Lecture 14: Cutting Tool Technology

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

- Worn cutting tool, showing the principal locations and types of wear that occur.
Tool Wear vs. Time

- Tool wear (flank wear) as a function of cutting time
Effect of Cutting Speed

Taylor Tool Life Equation

\[ vT^n = C \]

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.

- Natural log-log plot of cutting speed vs. tool life
Tool Materials

- The important properties for tool material:
  - 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
Typical hot hardness relationships for selected tool materials.

- High speed steel is much better than plain C steel.
- Cemented carbides and ceramics are significantly harder at elevated temperatures.

Quiz: List reasons for hardness decrease with higher T.
## Typical Values of $n$ and $C$

<table>
<thead>
<tr>
<th>Tool material</th>
<th>$n$</th>
<th>$C$ (m/min)</th>
<th>$C$ (ft/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High speed steel:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-steel work</td>
<td>0.125</td>
<td>120</td>
<td>350</td>
</tr>
<tr>
<td>Steel work</td>
<td>0.125</td>
<td>70</td>
<td>200</td>
</tr>
<tr>
<td><strong>Cemented carbide</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-steel work</td>
<td>0.25</td>
<td>900</td>
<td>2700</td>
</tr>
<tr>
<td>Steel work</td>
<td>0.25</td>
<td>500</td>
<td>1500</td>
</tr>
<tr>
<td><strong>Ceramic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel work</td>
<td>0.6</td>
<td>3000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

**Quiz:** Comparing high speed steel with Cemented carbide: which one has tool life that is more sensitive to cutting speed?
High Speed Steel (HSS)

Highly alloyed tool steel capable of maintaining hardness at elevated temperatures

Especially suited to applications involving complicated tool shapes: drills, taps, milling cutters, and broaches

• Two basic types of HSS (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 (brittle)
- High hardness (90 to 95 HRA)
- Good hot hardness
- Good wear resistance
- High thermal conductivity
- High elastic modulus - $600 \times 10^3$ MPa
- Toughness lower than high speed steel

Quiz: Why carbides for machining tools?
Steel Cutting Carbide Grades

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

Cemented carbide insert coated with one or more layers of TiC, TiN, and/or Al₂O₃ or other hard materials

- Coating thickness = 2.5 - 13 μm (0.0001 to 0.0005 in)
  - Coating applied by chemical vapor deposition or physical vapor deposition

- Applications: cast irons and steels in turning and milling operations
  - Best applied at high speeds where dynamic force and thermal shock are minimal
Ceramics

Primarily fine-grained Al$_2$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
- Al$_2$O$_3$ also widely used as an abrasive in grinding
Cermets

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

- Applications: high speed finishing and semifinishing of steels, stainless steels, and cast irons
  - Higher speeds and lower feeds than steel-cutting cemented carbide grades
  - Better finish achieved, often eliminating need for 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 reinforced polymer, graphite, and wood
  – Not for steel cutting
Cubic Boron Nitride

- Next to diamond, cubic boron nitride (cBN) is the hardest material known.
- Fabrication into cutting tool inserts same as sintered polycrystalline diamond (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
Holding and Presenting a Single-Point Tool

- (a) Solid shank tool, typical of HSS; (b) brazed cemented carbide insert; and (c) mechanically clamped insert, used for cemented carbides, ceramics, and other very hard tool materials.

http://www.youtube.com/watch?v=J63dZsw7Ia4
Common Insert Shapes

- (a) Round, (b) square, (c) rhombus with 80° point angles, (d) hexagon with 80° point angles, (e) triangle, (f) rhombus with 55° point angles, (g) rhombus with 35° point angles
Twist Drill

- Most common cutting tools for hole-making
- Usually made of high speed steel
- Shown below is standard twist drill geometry
Twist Drill Operation - Problems

• Chip removal
  – Flutes must provide sufficient clearance to allow chips to move from bottom of hole during cutting
  – 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 moving in opposite direction
Milling Cutters

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

- Tool geometry elements of an 18-tooth plain milling cutter
Face Milling Cutter

- 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 the 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
Cutting Fluid Classification

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
Machinability

Relative ease with which a material (usually a metal) can be machined using appropriate tooling and cutting conditions

• Depends not only on work material
  – Type of machining operation, tooling, and cutting conditions are also important factors
Machinability Criteria in Production

• Tool life – longer tool life for the given work material means better machinability
• Forces and power – lower forces and power mean better machinability
• Surface finish – better finish means better machinability
• Ease of chip disposal – easier chip disposal means better machinability
Mechanical Properties and Machinability

• Hardness
  – High hardness means abrasive wear increases so tool life is reduced

• Strength
  – High strength means higher cutting forces, specific energy, and cutting temperature

• Ductility
  – High ductility means tearing of metal to form chip, causing chip disposal problems and poor finish
HW assignment

- Reading assignment: Chapters 10

- Review Questions: 17.2, 17.3, 17.4, 17.7, 17.8, 17.9, 17.12, 17.13,

- Problems: 17.1, 17.3, 17.4, 17.5, 17.6,