Mechanics of Machining Processes

IME 340/240
Types of Chips

- **Four Types:**
  - Continuous
  - Built-up edge
  - Serrated or Segmented
  - Discontinuous

- **Tool side of chip is shiny or burnished**

(a) continuous chip with narrow, straight primary shear zone; (b) secondary shear zone at the chip-tool interface; (c) continuous chip with large primary shear zone; (d) continuous chip with built-up edge; (e) segmented or nonhomogeneous chip and (f) discontinuous chip. *Source:* After M. C. Shaw, P. K. Wright, and S. Kalpakjian.
Continuous Chips

- Ductile materials, High cutting speeds, High rake angles
- Narrow (primary) shear zone
- Possible secondary shear zone at tool-chip interface (becomes thicker as friction increases)
- With soft metals and low speeds or rake angles, could have a wide primary shear zone with curved boundaries; leads to poor surface finish and residual surface stresses
- Continuous chips can cause problems by becoming entangled in the tool holder, fixturing, workpiece, or chip-disposal system
- Chip breakers can help this problem
Built-Up Edge (BUE) Chips

- Layers of workpiece material are gradually deposited on the tool
- BUE eventually breaks off and is carried away by the chip and/or deposited randomly on the workpiece surface
- Large tool tip radius with BUE
- Produces rough surface finishes
- Generally undesirable but a thin, stable BUE can reduce wear and protect the rake face
- Reduce probability of BUE forming by:
  - Decreasing depth of cut
  - Increasing rake angle
  - Using a sharp tool
  - Using an effective cutting fluid
  - Using cold-worked metals rather than annealed

(b) Surface finish in turning 5130 steel with a built-up edge. (c) Surface finish on 1018 steel in face milling. Magnifications: 15X. Source: Courtesy of Metcut Research Associates, Inc.
Hardness of Built-Up Edge (BUE) Chips

Figure 20.6 (a) Hardness distribution in the cutting zone for 3115 steel. Note that some regions in the built-up edge are as much as three times harder than the bulk metal. Source: Courtesy of Metcut Research Associates, Inc.
Serrated and Discontinuous Chips

- Serrated chips have a sawtooth-like appearance
  - Also called segmented or nonhomogeneous chips
  - Have zones of low and high shear strain
  - Metals with low thermal conductivity or strength that decreases with temperature (such as titanium)

- Discontinuous chips have firmly or loosely connected segments
  - Brittle materials cannot withstand the high shear strains of cutting (thermoset plastics or ceramics)
  - Workpiece materials with hard inclusions or impurities or structures such as graphite flakes in gray cast iron
  - Very low or very high cutting speeds
  - Large depths of cut or Low rake angles
  - Lack of an effective cutting fluid or low machine tool stiffness

- Both chip types cause variations in cutting forces, and thus require stiffness in the tool holder, work holder, and machine tool to avoid machine vibration and chatter (which causes surface finish, dimensional accuracy, and tool wear problems)
Cutting Parameters and 2-dimensional Model

- Depth of cut – measured in mm or inches
- Feed (rate) – distance tool travels per unit revolution (mm/rev, in/rev)
- Velocity, \( V \) – cutting tool velocity
- \( t_o \) – depth of cut (equiv. to feed in turning)
- \( t_c \) – chip thickness

\[ \alpha \] – rake angle
\[ \phi \] – shear angle
Orthogonal (2D) Cutting Model

- Cutting ratio, $r$ (usually $<1$)
- Chip compression ratio, $1/r$
- We can find shear angle, $\phi$, because $t_o$ is a machine setting, and $t_c$ and $\alpha$ rake angle can be measured with micrometers or calipers
- Shear angle affects force and power requirements, chip thickness, and temperature

$$r = \frac{t_o}{t_c} = \frac{\sin \phi}{\cos(\phi - \alpha)}$$
Shear Strain

\[
\text{Shear Strain} = \gamma = \frac{AB}{OC} = \frac{AO}{OC} + \frac{OB}{OC} = \cot \phi + \tan(\phi - \alpha)
\]

- Large shear strains due to low shear angles or rake angles that are low or negative
- Shearing occurs at a very high rate
Velocity

- Based on mass continuity:
  \[ Vt_o = V_c t_c \]

\[
V_c = V_r = \frac{V \sin \phi}{\cos(\phi - \alpha)}
\]

\[
\frac{V}{\cos(\phi - \alpha)} = \frac{V_s}{\cos \alpha} = \frac{V_c}{\sin \phi}
\]

\[ r = \frac{t_o}{t_c} = \frac{V_c}{V} \]
Cutting Forces and Power

- Machine tools with enough power must be selected.
- With known cutting forces, machine tools can be designed to avoid excessive distortion and maintain desired tolerances.
- Engineers can determine if the workpiece will withstand the cutting forces without distortion.
- The tool holder, workholding device, and machine tool must be sufficiently stiff to minimize deflections caused by the thrust force so that the tool is not pushed away from the workpiece (reducing depth of cut and causing dimensional inaccuracy).
- Cutting forces can be measured by mounting on the tool:
  - Dynamometers
  - Force transducers (piezoelectric crystals)
- Cutting forces can also be calculated if you know the power consumption of the machine.
- Duller tools require higher forces and power.
**Cutting Forces and Power**

Resultant force, $R$ decomposes into:

1. Cutting force, $F_c$ in the direction of $V$
2. Thrust force, $F_t$ normal to $V$
   (both of the above are measurable)

1. Friction force, $F$
2. Normal force, $N$

\[
F = R \sin \beta = F_c \sin \alpha + F_t \cos \alpha
\]

\[
N = R \cos \beta = F_c \cos \alpha - F_t \sin \alpha
\]

1. Shear force, $F_s$
2. Normal force, $F_n$

\[
F_s = F_c \cos \phi - F_t \sin \phi
\]

\[
F_n = F_c \sin \phi + F_t \cos \phi
\]

\[
\mu = \frac{F}{N} = \frac{F_t + F_c \tan \alpha}{F_c - F_t \tan \alpha}
\]

$\mu$ typically ranges from 0.5 to 2 in metal cutting
Power

- Power is dissipated in the shear zone and along the tool rake face

\[ \text{Power} = P = F_c V \]

- Specific energy for shearing

\[ \text{Shearing Power} = P_s = F_s V_s \]

\[ u_s = \frac{F_s V_s}{w t_o V} \]

- Specific energy for friction

\[ \text{Friction Power} = P_f = F V_c \]

\[ u_f = \frac{F V_c}{w t_o V} = \frac{F r}{w t_o} \]

Total specific energy

\[ u_t = u_s + u_f \]

Required motor power, where \( e_m \) is efficiency

\[ P_m \geq \frac{P}{e_m} \]
Analysis based on assumption that shear angle adjusts itself to minimize cutting energy.

- Friction angle, $\beta$
- Coefficient of friction, $\mu$
- Thus, as rake angle decreases or as friction along the tool chip interface (rake face) increases, the shear angle decreases and the chip becomes thicker.
- Thicker chips dissipate more energy because the shear strain is higher, thus the temperature rise is higher.

Friction

$$\phi = 45^\circ + \frac{\alpha}{2} - \frac{\beta}{2}$$

$$\mu = \tan \beta$$
Figure 2.22 Model of chip–tool friction in orthogonal cutting, where $\sigma_{f_{\text{max}}}$ = maximum normal stress, $\sigma_f$ = normal stress, $\tau_f$ = shear stress, $\tau_{st}$ = shear strength of chip material in the sticking region, $l_f$ = chip–tool contact length, and $l_{st}$ = length of sticking contact region. (After Zorev [26].)
Chip Curl

- Chips develop a curvature as they leave the workpiece material for metals and plastics
- Reasons are not fully understood
- Affected by process variables, material properties, and cutting fluids
- Decreased depth of cut increases curliness which increases the effective rake angle and decreases friction

Figure 20.8 Various chips produced in turning: (a) tightly curled chip; (b) chip hits workpiece and breaks; (c) continuous chip moving away from workpiece; and (d) chip hits tool shank and breaks off. Source: G. Boothroyd, Fundamentals of Metal Machining and Machine Tools. Copyright ©1975; McGraw-Hill Publishing Company. Used with permission.
Oblique Cutting

• Most tools are three-dimensional (oblique)
• Cutting edge is now at an inclination angle, $i$
• Chip moves away sideways, as with an angled snow plow
• $\alpha_n$ is the normal rake angle, a property of tool geometry
• $\alpha_c$ has been shown experimentally to be about equal to $i$
• Effective rake angle

$$\alpha_e = \sin^{-1}(\sin^2 i + \cos^2 i \sin \alpha_n)$$
Cutting Temperatures

- The energy dissipated is converted into heat which raises the temperature in the cutting zone
  - in the shear zone
  - strain rates in machining operations are very high
  - along the tool-chip interface
  - Possibly where a dull tool rubs against the machined surface

- Increased temperatures:
  - Adversely affects strength, hardness, and wear resistance of cutting tool
  - Causes dimensional changes in the workpiece
  - Induces thermal damage to the machined surface, affecting its properties
  - Causes distortion of the tool or machine, and thus poor dimensional control

- Temperature is proportional to cutting speed and feed (depth of cut), and dependent upon the materials of the tool and workpiece

\[ \text{MeanTemp} \propto V^a f^b \]

- Temperatures are also affected by the use of cutting fluids (coolants!)
- High temperature workpieces and chips are a safety issue for operators
Most heat generated is carried away by the chip.

High speed machining has advantages due to economics and also because as cutting speed increases, a larger proportion of the heat generated is carried away by the chip.

Percentage of the heat generated in cutting going into the workpiece, tool, and chip, as a function of cutting speed.

Typical temperature distribution the cutting zone. Note the steep temperature gradients within the tool and the chip. *Source: G. Vieregge.*
Tool Wear

- Tool wear is gradual and depends on tool and workpiece materials, tool shape, cutting fluids, process parameters, and machine tools.
- Two basic types of wear: Flank wear and Crater wear.

Figure 20.15 (a) Flank and crater wear in a cutting tool. Tool moves to the left. (b) View of the rake face of a turning tool, showing nose radius $R$ and crater wear pattern on the rake face of the tool. (c) View of the flank face of a turning tool, showing the average flank wear land $VB$ and the depth-of-cut line (wear notch). See also Fig. 20.18. (d) Crater and (e) flank wear on a carbide tool. 

*Source*: J.C. Keefe, Lehigh University.
Types of Tool Wear

- Abrasive wear – material loss due to hard particles
- Adhesive wear – frictional contact between surfaces
- Diffusion related wear – degradation of tool material resulting from solid state diffusion
In addition to gradual wear problems, cutting tools can also fail suddenly by chipping, caused by mechanical shock (impact due to interrupted cutting) or thermal fatigue.
Figure 4.2 Development of flank wear with time for a carbide tool at a cutting speed of 1 m/s.
Tool Life

- Flank wear is caused by
  - the tool rubbing along the machined surface causing adhesive or abrasive wear
  - High temperatures affecting tool-material properties and workpiece surface

- Taylor Tool Life Formula
  - $V T^n = C$
  - $C$ is a constant
  - $V$ is cutting speed
  - $T$ is time (minutes) to develop a certain flank wear land (VB on previous slide)
  - Exponent $n$ depends on tool and workpiece materials and cutting conditions
  - $C$ and $n$ are determined experimentally

- Depth of cut and feed rate also influence tool life
  - $V T^n d^x f^y = C$

- For constant tool life, increasing $f$ or $d$ means decreasing $V$
- Depending on exponents, a reduction in speed can result in an increase in material removal
Tool Life Curves

- Plots of experimental data for specific materials and conditions
- Generally plotted on log-log paper and used to determine $n$

**TABLE 20.3 Range of $n$ Values for Eq. (20.20) for Various Tool Materials**

<table>
<thead>
<tr>
<th>Tool life (min)</th>
<th>Cutting speed (ft/min)</th>
<th>m/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. As cast 265</td>
<td>50 100 150 200 250</td>
<td>120</td>
</tr>
<tr>
<td>b. As cast 215</td>
<td>100 300 500 700 900</td>
<td>80</td>
</tr>
<tr>
<td>c. As cast 207</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>d. Annealed 183</td>
<td></td>
<td>97</td>
</tr>
<tr>
<td>e. Annealed 170</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

**TABLE 20.3**

<table>
<thead>
<tr>
<th>High-speed steels</th>
<th>0.08–0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast alloys</td>
<td>0.1–0.15</td>
</tr>
<tr>
<td>Carbides</td>
<td>0.2–0.5</td>
</tr>
<tr>
<td>Ceramics</td>
<td>0.5–0.7</td>
</tr>
</tbody>
</table>

Tool Life curves should not be extrapolated!
Wear Land

- Resharpen or replace tools when
  - Workpiece surface finish deteriorates
  - Cutting forces increase significantly
  - Temperature rises significantly
  - Allowable wear land is exceeded
- Recommended cutting speed for high-speed steel tools yields a tool life of 60-120 minutes
- Recommended cutting speed for carbide tools yields a tool life of 30-60 minutes

<table>
<thead>
<tr>
<th>Operation</th>
<th>High-speed Steels</th>
<th>Carbides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turning</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Face milling</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>End milling</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Drilling</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Reaming</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Note: 1 mm = 0.040 in.
Crater Wear and Monitoring Tool Wear

- Crater wear occurs on the rake face of the tool and changes the chip-tool interface geometry
- Crater wear is caused by
  - Temperature at the chip-tool interface
  - Chemical affinity between tool and workpiece materials
  - Factors that affect flank wear, to a lesser extent

![Graph showing the relationship between crater wear rate and average tool-chip interface temperature.](image)

Relationship between crater-wear rate and average tool-chip interface temperature: (a) High-speed steel; (b) C-1 carbide; and (c) C-5 carbide. Note how rapidly crater-wear rate increases as the temperature increases. **Source:** B. T. Chao and K. J. Trigger.

- Monitor tool wear by
  - Direct observation with a toolmakers microscope (offline)
  - Indirectly monitoring forces, vibrations, torque, etc,
  - Indirectly using the acoustic emission technique, using a piezoelectric transducer attached to the tool holder
  - Using established tool-cycle times
Requirements of Tool Materials

• High temperature physical and chemical stability – particularly strength and hardness
• High wear resistance
• Resistance to brittle fracture
• Obtaining high performance in all these characteristics is difficult – hard strong materials tend to be brittle
Main Classes of Tool Material

Table 4.2  Major Classes of Tool Material

1. Carbon steels
2. High-speed steels
3. Cast alloys
4. Tungsten carbides
5. Cermets
6. Titanium carbides
7. Ceramics
8. Polycrystalline diamond and cubic boron nitride
9. Single-crystal diamond
Modern Cutting Tools
### TABLE 8-3  HARDNESS OF TYPICAL TOOL MATERIALS OR THEIR CONSTITUENTS*

<table>
<thead>
<tr>
<th>Material or constituent</th>
<th>Hardness, HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martensitic steel</td>
<td>500–1000</td>
</tr>
<tr>
<td>Nitrided steel</td>
<td>950</td>
</tr>
<tr>
<td>Cementite (Fe₃C)</td>
<td>850–1100</td>
</tr>
<tr>
<td>Hard chromium coating</td>
<td>1200</td>
</tr>
<tr>
<td>Alumina</td>
<td>2100–2400</td>
</tr>
<tr>
<td>WC (Co-bonded)</td>
<td>1800–2200</td>
</tr>
<tr>
<td>WC</td>
<td>2600</td>
</tr>
<tr>
<td>WC₃C</td>
<td>2200</td>
</tr>
<tr>
<td>(Fe, Cr)₇C₃</td>
<td>1200–1600</td>
</tr>
<tr>
<td>Mo₂C</td>
<td>1500</td>
</tr>
<tr>
<td>VC</td>
<td>2800</td>
</tr>
<tr>
<td>TiC</td>
<td>3200</td>
</tr>
<tr>
<td>TiN</td>
<td>3000</td>
</tr>
<tr>
<td>B₄C₃</td>
<td>3700</td>
</tr>
<tr>
<td>SiC</td>
<td>2600</td>
</tr>
<tr>
<td>Cubic boron nitride</td>
<td>6500</td>
</tr>
<tr>
<td>Polycrystalline diamond/WC</td>
<td>5500–8000</td>
</tr>
<tr>
<td>Diamond</td>
<td>8000–12000</td>
</tr>
</tbody>
</table>

The hardness of various cutting-tool materials as a function of temperature (hot hardness). The wide range in each group of materials is due to the variety of tool compositions and treatments available for that group.
## Cutting Tool Properties

### Table 21.1

<table>
<thead>
<tr>
<th>Property</th>
<th>High-speed steels</th>
<th>Cast alloys</th>
<th>WC</th>
<th>TiC</th>
<th>Ceramics</th>
<th>Cubic boron nitride</th>
<th>Single-crystal diamond*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>83– 86 HRA</td>
<td>82– 84 HRA</td>
<td>90– 95 HRA</td>
<td>91– 93 HRA</td>
<td>91– 95 HRA</td>
<td>4000– 5000 HK</td>
<td>7000– 8000 HK</td>
</tr>
<tr>
<td>Compressive strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPa</td>
<td>4100– 4500</td>
<td>1500– 2300</td>
<td>4100– 5850</td>
<td>3100– 3850</td>
<td>2750– 4500</td>
<td>6900</td>
<td>6900</td>
</tr>
<tr>
<td>psi x10³</td>
<td>600– 650</td>
<td>220– 335</td>
<td>600– 850</td>
<td>450– 560</td>
<td>400– 650</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Transverse rupture strength</td>
<td>2400– 4800</td>
<td>1380– 2050</td>
<td>1050– 2600</td>
<td>1380– 1900</td>
<td>345– 950</td>
<td>700</td>
<td>1350</td>
</tr>
<tr>
<td>psi x10³</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact strength</td>
<td>1.35– 8</td>
<td>0.34– 1.25</td>
<td>0.34– 1.35</td>
<td>0.79– 1.24</td>
<td>&lt; 0.1</td>
<td>&lt; 0.5</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>in.- lb</td>
<td>12– 70</td>
<td>3– 11</td>
<td>3– 12</td>
<td>7– 11</td>
<td>&lt; 1</td>
<td>&lt; 5</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>GPa</td>
<td>30</td>
<td>–</td>
<td>75– 100</td>
<td>45– 65</td>
<td>45– 60</td>
<td>125</td>
<td>120– 150</td>
</tr>
<tr>
<td>psi x10⁶</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>8600</td>
<td>8000– 8700</td>
<td>10,000– 15,000</td>
<td>5500– 5800</td>
<td>4000– 4500</td>
<td>3500</td>
<td>3500</td>
</tr>
<tr>
<td>kg/m³</td>
<td>0.31</td>
<td>0.29– 0.31</td>
<td>0.36– 0.54</td>
<td>0.2– 0.22</td>
<td>0.14– 0.16</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>lb/in.³</td>
<td>7– 15</td>
<td>10– 20</td>
<td>70– 90</td>
<td>–</td>
<td>100</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Volume of hard phase, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting or decomposition temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>°C</td>
<td>1300</td>
<td>–</td>
<td>1400</td>
<td>1400</td>
<td>2000</td>
<td>1300</td>
<td>700</td>
</tr>
<tr>
<td>°F</td>
<td>2370</td>
<td>–</td>
<td>2550</td>
<td>2550</td>
<td>3600</td>
<td>2400</td>
<td>1300</td>
</tr>
<tr>
<td>Thermal conductivity, W/m K</td>
<td>30– 50</td>
<td>–</td>
<td>42– 125</td>
<td>17</td>
<td>29</td>
<td>13</td>
<td>500– 2000</td>
</tr>
<tr>
<td>Coefficient of thermal expansion, x10⁻⁶ °C</td>
<td>12</td>
<td>–</td>
<td>4– 6.5</td>
<td>7.5– 9</td>
<td>6– 8.5</td>
<td>4.8</td>
<td>1.5– 4.8</td>
</tr>
</tbody>
</table>

*The values for polycrystalline diamond are generally lower, except impact strength, which is higher.
Cutting Tool Inserts

Typical carbide inserts with various shapes and chip-breaker features; round inserts are also available. The holes in the inserts are standardized for interchangeability. Source: Courtesy of Kyocera Engineered Ceramics, Inc., and Manufacturing Engineering Magazine, Society of Manufacturing Engineers.

Inserts with polycrystalline cubic boron nitride tips (top row) and solid polycrystalline cBN inserts (bottom row). Source: Courtesy of Valenite.
## Machine Tool Cost and Failure Risk

### TABLE 21.6

<table>
<thead>
<tr>
<th>Tool</th>
<th>Size (in.)</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-speed steel tool bits</td>
<td>1/4 sq. x 2 1/2 long</td>
<td>1–2</td>
</tr>
<tr>
<td></td>
<td>1/2 sq. x 4</td>
<td>3–7</td>
</tr>
<tr>
<td>Carbide-tipped (brazed) tools for turning</td>
<td>1/4 sq.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3/4 sq.</td>
<td>4</td>
</tr>
<tr>
<td>Carbide inserts, square 3/16&quot; thick</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain</td>
<td>1/2 inscribed circle</td>
<td>5–9</td>
</tr>
<tr>
<td>Coated</td>
<td>1/2 inscribed circle</td>
<td>6–10</td>
</tr>
<tr>
<td>Ceramic inserts, square</td>
<td>1/2 inscribed circle</td>
<td>8–12</td>
</tr>
<tr>
<td>Cubic boron nitride inserts, square</td>
<td>1/2 inscribed circle</td>
<td>60–90</td>
</tr>
<tr>
<td>Diamond-coated inserts</td>
<td>1/2 inscribed circle</td>
<td>50–60</td>
</tr>
<tr>
<td>Diamond-tipped inserts (polycrystalline)</td>
<td>1/2 inscribed circle</td>
<td>90–100</td>
</tr>
</tbody>
</table>

Relative edge strength and tendency for chipping and breaking of insets with various shapes. Strength refers to the cutting edge shown by the included angles. 
*Source:* Kennametal, Inc.
Multiphase coatings on a tungsten-carbide substrate. Three alternating layers of aluminum oxide are separated by very thin layers of titanium nitride. Inserts with as many as thirteen layers of coatings have been made. Coating thicknesses are typically in the range of 2 to 10 μm. **Source:** Courtesy of Kennametal, Inc., and *Manufacturing Engineering Magazine*, Society of Manufacturing Engineers.
Cutting Fluids

• Reduce friction and wear – improved tool life and surface finish; reduce forces and power required
• Cool cutting zone – reducing temperatures and improving tool life
• Flush away chips from the cutting zone
• Represent a significant cost – may be as much as 15-18% of overall costs
• Can be an environmental hazard
Types of Cutting Fluid

- Oils (straight oils) – mineral, animal, vegetable, synthetics – mainly slow speed operations
- Emulsions (soluble oils) – mixture of oil, water and additives – coolants
- Semi-synthetics – chemical emulsions containing little oil diluted with water, including additives to reduce oil particle size.
- Synthetics – chemicals with additives, diluted with water and containing no oil
Cutting Fluid Application

- **Flooding** – low pressure jets; most common method of application
- **Mist** – atomized with air; good accessibility
- **High pressure systems** – for improved heat dissipation; may be refrigerated
- **Through the cutting tool** – improved lubrication and flushing; particularly drilling applications
Cutting Fluid Application

Schematic illustration of proper methods of applying cutting fluids in various machining operations: (a) turning, (b) milling, (c) thread grinding, and (d) drilling.
# Chip Types in Machining

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*Figure 8.1* Chip forms produced in machining operations.
Basic Chip Breaker Types

Figure 8.2 Groove-type chip breaker, where $d_n =$ chip-breaker-groove depth, $e_n =$ chip-breaker land width, $l_n =$ chip-breaker distance, and $q_n =$ chip-breaker groove radius.

Figure 8.3 Obstruction-type chip breakers, where $h =$ chip-breaker height, $l_n =$ chip-breaker distance, $\sigma =$ chip-breaker wedge angle, and $\rho_{\gamma 1} =$ chip-breaker angle. (a) Attached; (b) integral.
Modern Chip Breaking Geometries
Surface Finish – Dull Tools and Feed Marks

Schematic illustration of a dull tool in orthogonal cutting (exaggerated). Note that at small depths of cut, the positive rake angle can effectively become negative, and the tool may simply ride over and burnish the workpiece surface.

Turning and other cutting operations leave a spiral profile on the machined surface, especially at higher feed rates \( f \) and smaller tool-nose radii \( R \).
Geometric Surface Roughness

Underlying surface roughness depends upon tool geometry and feed. Roughness is reduced by lowering the feed rate.
Cutting Speed and Surface Roughness

"Ideal" roughness = 1.56 μm (62.5 μin.)

FIG. 5.9 Effect of cutting speed on the surface roughness of turned specimens of mild steel.

Roughness is improved at higher cutting speeds
Machine Tool Economics

- Cost Components (labor, overhead, and machine-tool costs in each category below)
  - Nonproductive cost – during set-up, fixturing, advancing and retracting cutting tool
  - Machining cost – while cutting is occurring
  - Tool-change cost – during tool changes
  - Cutting tool cost – only 5% of costs

Graphs showing (a) cost per piece and (b) time per piece in machining. Note the optimum speeds for both cost and time. The range between the two is known as the high-efficiency machining range.