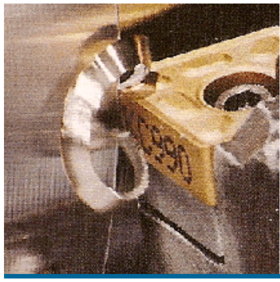

TA202A: Introduction to Manufacturing Processes

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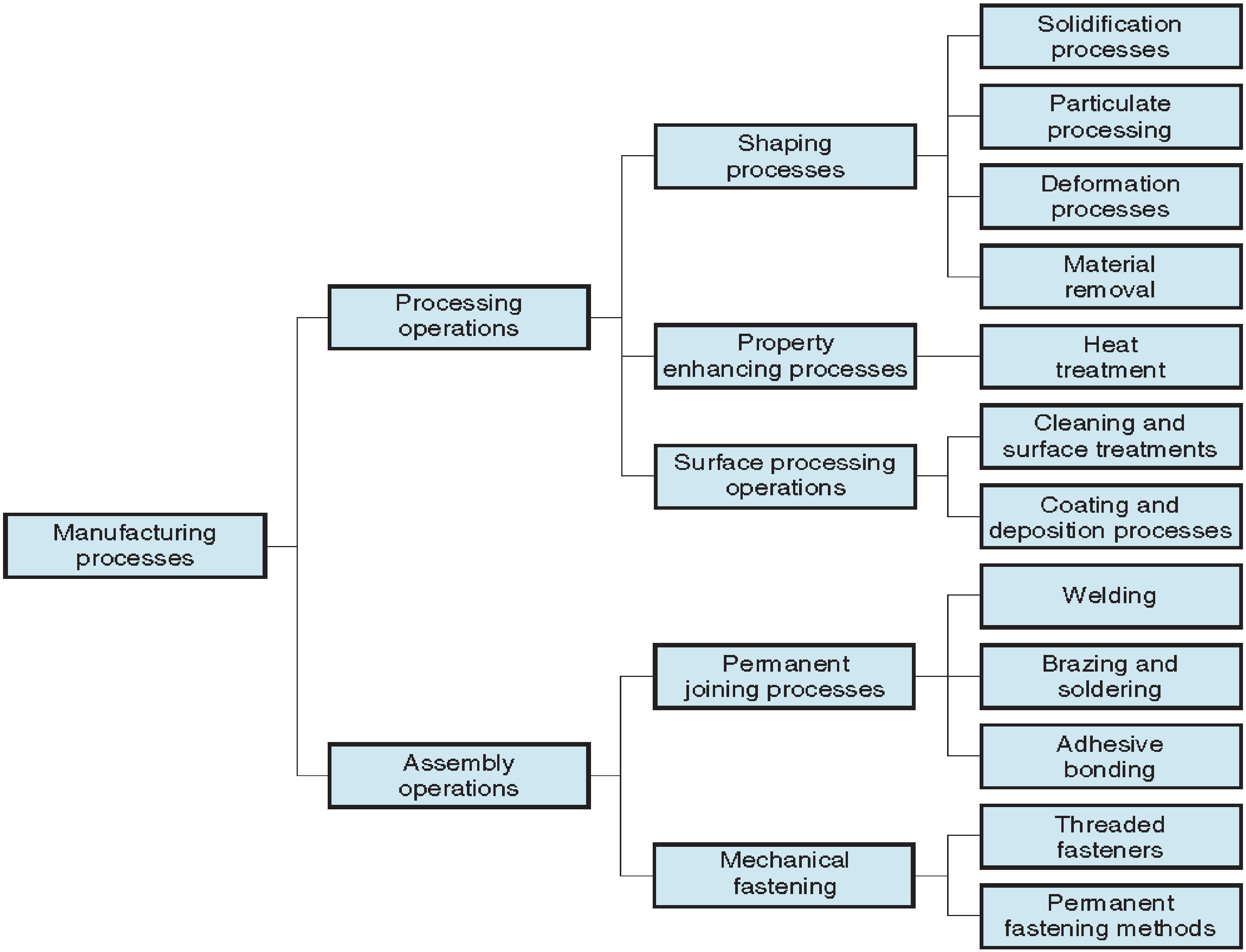
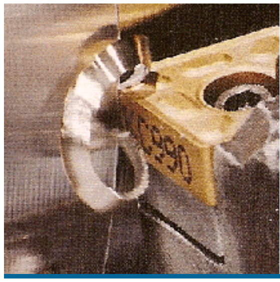

Manufacturing processes
Processing operations
Assembly operations
Shaping processes
Property enhancing processes
Surface processing operations
Permanent joining processes
Mechanical fastening
Solidification processes
Particulate processing
Deformation processes
Material removal
Heat treatment
Cleaning and surface treatments
Coating and deposition processes
Welding
Brazing and soldering
Adhesive bonding
Threaded fasteners
Permanent fastening methods

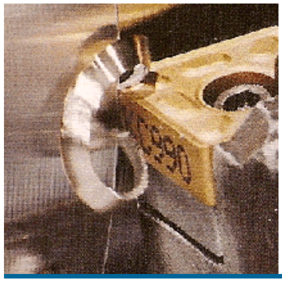


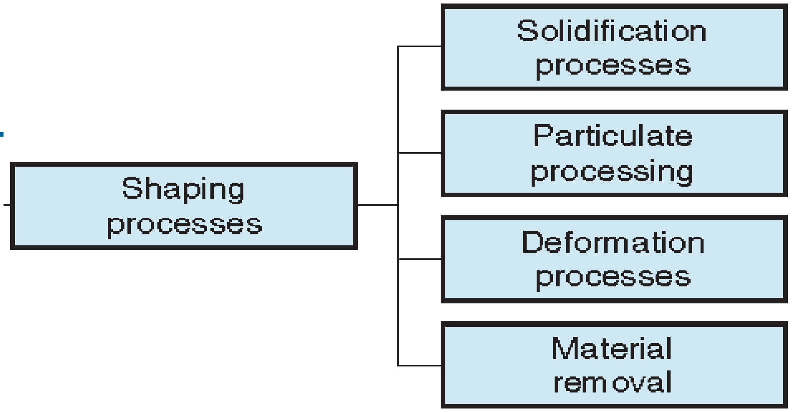
Processing Operations

Alters a material's shape, physical properties, or appearance in order to add value

- Three categories of processing operations:
  1. **Shaping operations -** alter the geometry of the starting work material
  2. **Property-enhancing operations -** improve physical properties without changing shape
  3. **Surface processing operations -** clean, treat, coat, or deposit material on surface of work

Shaping Processes



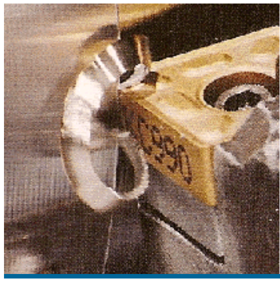


1. **Solidification processes -** starting material is a heated liquid or semifluid

2. **Particulate processing -** starting material consists of powders

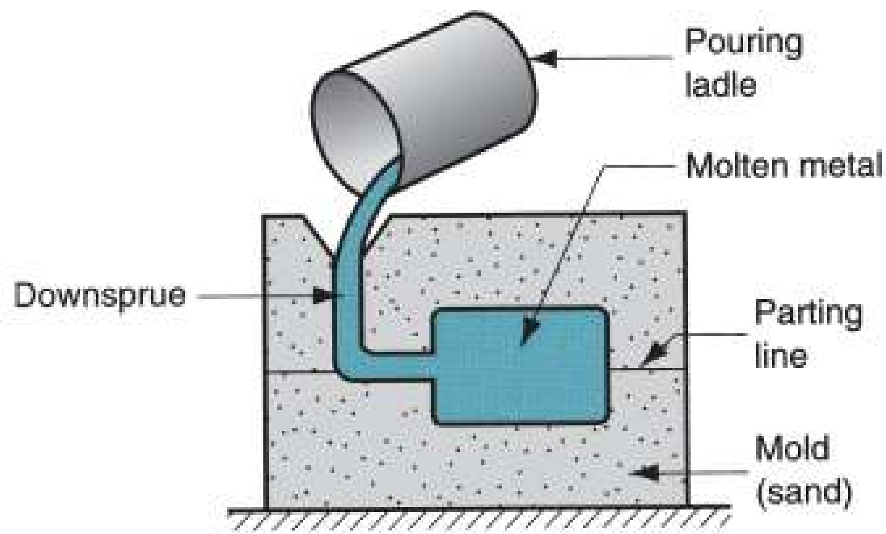
3. **Deformation processes -** starting material is a ductile solid (commonly metal)

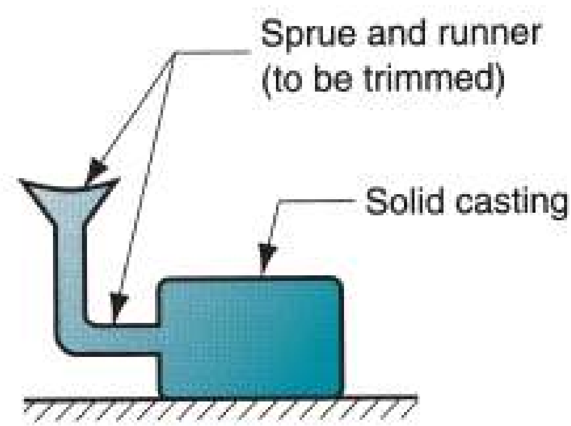
4. **Material removal processes -** starting material is a ductile or brittle solid

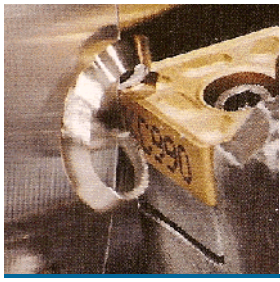


Solidification Processes

- Starting material is heated sufficiently to transform it into a liquid or highly plastic state
- Casting process at left and casting product at right

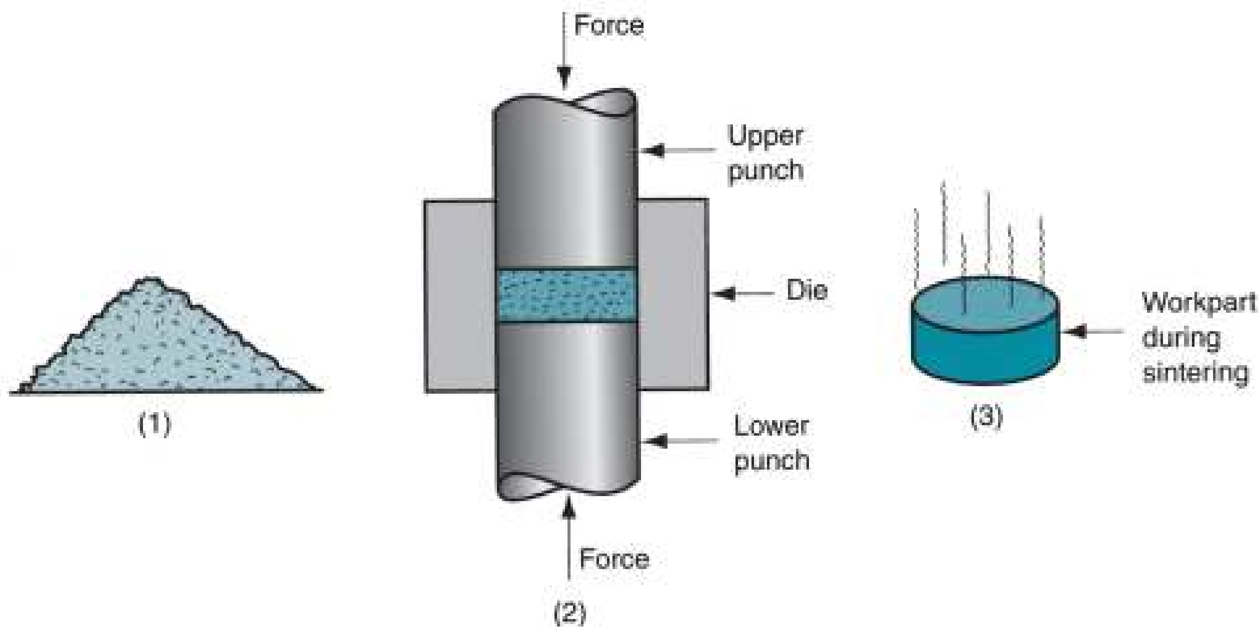


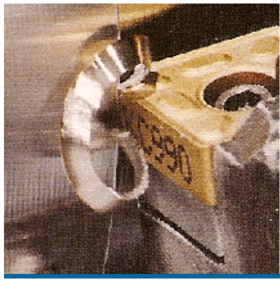




Particulate Processing

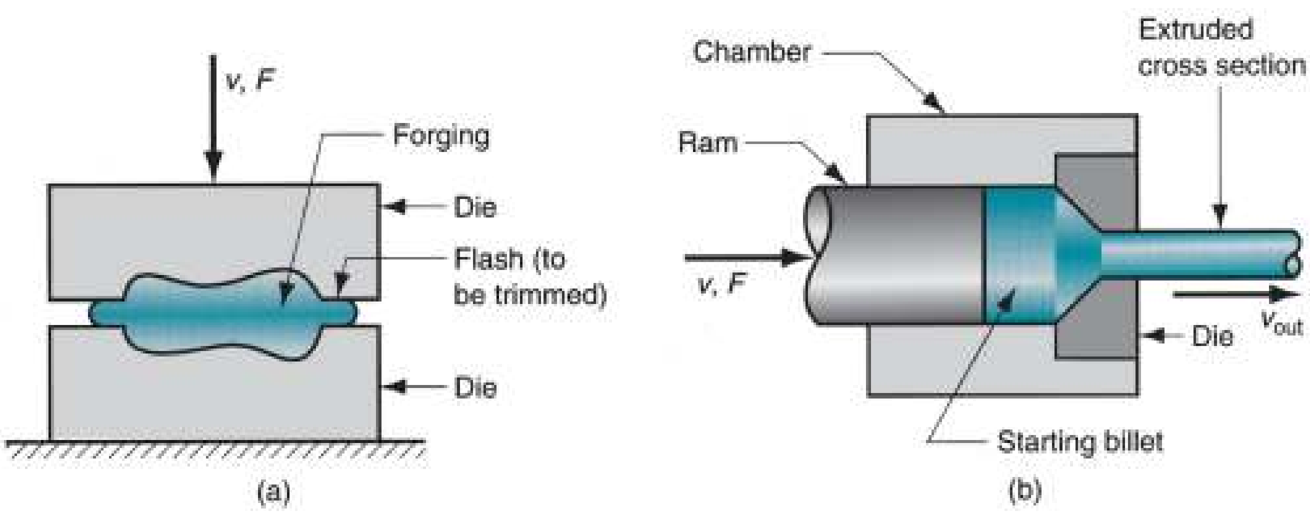
- (1) Starting materials are metal or ceramic powders, which are (2) pressed and (3) sintered

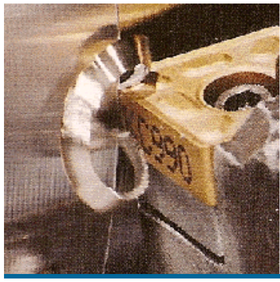




Deformation Processes

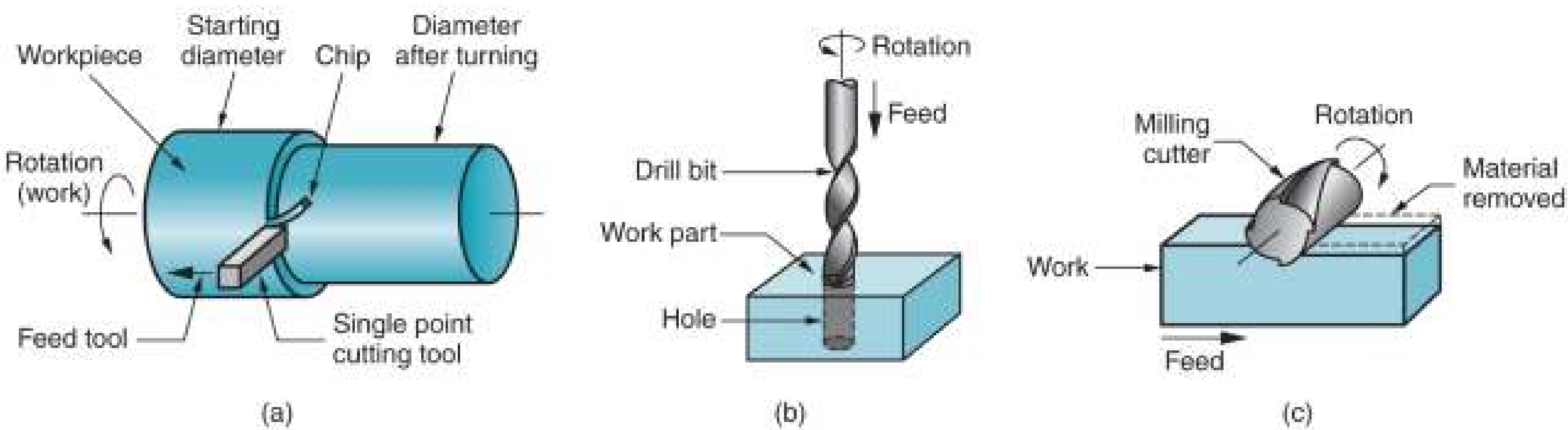
- Starting workpart is shaped by application of forces that exceed the yield strength of the material
- Examples: (a) forging and (b) extrusion

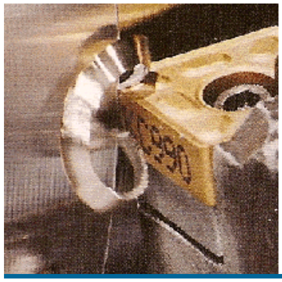




Material Removal Processes

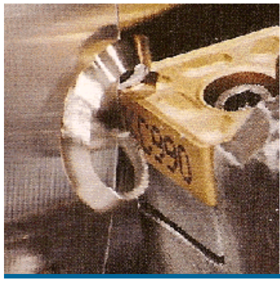
- Excess material removed from the starting piece so what remains is the desired geometry
- Examples: (a) turning, (b) drilling, and (c) milling



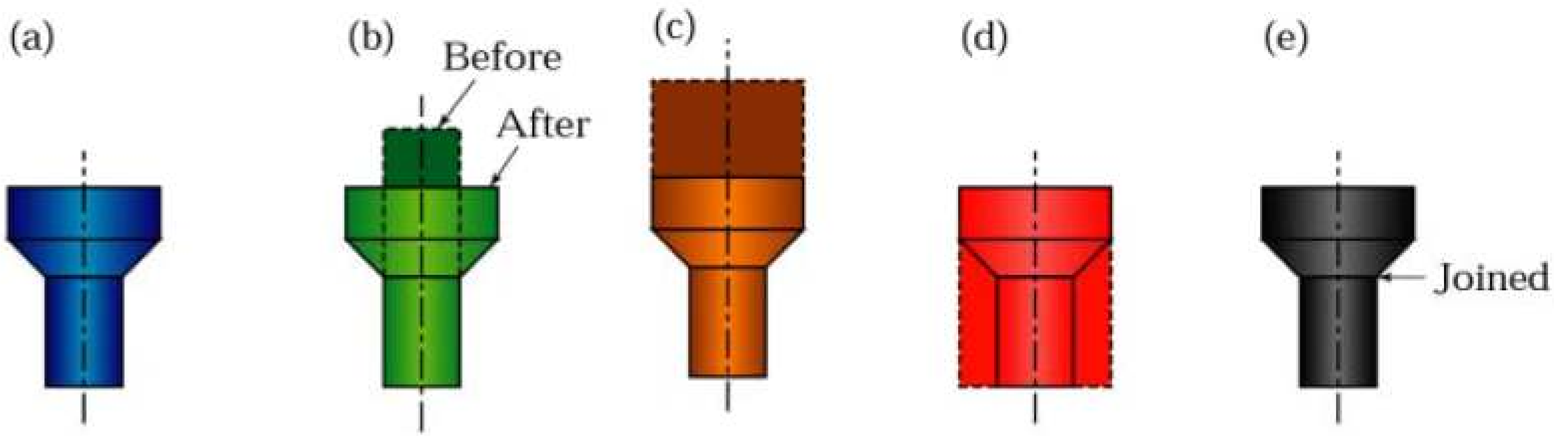


Waste in Shaping Processes

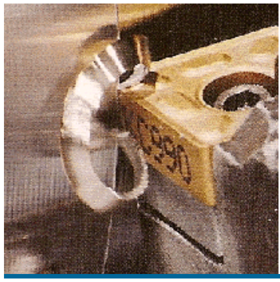
- It is desirable to minimize waste in part shaping
- Material removal processes are wasteful in the unit operations, but molding and particulate processing operations waste little material
- Terminology for minimum waste processes:
  - *Net shape* processes - little or no waste of the starting material and no machining is required
  - *Near net shape* processes - when minimum machining is required



Manufacturing Process Selection



Various methods of making a simple part: (a) casting or powder metallurgy, (b) forging or upsetting, (c) extrusion, (d) machining, (e) joining two pieces (Mass Addition Process).



Manufacturing Process Selection

Two stage decision process

- "Feasible" stage ("must" stage)–
  - Can the shape be produced by the process?
  - Can the material be shaped by the process?
- "Optimal" stage ("want" stage) –
  - Eliminate processes that cannot meet the minimum acceptable process performance criteria.
  - Select the best process from the remaining processes under consideration by optimizing process performance criteria.

Process performance criteria: cycle time, material utilization, process flexibility, quality/reliability, operating costs, surface finish, tolerances.

Manufacturing Process Selection

STAGE 1

A. i) Select Product Performance Criteria
ii) Select Material for Evaluation

B. i) Eliminate Processes which DO NOT meet desired Product Performance Criteria
ii) Eliminate Processes which CANNOT process Material

↓

Number of Potential Processes < 6

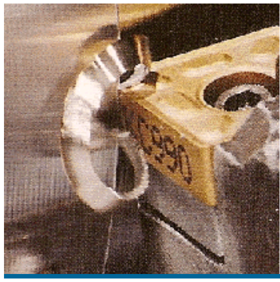
NO → **STAGE 2A**

A. i) Select Minimum Process Performance Criteria
ii) Eliminate Processes which DO NOT meet Minimum Process Criteria

Yes ↓

STAGE 2B

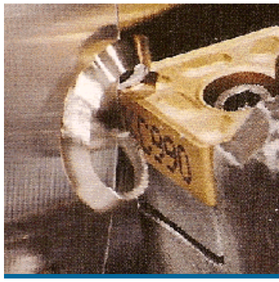
B. i) Select weights for Process Performance Criteria and Evaluate Processes
ii) Select the best/optimal Processes for Material
iii) Consider any adverse consequences of the processes which have not been considered in the selection system; if serious adverse consequences exist and may occur, then consider the next best process



Material Removal Processes

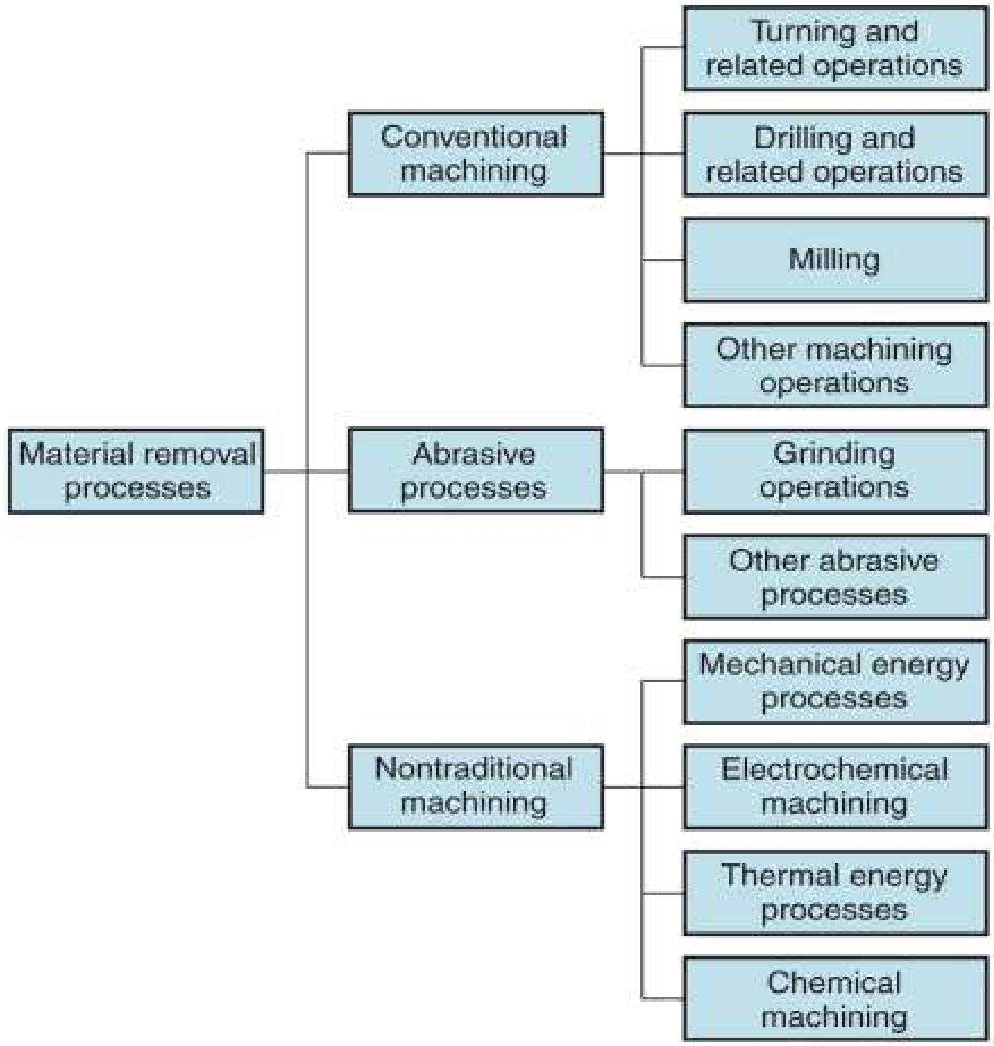
A family of shaping operations, the common feature of which is removal of material from a starting work part so the remaining part has the desired geometry

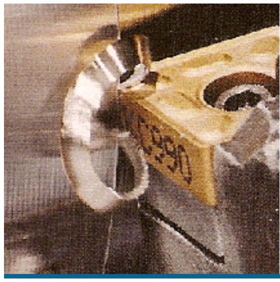
- Machining – material removal by a sharp cutting tool, e.g., turning, milling, drilling
- Abrasive processes – material removal by hard, abrasive particles, e.g., grinding
- Nontraditional processes - various energy forms other than sharp cutting tool to remove material



Material Removal Processes

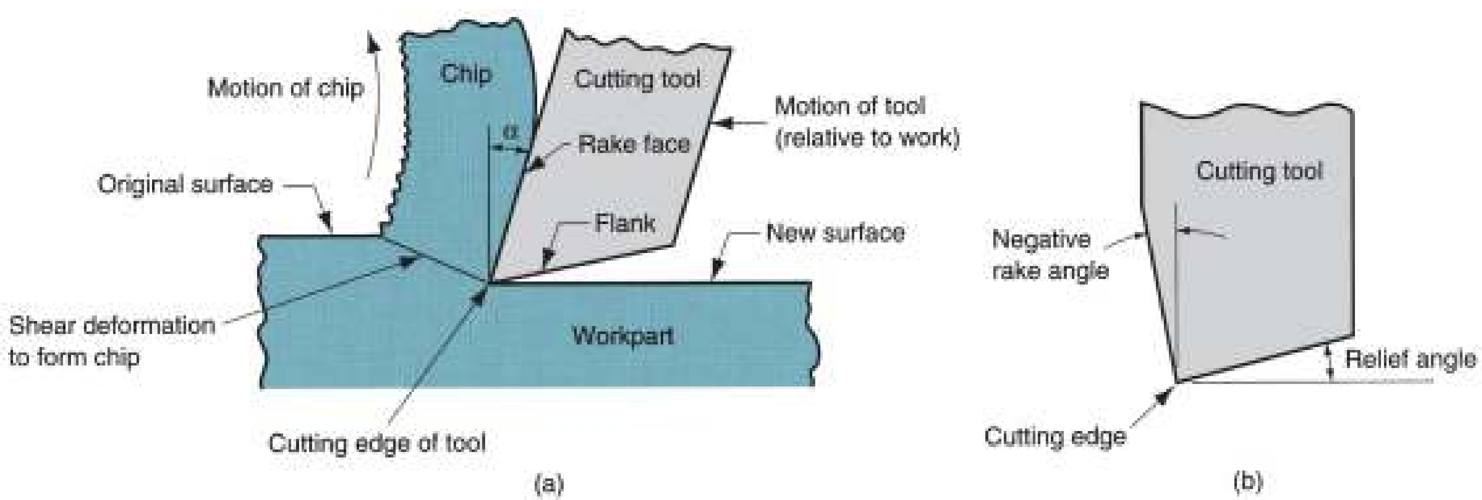
- The family tree

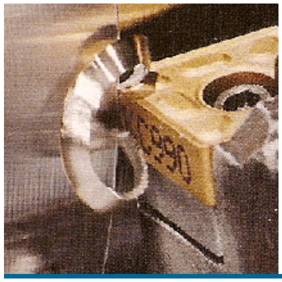




Machining

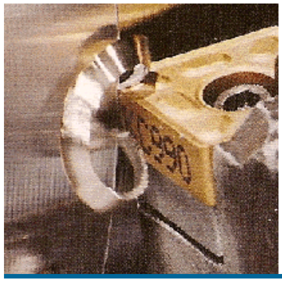
- Cutting action involves shear deformation of work material to form a chip, and as chip is removed, new surface is exposed: (a) positive and (b) negative rake tools





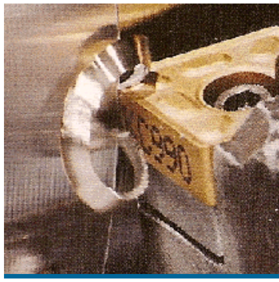
Why Machining is Important?

- Variety of work materials can be machined
  - Most frequently used to cut metals
- Variety of part shapes and special geometric features possible:
  - Screw threads
  - Accurate round holes
  - Very straight edges and surfaces
- Good dimensional accuracy and surface finish



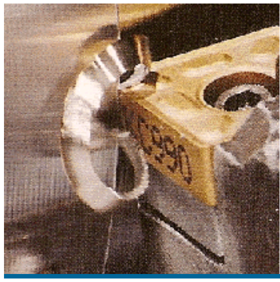
Disadvantages with Machining

- Wasteful of material
  - Chips generated in machining are wasted material
- Time consuming
  - A machining operation generally takes longer to shape a given part than alternative shaping processes



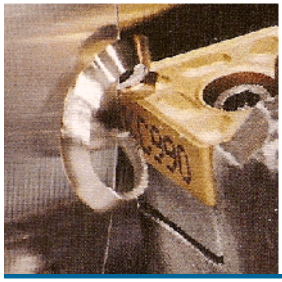
Machining in the Manufacturing Sequence

- Generally performed after other manufacturing processes, such as casting, forging, and bar drawing
  - Other processes create the general shape of the starting work part
  - Machining provides the final shape, dimensions, finish, and special geometric details that other processes cannot create



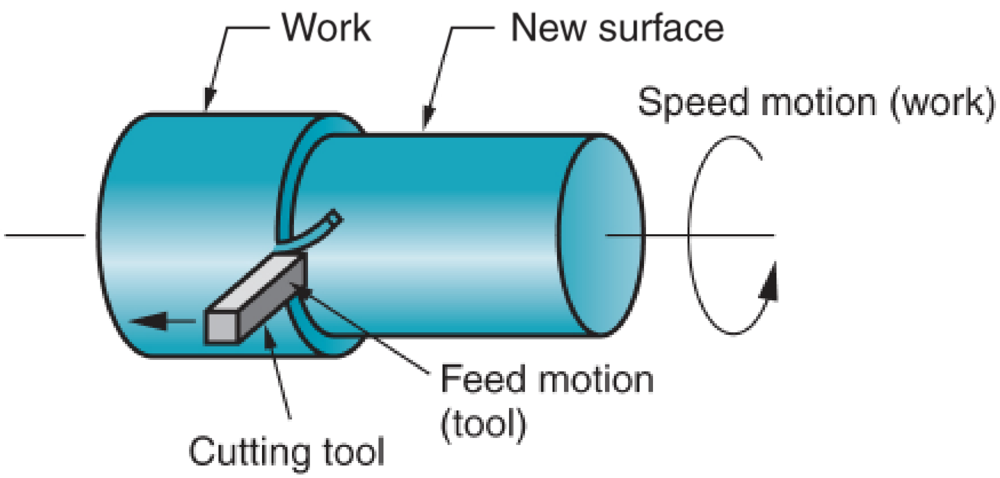
Machining Operations

- Most important machining operations:
  - Turning
  - Drilling
  - Milling
- Other machining operations:
  - Shaping and planing
  - Broaching
  - Sawing

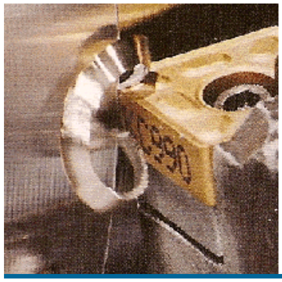


Turning

- Single point cutting tool removes material from a rotating workpiece to form a cylindrical shape

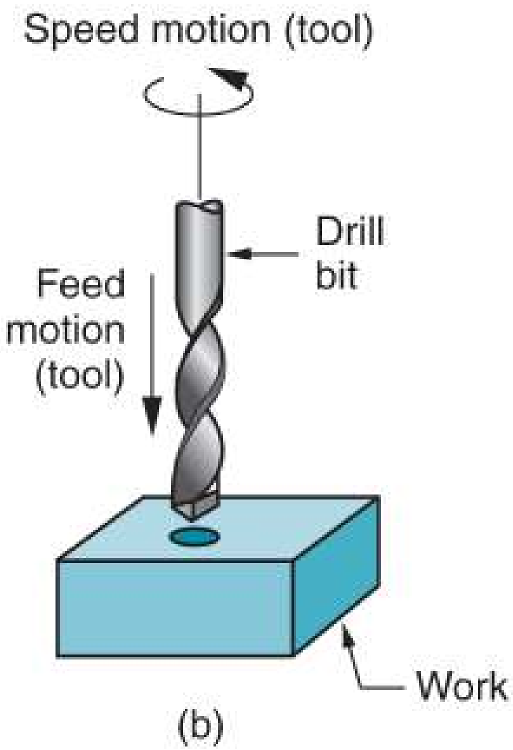


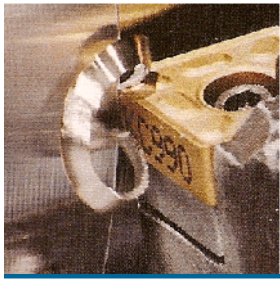
(a)



Drilling

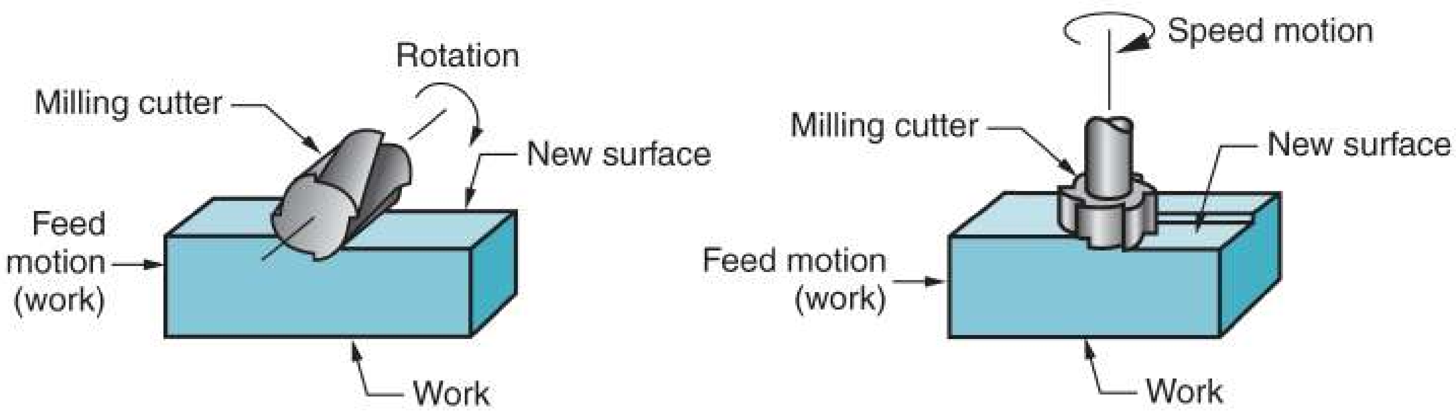
- Used to create a round hole, usually by means of a rotating tool (drill bit) with two cutting edges





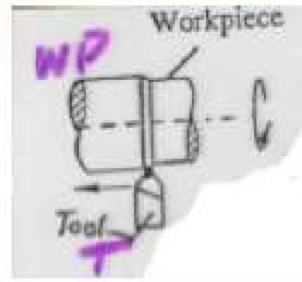
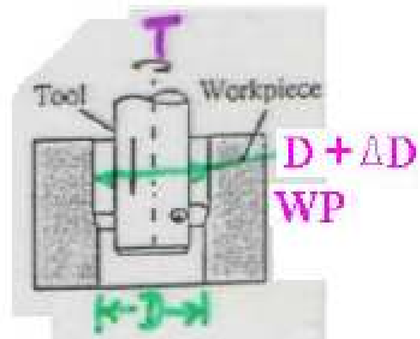
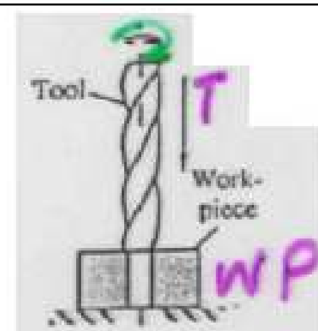
Milling

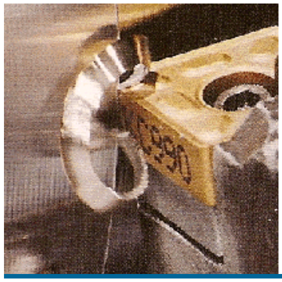
- Rotating multiple-cutting-edge tool is moved across work to cut a plane or straight surface
- Two forms: (c) peripheral milling and (d) face milling



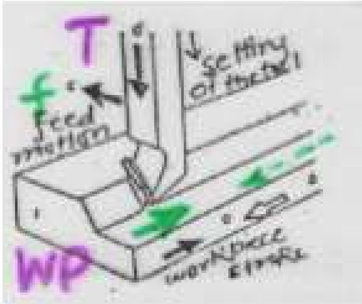
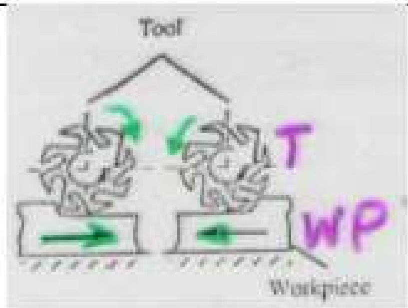
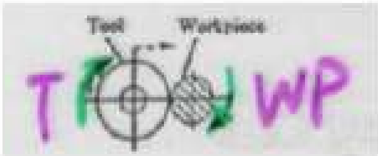
(c) (d)

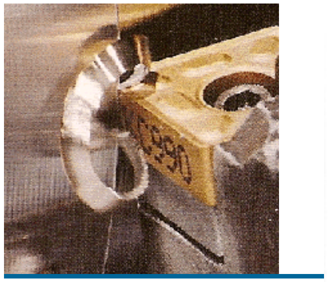
NATURE OF RELATIVE MOTION BETWEEN THE TOOL AND WORKPIECE

OPERATION	MOTION OF JOB	MOTION OF CUTTING TOOL	FIGURE OF OPEARTION
TURNING	ROTARY	TRANSLATORY (FORWARD)	
BORING	ROTATION	TRANSLATION (FORWARD)	
DRILLING	FIXED (NO MOTION)	ROTATION AS WELL AS TRANSLATORY FEED	



Nature of Relative Motion Between Tool and Workpiece

PLANING	TRANSLATORY	INTERMITTENT TRANSLATION	
MILLING	TRANSLATORY	ROTATION	
GRINDING	ROTARY / TRANSLATORY	ROTARY	



Machining Parameters

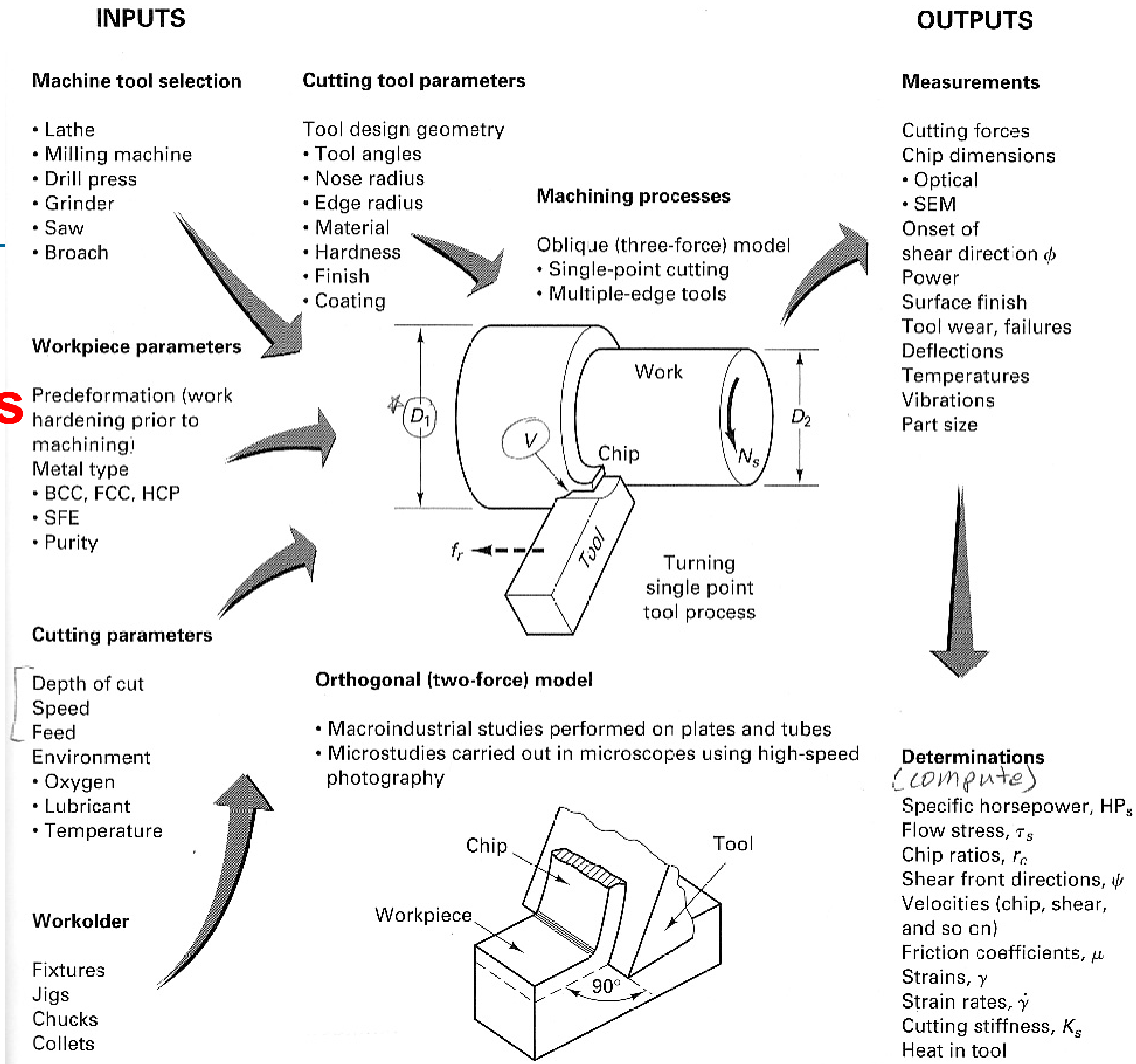
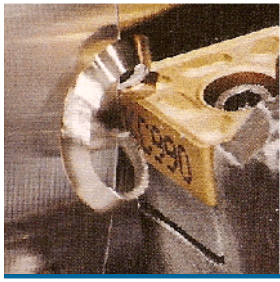
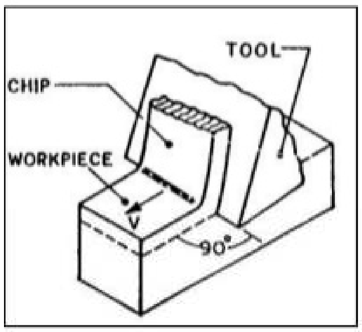


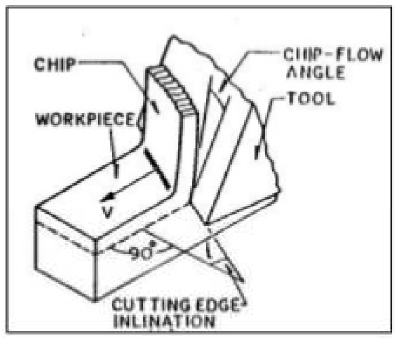
FIGURE 21-1 The fundamental inputs and outputs to machining processes.

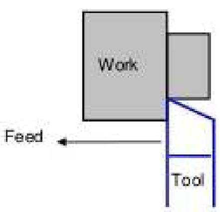


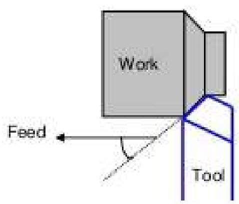
Orthogonal Cutting



Oblique Cutting





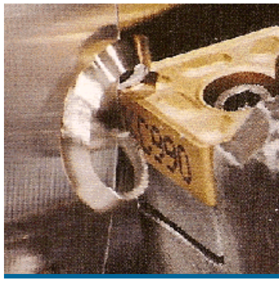


Orthogonal Cutting

Cutting edge is straight, parallel to the original plane surface at the work piece and perpendicular to the direction of cutting.

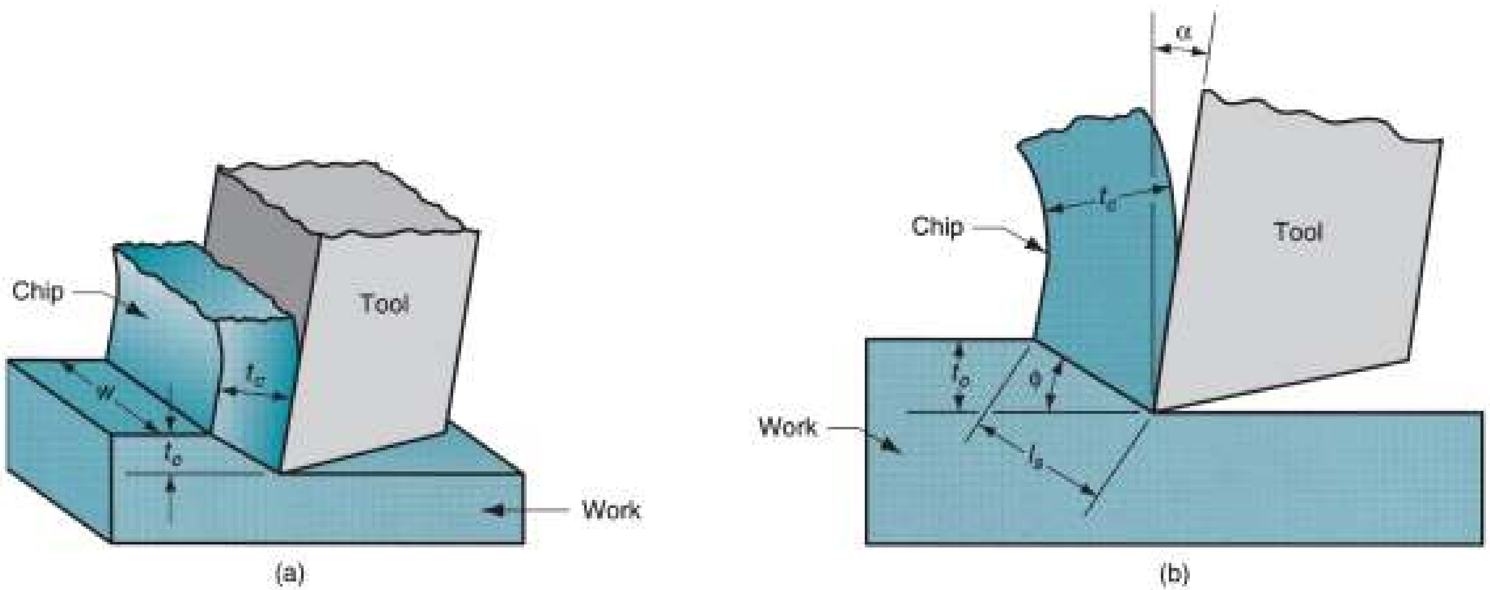
Oblique Cutting

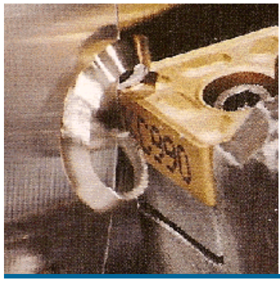
Cutting edge of the tool is inclined to the line normal to the cutting direction. In actual machining, Turning, Milling etc/ cutting operations are oblique cutting



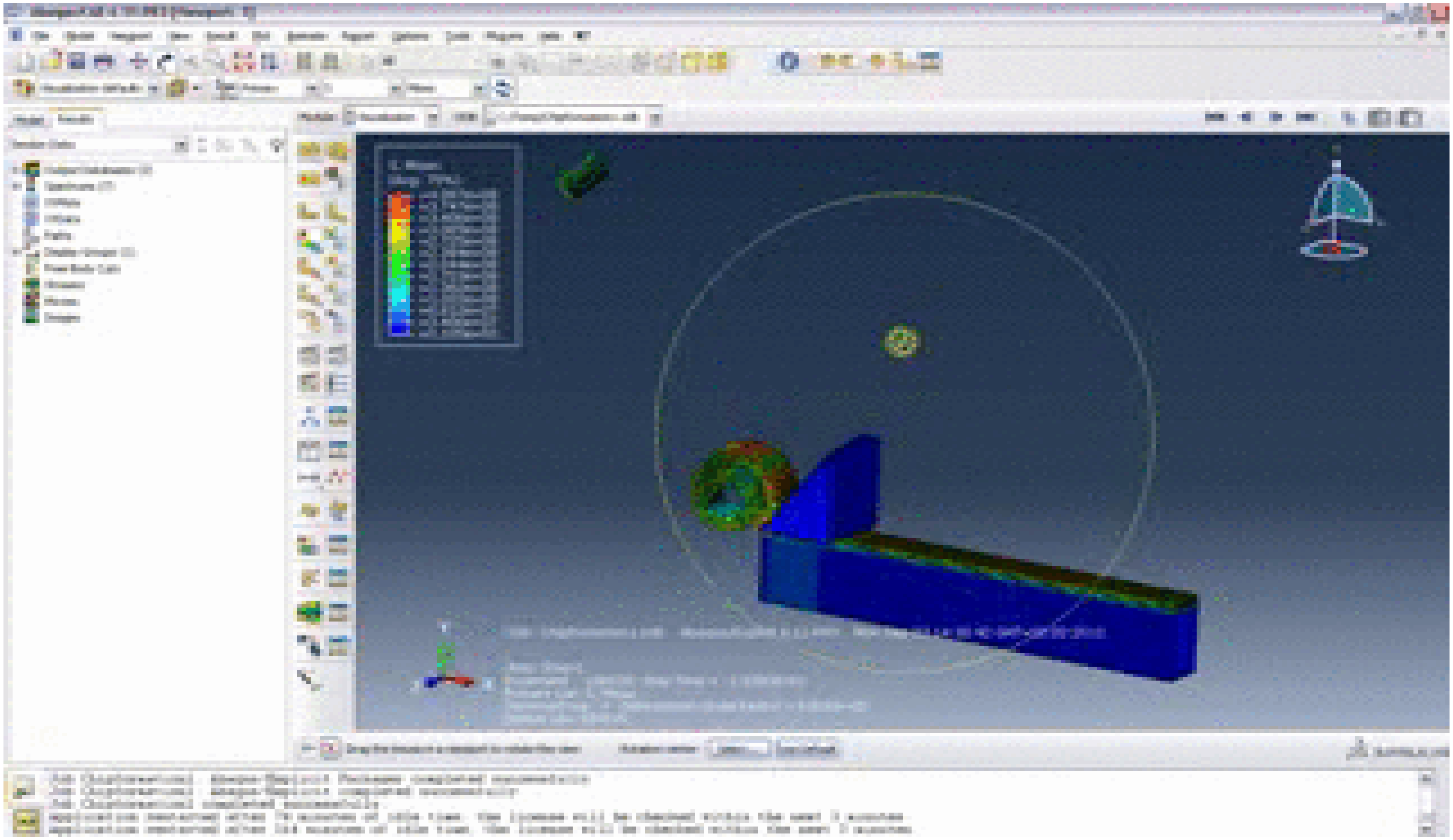
Orthogonal Cutting Model

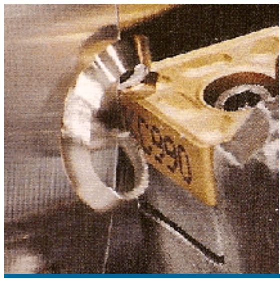
- Simplified 2-D model of machining that describes the mechanics of machining fairly accurately





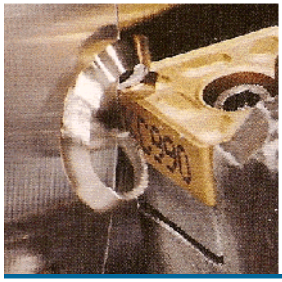
Simulation of orthogonal cutting



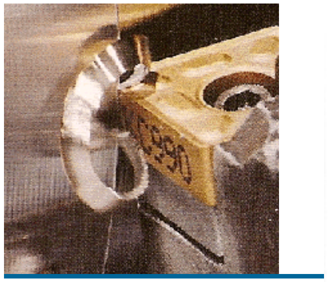


Importance of Machining

- In the US, more than $100 billion were spent annually on machining and related operations
- Typically, a large majority (above 80%) of all the machine tools used in manufacturing industry are metal cutting in nature



Versatility of Machining



Machining Parameters

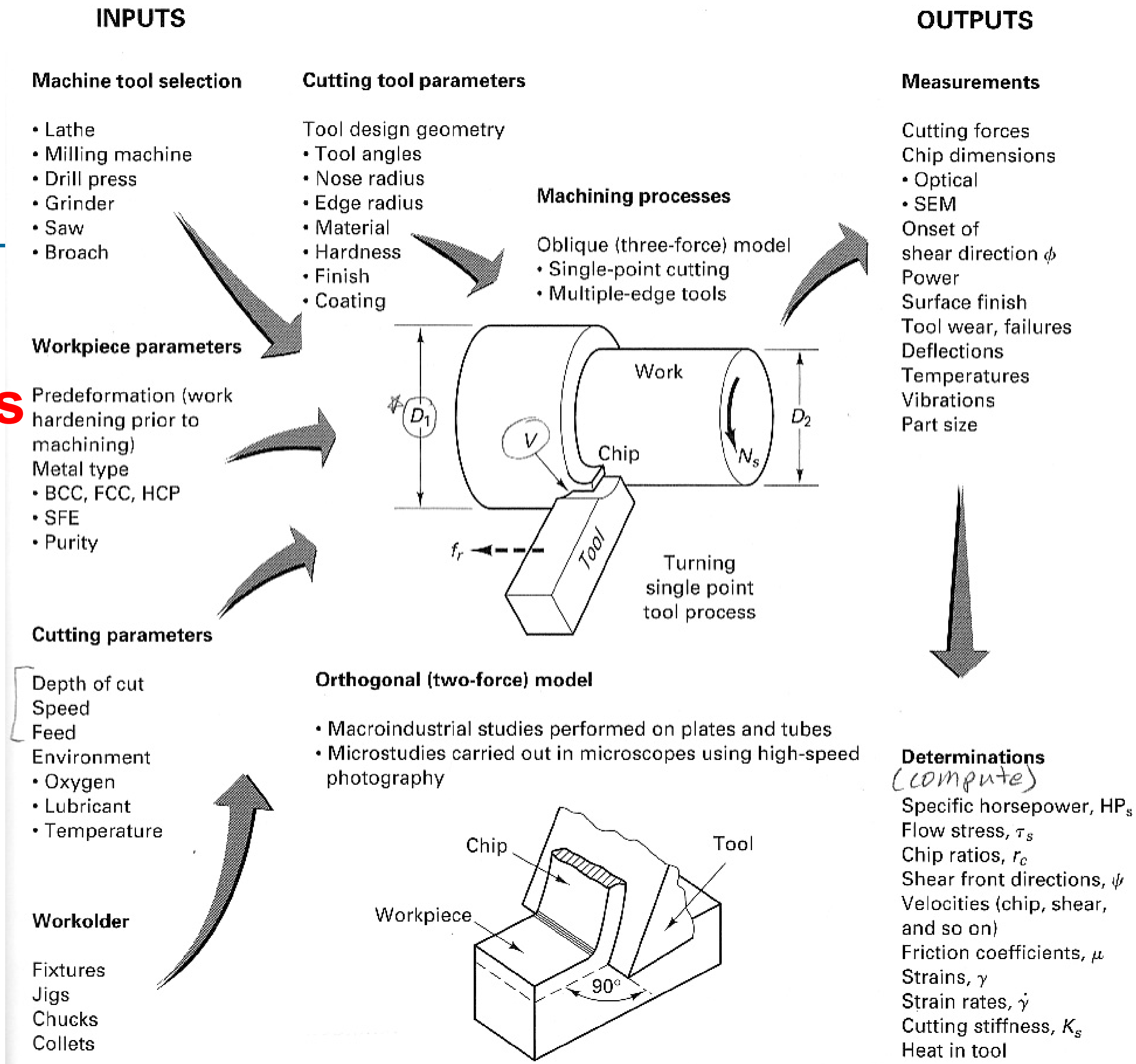
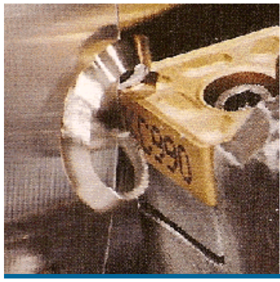
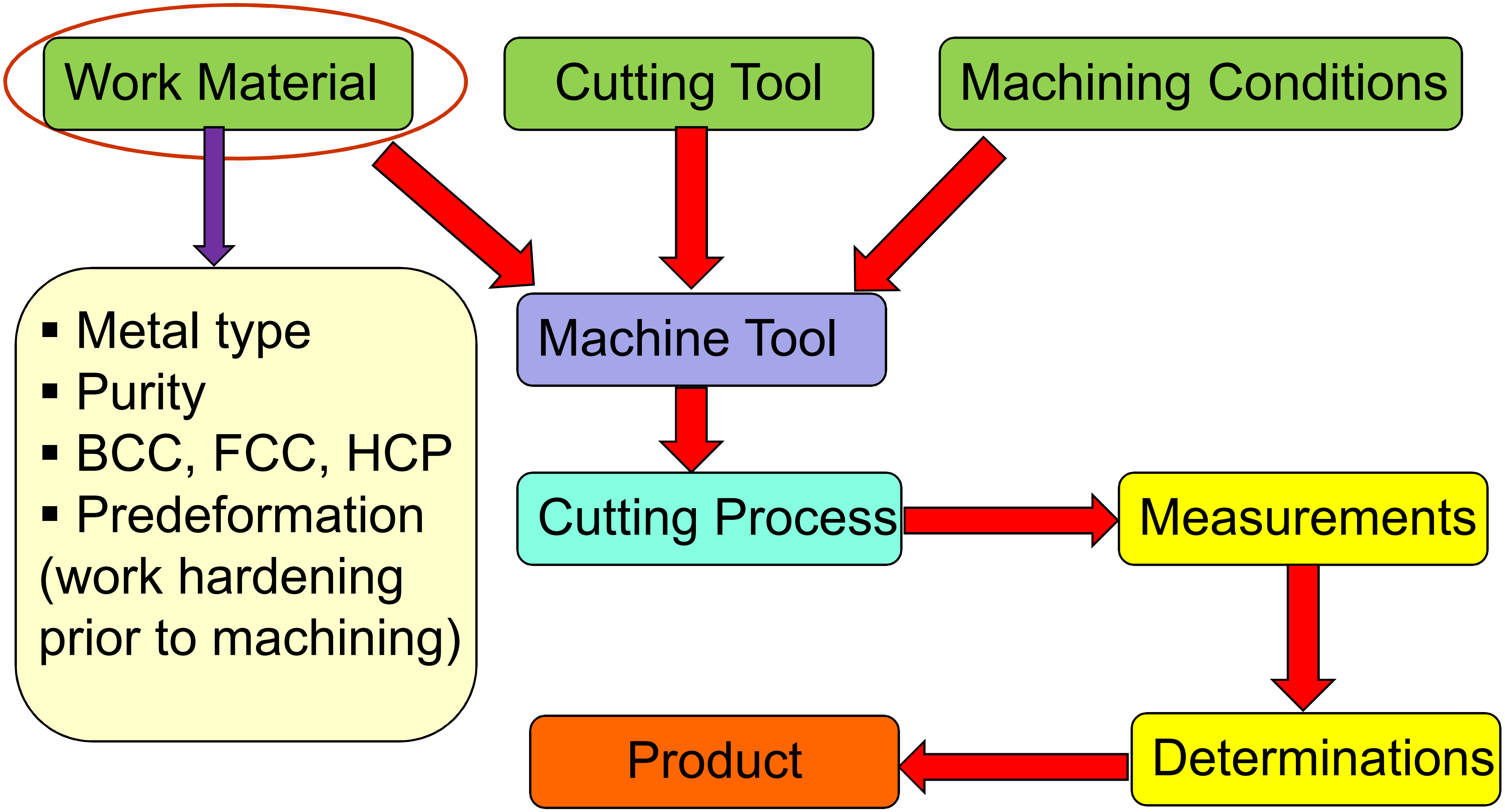
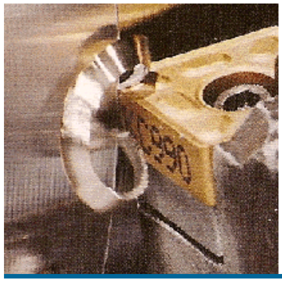


FIGURE 21-1 The fundamental inputs and outputs to machining processes.




Work Material
Cutting Tool
Machining Conditions
Machine Tool
Cutting Process
Measurements
Determinations
Product
▪ Metal type
▪ Purity
▪ BCC, FCC, HCP
▪ Predeformation (work hardening prior to machining)

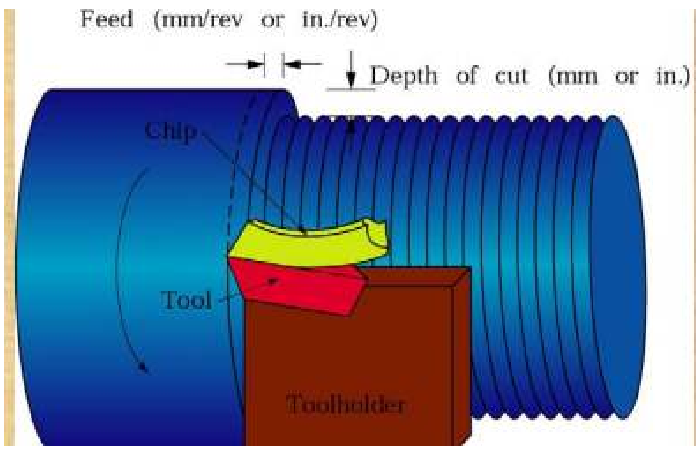


Machining Conditions

- Cutting parameters
  - Depth of cut
  - Speed
  - Feed

- Environment
  - Lubricant (cutting fluid)
  - Oxygen
  - Temperature

- Workholder
  - Fixtures
  - Jigs
  - Chucks
  - Collets

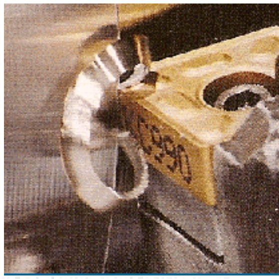


- Cutting speed (*v)* – primary motion

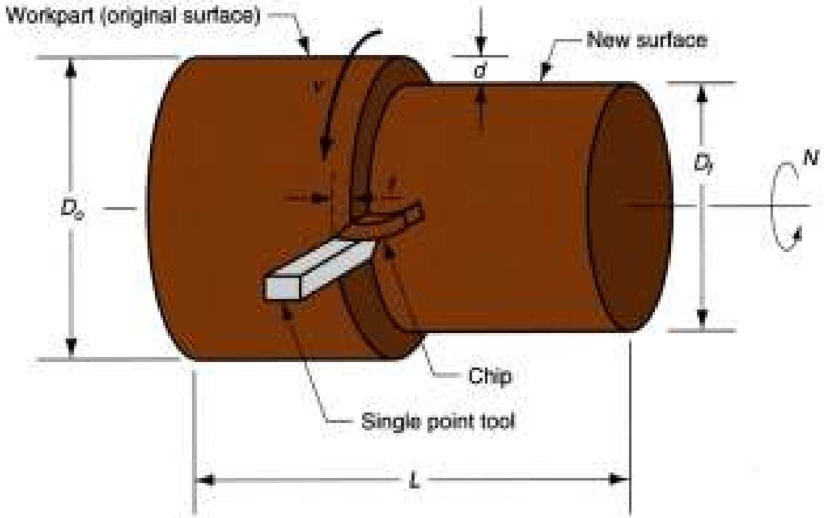
  The speed at which the work moves with respect to the tool

- Feed (*f)* – secondary motion

- Depth of cut (*d)* – penetration of tool below original work surface



Machining Conditions in Turning



- Spindle Speed - N

$$N = \frac{v}{\pi D_o}$$

  - v = cutting speed
  - D_o = outer diameter

- Feed Rate - f_r

$$f_r = N f$$

  - f = feed per rev

- Depth of Cut - d

$$d = \frac{D_o - D_f}{2}$$

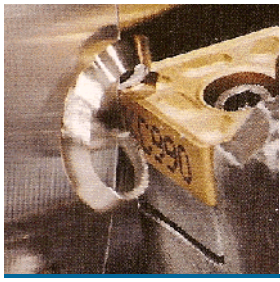
- Machining Time - T_m

$$T_m = \frac{L}{f_r}$$

  - L = length of cut

- Material Removal Rate - MRR

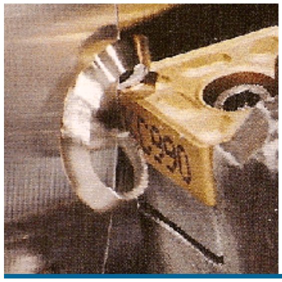
$$MRR = v\, f\, d$$



Cutting Fluids

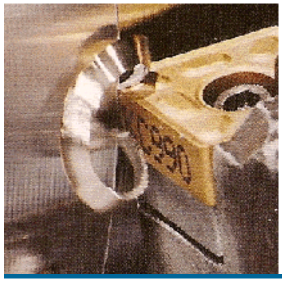
Any liquid or gas applied directly to machining operation to improve cutting performance

- Two main problems addressed by cutting fluids:
  1. Heat generation at shear zone and friction zone
  2. Friction at the 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



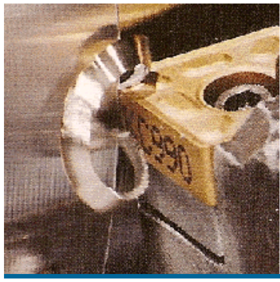
Cutting Fluid Functions

- 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



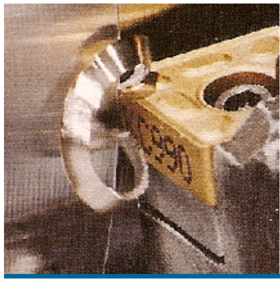
Coolants

- 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)

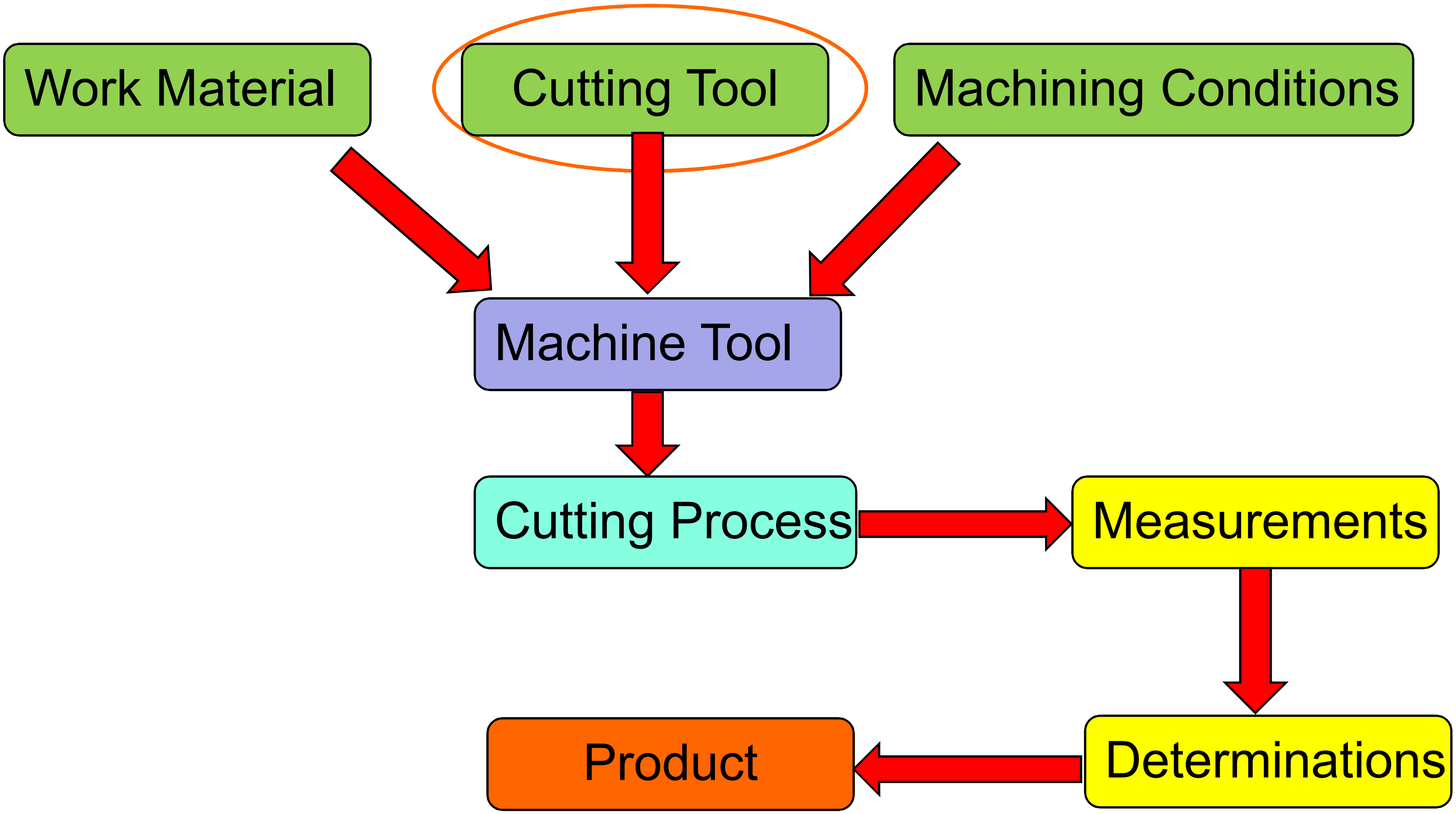


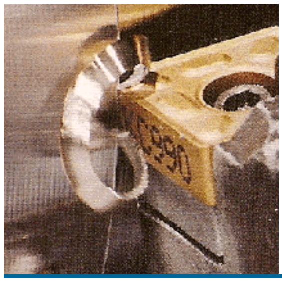
Lubricants

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



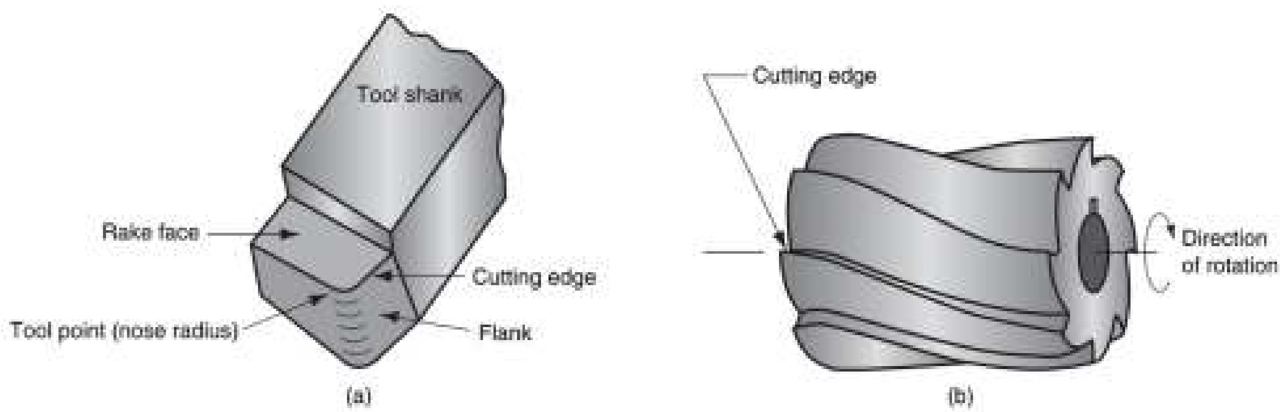
What we discussed in the last class?

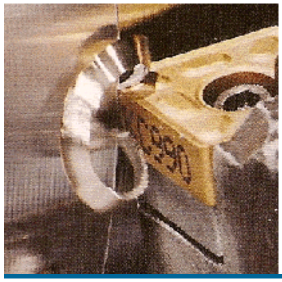




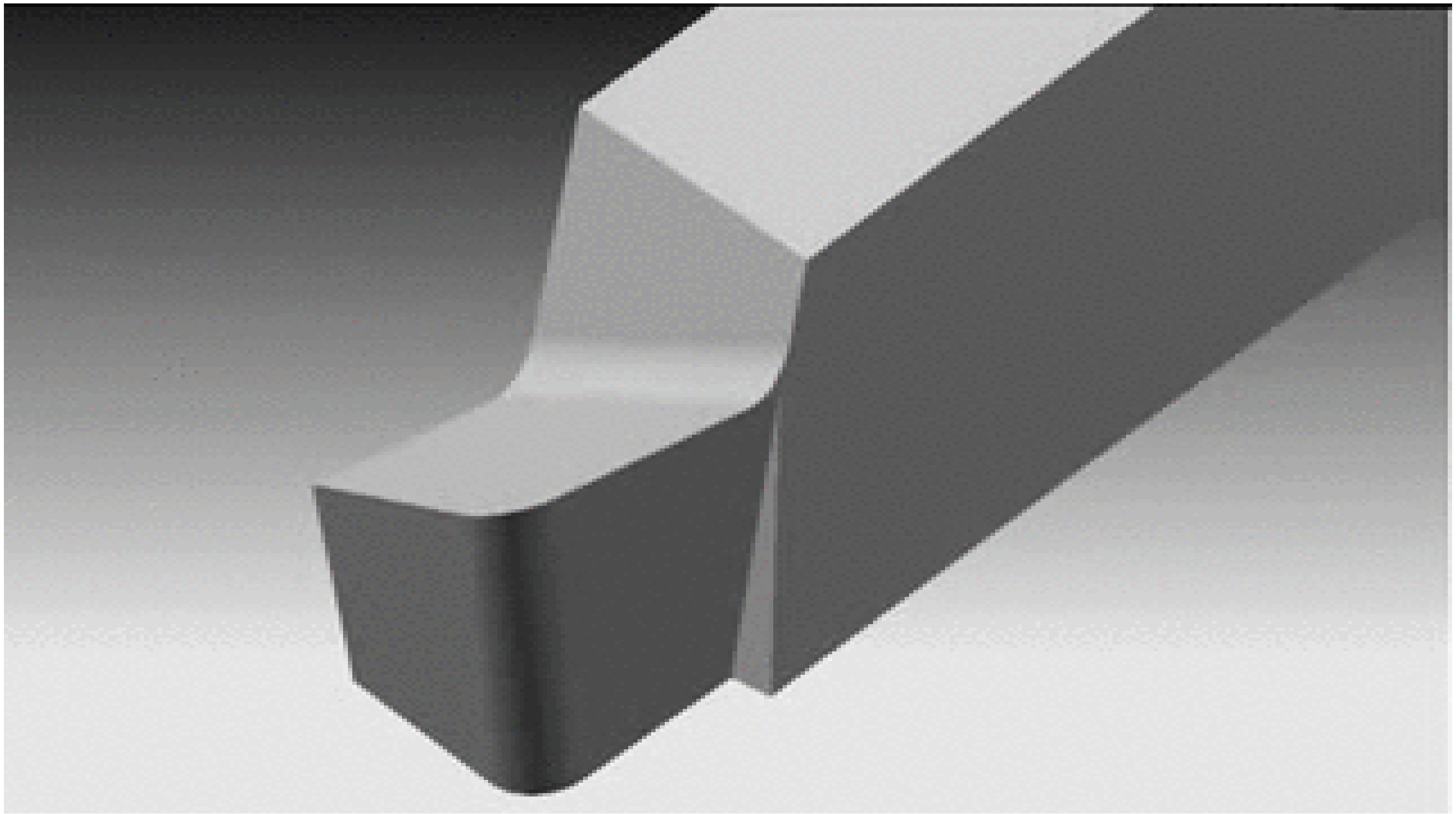
Cutting Tool Classification

1. Single-Point Tools
   - One dominant cutting edge
   - Point is usually rounded to form a nose radius
   - Turning uses single point tools
2. Multiple Cutting Edge Tools
   - More than one cutting edge
   - Motion relative to work achieved by rotating
   - Drilling and milling use rotating multiple cutting edge tools

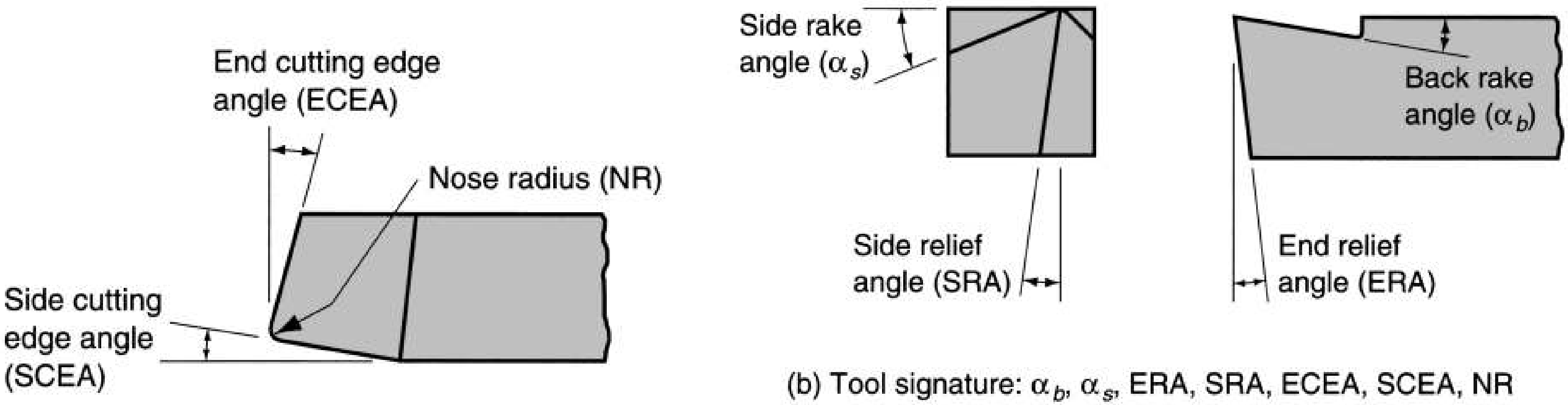




Geometry of single point cutting tool

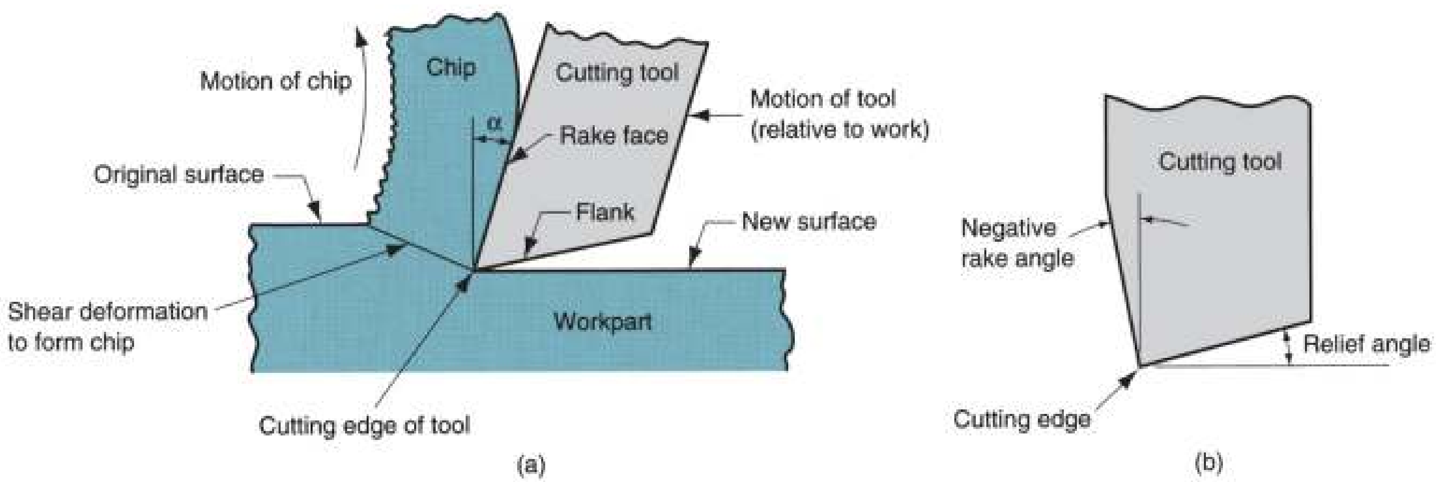


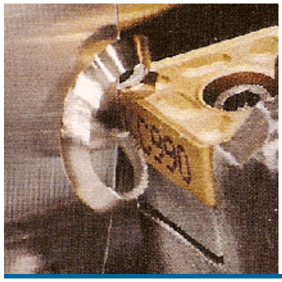
Single-Point Tool Geometry



(a)

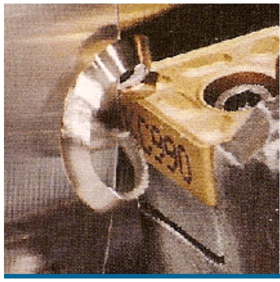
Figure: (a) Seven elements of single-point tool geometry; and (b) the tool signature convention that defines the seven elements





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



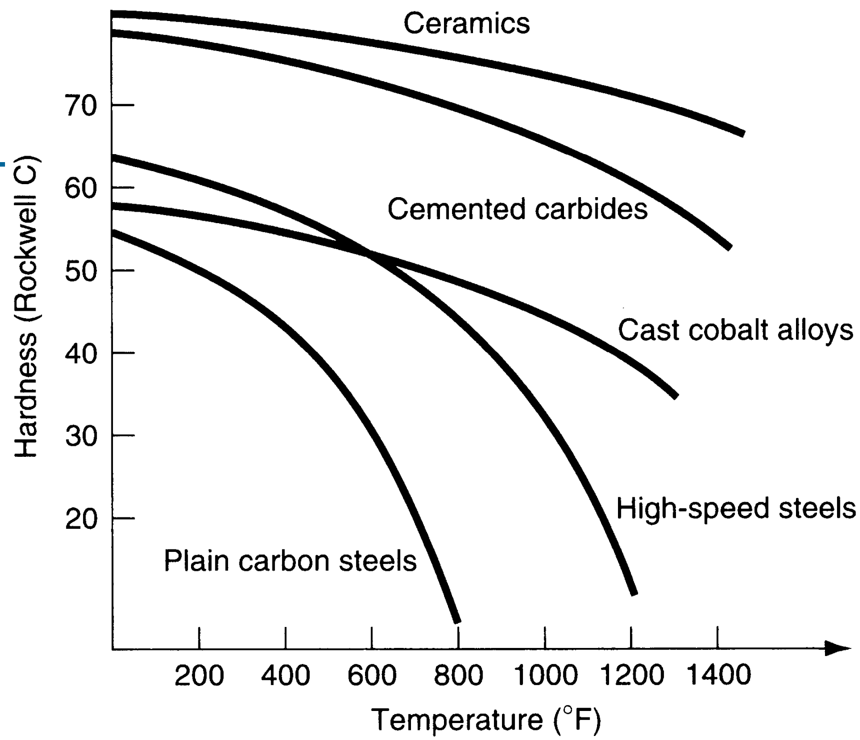
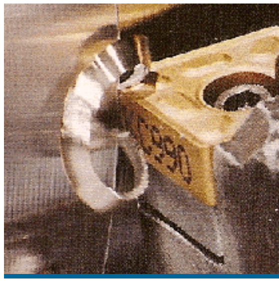


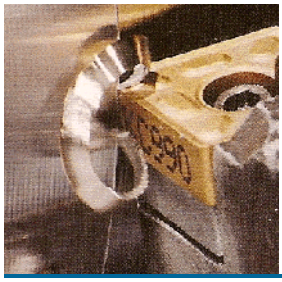
Figure - Typical hot hardness relationships for selected tool materials. Plain carbon steel shows a rapid loss of hardness as temperature increases. High speed steel is substantially better, while cemented carbides and ceramics are significantly harder at elevated temperatures.



High Speed Steel (HSS)

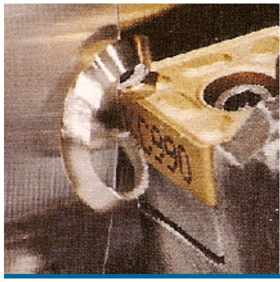
Highly alloyed tool steel capable of maintaining hardness at elevated temperatures better than high carbon and low alloy steels

- 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

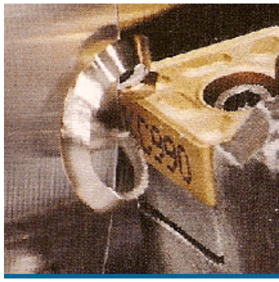
- Typical alloying ingredients:
  - Tungsten and/or Molybdenum
  - Chromium and Vanadium
  - Carbon, of course
  - Cobalt in some grades
- Typical composition:
  - Grade T1: 18% W, 4% Cr, 1% V, and 0.9% C



Cemented Carbides

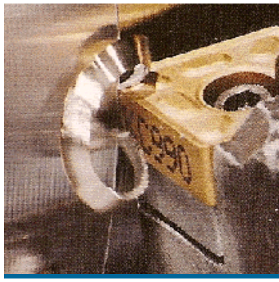
Class of hard tool material based on tungsten carbide (WC) using powder metallurgy techniques with cobalt (Co) as the binder

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



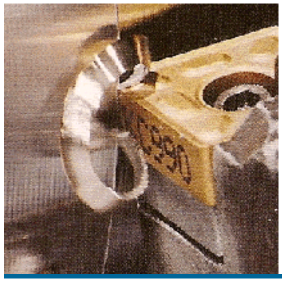
Cemented Carbides – General Properties

- 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 x 10^3 MPa (90 x 10^6 lb/in^2)
- Toughness lower than high speed steel



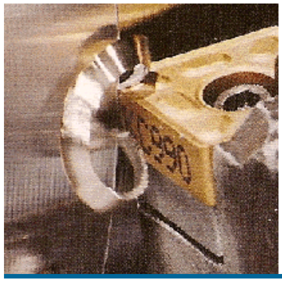
Non-steel Cutting Carbide Grades

- 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

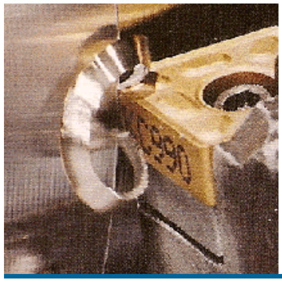
- Used for low carbon, stainless, and other alloy steels
    - For these grades, TiC and/or TaC are substituted for some of the WC
    - This composition increases crater wear resistance for steel cutting, but adversely affects flank wear resistance for non-steel cutting applications



Cermets

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

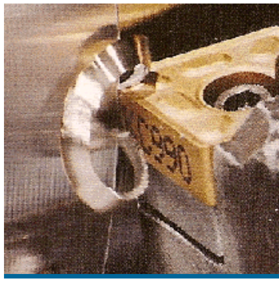
- Some chemistries are more complex
- Applications: high speed finishing and semifinishing of steels, stainless steels, and cast irons
  - Higher speeds and lower feeds than steel-cutting carbide grades
  - Better finish achieved, often eliminating need for grinding



Coated Carbides

Cemented carbide insert coated with one or more thin layers of wear resistant materials, such as TiC, TiN, and/orAl_2O_3

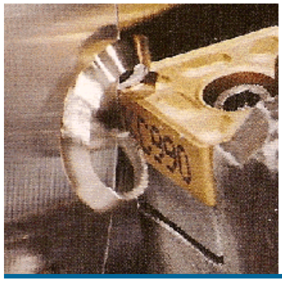
- Coating applied by chemical vapor deposition or physical vapor deposition
- Coating thickness = 2.5 - 13 μm (0.0001 to 0.0005 in)
- Applications: cast irons and steels in turning and milling operations
- Best applied at high speeds where dynamic force and thermal shock are minimal



Ceramics

Primarily fine-grained Al_2O_3, pressed and sintered at high pressures and temperatures into insert form with no binder

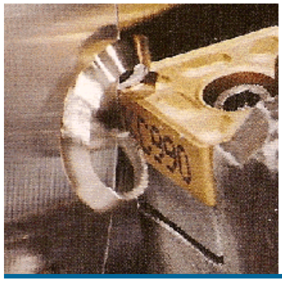
- Applications: high speed turning of cast iron and steel
- Not recommended for heavy interrupted cuts (e.g. rough milling) due to low toughness
- Al_2O_3 also widely used as an abrasive in grinding



Synthetic Diamonds

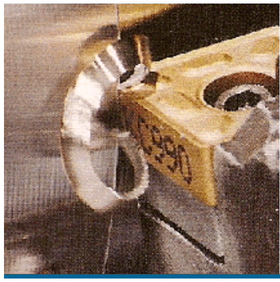
Sintered polycrystalline diamond (SPD) - fabricated by sintering very fine-grained diamond crystals under high temperatures and pressures into desired shape with little or no binder

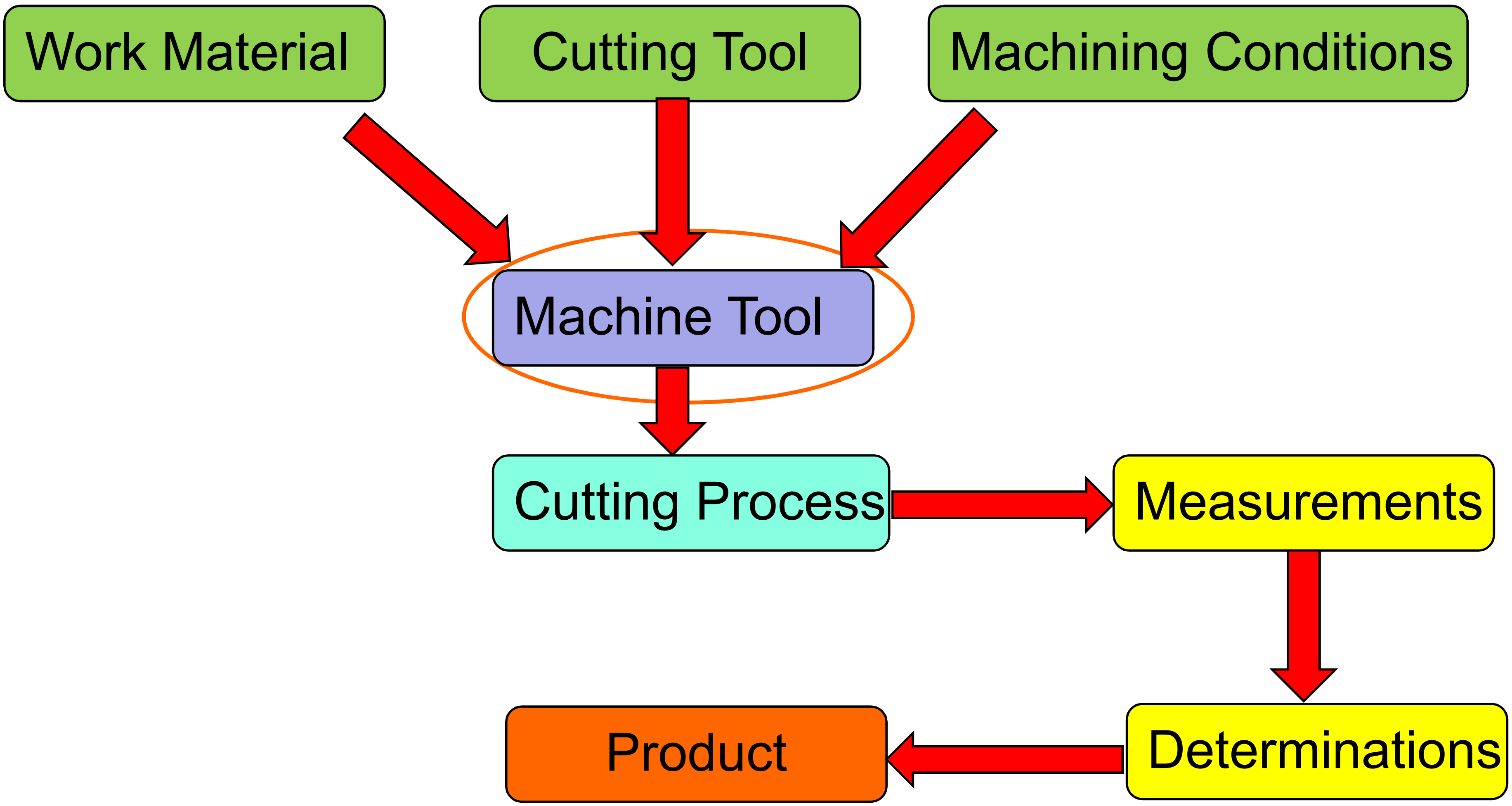
- Usually applied as coating (0.5 mm thick) on WC-Co insert
- Applications: high speed machining of nonferrous metals and abrasive nonmetals such as fiberglass, graphite, and wood
  - Not for steel cutting

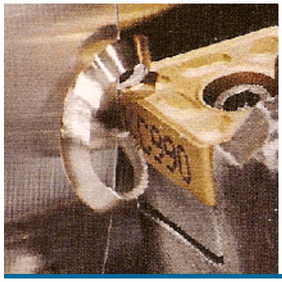


Cubic Boron Nitride

- 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

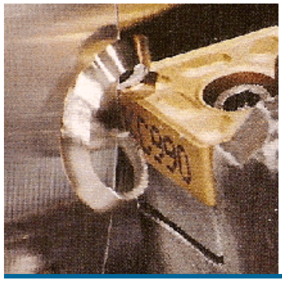



Work Material
Cutting Tool
Machining Conditions
Machine Tool
Cutting Process
Measurements
Determinations
Product



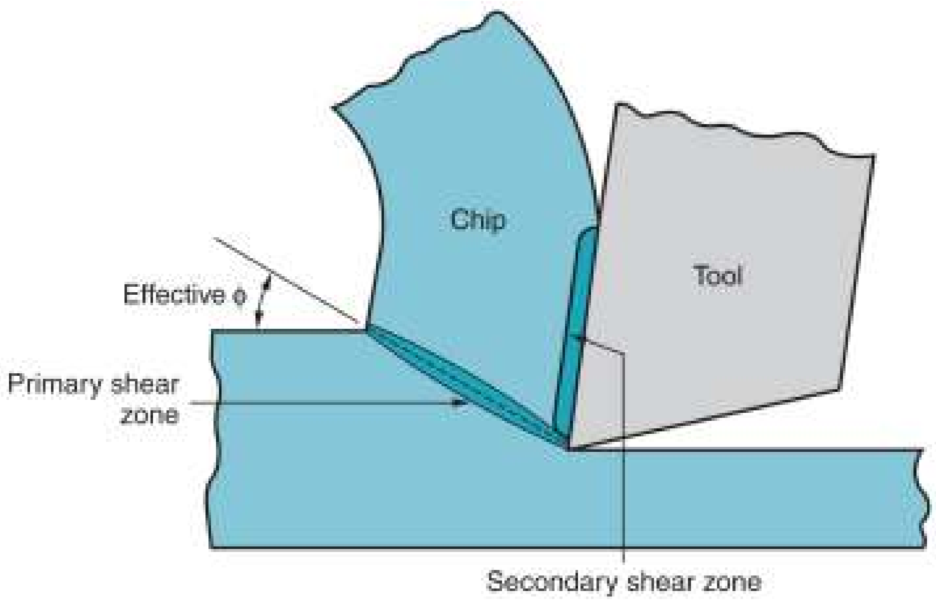
Machine Tool

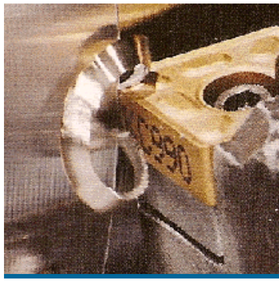
- While holding the cutting tools would be able to remove metal from a workpiece, in order to generate the given job size, configuration and finish.
- It is different from a machine, which essentially is a means of converting a source of power from one form to the other.



Cutting Process: Chip Formation

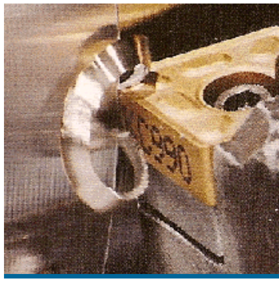
- More realistic view of chip formation, showing shear zone rather than shear plane
- Also shown is the secondary shear zone resulting from *tool-chip friction*





Four Basic Types of Chip in Machining

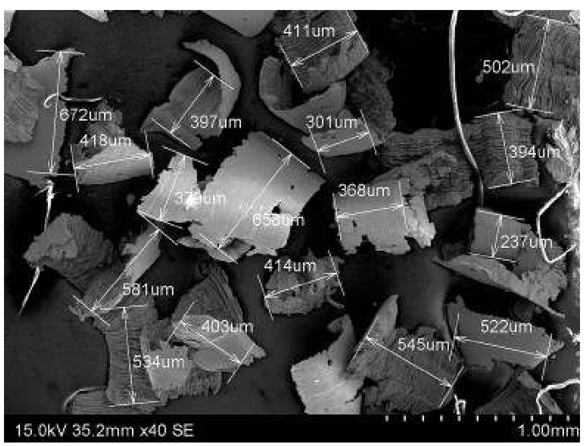
1. Discontinuous chip
2. Continuous chip
3. Continuous chip with Built-up Edge (BUE)
4. Serrated chip

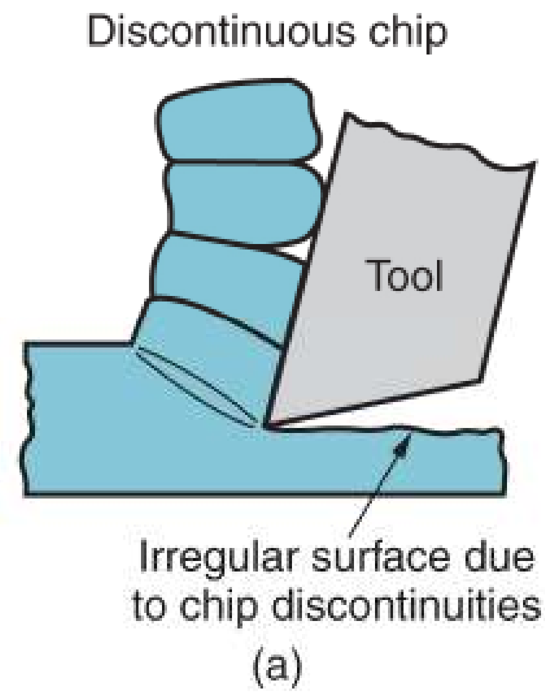


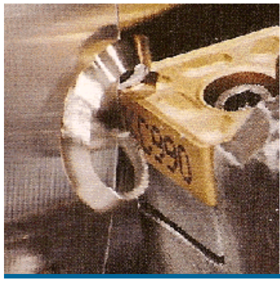
Discontinuous Chip

- Brittle work materials
- Low cutting speeds
- Large feed and depth of cut
- High tool-chip friction

Optics and Lasers in Engineering, Volume 49, Issue 2, February 2011, Pages 240–247



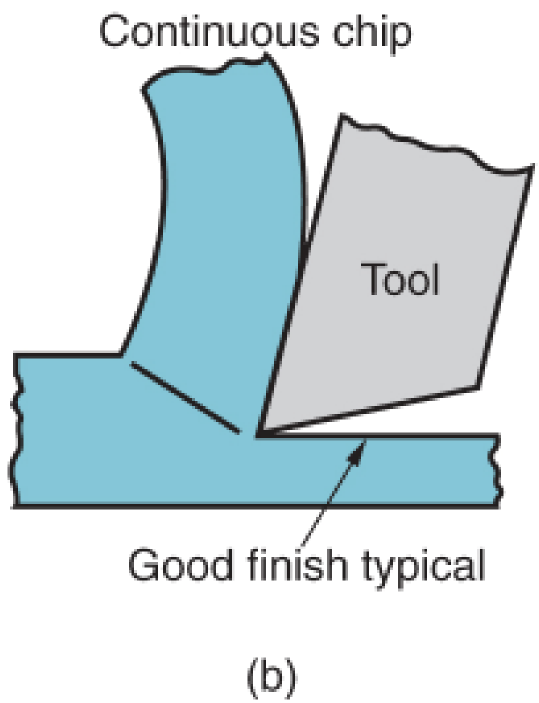


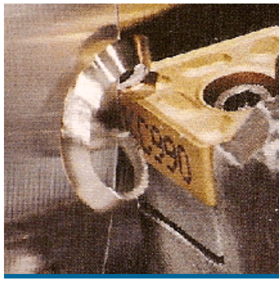


Continuous Chip

- Ductile work materials
- High cutting speeds
- Small feeds and depths
- Sharp cutting edge
- Low tool-chip friction

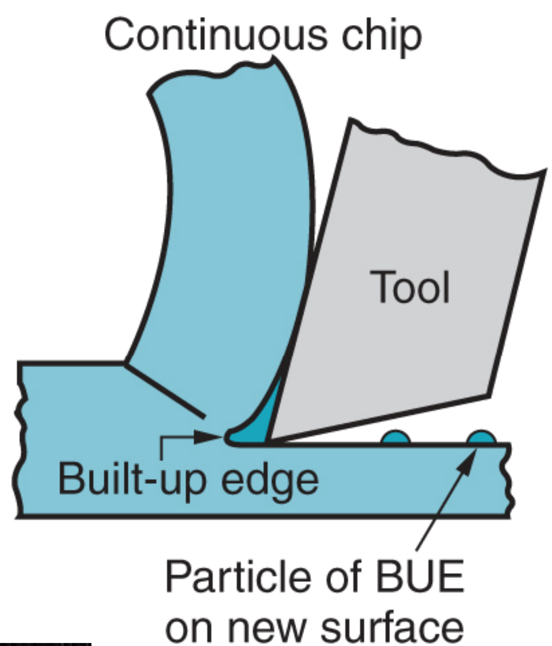
Journal of Materials Processing Technology, Volume 121, Issues 2–3, 28 February 2002, Pages 363–372





Continuous with BUE

- Ductile materials
- Low-to-medium cutting speeds
- Tool-chip friction causes portions of chip to adhere to rake face
- BUE forms, then breaks off, cyclically



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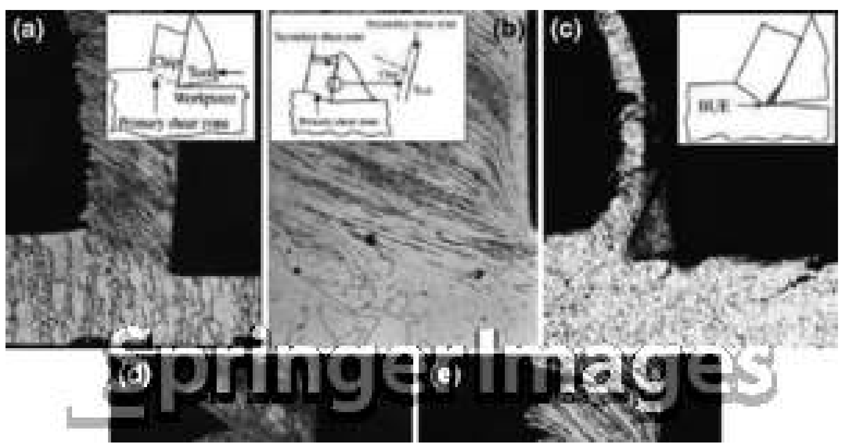
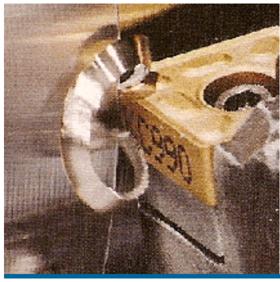
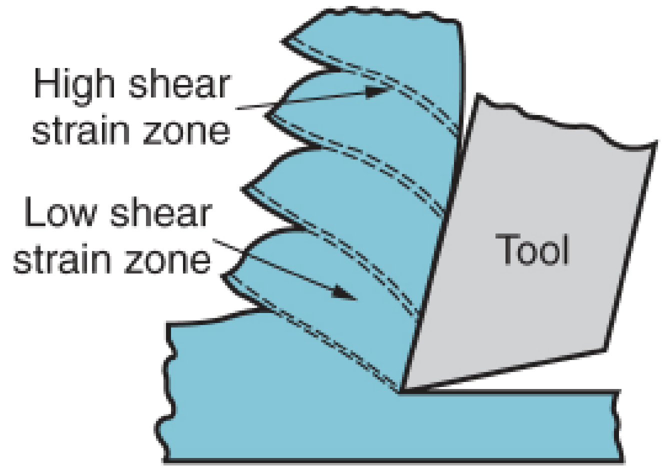




Serrated Chip

- Semi-continuous - saw-tooth appearance
- Cyclical chip forms with alternating high shear strain then low shear strain
- Associated with difficult-to-machine metals at high cutting speeds



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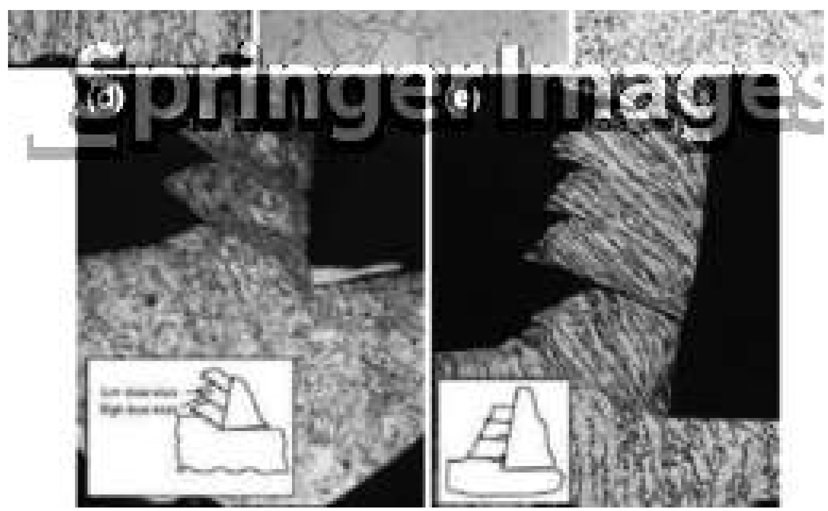
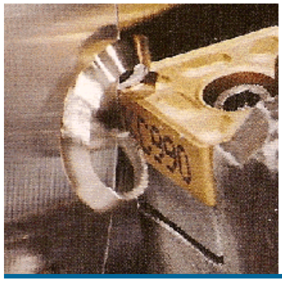
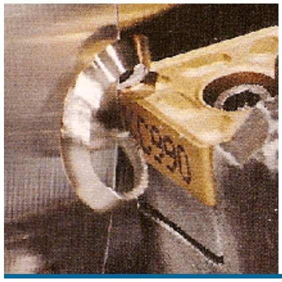




Roughing vs. Finishing Cuts

- Higher the rake angle, better is the cutting and less is the cutting force. Several roughing cuts are usually taken on a part, followed by one or two finishing cuts
  - Roughing - removes large amounts of material from starting workpart
    - Some material remains for finish cutting
    - High feeds and depths, low speeds
  - Finishing - completes part geometry
    - Final dimensions, tolerances, and finish
    - Low feeds and depths, high cutting speeds



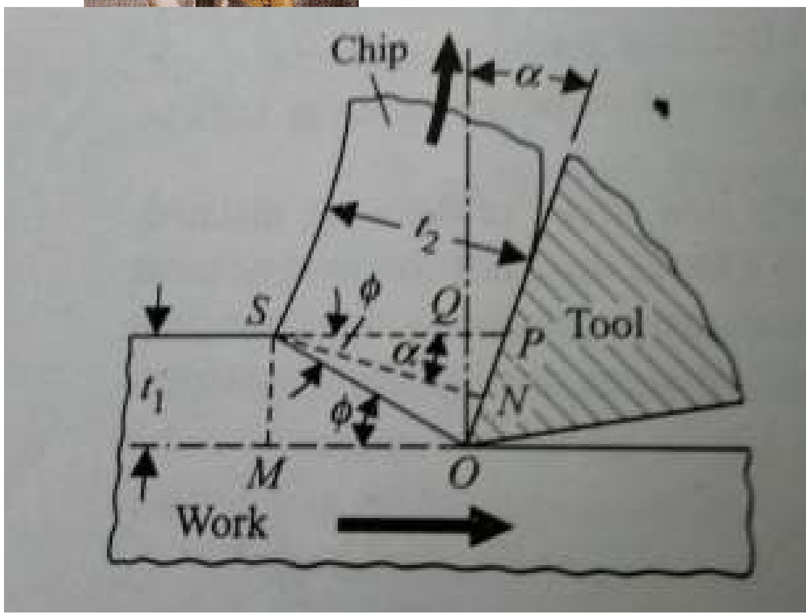
Chip Thickness Ratio

$$r = \frac{t_o}{t_c}$$

where r = *chip thickness ratio*; t_o = thickness of the chip prior to chip formation; and t_c = chip thickness after separation

- Chip thickness after cut is always greater than before, so chip ratio is always less than 1.0
- Why is $t_c > t_o$?

Determining Shear Plane Angle



Considering two right angle triangles ΔSNO and ΔQPO

$$\angle PSN = \angle POQ = \alpha$$

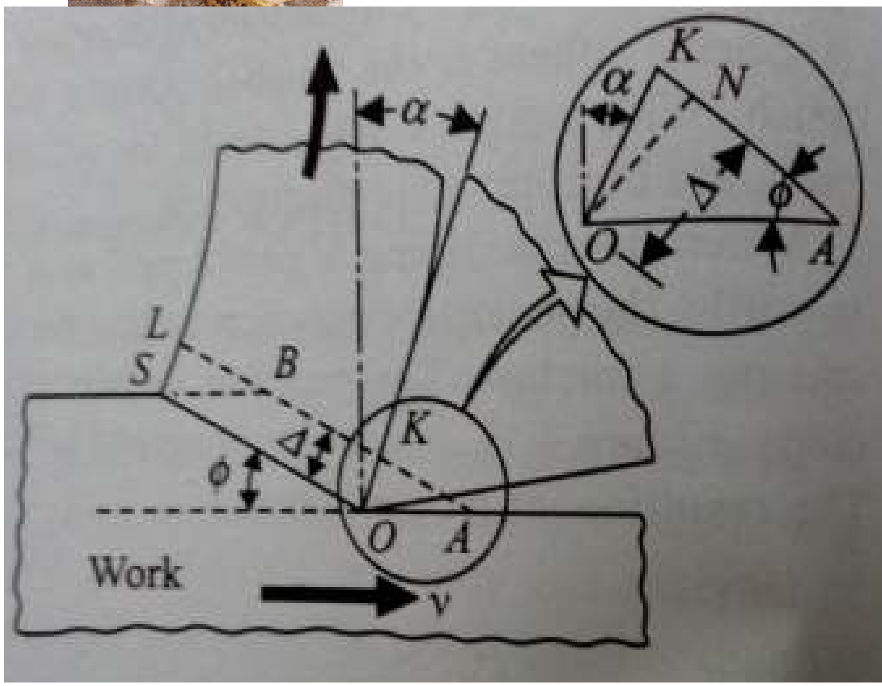
$$\angle NSO = \angle PSO - \angle PSN = \phi - \alpha$$

$$OS = \frac{SN}{\cos(\phi - \alpha)} = \frac{t_2}{\cos(\phi - \alpha)} = \frac{SM}{\sin\phi} = \frac{t_1}{\sin\phi}$$

$$\frac{t_1}{t_2} = \frac{\sin\phi}{\cos(\phi - \alpha)} = r \qquad \text{or} \qquad \tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

where r = chip ratio, and α = rake angle

Shear Strain in Chip Formation



Let us consider an element of the undeformed work material ABSO of thickness Δ.

Due to presence of the tool, it is sheared to the shape KLSO.

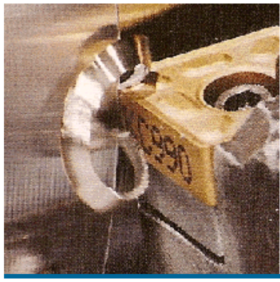
$$\angle KAO = \phi$$

$$\angle OKA = \frac{\pi}{2} + \alpha - \phi$$

Shear strain $\gamma = \dfrac{AK}{\Delta} = \dfrac{AN + NK}{ON} = \cot\phi + \tan\angle KON$

$$\gamma = \tan(\phi - \alpha) + \cot\phi$$

where γ = shear strain, ϕ = shear plane angle, and α = rake angle of cutting tool



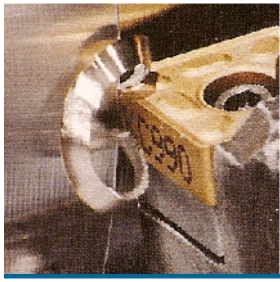
Example 1

Question: In an orthogonal cutting operation, the 0.250 in wide tool has a rake angle of 5°. The lathe is set so the chip thickness before the cut is 0.010 in. After the cut, the deformed chip thickness is measured to be 0.027 in. Calculate (a) the shear plane angle and (b) the shear strain for the operation.

Solution: (a) $r = t_o/t_c = 0.010/0.027 = 0.3701$

$\phi = \tan^{-1}(0.3701 \cos 5/(1 - 0.3701 \sin 5)) = \tan^{-1}(0.3813) = \mathbf{20.9°}$

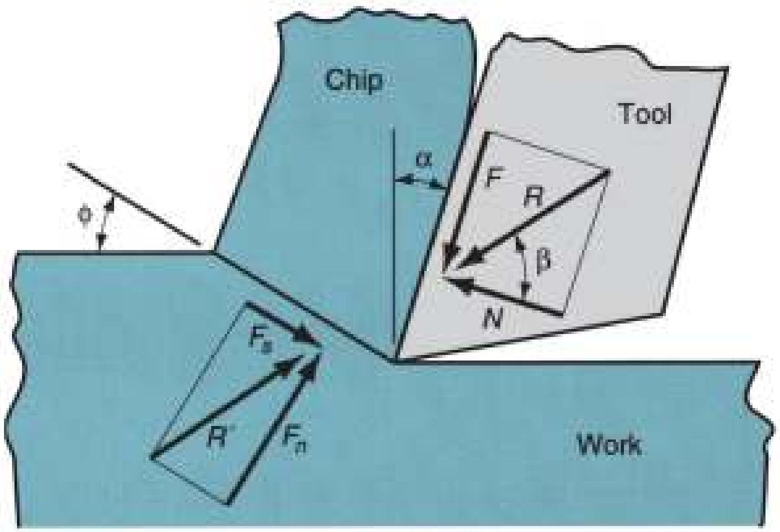
(b) Shear strain $\gamma = \cot 20.9 + \tan (20.9 – 5) = 2.623 + 0.284 = \mathbf{2.907}$



Forces Acting on Chip

(a) Friction force *F* and Normal force to friction *N*

(b) Shear force F_s and Normal force to shear F_n



(a)

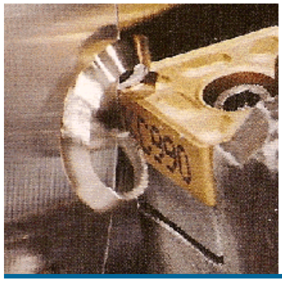
- Coefficient of friction between tool and chip

$$\mu = \frac{F}{N}$$

- Friction angle related to coefficient of friction as $\mu = \tan\beta$

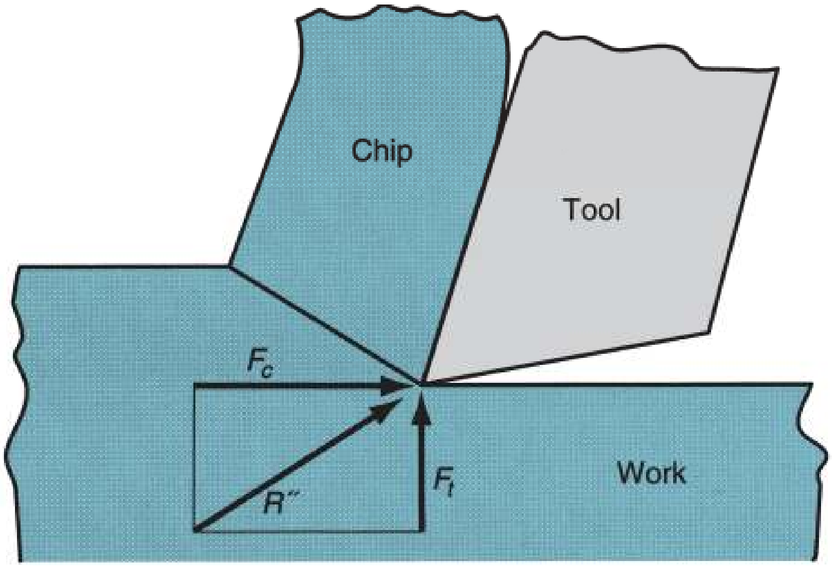
- Shear stress acting along the shear plane $S = \frac{F_s}{A_s}$

where A_s = area of the shear plane $A_s = \frac{t_o w}{\sin\phi}$

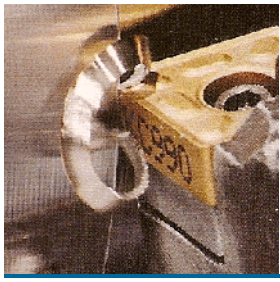


Cutting Force and Thrust Force

- F, N, F_s, and F_n cannot be directly measured
- Forces acting on the tool that can be measured: Cutting force F_c and Thrust force F_t

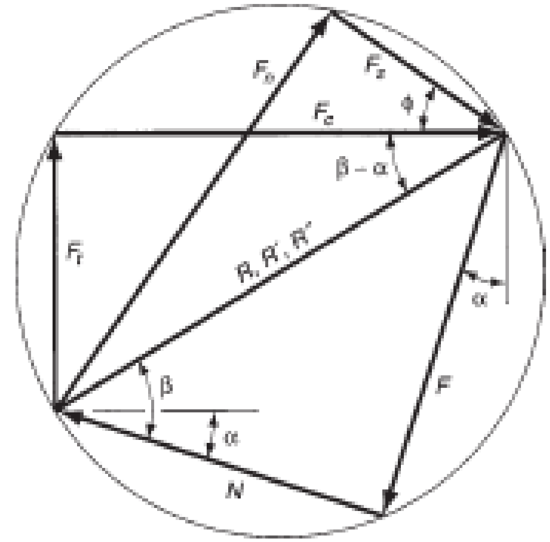


(b)



Forces in Metal Cutting

- Equations to relate the forces that cannot be measured to the forces that can be measured:



$$F = F_c \sin\alpha + F_t \cos\alpha$$

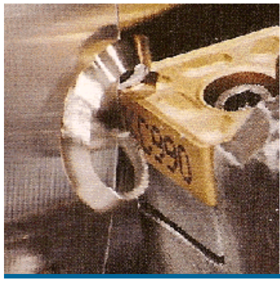
$$N = F_c \cos\alpha - F_t \sin\alpha$$

$$F_s = F_c \cos\phi - F_t \sin\phi$$

$$F_n = F_c \sin\phi + F_t \cos\phi$$

- Based on these calculated force,

  shear stress and coefficient of friction can be determined

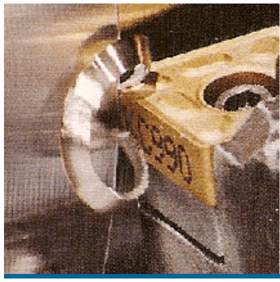


The Merchant Equation

- Of all the possible angles at which shear deformation can occur, the work material will select a shear plane angle ϕ that minimizes energy

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

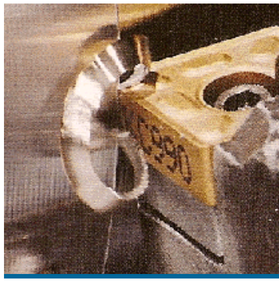
- Derived by Eugene Merchant
- Based on orthogonal cutting, but validity extends to 3-D machining



What the Merchant Equation Tells Us

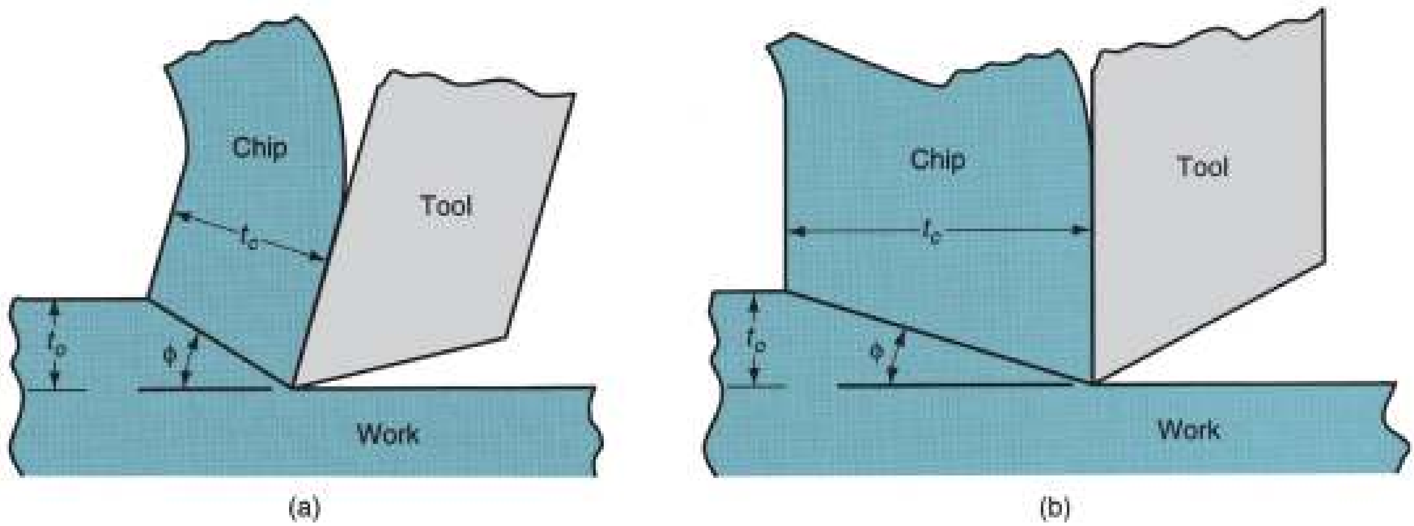
$$\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2}$$

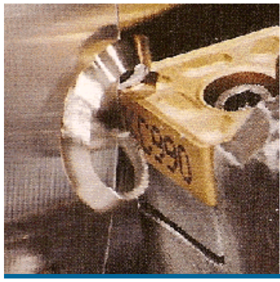
- To increase shear plane angle
  - Increase the rake angle
  - Reduce the friction angle (or reduce the coefficient of friction)



Effect of Higher Shear Plane Angle

- Higher shear plane angle means smaller shear plane which means lower shear force, cutting forces, power, and temperature





Power and Energy Relationships

- A machining operation requires power
- The power to perform machining can be computed from:

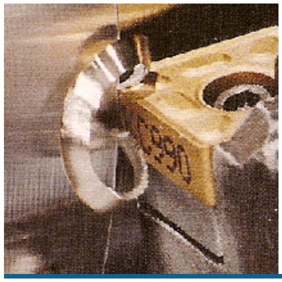
$$P_c = F_c v$$

where P_c = cutting power; F_c = cutting force; and v = cutting speed

- In U.S. customary units, power is traditional expressed as horsepower (dividing ft-lb/min by 33,000)

$$HP_c = \frac{F_c v}{33{,}000}$$

where HP_c = cutting horsepower, hp



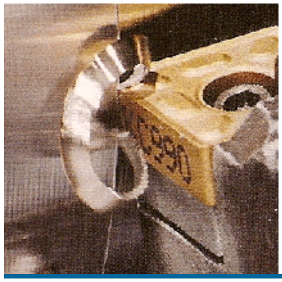
Power and Energy Relationships

- Gross power to operate the machine tool P_g or HP_g is given by

$$P_g = \frac{P_c}{E} \quad \text{or} \quad HP_g = \frac{HP_c}{E}$$

where E = mechanical efficiency of machine tool

- Typical E for machine tools $\sim$ 90%

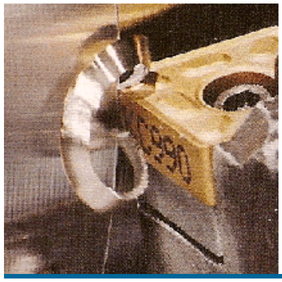


Unit Power in Machining

- It is often useful to convert power into power per unit volume rate of metal cut
- Called *unit power*, P_u or *unit horsepower*, HP_u

$$P_U = \frac{P_c}{R_{MR}} \quad \text{or} \quad HP_u = \frac{HP_c}{R_{MR}}$$

where R_{MR} = material removal rate

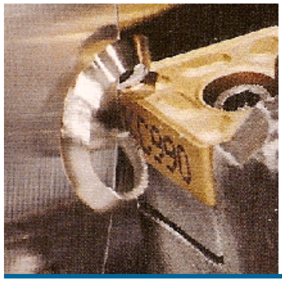


Specific Energy in Machining

- Unit power is also known as the *specific energy U*

$$U = P_u = \frac{P_c}{R_{MR}} = \frac{F_c v}{v t_o w}$$

where Units for specific energy are typically
N-m/mm^3 or J/mm^3 (in-lb/in^3)



Example 2

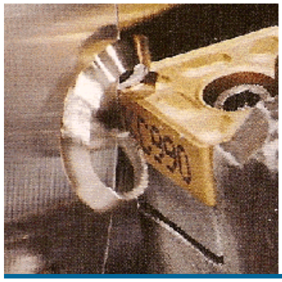
Question: In a turning operation on stainless steel with hardness = 200 HB, the cutting speed = 200 m/min, feed = 0.25 mm/rev, and depth of cut = 7.5 mm. How much power will the lathe draw in performing this operation if its mechanical efficiency = 90%. From Table, U = 2.8 N-m/mm^3 = 2.8 J/mm^3.

Solution:

$R_{MR} = vfd$ = (200 m/min)(10^3 mm/m)(0.25 mm)(7.5 mm) = 375,000 mm^3/min = 6250 mm^3/s

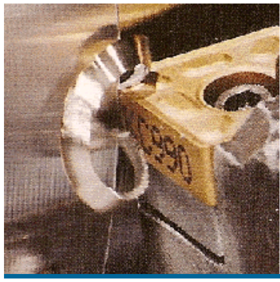
P_c = (6250 mm^3/s)(2.8 J/mm^3) = 17,500 J/s = 17,500 W = 17.5 kW

Accounting for mechanical efficiency, P_g = 17.5/0.90 = **19.44 kW**



Cutting Temperature

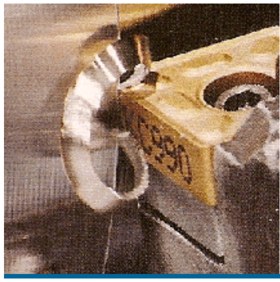
- Approximately 98% of the energy in machining is converted into heat
- This can cause temperatures to be very high at the tool-chip
- The remaining energy (about 2%) is retained as elastic energy in the chip



Cutting Temperatures are Important

High cutting temperatures

1. Reduce tool life
2. Produce hot chips that pose safety hazards to the machine operator
3. Can cause inaccuracies in part dimensions due to thermal expansion of work material

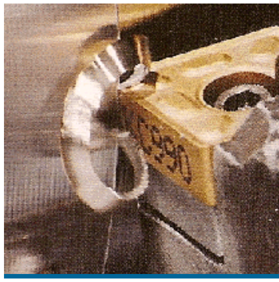


Cutting Temperature

- Analytical method derived by Nathan Cook from dimensional analysis using experimental data for various work materials

$$T = \frac{0.4U}{\rho C}\left(\frac{vt_o}{K}\right)^{0.333}$$

where T = temperature rise at tool-chip interface; U = specific energy; v = cutting speed; t_o = chip thickness before cut; ρC = volumetric specific heat of work material; K = thermal diffusivity of work material

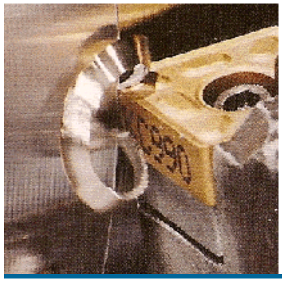


Cutting Temperature

- Experimental methods can be used to measure temperatures in machining
  - Most frequently used technique is the *tool-chip thermocouple*
- Using this method, Ken Trigger determined the speed-temperature relationship to be of the form:

$$T = K\,v^{m}$$

where T = measured tool-chip interface temperature, and v = cutting speed



Example 3

Consider a turning operation performed on steel whose hardness = 225 HB at a speed = 3.0 m/s, feed = 0.25 mm, and depth = 4.0 mm. Using values of thermal properties and the appropriate specific energy value from tables, compute an estimate of cutting temperature using the Cook equation. Assume ambient temperature = 20°C.

Solution: From Table, $U = 2.2$ N-m/mm^3 = 2.2 J/mm^3

From Table, $\rho = 7.87$ g/cm^3 = 7.87(10^{-3}) g/mm^3

From Table, $C = 0.11$ Cal/g-°C. From note “a” at the bottom of the table, 1 cal = 4.186 J.

From Table, thermal conductivity $k = 0.046$ J/s-mm-°C

Thus, $C = 0.11(4.186) = 0.460$ J/ g-°C

ρC = (7.87 g/cm^3)(0.46 J/g-°C) = 3.62(10^{-3}) J/mm^3-°C

Also, thermal diffusivity $K = k/\rho C$

K = 0.046 J/s-mm-°C /[(7.87 x 10^{-3} g/mm^3)(0.46 J/g-°C)] = 12.7 mm^2/s

Using Cook’s equation, $t_o = f = 0.25$ mm

$T = (0.4(2.2)/3.62(10^{-3}))[3(10^3)(0.25)/12.7]^{0.333} = 0.2428(10^3)(59.06)^{0.333}$

= 242.8(3.89) = 944.4 C°

Final temperature, taking ambient temperature in account T = 20 + 944 = **964°C**