Think efficiency, Think HSS
ZOOM ON A MILLING CUTTER

Coating Cutting edge profiles: N, NR, NRF, …

End types: square, corner chamfer, ballnose, …

Helix angles: 25°, 40°, 50°, etc.

Number of teeth: from 1 to 10

Dimensions

Tool material

Number of teeth:

from 1 to 10

Helix angles:

25°, 40°, 50°, etc.

Dimensions

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Dimensions

Tool material

Shank types: Weldon, plain, Clarkson, …
<table>
<thead>
<tr>
<th>Tool Maker’s Tip</th>
<th>HSS</th>
<th>HSS-E 5% cobalt</th>
<th>HSS-E 8% cobalt</th>
<th>HSS-PM (powder metallurgy)</th>
<th>HSS-E-PM (powder metallurgy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attain the highest performance with HSS-PM</td>
<td>Seldom used for milling cutters</td>
<td>Basic choice</td>
<td>The most popular grade</td>
<td>High performance in roughing</td>
<td>High performance in finishing, but also in roughing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>For higher cutting speeds</td>
<td>Long tool life</td>
<td>High cutting speeds</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>For high productivity</td>
<td>Best suited for nickel alloys or titanium alloys</td>
<td>Long tool life</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Suitable for dry machining</td>
<td>Suitable for dry machining</td>
</tr>
</tbody>
</table>

WHICH HSS FOR MAXIMUM EFFICIENCY?
<table>
<thead>
<tr>
<th>Coating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiN Gold</td>
<td>• Conventional, general purpose coating</td>
</tr>
<tr>
<td></td>
<td>• Reduces friction</td>
</tr>
<tr>
<td></td>
<td>• Good abrasion-wear resistance</td>
</tr>
<tr>
<td>TiCN Grey-violet</td>
<td>• Multi-purpose coating, especially for roughing end mills</td>
</tr>
<tr>
<td></td>
<td>• High abrasion-wear resistance</td>
</tr>
<tr>
<td></td>
<td>• Available as mono- or multilayer</td>
</tr>
<tr>
<td></td>
<td>• Recommended for construction steels (Rm&lt;1000 Mpa)</td>
</tr>
<tr>
<td>TiAlN/ TiAlCN Black-violet</td>
<td>• High performance coating for a wide range of cutting parameters</td>
</tr>
<tr>
<td></td>
<td>• 2x to 6x longer tool life than with conventional coatings</td>
</tr>
<tr>
<td></td>
<td>• Reduced heating of the tool</td>
</tr>
<tr>
<td></td>
<td>• Multilayered, nanostructured or alloyed versions offer even better performance</td>
</tr>
<tr>
<td></td>
<td>• Suitable for dry machining</td>
</tr>
<tr>
<td>MoS₂/ WC-C Grey-black</td>
<td>• Reduces friction</td>
</tr>
<tr>
<td></td>
<td>• Limited temperature resistance</td>
</tr>
<tr>
<td></td>
<td>• Recommended for aluminium alloys, copper and non metallic materials</td>
</tr>
</tbody>
</table>

**TOOL MAKER’S TIP**

For maximum coating efficiency, prefer a HSS -PM substrate.
VOCABULARY

A MILLING CUTTER
AROUND THE WORLD

French: une fraise
German: ein Fräser
Italian: una fresa
Spanish: una fresa

Length of cut
Mill diameter
Overall length
Shank diameter
Shank

Radial primary relief angle
Radial primary relief width
Land width
Radial secondary clearance angle
Cutting face
Radial rake angle
Chip room
Flute
Axial primary relief width
End gash
Helix angle
End teeth
Axial rake angle
Axial secondary clearance angle

Hack taper

End cutting edge concavity angle
**CHOOSE THE RIGHT DESIGN**

**Solid end mill**
- For small tool diameters (1 to 32 mm or up to 63 mm)
- For complex geometries (3D surfaces) : pocket, radius, axial plunging, etc.
- For modern machining centers
- For both roughing and finishing operations

**End mill with HSS indexable inserts**
- For large tool diameters (10 to 160 mm)
- Sharper edge and more positive cutting angle than carbide inserts
- Suitable when carbide inserts fail, especially in stainless steels
- No resharpening needed (throw-away inserts)

**Solid shell end mill**
- Mounted on an arbor.
- For large tool diameters (32 to 100 mm).
- Very productive in roughing operations
- Fragile body (due to the large clamping hole)
- Only for operation without center cut

**Side and face milling cutters**
- Mounted on an arbor.
- Possible to pile up several cutters for precise large slots
- Good torque transmission
- Accurate tolerance of the clamping hole necessary to avoid out-of-true

---

**TOOL MAKER’S TIP**

HSS inserts are recommended when carbide inserts fail
Chip breakers are essential to increase the depth of cut and decrease the power and cutting forces.

### Roughing Profiles

- **NR (Normal Round)**
  - Rounded chip breakers
  - Normal pitch
  - For roughing and deep slotting
  - Lower surface quality
    - $Ra > 6.3$
  - For steels, cast iron

- **HR**
  - Rounded chip breakers
  - Fine pitch
  - For roughing-finishing

### Finishing Profiles

- **N (Normal)**
  - For all materials
  - Universal profile
  - Most used profile

- **H**
  - For hard materials
  - Short chips
  - Excellent surface quality

- **W**
  - For non ferrous
  - Excellent surface quality

---

**Workpiece**

- Feed per revolution
- Coarse Pitch
- Large chip
- END MILL

**Surface of a workpiece after roughing**

---

**Select an Edge Profile**

---
TOOL MAKER’S TIP

Thanks to the properties of HSS, tool producers can design proprietary cutting edge profiles to solve specific machining problems.

ROUGHING - FINISHING PROFILES

- **WR**
  - For non ferrous
  - For roughing-finishing

- **NF**
  - Normal pitch
  - For roughing-finishing
  - Flat chip breakers

- **HFS**
  - Flat chip breakers
  - Normal pitch
  - For roughing/finishing
2 teeth
- Large chip room and small web diameter
- Good results in roughing and in slot milling
- Also used for plunging and drilling in aluminium alloys and materials with long chips

3 teeth
- The most universal milling tool
- Excellent choice for slot milling and “ramping” in ferrous materials and heat resistant alloys

4 teeth
- Universal geometry, used for side and face milling and peripheral milling
- High tool rigidity due to the large web diameter
- Lower chip removal rate in slot milling than with a 3-tooth endmill

5 teeth and more
- Mainly for finishing - good surface finish
- Allow a high feed rate
- Soft cut because there is always a tooth in the workpiece material
- Also for roughing with tool diameters > 20 mm

TOOL MAKER’S TIP
Prefer a 2-tooth cutter for soft materials. Prefer a 4-tooth cutter for difficult-to-machine materials
## TOOL MAKER’S TIP
Select the helix angle according to the workpiece material and the type of operation (roughing / finishing)

### UNDER 25°
For roughing and finishing in large diameters
+ Used in steel and cast iron and for all materials when large tool diameters are required
+ Low axial cutting force (interesting in large tool diameters)
- Not for deep slot milling due to radial chip removal
- Shocks due to discontinuous contact between the tool and the workpiece

### 25 TO 35°
Basic choice for roughing and finishing in all materials
+ Universal use, with a good balance of cutting forces
- Not always the most productive

### 40 TO 50°
For roughing and finishing of non-ferrous alloys
+ High depth of cut in ferrous alloys when combined with a small number of teeth.
+ Constant tooth contact with the workpiece
- Fragile corners
- High axial cutting forces in roughing operations with large diameter tools

### ABOVE 50°
For finishing of hardened materials
+ Very good surface quality and high productivity, when combined with a large number of teeth
- Fragile corner if no corner chamfer or corner radius exists

---

## UNDER

- 25°
- 25 TO 35°
- 40 TO 50°
- ABOVE 50°

## DIFFERENT HELIX ANGLES
<table>
<thead>
<tr>
<th>Design</th>
<th>Industry</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square</td>
<td>Gen. mechanics</td>
<td>• True square angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fragile corner</td>
</tr>
<tr>
<td>Corner chamfer</td>
<td>Gen. mechanics</td>
<td>• Resistant corners</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Good cutting in roughing operations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Suitable for coated tools</td>
</tr>
<tr>
<td>Corner radius</td>
<td>Aeronautics</td>
<td>• Typical use: roughing 3D parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High corner resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Suitable for coated tools</td>
</tr>
<tr>
<td>Ball nose</td>
<td>Moulds and dies</td>
<td>• Finishing 3D parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Zero cutting speed at center: poor surface quality in soft materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Used to round corners</td>
</tr>
<tr>
<td>Corner rounding</td>
<td>Gen. mechanics</td>
<td>• Fragile corner</td>
</tr>
</tbody>
</table>

**DID YOU KNOW?**
The toughness of HSS prolongs the tool life of square end mills.

**POPULAR END DESIGNS**
DIMENSIONS AND TOLERANCES

Four typical tool lengths (ISO 1641/1)
The cutting length defines the depth which can be machined in one pass.
For highest performance, especially in roughing, use the shortest cutters and work as close to the machine head as possible.

Diameter
Tolerances on shank diameter (h6) are very tight (need for accuracy in milling operations).
Tolerances on cutting diameter depend on the type of operation (roughing, finishing, slotting), and on international or tool-maker standards.

DID YOU KNOW?
The tolerances of HSS end mills are identical to the tolerances of carbide endmills.
TOOL MAKER’S TIP
For longer tool life and improved tolerances, HSS milling cutters can be shrink fitted!

**Weldon Shank**
- Basic choice
- Choice of one or two clamping flats
- Simple clamping, without tuning of the cutting length
- Good capacity of torque transmission in roughing
- Large tool holder
- Out-of-balance problems at high speeds due to the screw

**Plain Shank**
- Good choice for very small tool diameters
- Adjustable tool length
- Suitable for precision clamping or shrink fitting
- No unbalance at high rotating speeds (no flat, no screw)
- Low torque transmission when clamped with a collet
- Not for roughing if tool diameters > 12 mm.

**Clarkson Shank**
- Former basic choice
- Low torsion rigidity
- No possible adjustment of the overhang length in the tool holder

**Morse Taper Shank**
- Former basic choice
- Good coaxiality (conical assembly)
- Moderately large tool holder allows use in difficult-to-access cases
- Limited torque transmission
- Tool length too long for roughing

**Tool Maker’s Tip**
For longer tool life and improved tolerances, HSS milling cutters can be shrink fitted!
With tenon
For both face milling and surface cutters
+ Good torque transmission

With keyway
For side milling cutters
+ Good torque transmission
+ Permits « piling-up » of several tools

Plain
The economical choice
+ Adapted to thin tools
+ Careful clamping prevents the tool from sliding on the tool holder
Milling is a machining operation with interrupted cut. The cutting edge moves circularly, producing a chip of varying thickness. At each turn, the tooth goes in and out of the workpiece material. Combined with variable chip thickness, this alternate motion leads to a continuous variation of cutting forces and produces shocks.
OPERATING MODES OF END MILLS

- Side milling
- Face milling
- Side and face milling
- Slot milling
- Plunging
- Diagonal plunging
- Pocketing
- Helical interpolation
OPERATING MODES OF OTHER MILLING CUTTERS

- T-slot cutter
- Woodruff cutter
- Side and face cutters
- Angular cutter
- Angular cutter
- Corner-rounding cutter
Conventional milling
The width of the chip starts at zero and increases to a maximum at the end of the cut.
+ Used only when the machine tool lacks rigidity or works loosely (old milling machine, low quality machine, worn machine)
- Tendency to push workpiece away
- Tool edge slides instead of cutting, causing high friction between tool flank face and material

Climb milling
The tooth meets the work at the top of the cut, producing the thickest part of the chip first.
+ Efficient cutting
+ Long and reliable tool life
+ Better surface finish, especially with stainless steels, aluminium or titanium alloys
- Risk of tool breakage, due to sudden machine backlash when the machine lacks rigidity
TYPICAL CUTTING SPEEDS

- Graphite
- Duplex / highly alloyed stainless steels
- Nickel alloys > 850 Mpa
- Titanium alloys (type TA6V)
- Ferritic, martensitic, ferritic-austenitic stainless steels
- Nickel alloys < 850 Mpa
- Cu Al Fe
- Lamellar graphite cast iron
- Thermosetting plastics
- Pure Titanium
- Cooper alloys - short chips
- Cooper alloys - long chips
- Magnesium
- Pure copper
- Aluminium Si < 5% (Plastics)
- Steels 850 - 1200 Mpa
- Austenitic stainless steels
- Steels: 550 - 850 Mpa
- Cu Al Ni
- Hardened cast iron > 270 HB
- Steels 550 - 850 Mpa
- Cu Al Fe
- Steel: < 550 Mpa
- Nickel alloys < 850 Mpa
- Titanium alloys (type TA6V)
- Nickel alloys > 850 Mpa
- Duplex / highly alloyed stainless steels
- Graphite

Cutting speed in m/min
The metal removal rate depends on two parameters, feed (fz) and speed (N): 
\[ Q = a_d \times a_e \times N \times z_i \times f_z / 1000 \]

For high productivity in milling, increase the feed before increasing the speed, especially in roughing operations.

A minimum feed is also necessary. When the feed is too low, the milling cutter no longer cuts but tears off the material.

### SUCCESS STORIES

#### Construction Steel

- **Operation**
  - Roughing

- **Cutting data**
  - N 1350 tr/min, v_c 68 m/min, f_z 0.1 mm (100% higher than with a carbide tool)

- **Metal removal rate**
  - Q 103.7 cm³/min

#### Aluminium (<6% Si)

- **Operation**
  - Slot milling

- **Cutting data**
  - N 15650 tr/min, v_c 295 m/min, f_z 0.3 mm

- **Metal removal rate**
  - Q 50.8 cm³/min (30% higher than with a carbide tool)

#### Inconel 718

- **Operation**
  - Roughing with a 6-tooth HSS-PM 8%Co + TiCN tool

- **Cutting data**
  - N 5 m/min, f_z 0.16 mm (double than with a carbide tool)

- **Benefits**
  - Q 11.5 cm³/min (same as carbide) and longer tool life: 2.1 m vs. 0.45 m for carbide
Cutting fluids in milling
- Usual cutting fluids: soluble oil, or oil. Soluble oils with additives significantly increase the tool life of HSS milling cutters.
- Cutting fluids are essential when non-coated tools are used, especially in slot milling where the contact time between the tool and material is important.

The coolant should be carefully oriented:
- When the tool enters the workpiece, for efficient cooling during the milling operation.
- When the tool comes out of the workpiece, to evacuate chips and calories properly.

SUCCESS STORY

Tool steel
(Rm 1040 N/mm²)

Operation
Cutting data
Benefits

Dry milling with a HSS cutter!
- Roughing with a HSS-PM 8% Co + Ti₂CN tool aₜ 12 mm, aₜ 8 mm in tool steel 40CrMnMo7
- vₑ 45 m/min, fₑ 0.03 mm

Compared with wet machining:
- Reduction of the specific cutting energy (56.8 vs. 46.6 W/cm³/min)
- Tool life only slightly modified (7 m vs. 8.1 m)
- Potential for an increase in feed and productivity

Dry milling
- HSS milling cutters can also be used either with minimum quantity lubricant or dry.
- TiAlN coatings, a real thermal barrier, also allow high productivity dry milling with HSS milling cutters.

DID YOU KNOW?
Thermal shocks caused by cooling problems?
Only HSS resists!
<table>
<thead>
<tr>
<th>Problem</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>No perpendicularity on side</td>
<td>Decrease speed. Decrease depth and width of cut. Decrease overall length. Use an end mill with more flutes.</td>
</tr>
<tr>
<td>No dimensional accuracy</td>
<td>Decrease depth and width of cut. Improve the rigidity of holder and piece clamping. Use an end mill with more flutes.</td>
</tr>
<tr>
<td>Chattering</td>
<td>Reduce feed or speed. Improve the rigidity of holder and piece clamping. Decrease relief angle. Decrease depth of cut. Use a shorter end mill.</td>
</tr>
<tr>
<td>Chip packing</td>
<td>Reduce feed or speed. Use an end mill with less flutes. Increase coolant flow.</td>
</tr>
<tr>
<td>Burrs</td>
<td>Regrind earlier. Correct milling data and correct cutting angle.</td>
</tr>
<tr>
<td>Rough surface finish</td>
<td>Reduce feed and increase speed. Regrind earlier. Decrease chip removal rate.</td>
</tr>
<tr>
<td>Breakage of end mill</td>
<td>Reduce speed and feed per tooth. Use a shorter end mill. Regrind earlier.</td>
</tr>
<tr>
<td>Short tool life</td>
<td>Regrind earlier. Use a HSS-PM end mill. Correct milling data and cutting angle.</td>
</tr>
</tbody>
</table>
### How to Monitor Wear

<table>
<thead>
<tr>
<th>Tool Wear</th>
<th>Normal Wear Pattern</th>
<th>To Be Limited</th>
<th>To Be Avoided</th>
<th>To Be Limited</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flank wear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal wear pattern</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>If too high, decrease first the cutting speed ($v_c$) then the width of cut ($a_w$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase the coolant flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use HSS-PM and coating</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Crater wear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>To be limited</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decrease the cutting speed ($v_c$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use a coated tool and a 8% Co HSS material</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check coolant flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chipping</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>To be avoided</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decrease first the feed ($f_z$) and second the depth of cut ($a_p$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use a tougher material (HSS-PM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Deformation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>To be avoided</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decrease first the cutting speed ($v_c$), then the feed ($f_z$) and third $a_p$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use a coated tool and 8% Co HSS or HSS-PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase the coolant flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Built-up edge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>To be limited</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase the cutting speed ($v_c$) and/or the feed ($f_z$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase the effective cutting angle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase the coolant flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Use a low friction coating</td>
<td></td>
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</tr>
</tbody>
</table>

**Tool Maker’s Tip**

In milling, careful monitoring of corner wear prolongs tool life.
Shape of chips
A milling chip has a spiral shape.
The extremity lying inside the spiral is formed when the edge enters the workpiece.
In conventional milling, this extremity will be the thickest.
Due to the interrupted cut, the chip length is limited to the length of the arc of the cut in the material.

Chip control
Control the milling operation by measuring and observing the chip:
- The width depends on the depth of cut: the longest chip is obtained in slot milling operations.
- The length depends on the width of cut and the tool diameter; the larger the tool diameter, the longer the chip.
- The thickness is proportional to the feed per tooth combined with the width of cut.
- Milling chips should be regular.
- Milling chips should present an homogeneous color.

- When a coolant is used, there should be no trace of thermal effects on the chip.

How to avoid problems?
It is important that chips not remain in the cutting area.
If chips are irregular, if there are needle chips, or if chips have several colors, this means that the cutting data is not well chosen, that the cooling is not efficient, that there are vibrations or that the tool cutting edges are worn.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Name</th>
<th>Formulae</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>mm</td>
<td>Tool diameter</td>
<td>$v_c = \frac{\pi DN}{1000}$</td>
</tr>
<tr>
<td>T</td>
<td>mm</td>
<td>Machining time</td>
<td>$N = \frac{1000v_f}{\pi D}$</td>
</tr>
<tr>
<td>Z</td>
<td></td>
<td>No. of teeth</td>
<td>$v_f = NZ f_z$</td>
</tr>
<tr>
<td>$a_p$</td>
<td>mm</td>
<td>Depth of cut</td>
<td>$f_z = \frac{v_f}{NZ}$</td>
</tr>
<tr>
<td>$a_e$</td>
<td>mm</td>
<td>Width of cut</td>
<td>$Q = \frac{a_p a_e NZ f_z}{1000}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Name</th>
<th>Formulae</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_m$</td>
<td>mm</td>
<td>Average chip thickness</td>
<td>$\frac{\sqrt{a_e}}{D f_z}$</td>
</tr>
<tr>
<td>$h_{\text{max}}$</td>
<td>mm</td>
<td>Maximum chip thickness</td>
<td>$\frac{\sqrt{a_e}}{D f_z}$</td>
</tr>
</tbody>
</table>