ
	Copper-Lead alloy castings for bearings	KJ

Hardness Scale Comparison Chart

● Approximate Corresponding Values for Steel Hardness on the Brinell Scale

Brinell Hardness 3,000kgf HB	Rockwell Hardness				Vickers Hardness 50kgf HV	Shore Hardness HS	Traverse Rupture Strength (GPa)
	A Scale 60kgf brale brale HRA	B Scale 100kgf 1/10in Ball HRB	C Scale 150kgf brale brale HRC	D Scale 100kgf brale brale HRD			
—	85.6	—	68.0	76.9	940	97	—
—	85.3	—	67.5	76.5	920	96	—
—	85.0	—	67.0	76.1	900	95	—
767	84.7	—	66.4	75.7	880	93	—
757	84.4	—	65.9	75.3	860	92	—
745	84.1	—	65.3	74.8	840	91	—
733	83.8	—	64.7	74.3	820	90	—
722	83.4	—	64.0	73.8	800	88	—
712	—	—	—	—	—	—	—
710	83.0	—	63.3	73.3	780	87	—
698	82.6	—	62.5	72.6	760	86	—
684	82.2	—	61.8	72.1	740	—	—
682	82.2	—	61.7	72.0	737	84	—
670	81.8	—	61.0	71.5	720	83	—
656	81.3	—	60.1	70.8	700	—	—
653	81.2	—	60.0	70.7	697	81	—
647	81.1	—	59.7	70.5	690	—	—
638	80.8	—	59.2	70.1	680	80	—
630	80.6	—	58.8	69.8	670	—	—
627	80.5	—	58.7	69.7	667	79	—
601	79.8	—	57.3	68.7	640	77	—
578	79.1	—	56.0	67.7	615	75	—
555	78.4	—	54.7	66.7	591	73	2.06
534	77.8	—	53.5	65.8	569	71	1.98
514	76.9	—	52.1	64.7	547	70	1.89
495	76.3	—	51.0	63.8	528	68	1.82
477	75.6	—	49.6	62.7	508	66	1.73
461	74.9	—	48.5	61.7	491	65	1.67
444	74.2	—	47.1	60.8	472	63	1.59
429	73.4	—	45.7	59.7	455	61	1.51
415	72.8	—	44.5	58.8	440	59	1.46
401	72.0	—	43.1	57.8	425	58	1.39
388	71.4	—	41.8	56.8	410	56	1.33
375	70.6	—	40.4	55.7	396	54	1.26
363	70.0	—	39.1	54.6	383	52	1.22
352	69.3	(110.0)	37.9	53.8	372	51	1.18
341	68.7	(109.0)	36.6	52.8	360	50	1.13
331	68.1	(108.5)	35.5	51.9	350	48	1.10
321	67.5	(108.0)	34.3	50.1	339	47	1.06
311	66.9	(107.5)	33.1	50.0	328	46	1.03
302	66.3	(107.0)	32.1	49.3	319	45	1.01
293	65.7	(106.0)	30.9	48.3	309	43	0.97
285	65.3	(105.5)	29.9	47.6	301	—	0.95
277	64.6	(104.5)	28.8	46.7	292	41	0.92
269	64.1	(104.0)	27.6	45.9	284	40	0.89
262	63.6	(103.0)	26.6	45.0	276	39	0.87
255	63.0	(102.0)	25.4	44.2	269	38	0.84
248	62.5	(101.0)	24.2	43.2	261	37	0.82
241	61.8	100.0	22.8	42.0	253	36	0.80
235	61.4	99.0	21.7	41.4	247	35	0.78
229	60.8	98.2	20.5	40.5	241	34	0.76
223	—	97.3	(18.8)	—	234	—	—
217	—	96.4	(17.5)	—	228	33	0.73
212	—	95.5	(16.0)	—	222	—	0.71
207	—	94.6	(15.2)	—	218	32	0.69
201	—	93.8	(13.8)	—	212	31	0.68
197	—	92.8	(12.7)	—	207	30	0.66
192	—	91.9	(11.5)	—	202	29	0.64
187	—	90.7	(10.0)	—	196	—	0.62
183	—	90.0	(9.0)	—	192	28	0.62
179	—	89.0	(8.0)	—	188	27	0.60
174	—	87.8	(6.4)	—	182	—	0.59
170	—	86.8	(5.4)	—	178	26	0.57
167	—	86.0	(4.4)	—	175	—	0.56
163	—	85.0	(3.3)	—	171	25	0.55
156	—	82.9	(0.9)	—	163	—	0.52
149	—	80.8	—	—	156	23	0.50
143	—	78.7	—	—	150	22	0.49
137	—	76.4	—	—	143	21	0.46
131	—	74.0	—	—	137	—	0.45
126	—	72.0	—	—	132	20	0.43
121	—	69.8	—	—	127	19	0.41
116	—	67.6	—	—	122	18	0.40
111	—	65.7	—	—	117	15	0.38

1) Figures within the ( ) are not commonly used
2) Rockwell A, C and D scales utilise a diamond brale
3) This chart was taken from the JIS Iron and Steel Handbook (1980)

Standard of Tapers

Morse Taper

Fig. 1 With Tang Type

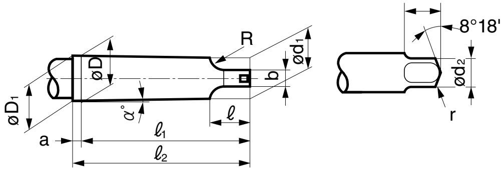
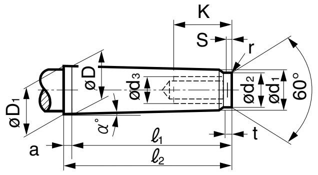


Fig. 2 Drawing Thread Type



(Units: mm)

Morse Taper Number	Taper[1]		Taper Angle (α°)	Taper						Tang						Fig
				D	a	D_1[2] (Estimated)	d_1[2] (Estimated)	ℓ_1 (Max)	ℓ_2 (Max)	d_2 (Max)	b	C (Max)	e (Max)	R	r	
0	$\frac{1}{19.212}$	0.05205	1°29'27"	9.045	3	9.2	6.1	56.5	59.5	6.0	3.9	6.5	10.5	4	1	1
1	$\frac{1}{20.047}$	0.04988	1°25'43"	12.065	3.5	12.2	9.0	62.0	65.5	8.7	5.2	8.5	13.5	5	1.2	
2	$\frac{1}{20.020}$	0.04995	1°25'50"	17.780	5	18.0	14.0	75.0	80.0	13.5	6.3	10	16	6	1.6	
3	$\frac{1}{19.922}$	0.05020	1°26'16"	23.825	5	24.1	19.1	94.0	99.0	18.5	7.9	13	20	7	2	
4	$\frac{1}{19.245}$	0.05194	1°29'15"	31.267	6.5	31.6	25.2	117.5	124.0	24.5	11.9	16	24	8	2.5	
5	$\frac{1}{19.002}$	0.05263	1°30'26"	44.399	6.5	44.7	36.5	149.5	156.0	35.7	15.9	19	29	10	3	
6	$\frac{1}{19.180}$	0.05214	1°29'36"	63.348	8	63.8	52.4	210.0	218.0	51.0	19.0	27	40	13	4	
7	$\frac{1}{19.231}$	0.05200	1°29'22"	83.058	10	83.6	68.2	286.0	296.0	66.8	28.6	35	54	19	5	

Morse Taper Number	Taper[1]		Taper Angle (α°)	Taper						Tang					Fig
				D	a	D_1[2] (Estimated)	d_1[2] (Estimated)	ℓ_1 (Max)	ℓ_2 (Max)	d_2 (Max)	d_3	K (Min)	t (Max)	r	
0	$\frac{1}{19.212}$	0.05205	1°29'27"	9.045	3	9.2	6.4	50	53	6	—	—	4	0.2	2
1	$\frac{1}{20.047}$	0.04988	1°25'43"	12.065	3.5	12.2	9.4	53.5	57	9	M 6	16	5	0.2	
2	$\frac{1}{20.020}$	0.04995	1°25'50"	17.780	5	18.0	14.6	64	69	14	M10	24	5	0.2	
3	$\frac{1}{19.922}$	0.05020	1°26'16"	23.825	5	24.1	19.8	81	86	19	M12	28	7	0.6	
4	$\frac{1}{19.254}$	0.05194	1°29'15"	31.267	6.5	31.6	25.9	102.5	109	25	M16	32	9	1	
5	$\frac{1}{19.002}$	0.05263	1°30'26"	44.399	6.5	44.7	37.6	129.5	136	35.7	M20	40	9	2.5	
6	$\frac{1}{19.180}$	0.05214	1°29'36"	63.348	8	63.8	53.9	182	190	51	M24	50	12	4	
7	$\frac{1}{19.231}$	0.05200	1°29'22"	83.058	10	83.6	70.0	250	260	65	M33	80	18.5	5	

(1) The fractional values are the taper standards.

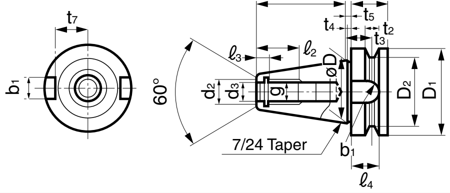
(2) Diameters (D1) and (d1) are calculated from the values of (D) and other values of the taper. (values are rounded up to one decimal place).

Remarks 1. Tapers are measured using JIS B 3301 ring gauges. At least 75% must be correct.

2. Screws must have metric coarse screw thread as per JIS B 0205, and 3rd grade precision as per JIS B 0209.

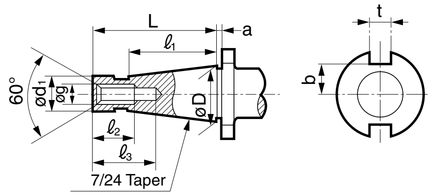
Bottle Grip Taper

Fig 3



American Standard Taper (National Taper)

Fig 4



Bottle Grip Taper

(Units: mm)

Taper No.	D (Standard)	D_1	D_2	t_1	t_2	t_3	t_4	t_5	d_2	d_3	L	ℓ_2	ℓ_3	ℓ_4	g	b_1	t_7	Fig
BT30	31.75	46	38	20	8	13.6	2	2	14	12.5	48.4	24	7	17	M12	16.1	16.3	3
BT35	38.10	53	43	22	10	14.6	2	2	14	12.5	56.4	24	7	20	M12	16.1	19.6	
BT40	44.45	63	53	25	10	16.6	2	2	19	17	65.4	30	8	21	M16	16.1	22.6	
BT45	57.15	85	73	30	12	21.2	3	3	23	21	82.8	36	9	26	M20	19.3	29.1	
BT50	69.85	100	85	35	15	23.2	3	3	27	25	101.8	45	11	31	M24	25.7	35.4	
BT60	107.95	155	135	45	20	28.2	3	3	33	31	161.8	56	12	34	M30	25.7	60.1	

American Standard Taper (National Taper)

(Units: mm)

Taper No.	Nominal Diameter	D	d_1		L	ℓ_1 (Min)	ℓ_2 (Min)	ℓ_3 (Min)	g	a	t	b	Fig
30	$1^1/_{4"}$	31.750	17.4	$^{-0.29}_{-0.36}$	68.4	48.4	24	34	$^1/_{2"}$	1.6	15.9	16	4
40	$1^3/_{4"}$	44.450	25.3	$^{-0.30}_{-0.384}$	93.4	65.4	32	43	$^5/_{8"}$	1.6	15.9	22.5	
50	$2^3/_{4"}$	69.850	39.6	$^{-0.31}_{-0.41}$	126.8	101.8	47	62	1"	3.2	25.4	35	
60	$4^1/_{4"}$	107.950	60.2	$^{-0.34}_{-0.46}$	206.8	161.8	59	76	$1^1/_{4"}$	3.2	25.4	60	

Dimensional Tolerances for Regularly Used Fits [Taken from JIS B 0401 (1999)]

Dimensional Tolerances for Regularly Used Shaft Fits

Base Dimension (mm)		Tolerance Zone Class of Shaft																														Units μm
More than	Max.	b9	c9	d8	d9	e7	e8	e9	f6	f7	f8	g5	g6	h5	h6	h7	h8	h9	js5	js6	js7	k5	k6	m5	m6	n6	p6	r6	s6	t6	u6	x6
—	3	-140 -165	-60 -85	-20 -34	-20 -45	-14 -24	-14 -28	-14 -39	-6 -12	-6 -16	-8 -20	-2 -6	-2 -8	0 -4	0 -6	0 -10	0 -14	0 -25	±2	±3	±5	+4 0	+6 0	+6 +2	+8 +2	+10 +4	+12 +6	+16 +10	+20 +14	—	+24 +18	+26 +20
3	6	-140 -170	-70 -100	-30 -48	-30 -60	-20 -32	-20 -38	-20 -50	-10 -18	-10 -22	-10 -28	-4 -9	-4 -12	0 -5	0 -8	0 -12	0 -18	0 -30	±2.5	±4	±6	+6 +1	+9 +1	+9 +4	+12 +4	+16 +8	+20 +12	+23 +15	+27 +19	—	+31 +23	+36 +28
6	10	-150 -186	-80 -116	-40 -62	-40 -76	-25 -40	-25 -47	-25 -61	-13 -22	-13 -28	-13 -35	-5 -11	-5 -14	0 -6	0 -9	0 -15	0 -22	0 -36	±3	±4.5	±7.5	+7 +1	+10 +1	+12 +6	+15 +6	+19 +10	+24 +15	+28 +19	+32 +23	—	+37 +28	+43 +34
10	14	-150 -193	-95 -138	-50 -77	-50 -93	-32 -50	-32 -59	-32 -75	-16 -27	-16 -34	-16 -43	-6 -14	-6 -17	0 -8	0 -11	0 -18	0 -27	0 -43	±4	±5.5	±9	+9 +1	+12 +1	+15 +7	+18 +7	+23 +12	+29 +18	+34 +23	+39 +28	—	+44 +33	+51 +40
14	18																														+56 +45
18	24	-160 -212	-110 -162	-65 -98	-65 -117	-40 -61	-40 -73	-40 -92	-20 -33	-20 -41	-20 -53	-7 -16	-7 -20	0 -9	0 -13	0 -21	0 -33	0 -52	±4.5	±6.5	±10.5	+11 +2	+15 +2	+17 +8	+21 +8	+28 +15	+35 +22	+41 +28	+48 +35	—	+54 +41	+67 +54
24	30																													+54 +41	+61 +48	+77 +64
30	40	-170 -232	-120 -182	-80 -119	-80 -142	-50 -75	-50 -89	-50 -112	-25 -41	-25 -50	-25 -64	-9 -20	-9 -25	0 -11	0 -16	0 -25	0 -39	0 -62	±5.5	±8	±12.5	+13 +2	+18 +2	+20 +9	+25 +9	+33 +17	+42 +26	+50 +34	+59 +43	+64 +48	+76 +60	—
40	50	-180 -242	-130 -192																									+70 +54	+86 +70	
50	65	-190 -264	-140 -214	-100 -146	-100 -174	-60 -90	-60 -106	-60 -134	-30 -49	-30 -60	-30 -76	-10 -23	-10 -29	0 -13	0 -19	0 -30	0 -46	0 -74	±6.5	±9.5	±15	+15 +2	+21 +2	+24 +11	+30 +11	+39 +20	+51 +32	+60 +41	+72 +53	+85 +66	+106 +87	—
65	80	-200 -274	-150 -224																							+62 +43	+78 +59	+94 +75	+121 +102	
80	100	-220 -307	-170 -257	-120 -174	-120 -207	-72 -107	-72 -126	-72 -159	-36 -58	-36 -71	-36 -90	-12 -27	-12 -34	0 -15	0 -22	0 -35	0 -54	0 -87	±7.5	±11	±17.5	+18 +3	+25 +3	+28 +13	+35 +13	+45 +23	+59 +37	+73 +51	+93 +71	+113 +91	+146 +124	—
100	120	-240 -327	-180 -267																							+76 +54	+101 +79	+126 +104	+166 +144	
120	140	-260 -360	-200 -300	-145 -208	-145 -245	-85 -125	-85 -148	-85 -185	-43 -68	-43 -83	-43 -106	-14 -32	-14 -39	0 -18	0 -25	0 -40	0 -63	0 -100	±9	±12.5	±20	+21 +3	+28 +3	+33 +15	+40 +15	+52 +27	+68 +43	+88 +63	+117 +92	+147 +122	—	—
140	160	-280 -380	-210 -310																							+90 +65	+125 +100	+159 +134		
160	180	-310 -410	-230 -330																							+93 +68	+133 +108	+171 +146		
180	200	-340 -455	-240 -355	-170 -242	-170 -285	-100 -146	-100 -172	-100 -215	-50 -79	-50 -96	-50 -122	-15 -35	-15 -44	0 -20	0 -29	0 -46	0 -72	0 -115	±10	±14.5	±23	+24 +4	+33 +4	+37 +17	+46 +17	+60 +31	+79 +50	+106 +77	+151 +122	—	—	—
200	225	-380 -495	-260 -375																							+109 +80	+159 +130			
225	250	-420 -535	-280 -395																							+113 +84	+169 +140			
250	280	-480 -610	-300 -430	-190 -271	-190 -320	-110 -162	-110 -191	-110 -240	-56 -88	-56 -108	-56 -137	-17 -40	-17 -49	0 -23	0 -32	0 -52	0 -81	0 -130	±11.5	±16	±26	+27 +4	+36 +4	+43 +20	+52 +20	+66 +34	+88 +56	+126 +94	—	—	—	—
280	315	-540 -670	-330 -460																							+130 +98				
315	355	-600 -740	-360 -500	-210 -299	-210 -350	-125 -182	-125 -214	-125 -265	-62 -98	-62 -119	-62 -151	-18 -43	-18 -54	0 -25	0 -36	0 -57	0 -89	0 -140	±12.5	±18	±28.5	+29 +4	+40 +4	+46 +21	+57 +21	+73 +37	+98 +62	+144 +108	—	—	—	—
355	400	-680 -820	-400 -540																							+150 +114				
400	450	-760 -915	-440 -595	-230 -327	-230 -385	-135 -198	-135 -232	-135 -290	-68 -108	-68 -131	-68 -165	-20 -47	-20 -60	0 -27	0 -40	0 -63	0 -97	0 -155	±13.5	±20	±31.5	+32 +5	+45 +5	+50 +23	+63 +23	+80 +40	+108 +68	+166 +126	—	—	—	—
450	500	-840 -995	-480 -635																							+172 +132				

■ Dimensional Tolerances for Regularly Used Fits [Taken from JIS B 0401 (1999)]

● Dimensional Tolerances for Regularly Used Fits

Base Dimension (mm)		Tolerance Zone Class of Hole																																	Units µm
More than	Max.	B10	C9	C10	D8	D9	D10	E7	E8	E9	F6	F7	F8	G6	G7	H6	H7	H8	H9	H10	JS6	JS7	K6	K7	M6	M7	N6	N7	P6	P7	R7	S7	T7	U7	X7
—	3	+180 +140	+85 +60	+100 +60	+34 +20	+45 +20	+60 +20	+24 +14	+28 +14	+39 +14	+12 +6	+16 +6	+20 +6	+8 +2	+12 +2	+6 0	+10 0	+14 0	+25 0	+40 0	±3	±5	0 -6	0 -10	-2 -8	-2 -12	-4 -10	-4 -14	-6 -12	-6 -16	-10 -20	-14 -24	—	-18 -28	-20 -30
3	6	+188 +140	+100 +70	+118 +70	+48 +30	+60 +30	+78 +30	+32 +20	+38 +20	+50 +20	+18 +10	+22 +10	+28 +10	+12 +4	+16 +4	+8 0	+12 0	+18 0	+30 0	+48 0	±4	±6	+2 -6	+3 -9	-1 -9	0 -12	-5 -13	-4 -16	-9 -17	-8 -20	-11 -23	-15 -27	—	-19 -31	-24 -36
6	10	+208 +150	+116 +80	+138 +80	+62 +40	+76 +40	+98 +40	+40 +25	+47 +25	+61 +25	+22 +13	+28 +13	+35 +13	+14 +5	+20 +5	+9 0	+15 0	+22 0	+36 0	+58 0	±4.5	±7.5	+2 -7	+5 -10	-3 -12	0 -15	-7 -16	-4 -19	-12 -21	-9 -24	-13 -28	-17 -32	—	-22 -37	-28 -43
10	14	+220 +150	+138 +95	+165 +95	+77 +50	+93 +50	+120 +50	+50 +32	+59 +32	+75 +32	+27 +16	+34 +16	+43 +16	+17 +6	+24 +6	+11 0	+18 0	+27 0	+43 0	+70 0	±5.5	±9	+2 -9	+6 -12	-4 -15	0 -18	-9 -20	-5 -23	-15 -26	-11 -29	-16 -34	-21 -39	—	-26 -44	-33 -51
14	18																																		-38 -56
18	24	+244 +160	+162 +110	+194 +110	+98 +65	+117 +65	+149 +65	+61 +40	+73 +40	+92 +40	+33 +20	+41 +20	+53 +20	+20 +7	+28 +7	+13 0	+21 0	+33 0	+52 0	+84 0	±6.5	±10.5	+2 -11	+6 -15	-4 -17	0 -21	-11 -24	-7 -28	-18 -31	-14 -35	-20 -41	-27 -48	—	-33 -54	-46 -67
24	30																																-33 -54	-40 -61	-56 -77
30	40	+270 +170	+182 +120	+220 +120	+119 +80	+142 +80	+180 +80	+75 +50	+89 +50	+112 +50	+41 +25	+50 +25	+64 +25	+25 +9	+34 +9	+16 0	+25 0	+39 0	+62 0	+100 0	±8	±12.5	+3 -13	+7 -18	-4 -20	0 -25	-12 -28	-8 -33	-21 -37	-17 -42	-25 -50	-34 -59	-39 -64	-51 -76	—
40	50	+280 +180	+192 +130	+230 +130																													-45 -70	-61 -86	
50	65	+310 +190	+214 +140	+260 +140	+146 +100	+174 +100	+220 +100	+90 +60	+106 +60	+134 +60	+49 +30	+60 +30	+76 +30	+29 +10	+40 +10	+19 0	+30 0	+46 0	+74 0	+120 0	±9.5	±15	+4 -15	+9 -21	-5 -24	0 -30	-14 -33	-9 -39	-26 -45	-21 -51	-30 -60	-42 -72	-55 -85	-76 -106	—
65	80	+320 +200	+224 +150	+270 +150																											-32 -62	-48 -78	-64 -94	-91 -121	
80	100	+360 +220	+257 +170	+310 +170	+174 +120	+207 +120	+260 +120	+107 +72	+126 +72	+159 +72	+58 +36	+71 +36	+90 +36	+34 +12	+47 +12	+22 0	+35 0	+54 0	+87 0	+140 0	±11	±17.5	+4 -18	+10 -25	-6 -28	0 -35	-16 -38	-10 -45	-30 -52	-24 -59	-38 -73	-58 -93	-78 -113	-111 -146	—
100	120	+380 +240	+267 +180	+320 +180																											-41 -76	-66 -101	-91 -126	-131 -166	
120	140	+420 +260	+300 +200	+360 +200	+208 +145	+245 +145	+305 +145	+125 +85	+148 +85	+185 +85	+68 +43	+83 +43	+106 +43	+39 +14	+54 +14	+25 0	+40 0	+63 0	+100 0	+160 0	±12.5	±20	+4 -21	+12 -28	-8 -33	0 -40	-20 -45	-12 -52	-36 -61	-28 -68	-48 -88	-77 -117	-107 -147	—	—
140	160	+440 +280	+310 +210	+370 +210																											-50 -90	-85 -125	-119 -159		
160	180	+470 +310	+330 +230	+390 +230																											-53 -93	-93 -133	-131 -171		
180	200	+525 +340	+355 +240	+425 +240	+242 +170	+285 +170	+355 +170	+146 +100	+172 +100	+215 +100	+79 +50	+96 +50	+122 +50	+44 +15	+61 +15	+29 0	+46 0	+72 0	+115 0	+185 0	±14.5	±23	+5 -24	+13 -33	-8 -37	0 -46	-22 -51	-14 -60	-41 -70	-33 -79	-60 -106	-105 -151	—	—	—
200	225	+565 +380	+375 +260	+445 +260																											-63 -109	-113 -159			
225	250	+605 +420	+395 +280	+465 +280																											-67 -113	-123 -169			
250	280	+690 +480	+430 +300	+510 +300	+271 +190	+320 +190	+400 +190	+162 +110	+191 +110	+240 +110	+88 +56	+108 +56	+137 +56	+49 +17	+69 +17	+32 0	+52 0	+81 0	+130 0	+210 0	±16	±26	+5 -27	+16 -36	-9 -41	0 -52	-25 -57	-14 -66	-47 -79	-36 -88	-74 -126	—	—	—	—
280	315	+750 +540	+460 +330	+540 +330																											-78 -130				
315	355	+830 +600	+500 +360	+590 +360	+299 +210	+350 +210	+440 +210	+182 +125	+214 +125	+265 +125	+98 +62	+119 +62	+151 +62	+54 +18	+75 +18	+36 0	+57 0	+89 0	+140 0	+230 0	±18	±28.5	+7 -29	+17 -40	-10 -46	0 -57	-26 -62	-16 -73	-51 -87	-41 -98	-87 -144	—	—	—	—
355	400	+910 +680	+540 +400	+630 +400																											-93 -150				
400	450	+1010 +760	+595 +440	+690 +440	+327 +230	+385 +230	+480 +230	+198 +135	+232 +135	+290 +135	+108 +68	+131 +68	+165 +68	+60 +20	+83 +20	+40 0	+63 0	+97 0	+155 0	+250 0	±20	±31.5	+8 -32	+18 -45	-10 -50	0 -63	-27 -67	-17 -80	-55 -95	-45 -108	-103 -166	—	—	—	—
450	500	+1090 +840	+635 +480	+730 +480																											-109 -172				

Dimensional Tolerances and Fits [Taken from JIS B 0401 (1999)]

● Standard Hole Fit for Regular Use

Standard Hole	Tolerance Zone Class of Shaft																
	Clearance Fit							Transition Fit			Interference Fit						
H6						g5	h5	js5	k5	m5							
					f6	g6	h6	js6	k6	m6	n6*	p6*					
H7					f6	g6	h6	js6	k6	m6	n6	p6*	r6*	s6	t6	u6	x6
				e7	f7		h7	js7									
H8					f7		h7										
				e8	f8		h8										
			d9	e9													
H9			d8	e8			h8										
		c9	d9	e9			h9										
H10	b9	c9	d9														

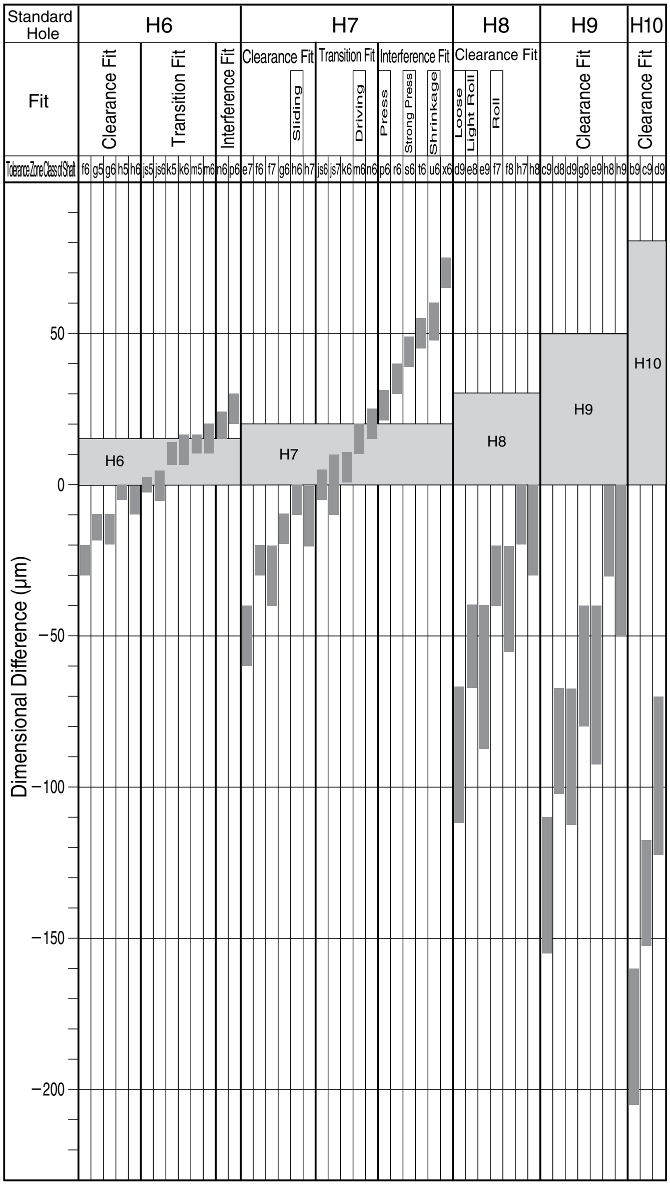
Note: These fittings produce exceptions depending on dimension category.

● Standard Shaft Fit for Regular Use

Standard Shaft	Tolerance Zone Class of Hole																
	Clearance Fit							Transition Fit			Interference Fit						
h5							H6	JS6	K6	M6	N6*	P6					
h6					F6	G6	H6	JS6	K6	M6	N6	P6*					
					F7	G7	H7	JS7	K7	M7	N7	P7*	R7	S7	T7	U7	X7
h7				E7	F7		H7										
					F8		H8										
h8			D8	E8	F8		H8										
			D9	E9			H9										
h9			D8	E8			H8										
		C9	D9	E9			H9										
	B10	C10	D10														

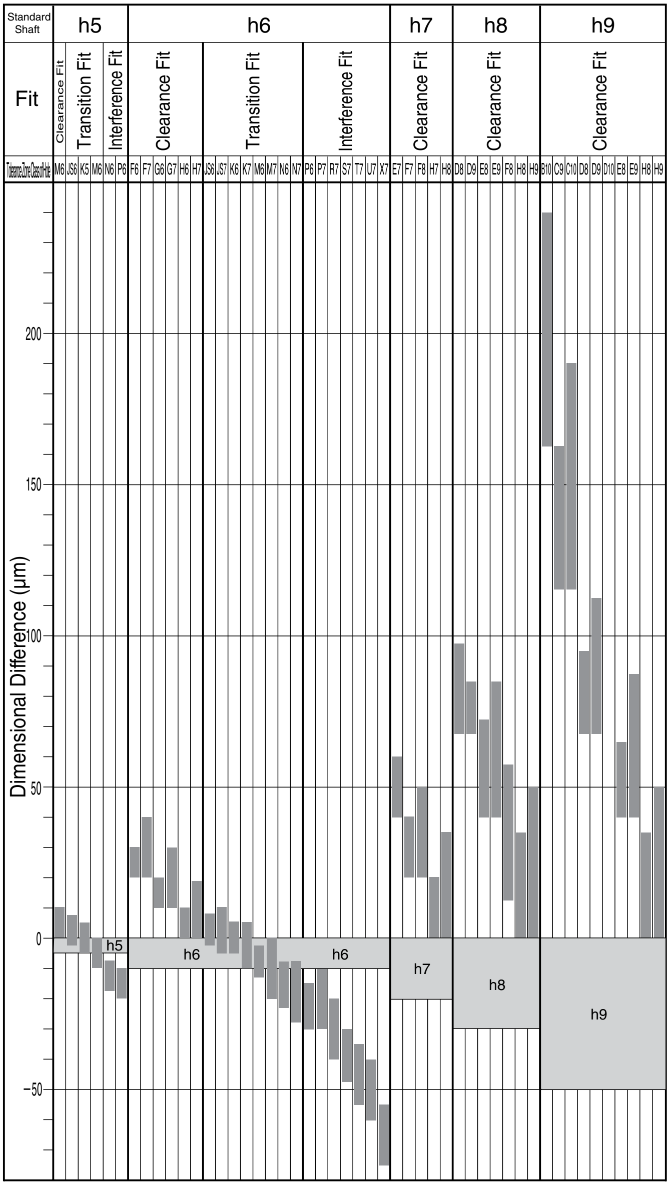
Note: These fittings produce exceptions depending on dimension category.

● Interrelationship of Tolerance Zones for Regularly Used Standard Hole Fits



Note: The above table is for standard dimensions of more than 18 mm and less than or equal to 30 mm.

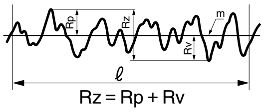
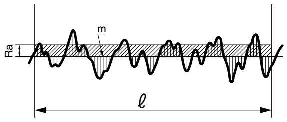
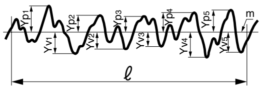
● Interrelationship of Tolerance Zones for Regularly Used Standard Shaft Fits



Note: The above table is for standard dimensions of more than 18 mm and less than or equal to 30 mm.

Finished Surface Roughness

● Types and Definitions of Typical Surface Roughness

Types	Symbol	Method of Determination	Descriptive Figure
Maximum Height	*1) Rz	This is the value expressed in micrometers (μm), obtained by extracting from the roughness curve a segment of the reference length in the direction of the mean line and measuring the distance from the deepest valley to the highest peak of the extracted segment in the direction of the longitudinal magnification of that roughness curve. Remarks: When obtaining Rz, care must be taken to extract a segment of the reference length from a portion having no unusually high peaks and deep valleys as they are considered as flaws.	 Rz = Rp + Rv
Calculated Roughness	Ra	This is the value expressed in micrometers (μm), obtained by extracting from the roughness curve a segment of the reference length in the direction of the mean line, plotting a roughness curve of y = f(x) with the X-axis set in the direction and the Y-axis set in the direction of the extracted segment, and using the following formula.	 $Ra=\frac{1}{\ell}\int_0^{\ell}\{f(x)\}dx$
Ten-point Mean Roughness	*2) RzJIS	This is the value expressed in micrometers (μm), obtained by extracting from the roughness curve a segment of the reference length in the direction of the mean line, measuring the heights of the highest to 5th highest peaks (Yp) as well as the heights of the deepest to 5th deepest valleys (Yv) in the direction of the longitudinal magnification of that mean line of the that roughness curve, and calculating the sum of the mean of the absolute values of Yp and that of Yv.	 $Rz_{JIS}=\frac{(Yp_1+Yp_2+Yp_3+Yp_4+Yp_5)+(Yv_1+Yv_2+Yv_3+Yv_4+Yv_5)}{5}$

Designated values of the above types of surface roughness, standard reference length values and the triangular symbol classifications are shown on the table on the right.

● Relationship with Triangular Symbols

Designated Values for *1) Rz	Designated Values for Ra	Designated Values for *2) RzJIS	Standard Reference Length Values, (mm)	Triangular Symbols *
(0.05) 0.1 0.2 0.4	(0.012) 0.025 0.05 0.10	(0.05) 0.1 0.2 0.4	0.25	▽▽▽▽
0.8	0.20	0.8		
1.6 3.2 6.3	0.40 0.80 1.6	1.6 3.2 6.3	0.8	▽▽▽
12.5 (18) 25	3.2 6.3	12.5 (18) 25	2.5	▽▽
(35) 50 (70) 100	12.5 25	(35) 50 (70) 100	8	▽
(140) 200 (280) 400 (560)	(50) (100)	(140) 200 (280) 400 (560)	—	—

Remarks: The designated values in the brackets do not apply unless otherwise stated.

* Due to the revision of JIS in 1994, the finishing symbols, triangular (▽) and wavy (~) symbols, were abolished.