# CUTTING TOOL TECHNOLOGY

1. Tool life
2. Tool Materials
3. Tool Geometry
4. Cutting fluids

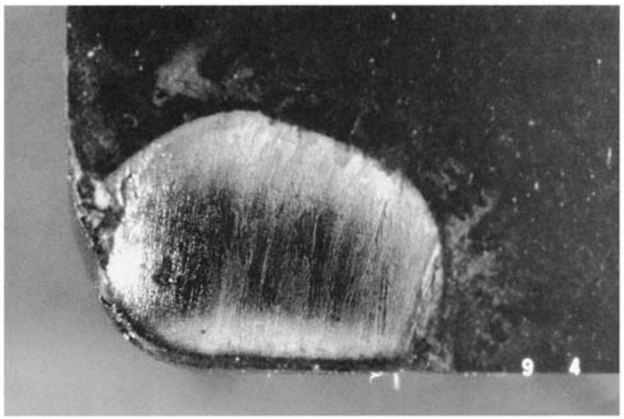
# Introduction

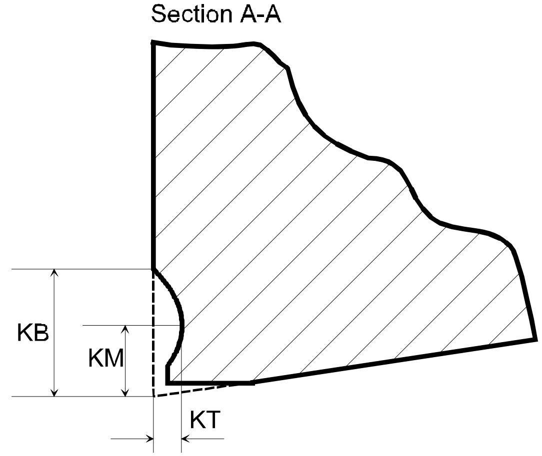
- Machining is accomplished by cutting tools.
- Cutting tools undergo high force and temperature and temperature gradient.
- Tool life
- Two aspects of design
  - Tool Materials
  - Tool Geometry
- Cutting fluids

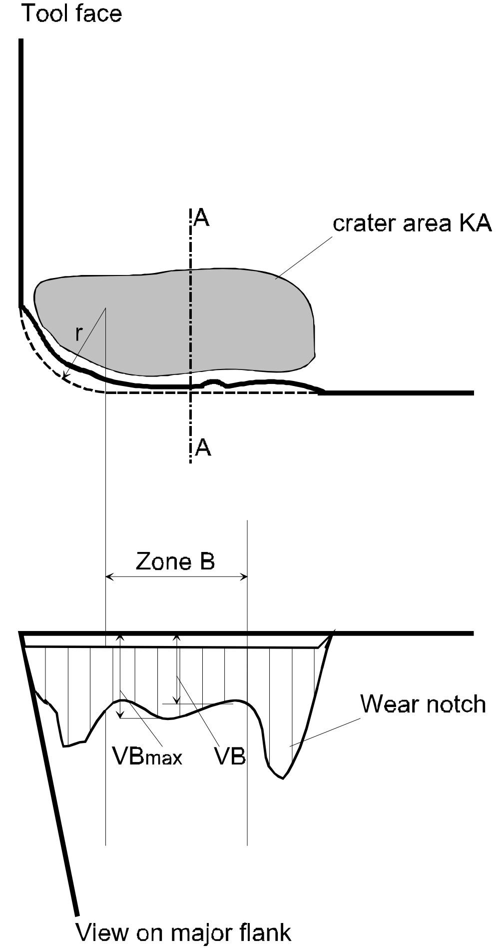
# 1. Tool life

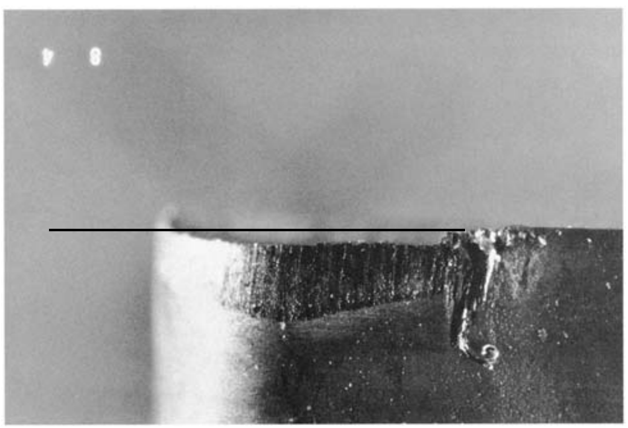
- Three modes of failure
  - Premature Failure
    - Fracture failure - Cutting force becomes excessive and/or dynamic, leading to brittle fracture
    - Thermal failure - Cutting temperature is too high for the tool material
  - Gradual Wear
    - Gradual failure
- Tool wear: Gradual failure
  - **Flank wear -** flank (side of tool)
  - **Crater wear -** top rake face
  - **Notch wear**
  - **Nose radius wear**

# Crater and Flank Wear





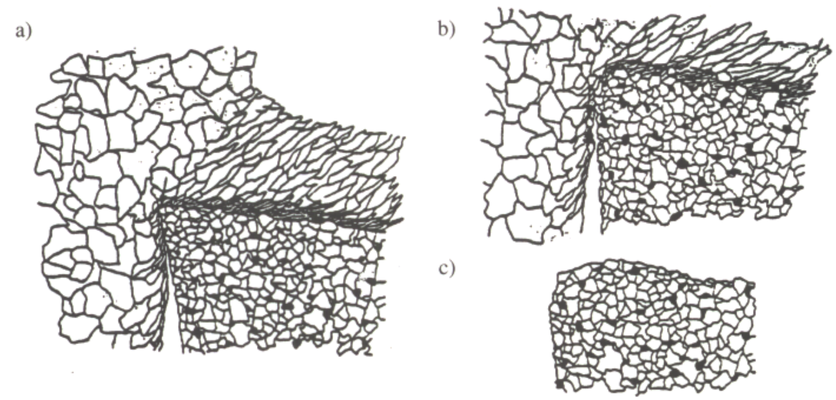



**ISO Standard 3685-1977 (E)**

KB= crater width
KM=crater centre distance
KT=crater depth
KA=crater area (self defined)
VB=average wear-land width
$VB_{max}$=maximum wear-land width
r=radius of cutting edge

# Possible Wear Mechanisms

- **Abrasion** – Flank and Crater wear
  - Hard Inclusions abrading Cutting tools
  - Hot Hardness Ratio
- Erosion
- Attrition
- Adhesion
  - Compatibility chart

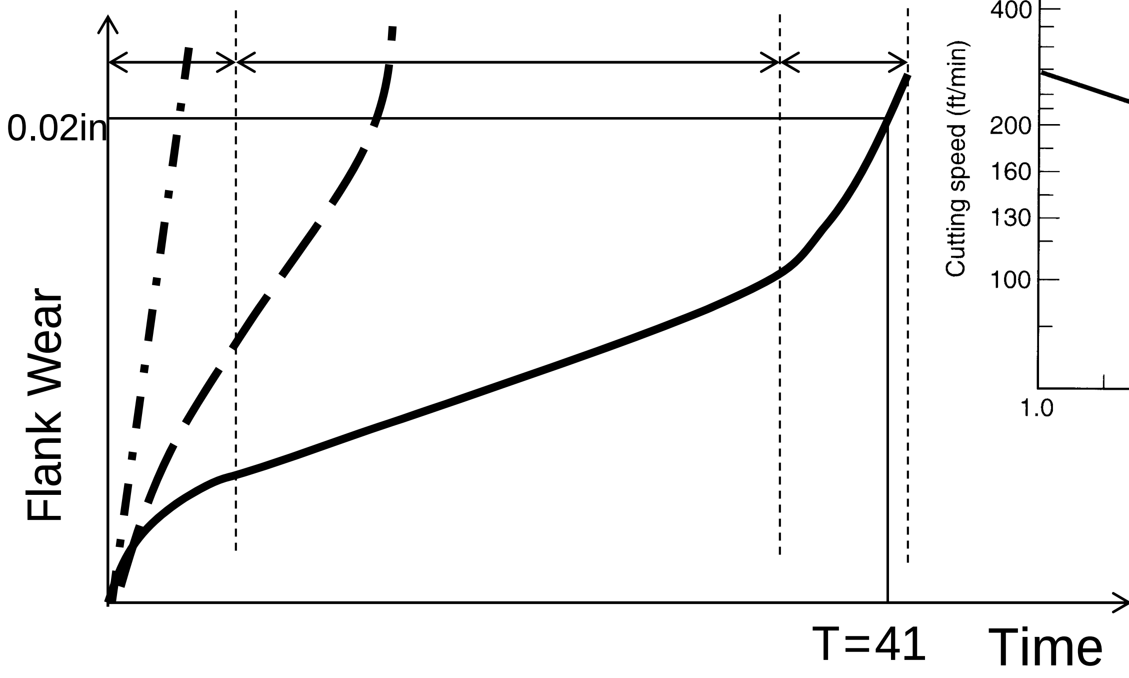


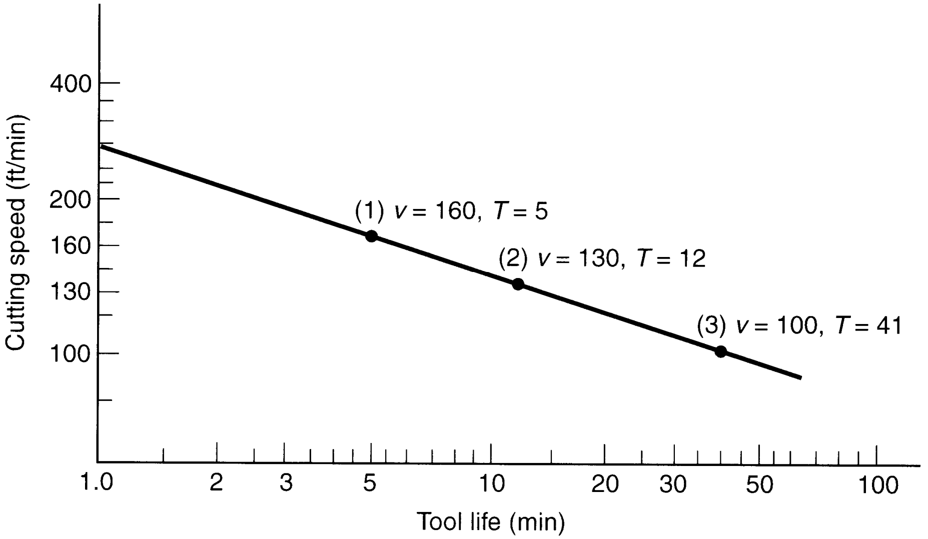
Attrition Wear (from Tlusty, 2000)

- **Diffusion/Dissolution** – Crater wear
  - Chemical solubility
  - Diamond dissolves into iron.
  - Oxide coating resists crater wear.
- Plastic deformation

# Tool life

- Tool life – the length of cutting time that the tool can be used
  - Break-in period
  - Steady-state wear region
  - Failure region



# Taylor's Equation

- F. W. Taylor [1900]'s Equation $vT^n = C$
- Generalized Taylor's Equation $vT^n f^m d^p = C$
  - where $v$ = cutting speed; $T$ = tool life; and $n$ and $C$ depend on feed, depth of cut, work material and, tooling material
    - $n$ is the slope of the plot
    - $C$ is the intercept on the speed axis

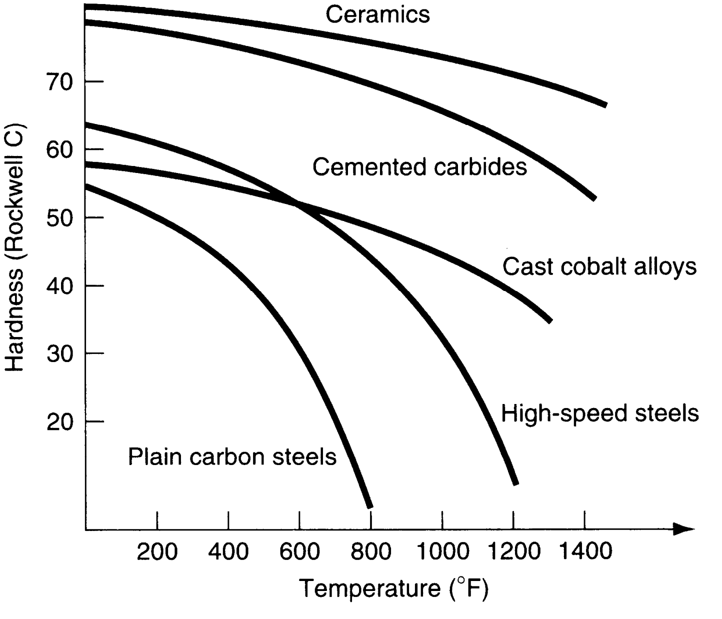
| **Tool material** | **n** | **C (m/min)** | **C (ft/min)** |
|---|---|---|---|
| High speed steel: | | | |
| Non-steel work | 0.125 | 120 | 350 |
| Steel work | 0.125 | 70 | 200 |
| Cemented carbide | | | |
| Non-steel work | 0.25 | 900 | 2700 |
| Steel work | 0.25 | 500 | 1500 |
| Ceramic | | | |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

# Tool Life Criteria in practice

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 ribbony, stringy, and difficult to dispose of
6. Degradation of surface finish
7. Increased power
8. Workpiece count
9. Cumulative cutting time

# 2. Tool Materials

- Important properties
  - Toughness – avoid fracture
  - Hot hardness – resist abrasion
  - Wear resistance - solubility
- Cutting tool materials
  - Plain carbon and low alloy steels
  - High-speed steels
  - Cemented carbides, cermets and coated carbides
  - Ceramics
  - Synthetic diamond and CBN



# Tool Materials

- Plain Carbon and Low Alloy Steels
  - Before High Speed Steels
  - Due to a high carbon content, heat treated to $R_c$=60
  - Poor hot hardness
- High-speed steels (HSSs)
  - tungsten type (T-grade)– 12-20% of W
  - molybdenum type (M-grade)- 6% W and 5% Mo
  - Other elements: Tungsten and/or Molybdenum, Chromium and Vanadium, Carbon, Cobalt in some grades
  - Typical composition: Grade T1: 18% W, 4% Cr, 1% V, and 0.9% C

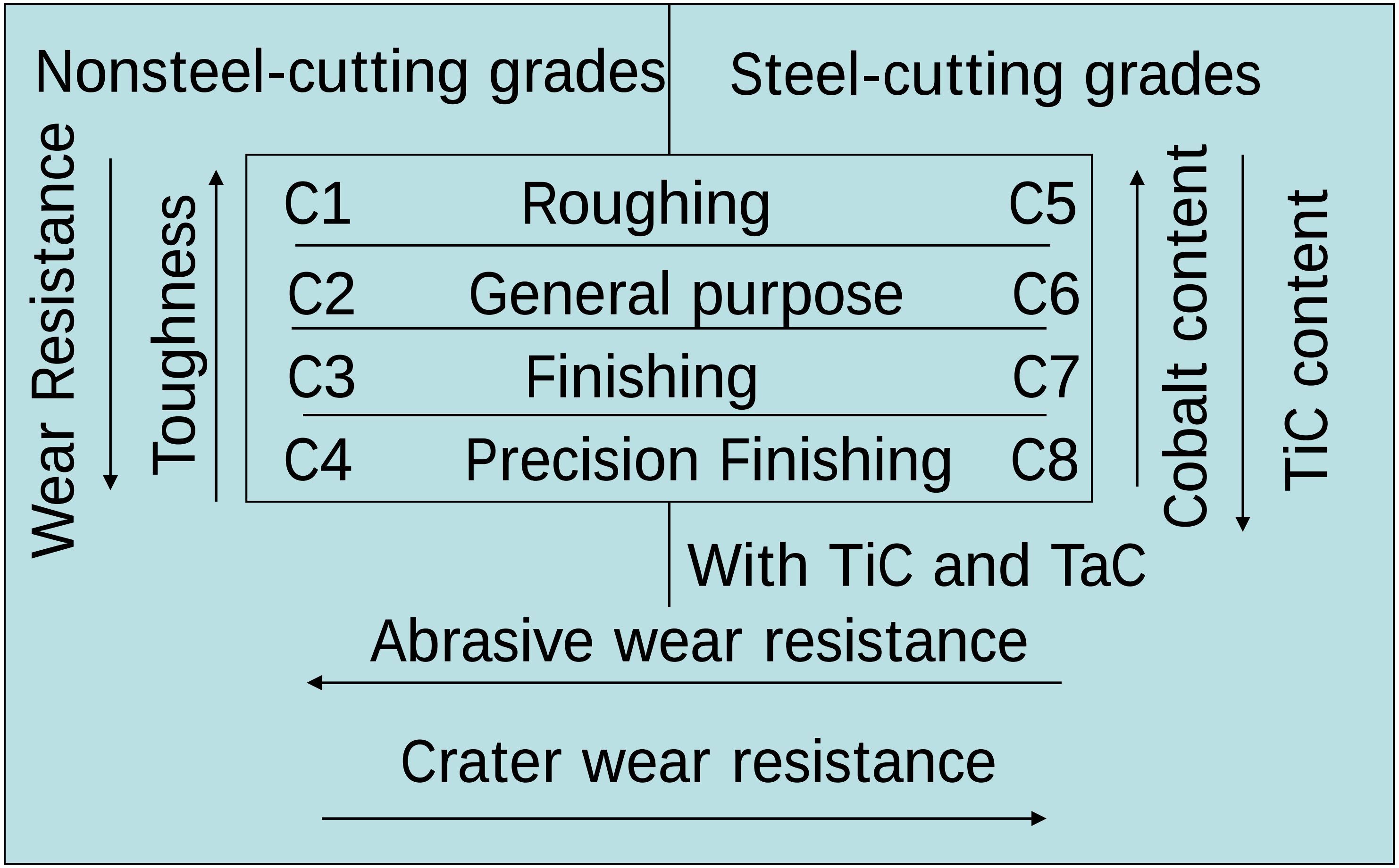
# Tool Materials

- HSSs
  - Still used extensively for complex geometry such as drills
  - Heat treated to $R_c$=65
  - Re-grinded for reuse
  - Thin coating
- Cast Cobalt Alloys
  - 40-50% Co, 25-35% W, 15-20% others
  - Casting in a graphite mold and grind
  - Toughness is not as good as HSS but hot hardness is better.
  - Not so important

# Cemented Carbides

- Advantages (Cemented Carbide, Cermets & Coated Carbides)
  - High compressive strength and modulus
  - High room and hot hardness
  - Good wear resistance
  - High thermal conductivity
  - Lower in toughness that HSSs
- Grades
  - Nonsteels grade – WC-Co
  - Steel grades – add TiC and TaC due to the high solubility of WC into steels resulting in extensive crater wear
- Cemented Carbides – Mainly WC-Co
  - As grain size is increased, hardness decreases but TRS increases.
  - As the content of cobalt increase, TRS increases but hardness decreases.
  - For roughing or milling, high cobalt is desirable
  - For finishing, low cobalt is desirable.

# Classification of C-grade carbides



# Cermets

- Cermets – TiC, TiN and TiCN with Ni or Mo as binders
  - Applications: High speed finishing and semifinishing of steels, stainless steels and cast iron
  - Higher speeds than carbides
  - For better finish, low feed

# Coated carbides

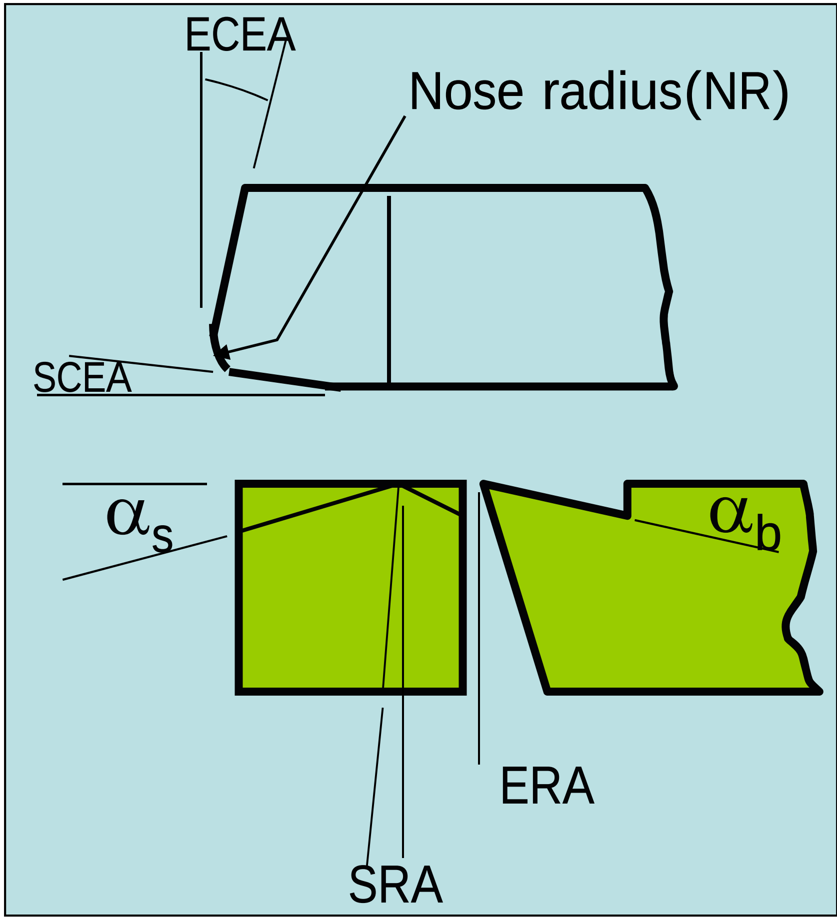
- Since 1970, they improve machinability.
- One or more layer of **thin** layers of wear resistance CVD or PVD coating such as TiC, TiN, $Al_2O_3$, ZrN, CrC or Diamond.
- Coating thickness = 2.5 - 13 μm (0.0001 to 0.0005 in)
- Applications: cast irons and steels in turning and milling operations
- Best applied at high speeds where dynamic force and thermal shock are minimal

# Ceramics, Synthetic diamond and CBN

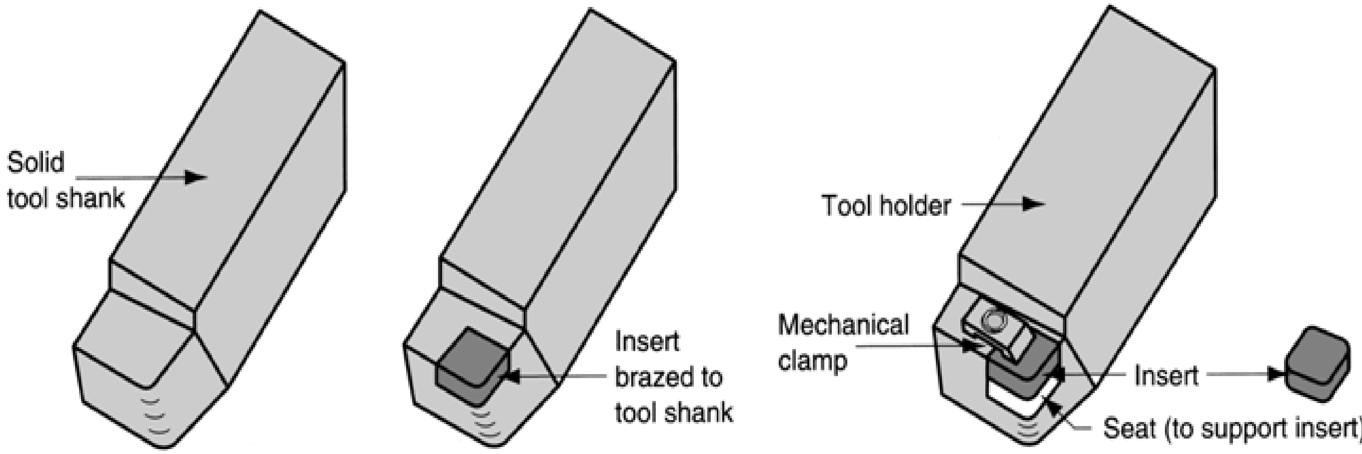
- Ceramics
  - Fine alumina powder is pressed and sintered at High pressure and temperature.
  - Other oxide such $ZrO_2$ are added.
  - Used in finishing of harden steels, high v, low d and f and rigid work setup.
  - Not for heavy interrupted cutting
  - Other ceramic tools: $Si_3N_4$, sialon($Si_3N_4$-$Al_2O_3$), Alumina and TiC and SiC whiskers-reinforced alumina.
- Diamond – the hardest material.
  - Usually applied as coating (0.5 mm thick) on WC-Co insert
  - Sintered polycrystalline diamond
  - Applications: high speed cutting of nonferrous metals
- Cubic Boron Nitrides (CBN)
  - For steels and Nickel alloys
  - Expensive

# 3. Tool Geometry

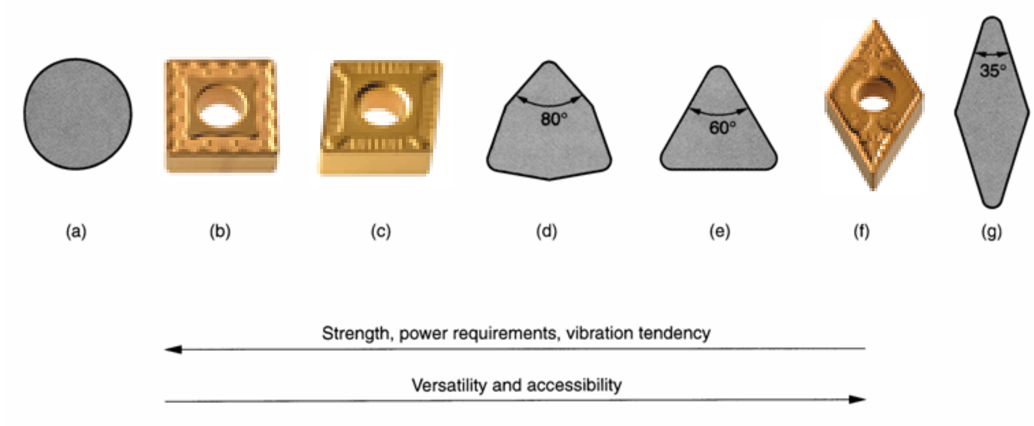
- Single-point Tool geometry
  - Back rake angle ($\alpha_b$)
  - Side rake angle ($\alpha_s$)
  - End relief angle (ERA)
  - Side relief angle (SRA)
  - Side cutting edge angle (SCEA)
  - Nose radius (NR)
  - End cutting edge angle(ECEA)



# Cutting edge for a single-point tool



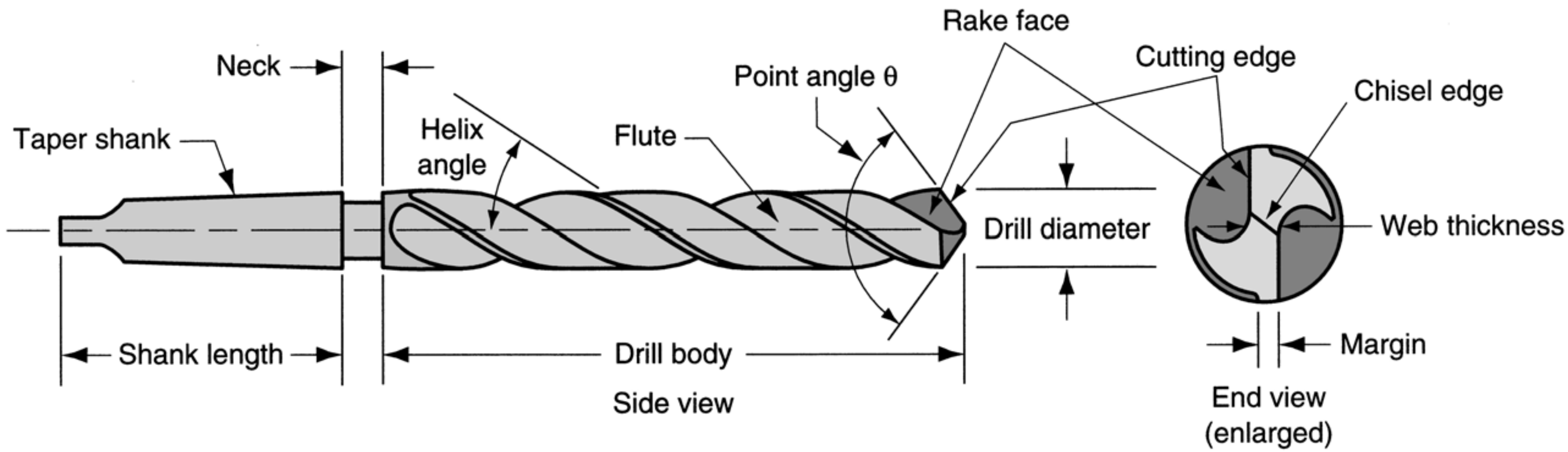

(a) Solid tool (b) Brazed insert (c) Mechanically clamped insert



# Tool geometry

- Chip Breakers
  - For single-point tools, chip breaker forces the chip to curl so that it fractures
  - Groove and obstruction types
- Effect of Tool Material
  - Positive rake angle -> reduce cutting force, temp. and power consumption
  - HSS: +5°< rake angle<+20°
  - Carbides: -5°< rake angle <+10°
  - Ceramics: -5°< rake angle <-15°
  - The cutting edge: solid, brazed insert and clamped insert.

# Twist Drills



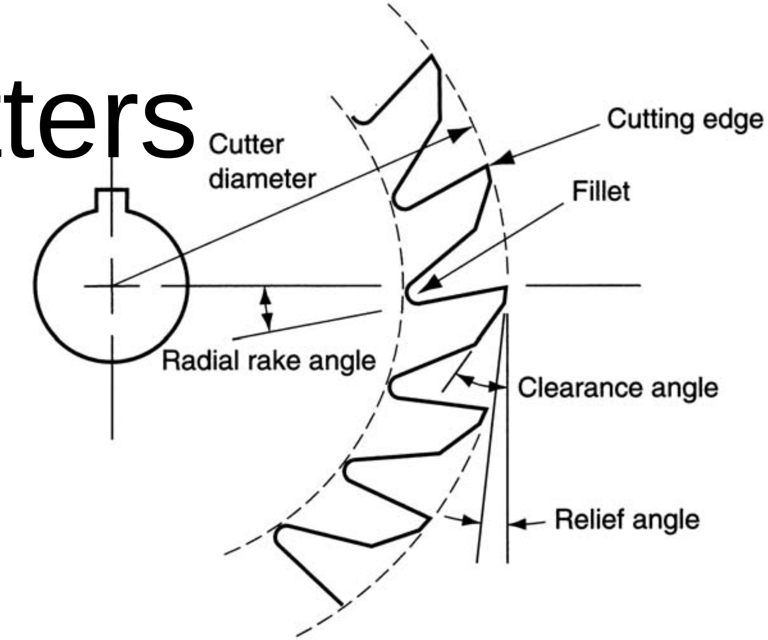

The most common cutting tools for hole-making
Usually made of high speed steel

# Twist Drill Operation

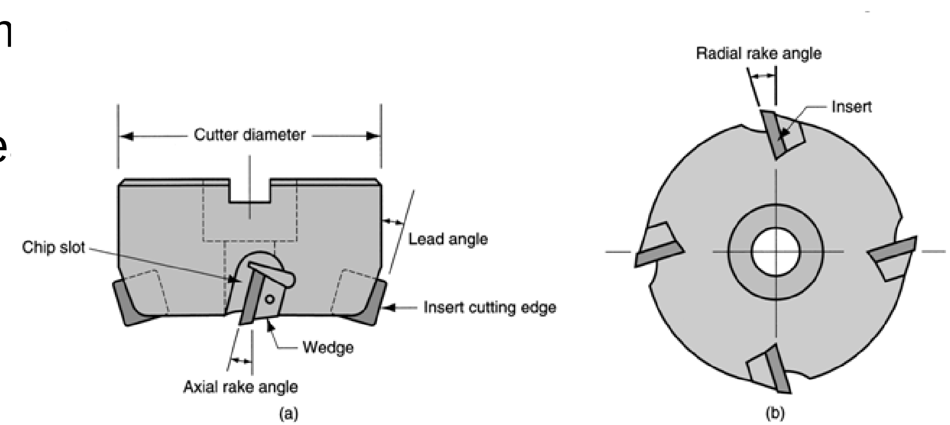
- Rotation and feeding result in relative motion between cutting edges and workpiece
  - Cutting speed varies along cutting edges as a function of distance from axis of rotation
  - Zero Relative velocity at drill point (no cutting)
  - A large thrust force to drive the drill forward
- Chip removal
  - Flutes allow chips to be extracted
- Friction makes matters worse
  - Rubbing between outside diameter and wall
  - Delivery of cutting fluid to drill point

# Milling Cutters

- Principal types:
  - Plain milling cutter – Peripheral or slab milling (can be Helical)
  - Form milling cutter -Peripheral milling cutter in which cutting edges have special profile to be imparted to work
    - Important application - gear-making, in which the forn milling cutter is shaped to cut the slots between adjacent ge teeth
  - Face milling cutter
  - End milling cutter




18-teeth Plain Milling Cutter
Used for Peripheral or Slab Milling




Four-tooth Face Milling Cutter

# 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

# Milling Cutter

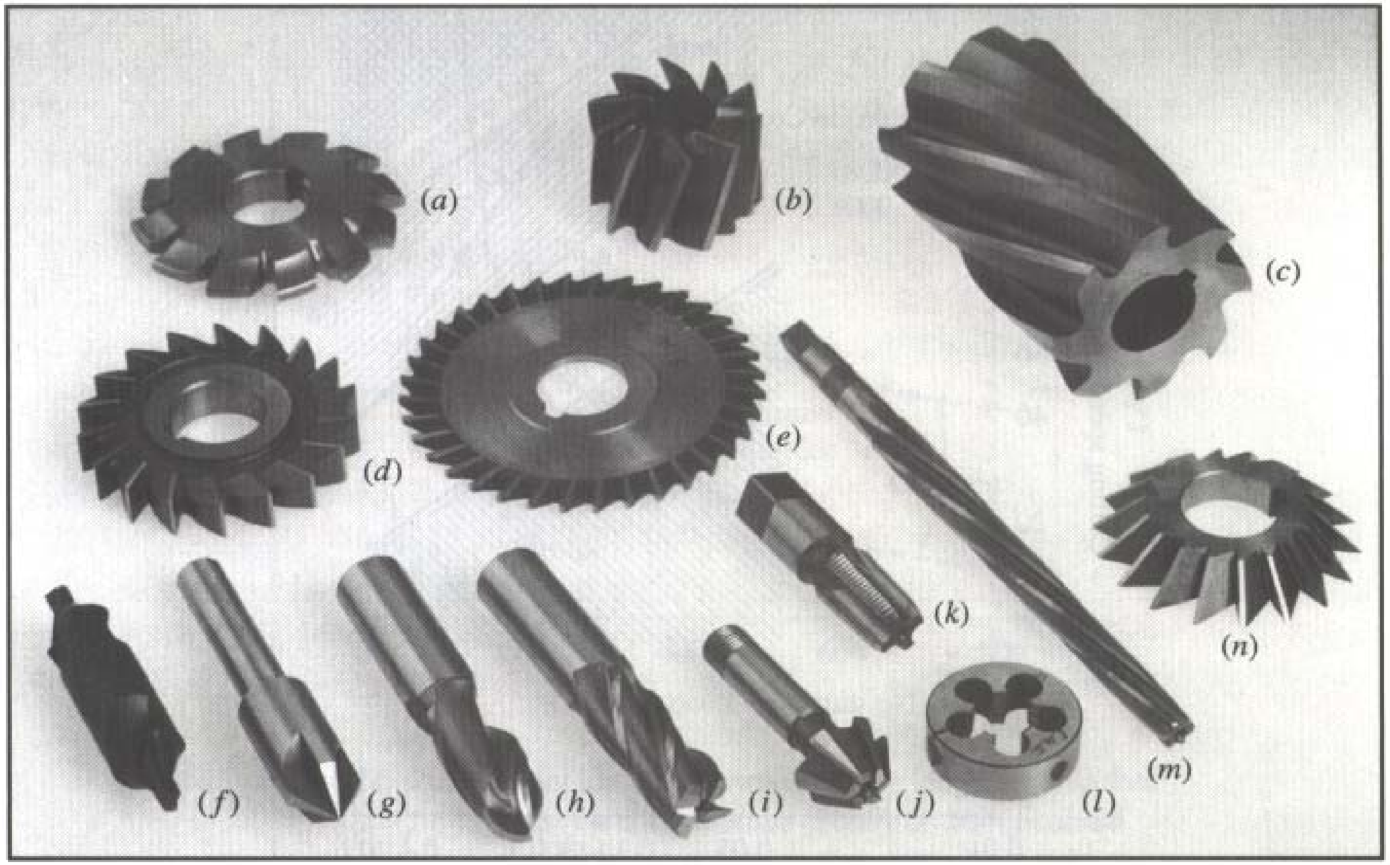
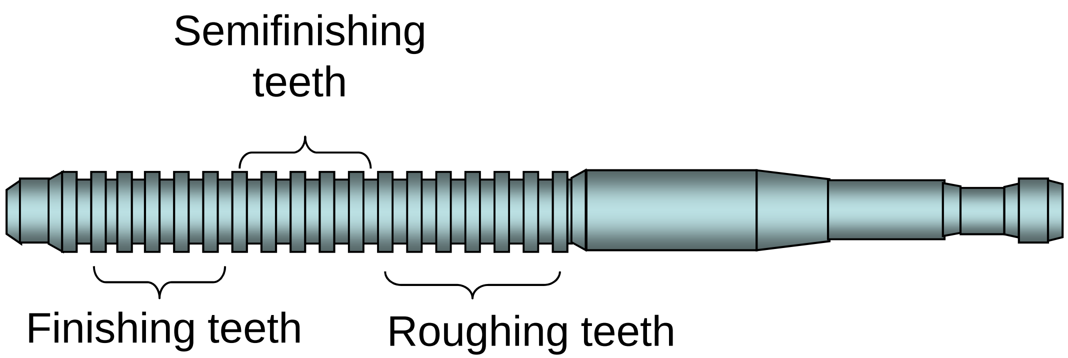
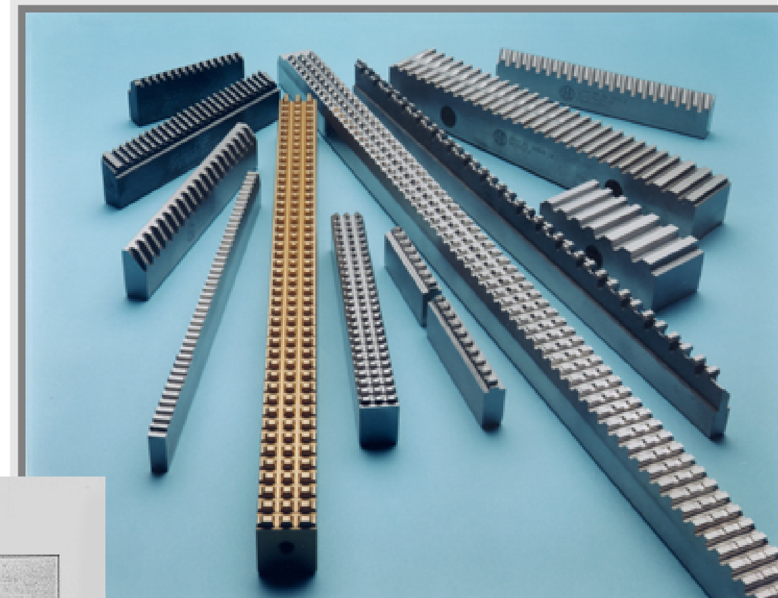



**Figure 16–18** Some high-speed steel (HSS) tools commonly encountered: (*a*) gear-tooth cutter, (*b*) shell-end mill, (*c*) slab mill, (*d*) side mill, (*e*) slotting mill, (*f*) combined drill and countersink, (*g*) countersink, (*h*) ball-end mill, (*i*) square-end mill, (*j*) single-angle cutter, (*k*) tap, (*l*) thread-cutting die, (*m*) reamer, and (*n*) angular cutter.

From Schey [2000]

# Broaches and Saw Blades



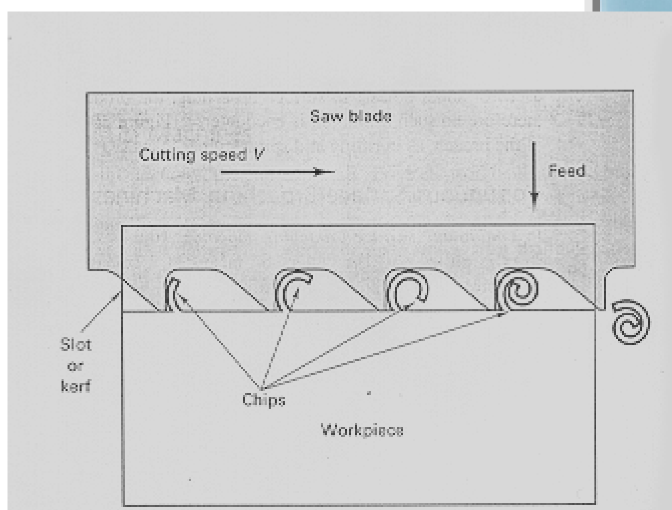


FIGURE 26-15 Formation of chips in sawing. *(Courtesy of DoALL Company.)*

Saw Blade (Straight & Undercut tooth or Straight & Raker sets)

# 4. Cutting fluids

- Reduces heat generation at shear zone and friction zone (**coolants**)
  - High specific heat and thermal conductivity (water-based coolants)
  - Effective at high cutting speeds
- Reduces friction between tool and chip (**lubricants**)
  - Effective at low cutting speeds
  - Oil-based lubricants
  - Low friction means low friction angle, which means shear angle decreases, which reduces heat.

# Cutting fluids

- Chemical formulation
  - Cutting oils
  - Emulsified oils
  - Chemical fluids
- Application Methods
  - Flooding
  - Mist
  - Manual
- Filtration
- Dry machining for Green Manufacturing