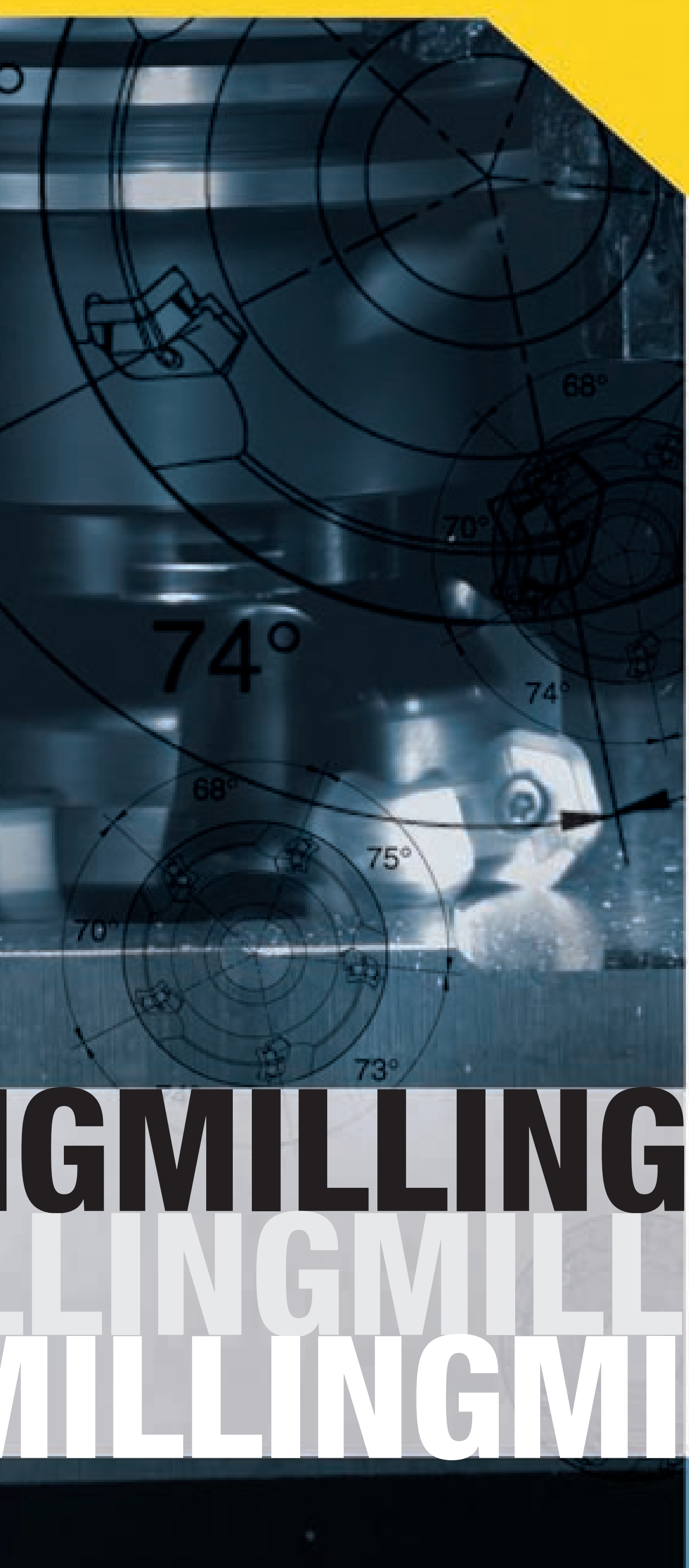
KENNAMETAL®

Engineering Your Competitive Edge



Technical Data

TABLE OF CONTENTS

Choosing Cutter Diameter

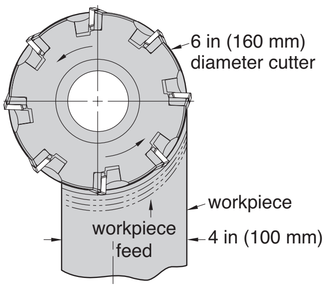
Workpiece dimensions determine the best face mill diameter to select.

Cutter-to-part width-of-cut ratio should be approximately 3:2 or 1 1/2 times the part width. For example, if the width of cut is 4 inches (100 mm), choose a 6-inch (160 mm) diameter cutter. If the width is extremely wide, select a cutter diameter that matches the spindle capacity and take multiple passes. For example, if the width of cut is 24 inches (610 mm) and the machine has a standard #50 taper spindle, you should use an 8-inch (200 mm) diameter cutter and take five passes, at slightly less than 5-inches (125 mm) per pass, or four passes at 6-inches (160 mm) per pass, depending on horsepower and rigidity.

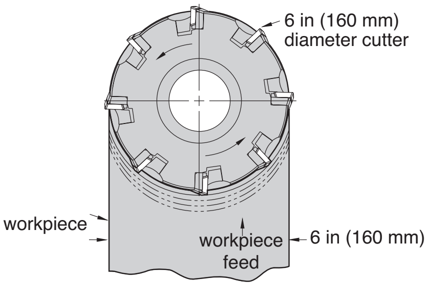
An undesirable situation is when the cutter diameter is about equal to the width of cut. The chip being formed at the entrance and exit of the cut will be very thin. The thin chips formed cannot carry away heat as well as thicker chips, therefore the heat is transferred back into the insert causing premature edge failure. Work-hardening is also more likely to occur in the entry and exit area.

When the proper cutter diameter is not available, proper cutter positioning will provide positive results.

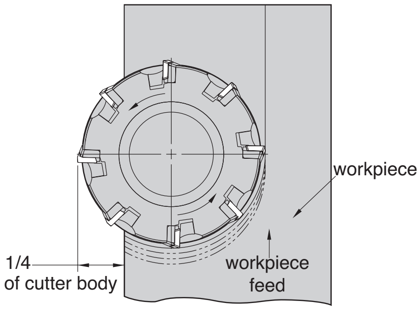
- Position cutter with approximately 1/4 of the cutter body outside the workpiece and make two passes.
- Produces negative angle of entry (desirable).
- Can result in longer tool life.



desirable



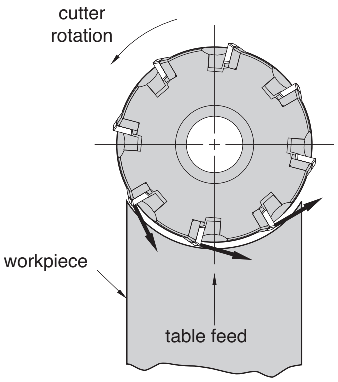
undesirable

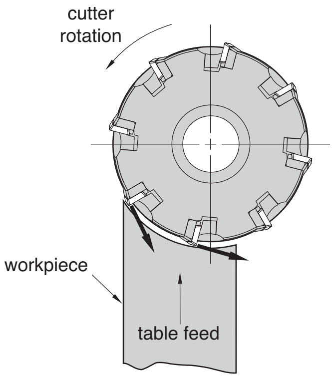


cutter position

Cutter Positioning/Cutting Forces

The cutting forces are constantly changing as the inserts move through the cut. We should understand that in changing the position of the cutter in relation to the workpiece, we can re-direct the cutting forces. This is important to ensure a safe operation based on fixture design, workpiece design, and workpiece considerations.





Pitch, or density, refers to the number of inserts in a cutter. Cutters can be classified as having either coarse, medium, or fine pitch. When designing a cutter, the engineer must take the depth of cut and feed per tooth into consideration. He then must provide the necessary chip clearance in the body so that the chip can pass without restricting its formation. For this reason, cutters designed for heavy metal removal have maximum chip clearance. This, therefore, restricts the number of inserts in the cutter, making it a coarse pitch cutter.

In medium pitch cutters, the chip clearance area in the body is usually slightly smaller than a coarse pitch cutter. And, in fine pitch cutters, the chip clearance is considerably less.

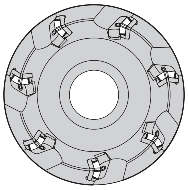
Coarse pitch is recommended for general purpose milling where adequate horsepower is available, and where maximum depth of cut is required.

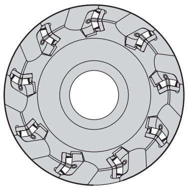
Medium pitch is recommended when moderate feed per insert is required, and where it is more advantageous to have more than one insert in the cut. Medium pitch also reduces entry shock and cutting pressure while maintaining feed rates.

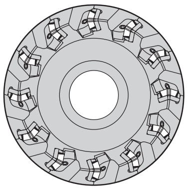
Fine pitch is ideal when milling a severely interrupted surface such as a manifold block. Fine pitch cutters are capable of higher inch/mm per minute feed rates than medium or coarse pitch cutters. They also experience higher cutting forces and greater horsepower consumption than medium or coarse pitch cutters do.

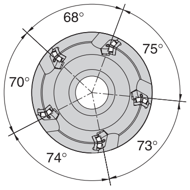
Differential Pitch

A cutter with unequally spaced inserts is a differential-pitch milling cutter. This configuration breaks up the harmonics that result from equally spaced inserts, greatly reducing the chance of vibration. Most cutters use this design regardless of the cutter pitch.


coarse pitch


medium pitch


fine pitch



differential pitch

Lead Angles/Cutting Forces on Workpiece and Fixturing

Cutting forces produced during the milling process are constantly changing as the insert moves through the cut. Understanding the relationship of these forces will help ensure safe operation by preventing workpiece movement during the cut. For example, fixture design and clamp positioning are determined by the cutting forces produced in milling. Equally important is an understanding of the effect lead angle has on cutting force direction, actual chip thickness, and tool life.

0° lead angle

advantages:
When 90° shoulder is required
- Can be a problem solver on thin wall workpieces

disadvantages:
Highest radial cutting forces
- High entry shock load
- Increased chance of burr on insert exit side of part

15° and 20° lead angle

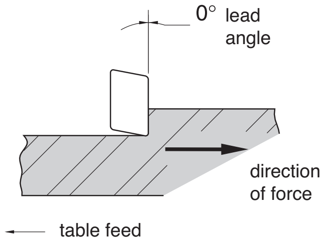
advantages:
- For general milling applications and relatively rigid conditions
- Good relation of insert size and maximum depth of cut
- Reduced entry shock load

disadvantages:
- Higher radial forces can cause problems in weak machine/workpiece/fixture conditions

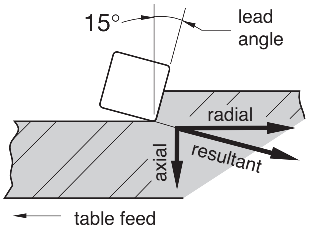
45° lead angle

advantages:
- Well balanced axial and radial cutting forces
- Less breakout on workpiece corner
- Entry shock minimized
- Less radial forces directed into spindle bearings
- Higher feed rates possible

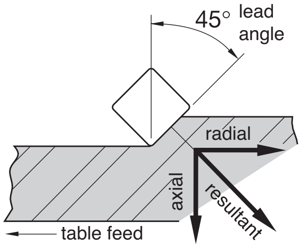
disadvantages:
- Reduced maximum depth of cut due to lead angle
- Larger body diameter can cause fixture clearance problems



0° lead



15° and 20° lead



45° lead

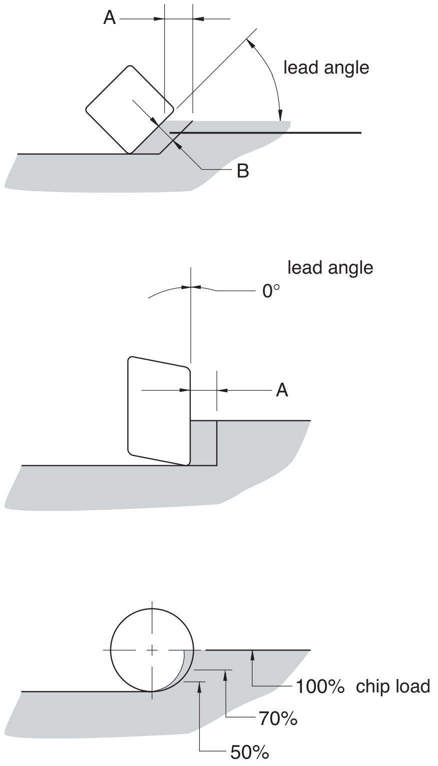
Lead Angle/Chip Thickness

Chip thickness is affected by lead angle. The greater the lead angle, the thinner the chip will be since it's distributed over a greater length of the cutting edge. To achieve greater productivity and problem-free milling, use a lead angle cutter whenever possible.

lead angle	feed per tooth	actual chip thickness "B"
0°	A	A
15°	A	.96 x A
20°	A	.94 x A
30°	A	.86 x A
45°	A	.707 x A

example:

0°	.010in. (0,25mm)	.010in. (0,25mm)
15°	.010in. (0,25mm)	.0096in. (0,25mm)
20°	.010in. (0,25mm)	.0094in. (0,24mm)
30°	.010in. (0,25mm)	.0086in. (0,22mm)
45°	.010in. (0,25mm)	.0071in. (0,18mm)



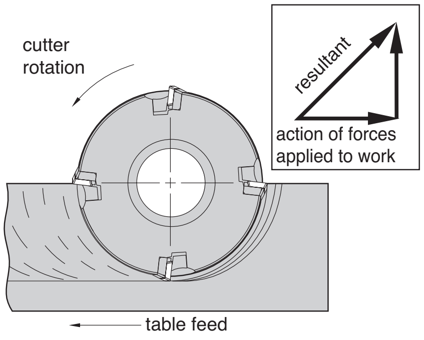
On round inserts, the chip load and lead angle vary with the depth of cut.

lead angle/chip thickness

Conventional Milling

For many years it was common practice to mill against the direction of the feed, due to the use of high-speed steel cutters and an absence of backlash-eliminating devices. The milling procedure became known as conventional, or up-milling.

In conventional milling, friction and rubbing occur as the insert enters into the cut, resulting in chip welding and heat dissipation into the insert and workpiece. Resultant forces in conventional milling are against the direction of the feed. Work-hardening is also likely to occur.

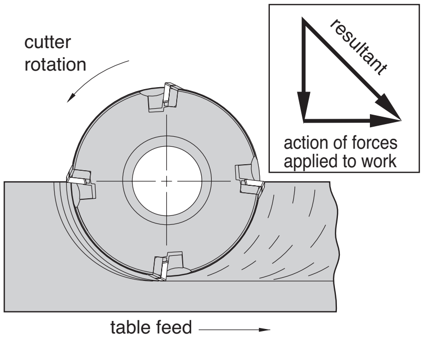


conventional milling

Climb Milling (preferred)

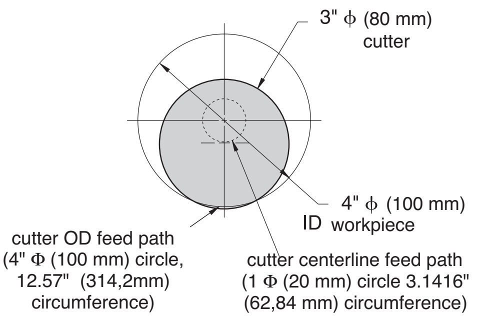
Climb milling is normally recommended. The insert enters the workpiece material with some chip load and produces a chip that thins as it exits the cut. This reduces the heat by dissipating it into the chip. Work-hardening is minimized.

Climb milling forces tend to push the workpiece toward the fixture and in the direction of the feed. Climb milling is preferred over conventional milling in most situations.



climb milling

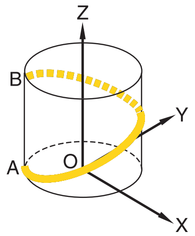
circular interpolation: Consists of a cutter rotating about its own axis while traveling in an orbiting motion about an ID or OD workpiece circumference without any vertical shift during the operation. This orbiting movement utilizes the "X" and "Y" axis.



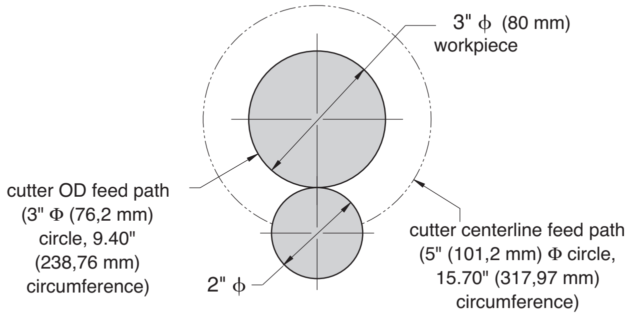
ID circular interpolation

helical interpolation: This application requires a milling machine with three-axis control capability. The operation consists of a cutter rotating about its own axis together in an orbiting motion about an ID or OD workpiece circumference in the "X" and "Y" plane. The circular movement about the "X" and "Y" plane, with a simultaneous linear movement in the Z-axis plane (which is perpendicular to the "X" and "Y" plane), creates the helical movement. For example, the path from point A to point B on the envelope of the cylinder combines a circular movement in the "X" and "Y" plane with a linear movement in the "Z" direction. On most CNC systems, this function can be executed in two different ways:

- GO2: helical interpolation in a clockwise direction.
- GO3: helical interpolation in a counterclockwise direction.



helical interpolation



OD circular interpolation

calculation of feed rate for circular and helical interpolation:

On most CNC machines, the feed rate required for programming contour (circular or helical) milling is calculated based on the centerline of the tool. When dealing with linear tool movement, the feed rate at the cutting edge and centerline are identical, but with circular tool movement, this is not the case.

calculate feed rate at the cutting edge: First calculate the tool feed rate at the cutting edge with the following formula.

F_1 = fz x z x n

F_1 = tool feed rate at the cutting edge (in./min.)

fz = inch per tooth (chip load)

Z = number of effective inserts in the cutter

n = revolutions per minute

Calculation of the Feed Rate at the Tool Centerline: Use the following equations to define the relationship between feed rates at the cutting edge and at the tool centerline.

inside diameter (ID) helical interpolation

$$F_2 = \frac{F_1 \quad x \quad (D - d_1)}{D}$$

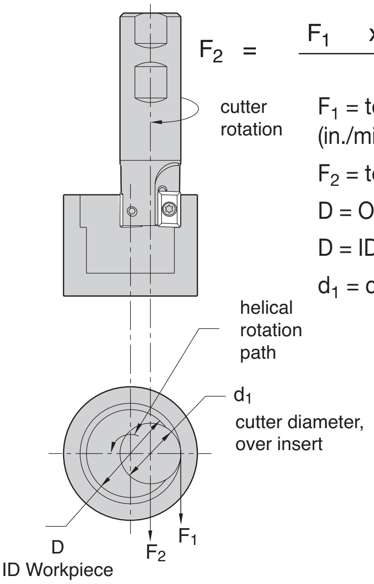
F_1 = tool feed rate at the cutting edge (in./min.)

F_2 = tool centerline feed rate (in./min.)

D = OD workpiece diameter

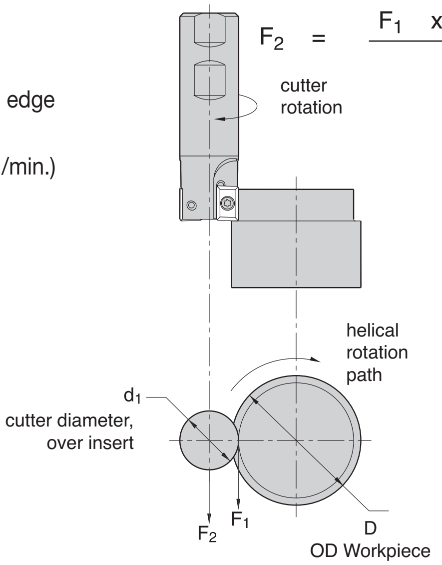
D = ID workpiece diameter

d_1 = cutter diameter, over insert



outside diameter (OD) helical interpolation

$$F_2 = \frac{F_1 \quad x \quad (d_1 + D)}{D}$$



ID and OD Circular and Helical Interpolation (cont'd.)

In ID contour applications, you will find the tool centerline feed is always less than the cutting edge feed rate.

example for ID

D = 4" ID workpiece (100 mm)
d_1 = 3" cutter diameter (80 mm)
fz = .008 ipt (0,2 mm/tooth)
n = 637 rpm 637 rpm
z = 7 effective inserts 7

1. Calculate feed rate at the cutting edge.

$F_1 = F_2 \times z \times n$

$F_1 = .008 \times 7 \times 637 = 35.7$ in./min. $.2 \times 7 \times 637 = 892$ mm/min.

2. Calculate feed rate at the tool centerline.

$$F_2 = \frac{F_1 \times (D - d_1)}{D}$$

$$F_2 = \frac{35.7 \times (4.0 - 3.0)}{4.0} = 8.9 \text{ in./min.}$$

$$\frac{892 \times (100 - 80)}{100} = 178 \text{ mm/min}$$

To have (F_1) 35.7 in./min. (892 mm/min.) at the cutting edge feed rate, we must program the machine tool for (F_2) 8.9 in./min. (178 mm/min.) at the tool centerline feed rate. This is a difference of approximately 75% less feed than the cutting edge feed rate (F_1).

In OD contour applications, you will find the tool centerline feed rate is always larger than the cutting edge feed rate.

example for OD

D = 5" OD workpiece 125 mm
d_1 = 2" cutter diameter 50 mm
fz = .008 ipt 0,2 mm/tooth
n = 955 rpm 955 rpm
z = 5 effective teeth 5

1. Calculate feed rate at the cutting edge.

$F_1 = F_2 \times z \times n$

$F_1 = .008 \times 5 \times 955 = 38.2$ in./min. $.2 \times 5 \times 955 = 955$ mm/min.

2. Calculate feed rate at the tool centerline.

$$F_2 = \frac{F_1 \times (d_1 + D)}{D}$$

$$F_2 = \frac{38.2 \times (2 + 5)}{5} = 53.5 \text{ in./min.}$$

$$\frac{955 \times (50 + 125)}{125} = 1{,}337 \text{ mm/min}$$

To have (F_1) 38.2 in./min. (955 mm/min.) at the cutting edge feed rate, we must program the machine tool for (F_2) 53.5 in./min. (1,337 mm/min.)at the tool centerline feed rate. This translates to an increase of about 40% more feed rate than the cutting edge feed rate (F_1).

Large Surfaces

Interpolating with a smaller cutter may be faster than using a large-diameter cutter. Also, keep the cutter in contact with the workpiece rather than exiting and re-entering.

Maximize Metal Removal Rate

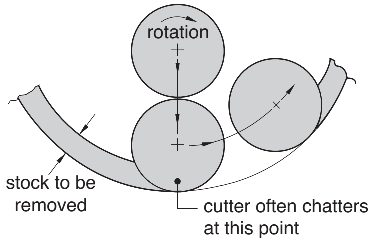
Concentrate on mrr (metal removal rate), not just on higher sfm (speeds). Increasing spindle speed without increasing chip load will not improve mrr. However, by doubling ipm, mrr does increase and horsepower consumption only increases by approximately 50%.

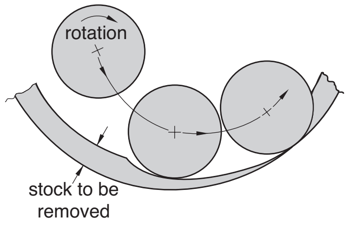
Preset

Use cutter preset areas for proper setting of cutters rather than indexing cutters at the machine, if possible.

Ramp In and Out

As shown below, ramping gradually into the cut will provide greater tool life. Also, by keeping the cutter constantly moving when entering and exiting the cut, dwell marks will be eliminated on the workpiece.

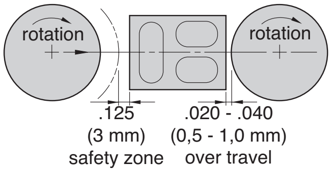




Safety and Over Travel

Program the milling cutter to rapid advance up to the part, within a range of .125 (3 mm) before engaging the workpiece. This allows the machine to reach its proper operating parameters before actual chip making begins.

Rapid advance to the next cutting location, when the cutter is .020 (0,5 mm) to .040 (1 mm) past the edge of the part. If the spindle has built-in tilt or programmed runout, the cutter can be advanced to the next cutting location while the back half of the cutter is still over the finished milled surface.

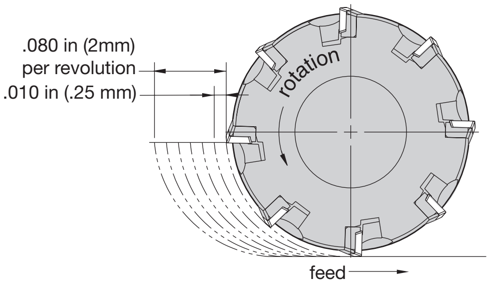


to find	given	formula
Vc	D n	$Vc = \frac{\pi \times D \times n}{12}$
n	D Vc	$n = \frac{12 \times Vc}{\pi \times D}$
Vf	fz n z	**Vf = fz x z x n**
fz	z Vf n	$fz = \frac{Vf}{2 \times n}$

legend

Vc = surface feet per minute
n = revolutions per minute
D = cutter diameter
Vf = (feed) inches per minute
fz = inch per tooth (chip load)
z = number of effective teeth or inserts in cutter
π = 3.1416

given	calculated		
D = 6" cutter diameter Z = 8 teeth in cutter Vc = 600 sfm fz = .010 ipt	n =	$\frac{12 \times 600}{3.1416 \times 6}$	= 382
	Vf (ipm) =	**.010 x 8 x 382**	**= 30.6**

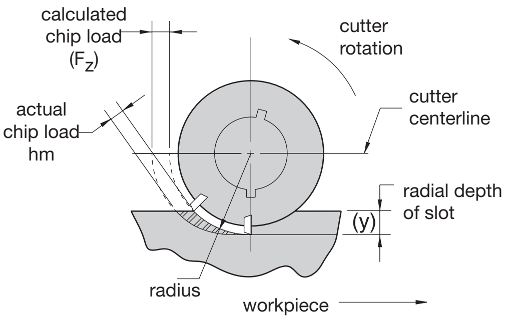


Slotting or Periphery Milling

True or actual chip load on the cutting edge of the insert is equal to the programmed chip load only when 50% or more of the cutter's diameter is engaged in the cut (lead angle not considered). Anything less than half the diameter of the cutter means that the actual chip load is reduced by some percentage. The smaller the radial depth of cut, the greater the decrease in actual chip load.

It's very important to maintain a chip load which is great enough to ensure heat dissipation and prevent work hardening. A sufficient chip load will also create stability between the cutter and the workpiece.

The formulas shown below are used to determine the programmed chip load, or feed rate necessary to obtain the desired load on the insert cutting edge as it enters the workpiece. These formulas should be applied whenever an arbor mounted slotting cutter is being used, or when less than half the diameter of a face mill or end mill is engaged in the cut. The lighter the radial depth of cut, the more important it becomes to apply these productivity formulas.

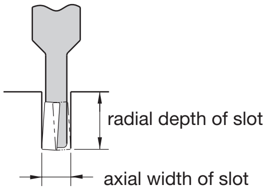


Productivity Formulas

$$\text{chip load } (F_z) = \frac{\left(\frac{\sqrt{(\text{dia.} - y) \times (y)}}{\text{radius}}\right) \times \left(\frac{vf}{n}\right)}{z}$$

or

$$F = \frac{n \times z \ fz}{\left(\frac{\sqrt{(\text{dia.} - y) \times (y)}}{\text{radius}}\right)}$$

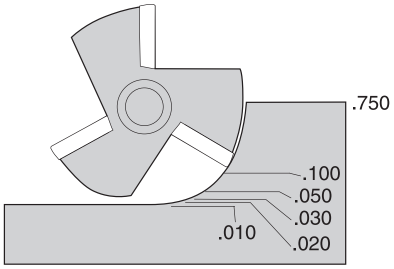


slot milling

Feed Rate Compensation

Operations such as **periphery milling with a light radial depth of cut or slotting with an arbor mounted cutter** require a calculation for feed rate compensation to maintain the proper chip load on the insert edge at entry into the cut. The calculated chip load and actual chip load can be dramatically different, depending on the radial depth and the cutter diameter. For instance, the actual chip load on entry for a 3/4" diameter cutter taking a .010 radial depth cut is only 23% of the calculated chip load. It is not uncommon to encounter built-up edge, work-hardening, or chatter problems if the following formula is not applied. Minimal cutter runout is critical to obtaining an equal chip load on each flute of the cutter too. A side benefit to applying this formula is increased productivity as feed rates can increase dramatically.

radial depth of cut	actual chip load (ipt)	feed required (ipm) to maintain .004 ipt	increase
.750	.0040	5.5	0%
.100	.0020	11.5	109%
.050	.0014	15.3	178%
.030	.0011	19.6	256%
.020	.0009	23.9	335%
.010	.0006	33.8	515%



1.5"B end mill – 6 flutes
90 sfm 230 rpm
.004 ipt 5.5 ipm

Formulas—Horsepower

metal removal rate

The metal removal rate (MRR) calculation is a good basis for determining metalcutting efficiency.

MRR = doc x woc x F = cu. inches/min.

horsepower consumption

Milling cutters can consume significant amounts of horsepower. Very often it is the lack of horsepower that is the limiting factor when deciding on a particular operation. On applications where large diameter cutters or heavy stock removal is necessary, it's advantageous to first calculate the necessary horsepower requirements.

NOTE: Spindle efficiency "E" varies from 75 to 90%.

(E = .75 to .90)

A suitable formula for calculating horsepower (HPc) at the cutter is:

$$HP_c = \frac{MRR}{K}$$

example:

width of cut . . . . . 1.64"
depth of cut 200
feed . . . . 19.5 ipm
4140 220 HB . . . . "K" factor 1.56

MRR= .200 x 1.64 x 19.5 = 6.4 cu. in./mi

$$HP_c = \frac{6.4}{1.56} = 4.1 \text{ HP at the cutter}$$

For horsepower at the motor (HP_m), use formula:

$$HP_m = \frac{HP_c}{E} \qquad HP_m = \frac{4.1}{.8} = 5.1$$

In determining horsepower consumption, "K" factors must be used. The "K" factor is a power constant that represents the number of cubic inches of metal per minute that can be removed by one horsepower.

NOTE: "K" factors vary depending on the hardness of the material.

"K" Factors

workpiece material	hardness HB	"K" factor
steels, and wrought and cast irons (plain carbon alloy steels, and tool steels)	85-200	1.64
	201-253	1.56
	254-286	1.28
	287-327	1.10
	328-371	.88
	372-481	.69
	482-560	.59
	561-615	.54
precipitation hardening stainless steels	150-450	1.27-.42
cast irons (gray, ductile, and malleable)	150-175	2.27
	110-190	2.0
	176-200	1.89
	201-250	1.52
	251-300	1.27
	301-320	1.19
stainless steels, and wrought and cast irons (ferritic, austenitic, and martensitic)	135-275	1.54-.76
	286-421	.74-.50
titanium	250-375	1.33-.87
high-temperature alloys, nickel, cobalt base	200-360	.83-.48
iron base	180-320	.91-.53
nickel alloys	80-360	.91-.53
aluminum alloys	30-150 (500 kg)	6.25-3.33
magnesium alloys	40-90 (500 kg)	10.0-6.67
copper	150	3.33
copper alloys	100-150	3.33
	151-243	2.0

Over the past 50 years, metal removal rates (MRR) and power constants have served as the conventional values used to calculate horsepower. Although this is a relatively common method of calculating horsepower, a more accurate method has been developed when milling with high shear cutters. This new approach utilizes the following information:

1. calculating tangential force (F_t)
2. ultimate material strength
3. cross-sectional area of the chip
4. number of inserts in the cut
5. machinability factor
6. tool wear factor
7. calculating torque
8. calculating horsepower at cutter
9. calculating horsepower at motor

Tangential Force, Torque, and Horsepower Calculations in Face Milling with High Shear Milling Cutters

1. calculation of tangential force (ft.-lbs.)

Calculation of tangential force is important since it produces torque at the spindle and accounts for the greatest portion of machining power at the cutting tool. Using this tangential force formula is a quick way to determine the approximate forces that fixtures, part wall sections, or spindle bearings will endure. Tangential force is calculated with the following formula:

$F_t = S \times A \times Z_c \times C_m \times C_w$ (lbs.)

where: S = ultimate strength of the work material (psi)
A = cross-sectional area of the chip removed by the milling insert (in.^{2})
Z_c = number of inserts in cut
C_m = machinability factor
C_w = tool wear factor

2. ultimate material strength (psi)

The approximate relationship between the ultimate material strength and hardness of the most commonly used work materials such as steels, irons (for example: gray cast iron), titanium alloys (Ti – 6Al – 4V), and aluminum alloys (2024, 5052) can be expressed by the empirical formula:

$S = 500 \times HB$ (psi)

where HB = Brinell hardness numbers obtained, primarily, at the 3000-kgf load. When testing soft metals such as aluminum alloys, the 500-kgf load is used. Hardness obtained at the 500-kgf load should be converted into the hardness equivalent of the 3000-kgf load by using the load factor of 1.15. For example, 130 HB at the 500-kgf load is equivalent to 150 HB at the 3000-kgf load (130 x 1.15 = 150). If hardness is given in Rockwell "B" or Rockwell "C" numbers, see Appendix 1 (page 510).

3. cross-sectional area of the chip (A)

Cross-sectional area of the chip (Fig. 1) is defined by:

$A = d\,f$ (in.^{2}, or mm^2)

where: d = axial depth of cut (in., or mm)
f = feed per tooth (in., or mm)

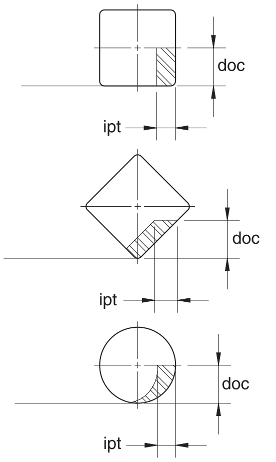


Figure 1: Cross-sectional area of the chip and insert's shape

4. number of inserts in cut (Zc)

The number of inserts in the cut (simultaneously engaged with work material) depends on the number of inserts in the cutter "Z" and the engagement angle (α). This relationship is shown by the formula:

$$Z_c = \frac{Z \times \alpha^\circ}{360^\circ}$$

The engagement angle depends on the width of cut "W" and cutter diameter "D". This angle is found from the geometry of figure 2 (formulas to calculate engagement angle and the number of inserts in the cut at any width of cut are given in Appendix 2, page 510).

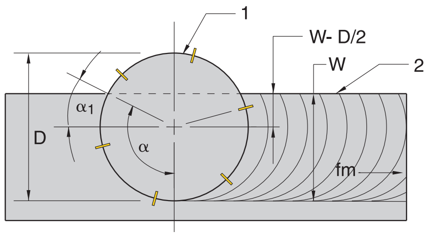


Figure 2: Schematic for calculating the number of inserts in cut

1 = milling cutter
2 = workpiece
α = engagement angle
α_1 = the angle between cutter centerline and cutter radius to the peripheral point of exit or entry
W = width of cut (woc)
D = cutter diameter
fm = workpiece feed motion

Tangential Force, Torque, and Horsepower Calculations in Face Milling with High Shear Milling Cutters

If the width of cut equals cutter diameter (W/D = 1.0), the engagement angle $\alpha = 180°$ and $Z_c = \frac{Z \times 180°}{360°} = 0.5Z$.

If the width of cut is equal to half of the cutter diameter (W/D = 0.5), the engagement angle $\alpha = 90°$ and $Z_c = \frac{Z \times 90°}{360°} = .25Z$.

The values of Z_c depending on the given W/D ratios, are shown in table 1.

Table 1

W/D	.88	.80	.75	.67	.56	.38	.33	.19	.125
Z_c	.38Z	.35Z	.33Z	.30Z	.27Z	.21Z	.20Z	.14Z	.12Z

5. machinability factor (C_m)

Machinability factor is used to indicate degree of difficulty in machining various workpiece materials. Table 2 shows machinability factor values for some of the most common workpiece materials.

Table 2

workpiece material	C_m		
	W/D≤.67	.67<W/D<1.0	W/D=1.0
carbon and alloy steels	1.0	1.15	1.3
stainless steel	2.0	2.15	2.3
gray cast iron	1.0	1.15	1.3
titanium alloys	1.0	1.20	1.4
aluminum alloys	1.0	1.05	1.1

The values of C_m are based on milling tests with a torque dynamometer at different cutting conditions. It has been found that machinability factor depends on type of work material and the ratio of radial width of cut to cutter diameter (W/D).

This ratio determines the uniformity of the chip thickness. When W/D = 1.0, the chip at the point of entry starts off at zero thickness. It increases to a maximum thickness at the centerline of the cutter, and thins off to zero again at the point of exit. This type of cut generates maximum friction at the cutting edge, and machinability factor reaches its maximum value. The optimal cutting conditions are obtained when W/D = 2/3 = .67. The thickness of the chip is practically uniform, the friction is minimal, and machinability factor decreases to its minimum value.

More extensive testing will determine machinability factors for a larger variety of work materials and improve the accuracy for calculating tangential force and power consumption.

6. tool wear factor (C_w)

For milling with sharp cutting tools (short time operation), tool wear factor $C_w = 1.0$. For a longer operation (before the inserts are indexed), the following tool wear factors are considered:

- light face milling $C_w = 1.1$
- general face milling $C_w = 1.2$
- heavy-duty face milling $C_w = 1.3$

7. calculation of torque (in.-lb.)

The torque "T" generated by tangential force is calculated using the following formula:

$T = F_t \times D/2$ (in.-lb.)

where D = cutter diameter inch

8. calculating horsepower (HP_c or HP_m)

The machining power at the cutter (sharp edges) is calculated by either of these two formulas:

$$HP_c = \frac{F_t \times \text{sfm}}{33{,}000}$$

or

$$HP_c = \frac{T \times \text{rpm}}{63{,}000}$$

where sfm = peripheral cutting speed (sfm)
rpm = spindle speed (rpm)
33,000 and 63,000 = conversion factors

9. The required power at the motor is calculated using the following formula (HP_m):

$$HP_m = \frac{HP_c}{E}$$

where E = machine tool efficiency factor (E = .75 to .90)

NOTE: Spindle efficiency varies from 75 to 90%.

Tangential Force, Torque, and Horsepower Calculations in Face Milling with High-Shear Milling Cutters (cont'd.)

Example for Calculating Horsepower

given values

milling cutter KSSISR – 492 – SE443 – 45 – 06:
effective diameter $D = 4.92$ in.
number of inserts $Z = 6$

workpiece material:
alloy steel AISI 4140
hardness 220 HB

machining conditions:

spindle speed $n = 349$
cutting speed $Vc = 450$
machine feed rate $F = 19.5$
inch per tooth (chip load) $fz = .008$ in.
axial depth of cut $doc = .200$ in.
radial width of cut $woc = 1.64$ in.
W/D ratio $W/D = .33$

Step-By-Step Calculations

1. calculating tangential force

1.1 ultimate strength of the workpiece material

$S = 500 \times HB = 500 \times 220 = 110{,}000$ psi

1.2 cross-sectional area of the chip

$A = doc \times ipt = .200 \times .008 = .0016$ in.^{2}

1.3 number of inserts in cut:

width of cut-to-diameter ratio (w/d)

$W/D = 1.64 / 4.92 = .33$ (See Table 1, page 496)

Now use Z_c value shown in Table 1 under .33.

$Z_c = .20 \times Z = .20 \times 6 = 1.2$ inserts in cut.

NOTE: Z = number of inserts in cutter.

1.4 tangential force

$F_t = S \times A \times Z_c \times C_m \times C_w$

$F_t = 110{,}000 \times .0016 \times 1.2 \times 1.1 \times 1.1 = 256$ lbs.

NOTE: $C_m = 1.1$ and $C_w = 1.1$

2. calculating torque at the cutter

$$T = (F_t \times D)/2 = \frac{256 \times 4.92}{2} = 630 \text{ in.-lb.}$$

3. calculating horsepower

- At the cutter...reference formulas in paragraph 8 on page 496

$$HP_c = \frac{F_t \times sfm}{33{,}000} = \frac{256 \times 450}{33{,}000} = 3.5 \text{ hp}$$

or

$$HP_c = \frac{T \times rpm}{63{,}000} = \frac{630 \times 349}{63{,}000} = 3.5 \text{ hp}$$

- At the motor...reference formula in paragraph 9 on page 496
- Where E = machine tool efficiency factor (E = .75 to .90)

$$HP_m = \frac{HP_c}{E} = \frac{3.5}{.8} = 4.4 \text{ hp}$$

Surface Finish

Surface finish may be an important specification on a machined part. Finishes produced by indexable insert cutters usually range from 0.80-3.2 (32 to 150) Ra. This broad range can be affected by several variables such as work material, machine rigidity, spindle alignment, fixturing, insert nose geometry, insert wear, cutting feed and speed, heat-generated chip welding, and chatter.

Good finishes will result when you use the right combination of cutter geometry, insert style, and cutting speeds and feeds for the material being milled. It is also important to have the part adequately fixtured, and the machine properly maintained.

Figure 1 illustrates that finer finishes can be obtained by using a larger corner radius, flat, or wiper on the insert. This tends to wipe out or reduce feed marks. In addition to the corner geometry of the insert, it is important to correctly set each insert relative to the other inserts. For example, if all of the inserts have the same corner geometry, and are set in the cutter body to a face height of approximately .001 in (0,025 mm) relative to each other, the finish produced will be better than if the inserts were set to within .003 in (0,07 mm).

Improved finishes can also be obtained by increasing speeds and reducing feeds. Be aware, however, that increased speed also increases cutting temperatures, and may reduce insert edge life.

Finish will not necessarily be the same on all areas of the milled surface. Figure 2 shows that the Ra finish will be lower on the area where the feed marks are close to each other, and higher where feed marks are farther apart.

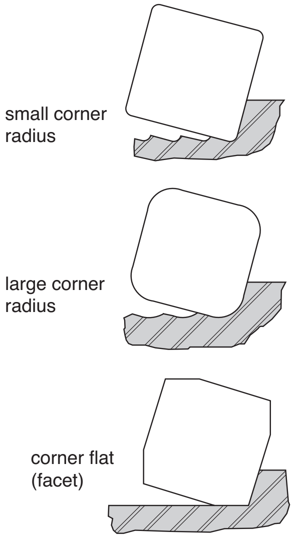


Figure 1: Larger insert corner radii or flats produce finer milling finishes.

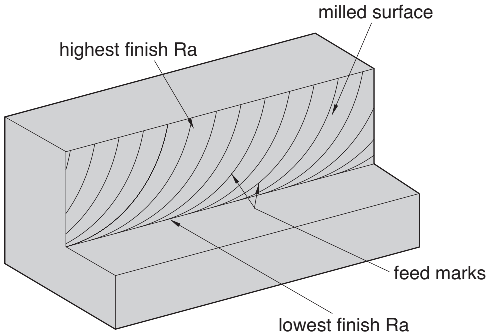


Figure 2: Quality of Ra finish corresponds to the distance between feed marks.

In figure 3, the Ra value will be lower near the outside diameter of the cut where the feed marks are at their closest, and higher at the center where the feed marks are farthest apart. Peaks produced are highest at the center of the cutter as it is positioned in the cut, and lowest at the outside diameter of the cutter, as illustrated below in figures 3 and 4.

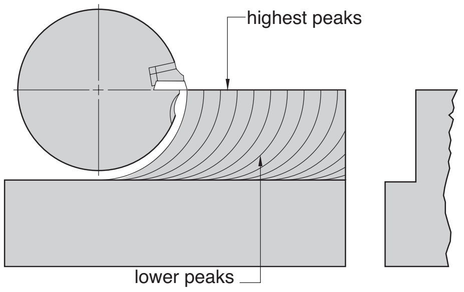


Figure 3: Ra finish is higher at the widest feed marks.

Both finish and flatness are affected by feed marks. A taper will be produced from the high peaks down to the low peaks.

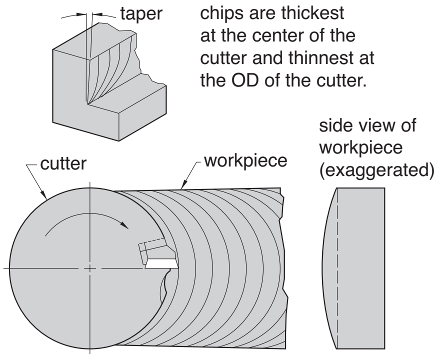


Figure 4: A taper is produced from the high peaks to the low ones.

Both finish and flatness are affected by feed marks. A taper will be produced from the high peaks down to the low peaks.

Flatness also affects part tolerance. This effect is more predominant in side milling both sides of a part as shown in figure 5.

An obvious solution to obtaining a more consistent and improved surface finish with a minimum of taper is to reduce or flatten the peaks between feed marks. This can be done by introducing an insert with a corner configuration capable of wiping out or reducing these peaks. Shown in figure 5 is an exaggerated change in part width due to flatness and taper.

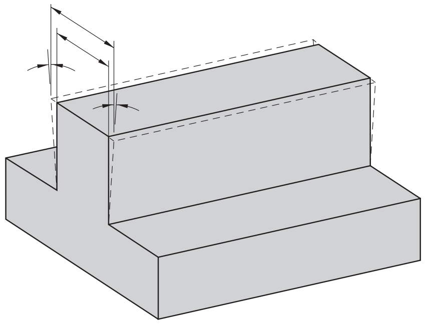


Figure 5: Flatness affects part tolerance more when milling both sides of a part.

Figures 6 and 7 compare the feed marks produced with a nose radius insert to those produced with a wiper insert. A wiper insert with a large radius for wiping out or reducing peaks (figure 7) has been effective in producing finishes below 3.2 (100) Ra. Figures 6 and 7 show the wiper insert is designed to "top off" the peaks of the feed marks. An improved surface finish, surface flatness, and reduced taper will result.

Wiper inserts are normally set at .001 to .0015 in (0,025-0,04 mm) above the highest positioned insert in the cutter to ensure a good wiping action. Kennametal wiper inserts are typically designed to fit into any pocket in the cutter body. This means one or more wiper inserts can be used. Interchangeable wipers can be used to share the load on the periphery of the cut in feed per tooth.

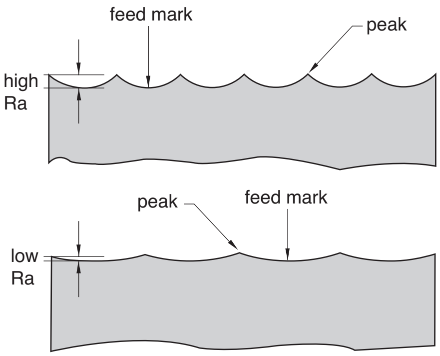


Figure 6: Peaks produced with a standard radii insert (top) compared to those produced with a large radius wiper insert (bottom).

Poor Surface Finish

cause	solution
cutter runout	Check for high insert, dirt in the pockets, or dirty spindle and cutter mounting face. Also, look for burrs on the cutter and damaged cutter pocket.
worn or chipped insert	Index insert.
feed per revolution exceeding flat on wiper	Reduce feed rate or install wiper with greater effective insert facet width.
wiper insert is set too high	Set the wiper insert .001 to .0015 in (0,025 to 0,04 mm) above highest insert.
chatter	Check rigidity of machine and table fixturing. Check arbor and spindle, adjust feed rates, adjust rpm, or reduce cut width. Consider cutter with fewer pockets.

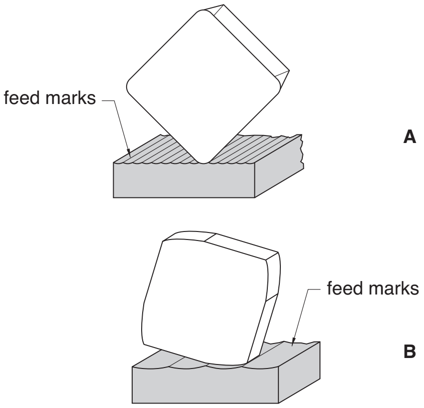


Figure 7: Feed marks produced with a nose radius insert (A) compared to marks produced with a wiper insert (B).

Surface Finish (cont'd.)

Measuring Finish Produced in a Milling Operation

Do not rely on your eye or fingernail to determine surface finish. Fingernails are about 25 times as thick as the stylus tip of a surface measuring instrument. They will skid across surface peaks, missing the valleys. Use a surface measuring instrument since the appearance of the surface finish may be deceiving. For example, reflected light on a uniformly milled surface pattern will look smoother than a random pattern. Also, a shiny surface will appear smoother than a dull surface.

Placement of the measuring device in a specific area on the milled surface will affect the reading. Also, a surface finish measured perpendicular to the feed direction is better than measuring parallel to the feed direction. This is usually the case regardless of workpiece condition and material (see figure 8).

Changing the cut-off width of the surface measuring instrument will affect the Ra value of the measurement.

Surface Profile Record

Figure 9 shows the variation in roughness created by increasing the cut-off width on the instrument. The greater the cut-off, (see figure 9), the higher the Ra finish. For example, figure 10 illustrates that a .010 in (0,25 mm) cut-off width will produce a .6 (25) Ra finish; whereas, a .100 in (0,76 mm) cut-off width will produce a 2.0 (75) Ra finish.

Also, figure 10 demonstrates that most measuring devices are provided with .010 in (0,25 mm), .030 in (0,76 mm), and .100 in (2,54 mm) cut-offs. In most cases, the .030 in (0,76 mm) width cut-off is preferred.

Figure 11 shows the standard surface symbols specifying maximum and minimum roughness, waviness, and lay, which is the direction in which the measurement is taken.

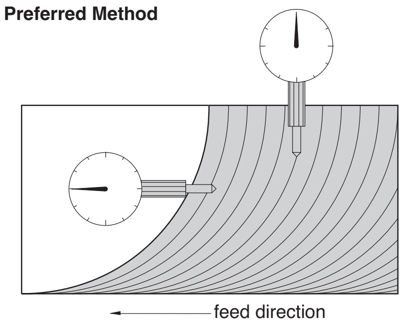


Figure 8: Measuring surface finish

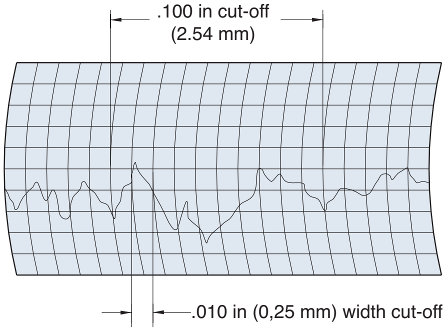


Figure 9: Increasing the cut-off width creates a variation in roughness.

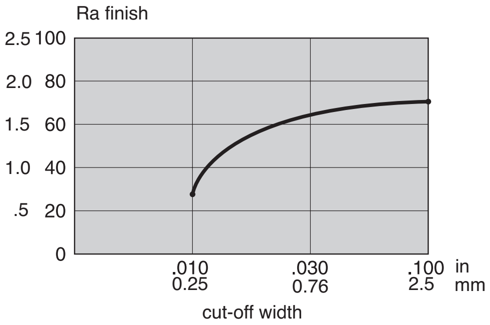


Figure 10: Finish quality is directly proportional to the cut-off width.

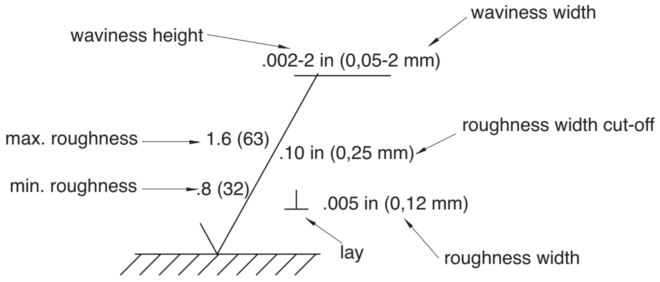


Figure 11: Standard surface symbols

Introduction

Troubleshooting should be performed in a sequential method to identify and solve your milling problems. These problems can be recognized as premature insert edge failure, part appearance, machine noise or vibration, and the cutter's appearance. Successful troubleshooting requires that we correctly identify the problem, then take the necessary corrective action one step at a time. The five key areas of concern are:

1. cutting tool material (grade)
2. cutter/adapter
3. machine
4. workpiece
5. set-up/fixturing

This section will discuss possible causes and will recommend corrective actions for each of the five areas listed. Remember, if more than one step is taken concurrently, the real cause of the problem may never be discovered. Always perform one corrective measure at a time.

Edge Condition Problems and Solutions

1. chipping: Appears like normal flank wear to the untrained eye. Actually, normal flank wear lands have a fine, smooth wear pattern, while a land formed by chipping has a saw-toothed, uneven surface. If chipping is not detected soon enough, it may be perceived as depth-of-cut notching.

Chipping can also be caused by recutting of chips. A good example of this would be a slotting operation where chip clearance or chip gullet space does not allow the chips to evacuate cleanly. In this instance, packing of the chips also occurs.

In most cases, by changing to a stronger grade and/or to a different edge preparation such as a larger hone or T-land, or from a 90˚ (0˚) cutter geometry to a lead angle cutter geometry, will resolve the problem.

problem	cause	solution
chipping 	• chatter	• Check system rigidity for proper part clamping. • Correct worn gibs/bearings. • Check for improper cutter mounting.
	• edge prep	• Use largest hone or T-land possible.
	• grade	• Use a tougher grade.
	• built-up edge	• Increase speed.
	• feed	• Reduce feed per tooth.
	• recutting chips	• Choose cutter geometry with correct pitch for chip clearance. • Use air blast or coolant to remove chips.

2. depth-of-cut notching: Appears when chipping or localized wear at the depth-of-cut line on the rake face and flank of the insert occurs. Notching is primarily caused by the condition of the workpiece material. Material conditions prone to depth-of-cut notch include: an abrasive workpiece skin of scale, abrasive properties of high-temperature alloys like Inconel, a work-hardened outer layer resulting from a previous machining operation, or heat-treated material above 55 HRC.

problem	cause	solution
depth-of-cut notching 	• cutter geometry	• Change to a lead angle cutter.
	• grade	• Use a more wear-resistant grade of carbide.
	• feed	• Reduce feed per tooth.
	• speed	• Reduce speed.
	• edge-prep	• Use honed or T-land inserts.
	• programming	• Vary depth of cut on very abrasive materials.

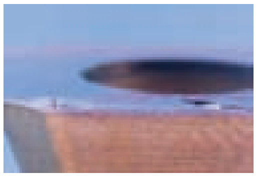
Edge Condition Problems and Solutions (cont'd.)

3. thermal cracks: These cracks run perpendicular to the insert's cutting edge and are caused by the extreme temperature variations involved in milling. In one revolution of a milling cutter, the insert starts to cut and the temperature quickly rises as the insert enters the cut. The varying chip thickness also changes the temperature throughout the cut. When the insert comes out of the cut, air or coolant flow rapidly cools the insert before it reenters the cut.

These temperature variations create heat stresses in the insert which can result in thermal cracks. To the untrained eye, advanced thermal cracking could appear as chipping.

problem	cause	solution
thermal cracks 	• speed and feed	• Reduce cutting edge temperature by reducing the cutting speed and possibly the feed per tooth.
	• coolant	• Shut off coolant.
	• grade	• Use coated grade designed for wet milling.

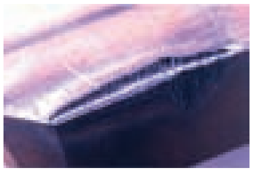
4. built-up edge: This condition involves the adhesion of layers of workpiece material to the top surface of the insert. Hardened pieces of the adhered material periodically break free, leaving an irregularly shaped depression along the cutting edge. This causes damage to the part and insert. Cutting forces also will be increased due to built-up edge.

problem	cause	solution
built-up edge 	• speed	• Increase sfm.
	• feed	• Increase feed per tooth.
	• coolant	• Use mist or flood coolant to avoid chips sticking to the insert when machining stainless steel and aluminum alloys.
	• grade	• Use sharp edge PVD inserts.
		• Higher speeds require diamond-tipped inserts or diamond-coated inserts on certain non-ferrous alloys.
	• edge-prep	• Use sharp edge, positive rake PVD inserts, or polished (J-polished) inserts.

5. crater wear: A relatively smooth, regular depression is produced on the insert's rake face. Crater wear occurs in two ways:

1. Material adhering to the insert's top surface is dislodged, carrying away minute fragments of the top surface of the insert.
2. Frictional heat builds up from the flow of chips over the top surface of the insert. Eventually, this heat buildup softens the insert behind the cutting edge and removes minute particles of the insert until a crater forms.

Crater wear is rarely encountered in milling, but can appear when machining certain steel and cast iron alloys. If crater wear becomes severe, there is a risk that the cutting edge will break, destroying the insert.

problem	cause	solution
crater wear 	• grade	• Use a more wear-resistant grade.
	• speed	• Reduce cutting speed.
	• edge-prep	• Use smaller T-land or increase feed to proper range for T-land.

6. flank wear: Uniform flank wear is the preferred method of insert failure because it can be predicted. Excessive flank wear increases cutting forces and contributes to poor surface finish. When wear occurs at an unacceptable rate or becomes unpredictable, the key elements that must be investigated are speed, feed, grade, and insert/cutter geometry.

NOTE: Inserts should be indexed when roughing (.015 to .020 in (0,38 to 0,50 mm) flank wear is reached) and finishing (.010 to .015 in (0,25 to 0,38 mm) flank wear or sooner).

problem	cause	solution
flank wear 	• speed	• Check this area first. Recalculate sfm (Vc) to assure correctness. • Speed should be reduced without changing feed per tooth.
	• feed	• Increase feed per tooth (feed should be high enough to avoid the pure rubbing which occurs with small chip thickness).
	• grade	• Use more wear-resistant grade. • Change to a coated grade if you are now using an uncoated grade.
	• insert geometry	• Inspect insert to determine if proper style is being used in the cutter.

7. multiple factors: When wear, chipping, thermal cracking, and breakage occur at once, the machine operator must look beyond the normal feed, speed, and depth-of-cut adjustments to find the root cause of the problem. Speed, feed, and depth-of-cut parameters should be re-examined for accuracy, but the system's rigidity should also be closely inspected for loose or worn parts as well.

problem	cause	solution
multiple factors 	• system rigidity	• Check system for loose cutter mounting. • Improve fixture and cutter rigidity. • Check for worn hardware or improper insert installation. • Reduce the guage length of the cutter and arbor assembly.
	• feed	• Reduce feed rate to relieve cutting forces.
	• cutter geometry	• If possible, use a lead angle cutter to redirect cutting forces away from the insert nose.
	• insert/grade	• If possible, use a larger nose radius. • Use T-land insert. • Use a tougher grade of carbide.

Troubleshooting Matrix for Advanced Cutting Tool Materials

This matrix explains the specific areas where advanced cutting tool materials perform differently from uncoated and coated carbide grades during the troubleshooting identification process.

cutting tool material	problem	solution	comments
cermets KT530M	• chipping	• Reduce feed per insert. • Turn off coolant. • Apply hone or T-land insert.	• Excellent resistance to built-up edge. • Dry milling grades, do not use coolant. • KT530M is noted for maximum toughness and edge chipping resistance at moderate speeds and medium chip loads.
	• breakage (fracture)	• Reduce depth of cut and chip load. • Increase speed. • Apply hone or T-land insert.	
sialon Kyon 1540 Kyon 2100	• depth-of-cut notch	• Reduce hone or size of T-land edge preparation. • Pre-chamfer part to eliminate stress points on cutting edge of insert. • Vary depth of cut.	• Excellent for machining nickel-base materials over 35 HRC. • Available in positive rake inserts. • Run dry – no coolant. • Works well on PH stainless steels. • Use KY1540 at less than 2000 sfm.
	• minor chipping	• Minor chipping is normal, especially on Inconel.	
	• flank wear	• Use 0.2 mm (.008 in) as indexing criterion.	
	• fracture	• Do not over-torque clamping.	
silicon nitride Kyon 3500	• flank wear	• Reduce speed. • Increase feed.	• Use without coolant. • Will provide optimum combination of increased toughness and wear resistance in high-speed machining of cast irons. • Wide range of sfm (Vc). • Kyon 3500 is your first choice for maximum toughness and edge chipping resistance at high-speed and heavy-to moderate feeds.
	• chipping	• Change edge preparation. • Reduce chip load.	
	• breakage	• Reduce doc. • Use thicker inserts.	

Troubleshooting Matrix for Advanced Cutting Tool Materials (cont'd.)

cutting tool material	problem	solution	comments
polycrystalline diamond (tipped) KD1410 KD1415 KD1420	• chipping and breaking	• Check system rigidity. • Reduce chip load. • Increase sfm (Vc). • Edge prep	• Excellent wear resistance for improved size control and surface finish. • Unsurpassed tool life when machining aluminum alloys, non-ferrous and non-metallics at high sfm's (Vc). • Can be used with coolant. • Regrindable/resettable.
diamond film coating KDF300	• burrs and finish	• Use a KD1410 tipped insert in one or two pockets as a wiper insert.	• Roughing to semi-finishing grade. • Excellent tool life when machining aluminum alloys that have 12% or less silicon content. • Multiple cutting edges versus single-edge on tipped PCD. • Less expensive than ground, PCD-tipped KD1410.
KB1340 cubic boron nitrides	• chipping and breaking	• Check system rigidity. • Additional edge preparation may be required (hone or T-land).	• Use on hardened tool steels, cast irons, and some high-temperature alloys (Ni-base). • Applications on: Ni-hards, high-chrome irons, chilled cast irons, hard alloys, and hardened tool steels (50-65 HRC). • KD1340 tipped CBN for finishing only; one cutting edge. • Regrindable/resettable.

Conversion Charts

hardness

Brinell	Rockwell		Brinell	Rockwell	
HB	HRB	HRC	HB	HRB	HRC
654	—	60	253	101.5	25
634	—	59	247	101.0	24
615	—	58	243	100.0	23
595	—	57	237	99.0	22
577	—	56	231	98.5	21
560	—	55	228	98.0	20
543	—	54	222	97.0	18.6
525	—	53	216	96.0	17.2
512	—	52	210	95.0	15.7
496	—	51	205	94.0	14.3
481	—	50	200	93.0	13
469	—	49	195	92.0	11.7
455	—	48	190	91.0	10.4
443	—	47	185	90.0	9.2
432	—	46	180	89.0	8
421	—	45	176	88.0	6.9
409	—	44	172	87.0	5.8
400	—	43	169	86.0	4.7
390	—	42	165	85.0	3.6
381	—	41	162	84.0	2.5
371	—	40	159	83.0	1.4
362	—	39	156	82.0	0.3
353	—	38	153	81.0	—
344	—	37	150	80.0	—
336	109.0	36	147	79.0	—
327	108.5	35	144	78.0	—
319	108.0	34	141	77.0	—
311	107.5	33	139	76.0	—
301	107.0	32	137	75.0	—
294	106.0	31	135	74.0	—
286	105.5	30	132	73.0	—
279	104.5	29	130	72.0	—
271	104.0	28	127	71.0	—
264	103.0	27	125	70.0	—
258	102.5	26	123	69.0	—

NOTE: Values in shaded areas are beyond normal range and are given for information only.

inch to metric

diameter Ø		diameter Ø	
inches	mm	inches	mm
.314	8,0	3.000	76,2
.375	9,5	3.149	80,0
.393	10,0	3.500	88,9
.472	12,0	3.937	100,0
.500	12,7	4.000	101,6
.625	15,9	4.921	125,0
.630	16,0	5.000	127,0
.750	19,1	6.000	152,4
.787	20,0	6.299	160,0
.875	22,2	7.000	177,8
.984	25,0	7.874	200,0
1.000	25,4	8.000	203,2
1.259	32,0	9.842	250,0
1.500	38,1	10.000	254,0
1.968	50,0	12.000	304,8
2.000	50,8	12.401	315,0
2.480	63,0	14.000	355,6
2.500	63,5	15.748	400,0

doc		speed	
inches	mm	sfm	m/min.
.010	0,254	300	91
.015	0,381	400	122
.030	0,762	500	152
.050	1,270	600	183
.100	2,540	800	244
.125	3,175	1000	305
.150	3,810	1200	366
.250	6,350	2000	610
.375	9,525	4000	1219
.500	12,700	10000	3048

feed C.P.T.		surface finish (Ra)	
inch/T	mm/T	μ inch	μm
.003	0,076	500	12,5
.004	0,12	250	6,3
.005	0,127	125	3,2
.006	0,152	63	1,6
.007	0,178	32	0,8
.008	0,203	16	0,4
.009	0,229		
.010	0,254		
.011	0,279		
.012	0,305		

English Measures — unless otherwise designated, are those used in the United States, and the units of weight and mass are avoirdupois units.

Gallon — designates the U.S. gallon. To convert into the Imperial gallon, multiply the U.S. gallon by 0.83267. Likewise, the word ton designates a short ton, 2,000 pounds.

Exponents — the figures 10^{-1}, 10^{-2}, 10^{-3}, etc. denote 0.1, 0.01, 0.001, etc. respectively. The figures 10^{1}, 10^{2}, 10^{3}, etc. denote 10, 100, 1000, etc. respectively.

Properties of water — it freezes at 32°F., and is at its maximum density at 39.2°F. In the multipliers using the properties of water, calculations are based on water at 39.2°F. in a vacuum, weighing 62.427 pounds per cubic foot, or 8.345 pounds per U.S. gallon.

multiply	by	to obtain
B.T.U./Min.	12.96	foot–lbs./sec.
B.T.U./Min.	0.02356	horsepower
B.T.U./Min.	0.01757	kilowatts
B.T.U./Min.	17.57	watts
centigrams	0.01	grams
centiliters	0.01	liters
centimeters	0.3937	inches
centimeters	0.01	meters
centimeters	10	millimeters
centimeters/second	1.969	feet/minute
centimeters/second	0.03281	feet/second
centimeters/second	0.036	kilometers/hour
centimeters/second	0.6	meters/minute
centimeters/second	0.02237	miles/hour
centimeters/second	3.728 x 10^{-4}	miles/minute
cms./sec./sec.	0.03281	feet/sec./sec.
cubic centimeters	3.531 x 10^{-5}	cubic feet
cubic centimeters	6.102 x 10^{-2}	cubic inches
cubic centimeters	10^{-6}	cubic meters
cubic centimeters	1.308 x 10^{-6}	cubic yards
cubic centimeters	2.642 x 10^{-4}	gallons
cubic centimeters	10^{-3}	liters
cubic centimeters	2.113 x 10^{-3}	pints (liquid)
cubic centimeters	1.057 x 10^{-3}	quarts (liquid)
cubic inches	16.39	cubic centimeters
cubic inches	5.787 x 10^{-4}	cubic feet
cubic inches	1.639 x 10^{-5}	cubic meters
cubic inches	2.143 x 10^{-5}	cubic yards
cubic inches	4.329 x 10^{-3}	gallons
cubic inches	1.639 x 10^{-2}	liters
cubic inches	0.03463	pints (liquid)
cubic inches	0.01732	quarts (liquid)
cubic meters	10^{6}	cubic centimeters
cubic meters	35.31	cubic feet
cubic meters	61.023	cubic inches
cubic meters	1.308	cubic yards
cubic meters	264.2	gallons
cubic meters	10^{3}	liters
cubic meters	2113	pints (liquid)
cubic meters	1057	quarts (liquid)
cubic yards	7.646 x 10^{5}	cubic centimeters
cubic yards	27	cubic feet
cubic yards	46,656	cubic inches
cubic yards	0.7646	cubic meters
cubic yards	202.0	gallons
cubic yards	764.6	liters
cubic yards	1616	pints (liquid)
cubic yards	807.9	quarts (liquid)
decigrams	0.1	grams
deciliters	0.1	liters

multiply	by	to obtain
decimeters	0.1	meters
degrees (angle)	60	minutes
degrees (angle)	0.01745	radians
degrees (angle)	3600	seconds
degrees/second	0.01745	radians/second
degrees/second	0.1667	revolutions/minute
degrees/second	0.002778	revolutions/second
dekagrams	10	grams
dekaliters	10	liters
dekameters	10	meters
drams	27.34375	grains
drams	0.0625	ounces
drams	1.771845	grams
feet	30.48	centimeters
feet	12	inches
feet	0.3048	meters
feet	1/3	yards
feet/minute	0.5080	centimeters/second
feet/minute	0.01667	feet/second
feet/minute	0.01829	kilometers/hour
feet/minute	0.3048	meters/minute
feet/minute	0.01136	miles/hour
feet/second	30.48	centimeters/second
feet/second	1.097	kilometers/hour
feet/second	0.5921	knots
feet/second	18.29	miles/minute
feet/second	0.6818	miles/hour
feet/second	0.01136	miles/minute
foot/sec./sec.	30.48	cms./sec./sec.
foot/sec./sec.	0.3048	meters/sec./sec.
foot–pounds	1.286 x 10^{-3}	British Thermal Units
foot–pounds	5.050 x 10^{-7}	horsepower–hrs.
foot–pounds	3.241 x 10^{-4}	kilogram–calories
foot–pounds	0.1383	kilogram–meters
foot–pounds	3.766 x 10^{-7}	kilowatt–hours
foot–pounds/minute	1.286 x 10^{-3}	B.T.U./minute
foot–pounds/minute	0.01667	foot–pounds/second
foot–pounds/minute	3.030 x 10^{-5}	horsepower
foot–pounds/minute	3.241 x 10^{-4}	kg.–calories/minute
foot–pounds/minute	2.260 x 10^{-5}	kilowatts
foot–pounds/second	7.717 x 10^{-2}	B.T.U./minute
foot–pounds/second	1.818 x 10^{-3}	horsepower
foot–pounds/second	1.945 x 10^{-2}	kg.–calories/minute
foot–pounds/second	1.356 x 10^{-3}	kilowatts
gallons/minute	0.06308	liters/second
gallons/minute	8.0208	cubic feet/hour
gallons/minute	8.0208	overflow rate
	area (square foot)	feet/hour
grams	980.7	dynes
grams	15.43	grains
grams	10^{-3}	kilograms
grams	10^{3}	milligrams
grams	0.03527	ounces
grams	0.03215	ounces (troy)
grams	2.205 x 10^{-3}	pounds
grams/cm.	5.600 x 10^{-3}	pounds/inch
grams/cubic cm.	62.43	pounds/cubic foot
grams/cubic cm.	0.03613	pounds/cubic inch
hectograms	100	grams
hectoliters	100	liters
hectometers	100	meters
hectowatts	100	watts
horsepower	42.44	B.T.U./minute
horsepower	33,000	foot–lbs./minute
horsepower	550	foot–lbs./second

multiply	by	to obtain
horsepower	1.014	horsepower (metric)
horsepower	10.70	kg.–calories/minute
horsepower	0.7457	kilowatts
horsepower	745.7	watts
inches	2.540	centimeters
kilograms	980,665	dynes
kilograms	2.205	lbs.
kilograms	1.102 x 10^{-3}	tons (short)
kilograms	10^{3}	grams
kiloliters	10^{3}	liters
kilometers	10^{5}	centimeters
kilometers	3281	feet
kilometers	10^{3}	meters
kilometers	0.6214	miles
kilometers	1094	yards
kilometers/hour	27.78	centimeters/second
kilometers/hour	54.68	feet/minute
kilometers/hour	0.9113	feet/second
kilometers/hour	0.5396	knots
kilometers/hour	16.67	meters/minute
kilometers/hour	0.6214	miles/hour
kilowatts	56.92	B.T.U./min.
kilowatts	4.425 x 10^{4}	foot–lbs./min.
kilowatts	737.6	foot–lbs./sec.
kilowatts	1.341	horsepower
kilowatts	14.34	kg.–calories/min.
kilowatts	10^{3}	watts
kilowatt–hours	3415	B.T.U.
kilowatt–hours	2.655 x 10^{6}	foot–lbs.
kilowatt–hours	1.341	horsepower–hrs.
kilowatt–hours	860.5	kilogram–calories
kilowatt–hours	3.671 x 10^{5}	kilogram–meters
liters	10^{3}	cubic centimeters
liters	0.03531	cubic feet
liters	61.02	cubic inches
liters	10^{-3}	cubic meters
liters	1.308 x 10^{-3}	cubic yards
liters	0.2642	gallons
liters	2.113	pints (liquid)
liters	1.057	quarts (liquid)
liters/min.	5.886 x 10^{-4}	cubic feet/second
liters/min.	4.403 x 10^{-3}	gallons/second
meters	100	centimeters
meters	3.281	feet
meters	39.37	inches
meters	10^{-3}	kilometers
meters	10^{3}	millimeters
meters	1.094	yards
meters/minute	1.667	centimeters/second
meters/minute	3.281	feet/minute
meters/minute	0.05468	feet/second
meters/minute	0.06	kilometers/hour
meters/minute	0.03728	miles/hour
meters/second	196.8	feet/minute
meters/second	3.281	feet/second
meters/second	3.6	kilometers/hour
meters/second	0.06	kilometers/minute
meters/second	2.237	miles/hour
meters/second	0.03728	miles/minute
miles	5280	feet
miles	1.609	kilometers
miles	1760	yards
miles/hour	44.7	centimeters/second
miles/hour	88	feet/minute
miles/hour	1.467	feet/second

multiply	by	to obtain
miles/hour	1.609	kilometers/hour
miles/hour	0.8684	knots
miles/hour	26.82	meters/minute
miles/minute	2682	centimeters/second
miles/minute	88	feet/second
miles/minute	1.609	kilometers/minute
miles/minute	60	miles/hour
milligrams	10^{-3}	grams
milliliters	10^{-3}	liters
millimeters	0.1	centimeters
millimeters	0.03937	inches
minutes (angle)	2.909 x 10^{-4}	radians
ounces	16	drams
ounces	437.5	grains
ounces	0.0625	pounds
ounces	28.349527	grams
ounces	0.9115	ounces (troy)
ounces	2.790 x 10^{-5}	tons (long)
ounces	2.835 x 10^{-5}	tons (metric)
pounds	16	ounces
pounds	256	drams
pounds	7000	grains
pounds	0.0005	tons (short)
pounds	453.5924	grams
pounds	1.21528	pounds (troy)
pounds	14.5833	ounces (troy)
pounds/foot	1.488	kgs./meter
pounds/inch	178.6	grams/cm.
quadrants (angle)	90	degrees
quadrants (angle)	5400	minutes
quadrants (angle)	1.571	radians
radians	57.30	degrees
radians	3438	minutes
radians	0.637	quadrants
radians/second	57.30	degrees/second
radians/second	0.1592	revolutions/second
radians/second	9.549	revolutions/minute
radians/second/second	573.0	revolutions/minute/minute
radians/second/second	0.1592	revolutions/second/second
revolutions	360	degrees
revolutions	4	quadrants
revolutions	6.283	radians
revolutions/min.	6	degrees/second
revolutions/min.	0.1047	radians/second
revolutions/min.	0.01667	revolutions/second
revolutions/min./min.	1.745 x 10^{-3}	radians/second/second
revolutions/min./min.	2.778 x 10^{-4}	revolutions/second/second
revolutions/second	360	degrees/second
revolutions/second	6.283	radians/second
revolutions/second	60	revolutions/minute
revolutions/second/second	6.283	radians/second/second
revolutions/second/second	3600	revolutions/minute/minute
seconds (angle)	4.848 x 10^{-6}	radians
square centimeters	1.076 x 10^{-3}	square feet
square centimeters	0.1550	square inches
square centimeters	10^{-4}	square meters
square centimeters	100	square millimeters
square feet	2.296 x 10^{-5}	acres
square feet	929.0	square centimeters
square feet	144	square inches
square feet	0.09290	square meters
square feet	3.587 x 10^{-8}	square miles
square feet	1/9	square yards
square inches	6.452	square centimeters
square inches	6.944 x 10^{-3}	square feet

multiply	by	to obtain
square inches	645.2	square millimeters
square kilometers	247.1	acres
square kilometers	10.76 x 10^{6}	square feet
square kilometers	10^{6}	square meters
square kilometers	0.3861	square miles
square kilometers	1.196 x 10^{6}	square yards
square meters	2.471 x 10^{-4}	acres
square meters	10.76	square feet
square meters	3.861 x 10^{-7}	square miles
square meters	1.196	square yards
square miles	640	acres
square miles	27.88 x 10^{6}	square feet
square miles	2.590	square kilometers
square miles	3.098 x 10^{6}	square yards
square millimeters	0.01	square centimeters
square millimeters	1.550 x 10^{-3}	square inches
square yards	2.066 x 10^{-4}	acres
square yards	9	square feet
square yards	0.8361	square meters
square yards	3.228 x 10^{-7}	square miles
Temperature (°C.) + 273	1	Abs. temperature (°C.)
Temperature (°C.) + 17.78	1.8	temperature (°F.)
Temperature (°F.) + 460	1	Abs. temperature (°F.)
Temperature (°F.) -32	5/9	temperature (°C.)
tons (short)	2000	pounds
tons (short)	32,000	ounces
tons (short)	907.18486	kilograms
tons (short)	2430.56	pounds (troy)
tons (short)	0.89287	tons (long)
tons (short)	29166.66	ounces (troy)
tons (short)	0.90718	tons (metric)
watts	0.05692	B.T.U./minute
watts	44.26	foot–pounds/minute
watts	0.7376	foot–pounds/second
watts	1.341 x 10^{-3}	horsepower
watts	0.01434	kilogram–calories/minute
watts	10^{-3}	kilowatts
watts–hours	3.415	B.T.U.
watts–hours	2655	foot–pounds
watts–hours	1.341 x 10^{-3}	horsepower–hours
watts–hours	0.8605	kilogram–calories
watts–hours	367.1	kilogram–meters
watts–hours	10^{-3}	kilowatt–hours
yards	91.44	centimeters
yards	3	feet
yards	36	inches
yards	0.9144	meters

Appendix 1—Rockwell/Brinell Hardness Conversion

If the work materials hardness is available in Rockwell B (HRB) or Rockwell C (HRC) numbers, they should be converted into Brinell hardness numbers by the following equations shown in Table A and Table B.

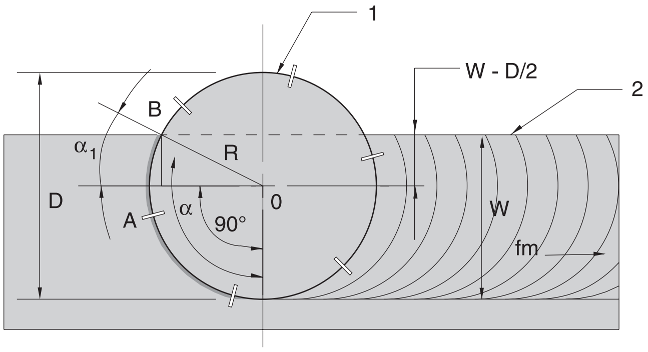
Table A. Brinell-Rockwell C Hardness Relationship

Rockwell C Hardness Numbers (HRC)		Equations to Convert Rockwell C Hardness (HRC) into Brinell Hardness (HB)
from	to	
21	30	HB = 5.970 x HRC + 104.7
31	40	HB = 8.570 x HRC + 27.6
41	50	HB = 11.158 x HRC + 79.6
51	60	HB = 17.515 x HRC - 401

Table B. Brinell-Rockwell B Hardness Relationship

Rockwell B Hardness Numbers (HRB)		Equations to Convert Rockwell B Hardness (HRB) into Brinell Hardness (HB)
from	to	
55	69	HB = 1.646 x HRB + 8.7
70	79	HB = 2.394 x HRB - 42.7
80	89	HB = 3.297 x HRB - 114
90	100	HB = 5.582 x HRB - 319

Appendix 2 — Engagement Angle and Number of Inserts in Cut



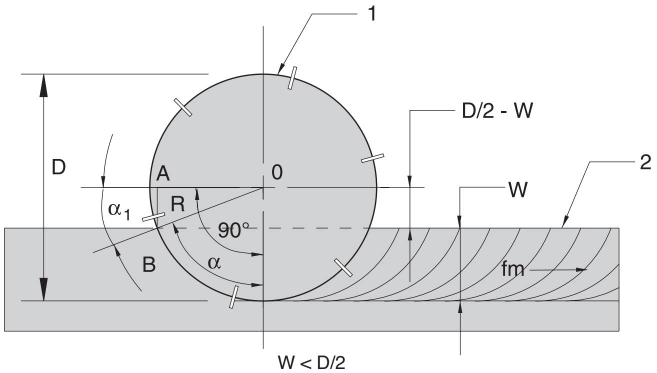
D/2 < W < D

$$Z_c = \frac{Z \times \alpha^\circ}{360^\circ} \qquad \alpha = 90^\circ + \alpha_1$$

$$\sin \alpha_1 = \frac{AB}{OB} = \frac{W - D/2}{D/2} = \frac{2(W - D/2)}{D} = \frac{2W - D}{D};$$

$$\alpha_1 = \text{arc sin}\ \frac{2W - D}{D};$$

$$Z_c = \frac{Z\left(90^\circ + \text{arc sin}\ \frac{2W - D}{D}\right)}{360^\circ}$$



W < D/2

$$Z_c = \frac{Z \times \alpha^\circ}{360^\circ} \qquad \alpha = 90^\circ - \alpha_1$$

$$\sin \alpha_1 = \frac{AB}{OB} = \frac{D/2 - W}{D/2} = \frac{2(D/2 - W)}{D} = \frac{D - 2W}{D};$$

$$\alpha_1 = \text{arc sin}\ \frac{D - 2W}{D}$$

$$Z_c = \frac{Z\left(90^\circ - \text{arc sin}\ \frac{D - 2W}{D}\right)}{360^\circ}$$

D = cutter diameter
W = width pf cut (woc)
α = engagement angle
α_1 = angle between cutter centerline and cutter radius to the peripheral point of exit or entry
Z = number of inserts in cutter
Z_c = number of inserts in cut

AA (Arithmetic Average) - See “Ra”.

Abrasion Wear - Wear that occurs when hard particles on the underside of the chip pass over the tool face and remove tool material by mechanical action. These particles could be abrasive inclusions in the workpiece, fragments of a built-up edge, or particles of tool material which have been removed by adhesion.

Adhesion - Metal build-up on cutting edge, usually caused by operation at too low speeds.

Adhesion Wear - Wear caused by the fracture of welds which are formed as part of the friction mechanism between the chip and the tool. When these minute junctions are fractured, small bits of tool material are torn out and carried away on the underside of the chip or by the workpiece.

Advanced Cutting Tool Materials - Cutting tool materials able to withstand the extremely harsh environment of elevated cutting tool speeds and the resulting temperatures. These materials include ceramic, PCD and PCBN substrates.

Amorphous - Noncrystalline; having no molecular lattice structure, which is characteristic of the solid state.

ANSI - American National Standards Institute.

Arbor - A device designed to carry and drive an arbor-type cutting tool. It can be mounted in or on the spindle of a machine tool.

Backlash - A reaction during the metalcutting process where the potential energy of the object in motion is suddenly released when the object stops, typically causing the device to quickly snap backwards relative to the last direction of motion.

Base - The surface of the shank which bears against the support and takes the tangential pressure of the cut.

Black Oxide - A black finish on a metal produced by immersing it in hot oxidizing salts or salt solutions.

Boring - A machining process in which internal diameters are made in true relation to the centerline of the spindle. It is most commonly used for enlarging or finishing holes or other circular contours.

Breakout - Term used to describe an uneven break of workpiece material as the insert exits the part.

Brinell Hardness (BHN) - A test to determine the hardness of metallic materials. It consists in applying a known load to the material surface to be tested through a hardened steel ball of known diameter. The diameter of the resulting permanent impression in the metal is measured and then calculated in the Brinell hardness number.

Built-Up Edge (BUE) - An insert edge condition problem that is characterized by the adhesion, or build-up, of layers of workpiece material to the top rake surface of the insert.

Burring - A condition whereby small slivers of workpiece material roll out over the shoulders and points of the workpiece as the tool exits the cut.

CAD (Computer-Aided Design) - Product design functions performed with the help of computers and special software.

CAE (Computer-Aided Engineering) - Engineering functions performed with the help of computers and special software.

CAM (Computer-Aided Manufacturing) - The use of computers to control machining and manufacturing.

Cemented Carbide - A sintered combination of cobalt or other binder metal and refractory metal carbides suitable for use as a cutting tool material.

Ceramics - A cutting tool material (substrate) comprised of aluminum oxide and metal alloys (i.e.: TiC), or silicon nitride. Ceramics are capable of higher speed machining than carbides on steel, irons and super-alloys, but have less toughness and thermal shock resistance.

Cermets - A cutting tool material (substrate) comprised of titanium carbonitride and metallic binder, usually nickel and/or cobalt. Cermets combine some of the high-speed characteristics of ceramics with improved toughness for semi-finish and finish machining of steel and stainless steels. Cermets have greater chemical wear resistance than most tungsten carbide grades, but have less toughness and thermal shock resistance.

Chamfer -

(1) A beveled surface to eliminate an otherwise sharp corner.

(2) A relieved angular cutting edge at a tooth corner.

(3) The surface formed by cutting away sharp corners and edges formed by two faces a piece of metal.

(4) A bevel on the cutting edge of a carbide cutting tool for the purpose of increasing its strength. The angle is measured from the cutting face downward and may vary from 1 to 45 degrees.

Chamfering - Metal turning operation used to remove sharp edges from workpiece diameter.

Chatter - Chatter is a condition of vibration involving the machine, workpiece and cutting tool. Once this condition arises it is often self-sustaining until the problem is corrected. Chatter can be identified when lines or grooves appear at regular intervals in the workpiece.

Chemical Vapor Deposition - See CVD.

Chipping - An insert edge condition problem that is characterized by breakage of the insert’s cutting tip during the cutting action.

Chuck - An attachment for holding a workpiece or a tool in a machine.

Chucker - Machine normally used to cut a part whose diameter is larger than length.

CIM (Computer-Integrated Manufacturing) - The use of interconnected computers and special software to assist in all phases of production.

Clearance - The angle below or behind the cutting edge to be forced into the work. Without clearance, the tool will not cut. It is also the term used for secondary relief in some cases.

Coated Carbide - Coated carbides have a thin layer of very hard material deposited on their surface. This material can be deposited by either physical or chemical vapor deposition. Coated carbides permit a significant increase in cutting speed and add crater and abrasion resistance in high productivity machining operations. Also see CVD and PVD.

Collet - Flexible-sided device that secures a tool or workpiece in a similar fashion as a chuck, but can accommodate only a narrow size range. Collets typically provide greater gripping force and precision than do chucks.

Composites - Materials composed of different elements held together by a compatible binder.

Counterbore - As applied to a milling cutter. An enlargement of the cutter bore at one or both ends to provide space for a nut, screw or bolts, or to provide clearance for a shoulder on arbor or spindle. A recess to facilitate manufacturing.

Crater Wear - An insert edge condition problem that resembles a relatively smooth, regular depression produced on the top of the insert (rake face).

Crest (screw thread) - The outer most surface of the thread form which joins the flanks.

Cubic Boron Nitride - See PCBN.

CVD (Chemical Vapor Deposition) - A process that deposits, or coats a film of hard refractory material on the cutting tool in a sealed reactor to about 1000° C with gaseous hydrogen at atmospheric or lower pressure. Volatile compounds are then added to the hydrogen to supply the constituents of the coating. The higher temperature CVD process provides improved abrasion and crater wear than the PVD process, although it causes poorer toughness through residual tensile stresses in the coatings.

Cycle Time - The time required to complete all machining operations on the workpiece.

Deformation - The permanent change in the shape of a cutting tool due to cutting forces and temperature. Deformation generally occurs in high speed or heavy machining. Deformation can be “plastic” (permanent) or “elastic” (non-permanent).

Depth Of Cut (doc) - The perpendicular distance between the original and final surfaces of the workpiece.

Depth Of Cut Notch (docn) - An insert edge problem that appears as chipping or wear at the doc line on the rake face and flank of the insert.

DIN - German Institute for Normalization (DIN) standards that are developed by a non-profit organization of approximately 130 standards committees with representatives from all technical areas.

Drilling - Hole making with a rotary, end-cutting tool having one or more cutting lips and one or more helical or straight flutes or tubes for the ejection of chips and the passage of cutting fluid.

Ductility - The ability of a material to deform plastically without fracturing, being measured by elongation or reduction of area in a tensile test, by height of cupping in an Erichsen test, or by other means.

Economics - Economics dictate that the cutting tool material or grade you select should ideally be one that will yield the highest productivity (metal removal rate) at the lowest cost while providing correct and consistent tool life.

Edge Preparation (insert) - A conditioning of the cutting edge. Edge preparations include chamfering, honing, and T-land or a combination of hones and lands.

Edge Wear - Edge wear appears as wear along the flank of the insert, below and immediately adjacent to the cutting edge. Uniform edge wear is the preferred method of insert failure because it can be predicted. Also referred to as flank wear.

End Cutting Angle - The angle between the cutting edge on the end of the tool and a line perpendicular to the side edge of the straight portion of the tool shank.

Engine Lathe - A floor mounted machine on which work is rotated about a horizontal axis and shaped by a cutting tool. This definition can also apply to CNC lathes. The term “engine lathe” is a carry-over from when lathes were powered by steam engines.

Face -

(1) The surface of the cutting tool on which the chip impinges as it is separated from the workpiece.

(2) To machine the flat, or end surface of the workpiece, such as facing a surface of a bar before or after turning.

Facing - Machining along the centerline towards the center of the end of the workpiece. Cleaning of one end of material for the purpose of ultrasonic evaluation. This process is also used to make two ends parallel to each other.

Feed Rate - The rate of change of position of the insert relative to the work while cutting. Usually expressed in inches per minute (ipm) when milling and inches per revolution (ipr) when turning.

Finish (surface) - See Surface Finish.

Flank - That surface which is adjacent to the cutting edge and below it when the tool is in a horizontal position for turning. The flank of a thread is either surface connecting the crest with the root. The flank surface intersection with an axial plane is theoretically a straight line.

Flatness - An even, smooth horizontal surface without depressions or elevations when gauged along the same plane. Also see Surface Finish.

FMS (Flexible Manufacturing System) - An automated or near-automated manufacturing system that is designed to manufacture a variety of similar parts. Also associated with machine tools grouped in “cells” for efficient production.

Forging - Squeezing red-hot steel between dies to strengthen it.

Fracture (insert) - When a large enough part of the insert breaks off to cause immediate failure of the cutting edge.

Fracture Toughness - A measure of the energy a material will absorb prior to fracture.

Galling - Developing a condition on the rubbing surface of one or both mating parts where excessive friction between high spots results in localized welding with subsequent spalling and a further roughening of the surface.

Geometry (insert) - The physical characteristics of an insert.

Grade - A designation given to a composition for a particular coated or uncoated cemented carbide cutting tool material.

High-Speed Spindles - Generally speaking, high-speed spindles are regarded as highperformance spindles that run over 15,000 rpm and are balanced and/or balanceable.

Honed (Edge Preparation) - The process of blunting and strengthening of the cutting edge by means of abrasives. It may be done by hand or machine. Also see Edge Preparation.

Hot Hardness - See Red Hardness.

Hypereutectic - An aluminum alloy containing more than 12.2% silicon (Si). Silicon is added to aluminum to improve casting qualities in addition to providing corrosion resistance, low thermal expansion, and high thermal conductivity. Also see Hypoeutectic.

Hypoeutectic - An aluminum alloy containing less than 12.2% silicon (Si). Also see Hypereutectic.

Inscribed Circle - The circle which can be constructed internal to any closed figure or shape such that all sides of the figure are tangent to the circle. The inscribed circle is most often used to describe the dimensions of a triangle, pentagon, hexagon, or octagon.

Insert Lock Screw - Usually identifies a screw with a Torx or hex socket that is used to retain inserts in the toolholder.

ipr (advance (inch) per revolution) - A feed value reporting how far the insert advances during one revolution, defined as

$$\text{ipr} = \frac{\text{ipm}}{\text{rpm}}$$

ISO - From the Greek word Isosceles meaning “the same as”. The International Organization for Standardization located in Geneva, Switzerland, issues these standards for the purpose of setting standards which all countries can agree upon.

“K” Factor - The “K” factor is a power constant that represents the number of cubic inches of metal per minute that can be removed by one horsepower input.

K-Land - See T-land.

Knoop hardness - Microhardness determined from the resistance of metal to indentation by a pyramidal diamond indenter, having edge angles of 172° 30' and 130°, making a rhomodedral impression with one long and one short diagonal.

Land - Area immediately behind cutting edges.

Lead (screw thread) - The distance a screw thread advances axially in one revolution. On a single start, the pitch and lead are identical. The lead is equal to the pitch, times the number of starts.

Lead Angle (chip thickness) - Increasing the lead angle reduces chip thickness for any given feed rate. This chip thinning process occurs by spreading the same amount of material over a greater length of the insert cutting edge.

Lead Angle (cutting forces) - Increasing lead angle allows the cutting edge to gradually enter and exit the workpiece surface. This helps reduce radial pressure. However, increasing the lead angle increases axial pressure and can cause deflection of the machined surface of thin cross-section parts.

Lead Angle (defined) - The angle between the cutting edge of the insert.

Lead Angle (screw thread) - On a straight thread, the lead angle is the angle created by the helix of the thread at the pitch diameter with a plane perpendicular to the axis. The helix angle is the complement to the lead angle.

Lubricity - Slipperiness; the property that diminishes friction. Tantalum carbide and titanium carbide are used to produce lubricity in steel cutting grades of tungsten carbide to reduce crater and wear.

Machinability - The relative difficulty of a machining operation with regard to tool life, surface roughness, and power consumption.

Machinability Factor (Cm) - Indicator of the machinability, or degree of difficulty, in machining various workpiece materials.

Machinability Rating - A rating expressed as a percentage rating to the difficulty of machining a given material. It is usually based on the 100 percent rating of A.I.S.I. B-1112, Cold Rolled Steel when turned at 180 sfm under normal cutting conditions. A high rating number means the material is easier to machine.

Major Diameter (screw thread) - The largest diameter of a straight screw thread. This applies to both internal and external threads.

Mandrel - Workholder for turning that fits in the inner diameter of workpieces. Three common types of mandrels are expanding, pin, and threaded.

Microstructure - The structure of polished and etched metals as revealed by a microscope at a magnification greater than ten.

Minor Diameter (screw thread) - The smallest diameter of a straight screw thread. This applies to both internal and external threads.

Negative Rake - A rake angle that is less than 90° between insert rake face and surface of work.

Nest - A removable part of a toolholder or milling cutter designed to support the cutting insert. Also called anvil or seat.

Nose - The corner angle formed by joining the side-cutting and end-cutting edges of a tool.

Nose Radius - The radius on the tool between the end and side cutting edges.

Notching, Depth of Cut - See Depth of Cut Notch (docn).

Overshoot - A condition resulting in the deviation from the normal path or designated value caused by momentum carried over from the previous step, as when a tool is rapidly traversed over a considerable distance to begin a cut.

PCBN (Polycrystalline Cubic Boron Nitride) - An ultra-hard cutting tool material (substrate) consisting of polycrystalline cubic boron nitride with a metallic or ceramic binder. PCBN is available either as a tip brazed to a carbide insert carrier or as a solid insert. Primarily used to machine hardened ferrous material.

PCD (Polycrystalline Diamond) - An ultra-hard cutting tool material (substrate) consisting of a synthetic polycrystalline diamond tip brazed to a carbide insert carrier. Primarily used to machine non-ferrous materials at high speeds.

Pitch (screw thread) - The distance from a point on a screw thread to a corresponding point on the next thread measured parallel to the thread axis.

Pitch Diameter - (Simple Effective Diameter) On a straight thread, the pitch diameter is the diameter of the imaginary co-axial cylinder, the surface of which would pass through the thread profiles at such points as to make the width of the groove equal to one-half of the basic pitch. On a perfect thread, this occurs at the point where the widths of the thread and groove are equal. On a taper thread, the pitch diameter at a given position on the thread axis is the diameter of the pitch cone at that position.

Positive Rake - A rake angle that is more than 90° between insert rake face and work surface.

Profiling - Machine operation where the tool does not move parallel to the workpiece, but follows contours.

PVD (Physical Vapor Deposition) - PVD is a process that deposits, or coats, a film of hard refractory materials on the cutting tool by heating the tools in a sealed reactor to about 500° C in a vacuum chamber. A vaporized or ionized compound is then deposited on the tools by ion plating, magnetron sputtering, or arc evaporation. The PVD process is designed to improve coating toughness and prevent chipping of the cutting edge.

Quick-Change Tooling - This tool changing procedure involves changing an entire pre-gauged cutting unit as opposed to changing an individual insert. Quick-change tooling helps to minimize time lost for changing tools and making setups.

Ra - A measure of roughness. An arithmetical average (also referred to as “AA”) that is very close to root mean square (rms) except the Ra(AA) measures 11 percent lower. The squaring process used in obtaining the rms average gives added weight to the larger ordinates of the surface roughness.

Radial Runout - The total variation in a radial direction of all cutting edges in a plane of rotation. Also known as total indicator reading.

Rake Angle - The angle between the face of the cutting tool and the work. If the face of the tool lies perpendicular to the work, it has a zero-degree, or neutral rake. If the angle of the tool face makes the cutting edge more acute, then it has a positive rake, if more blunt, then it has a negative rake.

Red Hardness (Hot Hardness) - Ability of a cutting tool material to withstand extremely high temperatures without softening or degrading.

Refractory Metal - A metal having an extremely high melting point. The term is typically used in reference to metals that have a melting point above the range of iron.

Relief - The clearance angle behind or below the cutting edge which allows the cutting edge to be forced into the work. It is sometimes divided into primary relief (adjacent to the cutting edge) and secondary relief (beyond the primary relief). See Clearance.

Rigidity - The inflexibility, or stiffness of a machine set-up and the associated fixtures. Rigidity is extremely important for successful metalcutting.

RMS (root mean square) - A measure of roughness or average deviation from the mean surface of the machined workpiece. The mean surface is the perfect surface that would be formed if all of the roughness peaks were cut off and filled into the valleys below the surface.

Rockwell Hardness (HRC) - A measure of hardness calculated from the difference in depth of penetration of an indenture between a major and a minor load. The more commonly used Rockwell scales are Rockwell “C” (HRC), using a diamond spheroconical penetrator, and a Rockwell “B” (HRB), using a 1/16 inch diameter steel ball penetrator.

Root (screw thread) - The inner most surface of the thread form which joins the flanks.

Roughness - Fine irregularities in the part surface texture produced by the cutting action. See Surface Finish.

rpm (revolution per minute) - defined as

$$\text{rpm} = \frac{12 \times \text{sfm}}{\pi \times D}$$

Semisynthetic Cutting Fluid - Water-based chemical solution that contains some amount of oil.

sfm (surface feet per minute) - defined as

$$\text{sfm} = \frac{\pi \times D \times \text{rpm}}{12}$$

Shank - The main body of a single point tool or toolholder.

Side Cutting Edge Angle - The angle between the side cutting edge and the projected side of the shank or holder (also see Lead Angle).

Soluble-Oil Cutting Fluid - Fluid in which oil is suspended in water. Also known as emulsified oil, the fluid is a mix of oil and water in ratios of 1:5 to 1:100, depending on the oil and the machining application.

Square Shoulder - Lead angles of 0° create 90°, or square, shoulders.

Starting Feeds and Speeds - The process of correctly setting the initial cutting specifications. Correct starting feeds and speeds will dramatically increase productivity and reduce costs.

Surface Finish -

(1) Condition of a surface as a result of a final treatment.

(2) Measured surface profile characteristics, the preferred term being roughness.

(3) Physical characteristics of the machined workpiece surface.

Surface Symbols - ANSI approved symbols that are used to designate control of workpiece surface irregularities.

Synthetic Cutting Fluid - Water-based solution that contains no oil.

T-Land - A negative land that is ground on the face of the insert from the cutting edge inward. T-land and T-land with honed edge preparations offer maximum insert edge protection and strength, although significantly increasing the cutting pressure of the operation. See Edge Preparation.

Tangential Force - Action in a direction tangential to the revolving workpiece and represents the resistance to the rotation of the workpiece.

Thermal Cracks - Separations in the cutting tool generally visible in the crater or top face of the cutting tool due to high-temperature gradients encountered in some metalcutting operations. To decrease thermal cracking effects, a more heat-resistant grade is selected.

Thread Angle (included) - The included angle between the individual flanks of the thread form.

Threading - Producing external threads on a cylindrical surface. Three common types of threading are die threading, single-point threading, and thread milling.

Threads per inch (tpi) - The number of threads per inch measured axially. The terms pitch and tpi are often used interchangeably.

TIR (total indicator reading) - See Radial Runout.

Tool Wear Factor (Cw) - Indicator of approximate tool wear.

Torque - The torque generated by tangential forces is calculated using the following formula:

T = Ft x D/2 (in.-lb.)

Trepanning - Cutting a groove in a solid part in the form of a circle and removing the center core in one piece. Shallow trepanning, also called face grooving, is usually performed with a curved blade.

True Rake Angle (TRA) - Describes the angle between the reference plane and the face of the insert, as measured in a plane normal to the cutting edge. It affects horsepower consumption, cutting forces and tool life, and is derived from the combined angles of the axial rake, radial rake and lead angle. The true rake equals the radial rake when the lead angle equals zero.

Turning - A machining process in which a workpiece is held and rotated against a single-point tool to form flat or contoured surfaces concentric with the longitudinal axis of the workpiece.

Turning Center - A lathe-type NC machine tool capable of automatically boring, turning outer and inner diameters, threading, and facing parts. It is often equipped with a system for automatically changing or indexing cutting tools.

Turret Lathe - Differs from the engine lathe in that the normal compound rest is replaced by pivoting, multi-tool turrets mounted on the cross slide and tailstock.

Ultimate Material Strength - The maximum strength or stress that a material is capable of withstanding without breaking under a gradually and uniformly applied load.

Uncoated Carbide - Uncoated cemented carbide was first produced by combining tungsten carbide with a cobalt binder, and today this material can be modified with other materials. Uncoated tungsten carbide grade usage, in standard insert configurations, is slowly fading from the metalcutting scene due to productivity gains promised by coated carbides.

Undercut - A cut shorter than the programmed cut resulting in a command change in direction. Also a condition in generated gear teeth when any part of the fillet curve lies inside of a line drawn tangent to the working profile at its point of juncture with the fillet.

Undershoot - The tendency of a machine to round off the corners of a programmed path because of servo log, backlash, and overall quality and rigidity of the machine.

Waviness - The widest-spaced irregularities measured along the workpart surface. Also see Surface Finish.

Workhardening - When the cutting condition is such that a high temperature is produced at the cutting point engagement of the workpiece, the high temperature will cause the material to harden at a higher Rockwell rating than it was originally.

Custom Solution Milling Cutter

Quotation Request

Company Name
Date
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Address
Phone Number
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Zip
Sales Rep.

Please complete only the information that is required for your application.

Application Requirements:

☐ Face Milling
☐ Shoulder Milling (End milling)
☐ Slot Milling
☐ Plunge Milling (Z-axis)
☐ Ramping
☐ Contour Milling
☐ Helical / Circular Interpolation
☐ Drilling (Center Cutting)
☐ Thread Milling

Workpiece Material:

☐ Bar Stock
☐ Casting
☐ Forging
☐ Material =
☐ Hardness =

Surface Finish Requirements:

☐ Roughing
☐ Finishing ~ Req'd Finish =
☐ Ra
☐ Rz
☐ Microinch (MU)
☐ Micrometer (MU)

Mounting Requirements:

Arbor Mount
☐ Shell Mill Mount
☐ Type A (Cap Screw)
☐ Type B (Retaining Screw)
☐ Type C (Bolt Circle)
☐ Hub Mount (Shaft Mounting)

Shank Mount
☐ Plain Straight Shank (Smooth)
☐ Flatted Straight Shank (Weldon)
☐ Whistle Notch Straight Shank
☐ Threaded Shank
☐ R8 ~ Bridgeport Shank
☐ Morse

Integral Mount
☐ CV
☐ BT
☐ DV
☐ HSK
☐ Morse
Size =
Form =

Special requirements =

Insert Requirements:

☐ Insert Style =
☐ Insert Size =
☐ Insert Corner Radius =

Cutter Requirements:

☐ Design Units = ☐ Inch ☐ Metric

☐ Cutting Diameter	Dc (or D1) =	
☐ Cutter Height (Overall Length)	L =	
☐ Lead Angle	Kr (or Kri) =	
☐ Number of Effective Inserts	z (or Zs) =	
☐ Programmed Chip Load	fz =	
☐ Axial Depth of Cut	ap =	
☐ Radial Depth of Cut	ae =	

ap = Engagement measured parallel to (along) tool axis
ae = Engagement measured perpendicular to tool axis

☐ Cutting Direction = ☐ Right Hand ☐ Left Hand

☐ Through Tool Coolant

☐ Insert Spacing = ☐ Differential ☐ HARVI

Additional Information:

Material Grade Comparison Table

Steel

Mat. Group	Mat. No.	Germany DIN	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	U.S.A. AISI/SAE UNS	Japan JIS
	Plain Steel, Cast Steel, Free-Machining Steel								
P1	1.0332	St14		14491CR		1447		1008	
P1	1.1121	Ck10	CC10	040A10		1264		1010	S10C
P1	1.0721	10S20		210M15				1108	
P1	1.0401	C15	CC12	080M15	C15C16	1350	F.111	1015	S15C
P1	1.0402	C22	CC20	050A20	C20C21	1450	F.112	1020	S20C,S22C
P1	1.1141	Ck15	XC12	080M15	C16	1370	C15K	1015	S15C
P1	1.0036	USt37-3			FE37BFU				
P1	1.0715	9SMn28	S250	230M07	CF9SMn28	1912	11SMn28	1213	SUM22
P1	1.0718	9SMnPb28	S250Pb		CF9SMnPb28	1914	11SMnPb28	12L3	SUM22L
P2	1.0501	C35	CC35	060A35	C35	1550	F.113	1035	S35C
P2	1.0503	C45	CC45	080M46	C45	1650	F.114	1045	S45C
P2	1.1158	Ck25	XC25	070M25	C25			1025	S25C
P2	1.1183	Cf35	XC38TS	060A35	C36	1572		1035	S35C
P2	1.1191	Ck45	XC42	080M46	C45	1672	C45K	1045	S45C
P2	1.1213	Cf53	XC48TS	060A52	C53	1674		1050	S50C
P3	1.5415	15Mo3	15D3	1501-240	16Mo3KW	2912	16Mo3	ASTMA204GrA	
P3	1.5423	16Mo5		1503-245-420	16Mo5		16Mo5	4520	SB450M
P1	1.0050	St50-2			FE50				SM50YA
P3	1.7242	16CrMo 4	18CrMo4			18CrMo4			
P3	1.7337	16CrMo 4 4			A18CrMo45KW			A387Gr.12Cl.	
P3	1.7362	12CrMo 19 5	Z10CD5.05	3606-625	16CrMo205				
P1	1.0060	St60-2			FE60-2				SM570
P2	1.0535	C55		070M55	C55	1655		1055	S55C
P2	1.0601	C60	CC55	080A62	C60			1060	S60C
P2	1.1203	Ck55	XC55	070M55	C50		C55K	1055	S55C
P2	1.1221	Ck60	XC60	080A62	C60	1678		1060	S58C
P3/4	1.1545	C1051			C100KU				SK3
P3/4	1.1545	C105W1			C100KU				SK3
P1	1.0070	St70-2			FE70-2				
P3/4	1.7238	49CrMo4							
P3/4	1.7561	42CrV6							
P3/4	1.7701	51CrMoV4	51CDV4		51CrMoV4				
	Low-Alloy Steel, Cast Steel, Free-Machining Steel								
P3/4	1.2067	100Cr6	Y100C6	BL3			100Cr6	L3	SUJ2
P3/4	1.2210	115CrV3	100C3		107CrV3KU			L2	
P3/4	1.2241	51CrV4							
P3/4	1.2419	105WCr6	105WC13		10WCr6	2140	105WCr5		SKS31
P3/4	1.2419	105WCr6	105WC13		107WCr5KU				SKS31
P3/4	1.2542	45WCrV7		BS1	45WCrV8KU	2710	45WCrSi8	S1	
P3/4	1.2550	60WCrV7	55WC20		58WCr9KU	-2710		S1	
P3/4	1.2713	55NiCrMoV6	55NCDV7				F.520.S	L6	SKH1;SKT4
P3/4	1.2721	50NiCr13				-2550			
P3/4	1.2762	75CrMoNiW67							
P3/4	1.2762	75CrMoNiW67							
P3/4	1.2842	90MnCrV8	90MV8	BO2	88MnV8KU			O2	
P3/4	1.3505	100Cr6	100C6	534A99	100Cr6	2258		52100	SUJ2
P3	1.5622	14Ni6	16N6		14Ni6		15Ni6	ASTMA350LF5	
P3	1.5732	14NiCr10	14NC11		16NiCr11		15NiCr11	3415	SNC415(H)
P3	1.5752	14NiCr14	12NC15	655M13				3415;3310	SNC815(H)
P3/4	1.6511	36CrNiMo4	40NCD3	816M40	38NiCrM04(KB)		33NiCrMo4	9840	SNCM447
P3/4	1.6523	21NiCrMo2	20NCD2	805M20	20NiCrMo2	2506	20NiCrMo2	8620	SNCM220(H)
P3/4	1.6546	40NiCrMo22		311-TYPE7	40NiCrM02(KB)		40NiCrMo2	8740	SNCM240
P3/4	1.6582	35CrNiMo6	35NCD6	817M40	35NiCrMo6(KB)	2541		4340	SNCM447
P3	1.6587	17CrNiMo6	18NCD6	820A16			14NiCrMo13		
P3	1.6657	14NiCrMo34		832M13	15NiCrMo13		14NiCrMo131		
P3/4	1.7033	34Cr4	32C4	530A32		34Cr4(KB)	35Cr4	5132	SCR430(H)
P3/4	1.7035	41Cr4	42C4	530M40			42Cr4	5140	SCR440(H)
P3/4	1.7045	42Cr4	42C4TS	530A40	41Cr4	2245	42Cr4	5140	SCr440
P3	1.7131	16MnCr5	16MC5	(527M20)	16MnCr5	2511	16MnCr5	5115	SCR415
P3/4	1.7176	55Cr3	55C3	527A60				5155	SUP9(A)
P3/4	1.7218	25CrMo4	25CD4	1717CDS110	25CrMo4(KB)	2225	55Cr3	4130	SM420;SCM430
P3/4	1.7220	34CrMo4	35CD4	708A37	35CrMo4	2234	34CrMo4	4137;4135	SCM432;SCCRM3

Material Grade Comparison Table

Steel

Mat. Group	Mat. No.	Germany DIN	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	U.S.A. AISI/SAE UNS	Japan JIS
	Plain Steel, Cast Steel, Free-Machining Steel								
P3/4	1.7223	41CrMo4	42CD4TS	708M40	41CrMo4	2244	42CrMo4	4140;4142	SCM440
P3/4	1.7225	42CrMo4	42CD4	708M40	42CrMo4	2244	42CrMo4	4140	SCM440(H)
P3	1.7262	15CrMo5	12CD4			2216	12CrMo4		SCM415(H)
P3	1.7335	13CrMo44	15CD3.5/4.5	1501-620-Gr27	14CrMo45		14CrMo45	ASTMA182	SPVAF12
P3/4	1.7361	32CrMo12	30CD12	722M24	32CrMo12	2240	F.124.A		
P3	1.7380	10CrMo9 10		1501-622Gr31;45				ASTMA182F.22	SPVA,SCMV4
P3	1.7715	14MoV6 3		1503-660-440			13MoCrV6		
P3/4	1.8159	50CrV4	50CrV4	735A50	50CrV4	2230	51CrV4	6150	SUP10
P3/4	1.8159	50CrV4		735A50	51CrV4	2230		6150	SUP10
P3/4	1.3501	100Cr2	100C2					E50100	
P3/4	1.5710	36NiCr6	35NC6	640A35				3135	SNC236
P3/4	1.5736	36NiCr10	30NC11					3435	SNC631(H)
P3/4	1.5755	31NiCr14	18NC13	653M31					SNC836
P3/4	1.7733	24CrMoV55	20CDV6		21CrMoV511				
P3/4	1.7755	GS-45CrMoV104							
P3	1.8070	21CrMoV511			35NiCr9				
P3/4	1.8509	41CrALMo7	40CAD6,12	905M39	41CrAlMo7	2940	41CrAlMo7		SACM645
P3/4	1.8523	39CrMoV139		897M39	36CrMoV12				
P3/4	1.2311	40CrMnMo7			35CrMo8KU				
P5/6	1.4882	X50CrMnNiNbN219	Z50CMNNb21.09						
P3/4	1.5864	35NiCr18							
	High-Alloy Steel, Cast Steel								
P3/4	1.2343	X38CrMoV51	Z38CDV5	BH11	X37CrMoV51KU		X37CrMoV5	H11	SKD6
P3/4	1.2344	X40CrMoV51	Z40CDV5	BH13	X40CrMoV511KU	2242	X40CrMoV5	H13	SKD61
P3/4	1.2379	X155CrVMo121	Z160CDV12	BD2	X155CrVMo121KU			D2	SKD11
P3/4	1.2436	X210CrW12			X215CrW121KU	2312	X210CrW12		SKD2
P3/4	1.2581	X30WCrV93	Z30WCV9	BH21	X30WCrV93KU		X30WCrV9	H21	SKD5
P3/4	1.2601	X165CrMoV12			X165CrMoW12KU	2310	X160CrMoV12		
P3/4	1.2606	X37CrMoW 51	Z35CWDV5	BH12	X35CrMoW05KU		F.537	H12	SKD62
P5/6	1.5662	X8Ni9		1501.509;50	X10Ni9		XBNi09	ASTMA353	SL9N53
P3	1.5680	12Ni19	Z18N5					2515	
P3/4	1.3202	S12-1-4-5		BT15	HS12-1-5-5		12-1-5-5		
P3/4	1.3207	S10-4-3-10	Z130WKCDV	BT42	HS10-4-3-10				SKH57
P3/4	1.3243	S6-5-2-5	KCV06-05-05-04-02		HS6-5-2-5	2723	6-5-2-5	T15	SKH55
P3/4	1.3246	S7-4-2-5	Z110WKCDV07-05-04			HS7-4-2-5	7-4-2-5	M35	
P3/4	1.3247	S2-10-1-8	Z110DKCWV09-08-04		BM42	HS2-9-1-8	2-10-1-8	M41	SKH51
P3/4	1.3249	S2-9-2-8		BM34			2-9-2-8	M42	
P3/4	1.3343	S6-5-2	Z85WDCV	BM2	HS6-5-2-5	2722		M35	SKH9;SKH51
	Stainless Steel, Cast Steel								
P5/6	1.4000	X6Cr13	Z6C13	403S17	X6Cr3	2301	F.3110	403	SUS403
P5/6	1.4001	X6Cr14					F.8401		410S,429
P5/6	1.4002	X6CrAl13	Z8CA12	405S17	X6CrAl13			405	SUS405
P5/6	1.4006	(G-)X10Cr13	Z10C13	410S21	X12Cr13	2302	F.3401	SUS410	SUS410
P5/6	1.4016	X8Cr17	Z8C17	430S15	X8Cr17	2320	F.3113	430	SUS430
P5/6	1.4021	X20Cr13	Z20C13	420S37	X20Cr13	2303		420	SUS420J1
P5/6	1.4027	G-X20Cr14	Z20C13M	420C29					SCS2
P5/6	1.4086	G-X120Cr29		452C11					
P5/6	1.4104	X12CrMoS17	Z10CF17	441S29	X10CrS17	2383	F.3117	430F	SUS430F
P5/6	1.4113	X6CrMo17	Z8CD1701	434S17	X8CrMo17	2325		434	SUS434
P5/6	1.4340	G-X40CrNi274							
P5/6	1.4417	X2CrNiMoSi195				2376		S31500	
P5/6	1.4720	X20CrMo13							
P5/6	1.4724	X10CrA113	Z10C13	403S17	X10CrA112		F.311	405	SUS405
P5/6	1.4742	X10CrA118	Z10CAS18	430S15	X8Cr17		F.3113	430	SUS430
P5/6	1.4762	X10CrA124	Z10CAS24		X16Cr26	2322		446	SUH446
P5/6	1.4034	X46Cr13	Z40CM	420S45	X40Cr14	2304	F.3405		
P5/6	1.4057	X20CrNi17	Z6CNi6.02	431S29	X16CrNi16	2321		431	SUS431
P5/6	1.4125	X105CrMo17	Z100CD17		X 105CrMo17				SUS440C
P5/6	1.4534							13.8PH	
P5/6	1.4540	X4CrNiCuNb164	Z6CNU15.05					15.5PH	
P5/6	1.4542	X5CrNiCuNb174	Z7CNU17.04					17.4PH	SCS 24

Material Grade Comparison Table

KENNAMETAL

Stainless Steel and Cast Iron

Mat. Group	Mat. No.	Germany DIN	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	U.S.A. AISI/SAE UNS	Japan JIS
	Austenitic Stainless Steel								
M1	1.4301	X5CrNi189	Z6CN18.09	304S15	X5CrNi1810	2332	F.3551	304	SUS304
M1	1.4310	X12CrNi177	Z12CN17.07	301S21	X2CrNi1807	2331	F.3517	301	SUS301
M1	1.4311	X2CrNiN1810	Z2CN18.10	304S62	X2CrNiN1810	2371		304LN	SUS304LN
M1	1.4312	G-X10CrNi188	Z10CN18.9M	302C25					
M1	1.4350	X5CrNi189	Z6CN18.09	304S31	X5CrNi1810	2332/2333	F.3551	304	
M1	1.4362	X2CrNiN234	Z2CN23-04AZ			2327		S32304	
M2	1.4401	X5CrNiMo17122	Z6CND17.11	316S16	X5CrNiMo1712	2347	F.3543	316	SUS316
M2	1.4404	X2CrNiMo1810	Z2CND17.12	316S12	X2CrNiMo1712	2343/2348/2553			316L SUS316
M2	1.4410	G-X10CrNiMo189	Z5CND20.12M						
M2	1.4429	X2CrNiMoN17133	Z2CND17.13	316S63	X2CrNiMoN1713	2375		316LN	SUS316LN
M2	1.4435	X2CrNiMo18143	Z2CND17.12	316S13	X2CrNiMo1712	2353		316L	SCS16
M2	1.4436	X5CrNiMo17133	Z6CND18-12-03	316S33	X8CrNiMo1713	2343/2347		316	SUS316
M2	1.4438	X2CrNiMo18164	Z2CND19.15	317S12	X2CrNiMo1816	2367		317L	SUS317L
M2	1.4500	G-X7NiCrMoCuNb2520	23NCDU25.20M						
M2	1.4541	X10CrNiMoTi1810	Z6CNT18.10	321S12	X6CrNiTi1811	2337	F.3553F.3523	321	SUS321
M2	1.4550	X10CrNiNb	Z6CNNb18.10	347S17	X6CrNiNb1811	2338	F.3552F.3524	347	SUS347
M2	1.4552	G-X7CrNiNb189	Z4CNNb19.10M	347C17					
M2	1.4571	X10CrNiMoTi1810	Z6NDT17.12	320S17	X6CrNiMoTi1712	2350	F.3535	316Ti	SUS316TI
M2	1.4583	X10CrNiMoNb1812	Z6CNDN1713B		X6CrNiMoNb			318	
M2	1.4585	G-X7CrNiMoCuNb1818			X6CrNiMoTi1712				
M1	1.4828	X15CrNiSi2012	Z15CNS20.12	309S24				309	SUH309
M2	1.4845	X12CrNi2521	Z12CN2520	310S24	X6CrNi2520	2361	F.331	310S	SUH310;
	Austenitic/Ferritic Stainless Steel (Duplex)								
M3	1.4460	X8CrNiMo275				2324		S32900	SUS329J1
M3	1.4462	X2CrNiMoN2253	Z2CND22-05-03			2977			
M3	1.4821	X20CrNiSi254	Z20CNS25.04						
M3	1.4823	G-X40CrNiSi274							
	Gray Cast Iron								
K1	0.6010	GG10	Ft10D		G10	110		CLASS20	FC100
K1	0.6015	GG15	Ft15D	GRADE150	G15	115	FG15	CLASS25	FC150
K1	0.6020	GG20	Ft20D	GRADE220	G20	120	FG20	CLASS30	FC200
K1	0.6025	GG25	Ft25D	GRADE260	G25	125	FG25	CLASS35	FC250
K1	0.6030	GG30	Ft30D	GRADE300	G30	130	FG30	CLASS45	FC300
K1	0.6035	GG35	Ft35D	GRADE350	G35	135	FG35	CLASS50	FC350
K1	0.6040	GG40	Ft40D	GRADE400		140		CLASS55	FC400
	Gray Cast Iron with Nodular Graphite								
K2	0.7033	GGG35.3				0717-15			FCD350
K2	0.7040	GGG40	FCS400-12	SNG420/12	GGG40	0717-02	GGG40	60-40-18	FCD400
K2	0.7043	GGG40.3	FGS370-17	SNG370/17		0717-12			FCD400
K3	0.7050	GGG50	FGS500-7	SNG500/7	GGG50	0727-02	GGG50	80-55-06	FCD500
K3	0.7060	GGG60	FGS600-3	SNG600/3	GGG60	0732-03	GGG60		FCD600
K3	0.7070	GGG70	FGS700-2	SNG700/2	GGG70	0737-01	GGG70	100-70-03	FCD700
	White Malleable Cast Iron								
K1	0.8040	GTW-40	MB40-10	W410/4	GMB40		GTW40		
K1	0.8045	GTW-45			GMB45		GTW45		
K1	0.8055	GTW-55					GTW55		
K1	0.8065	GTW-65					GTW65		
K2	0.8135	GTS-35	MN35-10	B340/12		810	GTS35	32510	
K2	0.8145	GTS-45		P440/7		852	GTS45	40010	
K1	0.8035	GTW-35	MB35-7	W340/3			GTW35		
K3	0.8155	GTS-55	MP50-5	P510/4		854	GTS55	50005	
K3	0.8165	GTS-65	MP60-3	P570/3		856	GTS65	70003	
K3	0.8170	GTS-70	M870-2	P690/2		0862; 864	GTS70	90001	

Non-Ferrous Materials

Mat. Group	Mat. No.	Germany DIN	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	U.S.A. AISI/SAE UNS	Japan JIS
	Aluminum Alloys								
N1	3.0255	Al99.5	A59050C	L31/34/36				1000	
N1	3.3315	AlMg1							
N1	3.1655	AlCuSiPb							
N1	3.1754	G-AlCu5Ni1,5	3.4345	AlZnMgCu0,5	AZ4GU/9051	L86	811-04		7050
N2	3.2373	G-AlSi9Mg							
N2	3.2381	G-AlSi10Mg							
N2	3.2382	GD-AlSi10Mg							
N2	3.2383	G-AlSi10Mg (Cu)		LM9		4253		A360.2	
N2	3.2383	GK-AlSi10Mg (Cu)		LM9		4253		A360.2	
N2	3.2581	G-AlSi12		LM6		4261		A413.2	
N2	3.2582	GD-AlSi12				4247		A413.0	A6061
N2	3.2583	G-AlSi12 (Cu)		LM20		4260		A413.1	ADC12
N1	3.3561	G-AlMg5	A-SU 12	LN5		4252		GD-AlSi12	AC4A
N1	3.5101	G-MgZn4SE1Zr1	G-Z4TR	MAG5				ZE41	
N1	3.5103	MgSE3Zn2Zr1	G-TR3Z2	MAG6				EZ33	
N1	3.5106	G-MgAg3SE2Zr1	G-Ag22,5	MAG12				QE22	
N1	3.5812	G-MgAl8Zn1	G-A9	MAG1				AZ81	
N1	3.5912	G-MgAl9Zn1	G-A9Z1	MAG7				AZ91	
N1	2.1871	G-AlCu4TiMg							
N1	3.2371	G-AlSi7Mg						4218B	
	Copper Alloy								
N3	2.1090	G-CuSn7ZnPb	U-E7Z5Pb4					C93200	
N3	2.1096	G-CuSn5ZnPb	U-E5Pb5Z5	LG2				C83600	
N3	2.1098	G-CuSn2ZnPb							
N3	2.1176	G-CuPb10Sn	U-E10Pb10	LB2				C93700	
N3	2.1182	G-CuPb15Sn	U-Pb15E8	LB1				C93800	
N3	2.0240	CuZn15	CuZn15	CZ102				C23000	
N3	2.0265	CuZn30	CuZn30	CZ106				C26000	
N3	2.0321	CuZn37	CuZn36, CuZn37	CZ108	C2700,C2720			C27200, C27700	
N3	2.0592	G-CuZn35Al1	U-Z36N3	HTB1				C86500	
N3	2.0596	G-CuZn34Al2	U-Z36N3	HTB1				C86200	
N3	2.1188	G-CuPb20Sn	U-Pb20	LB5				C94100	
N3	2.1292	G-CuCrF35		CC1-FF				C81500	
N3	2.1293	CuCrZr	U-Cr0,8Zr	CC102				C18200	
N3	2.0966	CuAl10Ni5Fe4	U-A10N	Ca104				C63000	
N3	2.0975	G-CuAl10Ni						B-148-52	
N3	2.1050	G-CuSn10		CT1				C90700	
N3	2.1052	G-CuSn12	UE12P	Pb2				C90800	
N4		Nylon, Plastics, Rubbers, Phenolics and Resins							
N5		Carbon and Graphite Composites, brush alloys, Kevlar, Graphite (280 - 400 HB, 30 - 40 HRC)							
N6		MMC's (Aluminum-based Metal Matrix Composites)							

High-Temp Alloys

Mat. Group	Mat. No.	Germany DIN	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	U.S.A. AISI/SAE UNS	Japan JIS
	Super-Alloys Fe-based				**US Trade Designation**				
S1	1.4558	X2NiCrAlTi3220		NA15	Incoloy 800			N08800	
S1	1.4562	X1NiCrMoCu32287						N08031	
S1	1.4563	X1NiCrMoCuN31274	Z1NCDU31.27					N08028	
S1	1.4864	X12NiCrSi	Z12NCS35.16					330	SUH330
S1	1.4864	X12NiCrSi3616	Z12NCS35.16	NA17				N08330	SUH330
S1	1.4958	X5NiCrAlTi3120							
S1	1.4977	X40CoCrNi2020	Z42CNKDWNb						
S1					A-286			S66286	
S1					Greek Ascoloy			S41800	
S1					Haynes 556 (HS556)			R30556	
S1					N155			R30155	
	Super-Alloys Fe-based				**US Trade Designation**				
S2					Haynes 188			R30188	
S2					L605 (Haynes 25)			R30605	
S2					MARM-302, 322, 509				
S2					Stellite 6, 21, 31				
	Super-Alloys Ni-based				**US Trade Designation**				
S3	2.4360	NiCu30Fe	NU30	NA13	Monel 400				
S3	2.4610	NiMo16Cr16Ti			Hastelloy C-4				
S3	2.4630	NiCr20Ti	NC20T	HR5, 203-4	Nimonic 75			N06075	
S3	2.4642	NiCr29Fe	NC30Fe		Inconel 690				
S3	2.4810	G-NiMo30			Hastelloy C			N10276	
S3	2.4856	NiCr22Mo9Nb	NC22FeDNb	NA21	Inconel 625			N06625	
S3	2.4858	NiCr21Mo	NC21FeDU	NA16	Incoloy 825			N08825	
S3	2.4375	NiCu30 Al	NU30AT	NA18	Monel 718				
S3	2.4668	NiCr19FeNbMo	NC19FeNb		Inconel 718			N07718	
S3	2.4669	NiCr15Fe7TiAl	NC15TNbA		Inconel X-750			N07750	
S3	2.4685	G-NiMo28			Hastelloy B			N10001	
S3	2.4694	NiCr16Fe7TiAl			Inconel 751			N00751	
	Titanium and Titanium Alloys				**US Trade Designation**				
S4	3.7025	Ti 1		2TA1				R50250	
S4	3.7124	TiCu2		2TA21-24					
S4	3.7195	TiAl3V2.5							
S4	3.7225	Ti1Pd		TP1				R52250	
S4	3.7115	TiAl5Sn2							
S4	3.7145	TiAl6Sn2Zr4Mo2Si						R54620	
S4	3.7165	TiAl6V4	T-A6V	TA10-13; TA28	TiAl6V4			R56400	
S4	3.7175	TiAl6V6Sn2			Ti6V6Al2Sn			R56620	
S4	3.7185	TiAl4Mo4Sn2		TA45-51; TA57					

Mat. Group	Mat. No.	Germany DIN	France AFNOR	Great Britain BS	Italy UNI	Sweden SS	Spain UNE	U.S.A. AISI/SAE UNS	Japan JIS
	White Cast Iron								
H1	0.9620	G-X260NiCr42		Grade 2A		0512-00		Ni- Hard 2	
H1	0.9625	G-X330NiCr42		Grade 2B		0513-00		Ni- Hard 1	
H1	0.9630	G-X300CrNiSi952						Ni- Hard 4	
H1	0.9635	G-X300CrMo153							
	Hardened Cast Iron								
H1	0.9640	G-X300CrMoNi1521							
H1	0.9645	G-X260CrMoNi2021							
H1	0.9650	G-X260Cr27		Grade 3D		0466-00		A532IIIA25%Cr	
H1	0.9655	G-X300CrMo271							
H1	0.9655	G-X300CrMo271		Grade 3E				A532IIIA25%Cr	