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<td>Large cutting resistance and cutting edge flank</td>
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<td>Solutions</td>
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<td>Select a Harder Grade</td>
<td>Select a Grade with Better Thermal Shock Resistance</td>
<td>Select a Grade with Better Adhesion Resistance</td>
<td>Do Not Use Water-soluble Cutting Fluids</td>
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<td>Vibration occurs</td>
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<td>Chip Control</td>
<td>Uncontrolled, continuous / tangled</td>
<td>Improper cutting conditions</td>
<td>Wide chip control range</td>
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<td>Broken into short lengths and scatter</td>
<td>Improper cutting conditions</td>
<td>Small chip control range</td>
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CHIP CONTROL FOR TURNING

CHIP BREAKING CONDITIONS IN STEEL TURNING

<table>
<thead>
<tr>
<th>Type</th>
<th>A Type</th>
<th>B Type</th>
<th>C Type</th>
<th>D Type</th>
<th>E Type</th>
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<tbody>
<tr>
<td>Small Depth of Cut</td>
<td>d &lt; .276”</td>
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<tr>
<td>Large Depth of Cut</td>
<td>d = .276” – .591”</td>
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<tr>
<td>Curl Length</td>
<td>Curless</td>
<td>l ≥ 2inch</td>
<td>l ≤ 2inch</td>
<td>≈ 1 Curl</td>
<td>1 curl – half curl</td>
</tr>
</tbody>
</table>

Note
- Irregular continuous shape
- Tangle about tool and workpiece
- Regular continuous shape
- Long chips
- Good

Cutting Speed and Chip Control Range of Chip Breaker
In general, when cutting speed increases, the chip control range tends to become narrower.

Effects of Coolant on the Chip Control Range of a Chip Breaker
If the cutting speed is the same, the range of chip control differs according to whether coolant is used or not.
EFFECTS OF CUTTING CONDITIONS FOR TURNING

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

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

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

EFFECTS OF CUTTING CONDITIONS FOR TURNING

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

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

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

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

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

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

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

Effects of Flank Angle
1. Increasing flank angle decreases flank wear occurrence.
2. Increasing flank angle lowers cutting edge strength.

Chip Disposal and Rake Angle

When to Increase Rake Angle in the Negative (-) Direction
○ Hard workpiece.
○ When cutting edge strength is required such as in interrupted cutting and uncut surface cutting.

When to Increase Rake Angle in the Positive (+) Direction
○ Soft workpiece.
○ Workpiece is easily machined.
○ When workpiece or the machine have poor rigidity.

Chip Disposal and Rake Angle

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

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

When to Decrease Flank Angle
○ Hard workpieces.
○ When cutting edge strength is required.

When to Increase Flank Angle
○ Soft workpieces.
○ Workpieces suffer from work hardening easily.
FUNCTION OF TOOL FEATURES FOR TURNING

SIDE CUTTING EDGE ANGLE (LEAD ANGLE)
Side cutting edge angle lowers impact load and effect feed force, back force, and chip thickness.

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

When to Decrease Lead Angle
- Finishing with small depth of cut.
- Thin, long workpieces.
- When the machine has poor rigidity.

When to Increase Lead Angle
- Hard workpieces which produce high cutting temperature.
- When roughing a large diameter workpiece.
- When the machine has high rigidity.

END CUTTING EDGE ANGLE
End cutting edge angle prevents wear on tool and workpiece surface and is usually $5^\circ$–$15^\circ$.

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

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

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

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

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

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<th>When to Increase Honing Size</th>
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<td>- When finishing with small depth of cut and small feed.</td>
<td>- Hard workpieces.</td>
</tr>
<tr>
<td>- Soft workpieces.</td>
<td>- When the cutting edge strength is required such as for uncut surface cutting and interrupted cutting.</td>
</tr>
<tr>
<td>- When the workpiece and the machine have poor rigidity.</td>
<td>- When the machine has high rigidity.</td>
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</table>
FUNCTION OF TOOL FEATURES FOR TURNING

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

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

**When to Decrease Corner Radius**
- Finishing with small depth of cut.
- Thin, long workpieces.
- When the machine has poor rigidity.

**When to Increase Corner Radius**
- When the cutting edge strength is required such as in interrupted cutting and uncut surface cutting.
- When roughing a workpiece with large diameter.
- When the machine has high rigidity.

**Corner Radius and Chip Control Range**

(Note) Please refer to page N004 for chip shapes (A, B, C, D, E).
FORMULAS FOR CUTTING

**CUTTING SPEED (vc)**

\[
vc = \frac{\pi \cdot Dm \cdot n}{12} \quad \text{(SFM)}
\]

(Problem) What is the cutting speed when the main axis spindle speed is 700 min\(^{-1}\) and external diameter is 2" ?

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

\[
vc = \frac{\pi \cdot Dm \cdot n}{12} = \frac{3.14 \times 2 \times 700}{12} = 365 \text{SFМ}
\]

Cutting speed is 365SFМ.

**FEED (f)**

\[
f = \frac{l}{n} \quad \text{(IPR)}
\]

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

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

\[
f = \frac{l}{n} = \frac{4.72}{500} = .009 \text{IPР}
\]

The answer is .009IPР.

**CUTTING TIME (Tc)**

\[
Tc = \frac{Im}{l} \quad \text{(min)}
\]

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

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

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

Substitute the answer above into the formula.

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

The answer is 30 sec.

**THEORETICAL FINISHED SURFACE ROUGHNESS (h)**

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

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

(Answer) Substitute \(f = .008 \text{IPР}, R = .031\) into the formula.

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

The theoretical finished surface roughness is 258μinch.
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<td>Improper tool grade</td>
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<td>Improve Cutter Rigidity</td>
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<td>Improper cutting edge geometry</td>
<td>Select a Grade with Better Adhesion Resistance</td>
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<td>Decrease the Number of Teeth</td>
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<td></td>
<td>Welding occurs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chip thickness is too thin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cutter diameter is too small</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor chip disposal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FUNCTION OF TOOL FEATURES FOR FACE MILLING

FUNCTION OF EACH CUTTING EDGE ANGLE IN FACE MILLING

STANDARD INSERTS

- Positive and Negative Rake Angle

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

Standard Cutting Edge Shape

- Standard Cutting Edge Combinations

  - Axial Rake Angle (A.R.)
  - Radial Rake Angle (R.R.)

<table>
<thead>
<tr>
<th>Insert Used</th>
<th>Steel</th>
<th>Cast Iron</th>
<th>Aluminum Alloy</th>
<th>Difficult-to-Cut Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive (One Sided Use)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Negative (Double Sided Use)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Positive Insert (One Sided Use)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

CUT CORNER ANGLE (CH) AND CUTTING RESISTANCE

<table>
<thead>
<tr>
<th>SE300 Type 400 Type</th>
<th>SE415 Type 515 Type</th>
<th>SE445 Type 545 Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Angle</td>
<td>Cutting Angle</td>
<td>Cutting Angle</td>
</tr>
<tr>
<td>0°</td>
<td>15°</td>
<td>45°</td>
</tr>
</tbody>
</table>

- Principal Force
- Feed Force
- Back Force

Cutting Resistance Comparison between Different Insert Shapes

- Workpiece: Alloy Steel (281HB)
- Tool: 0° Single Insert
- Cutting Conditions: vc=410SFMP ap=.157inch ae=4.33inch

Three Cutting Resistance Forces in Milling

- Principal force: Force is in the opposite direction of face milling rotation.
- Back force: Force that pushes in the axial direction.
- Feed Force: Force is in the feed direction and is caused by table feed.
FUNCTION OF TOOL FEATURES FOR FACE MILLING

**CORNER ANGLE AND TOOL LIFE**

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

- **Corner Angle and Chip Thickness**

![Effects on chip thickness due to the variation of corner angles](image)

**Corner Angle and Crater Wear**

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

<table>
<thead>
<tr>
<th>Corner Angle</th>
<th>Tool Rotation</th>
<th>Workpiece Movement Direction</th>
<th>Portion Machined</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° Corner Angle</td>
<td>Up Cut Milling</td>
<td>Workpiece movement direction</td>
<td>Portion machined</td>
</tr>
<tr>
<td>15° Corner Angle</td>
<td>Tool rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45° Corner Angle</td>
<td>Down Cut Milling</td>
<td>Workpiece movement direction</td>
<td></td>
</tr>
</tbody>
</table>

**UP CUT AND DOWN CUT MILLING**

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

<table>
<thead>
<tr>
<th>Up Cut Milling</th>
<th>Down Cut Milling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool rotation</td>
<td>Tool rotation</td>
</tr>
<tr>
<td>Workpiece movement direction</td>
<td>Workpiece movement direction</td>
</tr>
<tr>
<td>Portion machined</td>
<td>Portion machined</td>
</tr>
<tr>
<td>Milling cutter inserts</td>
<td>Milling cutter inserts</td>
</tr>
</tbody>
</table>
**FINISHED SURFACE**

**Cutting Edge Run-out Accuracy**

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

![Diagram showing cutting edge run-out and accuracy in face milling]

**Improve Finished Surface Roughness**

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

![Diagram showing actual problems and countermeasures for finished surface roughness]

**How to Set a Wiper Insert**

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

### CUTTING SPEED (vc)

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

<table>
<thead>
<tr>
<th>(vc) (SFM)</th>
<th>Cutting Speed</th>
<th>(D_1) (inch)</th>
<th>Cutter Diameter</th>
<th>(n) (min(^{-1}))</th>
<th>Main Axis Spindle Speed</th>
</tr>
</thead>
</table>

(Problem) What is the cutting speed when main axis spindle speed is 350 min\(^{-1}\) and cutter diameter is 5" ?

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

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

The cutting speed is 457.9 SFM.

### FEED PER TOOTH (fz)

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

<table>
<thead>
<tr>
<th>(fz) (IPT)</th>
<th>Feed per Tooth</th>
<th>(z)</th>
<th>Insert Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>(vf) (inch/min)</td>
<td>Table Feed per Min.</td>
<td>(n)</td>
<td>Main Axis Spindle Speed (Feed per Revolution (fr = z \times fz))</td>
</tr>
</tbody>
</table>

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

(Answer) Substitute the above figures into the formula.

\[
fz = \frac{vf}{z \cdot n} = \frac{20}{10 \times 500} = 0.004 \text{ IPT}
\]

The answer is 0.004 IPT.

### TABLE FEED (vf)

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

<table>
<thead>
<tr>
<th>(vf) (inch/(\text{min}))</th>
<th>Table Feed per Min.</th>
<th>(z)</th>
<th>Insert Number</th>
<th>(n) (min(^{-1}))</th>
<th>Main Axis Spindle Speed</th>
</tr>
</thead>
</table>

(Problem) What is the table feed when feed per tooth is 0.004 IPT, with 10 inserts and main axis spindle speed is 500 min\(^{-1}\) ?

(Answer) Substitute the above figures into the formula.

\[
vf = fz \cdot z \cdot n = 0.004 \text{ IPT} \times 10 \times 500 = 20 \text{ inch/\(\text{min}\)}
\]

The table feed is 20 inch/\(\text{min}\).

### CUTTING TIME (Tc)

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

<table>
<thead>
<tr>
<th>(Tc) (min)</th>
<th>Cutting Time</th>
<th>(vf) (inch/(\text{min}))</th>
<th>Table Feed per Min.</th>
<th>(L) (inch)</th>
<th>Total Table Feed Length (Workpiece Length((l))+Cutter Diameter((D_1)))</th>
</tr>
</thead>
</table>

(Problem) What is the cutting time required for finishing 4" width and 12" length surface of a cast iron (GG20) block when cutter diameter is 8", the number of inserts is 16, the cutting speed is 410 SFM, and feed per tooth is .01" (spindle speed is 200 min\(^{-1}\))

(Answer) Calculate table feed per min \(vf = 0.01 \times 16 \times 200 = 32\text{ inch/\(\text{min}\)}\)

Calculate total table feed length. \(L = 12 + 8 = 20\text{ inch}\)

Substitute the above answers into the formula.

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

\[
0.625 \times 60 = 37.5 \text{ (sec.)}
\]

The answer is 37.5 sec.
# TROUBLE SHOOTING FOR END MILLING

<table>
<thead>
<tr>
<th>Trouble</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factors</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trouble</strong></td>
<td></td>
</tr>
<tr>
<td>Large wear at the peripheral</td>
<td>Non-coated insert is used</td>
</tr>
<tr>
<td>cutting edge</td>
<td>Not enough flutes</td>
</tr>
<tr>
<td>Improper cutting conditions</td>
<td></td>
</tr>
<tr>
<td>Up cut milling</td>
<td></td>
</tr>
<tr>
<td>Chipping</td>
<td></td>
</tr>
<tr>
<td>Improper cutting conditions</td>
<td></td>
</tr>
<tr>
<td>Fragile cutting edge</td>
<td></td>
</tr>
<tr>
<td>Insufficient clamping force</td>
<td></td>
</tr>
<tr>
<td>Poor clamping rigidity</td>
<td></td>
</tr>
<tr>
<td>Breakage during cutting</td>
<td></td>
</tr>
<tr>
<td>Improper cutting conditions</td>
<td></td>
</tr>
<tr>
<td>Poor end mill rigidity</td>
<td></td>
</tr>
<tr>
<td>Overhang longer than necessary</td>
<td></td>
</tr>
<tr>
<td>Chip packing</td>
<td></td>
</tr>
<tr>
<td>Vibration during cutting</td>
<td></td>
</tr>
<tr>
<td>Improper cutting conditions</td>
<td></td>
</tr>
<tr>
<td>Poor end mill rigidity</td>
<td></td>
</tr>
<tr>
<td>Poor clamping rigidity</td>
<td></td>
</tr>
<tr>
<td>Poor wall surface roughness</td>
<td>Large cutting edge wear</td>
</tr>
<tr>
<td>Improper cutting conditions</td>
<td></td>
</tr>
<tr>
<td>Chip jamming</td>
<td></td>
</tr>
<tr>
<td>Poor bottom surface roughness</td>
<td>The end cutting edge does not have a concave angle</td>
</tr>
<tr>
<td></td>
<td>Large pick feed</td>
</tr>
<tr>
<td>Out of vertical</td>
<td>Large cutting edge wear</td>
</tr>
<tr>
<td>Improper cutting conditions</td>
<td></td>
</tr>
<tr>
<td>Poor end mill rigidity</td>
<td></td>
</tr>
<tr>
<td>Poor surface finish accuracy</td>
<td>Improper cutting conditions</td>
</tr>
<tr>
<td></td>
<td>Poor clamping rigidity</td>
</tr>
<tr>
<td>Burr, workpiece chipping</td>
<td>Improper cutting conditions</td>
</tr>
<tr>
<td></td>
<td>Large helix angle</td>
</tr>
<tr>
<td>Quick burr formation</td>
<td>Notch wear occurs</td>
</tr>
<tr>
<td></td>
<td>Improper cutting conditions</td>
</tr>
<tr>
<td>Chip packing</td>
<td>Metal removal too large</td>
</tr>
<tr>
<td></td>
<td>Lack of flute chip space</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Insert Grade Selection</th>
<th>Cutting Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coated Tool</td>
<td>Cutting Speed, Up, Down, Decrease Pick Feed Rate, Down Cut, Air Blow</td>
</tr>
<tr>
<td>Cutting Fluids</td>
<td>Increase Coolant Quantity, Wet Cutting Fluid, Dry Cutting Fluid, Cold Cutting Fluid</td>
</tr>
<tr>
<td>Helix Angle</td>
<td>Number of Flutes, 90 Degree Angle of End Cutting Edge, Tool Diameter, Wiper Pocket</td>
</tr>
<tr>
<td>Improve End Mill Rigidity</td>
<td>Wider Chip Pocket, Spindle Collet Run-out, Tool Stability, Machine Stability, Rigidity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Style and Design of the Tool</th>
<th>Machine and Installation of Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spindle Collet Run-out Accuracy, Tool Installation Accuracy, Machine Stability, Rigidity</td>
</tr>
</tbody>
</table>

| TECHNICAL DATA |
END MILL FEATURES AND SPECIFICATION

**NOMENCLATURE**

- Cutter sweep
- Neck
- Shank (Handle)
- Diameter
- Length of cut
- Shank diameter
- Overall length
- Land width
- Relief width (Flank width)
- Radial primary relief angle
- Radial secondary clearance angle
- Radial rake angle
- Corner
- End cutting edge
- End gash
- Axial rake angle
- Axial primary relief angle
- Axial secondary clearance angle
- Helix angle
- Peripheral cutting edge
- Body (Cutting part)

**COMPARISON OF SECTIONAL AREA OF CHIP POCKET**

2-flutes 50%

3-flutes 45%

4-flutes 40%

6-flutes 20%

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

<table>
<thead>
<tr>
<th>Feature/Usage</th>
<th>2-flutes</th>
<th>3-flutes</th>
<th>4-flutes</th>
<th>6-flutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantage</td>
<td>Effective chip disposal.</td>
<td>Effective chip disposal.</td>
<td>High rigidity.</td>
<td>High rigidity. Superior cutting</td>
</tr>
<tr>
<td></td>
<td>Horizontal feed milling possible.</td>
<td>Horizontal feed milling possible.</td>
<td>edge durability.</td>
<td></td>
</tr>
<tr>
<td>Fault</td>
<td>Low rigidity.</td>
<td>Diameter is not measured easily.</td>
<td>Chip disposal is poor.</td>
<td>Chip disposal is poor.</td>
</tr>
<tr>
<td>Usage</td>
<td>Various cutting modes including</td>
<td>Sloting, shoulder milling</td>
<td>Shallow slotting, shoulder</td>
<td>Machining hardened steels.</td>
</tr>
<tr>
<td></td>
<td>slotting, shoulder milling and</td>
<td>Heavy cutting, finishing</td>
<td>milling Finishing</td>
<td>Shallow slotting, shoulder</td>
</tr>
<tr>
<td></td>
<td>drilling.</td>
<td></td>
<td></td>
<td>milling.</td>
</tr>
</tbody>
</table>
## END MILL TYPE AND GEOMETRY

### PERIPHERAL CUTTING EDGE

<table>
<thead>
<tr>
<th>Type</th>
<th>Shape</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary Flute</td>
<td><img src="image1" alt="Image" /></td>
<td>Regular flute geometry as shown is most commonly used for roughing and finishing of side milling, slotting and shoulder milling.</td>
</tr>
<tr>
<td>Tapered Flute</td>
<td><img src="image2" alt="Image" /></td>
<td>A tapered flute geometry is used for special applications such as mould drafts and for applying taper angles after conventional straight edged milling.</td>
</tr>
<tr>
<td>Roughing Flute</td>
<td><img src="image3" alt="Image" /></td>
<td>Roughing type geometry has a wave like edge form and breaks the material into small chips. Additionally the cutting resistance is low enabling high feed rates when roughing. The inside face of the flute is suitable for regrinding.</td>
</tr>
<tr>
<td>Formed Flute</td>
<td><img src="image4" alt="Image" /></td>
<td>Special form geometry as shown is used for producing corner radii on components. There are an infinite number of different geometry's that can be manufactured using such style of cutters.</td>
</tr>
</tbody>
</table>

### END CUTTING EDGE

<table>
<thead>
<tr>
<th>Type</th>
<th>Shape</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square End (With Center Hole)</td>
<td><img src="image5" alt="Image" /></td>
<td>Generally used for side milling, slotting and shoulder milling. Plunge cutting is not possible due to the center hole that is used to ensure accurate grinding and regrinding of the tool.</td>
</tr>
<tr>
<td>Square End (Center Cut)</td>
<td><img src="image6" alt="Image" /></td>
<td>Generally used for side milling, slotting and shoulder milling. Plunge cutting is possible and greater plunge cutting efficiency is obtained when using fewer flutes. Regrinding on the flank face can be done.</td>
</tr>
<tr>
<td>Ball End</td>
<td><img src="image7" alt="Image" /></td>
<td>Geometry completely suited for curved surface milling. At the extreme end point the chip pocket is very small leading to inefficient chip evacuation.</td>
</tr>
<tr>
<td>Corner Radius End</td>
<td><img src="image8" alt="Image" /></td>
<td>Used for radius profiling and corner radius milling. When pick feed milling an end mill with a large diameter and small corner radius can be efficiently used.</td>
</tr>
</tbody>
</table>

### SHANK AND NECK PARTS

<table>
<thead>
<tr>
<th>Type</th>
<th>Shape</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard (Straight Shank)</td>
<td><img src="image9" alt="Image" /></td>
<td>Most widely used type.</td>
</tr>
<tr>
<td>Long Shank</td>
<td><img src="image10" alt="Image" /></td>
<td>Long shank type for deep pocket and shoulder applications.</td>
</tr>
<tr>
<td>Long Neck</td>
<td><img src="image11" alt="Image" /></td>
<td>Long neck geometry can be used for deep slotting and is also suitable for boring.</td>
</tr>
<tr>
<td>Taper Neck</td>
<td><img src="image12" alt="Image" /></td>
<td>Long taper neck features are best utilized on deep slotting and mould draft applications.</td>
</tr>
</tbody>
</table>
### TECHNICAL DATA

**PITCH SELECTION OF PICK FEED**

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

![Diagram of an end mill with notation: \( h = R \left(1 - \cos \{ \sin^{-1}\left(\frac{P}{2R}\right)\} \right) \)](image)

- **R**: Radius of Ball Nose, Corner Radius
- **P**: Pick Feed
- **h**: Cusp Height

#### CORNER R OF END MILLS AND CUSP HEIGHT BY PICK FEED

<table>
<thead>
<tr>
<th>Pitch of Pick Feed (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R</strong></td>
</tr>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>12.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pitch of Pick Feed (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R</strong></td>
</tr>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>12.5</td>
</tr>
</tbody>
</table>

The table above provides the pitch selection of pick feed for different combinations of corner radius \( R \) and pick feed \( P \), along with the calculated cusp height \( h \) using the formula \( h = R \left(1 - \cos \{ \sin^{-1}\left(\frac{P}{2R}\right)\} \right) \).
<table>
<thead>
<tr>
<th>Troubles</th>
<th>Solutions</th>
<th>Cutting Conditions</th>
<th>Style and Design of the Tool</th>
<th>Machine and Installation of Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill breakage</td>
<td>Lack of drill rigidity, improper cutting conditions</td>
<td>Increase in cutting speed, feed rate, reducing the speed, feed rate.</td>
<td>Use a drill with coolant holes</td>
<td>Ensure tool accuracy, rigidity.</td>
</tr>
<tr>
<td></td>
<td>Large deflection of the tool holder, workpiece face inclined</td>
<td></td>
<td>Increase the depth of the hole</td>
<td></td>
</tr>
<tr>
<td>Large wear at the peripheral cutting edge</td>
<td>Improper cutting conditions, increase in temperature at the cutting point</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor run-out accuracy</td>
<td></td>
<td>Change to a drill with X-type thinning</td>
<td></td>
</tr>
<tr>
<td>Chipping of the peripheral cutting edge</td>
<td>Improper cutting conditions, large deflection of the tool holder, chatter, vibration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chisel edge chipping</td>
<td>The chisel edge width is too large, poor entry, chattering, vibration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hole diameter increases</td>
<td>Lack of drill rigidity, improper drill geometry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hole diameter becomes smaller</td>
<td>Increase in temperature at the cutting point, improper cutting conditions, improper drill geometry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor hole accuracy</td>
<td>Lack of drill rigidity, large deflection of the tool holder, poor guiding properties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor hole straightness</td>
<td>Lack of drill rigidity, large deflection of the tool holder, poor guiding properties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor hole positioning accuracy, roundness and surface finish</td>
<td>Lack of drill rigidity, poor entry, improper cutting conditions, large deflection of the tool holder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burrs at the hole exit</td>
<td>Improper drill geometry, improper cutting conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long chips</td>
<td>Improper cutting conditions, poor chip disposal</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Chip packing</td>
<td>Improper cutting conditions, poor chip disposal</td>
<td></td>
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TECHNICAL DATA

DRILL WEAR CONDITION AND CUTTING EDGE DAMAGE

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

![Diagram of drill wear condition](image)

- **We**: Chisel edge wear width
- **Wf**: Flank wear width (The middle of the cutting edge)
- **Wo**: Outer corner wear width
- **Wm**: Margin wear width
- **Wm’**: Margin wear width (Leading edge)

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

![Diagram of cutting edge damage](image)
### DRILL TERMINOLOGY AND CUTTING CHARACTERISTICS

#### NAMES OF EACH PART OF A DRILL

![Diagram of drill parts](image)

#### SHAPE SPECIFICATION AND CUTTING CHARACTERISTICS

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Helix Angle</strong></td>
<td>Is the inclination of the flute with respect to the axial direction of a drill, which corresponds to the rake angle. The rake angle of a drill differs according to the position along the cutting edge. The rake angle is largest at the periphery and smallest towards the center of the cutting edge. The chisel edge has a negative rake angle, crushing the work.</td>
</tr>
<tr>
<td><strong>Flute Length</strong></td>
<td>It is determined by depth of hole, guide bush length, and regrinding allowance. Since the influence on the tool life is great, it is necessary to minimize it as much as possible.</td>
</tr>
<tr>
<td><strong>Point Angle</strong></td>
<td>In general, the angle is 118° for high speed steel drills and 130─140° for carbide drills. Soft material with good machinability Small ←. Point angle → Large For hard material and high-efficiency machining</td>
</tr>
<tr>
<td><strong>Web Thickness</strong></td>
<td>It is an important element that determines the rigidity and chip disposal performance of a drill. The web thickness is set according to applications. Low cutting resistance, Low rigidity, Good chip disposal performance, Machinable material. Thin ←. Web thickness → Thick Large cutting resistance, High rigidity, Poor chip disposal, High-hardness material, cross hole drilling, etc.</td>
</tr>
<tr>
<td><strong>Margin</strong></td>
<td>The margin determines the drill diameter and functions as a drill guide during drilling. The margin width is decided taking into consideration the friction with in the hole to be drilled. Poor guiding performance Small ←. Margin width → Large Good guiding performance</td>
</tr>
<tr>
<td><strong>Diameter Back Taper</strong></td>
<td>To reduce friction with the inside of the drilled hole, the portion from the point to the shank is tapered slightly. The degree is usually represented by the quantity of reduction in the diameter with respect to the flute length, which is approx. 00.016&quot;─0.016&quot;/4&quot;.</td>
</tr>
</tbody>
</table>
TECHNICAL DATA

DRILL TERMINOLOGY
AND CUTTING CHARACTERISTICS

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

Typical Cutting Edge Geometries

<table>
<thead>
<tr>
<th>Grinding Name</th>
<th>Geometry</th>
<th>Features and Effect</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conical</td>
<td><img src="image" alt="Conical Geometry" /></td>
<td>• The flank is conical and the clearance angle increases toward the center of the drill.</td>
<td>• For general use.</td>
</tr>
<tr>
<td>Flat</td>
<td><img src="image" alt="Flat Geometry" /></td>
<td>• The flank is flat and facilitates cutting.</td>
<td>• Mainly for small diameter drills.</td>
</tr>
<tr>
<td>Three Rake Angles</td>
<td><img src="image" alt="Three Rake Angles Geometry" /></td>
<td>• As there is no chisel edge, the results are high centripetal force and small hole oversize.</td>
<td>• For drilling operations that require high hole accuracy and positioning accuracy.</td>
</tr>
<tr>
<td>Spiral Point</td>
<td><img src="image" alt="Spiral Point Geometry" /></td>
<td>• To increase the clearance angle near the center of the drill, conical grinding combined with irregular helix.</td>
<td>• For drilling that requires high accuracy.</td>
</tr>
<tr>
<td>Radial Lip</td>
<td><img src="image" alt="Radial Lip Geometry" /></td>
<td>• The cutting edge is ground radial with the aim of dispersing load.</td>
<td>• For cast iron and light alloy.</td>
</tr>
<tr>
<td>Center Point Drill</td>
<td><img src="image" alt="Center Point Drill Geometry" /></td>
<td>• This geometry has two-stage point angle for better concentricity and a reduction in shock when exiting the workpiece.</td>
<td>• For thin sheet drilling.</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Geometría</th>
<th>X type</th>
<th>XR type</th>
<th>S type</th>
<th>N type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Features</td>
<td>The thrust load substantially reduces, and the bite performance improves. This is effective when the web is thick.</td>
<td>The initial performance is slightly inferior to that of the X type, but the cutting edge is tough and the applicable range of workpiece materials is wide.</td>
<td>Popular design, easy cutting type.</td>
<td>Effective when the web is comparatively thick.</td>
</tr>
</tbody>
</table>
## DRILLING CHIPS

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

FORMULAS FOR DRILLING

**CUTTING SPEED (vc)**

\[
vc = \frac{\pi \cdot D1 \cdot n}{12} \quad \text{(SFM)}
\]

<table>
<thead>
<tr>
<th>vc (SFM)</th>
<th>Cutting Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>\pi (3.14)</td>
<td>Circular Constant</td>
</tr>
<tr>
<td>n (min(^{-1}))</td>
<td>Rotational Speed of the Main Spindle</td>
</tr>
</tbody>
</table>

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

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

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

\[
vc = \frac{\pi \cdot D1 \cdot n}{12} = \frac{3.14 \times .500 \times 1350}{12} = 176.6\text{SFM}
\]

The cutting speed is 176.6SFM.

**FEED OF THE MAIN SPINDLE (vf)**

\[
vf = fr \times n \quad \text{(inch/min)}
\]

<table>
<thead>
<tr>
<th>vf (inch/min)</th>
<th>Feed Speed of the Main Spindle (Z axis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>fr (IPR)</td>
<td>Feed per Revolution</td>
</tr>
<tr>
<td>n (min(^{-1}))</td>
<td>Rotational Speed of the Main Spindle</td>
</tr>
</tbody>
</table>

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

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

\[
vf = fr \times n = .008 \times 1350 = 10.8\text{inch/min}
\]

The spindle feed is 10.8inch/min.

**DRILLING TIME (Tc)**

\[
Tc = \frac{ld \times i}{n \times fr}
\]

<table>
<thead>
<tr>
<th>Tc (min)</th>
<th>Drilling Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>n (min(^{-1}))</td>
<td>Spindle Speed</td>
</tr>
<tr>
<td>ld (inch)</td>
<td>Hole Depth</td>
</tr>
<tr>
<td>fr (IPR)</td>
<td>Feed per Revolution</td>
</tr>
<tr>
<td>i</td>
<td>Number of Holes</td>
</tr>
</tbody>
</table>

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

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

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

\[
= .187 \times 60 = 11.2 \text{sec}
\]
## TOOL WEAR AND DAMAGE

### CAUSES AND COUNTERMEASURES

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

### CARBON STEEL

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<tr>
<th>USA</th>
<th>Japan</th>
<th>Germany</th>
<th>U. K.</th>
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## STAINLESS STEEL (FERRITIC, MARTENSITIC)

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## TECHNICAL DATA

- USA
- Japan
- Germany
- U. K.
- France
- Italy
- Spain
- Sweden
- China
### HEAT RESISTANT STEELS

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<th>U. K.</th>
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### GRAY CAST IRON

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<td>FGS 38-17</td>
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<td>FGS 500-7</td>
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<td>50005</td>
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<td>08 62</td>
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**TECHNICAL DATA**

**SURFACE ROUGHNESS**

(From JIS B 0601-1994)

**Arithmetical Mean Roughness**

- **Ra**
  - Ra means the value obtained by the following formula and expressed in micrometer (μm) when sampling only the reference length from the roughness curve in the direction of the mean line, taking X-axis in the direction of mean line and Y-axis in the direction of longitudinal magnification of this sampled part and the roughness curve is expressed by y=f(x):
  
  \[ Ra = \frac{1}{l} \int_{0}^{l} f(x) \, dx \, (\mu m) \]

- **Rz**
  - Rz shall be that only when the reference length is sampled from the roughness curve in the direction of its mean line, the distance between the top profile peak line and the bottom profile valley line on this sampled portion is measured in the longitudinal magnification direction of roughness curve and the obtained value is expressed in micrometer (μm).

  (Note) When finding Rz, a portion without an exceptionally high peak or low valley, which may be regarded as a flaw, is selected as the sampling length.

  \[ R_{Z} = R_{P} + R_{V} \, (\mu m) \]

- **RzJIS**
  - RzJIS shall be that only when the reference length is sampled from the roughness curve in the direction of its mean line, the sum of the average value of absolute values of the heights of five highest profile peaks (YP) and the depths of five deepest profile valleys (YV) measured in the vertical magnification direction from the mean line of this sampled portion and this sum is expressed in micrometer (μm).

  \[ R_{ZJIS} = \frac{(Y_{P1} + Y_{P2} + Y_{P3} + Y_{P4} + Y_{P5}) + (Y_{V1} + Y_{V2} + Y_{V3} + Y_{V4} + Y_{V5})}{5} \, (\mu m) \]

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

<table>
<thead>
<tr>
<th>Arithmetical Mean Roughness</th>
<th>Max. Height</th>
<th>Ten-Point Mean Roughness</th>
<th>Sampling Length for Rz • RzJIS</th>
<th>Conventional Finish Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Series Ra</td>
<td>Cutoff Value (mm)</td>
<td>Standard Series</td>
<td>Sampling Length for Rz • RzJIS</td>
<td>Conventional Finish Mark</td>
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<tr>
<td>0.012 a</td>
<td>0.08</td>
<td>0.05s</td>
<td>0.08</td>
<td>▼▼▼▼</td>
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<tr>
<td>0.025 a</td>
<td>0.25</td>
<td>0.1s</td>
<td>0.25</td>
<td>▼▼</td>
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<tr>
<td>0.05 a</td>
<td>0.2</td>
<td>0.2 s</td>
<td>0.2 z</td>
<td>▼</td>
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<tr>
<td>0.1 a</td>
<td>0.4</td>
<td>0.4 s</td>
<td>0.4 z</td>
<td>▼</td>
</tr>
<tr>
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<td>0.8</td>
<td>0.8 s</td>
<td>0.8 z</td>
<td>▼</td>
</tr>
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<td>1.6 s</td>
<td>1.6 z</td>
<td>▼</td>
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<td>3.2 s</td>
<td>3.2 z</td>
<td>▼</td>
</tr>
<tr>
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<td>6.3</td>
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<td>6.3 z</td>
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<td>12.5 z</td>
<td>▼</td>
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<td>—</td>
<td>400 s</td>
<td>400 z</td>
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</tbody>
</table>

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

### HARDNESS CONVERSION NUMBERS OF STEEL

<table>
<thead>
<tr>
<th>Brinell Hardness (HB), 10mm Ball, Load: 3000kgf</th>
<th>Rockwell Hardness (3)</th>
<th>Tensile Strength (Approx.) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Scale, Load: 60kgf, Diamond Point (HRA)</td>
<td>B Scale, Load: 100kgf, 1/16&quot; Ball (HRB)</td>
<td>C Scale, Load: 150kgf, Diamond Point (HRC)</td>
</tr>
<tr>
<td>Standard Ball</td>
<td>Tungsten Carbide Ball</td>
<td>Load: 60kgf</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------</td>
<td>-------------</td>
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<tr>
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<table>
<thead>
<tr>
<th>Brinell Hardness (HB), 10mm Ball, Load: 3000kgf</th>
<th>Rockwell Hardness (3)</th>
<th>Tensile Strength (Approx.) (MPa)</th>
</tr>
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<tbody>
<tr>
<td>A Scale, Load: 60kgf, Diamond Point (HRA)</td>
<td>B Scale, Load: 100kgf, 1/16&quot; Ball (HRB)</td>
<td>C Scale, Load: 150kgf, Diamond Point (HRC)</td>
</tr>
<tr>
<td>Standard Ball</td>
<td>Tungsten Carbide Ball</td>
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<tr>
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</tbody>
</table>

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

(Note 2) 1MPa = 1N/mm²

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

The chart below shows the relationship between various tool materials, in relation with hardness on a vertical axis and toughness on a horizontal axis.

Today, cemented carbide, coated carbide and TiC-TiN-based cermet are key tool materials in the market. As they offer a high balance of hardness and toughness.

GRADE CHARACTERISTICS

<table>
<thead>
<tr>
<th>Hard Materials</th>
<th>Hardness (HV)</th>
<th>Energy Formation (kcal/g · atom)</th>
<th>Solubility in Iron (%·1250°C)</th>
<th>Thermal Conductivity (W/m·k)</th>
<th>Thermal Expansion (x 10⁻⁶/k)</th>
<th>Tool Material</th>
</tr>
</thead>
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* 1W/m • K=2.39×10⁻³cal/cm • sec • °C
GRADE CHAIN

For Cutting Tools

Cemented Carbide
- P Steel
- M Stainless Steel
- K Cast Iron
- N Non-Ferrous
- S Heat Resistant/Alloyed Ti Alloy

Coated Carbide
- P Steel
- M Stainless Steel
- K Cast Iron
- N Non-Ferrous
- S Heat Resistant/Alloyed Ti Alloy

Hardened Materials
- H

Coated Cermet
- P Steel
- M Stainless Steel
- K Cast Iron

Cermet
- P Steel
- M Stainless Steel
- K Cast Iron

Polycrystallines
- N Non-Ferrous/Non-Metal
- M Sintered Alloy
- K Cast Iron

Micro-Grain Cemented Carbide
- Steel
- Cast Iron

TECHNICAL DATA
## GRADE COMPARISON TABLE

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* Coated Cermet

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## TECHNICAL DATA

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(Note) The above table is selected from a publication. We have not obtained approval from each company.
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* Peripheral ground type insert.

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

### 11° POSITIVE INSERT TYPE

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<th>Kennametal</th>
<th>Sandvik</th>
<th>Seco Tool</th>
<th>Walter</th>
<th>Taegu Tec</th>
<th>Sumitomo Electric</th>
<th>Tungaloy</th>
<th>Kyocera</th>
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