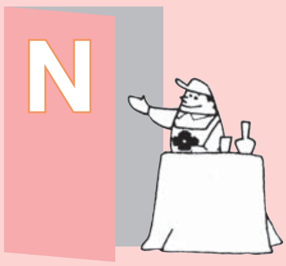
Technical Guidance Reference
N9 to N40

N



Turning Edition - The Basic of Turning

■ Calculating Cutting Speed

(1) Calculating spindle speed from cutting speed

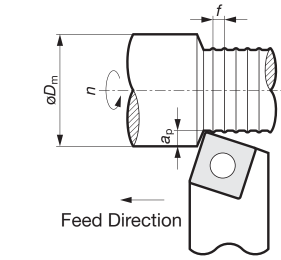
$n = \dfrac{1{,}000 \times v_c}{\pi \times D_m}$	n : Spindle Speed (min^{-1}) v_c : Cutting speed (m/min) D_m : Inner/outer diameter of workpiece (mm) π : ≈ 3.14

Example: v_c=150m/min, D_m=100mm

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

(2) Calculating cutting speed from spindle speed

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



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

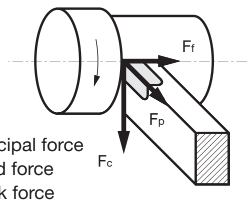
■ Calculating Power Requirements

$P_c = \dfrac{v_c \times f \times a_p \times k_c}{60 \times 10^3 \times \eta}$ $H = \dfrac{P_c}{0.75}$	P_c : Power requirements (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)

● Rough value of kc

Aluminum: 800MPa
General steel: 2,500 to 3,000MPa
Cast iron: 1,500MPa

■ Three Cutting Force Components

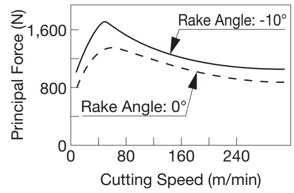


F_c: Principal force
F_f: Feed force
F_p: Back force

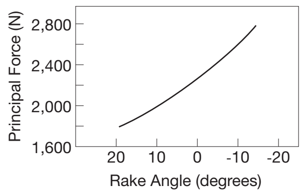
● Calculating cutting force

$P = \dfrac{k_c \times q}{1{,}000} = \dfrac{k_c \times a_p \times f}{1{,}000}$	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)

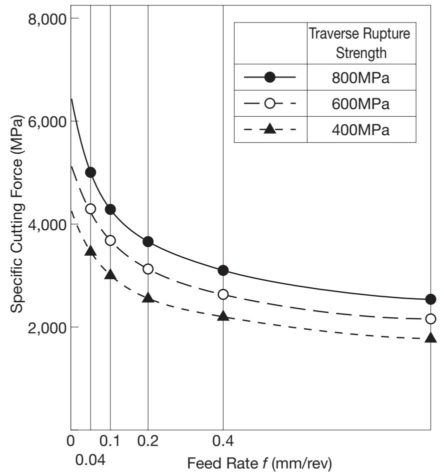
■ Relation Between Cutting Speed and Cutting Force



■ Relation between rake angle and cutting force



■ Relation Between Feed Rate and Specific Cutting Force (for carbon steel)

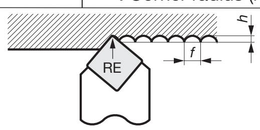


When feed rate decreases, specific cutting force increases.

■ Machined Surface Roughness

● Theoretical (geometrical) surface roughness

$h = \dfrac{f^2}{8 \times RE} \times 10^3$	h : Theoretical surface roughness (μm) f : Feed rate per revolution (mm/rev) RE : Corner radius (mm)



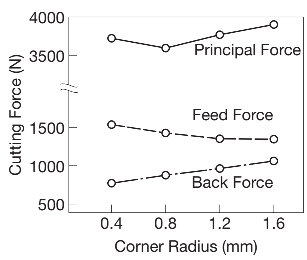
● Actual surface roughness

Steel:
Theoretical roughness × 1.5 to 3
Cast iron:
Theoretical roughness × 3 to 5

● Ways to improve surface finish roughness

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

■ Relation between corner radius and 3-part force

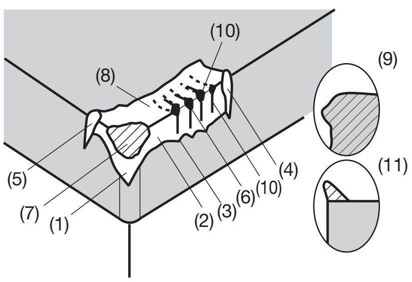


Large corner radius increases back force.

Work Material: SCM440 (38HS)
Insert: TNGA2204SS
Holder: PTGNR2525-43
Cutting Conditions: v_c=100m/min, a_p=4mm, f=0.45mm/rev

Turning Edition - Forms of Tool Failure and Tool Life

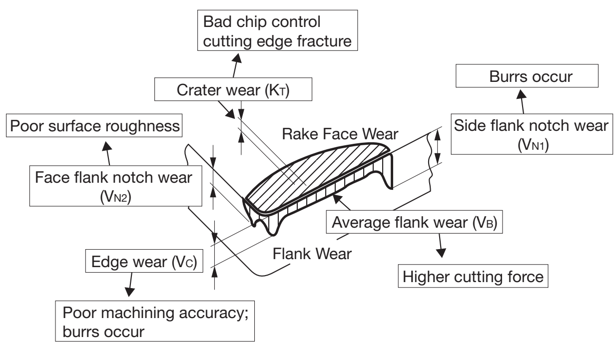
■ Forms of Tool Failure

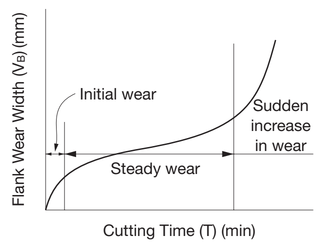
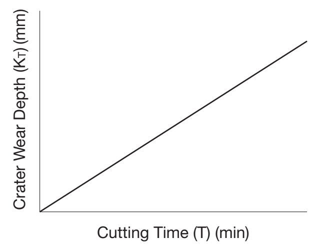


Classification	No.	Name of Failure	Major Causes of Failure
Failure Caused by Mechanical Factors	(1) to (5)	Flank wear	Wear caused by the scratching effect of hard grains contained in the work material
	(6)	Chipping	Fine breakages caused by high cutting loads or vibration
	(7)	Fracture	Large breakage caused by the impact of an excessive mechanical force acting on the cutting edge
Failure Caused by Thermal and Chemical Reactions	(8)	Crater wear	Cutting chips removing tool material as it flows over its top rake at high temperatures
	(9)	Plastic deformation	Deformation of cutting edge due to softening at high temperatures
	(10)	Thermal cracking	Fatigue from rapid, repeated heating and cooling cycles during interrupted cutting
	(11)	Built-up edges	Work material is pressure welded on the top face of the cutting edge

■ Tool Wear Curve

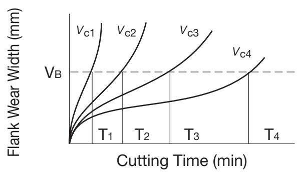
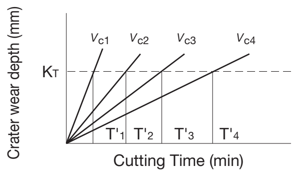
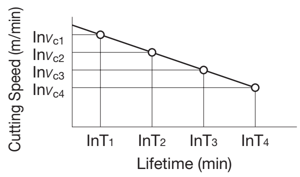
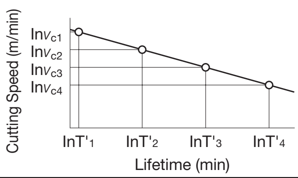
Forms of Tool Wear



Flank wear	Crater wear on rake face
	
· Wear increases rapidly right after starting cutting, then moderately and proportionally, and then rapidly again after a certain value.	· Wear increases proportionately to the cutting time.

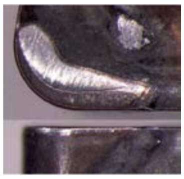
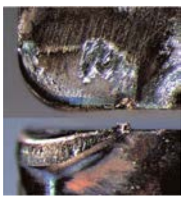
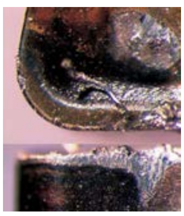
■ Tool Life (V-T)

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

	Flank wear	Crater wear
Tool wear		
Tool life		

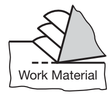
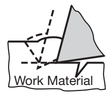
Turning Edition - Cutting Edge Failure and Countermeasures

■ Insert Failure and Countermeasures

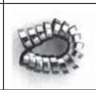
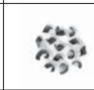
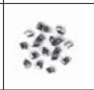
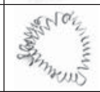
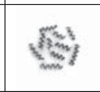
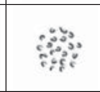
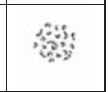
Insert Failure	Cause	Countermeasures
Flank Wear 	· Tool grade lacks wear resistance. · Cutting speed is too fast. · Feed rate is far too slow.	· Select a more wear-resistant grade. P30→P20→P10 K20→K10→K01 · Increase rake angle. · Decrease cutting speed. · Increase feed rate.
Crater Wear 	· Tool grade 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. · Increase rake angle. · Change the chipbreaker. · Decrease cutting speed. · Reduce feed rate and depth of cut.
Cutting Edge Chipping 	· Tool grade lacks toughness. · Cutting edge breaks due to chip adhesion. · Cutting edge is not strong enough. · 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 rate and depth of cut.
Cutting Edge Fracture 	·Tool grade lacks toughness. · Cutting edge is not strong enough. · Holder is not strong enough. · Feed rate and depth of cut are 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 rate and depth of cut.
Adhesion/Built-up Edges 	· Inappropriate grade selection. · Cutting edge is not sharp enough. · 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. · Increase rake angle. · Reduce honing. · Increase cutting speed. · Increase feed rate.
Plastic Deformation 	· Tool grade lacks thermal resistance. · Cutting speed is too fast. · Feed rate and depth of cut are too large. · Not enough coolant.	· Select a more crater wear-resistant grade. · Increase rake angle. · Decrease cutting speed. · Reduce feed rate and depth of cut. · Supply sufficient coolant.
Notch Wear 	· Tool grade lacks wear resistance. · Rake angle is too small. · Cutting speed is too fast.	· Select a more wear-resistant grade. P30→P20→P10 K20→K10→K01 · Increase rake angle. · Alter depth of cut to shift the notch location.

Turning Edition - Chip Control and Countermeasures

■ Type of Chip Generation

	Flowing	Shearing	Tearing	Cracking
Type				
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	General cutting of steel and light alloy	Steel, stainless steel (low speed)	Steel, cast iron (very low speed, very small feed rate)	Cutting of general cast iron and carbon
Influence factor	Large ◀— Deformation of work material —▶ Small Large ◀— Rake angle —▶ Small Small ◀— Depth of cut —▶ Large Large ◀— Cutting speed —▶ Small			

■ Type of Chip Control

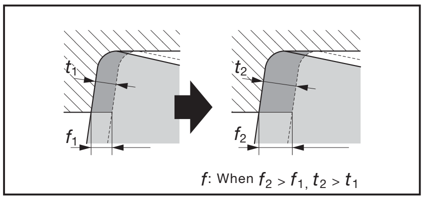
Classification of chip shapes	Depth of Cut	A	B	C	D	E
	Large					
	Small					
Evaluation	NC lathe (for automation)	×	×	○	○	△
	General-purpose lathe (for safety)	×	○	○	○ to △	×

Good: C type, D type

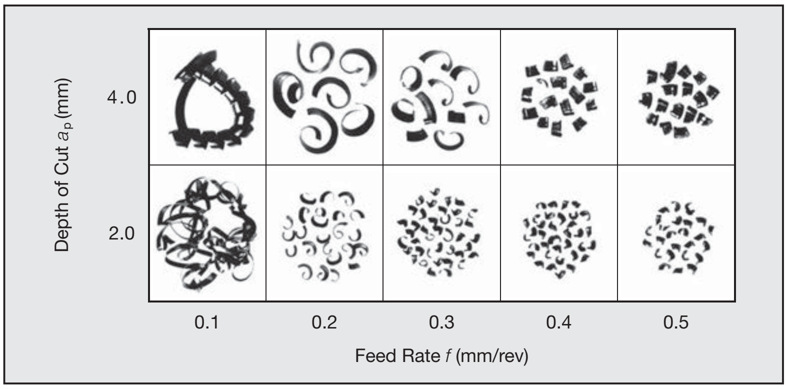
Poor
- A type: Twines around the tool or workpiece, damaging the machined surface and affecting safety.
- B type: Causes problems in the automatic chip conveyor and chipping occurs easily.
- E type: Causes spraying of chips and poor surface finish due to chattering, along with chipping, large cutting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

■ Chip Control Improvement Factors

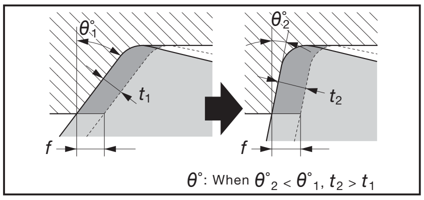
(1) Increase feed rate (*f*)



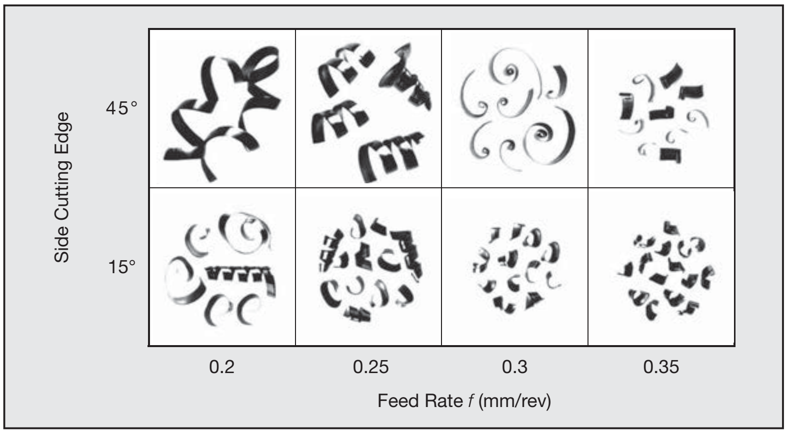
When the feed rate increases, the chip thickness (t) increases and chip control improves.



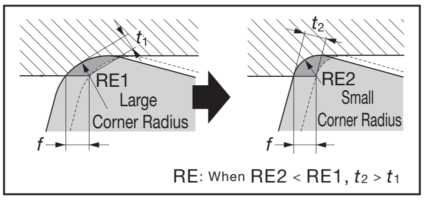
(2) Decrease side cutting edge (θ°)



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

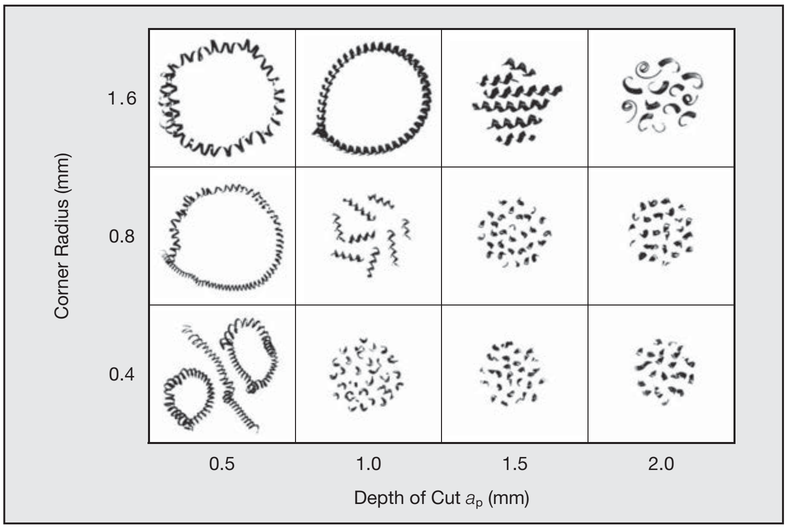


(3) Reduce corner radius (**RE**)



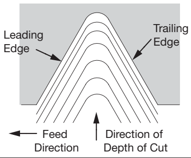
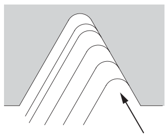
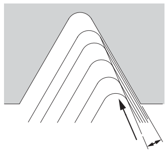
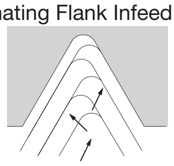
Even if the feed rate is the same, a smaller corner radius makes chips thicker and chip control improves.

* Cutting force increases proportionately to the length of the contact surface.
Therefore, a larger corner radius increases back force which induces chattering.
A smaller corner radius produces a rougher surface finish at the same feed rate.



Turning Edition - The Basics of Threading

■ Thread Cutting Methods

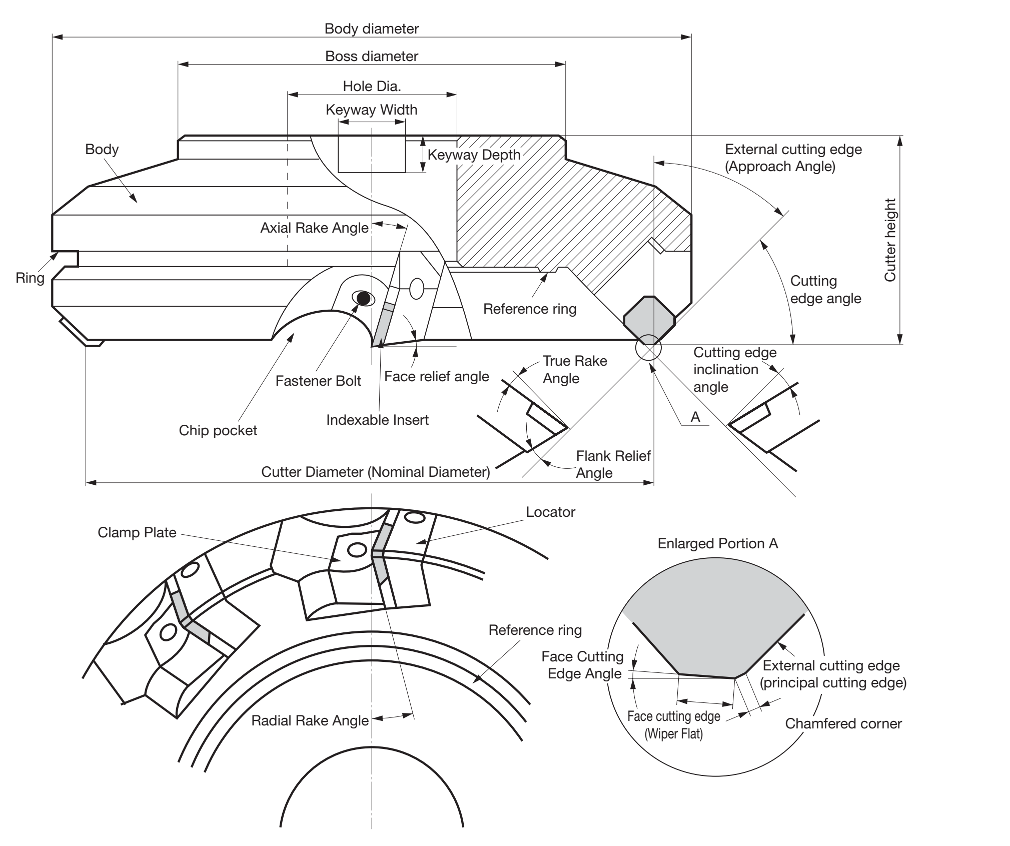
Cutting Method	Features
Radial Infeed 	· Most common threading technique, used mainly for small-pitched threads. · Easy to change cutting conditions such as depth of cut, etc. · Long contact point has a tendency to chatter. · Chip control is difficult. · Considerable damage tends to occur on the trailing edge side.
Flank Infeed 	· Effective for large-pitched threads and blemish-prone work material surfaces. · Chips evacuate from one side for good chip control. · The trailing edge is subjected to rubbing resulting in accelerated flank wear.
Modified Flank Infeed 	· Effective for large-pitched threads and blemish-prone work material surfaces. · Chips evacuate from one side for good chip control. · Inhibits flank wear on trailing edge side.
Alternating Flank Infeed 	· Effective for large-pitched threads and blemish-prone work material surfaces. · Wears evenly on right and left cutting edges. · Since both edges are used alternately, chip control is sometimes difficult.

■ Troubleshooting for Threading

Failure		Cause	Countermeasures
Cutting Edge Failure	Excessive Wear	· Tool grade	· Select a more wear-resistant grade
		· Cutting conditions	· Reduce cutting speed · Use a suitable quantity and concentration of coolant · Change the number of passes
	Uneven Wear on Right and Left Sides	· Tool mounting	· Check whether the cutting edge inclination angle is appropriate for the thread lead angle · Check whether the tool is mounted properly
		· Cutting conditions	· Change to modified flank infeed or alternating flank infeed
	Chipping	· Cutting conditions	· If built-up edge occurs, increase the cutting speed
	Fracture	· Biting of chips	· Supply enough coolant to the cutting edge
		· Cutting conditions	· Increase the number of passes and reduce the depth of cut for each pass · Use separate tools for roughing and finishing
Shape and Accuracy	Poor Surface Finish Roughness	· Cutting conditions	· 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 too small, make it larger
		· Tool grade	· Select a more wear-resistant grade
		· Inappropriate cutting edge inclination angle	· Select the correct shim to ensure relief on the side of the insert
	Inappropriate Thread Shape	· Tool mounting	· Check whether the tool is mounted properly
	Shallow Thread Depth	· Shallow depth of cut	· Check the depth of cut
		· Tool wear	· Check damage to the cutting edge

Milling Edition - The Basics of Milling

■ Parts



■ Milling Calculation Formulas

● Calculating cutting speed

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

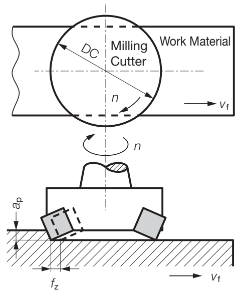
$$n = \frac{1{,}000 \times v_c}{\pi \times DC}$$

● 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
DC: Nominal cutting diameter (mm)
n : Rotation speed (min^{-1})
v_f : Feed rate per minute (mm/min)
f_z : Feed rate per tooth (mm/t)
z : Number of teeth



● Calculating power requirements

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

● Calculating horsepower requirements

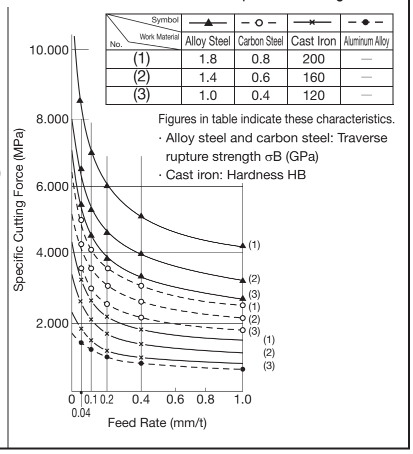
$$H = \frac{P_c}{0.75}$$

● Calculating chip evacuation amount

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

P_c: Power consumption (kw)
H : Required horsepower (HP)
Q : Chip evacuation amount (cm^3/min)
a_e: Cutting width (mm)
v_f : Feed rate per minute (mm/min)
a_p: Depth of cut (mm)
k_c: Cutting force (MPa)
Rough values: Steel: 2,500 to 3,000MPa; Cast iron: 1,500MPa; Aluminum: 800MPa
η : Machine efficiency (about 0.75)

● Relation between feed rate, work material and specific cutting force



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

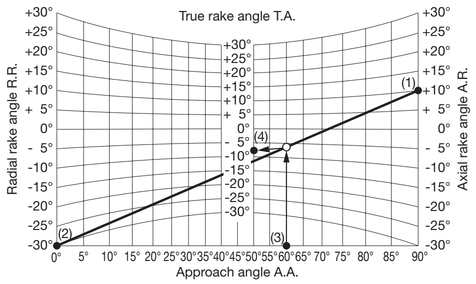
Figures in table indicate these characteristics.
· Alloy steel and carbon steel: Traverse rupture strength σB (GPa)
· Cast iron: Hardness HB

Milling Edition - The Basics of Milling

■ Functions of Cutting Edge Angles

	Material	Symbol	Function	Effect
(1) (2)	Axial rake angle Radial rake angle	A.R. R.R.	Determines chip evacuation direction, adhesion, thrust, etc.	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 and chip evacuation direction	Large: Thin chips Small cutting force
(4)	True rake angle	T.A.	Effective rake angle	Positive (Large): Excellent machinability and low chip adhesion. 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 finish roughness	Small: Excellent surface roughness.
(7)	Relief angle		Determines cutting edge strength, tool life, chattering	

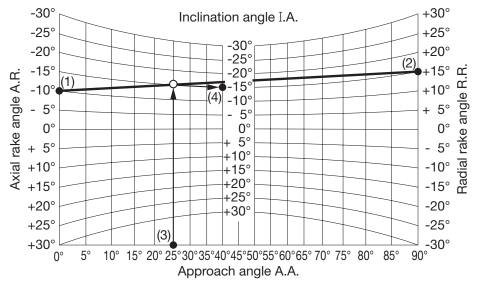
True rake angle (T.A.) table



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

Formula: tan T.A.=tan R.R./cos A.A. + tan A.R./sin A.A.

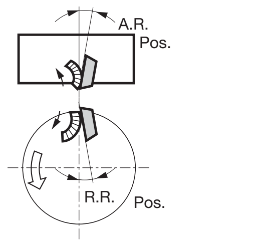
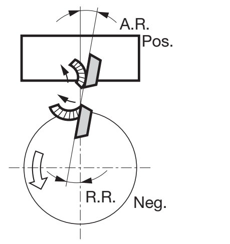
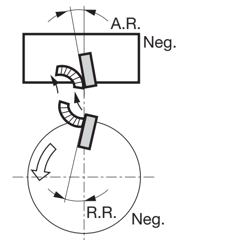
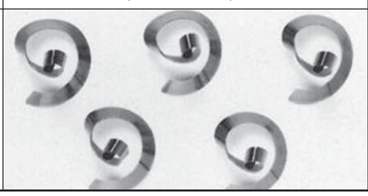
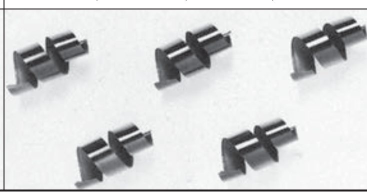
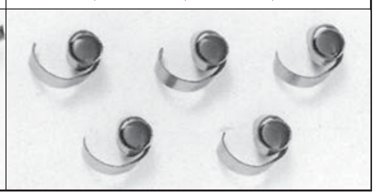
Inclination angle (I.A.) chart



Example: (1) A.R. (Axial rake angle) = - 10°, (2) R.R. (Radial rake angle) = +15°, (3) A.A. (Approach angle) = 25° -> (4) I.A. (inclination angle) = -15°

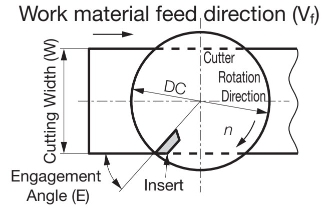
Formula: tan I.R.=tan A.R./cos A.A. - tan R.R./sin A.A.

■ Rake Angle Combination and Features

	Double Positive type	Negative - Positive type	Double Negative type
Edge combination and chip evacuation (A.R.: Axial rake angle R.R : Radial rake angle : Chip and evacuation direction : Cutter rotation direction)			
Advantages	Good sharpness	Excellent chip evacuation and sharpness	Economical design enabling use of both sides of insert Strong cutting edge
Disadvantages	Only single-sided inserts with a lower cutting edge strength can be used	Only single-sided inserts can be used	Dull cutting action
Applications	Machining of aluminum alloy and other materials requiring sharpness	Machining of steel, cast iron, and stainless steel, with suitable strength and good evacuation	For hard materials such as cast iron or poor surfaces such as castings
Cat. No.	ANX series, HF series, WAX series	WGX series, WFX series, RSX series, MSX series	TSX series, DGC series, DFC series, DNX series
Chips (Ex.) (· Work material: SCM435 · v_c=130m/min f_z=0.23mm/t a_p=3mm)			

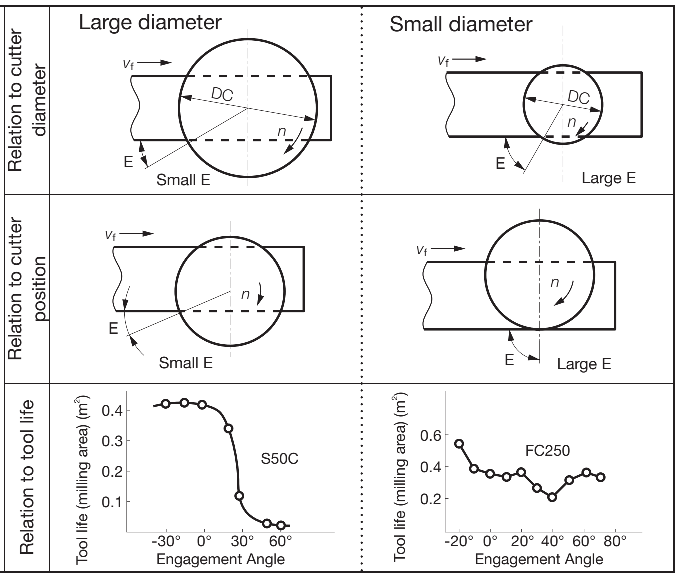
Milling Edition - The Basics of Milling

■ Relation between engagement angle and tool life



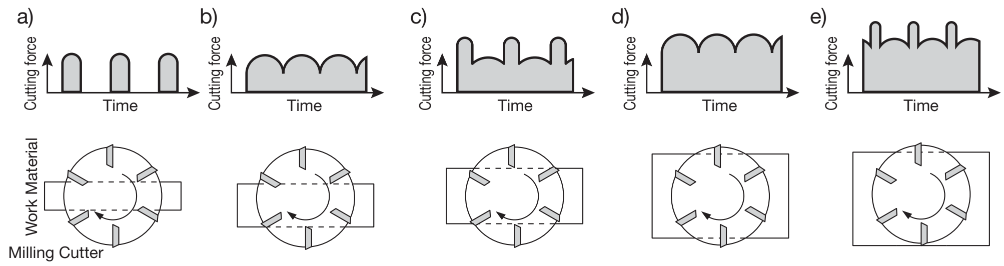
The engagement angle denotes the angle at which the full length of the cutting edge comes in contact with the work material, with reference to the feed direction.

- 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, a cutting width 70 to 80% of the cutter diameter is considered appropriate, as shown in example d). However, this may not apply due to the actual rigidity of the machine or workpiece, and the 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 edges in contact at any time.
- e) · 2 to 3 edges in contact.

■ Improving surface roughness

(1) Inserts with wiper flat

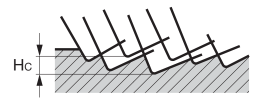
When all of the cutting edges have wiper flats, a few teeth protrude due to inevitable runout and act as wiper inserts.

- Insert equipped with straight wiper flat (Face angle: Around 15' to1°)
- Insert equipped with curved wiper flat (Curvature: ≈ R500 (example))

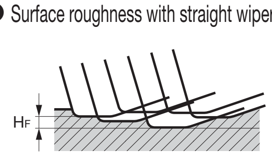
(2) **Wiper insert assembling system**

A system in which one or two inserts (wiper inserts) protrude with a smooth curved edge just a little beyond the other teeth to wipe the milled surface. (Applicable to WGX series, DGC series, etc.)

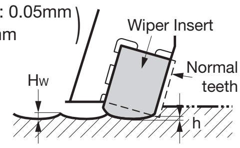
● Surface roughness without wiper flat



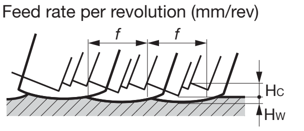
● Surface roughness with straight wiper flat



h: Projection value of wiper insert
(Cast Iron: 0.05mm
Al: 0.03mm)

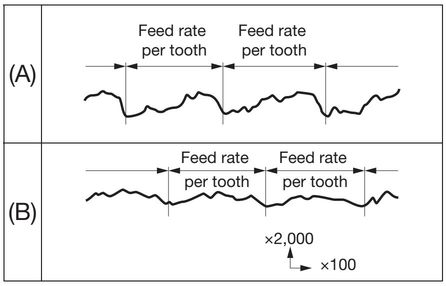


f: Feed rate per revolution (mm/rev)



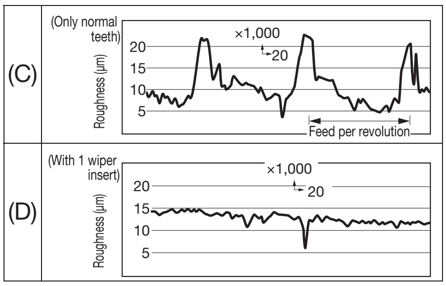
Hc: Surface roughness with only normal teeth
Hw: Surface roughness with wiper insert

● Surface roughness with wiper flat (difference in face cutting edge)



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

● Effects of wiper insert (example)

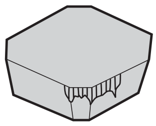


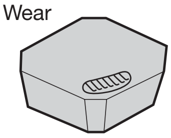
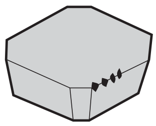
- Work material: FC250
- Cutter: DPG4100R
- Insert: SPCH42R
- Face runout: 0.015mm
- Runout: 0.04mm
  v_c = 105m/min
  f_z = 0.29mm/t
  (1.45 mm/rev)

(C): Normal teeth
(D): Per wiper edge

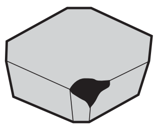
Milling Edition - Troubleshooting for Milling

■Troubleshooting for Milling

<table>
<tr><th colspan="2">Failure</th><th colspan="2">Basic Remedies</th><th>Countermeasure Examples</th></tr>
<tr><td rowspan="4">Cutting Edge Failure</td><td>Excessive Flank Wear
</td><td>Tool Grade

Cutting Conditions</td><td>· Select a more wear-resistant grade.
Carbide (P30→P20 / K20→K10) → (Coated / Cermet)
· Decrease the cutting speed.
· Increase feed rate.</td><td>· 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, T4500A (Cermet)</td><td>ACK100 (Coated)
BN7000 (SUMIBORON)</td><td>DA1000 (SUMIDIA)</td></tr><tr><td>Roughing</td><td>ACP100 (Coated)</td><td>ACK200 (Coated)</td><td>DL1000 (Coated)</td></tr></table></td></tr>
<tr><td>Excessive Crater Wear
</td><td>Tool Grade
Tool Design
Cutting Conditions</td><td>· Select a crater-resistant grade.
· Use a sharp chipbreaker. (G → L)
· Decrease the cutting speed.
· Reduce depth of cut and feed rate.</td><td>· 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, T4500A (Cermet)</td><td>ACK100 (Coated)</td><td>DA1000 (SUMIDIA)</td></tr><tr><td>Roughing</td><td>ACP100 (Coated)</td><td>ACK200 (Coated)</td><td>DL1000 (Coated)</td></tr></table></td></tr>
<tr><td>Chipping
</td><td>Tool Grade

Tool Design

Cutting Conditions</td><td>· Use a tougher grade.
P10→P20→P30
K01→K10→K20
· Select a negative/positive cutter with a large peripheral cutting edge angle (a small approach angle).
· Reinforce the cutting edge (honing).
· Select a stronger chipbreaker. (G → H)
· Reduce feed rate.</td><td>· Recommended Insert Grades<table><tr><th></th><th>Steel</th><th>Cast Iron</th></tr><tr><td>Finishing</td><td>ACP200 (Coated)</td><td>ACK200 (Coated)</td></tr><tr><td>Roughing</td><td>ACP300 (Coated)</td><td>ACK300 (Coated)</td></tr></table>· Recommended cutter: SEC-WaveMill WGX series
· Cutting conditions: Refer to H22</td></tr>
<tr><td>Fracture
</td><td>Tool Grade

Tool Design

Cutting Conditions</td><td>· If it is due to excessive low speeds or very low feed rates, select a grade resistant to adhesion.
· If the cause is thermal cracking, select a thermal impact resistant grade.
· Select a negative/positive (or double negative) cutter type 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).
· Select appropriate conditions for that particular application.</td><td>· Recommended Insert Grade<table><tr><th></th><th>Steel</th><th>Cast Iron</th></tr><tr><td>Roughing</td><td>ACP300 (Coated)</td><td>ACK300 (Coated)</td></tr></table>· Recommended cutter: SEC-WaveMill WGX series
· Insert Thickness: 3.18 → 4.76mm
· Chipbreaker type: Standard → Strong edge type
· Cutting conditions: Refer to H22</td></tr>
<tr><td rowspan="5">Others</td><td>Unsatisfactory Machined Surface Finish</td><td>Tool Grade

Tool Design

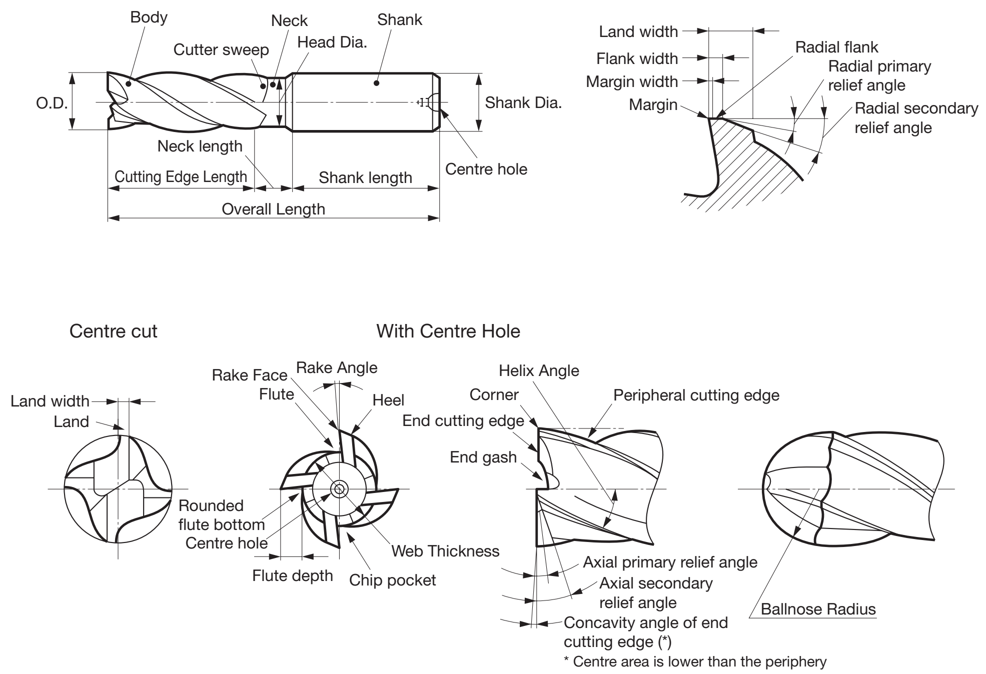
Cutting Conditions</td><td>· Select an adhesion-resistant grade.
Carbide → Cermet
· Improve axial runout of cutting edges.
(Use a cutter with less runout / Mount the correct insert)
· Use a wiper insert.
· Use cutters dedicated for finishing.
· Increase the cutting speed.</td><td>· Recommended Cutters and Insert Grades<table><tr><th></th><th></th><th>Steel</th><th>Cast Iron</th><th>Non-Ferrous Alloy</th></tr><tr><td rowspan="2">General-purpose</td><td>Cutter</td><td>WGX series*</td><td>DGC series</td><td>ANX series*</td></tr><tr><td>Insert</td><td>ACP200 (Coated)</td><td>ACK200 (Coated)</td><td>DA1000 (SUMIDIA)</td></tr><tr><td rowspan="2">Finishing</td><td>Cutter</td><td>WGX series</td><td>FMU series</td><td>ANX series</td></tr><tr><td>Insert</td><td>T4500A (Cermet)</td><td>BN7000 (SUMIBORON)</td><td>DA1000 (SUMIDIA)</td></tr></table>Cutters marked with * can be mounted with wiper inserts.</td></tr>
<tr><td>Chattering</td><td>Tool Design

Cutting Conditions
Others</td><td>· Select a cutter with sharp cutting edges.
· Use an irregular pitched cutter.
· Reduce the feed rate.
· Improve the rigidity of the workpiece and cutter clamp.</td><td>· Recommended Cutters
For steel: SEC-WaveMill WGX series
For cast iron: SEC-Sumi Dual Mill DGC series
For light alloy: High-efficiency PCD Cutter for Aluminum Alloys ANX series</td></tr>
<tr><td>Unsatisfactory Chip Control</td><td>Tool Design</td><td>· Select a cutter with good chip evacuation features.
· Reduce number of teeth.
· Use a wide chip pocket.</td><td>· Recommended cutter: SEC-WaveMill WGX series</td></tr>
<tr><td>Edge Chipping On Workpiece</td><td>Tool Design

Cutting Conditions</td><td>· Increase the peripheral cutting edge angle (decrease the approach angle).
· Change the chipbreaker blade type. (G → L)
· Reduce the feed rate.</td><td>· Recommended cutter: SEC-WaveMill WGX series</td></tr>
<tr><td>Burr Formation</td><td>Tool Design
Cutting Conditions</td><td>· Use a sharp-edged cutter.
· Increase feed rate.
· Use a burr-proof insert.</td><td>· Recommended cutter: SEC-WaveMill WGX series + FG Chipbreaker
SEC-Sumi Dual Mill DGC series + FG Chipbreaker</td></tr>
</table>

Endmilling Edition - The Basics of Endmilling

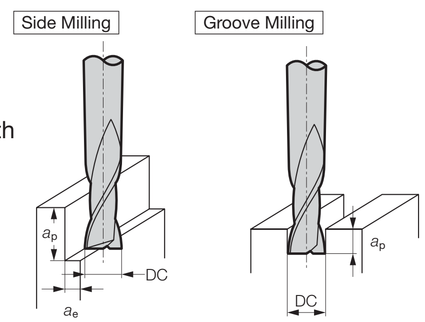
■ Parts



■ Calculating Cutting Conditions (Square Endmill)

● Calculating cutting speed

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



● Calculating feed rate per revolution and per tooth

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

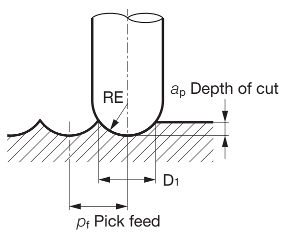
$$v_f = n \times f_z \times z \qquad f_z = \frac{f}{z} = \frac{v_f}{n \times z}$$

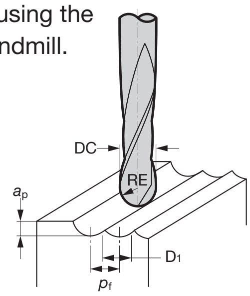
(Ballnose Endmill)

● Calculating notch width (D_1)

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

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

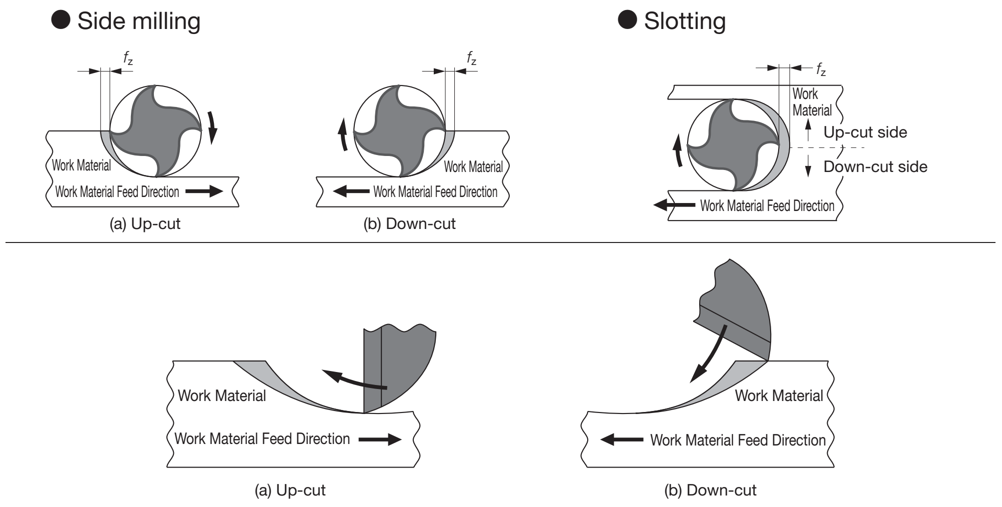




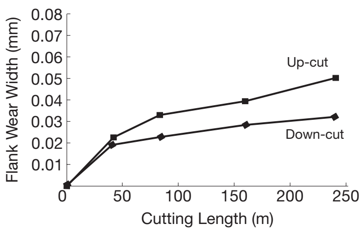
v_c : Cutting speed (m/min)
π : ≈3.14
DC : Endmill diameter (mm)
n : Spindle speed (min^{-1})
v_f : Feed rate (mm/min)
f : Feed rate per revolution (mm/rev)
f_z : Feed rate per tooth (mm/t)
z : Number of teeth
a_p : Depth of cut in axial direction (mm)
a_e : Depth of cut in radial direction (mm)
RE : Ballnose radius

Endmilling Edition - The Basics of Endmilling

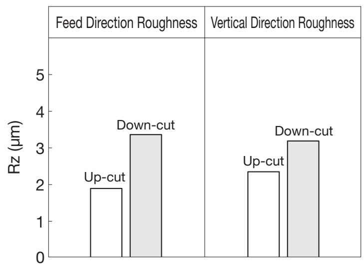
■ Up-cut and Down-cut



● Cutting Edge Wear Amount



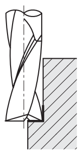
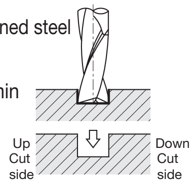
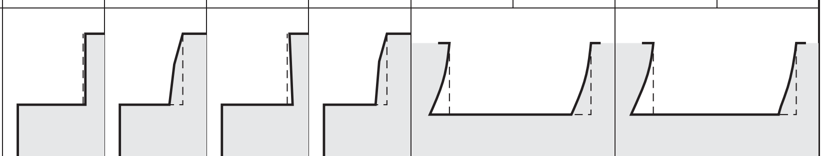
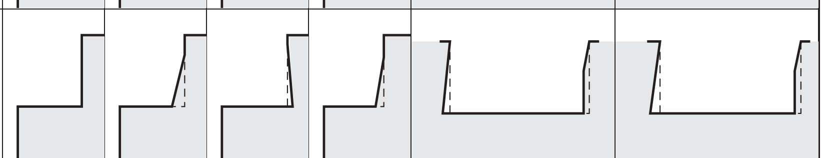
● Surface Roughness

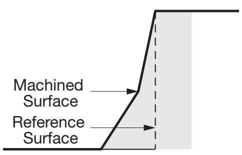


● Cutting Conditions

Work material: S50C
Tool: GSX21000C-2D
(ø10mm, 2 teeth)
Cutting conditions: v_c=88m/min
(n=2800min^{-1})
v_f=560mm/min
(f_z=0.1mm/t)
a_p=15mm
a_e=0.5mm
Side milling
Dry, air

■ Relation Between Cutting Conditions and Deflection

Endmill specifications			Side milling				Grooving			
			Work Material: Pre-hardened steel (40HRC) Cutting conditions: v_c=25m/min a_p=12mm a_e=0.8mm 				Work Material: Pre-hardened steel (40HRC) Cutting conditions: v_c=25m/min a_p=8mm a_e=8mm  Up Cut side / Down Cut side			
Cat. No.	Number of Teeth	Helix Angle	Feed Rate 0.16mm/rev		Feed Rate 0.11mm/rev		Feed Rate 0.05mm/rev		Feed Rate 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. · The 4-flute type 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. · The 4-flute type offers higher rigidity and less deflection.			



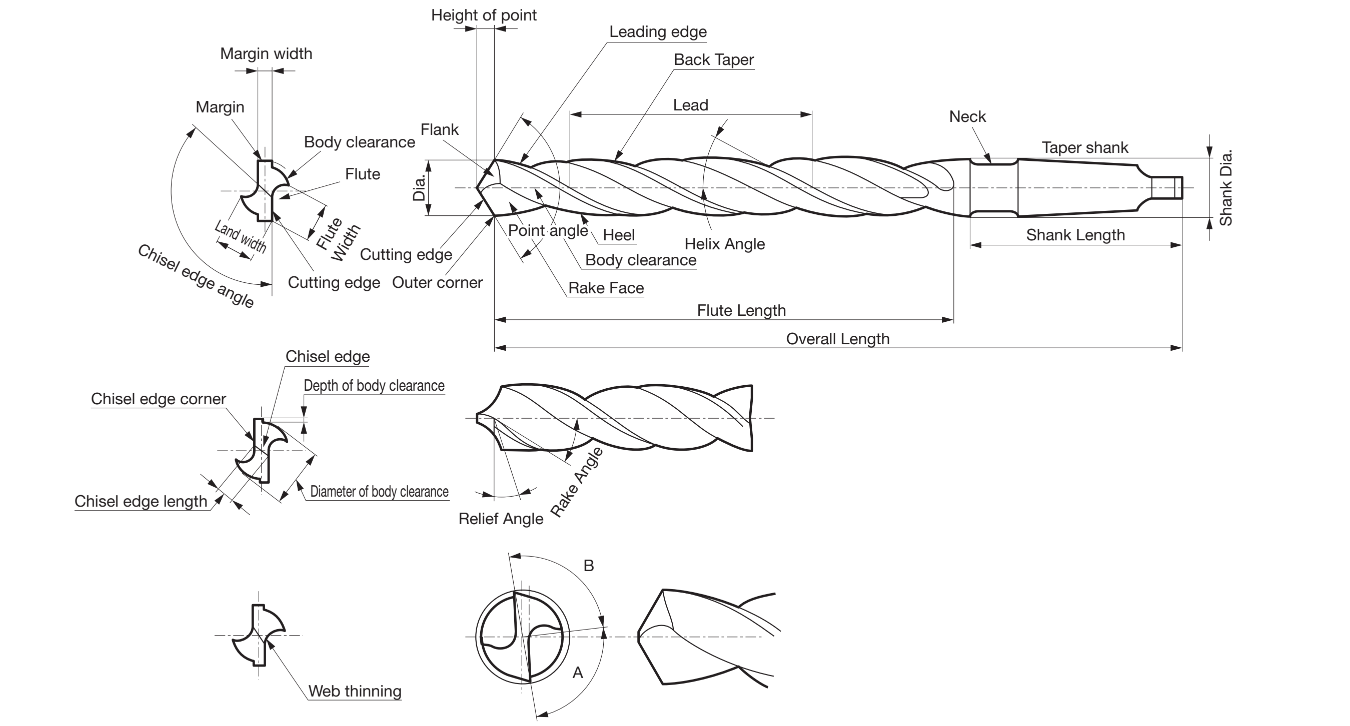
Endmilling Edition - Troubleshooting for Endmilling

■ Troubleshooting for Endmilling

Failure		Cause		Countermeasures
Cutting Edge Failure	Excessive Wear	· Cutting Conditions	· Cutting speed is too fast	· Decrease cutting speed and feed rate
			· Feed rate is too large	
		· Tool Shape	· The flank relief angle is too small	· Change to an appropriate flank relief angle
		· Tool Material	· Insufficient wear resistance	· Select a more wear-resistant substrate · Use a coated tool
	Chipping	· Cutting Conditions	· Feed rate is too large	· Decrease cutting speed
			· Depth of cut is too large	· Reduce depth of cut
			· Tool overhang is too long	· Adjust tool overhang to the correct length
		· Machine Area	· Workpiece clamping is too weak	· Clamp the workpiece firmly
			· Tool mounting is unstable	· Make sure the tool is seated in the chuck properly
	Fracture	· Cutting Conditions	· Feed rate is too large	· Decrease cutting speed
			· Depth of cut is too large	· Reduce depth of cut
			· Tool overhang is too long	· Reduce tool overhang as much as possible
			· Cutting edge is too long	· Select a tool with a shorter cutting edge
		· Tool Shape	· Web thickness is too small	· Change to more appropriate web thickness
Others	Deflection in Wall Surface	· Cutting Conditions	· Feed rate is too large	· Decrease cutting speed
			· Depth of cut is too large	· Reduce depth of cut
			· Tool overhang is too long	· Adjust tool overhang to the correct length
			· Cutting on the down-cut	· Change direction to up-cut
		· Tool Shape	· Helix angle is too large	· Use a tool with a smaller helix angle
			· Web thickness is too small	· Use a tool with the appropriate web thickness
	Unsatisfactory Machined Surface Finish	· Cutting Conditions	· Feed rate is too large	· Decrease cutting speed
			· Chip biting	· Use air blow · Use an insert with a larger relief pocket
	Chattering	· Cutting Conditions	· Cutting speed is too fast	· Decrease the cutting speed
			· Cutting on the up-cut	· Change direction to down-cut
			· Tool overhang is too long	· Adjust tool overhang to the correct length
		· Tool Shape	· Rake angle is too large	· Use a tool with an appropriate rake angle
		· Machine Area	· Workpiece clamping is too weak	· Clamp the workpiece firmly
			· Tool mounting is unstable	· Make sure the tool is seated in the chuck properly
	Chip Blockage	· Cutting Conditions	· Feed rate is too large	· Decrease cutting speed
			· Depth of cut is too large	· Reduce depth of cut
		· Tool Shape	· Too many teeth	· Reduce number of teeth
			· Chip biting	· Use air blow

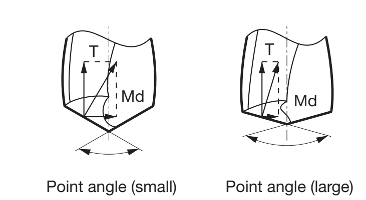
Drilling Edition - The Basics of Drilling

■ Drill Parts



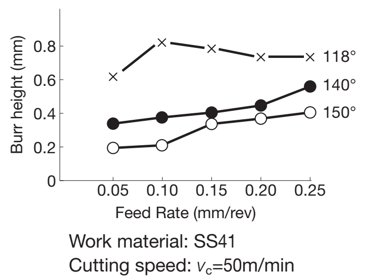
A:B or A/B = Groove width ratio

● Point angle and force



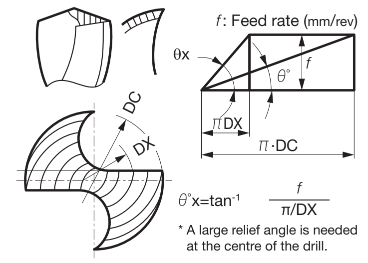
When point angle is large, thrust increases but torque decreases.

● Point angle and burrs

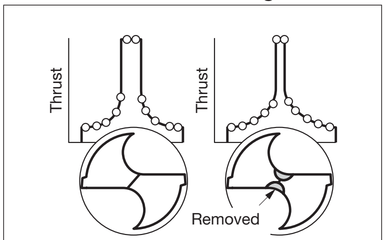


When point angle is large, burr height becomes low.

● Minimum requirement relief angle for drilling



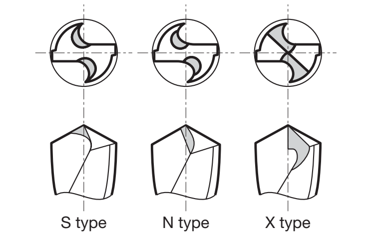
● Effects of web thinning



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

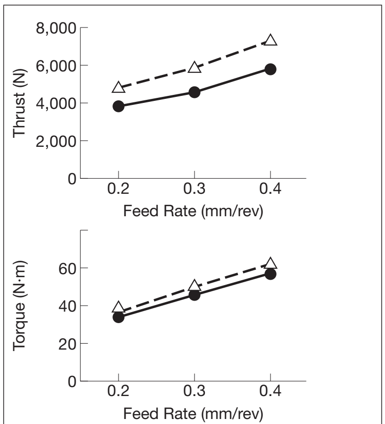
● Chisel width decreased by thinning

Typical types of thinning



S type: Standard type used for general-purposes.
N type: Suitable for thin web drills.
X type: For hard-to-cut materials or deep hole drilling. Entry easier.

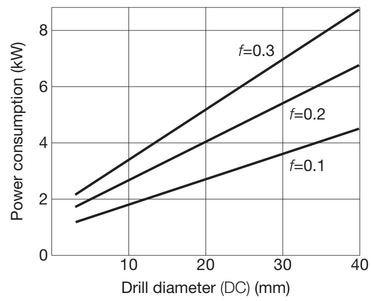
● Relation between edge treatment and cutting force

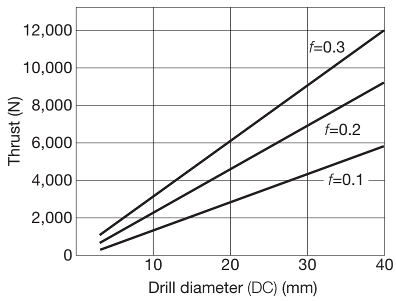


Drill: MULTIDRILL KDS215MAK
Edge treatment width: ●→0.15mm △→0.23mm
Work material: S50C (230HB)
Cutting conditions: v_c=50m/min Wet

Drilling Edition - The Basics of Drilling

■ Reference for Power Requirements and Thrust





f: Feed rate (mm/rev)

Work material: S48C (220HB)

■ Cutting Conditions Selection

● Control cutting force
For low-rigidity machines

The following table shows the relation between edge treatment width and cutting force. If the cutting force is too great and causes issues, take measures such as reducing the feed rate or reducing the cutting edge treatment of the drill.

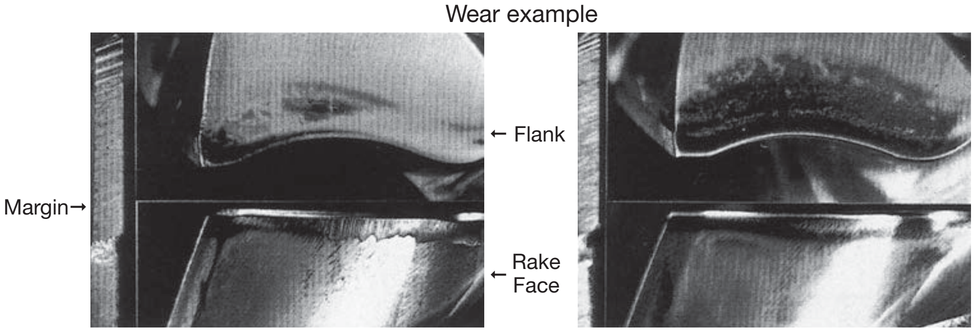
Cutting Conditions		Edge treatment width			
		0.15mm		0.05mm	
v_c (m/min)	*f* (mm/rev)	Torque (N/m)	Thrust (N)	Torque (N/m)	Thrust (N)
40	0.38	12.8	2,820	12.0	2,520
50	0.30	10.8	2,520	9.4	1,920
60	0.25	9.2	2,320	7.6	1,640
60	0.15	6.4	1,640	5.2	1,100

Drill diameter: ø10mm
Work material: S50C (230HB)

● High speed machining recommendation

If the machine has enough power and sufficient rigidity, reasonable tool life can be ensured even when adopting higher-efficiency machining. However, sufficient coolant must be supplied.

Wear example

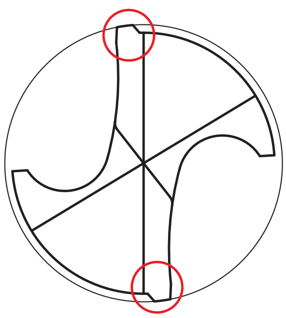


v_c=60m/min　　　v_c=120m/min

Work material : S50C (230HB)
Cutting conditions: *f* = 0.3mm/rev
H=50mm
Tool life : 600 holes (Cutting length: 30m)

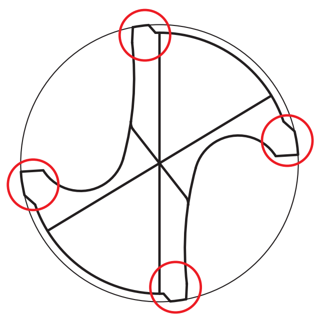
■ Explanation of Margins (Difference between single and double margins)

● Single Margin (2 guides: ○ part)



● Shape used on most drills

● Double Margin (4 guides: ○ part)

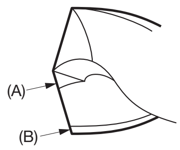


● 4-point guiding reduces hole bending and waviness for improved stability and accuracy during deep hole drilling.

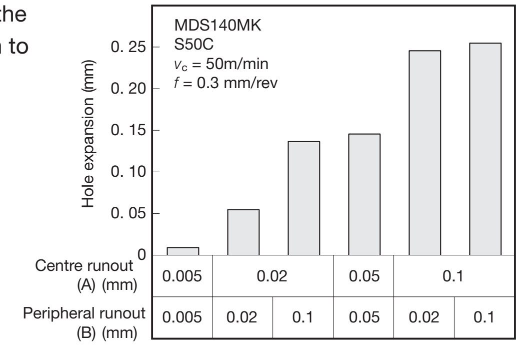
Drilling Edition - The Basics of Drilling

■ Runout Accuracy

For the runout accuracy of web-thinned drills, the runout after thinning (A) is important in addition to the difference in lip height (B).



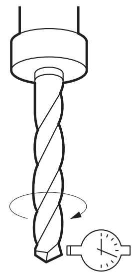
(A): Runout accuracy of thinning point
(B): The difference of the lip height



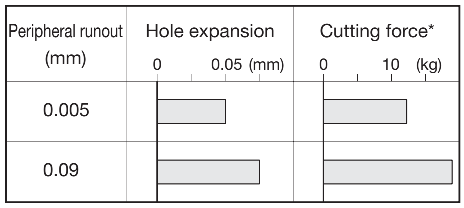
■ Drill Mounting Peripheral Runout Accuracy

● **When the tool rotates**

The peripheral runout accuracy of the drill mounted on the spindle should be controlled within 0.03mm. If the runout exceeds the limit, the drilled hole will become large with an increase in lateral cutting force, which may result in drill breakage.



Runout: Within 0.03mm

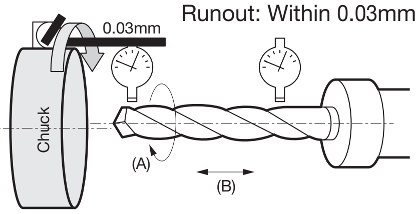


* Horizontal cutting force.
Drill: MDS120MK, work material: S50C (230HB)
Cutting Conditions: v_c=50m/min, f = 0. 3mm/rev, H = 38mm
Water-soluble Coolant

● **When the work material rotates**

The peripheral runout at the drill edge (A) and the concentricity at (B) should be controlled within 0.03mm.

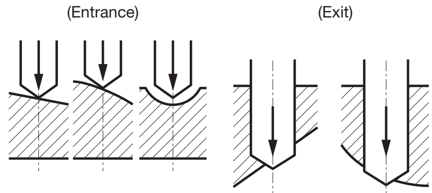
Runout: Within 0.03mm



■ Work Material Surface and Drill Performance

● **Work material with slanted or uneven surface**

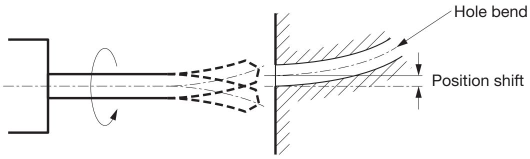
If the surface of the hole entrance or exit is slanted or uneven, decrease the feed rate to 1/3 to 1/2 of the recommended cutting conditions.



■ How to Use a Long Drill

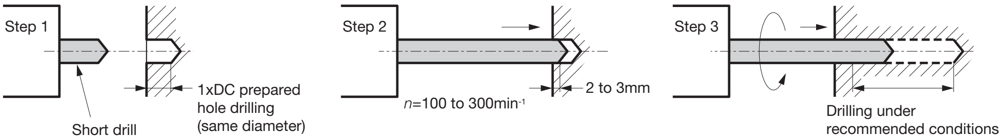
● **Problem**

When using a long drill (e.g. XHGS type), SMDH-D type drill or SMDH-12D type drill at high rotation speeds, the runout of the drill tip may cause a deviation at the entry point as shown on the right, bending the drill hole and resulting in drill breakage.



● **Remedies**

Method 1



Method 2 *Low rotation speed minimises centrifugal forces and prevents the drill from bending.

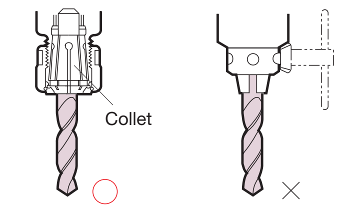
Drilling Edition - MULTIDRILL Usage Guidance Drilling Edition

■ Drill Retention

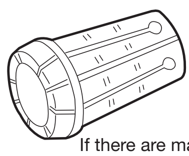
(1) Collet Selection and Maintenance

- Ensure proper chucking of drills to prevent vibration. Collet type chucks are recommended, as the grip is strong and can be used with ease.

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



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

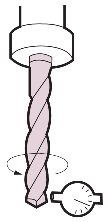


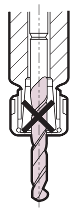
If there are marks, repair with an oilstone or change to a new one.

(2) Drill Mounting

- The peripheral runout of the drill mounted on the spindle must be within 0.03mm.
- Do not chuck on the drill flute.

(If the drill flute is inside the holder, chip evacuation will be obstructed, causing damage to the drill.)


Peripheral runout within 0.03mm.


Do not grip on the drill flute.

■ Using Cutting Oil

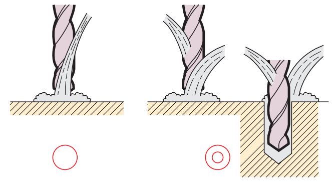
(1) Choosing Cutting Oil

- If the cutting speed is more than 40m/min, cutting oil (JISW1 type 2) is recommended as its cooling effects and chip control capacity are good, and it is highly soluble.
- For optimum tool life at cutting speeds of less than 40m/min, sulfo-chlorinated oil (JISA1 type 1) is recommended as it has a lubricating effect and is non-water soluble. * Insoluble cutting oil may be flammable. To prevent fire, a substantial amount of oil should be used to cool the component so that smoke and heat will not be generated.

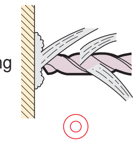
(2) Supply of Coolant

- External Coolant Supply
  There must be a sufficient external supply of coolant at the hole position.
  Coolant pressure 0.3 to 0.5MPa, coolant volume 3 to 10 ℓ/min is a guideline.
- Internal Coolant Supply
  For holes ø4 or smaller, the oil pressure must be at least 1.5MPa to ensure a sufficient supply of coolant. For ø6 and above, if L/D is < 3, the pressures should be at 0.5 to 1.0MPa. If L/D is > 3, a hydraulic pressure of at least 1 to 2MPa is recommended.

- External Coolant Supply
- Vertical drilling

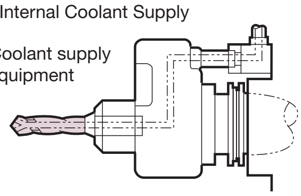


- Horizontal drilling

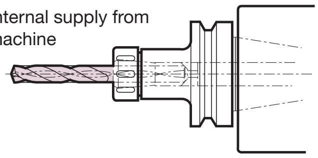


Use high pressure at entrance

- Internal Coolant Supply
- Coolant supply equipment



- Internal supply from machine

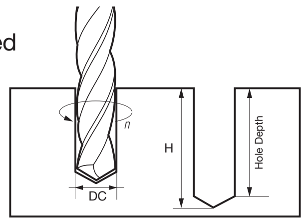


■ Calculation of Power Consumption and Thrust

- Calculating cutting speed

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

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



- Calculating feed rate per revolution and per tooth

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

- Calculating cutting time

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

v_c : cutting speed (m/min)
π : ≈ 3.14
DC : Drill diameter (mm)
n : Rotation speed (min^{-1})
v_f : Feed rate (mm/min)
f : Feed rate per revolution (mm/rev)
H : Drilling depth (mm)
T : Cutting time (min)
HB : Work material Brinell hardness

- Calculating power consumption and thrust <Experimental>

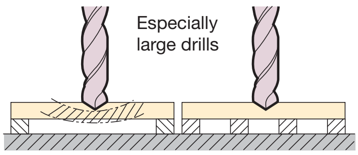
$$\text{Power consumption (kW)} = HB \times DC^{0.68} \times v_c^{1.27} \times f^{0.59} / 36{,}000$$

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

* When designing the machine, an allowance of 1.6 x power consumption and 1.4 x thrust should be given.

■ Clamping of the Workpiece

High thrust forces occur during high-efficiency drilling. Therefore, the workpiece must be supported to prevent fractures caused by deformation. Large torques and horizontal cutting forces also occur. Therefore, the workpiece must be clamped firmly enough to withstand them.

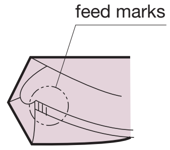


Deformation → chipping ×
Support needed ○

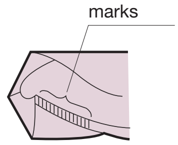
■ Drill Regrinding

- 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.
  Regrind promptly.
- How and where to regrind
  We recommend regrinding and recoating.
  Regrinding alone is fine, but if the work material is steel, 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 their vendor.

- Tool life determinant



○ Appropriate Tool Life



× Over-used

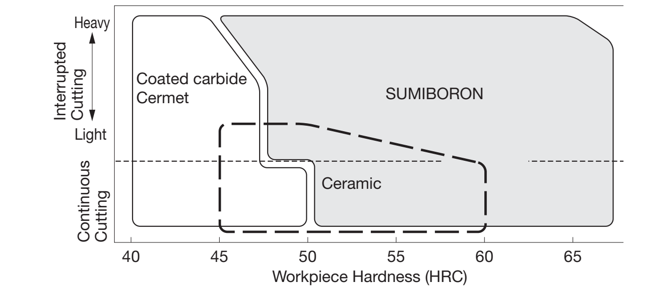
Drilling Edition - Troubleshooting for Drilling

■ Troubleshooting for Drilling

Failure		Cause	Basic Remedies	Countermeasure Examples
Drill Failure	Excessive Wear on Rake Face	· Inappropriate cutting conditions	· Use higher cutting speeds	· Refer to the upper limit of the recommended cutting conditions listed in this catalogue
			· Increase feed rate	· Refer to the upper limit of the recommended cutting conditions listed in this catalogue
		· Unsuitable coolant	· Reduce pressure if using internal coolant	· 1.5MPa or less (external coolant supply can be used at hole depths (L/D) of 2 or less)
			· Use coolant with more lubricity	· Use JIS A1 grade No. 1 or its equivalent
	Chisel Point Breakage	· Off-centre starts	· Reduce feed rate at entry point	· f=0.08 to 0.12mm/rev
			· Pre-machining of flat surface for entry	· Drill flat base with Flat MULTIDRILL
		· Equipment, work materials, etc. lack rigidity	· Change cutting conditions to reduce resistance	· Increase v_c to decrease f (reduce thrust)
			· Improve clamp strength of work material	
		· Cutting edge is too weak	· Increase size of chisel width	· Use a chisel with a width of 0.1 to 0.2mm
			· Increase amount of honing on cutting edge	· Increase the width of the thinning area at the centre by 1.5 times
	Breakage on Peripheral Cutting Edge	· Inappropriate cutting conditions	· Decrease the cutting speed	· Refer to the lower limit of the recommended cutting conditions listed in this catalogue
			· Reduce feed rate	· Refer to the lower limit of the recommended cutting conditions listed in this catalogue
		· Unsuitable coolant	· Use coolant with more lubricity	· Use JIS A1 grade No. 1 or its equivalent
		· Equipment, work materials, etc. lack rigidity	· Improve clamp strength of work material	
		· Cutting edge is too weak	· Increase amount of honing on cutting edge	· Increase the width of the outer cutting edge by 1.5 times
			· Reduce the front relief angle	· Reduce the front relief angle by 2 to 3°
		· Entry from peripheral cutting edge	· Increase margin width (W margin specification)	· Increase the margin width by 2 to 3 times
		· Interruption during drill engagement	· Reduce feed rate	· Refer to the lower limit of the recommended cutting conditions listed in this catalogue
			· Increase amount of honing on cutting edge	· Increase the width of the outer cutting edge by 1.5 times
			· Reduce the front relief angle	· Reduce the front relief angle by 2 to 3°
	Margin Wear	· Inappropriate cutting conditions	· Decrease the cutting speed	· Refer to the lower limit of the recommended cutting conditions listed in this catalogue
		· Unsuitable coolant	· Use coolant with more lubricity	· Use JIS A1 grade No. 1 or its equivalent
			· Use more coolant	· If using external coolant, switch to internal coolant
		· Remaining margin wear	· Schedule for earlier regrind and ensure back taper	· If margin damage occurs, regrind to 1mm or less
		· Improper tool design	· Increase amount of back taper	· Make back taper 0.5/100
			· Reduce margin width	· Reduce the margin width to around 2/3
	Drill Breakage	· Chip blockage	· Use the optimal cutting conditions and tools	· Refer to recommended cutting conditions listed in this catalogue
			· Use more coolant	· If using external coolant, switch to internal coolant
		· Collet clamp too weak	· Use a collet with strong grip force	· If the collet chuck is damaged, replace it · Change the collet holder to the next size up
		· Equipment, work materials, etc. lack rigidity	· Improve clamp strength of work material	
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 the recommended cutting conditions listed in this catalogue
			· Pre-machining of flat surface for entry	· Flat machining with endmill
		· Drill lacks rigidity	· Use the optimal drill type for the hole depth	· Refer to this catalogue
			· Improve overall drill rigidity	· Large web, small groove width
		· Drill has runout	· Improve drill mounting precision	· If the collet chuck is damaged, replace it
			· Improve drill retention rigidity	· Change the collet holder to the next size up
		· Equipment, work materials, etc. lack rigidity	· Improve clamp strength of work material	
	Poor Surface Roughness	· Inappropriate cutting conditions	· Increase cutting speed	· Refer to the upper limit of the recommended cutting conditions listed in this catalogue
			· Reduce feed rate	· Refer to the lower limit of the recommended cutting conditions listed in this catalogue
		· Unsuitable coolant	· Use coolant with more lubricity	· Use JIS A1 grade No. 1 or its equivalent
	Holes Not Straight	· Off-centre starts	· Increase feed rate	· Refer to the upper limit of the recommended cutting conditions listed in this catalogue
		· Drill is not mounted properly	· Improve drill mounting precision	· If the collet chuck is damaged, replace it
			· Improve drill retention rigidity	· Change the collet holder to the next size up
		· Equipment, work materials, etc. lack rigidity	· Improve clamp strength of work material	
			· Select a double margin tool	· Refer to this catalogue
Unsatisfactory Chip Control	Chips Clog	· Inappropriate cutting conditions	· Increase cutting speeds	· Refer to the upper limit of the recommended cutting conditions listed in this catalogue
			· Increase feed rate	· Refer to the upper limit of the recommended cutting conditions listed in this catalogue
		· Poor chip evacuation	· Increase volume if using internal coolant	
	Long Stringy Chips	· Inappropriate cutting conditions	· Increase feed rate	· Refer to the upper limit of the recommended cutting conditions listed in this catalogue
			· Increase cutting speeds	· Refer to the upper limit of the recommended cutting conditions listed in this catalogue
		· Strong cooling effect	· Reduce pressure if using internal coolant	· The pressure should be 1.5 MPa or less if using internal coolant
		· Dull cutting edge	· Reduce amount of edge honing	· Reduce the width to around 2/3

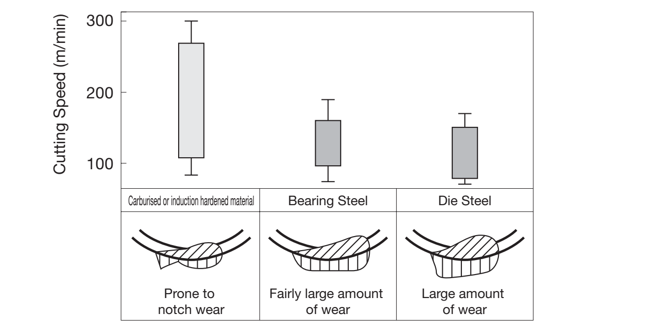
Hardened Steel Machining with SUMIBORON

■ Recommended zones for SUMIBORON by workpiece hardness and shape



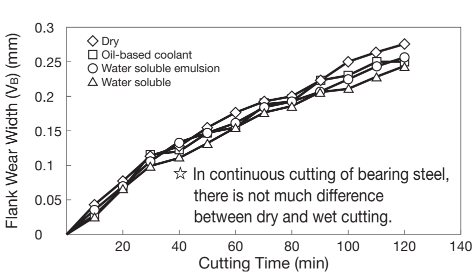
* While 50HRC is the limit for conventional coated carbide, coated carbide AC503U enables machining up to 62HRC (low-speed/continuous)

■ Cutting speed recommendations for each work material



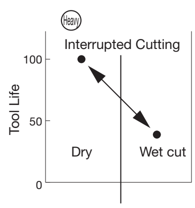
■ Influence of coolant on tool life

● Continuous Cutting



● Interrupted Cutting

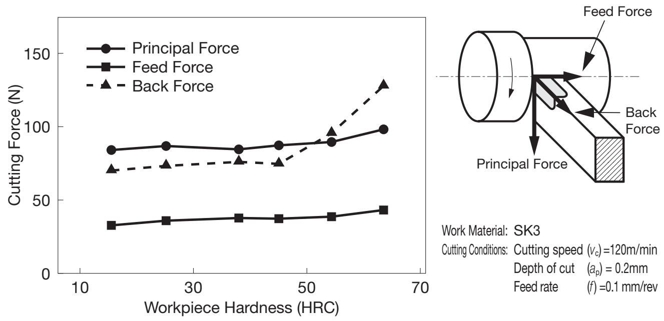
SKD11 with 4 U grooves
Cutting speed: v_c=100m/min
Depth of cut: a_p = 0.2 mm
Feed rate (f) =0.1 mm/rev



Work material: SUJ2(58 to 62 HRC)
Cutting conditions: TPGN160304
v_c=100m/min, a_p=0. 15mm, f=0. 1mm/rev
Continuous Cutting

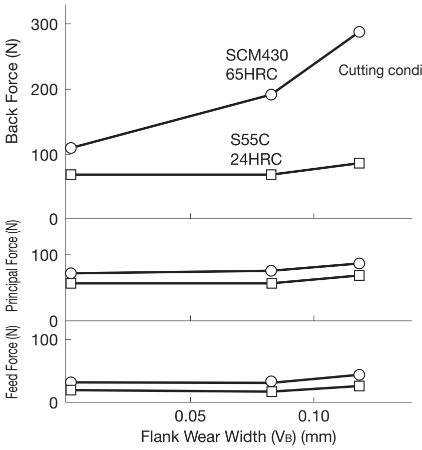
For continuous cutting, the influence of coolant on tool life is minimal.
For interrupted cutting, the thermal impact shortens the tool life in wet conditions.

■ Relation between work material hardness and cutting force



Back force increases substantially for harder workpieces.

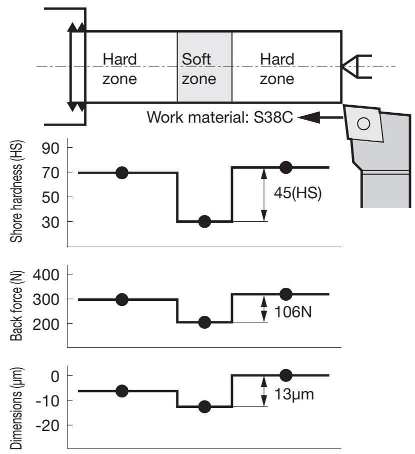
■ Relation between flank wear and cutting force



Cutting conditions: Cutting speed (v_c) = 80 m/min
Depth of cut (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.

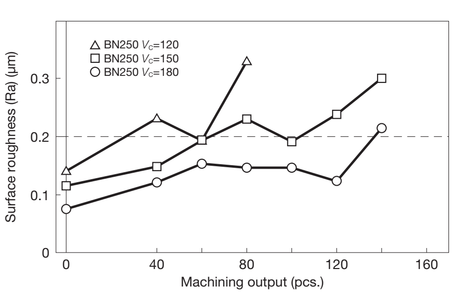
■ Influence of work material hardness on cutting force and accuracy



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

External dimensions in the soft zone are smaller due to lower cutting forces.

■ Relation between cutting speed and surface roughness

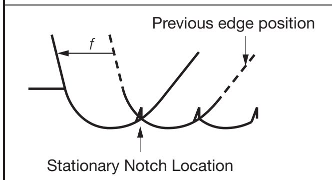
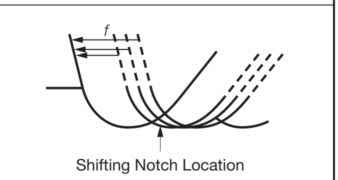
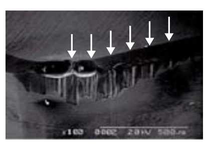


Work material: SCM420H
58 to 62HRC
Holder: MTXNR2525
Tool: NU-TNMA160408

Cutting Conditions:
v_c=120,150,180m/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
	
	

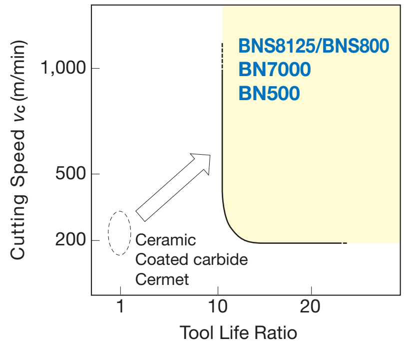
☆ Varying the feed rate spreads the notch location over a larger area.
→Surface finish improves and notch wear decreases.

High Speed Machining of Cast Iron with SUMIBORON

■ Advantages of using SUMIBORON for cast iron machining

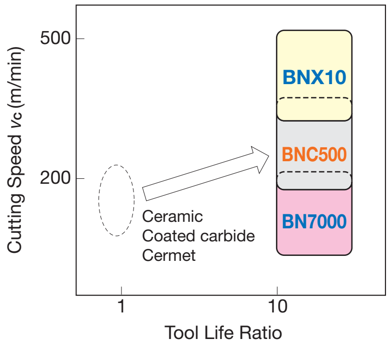
High-speed Machining

● Gray Cast Iron

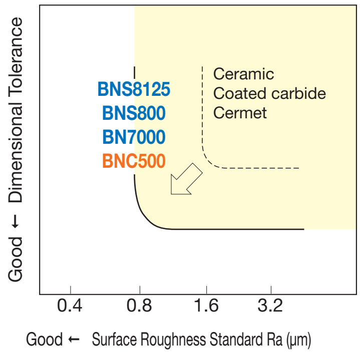


High-speed Machining

● Ductile Cast Iron

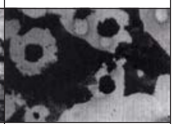
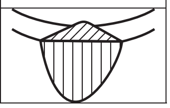


High-precision Machining

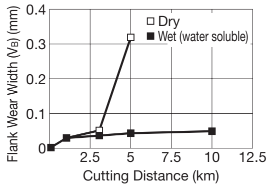


■ Turning

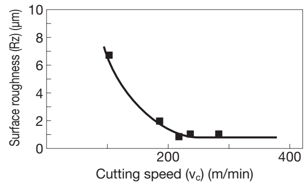
● Cast iron structure and wear shape examples

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

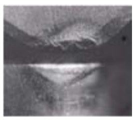
(v_c=200 to 500m/min)



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



WET (Water soluble)



DRY

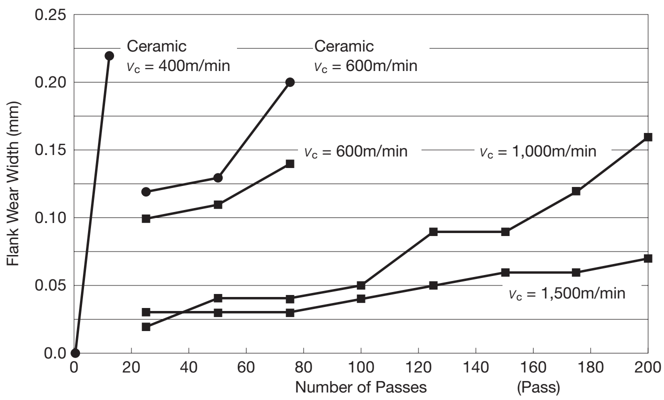
For turning cast iron with SUMIBORON, cutting speeds (v_c) should be 200m/min and above. Wet cutting is recommended.

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

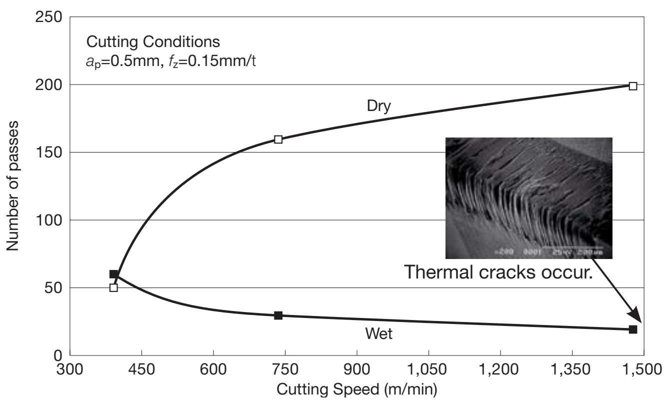
■ Milling

BN Finish Mill EASY (for high-speed finishing of cast iron)

- Enables cutting with v_c of 2,000m/min
- Surface finish roughness 3.2Rz (1.0Ra)
- Economical insert reduces running costs.
- Unit style enables easy runout adjustment.
- Employs safe, anti-centrifugal-force construction for high-speed conditions.



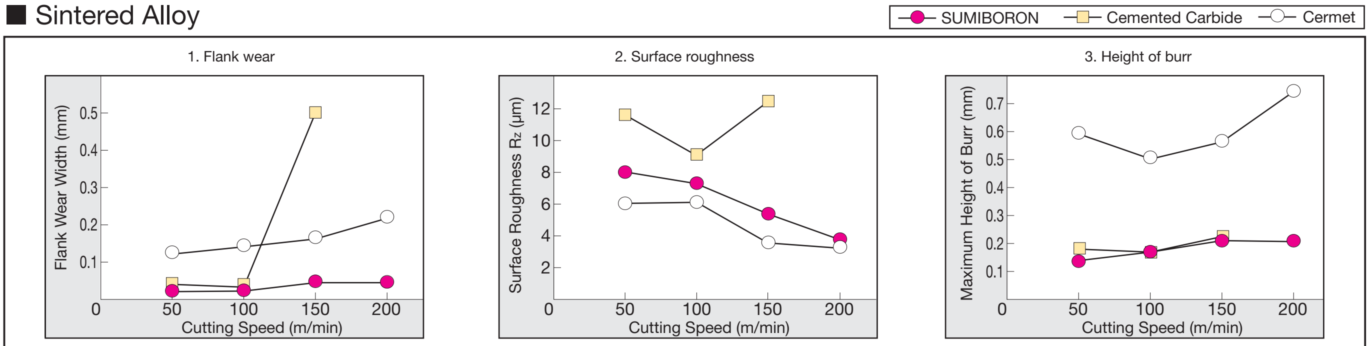
- Work material: Gray cast iron (FC250)
- Cutting conditions: a_p =0.5mm, f_z =0.1mm/t Dry
- Tool grade: BN7000



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

Machining Exotic Alloys with SUMIBORON

Sintered Alloy



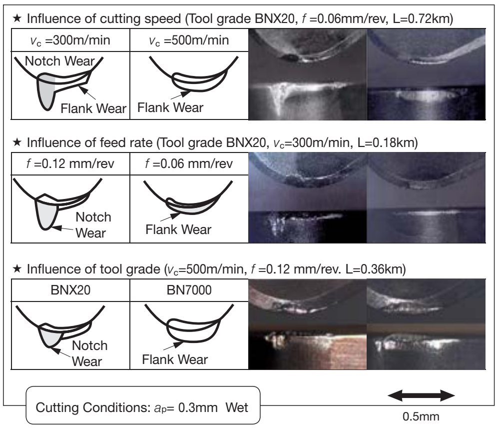
Work material: Equivalent to SMF4040, ø80-ø100mm heavy interrupted facing with grooves and drilled holes. (After 40 passes)
Cutting conditions: f=0.1mm/rev, a_p=0.1mm Wet
Tool Cat. No.: TNGA160404

Cemented carbide and cermet can perform at v_c up to 100m/min. However, if v_c is around 120m/min or higher, wear occurs rapidly, resulting in poorer surface roughness and greater spread of burrs. On the other hand, SUMIBORON exhibits stability and superior wear resistance, burr prevention and surface roughness, especially at high speeds.

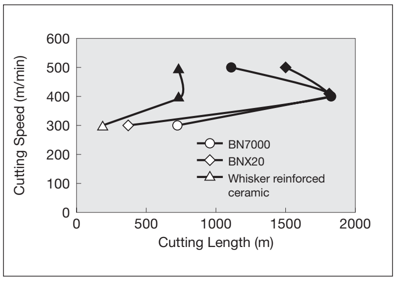
Heat-Resistant Alloy

Nickel based alloy

Typical tool damage of CBN tool when cutting Inconel 718

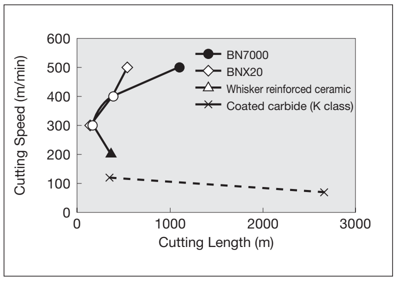


Cutting conditions: f = 0.06mm/rev, a_p= 0.3mm Wet



Tool life criteria
Notch wear = 0.25mm (○)
or flank wear = 0.25mm
BNX20 is recommended for high speed and low feed rates; BN7000 is recommended for cutting speeds below v_c=240m/min.

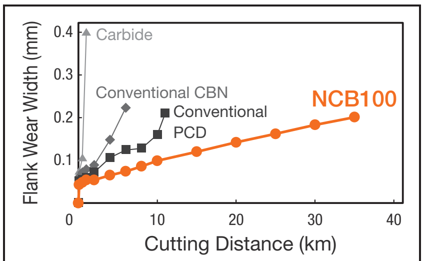
Cutting conditions: f = 0.12mm/rev, a_p= 0.3mm Wet



Tool life criteria
Notch wear = 0.25mm (○)
or flank wear = 0.25mm
BN7000 is recommended for cutting at high feed rates (over f=0.1mm/rev).

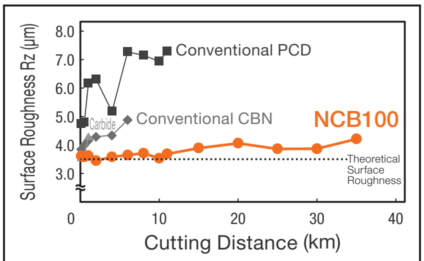
Cutting Performance (Machining Titanium Alloy)

Wear Resistance

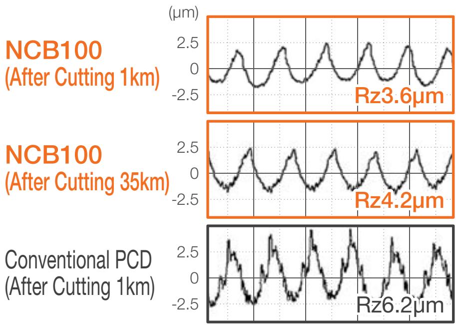


Work Material: Titanium Alloy (Ti-6Al-4V)
Tool Used: CNGA120408
Cutting Conditions: v_c = 150m/min, f = 0.15mm/rev, a_p = 0.5mm Wet (High Pressure Coolant)

Machined Surface Roughness



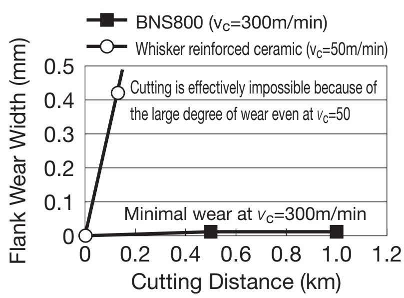
Work Material: Titanium Alloy (Ti-6Al-4V)
Tool Used: CNGA120408
Cutting Conditions: v_c = 150m/min, f = 0.15mm/rev, a_p = 0.5mm Wet (High Pressure Coolant)

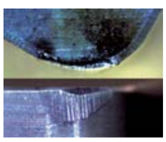


Hard Facing Alloys

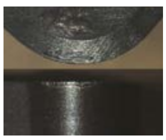
Work Material: Colmonoy No.6
(NiCr-based self-fluxing alloy)

Tool Cat. No. : SNGN090308
Cutting conditions : v_c=50,300m/min
f =0.1 mm/rev
a_p= 0.2mm
Dry





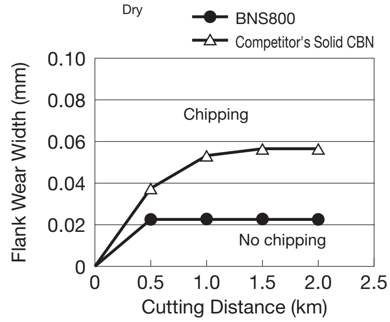
Whisker reinforced ceramic
(v_c =50m/min, after 0.1km of cutting)

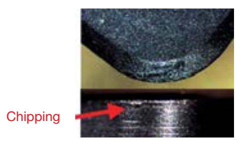


BNS800
(v_c =300m/min, after 1km of cutting)

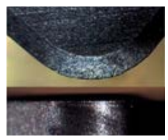
Work Material: Stellite SF-20
(Co-based self-fluxing alloy)

Tool Cat. No. : SNGN090308
Cutting conditions : v_c=50m/min
f =0.1 mm/rev
a_p= 0.2mm
Dry



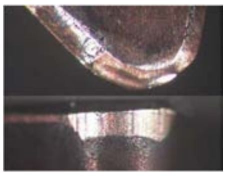
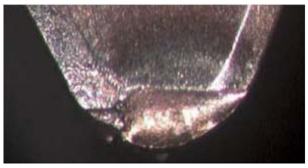
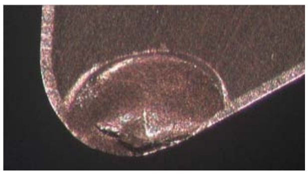
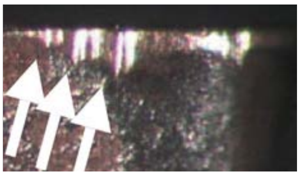
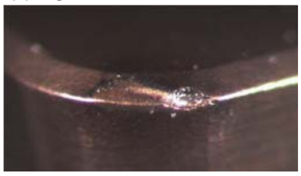
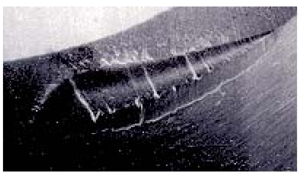


Competitor's Solid CBN
(After 2km of cutting)



BNS800
(After 2km of cutting)

Cutting Edge Failure and Countermeasures when Machining Hardened Steel

Insert Failure	Cause	Countermeasures
Flank Wear 	· Grade lacks wear resistance	· Select a more wear-resistant grade (e.g. BNC2115, BNC2010,BN1000 or BN2000)
	· Cutting speed is too fast	· Reduce the cutting speed to v_c=200m/min or less (higher feed rate also reduces tool-to-work contact time) · Use an insert with a larger relief angle
Crater Wear 	· Grade lacks crater wear resistance	· Select a higher-efficiency grade (e.g. BNC2115, BNC2010, BNX25 or BNX20)
Breakage at Bottom of Crater 	· Cutting speed is too fast	· Reduce the cutting speed to v_c=200m/min or less and increase the feed rate (low speed, high feed) (higher feed rate alone also reduces tool-to-work contact time)
Flaking 	· Grade lacks toughness	· Select a tougher grade (e.g. BNC2125, BNC2020 or BN2000)
	· Back force is too high	· Select an insert with a stronger cutting edge (increase negative land angle and perform honing) · If the grade is tough enough, improve the cutting edge sharpness
Notch Wear 	· High stress at boundary	· Change to a grade with a higher notch wear resistance (e.g. BNC2115, BNC2010 or BN2000) · Increase cutting speed (150 m/min or more) · Change to the Variable Feed Rate method, which alters the feed rate in fixed output intervals · Increase negative land angle and perform honing
Chipping at Forward Notch Position 	· Impact to front cutting edge is too large or occurs constantly	· Change to a micro-grained grade with a higher fracture resistance (e.g. BNC300 and BN350) · Increase the feed rate (higher feed rates are recommended to reduce chipping) · Select an insert with a stronger cutting edge (increase negative land angle and perform honing)
Chipping at Side Notch Position 	· Impact to side cutting edge is too large or occurs constantly	· Change to a grade with a higher fracture resistance (e.g. BN350 or BNC300) · Reduce feed rate · Use an insert with a larger side cutting angle · Use an insert with a larger corner radius · Select an insert with a stronger cutting edge (increase negative land angle and perform honing)
Thermal Crack 	· Thermal shock is too severe	· Completely dry conditions are recommended · Select a grade with better thermal conductivity · Reduce cutting speed, feed rate, and depth of cut to decrease the machining load

Reference: SI Unit Conversion List

■ Basic SI units

● Quantity as a reference of SI

Quantity	Material	Symbol
Length	Metre	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	Material	Symbol
Frequency	Hertz	Hz
Force	Newton	N
Pressure and stress	Pascal	Pa
Energy, work, and heat quantity	Joule	J
Power and efficiency	Watt	W
Voltage	Bolt	V
Electrical resistance	Ohm	Ω

■ SI prefixes

● Prefix showing integral powers of 10 combined with SI units

Coefficient	Material	Symbol	Coefficient	Material	Symbol	Coefficient	Material	Symbol
10^{24}	Yotta	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 (portions are SI units)

● Force

N	kgf
1	1.01972×10^{-1}
9.80665	1

● Stress

Pa(N/m²)	MPa(N/mm²)	kgf/mm²	kgf/cm²	kgf/m²
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/m², 1MPa = 1N/mm²

● Pressure

Pa(N/m²)	kPa	MPa	GPa	bar	kgf/cm²	mmHg or 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/m²

● Work/Energy/Heat quantity

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

● Power (efficiency and motive energy) / Thermal flow

1J=1W/s,1J=1N/m

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

● Rotation speed

min^{-1}	rpm
1	1

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

References

■ Metals Symbols Chart (Excerpt)

● Carbon Steel for Structural Use P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
S10C	1008 1010	C10E C10R 1.1122	08 10	040A10 045A10 045M10	XC10	08 10
S12C	1012	—	—	040A12	XC12	—
S15C	1015	C15E C15R 1.1132	15	055M15	—	15
S20C	1020	C22 CK22	20	070M20	—	20
S25C	1025	C25 C25E C25R C16D 1.0415	25	—	—	25
S30C	1030	C30 C30E C30R	30	080A30 080M30	—	30
S35C	1035	C35 C35E C35R 1.1172	35	080A35 080M36	—	35
S40C	1040 C40E	C40 C40E C40R 1.1186	40	060A40 080A40 080M40	—	40
S43C	1042 1043	—	—	080A42	XC42H1 XC42H2	40Г
S45C	1045 1045H	C45 C45E C45R 1.1191 1.1192	45	060A45 080M46	XC45	45
S50C	1049	C50 C50E C50R 1.1206	50	080M50	XC50	50
S53C	1050 1053	—	50Mn	080A52	XC54	—
S55C	1055	C55 C55E C55R 1.1203	55	070M55	XC55H1 XC55H2	55
S58C	1060	C60 C60E C60R	60	060A57 080A57	XC60	—
S60C	1059	C60E 1.1221	60 60Mn	—	—	60
S09CK	1010	C10E C10R	—	045A10 045M10	XC10	—
S15CK	1015	C15E C15R	—	—	XC12	—
S20CK	—	CK22	—	—	XC18	—

● Cr Steel P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SCr415	5115	17Cr3 1.7016	15Cr	—	—	15X
SCr420	5120	—	20Cr	—	20MC5	20X
SCr430	5130 5132	34Cr4 34CrS4 1.7033	30Cr	530A30 530A32	32C4	30X
SCr435	5135	37Cr4 1.7034	35Cr	530A36	38C4	35X
SCr440	5140	41Cr4 41CrS4 1.7035	40Cr	530M40 530A40	42C4	40X
SCr445	5147	—	45Cr	—	—	45X

● Nickel Chromium Steel P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SNC415	4720 4715	20NiCrMo2-2 10NiCr5-4 17CrNi6-6 1.5918 1.5805 1.6523	20CrNi 12CrNi2 15CrNi6K	—	—	20XH 12XH
SNC236	3140 4337	41crCrMo7-3-2 34CrNiMo6	40CrNi 34CrNi2	—	—	40XH
SNC246	8645	—	45CrNi	—	—	45XH
SNC815	E3310	15niCr13 1.5752	12CrNi3	—	—	12XH3A
SNC620	—	20NiCrMo13-4 1.6660	20CrNi3	—	—	20XH3A
SNC631	—	30NiCrMo16-6 1.6747	30CrNi3	—	—	30XH3A
SNC836	—	35NiCrMo16 1.6773	37CrNi3	—	—	—

● Ni-Cr-Mo Steel P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SNCM220	8615 8617 8620 8622 4718	20NiCrMo2-2 20NiCrMoS2-2 17NiCrMo6 1.6566 1.6523	20CrNiMo 18CrMnNiMo 20NiCrMoK	805A20 805M20 805A22 805M22	20NCD 2	20XH2M 18XHГM
SNCM240	8637 8640	39NiCrMo3 1.6510	40CrNiMo	—	—	40XH2MA
SNCM415	—	—	—	—	—	
SNCM420	4320	17NiCrMo6-4	20CrNi2Mo			20XH2M (20XHM)
SNCM439	4340	41NiCrMo7-3-2 1.6563	40CrNi2Mo	—	—	40XH2MA
SNCM447	4340	41NiCrMo7-3-2 1.6563	45CrNiMoV	—	—	—

● Cr-Mo Steel P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SCM415	—	18CrMo4 1.7243	15CrMo	—	—	15XM
SCM420	—	20MoCr4 1.7321	20CrMo	708M20	—	20XM

● Cr-Mo Steel (continued) P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SCM421	4121	18CrMo4 22CrMoS35 1.7243	20CrMnMo	—	—	25XГM
SCM425	—	25CrMo 1.7218	25CrMo	—	—	—
SCM430	4130	—	30CrMo	708A30	30CD4	30XM
SCM435	4135 4137	34CrMo4 1.7220	35CrMo	708A37 709A37	34CD4 38CD4 35CD4	35XM
SCM440	4142 4140	42CrMo4 42CrMoS4 1.7225	42CrMo	708M40 708A40 708A42 709A42 709M40	42CD4	38XM
SCM445	4145 4150	50CrMo4 1.7228	50CrMo	708A47	—	—

● Manganese Chromium Steel/Manganese Steel P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SMn420	1522 1524	18Mn5 1.0436	20Mn2	150M19 120M19	20M5	20Г
SMn433	1330	28Mn6 1.1170	30Mn2	—	—	30Г2
SMn438	1335 1541	—	35Mn2	150M36	40M6	35Г2
SMn443	1340 1345 1541	—	40Mn2 45Mn2	135M40 150M36	35M5	35Г2 45Г2
SMnC420	5120	20MnCr5 1.7147	20CrMn	—	—	18XГ
SMnC443	5140	41Cr4 1.7035	40CrMn	—	—	—

● Carbon Tool Steel P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SK140 SK1	W2-13A W1-13	—	T13	—	$Y_2$140	—
SK120 SK2	W1-11 1/2	C120U 1.1555	T12	BW1C	$Y_2$120	y12
SK105 SK3	W1-10 W1-10 1/2	C105U 1.1545 C105W1	T11	BW1B	$Y_1$105	—
SK95 SK4	W1-9 W1-9 1/2	C105U 1.1545	T10	BW1A	$Y_1$90 $Y_1$80	y10
SK85 SK5	W1-8C W1-8	C80W1	T8Mn	BW1A	—	y8Г
SK80	W1-8A	C80U 1.1525	T8	—	—	y8
SK70	1070	C70U 1.1520	T7	—	—	y7

● High Speed Steel P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SKH2	T1	HS18-0-1 1.3355	W18Cr4V	BT1	Z80WCV 18-04-01	P18
SKH3	T4	S18-1-2-5	—	BT4	Z80WKCV 18-05-04-01	—
SKH4	T5	—	—	BT5	Z80WKCV 18-10-04-02	—
SKH10	T15	S12-1-4-5	W12Cr4V5Co5	BT15	Z160WKCV 12-05-05-04	P12K5V5
SKH51	M2	S6-5-2 1.3339	W6Mo5Cr4V2	BM2	Z160WDCV 06-05-04-02	P6M5ø2
SKH52	M3-1	HS6-6-2 1.3350	W6Mo6Cr4V2	—	—	—
SKH53	M3-2	S6-5-3 HS6-5-3 1.3344	W6Mo5Cr4V3	—	Z160WDCV 06-05-04-03	P6M5ø3
SKH54	M4	—	W6Mo5Cr4V4	BM4	Z130WDCV 06-05-04-04	—
SKH55	M35 M41	S6-5-2-5 HS6-5-2-5 1.3243	W6Mo5Cr4V2Co5	BM35	Z190WDCV 06-05-05-04-02	P6M5K5
SKH56	M36	—	—	—	—	—
SKH57	M48	HS10-4-3-10 1.3207	W10Mo4Cr4V3Co10	—	Z130WKCDV 10-10-04-04-03	—
SKH58	M7	HS2-8-2 1.3348	W2Mo9Cr4V2	—	Z100DCWV 09-04-02-02	—
SKH59	M42	HS2-10-1-8 1.3247	W2Mo9Cr4VCo8	BM42	Z130DKCWV 09-08-04-02-01	P2M9K8ø

● Alloy Tool Steel P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SKS11	F2	—	—	—	—	—
SKS2	—	105WCr6	—	—	105WC13	—
SKS51	L6	—	—	—	—	—
SKS41	—	—	4CrW2Si	—	—	4XB2C
SKS43	W2-9 1/2	—	—	BW2	$Y_1$105V	—
SKS44	W2-8 1/2	—	—	—	—	—
SKS3	O1	95MnWCr5 1.2825	9CrWMn	—	—	9XBГ
SKS31	O7	105WCr6	CrWMn	—	105WC31	XBГ
SKD1	D3	X210Cr12 1.2080	Cr12	BD3	X200Cr12	X12
SKD4	—	—	30W4Cr2V	BH21	Z32WCV5	—
SKD5	H21	X30WCrV9-3 1.2581	3Cr2W8V	BH21	Z30WCV9	3X2B8ø
SKD6	H11	X37CrMoV5-1 1.2343	4Cr5MoSiV	BH11	X38CrMoV5	4X5MøC
SKD61	H13	X40CrMoV5-1 1.2344	4Cr5MoSiV1	BH13	Z40CDV5	4X5Mø1C
SKD7	H10	X32CrMoV33 1.2365	3Cr3Mo3V	BH10	32DCV28	—
SKD8	H19	38CrCoWV18-17-17 1.2661	3Cr3Mo3VCo3	BH19	—	—
SKD10	D2	X153CrMoV12 1.2379	Cr12Mo1V1	—	—	X12M1ø1

References
N
Parts
Technical Guidance
Reference

Alloy Tool Steel (continued) P

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SKD11	D2 D4	—	Cr12MoV	BD2	X160CrMoV12	X12Mø
SKD12	A2	X100CrMoV5 1.2363	Cr5Mo1V	BA2	Z100CDV5	—

Ferritic Stainless Steels M

SUS405	405 S40500	X10CrAl13 1.4002	0Cr13Al 06Cr13Al	405S17	26CA13	—
SUS429	429 S42900	—	1Cr15 10Cr15 022Cr15NbTi	—	—	—
SUS430	430 S43000	X6Cr17 1.4016	1Cr17 10Cr15 S11710	430S17	Z8C17	12X17
SUS430F	430F S43020	X12CrMoS17	Y1Cr17 Y10Cr17	—	210CF17	—
SUS434	434 S43400	X6CrMo17-1 1.4113	1Cr17Mo 10Cr17Mo	434S17	Z8CD17.01	—

Martensitic Stainless Steels M

SUS410	410 S41010	X10Cr13 1.4006	12Cr13 1Cr13	410S21	Z13C13	12X13
SUS403	403 S40300	—	12Cr12 1Cr12	—	—	—
SUS444	444 S44400	X2CrMoTi18-2 1.4521	019Cr19Mo2NbTi 00Cr18Mo2	—	—	—
SUS416	416 S41600	X12CrS13 1.4005	Y12Cr13 Y1Cr13	416S21	Z12CF13	—
SUS420J1	420 S42000	X20Cr13 1.4021	20Cr13 2Cr13	420S29	Z20C13	20X13
SUS420J2	420 S42000	X30Cr13 1.4028	30Cr13 3Cr13	420S45	Z30C13	30X13
SUS420F	420G S42020	X29Cr13 1.4029	Y30Cr13 Y3Cr13	—	Z30CF13	—
SUS431	431 S43100	X17CrNi16-2	17Cr16Ni2	431S29	—	—
SUS440C	440C S44004	—	108Cr17 11Cr17	—	Z100CD17	—

Stainless Steel (Precipitation Hardened Structure) M

SUS630	630 S17400	X5CrNiCuNb16-4 1.4542	0Cr17Ni4Cu4Nb 05Cr17Ni4Cu4Nb	—	Z6CNU17.04	—
SUS631	631 S17700	X7CrNiAl17-7 1.4568	0Cr17Ni7Al 07Cr17Ni7Al	—	Z8CNA17.07	09X17H7 Ю

Austenitic Stainless Steels M

SUS201	201 S20100	X12crMnNiN17-7-5 1.4372	1Cr17Mn6Ni5N 12Cr17Mn6Ni5N	—	Z12CMN17-07Az	—
SUS202	202 S20200	X12CrMnNiN18-9-5 1.4373	1Cr18Mn9Ni5N 12Cr18Mn9Ni5N	284S16	—	—
SUS301	301 S30100	X12CrNi17 7 1.4319 1.4310	1Cr17Ni7 12Cr17Ni7	—	Z12CN17.07	17X18H9
SUS302	302 S30200	X9CrNi18-9 1.4325	1Cr18Ni9 12Cr18Ni9	302S25	Z10CN18.09	12X18H9
SUS302B	302B S30215	—	1Cr18Ni9Si3 12Cr18Ni9Si3	—	—	—
SUS303	303 S30300	X8CrNiS18-9 X10CrNiS189 1.4305	Y1Cr18Ni9 Y12Cr18Ni9	303S21	Z10CNF18.09	—
SUS303Se	303Se S30323	—	Y12Cr18Ni9Se Y1Cr18Ni9Se	303S41	—	12X18H10E
SUS304	304 S30400	X5CrNi18-10 1.4301	0Cr18Ni9 06Cr19Ni10	304S31	Z6CN18.09	08X18H10
SUS304L	304L S30403	X2CrNi19-11 1.4306	00Cr19Ni10 022Cr19Ni10	304S11	Z2CN18.10	03X18H11
SUS304N1	304N S30451	X5CrNiN19-9 1.4315	06Cr19Ni10N 06Cr19Ni10NbN	—	Z6CN19-09Az	—
SUS305	305 S30500	X2CrNiN18-10 1.4311	1Cr18Ni12 10Cr18Ni12	305S19	Z8CN18.12	—
SUS309S	309S S30908	X6CrNi23-13 1.4950	0Cr23Ni13 06Cr23Ni13	—	—	0X23H12
SUS310S	310S S31008	X6CrNi25-20 1.4951	0Cr25Ni20 06Cr25Ni20	—	—	08X23H20
SUS316	316 S31600	X5CrNiMo17-12-2 1.4401	0Cr17Ni12Mo2 06Cr17Ni12Mo2	316S31	Z7CND17.12	—
SUS316L	316L S31603	X2CrNiMo17-12-2 1.4404	00Cr17Ni12Mo2 022Cr17Ni12Mo2	316S11	Z2CND17.12	03X17H14M2
SUS316N	316N S31651	—	0Cr17Ni12Mo2N 06Cr17Ni12Mo2N	—	—	—
SUS317	317 S31700	—	0Cr19Ni13Mo3 06Cr19Ni13Mo3	317S16	—	—
SUS317L	317L S31703	X2CrNiMo18-15-4 1.4438	00Cr19Ni13Mo3 022Cr19Ni13Mo3	317S12	Z2CND19.15	03X19H13M3
SUS321	321 S32100	X6CrNiTi18-10 1.4541	0Cr18Ni10Ti 06Cr18Ni1Ti	321S31	Z6CNT18.10	08X18H10T
SUS347	347 S34700	X6CrNiNb18-10 1.4550	0Cr18Ni11Nb 06Cr18Ni11Nb	347S31	Z6CNNb18.10	08X18H12Б

Ferritic Heat Resistant Steels S

SUH409	409 S40900	X6CrTi12	06Cr11Ti 0Cr11T1	409S19	Z6CT12	—
SUH446	446 S44600	—	2Cr25N 16Cr25N	—	Z12C24	—

Martensitic Heat Resistant Steel S

SUH1	—	—	45Cr9Si3	401S45	Z45CS9	—
SUH3	—	—	4Cr10Si2Mo 40Cr10Si2Mo	—	Z40CSD10	40X10C2M
SUH4	—	—	8Cr20Si2Ni 80Cr20Si2Ni	443S65	Z80CSN20.02	—

Martensitic Heat Resistant Steel (continued) S

JIS	AISI/ASTM	DIN/EN	GB	BS	AFNOR	ГОСТ
SUH11	—	—	4Cr9Si2 42Cr9Si2	—	—	40X 9C2
SUH600	—	—	2Cr12MoVNbN 18Cr12MoVNbN	—	—	—
SUH616	616 S42200	—	2Cr12NiMoWV 22Cr12NiWMoV	—	—	—

Austenitic Heat Resistant Steel S

SUH31	—	—	4Cr14Ni14W2Mo	331S42	—	45X14H14B2M
SUH35	—	X53CrMnNiN21-9-4 1.4871	5Cr21Mn9Ni4N 53Cr21Mn9Ni4N	349S52	Z52CMN21.09	55X20Г9AH4
SUH36	—	X53CrMnNi21 9	—	349S54	Z55CMN21-09Az	55X20Г9AH4
SUH37	—	X15CrNiSi20-12 1.4828	22Cr21Ni12N 2Cr21Ni12N	381S34	—	—
SUH38	—	—	—	—	—	—
SUH309	309 S30900	X12CrNi23-13 1.4833	16Cr23Ni13 2Cr23Ni13	309S24	Z15CN24.13	20X23H12
SUH310	310 S31000	—	2Cr25Ni21 20Cr25Ni20	310S24	Z15CN25.20	—
SUH330	—	X12CrNiMnMoN25-18-6-5 1.4565	1Cr16Ni35 12Cr16Ni35	—	Z12NCS35.16	—

Gray Cast Iron K

FC100	No 20B	GG-10	HT100	100	—	Cy10
FC150	No 25B	GG-15	HT150	150	FGL150	Cy15
FC200	No 30B	GG-20	HT200	200	FGL200	Cy20
FC250	No 35B	GG-25	HT250	250	FGL250	Cy25
FC300	No 45B	GG-30	HT300	300	FGL300	Cy30
FC350	No 50B	GG-35	HT350	350	FGL350	Cy35

Nodular Cast Iron K

FCD400	60-40-18	GGG-40	QT400-18	400/17	FGS370-17	By40
FCD450	—	GGG-40.3	QT450-10	420/12	FGS400-12	By45
FCD500	80-55-06	GGG-50	QT500-7	500/7	FGS500-7	By50
FCD600	—	GGG-60	QT600-3	600/7	FGS600-2	By60
FCD700	100-70-03	GGG-70	QT700-2	700/2	FGS700-2	By70
FCD800	120-90-02	GGG-80	—	800/2	FGS800-2	By80

Aluminum and Al Alloys - Sheets, plates and strips N

A1060P	1060	EN AW-1060	L2	—	—	—
A1050P	1050	A199.50	1A50	—	—	—
A1100P	1100	EN AW-1100	L5-1	—	—	—
A1200P	1200	EN AW-1200	L5	EN AW-1200	EN AW-1200	—
A2014P	2014	EN AW-2014	LD10	EN AW-2014	EN AW-2014	—
A2017P	2017	EN AW-2017	2A11(LY11)	EN AW-2017	EN AW-2017	—
A2219P	2219	EN AW-2219	2A16(LY16)	—	—	—
A2024P	2024	EN AW-2024	2A12(LY12)	EN AW-2024	EN AW-2024	—
A2124P	2124	EN AW-2124	2A12(LY12)	—	—	—
A3003P	3003	EN AW-3003	LF21	EN AW-3003	EN AW-3003	—
A3004P	3004	EN AW-3004	3004	—	—	—
A3005P	3005	EN AW-3005	3005	—	—	—
A3015P	3105	EN AW-3105	3105	—	—	—
A5005P	5005	EN AW-5005	5005	—	—	—
A5050P	5050	EN AW-5050	—	—	—	—
A5052P	5052	EN AW-5052	5A02	EN AW-5052	EN AW-5052	—
A5154P	5154	—	LF3	—	—	—
A5254P	5254	—	LF3	—	—	—
A5454P	5454	EN AW-5454	5454	EN AW-5454	EN AW-5454	—
A5456P	5456	EN AW-5456	—			
A6101P	6101	EN AW-6101	6101			
A6061P	6061	EN AW-6061	6061(LD30)	EN AW-6061	EN AW-6061	—
A7075P	7075	EN AW-7075	7A04	EN AW-7075	EN AW-7075	—
A7178P	7178	EN AW-7178	7A03(LC3)	—	—	—

Aluminum Alloy Die Castings N

ADC1	A413.0	EN AC-44300	YL102	—	—	—
ADC3	A360.0	EN AC-43400	YL104	EN AC-43400	EN AC-43400	—
ADC5	518.0	—	Al-Mg7	—	—	—
ADC10	—	EN AC-46000	YL112	—	—	—
ADC12	—	—	YL113	LM20	—	—
ADC14	B390.0	—	—	—	—	—
AC4C	357	G-AlSi7Mg	ZAlSi7Mg1A	LM25	A-S7G-03	—
AC4CH	356	G-AlSi7Mg	ZALSi7Mg	LM25	A-S7G	—
—	308	G-AlSi6Cu4	ZAlSi5Cu6Mg	LM21	—	—

Hardened Steel H

C4BS	440A	X100CrMo13	7Cr17	—	—	—
AC4A	610	X110CrMoV15	—	—	—	—
AC4A	0-2	X65CrMo14	—	—	—	—

■ Steel and Non-Ferrous Metal Symbols Chart (Excerpt)

● Classifications and Symbols of Steels

Classification	Material	Symbol	Symbol Description
Structural Steel	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 steel for general structures	SS	S for "Steel" and S for "Structure"
	Light gauge sections for general structures	SSC	"C" for "Cold" after SS
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" after ST
	Carbon steel tubes for general structures	STK	"K" for "Kozo" ("structure" in Japanese) after ST
	Carbon steel tubes for mechanical structures	STKM	"M" for "Machine" after STK
	Alloy steel tubes for structures	STKS	"S" for "Special" after STK
	Alloy steel tubes for piping	STPA	"A" for "Alloy" after STP
	Carbon steel tubes for pressure piping	STPG	"P" for "Piping" and "G" for "General" after ST
	Carbon steel tubes for high-temperature piping	STPT	"T" for "Temperature" after ST
	Carbon steel tubes for high-pressure piping	STS	"S" for "Special" after ST
	Stainless steel tubes for piping	SUS-TP	"T" for "Tube" and "P" for "Piping" after SUS
Steel for Mechanical Structures	Carbon steels for mechanical structures	SxxC	"C" for "Carbon"
	Aluminum-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" after "S" for "Steel"
	Nickel Chromium steels	SNC	"N" for "Nickel" and "C"for "Chromium"
	Nickel Chromium Molybdenum steels	SNCM	"M" for "Molybdenum" in SNC
	Manganese steels and manganese chromium steels for mechanical structures	SMn SMnC	"Mn" for "Manganese" "C" for "Chromium" in SMn
Special Steels – Tool Steels	Carbon tool steels	SK	"K" for "Kogu" ("tool" in Japanese)
	Hollow drill steels	SKC	"C" for "Chisel" after SK
	Alloy tool steel	SKS SKD SKT	S for "Special" after SK D for "Die" after SK T for "Tanzo" - ("forging" in Japanese) after SK
	High-speed tool steels	SKH	"H" for "High speed" after SK
Special Steels – Stainless Steel	Free cutting sulphuric steels	SUM	"M" for "Machinability" after SU
	High-carbon chromium bearing steels	SUJ	"J" for "Jikuuke" ("bearing" in Japanese) after SU
	Spring steels	SUP	"P" for "Spring" after SU
	Stainless steel	SUS	"S" for "Stainless Steel" after SU
Special Steels – Heat-resistant Steel	Heat-resistant steel	SUH	"U" for "Special Usage" and "H" for "Heat"
	Heat-resistant steel bars	SUH-B	"B" for "Bar" after SUH
	Heat-resistant steel sheets	SUHP	"P" for "Plate" after SUH
Forged Steels	Carbon steel forgings for general use	SF	"F" for "Forging"
	Carbon steel booms and billets for forgings	SFB	"B" for "Billet" after SF
	Chromium molybdenum steel forgings	SFCM	"C" for "Chromium" and "M" for "Molybdenum" after SF
	Nickel chromium molybdenum steel forgings	SFNCM	"N" for "Nickel" in SFCM
Cast Iron	Gray cast iron	FC	"F" for "Ferrous" and "C" for "Casting"
	Spherical graphite / Ductile cast irons	FCD	"D" for "Ductile" after FC
	Blackheart malleable cast irons	FCMB	"M" for "Malleable" and "B" for "Black" after FC
	Whiteheart malleable cast irons	FCMW	"W" for "White" after FCM
	Pearlite malleable cast iron	FCMP	"P" for "Pearlite" after FCM
Cast Steels	Carbon cast steels	SC	"C" for "Casting"
	Cast stainless steels	SCS	"S" for "Stainless Steel" after SC
	Heat-resistant cast steels	SCH	"H" for "Heat" after SC
	High-manganese cast steels	SCMnH	"Mn" for "Manganese" and "H" for "High" after SC

● Non-Ferrous Metals

Classification	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
Aluminum and Aluminum Alloys	Aluminum and Al alloys - Sheets, plates and strips	AxxxxP AxxxxPC
	Aluminum and Al alloys Rods, bars and wires	AxxxxBE AxxxxBD AxxxxW
	Aluminum and Al alloys - Extruded shapes	AxxxxS
	Aluminum and Al alloy castings	AxxxxFD AxxxxFH
Magnesium Wrought Alloys	Magnesium alloy sheets and plates	MP
Nickel Material	Nickel-copper alloy sheets and plates	NCuP
	Nickel-copper alloy rods and bars	NCuB
Titanium Wrought Materials	Titanium rods and bars	TB
Castings	Brass castings	YBsCx
	High-strength brass castings	HBsCx
	Bronze castings	BCx
	Phosphorus Bronze castings	PBCx
	Aluminum bronze castings	AlBCx
	Aluminum alloy castings	AC
	Magnesium alloy castings	MC
	Zinc alloy die castings	ZDCx
	Aluminum alloy die castings	ADC
	Magnesium alloy die castings	MDC
	White metals	WJ
	Aluminum 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 3,000kgf HB	Rockwell Hardness A Scale 60kgf brale HRA	B Scale 100kgf 1/10in ball HRB	C Scale 150kgf brale HRC	D Scale 100kgf brale HRD	Vickers 50kgf HV	Shore Hardness HS	Tensile Strength (GPa)
—	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).

References

■ Dimensional Tolerance of Standard Fittings [Excerpt from JIS B 0401 (1999)]

● Dimensional Tolerance Used for Shafts of Standard Fittings

Shaft Tolerance Class — Unit: μm

Classification of Reference Dimensions (mm) or greater	or less	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				

References

■ Dimensional Tolerance of Standard Fittings [Excerpt from JIS B 0401 (1999)]

● Dimensional Tolerance Used for Holes of Standard Fittings

Classification of Reference Dimensions (mm)		Hole Tolerance Class																																	Unit: μm
or greater	or less	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 Tolerance and Fittings [Excerpt from JIS B 0401 (1999)]

Standard Fittings for Holes

Reference Hole	Shaft Tolerance Class																
	Gap fitting							Intermediate fitting			Tight fitting						
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														

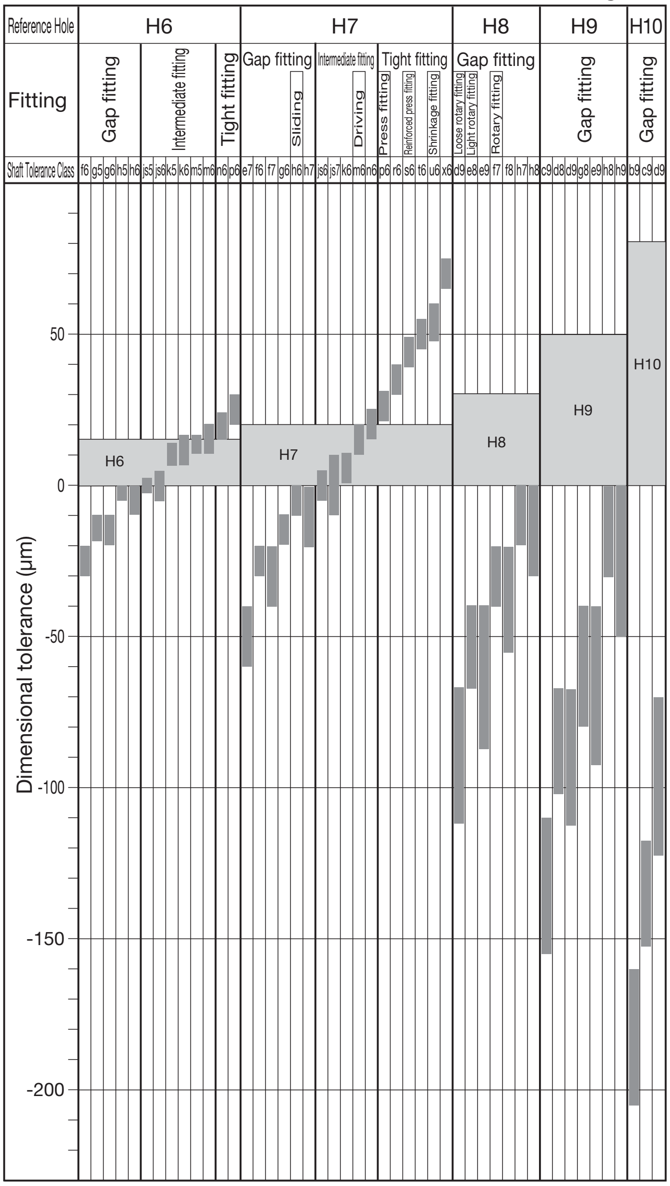
Note: *Exceptions may arise with these fittings depending on the dimension category.

Standard Fittings for Shafts

Reference Shaft	Hole Tolerance Class																
	Gap fitting							Intermediate fitting			Tight fitting						
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														

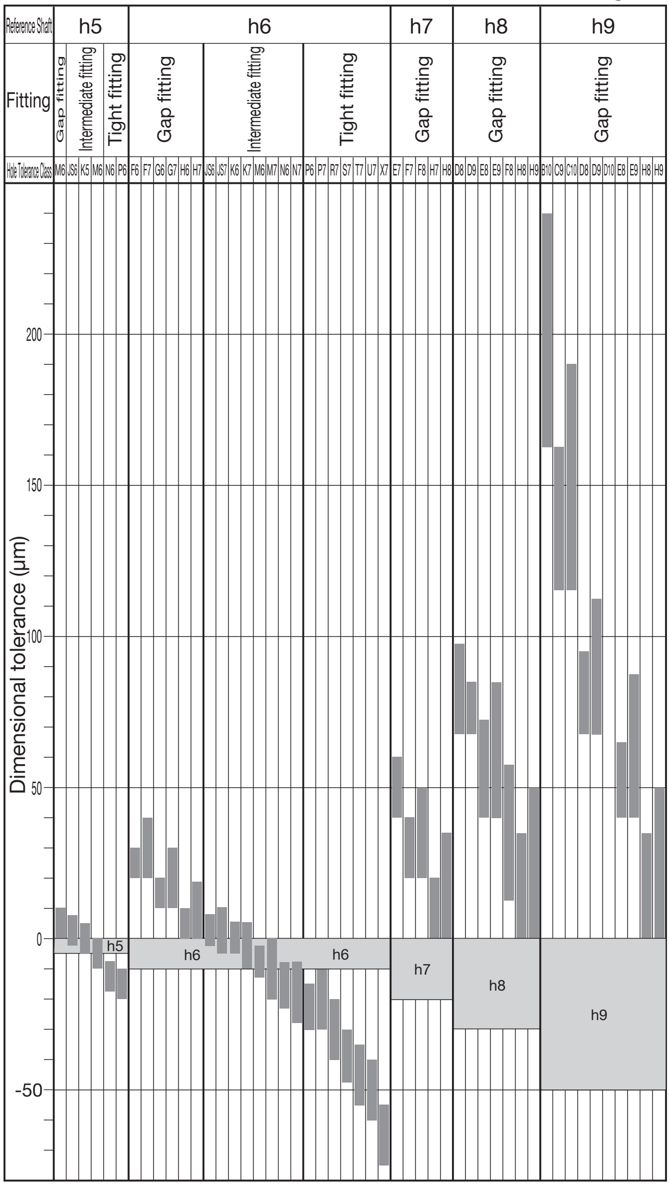
Note: *Exceptions may arise with these fittings depending on the dimension category.

Correlation of Tolerance Zones in Standard Hole Fittings



Note: The above table is for reference dimensions greater than 18mm up to 30mm.

Correlation of Tolerance Zones in Standard Shaft Fittings



Note: The above table is for reference dimensions greater than 18mm up to 30mm.

■ Standard of Tapers

● Morse Taper

Fig 1 With Tang

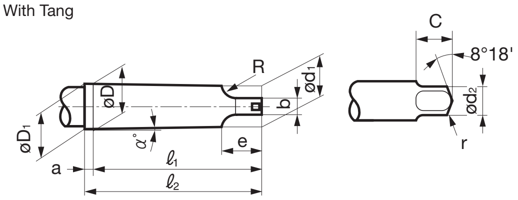
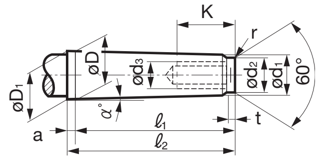


Fig 2 Drawing Thread type



(Unit: mm)

Morse Taper Number	Taper (1)		Taper Angle (α)	Taper D	a	D_1(2) (approx.)	d_1(2) (approx.)	ℓ_1 (Max)	ℓ_2 (Max)	Tang d_2 (Max)	b	C (Max)	e (Max)	R	r	Fig
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	$\frac{1}{20.047}$	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	1
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	

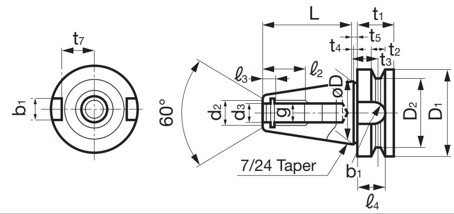
Morse Taper Number	Taper (1)		Taper Angle (α)	Taper D	a	D_1(2) (approx.)	d_1(2) (approx.)	ℓ_1 (Max)	ℓ_2 (Max)	Screw d_2 (Max)	d_3	K (Min)	t (Max)	r	Fig
0	$\frac{1}{19.212}$	0.05205	1°29'27"	9.045	3	9.2	6.4	50	53	6	—	—	4	0.2	
1	$\frac{1}{20.047}$	0.04988	1°25'43"	12.065	3.5	12.2	9.4	53.5	57	9	M 6	16	5	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	2
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	

Note (1) The fractional values are the taper standards.
(2) Diameters D_1 and d_1 are calculated from the diameter D value, the taper, a, and ℓ_1 and rounded up to one decimal place.

Remark 1. Tapers are measured using JIS B 3301 ring gauges. The contact rate must be at least 75%.
2. Screws must have metric coarse screw thread as per JIS B 0205 and Class 3 precision as per JIS B 0209.

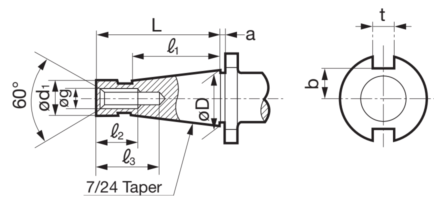
● Bottle Grip Taper

Fig 3



● American Standard Taper (National Taper)

Fig 4



● Bottle Grip Taper

(Units: mm)

Taper No.	D (Standard Dimensions)	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	
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	3
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	

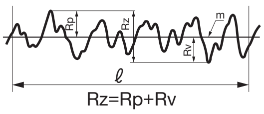
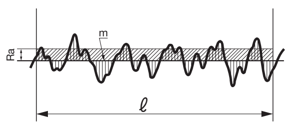
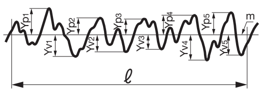
● American Standard Taper (National Taper)

(Units: mm)

Taper No.	Nominal Size	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	
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	4
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	

■ Surface Roughness

● Types and Definitions of Typical Surface Roughness

Type	Symbol	Method of Determination	Descriptive Figure
R Max.	[*1] Rz	This value is found by extracting the reference length in the mean line direction from the surface roughness curve, measuring the intervals between the peaks and valleys in the extracted area in the longitudinal magnification direction of the surface roughness curve, and expressing this value in micrometres (μm). Remarks: When finding Rz, any areas deemed to be scratches are removed before extracting the reference length from an area with no high peaks or low valleys.	 Rz=Rp+Rv
Calculated Roughness	Ra	This value is found by extracting the reference length in the mean line direction from the roughness curve, taking the average line direction of the extracted area as the X-axis and the longitudinal magnification direction as the Y-axis and expressing the value found by the equation below in micrometres (μm) with the roughness curve expressed by y=f(x).	 $Ra=\frac{1}{\ell}\int_0^{\ell}\{f(x)\}dx$
10-point Average Roughness	[*2] Rz JIS	This value is found by extracting the reference length in the mean line direction from the roughness curve, finding the sum of the mean absolute peak height taken from the five highest peaks (Yp) and the mean absolute valley height taken from the five lowest valleys (Yv) measured in the longitudinal magnification direction from the mean line direction of the extracted area and expressing this value in micrometres (μm).	 $Rz_{JIS}=\frac{(Yp_1+Yp_2+Yp_3+Yp_4+Yp_5)+(Yv_1+Yv_2+Yv_3+Yv_4+Yv_5)}{5}$

Designated values for the above types of maximum height (Rz)[*1], 10-point average roughness (Rz JIS[*2]), calculated average roughness (Ra) classifications, and reference length ℓ are shown on the table at right with triangular symbols.

[*1] The maximum height symbol (Rz) is calculated according to the new **JIS B 0601**:2001 standard. (This value was Ry under the old standard.)

[*2] The 10-point average roughness (Rz JIS) is calculated according to the new **JIS B 0601**:2001 standard. (This value was Rz under the old standard.)

● Relationship with Triangular Symbol Display

Designated values for maximum height [*1] (Rz)	Designated values for calculated average roughness (Ra)	Designated values for 10-point average roughness [*2] (Rz_{JIS})	Standard reference ℓ length value (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 ( ) do not apply unless otherwise stated.

* Finish symbols (triangular symbol (▽) and tilde (~)) were removed from JIS in the 1994 revision.