



# CUTTING TOOL TECHNOLOGY

---

1. Tool Life
2. Tool Materials
3. Tool Geometry
4. Cutting Fluids



# Cutting Tool Technology

---

Two principal aspects:

1. Tool material
2. Tool geometry



# Three Modes of Tool Failure

---

1. Fracture failure
  - Cutting force becomes excessive and/or dynamic, leading to brittle fracture
2. Temperature failure
  - Cutting temperature is too high for the tool material
3. Gradual wear
  - Gradual wearing of the cutting tool



# Preferred Mode: Gradual Wear

---

- Fracture and temperature failures are premature failures
- Gradual wear is preferred because it leads to the longest possible use of the tool
- Gradual wear occurs at two locations on a tool:
  - Crater wear – occurs on top rake face
  - Flank wear – occurs on flank (side of tool)

# Tool Wear

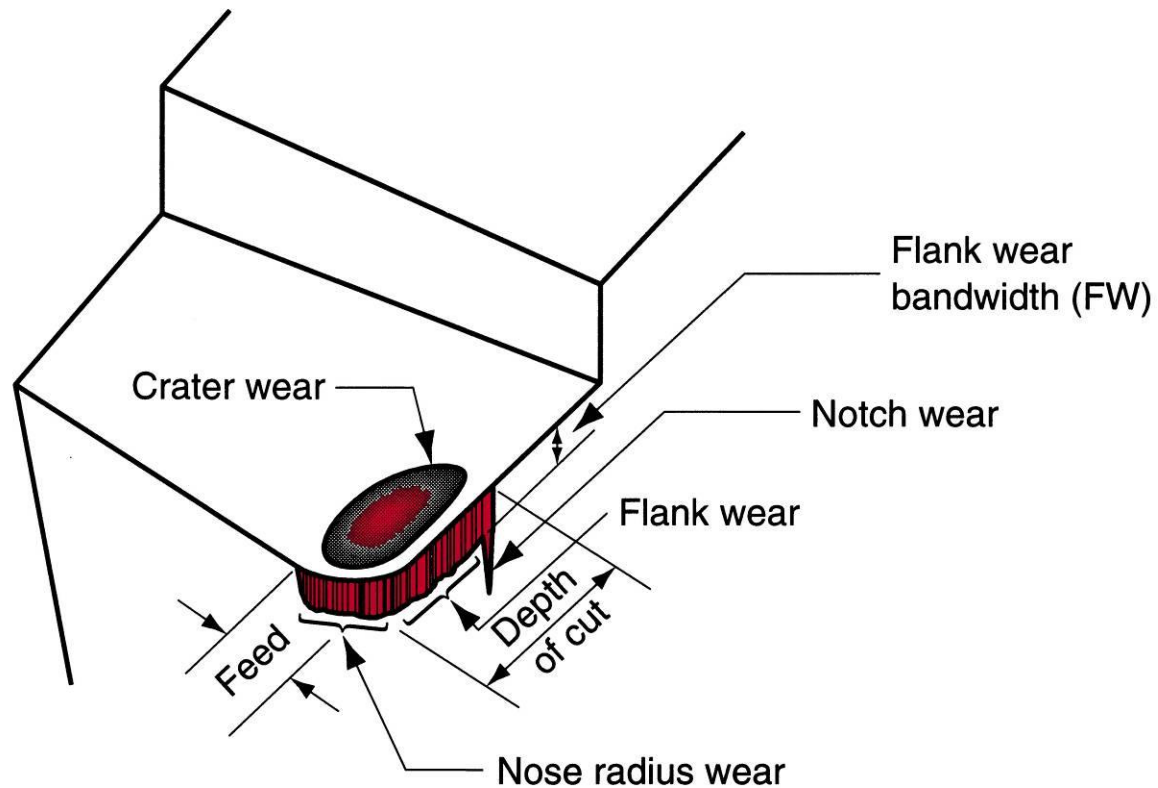


Figure 23.1 Diagram of worn cutting tool, showing the principal locations and types of wear that occur.

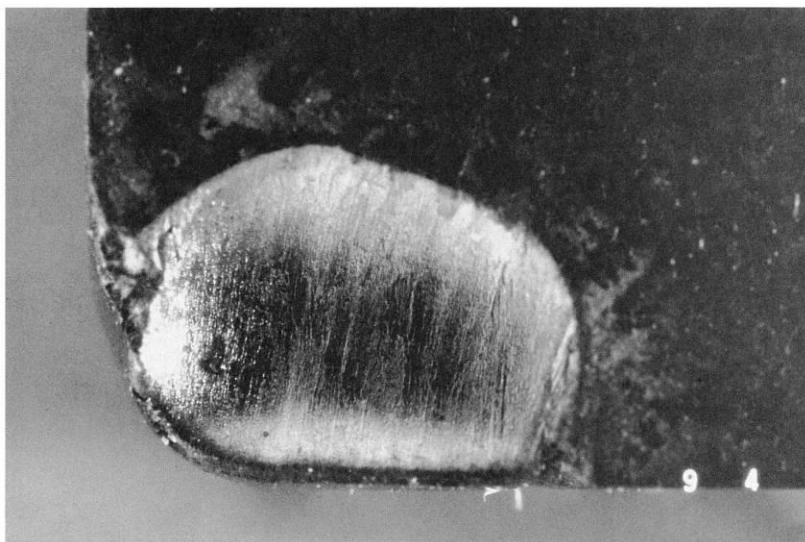
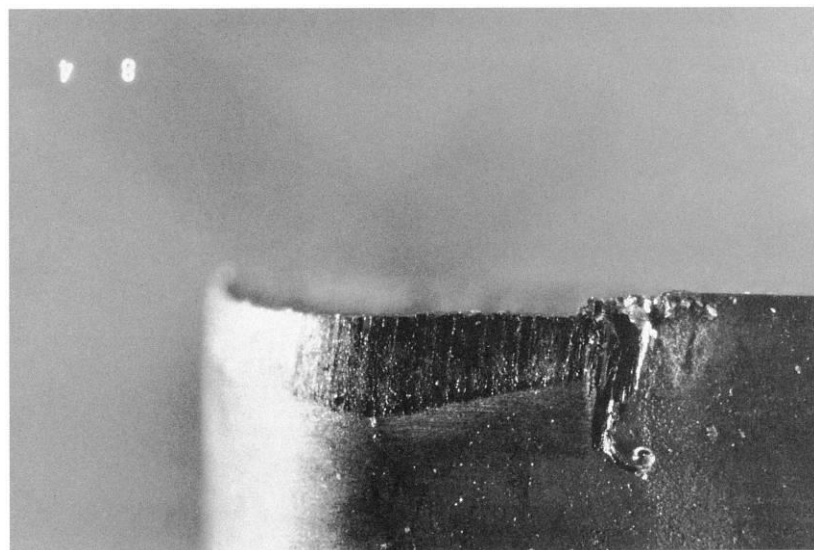


Figure 23.2 Crater wear, (above), and flank wear (right) on a cemented carbide tool, as seen through a toolmaker's microscope (photos by K. C. Keefe, Manufacturing Technology Lab, Lehigh University).



# Tool Wear vs. Time

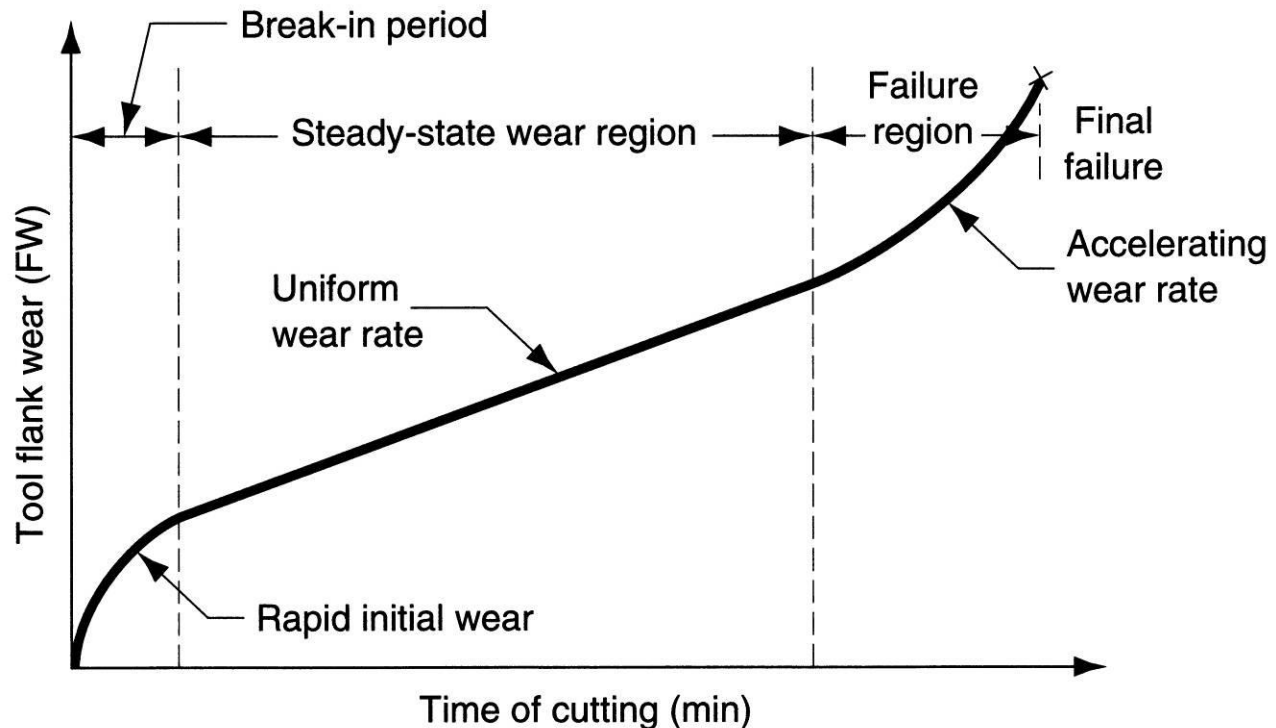


Figure 23.3 Tool wear as a function of cutting time. Flank wear (FW) is used here as the measure of tool wear. Crater wear follows a similar growth curve.

# Effect of Cutting Speed

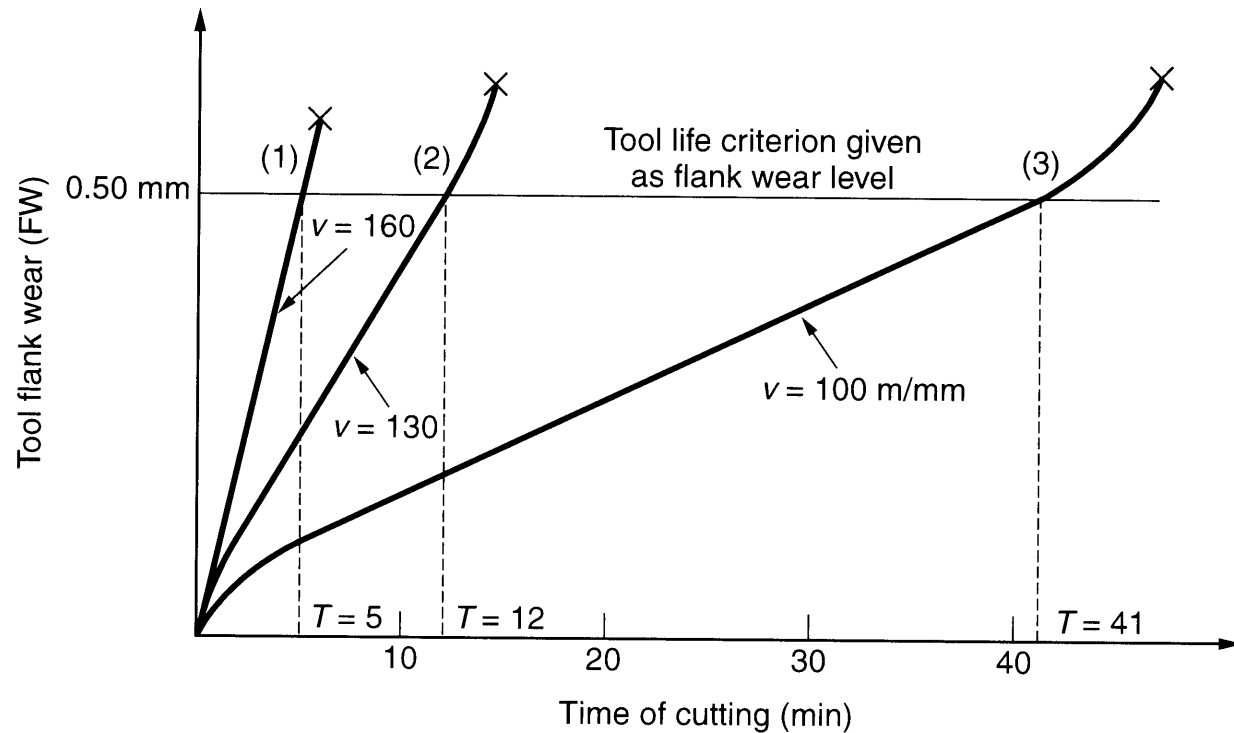


Figure 23.4 Effect of cutting speed on tool flank wear (FW) for three cutting speeds, using a tool life criterion of 0.50 mm flank wear.



# Tool Life vs. Cutting Speed

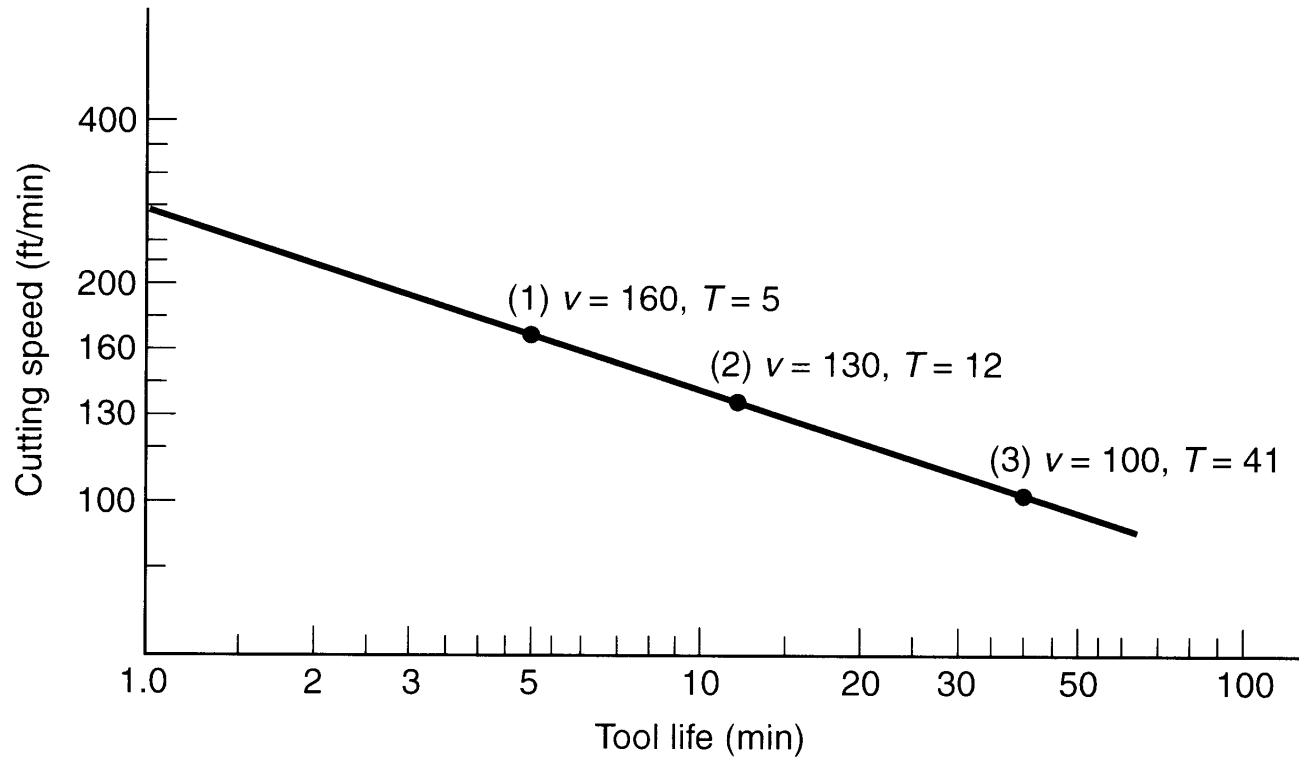


Figure 23.5 Natural log-log plot of cutting speed vs tool life.



# Taylor Tool Life Equation

---

Relationship is credited to F. W. Taylor

$$vT^n = C$$

where  $v$  = cutting speed;  $T$  = tool life; and  $n$  and  $C$  are parameters that depend on feed, depth of cut, work material, tooling material, and the tool life criterion used

- $n$  is the slope of the plot
- $C$  is the intercept on the speed axis at one minute tool life



# Tool Life Criteria in Production

---

1. Complete failure of cutting edge
2. Visual inspection of flank wear (or crater wear) by the machine operator
3. Fingernail test across cutting edge
4. Changes in sound emitted from operation
5. Chips become ribbon-like, stringy, and difficult to dispose of
6. Degradation of surface finish
7. Increased power
8. Workpiece count
9. Cumulative cutting time



# Tool Materials

---

- Tool failure modes identify the important properties that a tool material should possess:
  - Toughness - to avoid fracture failure
  - Hot hardness - ability to retain hardness at high temperatures
  - Wear resistance - hardness is the most important property to resist abrasive wear

# Hot Hardness

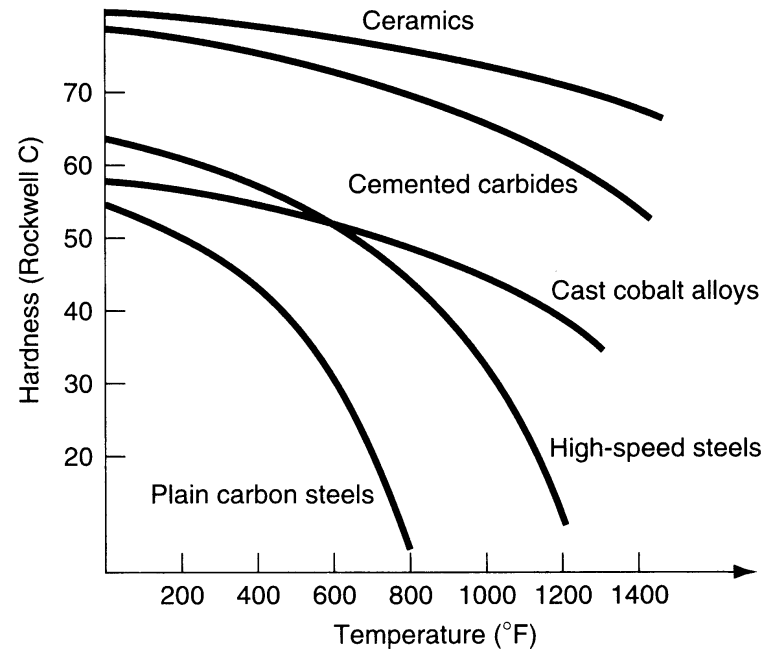


Figure 23.6 Typical hot hardness relationships for selected tool materials. Plain carbon steel shows a rapid loss of hardness as temperature increases. High speed steel is substantially better, while cemented carbides and ceramics are significantly harder at elevated temperatures.



# Typical Values of $n$ and $C$

---

<u>Tool material</u>	<u><math>n</math></u>	<u><math>C</math> (m/min)</u>	<u><math>C</math> (ft/min)</u>
High speed steel:			
Non-steel work	0.125	120	350
Steel work	0.125	70	200
Cemented carbide			
Non-steel work	0.25	900	2700
Steel work	0.25	500	1500
Ceramic			
Steel work	0.6	3000	10,000



# High Speed Steel (HSS)

---

Highly alloyed tool steel capable of maintaining hardness at elevated temperatures better than high carbon and low alloy steels

- One of the most important cutting tool materials
- Especially suited to applications involving complicated tool geometries, such as drills, taps, milling cutters, and broaches
- Two basic types (AISI)
  1. Tungsten-type, designated T- grades
  2. Molybdenum-type, designated M-grades



# High Speed Steel Composition

---

- Typical alloying ingredients:
  - Tungsten and/or Molybdenum
  - Chromium and Vanadium
  - Carbon, of course
  - Cobalt in some grades
- Typical composition (Grade T1):
  - 18% W, 4% Cr, 1% V, and 0.9% C





# Cemented Carbides

---

Class of hard tool material based on tungsten carbide (WC) using powder metallurgy techniques with cobalt (Co) as the binder

- Two basic types:
  1. Non-steel cutting grades - only WC-Co
  2. Steel cutting grades - TiC and TaC added to WC-Co



# Cemented Carbides – General Properties

---

- High compressive strength but low-to-moderate tensile strength
- High hardness (90 to 95 HRA)
- Good hot hardness
- Good wear resistance
- High thermal conductivity
- High elastic modulus -  $600 \times 10^3$  MPa ( $90 \times 10^6$  lb/in<sup>2</sup>)
- Toughness lower than high speed steel



# Non-steel Cutting Carbide Grades

---

- Used for nonferrous metals and gray cast iron
- Properties determined by grain size and cobalt content
  - As grain size increases, hardness and hot hardness decrease, but toughness increases
  - As cobalt content increases, toughness improves at the expense of hardness and wear resistance



# Steel Cutting Carbide Grades

---

- Used for low carbon, stainless, and other alloy steels
- TiC and/or TaC are substituted for some of the WC
- Composition increases crater wear resistance for steel cutting
  - But adversely affects flank wear resistance for non-steel cutting applications



# Cermets

---

Combinations of TiC, TiN, and titanium carbonitride (TiCN), with nickel and/or molybdenum as binders.

- Some chemistries are more complex
- Applications: high speed finishing and semifinishing of steels, stainless steels, and cast irons
  - Higher speeds and lower feeds than steel-cutting carbide grades
  - Better finish achieved, often eliminating need for grinding



# Coated Carbides

---

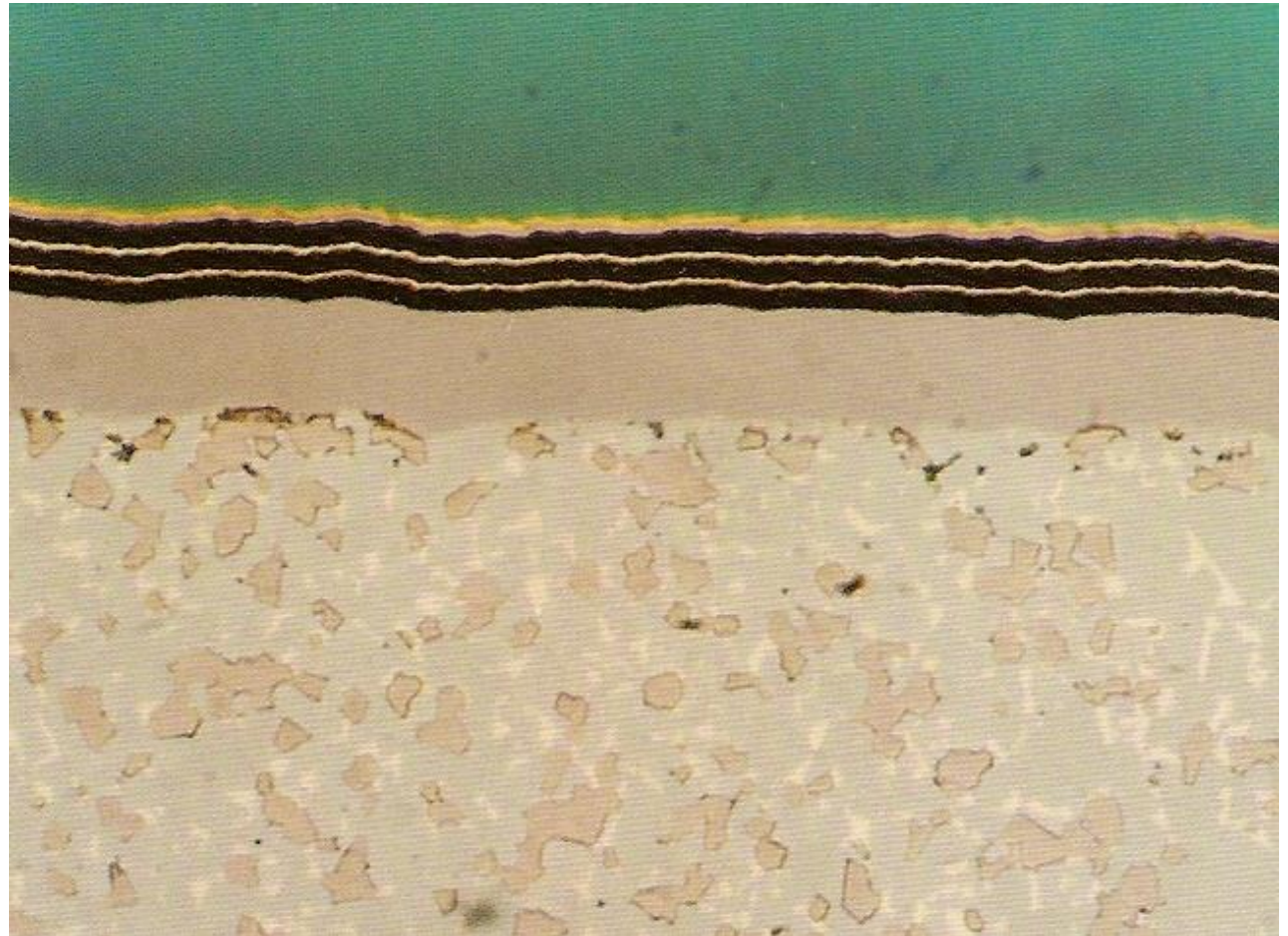
Cemented carbide insert coated with one or more thin layers of wear resistant materials, such as TiC, TiN, and/or  $\text{Al}_2\text{O}_3$

- Coating applied by chemical vapor deposition or physical vapor deposition
- Coating thickness = 2.5 - 13  $\mu\text{m}$  (0.0001 to 0.0005 in)
- Applications: cast irons and steels in turning and milling operations
- Best applied at high speeds where dynamic force and thermal shock are minimal

# Coated Carbide Tool



Photomicrograph  
of cross section of  
multiple coatings  
on cemented  
carbide tool (photo  
courtesy of  
Kennametal Inc.)





# Ceramics

---

Primarily fine-grained  $\text{Al}_2\text{O}_3$ , pressed and sintered at high pressures and temperatures into insert form with no binder

- Applications: high speed turning of cast iron and steel
- Not recommended for heavy interrupted cuts (e.g. rough milling) due to low toughness
- $\text{Al}_2\text{O}_3$  also widely used as an abrasive in grinding





# Synthetic Diamonds

---

Sintered polycrystalline diamond (SPD) - fabricated by sintering very fine-grained diamond crystals under high temperatures and pressures into desired shape with little or no binder

- Usually applied as coating (0.5 mm thick) on WC-Co insert
- Applications: high speed machining of nonferrous metals and abrasive nonmetals such as fiberglass, graphite, and wood
  - Not for steel cutting



# Cubic Boron Nitride

---

- Next to diamond, cubic boron nitride (cBN) is hardest material known
- Fabrication into cutting tool inserts same as SPD: coatings on WC-Co inserts
- Applications: machining steel and nickel-based alloys
- SPD and cBN tools are expensive



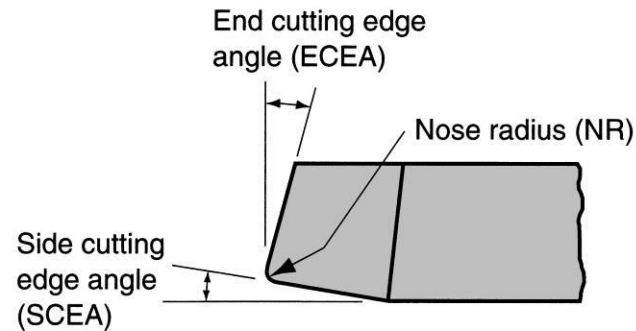
# Tool Geometry

---

Two categories:

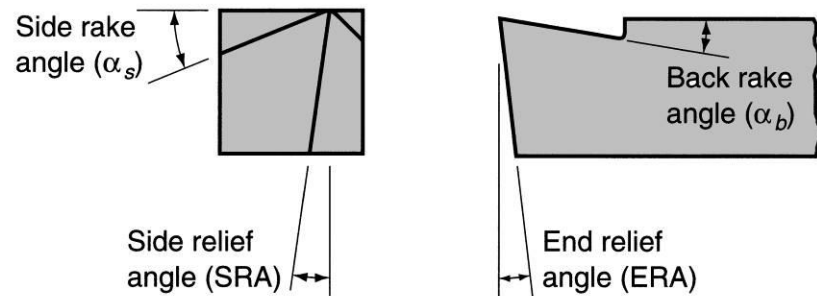
- Single point tools
  - Used for turning, boring, shaping, and planing
- Multiple cutting edge tools
  - Used for drilling, reaming, tapping, milling, broaching, and sawing

# Single-Point Tool Geometry



(a)

Figure 23.7 (a) Seven elements of single-point tool geometry; and (b) the tool signature convention that defines the seven elements.



(b) Tool signature:  $\alpha_b$ ,  $\alpha_s$ , ERA, SRA, ECEA, SCEA, NR

# Holding the Tool

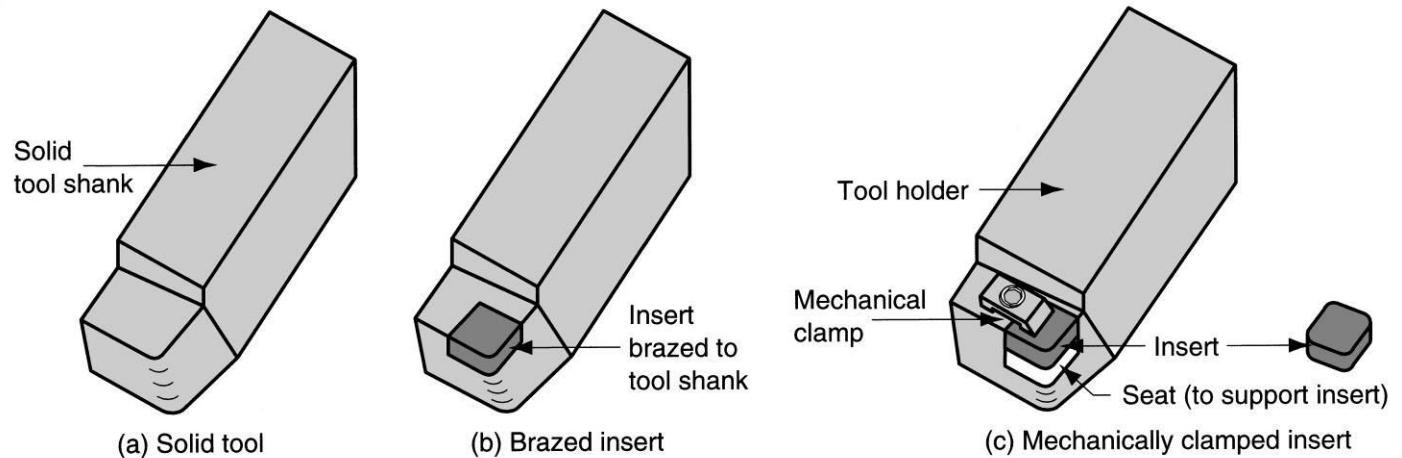


Figure 23.9 Three ways of holding and presenting the cutting edge for a single-point tool: (a) solid tool, typical of HSS; (b) brazed insert, one way of holding a cemented carbide insert; and (c) mechanically clamped insert, used for cemented carbides, ceramics, and other very hard tool materials.

# Common Insert Shapes

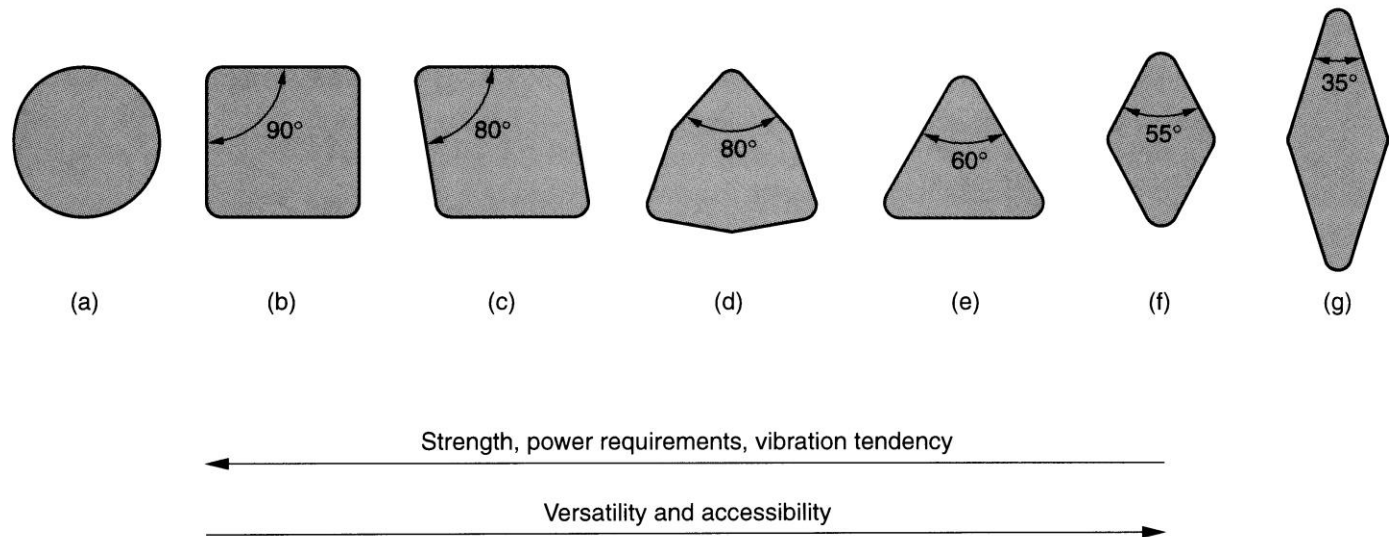


Figure 23.10 Common insert shapes: (a) round, (b) square, (c) rhombus with two  $80^\circ$  point angles, (d) hexagon with three  $80^\circ$  point angles, (e) triangle (equilateral), (f) rhombus with two  $55^\circ$  point angles, (g) rhombus with two  $35^\circ$  point angles. Also shown are typical features of the geometry.



A collection of metal cutting inserts made of various materials (photo courtesy of Kennametal Inc.).





# Twist Drills

- By far the most common cutting tools for hole-making
- Usually made of high speed steel

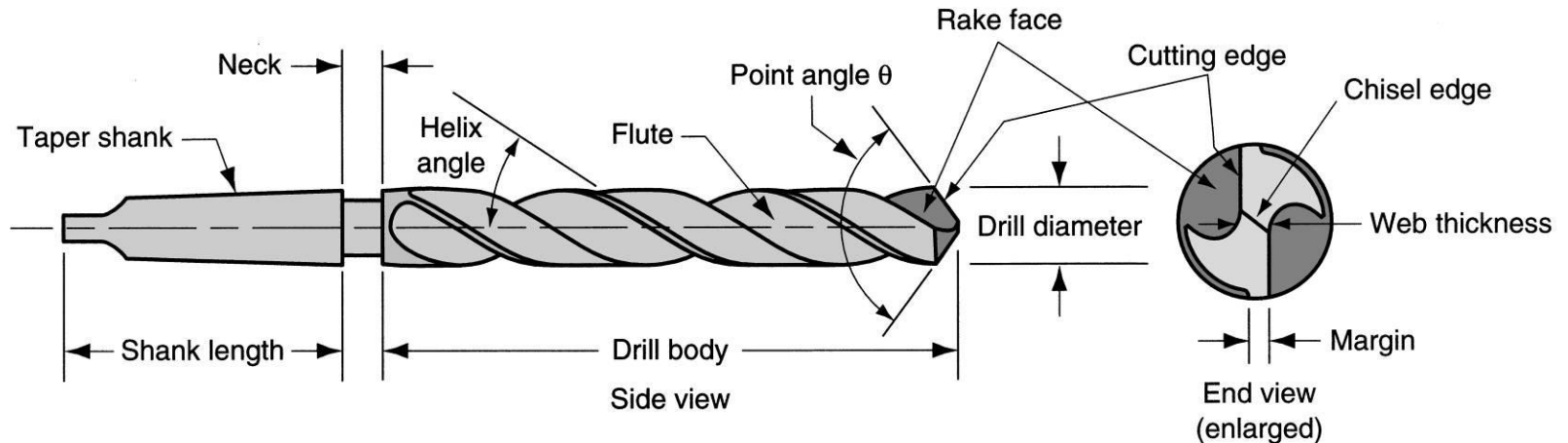


Figure 23.12 Standard geometry of a twist drill.





# Twist Drill Operation

---

- Rotation and feeding of drill bit result in relative motion between cutting edges and workpiece to form the chips
  - Cutting speed varies along cutting edges as a function of distance from axis of rotation
  - Relative velocity at drill point is zero, so no cutting takes place
  - A large thrust force is required to drive the drill forward into hole



# Twist Drill Operation - Problems

---

- Chip removal
  - Flutes must provide sufficient clearance to allow chips to be extracted from bottom of hole during the cutting operation
- Friction makes matters worse
  - Rubbing between outside diameter of drill bit and newly formed hole
  - Delivery of cutting fluid to drill point to reduce friction and heat is difficult because chips are flowing in opposite direction



# Milling Cutters

---

- Principal types:
  - Plain milling cutter
  - Face milling cutter
  - End milling cutter

# Plain Milling Cutter

- Used for peripheral or slab milling

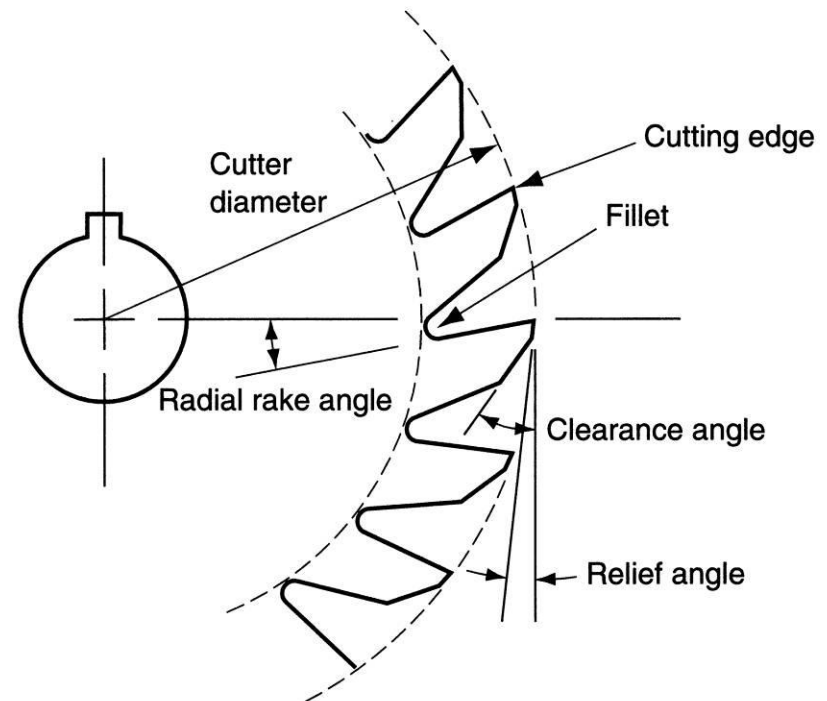


Figure 23.13 Tool geometry elements of an 18-tooth plain milling cutter

# Face Milling Cutter

- Teeth cut on side and periphery of the cutter

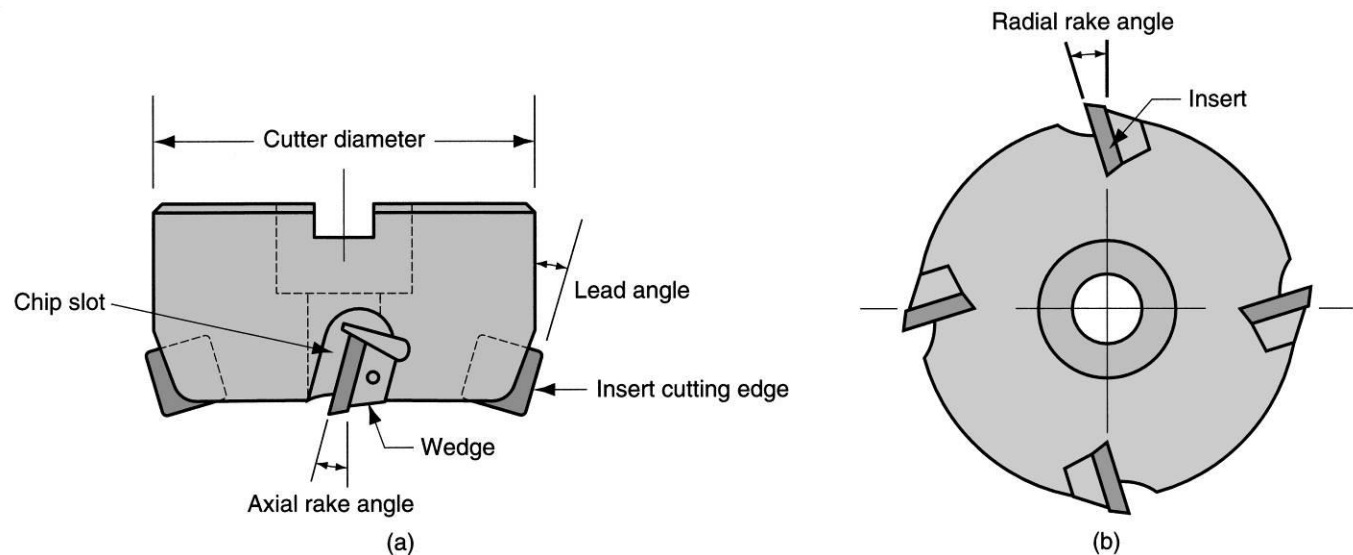


Figure 23.14 Tool geometry elements of a four-tooth face milling cutter: (a) side view and (b) bottom view.



# End Milling Cutter

---

- Looks like a drill bit but designed for primary cutting with its peripheral teeth
- Applications:
  - Face milling
  - Profile milling and pocketing
  - Cutting slots
  - Engraving
  - Surface contouring
  - Die sinking



# Cutting Fluids

---

Any liquid or gas applied directly to machining operation to improve cutting performance

- Two main problems addressed by cutting fluids:
  1. Heat generation at shear and friction zones
  2. Friction at tool-chip and tool-work interfaces
- Other functions and benefits:
  - Wash away chips (e.g., grinding and milling)
  - Reduce temperature of workpart for easier handling
  - Improve dimensional stability of workpart



# Cutting Fluid Functions

---

Cutting fluids can be classified according to function:

- Coolants - designed to reduce effects of heat in machining
- Lubricants - designed to reduce tool-chip and tool-work friction





# Coolants

---

- Water used as base in coolant-type cutting fluids
- Most effective at high cutting speeds where heat generation and high temperatures are problems
- Most effective on tool materials that are most susceptible to temperature failures (e.g., HSS)



# Lubricants

---

- Usually oil-based fluids
- Most effective at lower cutting speeds
- Also reduce temperature in the operation



# Cutting Fluid Contamination

---

- Tramp oil (machine oil, hydraulic fluid, etc.)
- Garbage (cigarette butts, food, etc.)
- Small chips
- Molds, fungi, and bacteria



# Dealing with Cutting Fluid Contamination

---

- Replace cutting fluid at regular and frequent intervals
- Use filtration system to continuously or periodically clean the fluid
- Dry machining



# Cutting Fluid Filtration

---

## Advantages:

- Prolong cutting fluid life between changes
- Reduce fluid disposal cost
- Cleaner fluids reduce health hazards
- Lower machine tool maintenance
- Longer tool life



# Dry Machining

---

- No cutting fluid is used
- Avoids problems of cutting fluid contamination, disposal, and filtration
- Problems with dry machining:
  - Overheating of tool
  - Operating at lower cutting speeds and production rates to prolong tool life
  - Absence of chip removal benefits of cutting fluids in grinding and milling