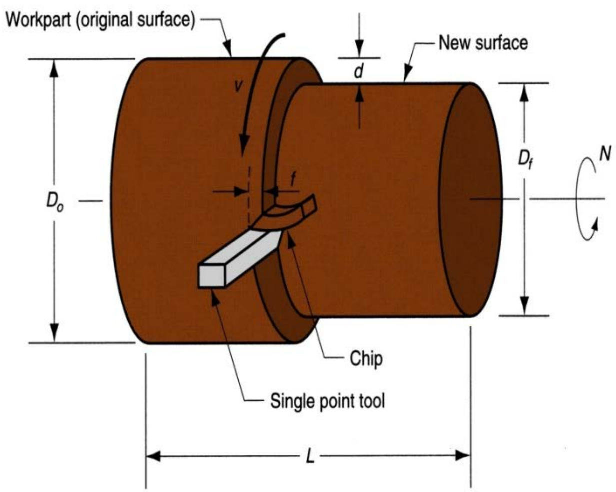
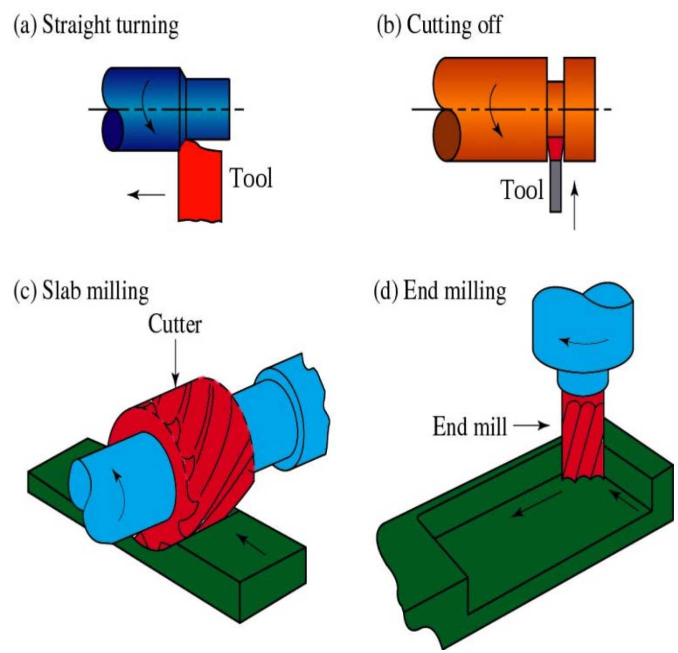
Machining Operations

In MACHINING, the shape, size, finish and accuracy are obtained by removing the excess material from the workpiece surface.

Various surfaces are obtained as an interaction between a workpiece and a cutting tool with the help of a contrivance known as MACHINE TOOL.





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Advantages and Disadvantages of Machining

- Variety of work materials can be machined.
  - Most frequently used to cut metals

- Variety of part shapes and special geometric features possible, such as:
  - Screw threads
  - Accurate round holes
  - Very straight edges and surfaces

- Good dimensional accuracy and surface finish
- Generally performed after other manufacturing processes, such as casting, forging, and bar drawing

Disadvantages:

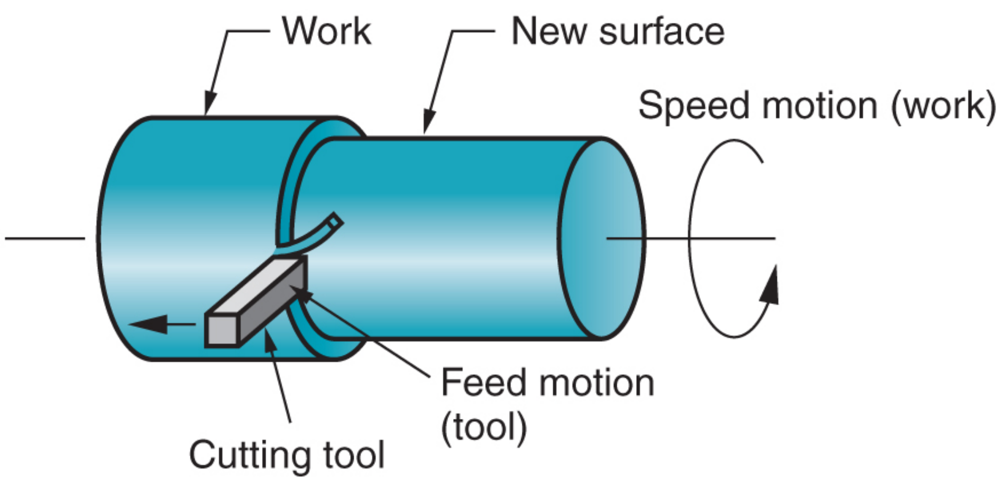
Wasteful of material and time consuming

Machining Operations

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

Turning

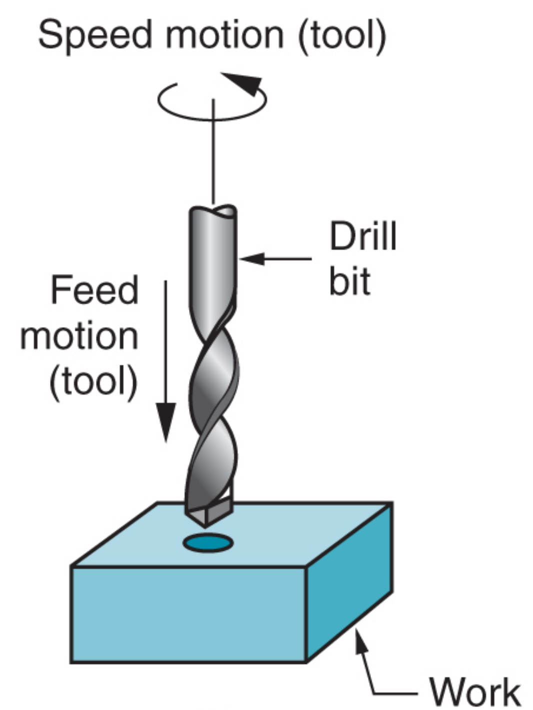
- Single point cutting tool removes material from a rotating workpiece to form a cylindrical shape



(a)

Drilling

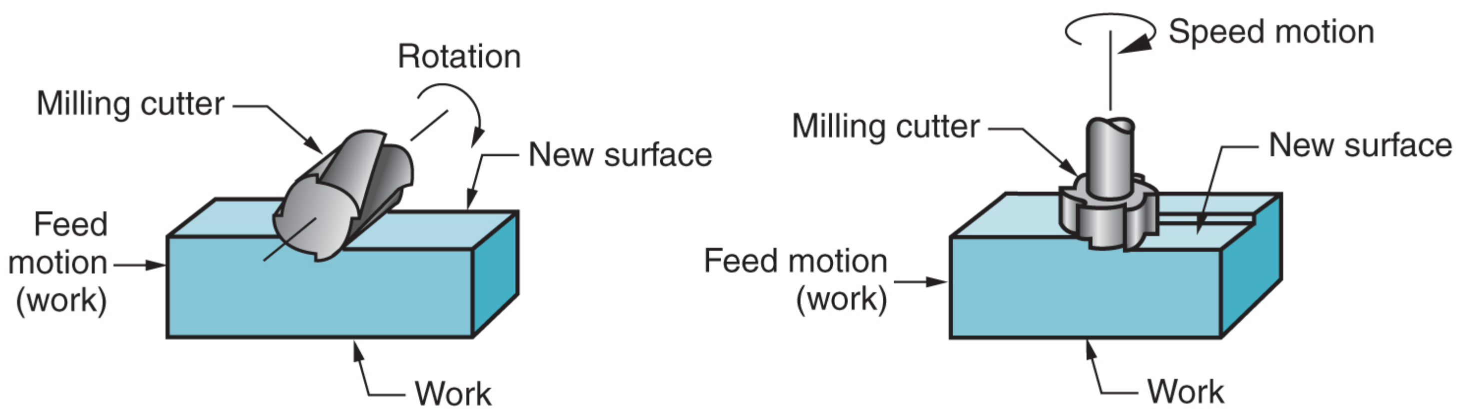
- Used to create a round hole, usually by means of a rotating tool (drill bit) with two cutting edges



(b)

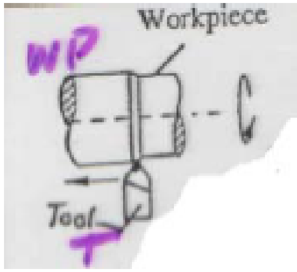
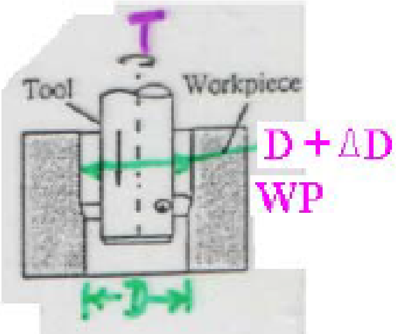
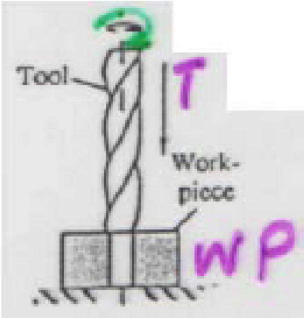
Milling

- 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

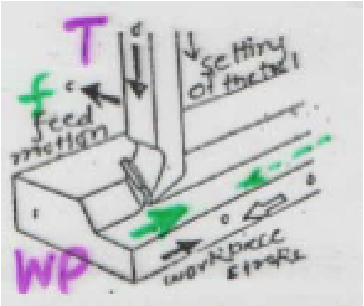
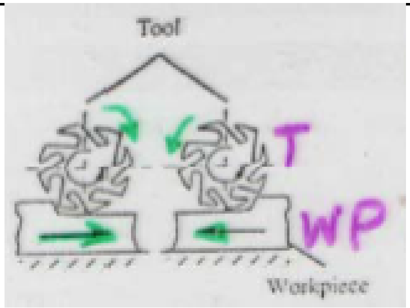
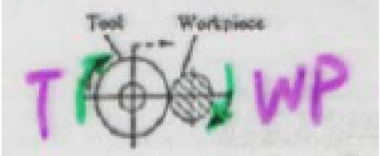


(c) (d)

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**	

Basic Machining Parameters

Speed (V) [m/min]

- Relates velocity of the cutting tool to the work piece (Primary motion).

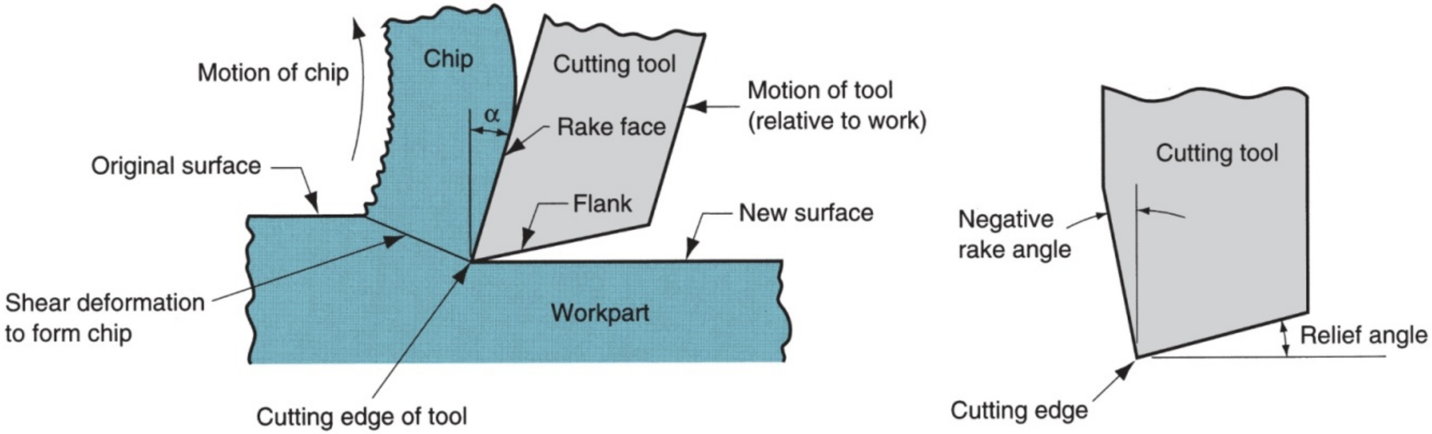
Feed (f) [mm/rev]

- Movement (advancement) of the tool per revolution of the workpiece

Depth of Cut (d) [mm]

- Distance the tool has plunged into the surface

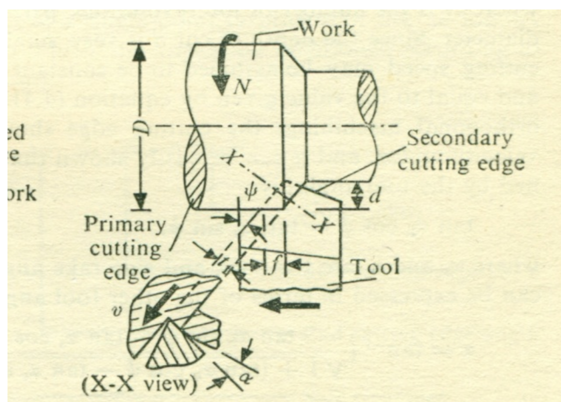
Chip Formation



(a) (b)

Cutting action involves shear deformation of work material to form a chip. As chip is removed, new surface is exposed.

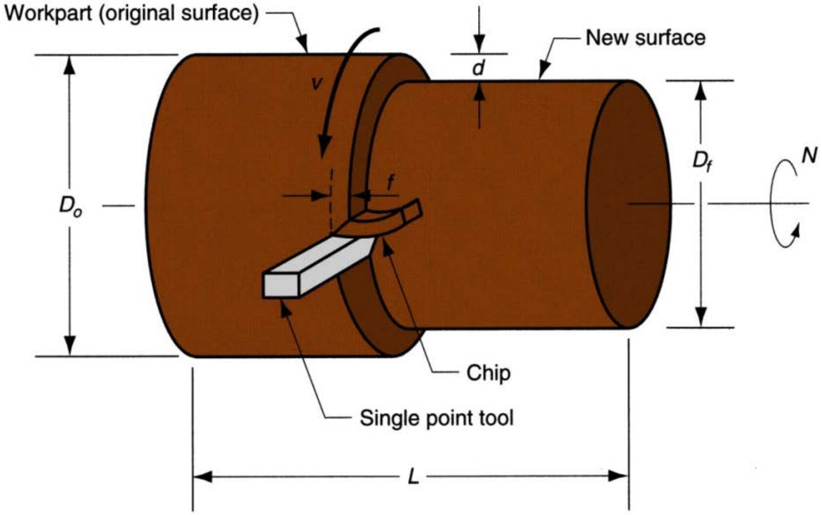
- t_1 – Uncut Thickness [mm]
- f – feed [mm/rev]
- w – Width of Cut [mm]
- d – Depth of Cut [mm]
- γ_s - Side Cutting Edge Angle



$$t_1 = f\cos\gamma_s$$

$$w = \frac{d}{\cos\gamma_s}$$

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

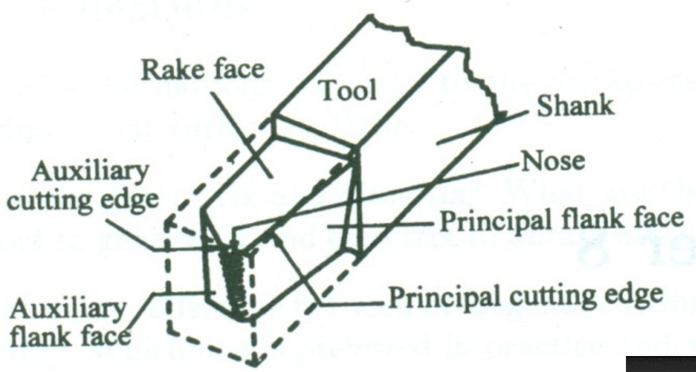
$$T_m = \frac{L}{f_r}$$

  - L = length of cut

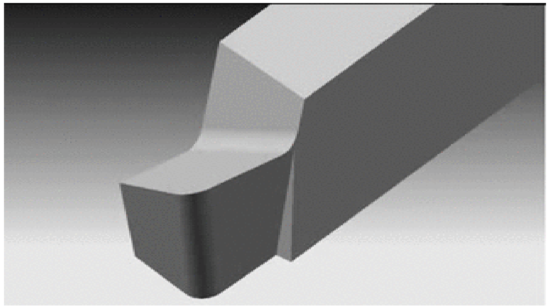
- Material Removal Rate - MRR

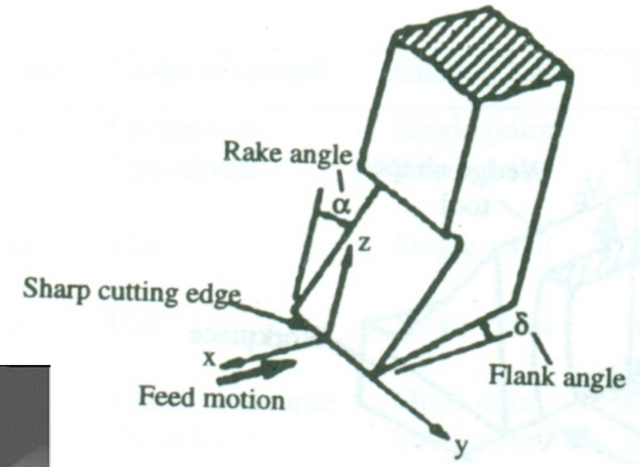
$$MRR = v f d$$

Cutting Tools & Types of Machining

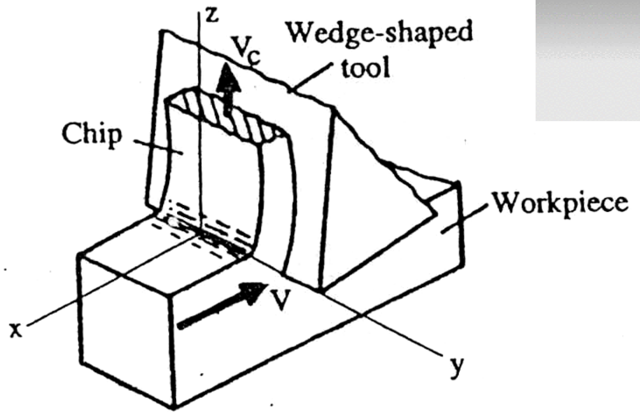


A Typical Lathe Tool

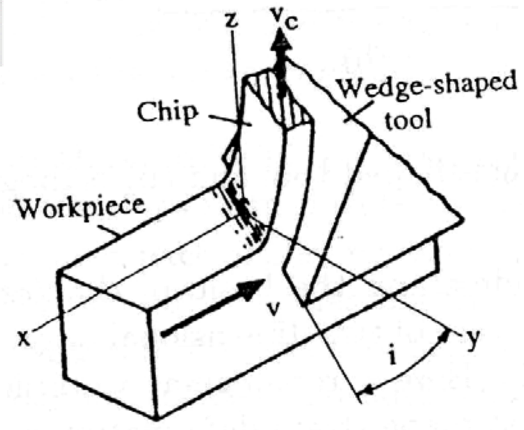




Wedge-Shaped tool



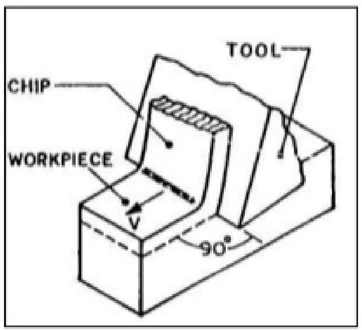
Orthogonal Cutting



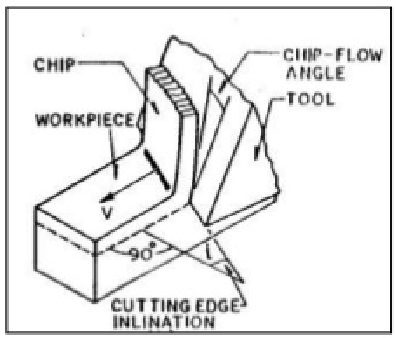
Oblique Cutting

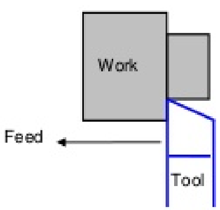
Cutting Tools & Types of Machining

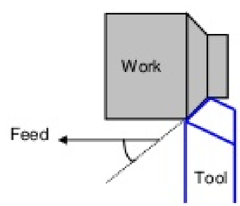
Orthogonal Cutting



Oblique Cutting







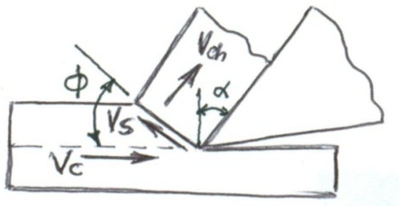
Orthogonal Cutting

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

Tool Angles



Rake Angles (α)

- Influence cutting forces, power and surface finish
- Large α

– lowers forces and improves surface finish

– In general, power consumption ↓by ~ 1% for 1 degree change in α

– Has adverse effect on tool strength because less metal is available to support the tool.

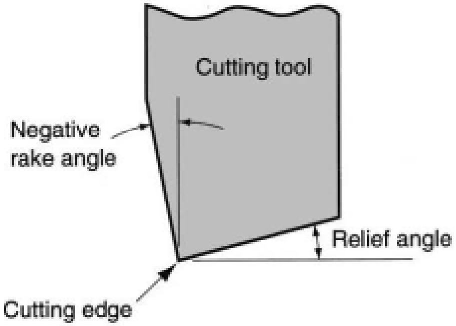
– Greatly reduced capacity to conduct heat away from the cutting edge

Tool Angles

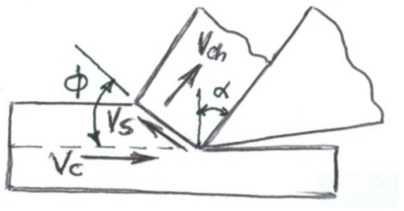
- 0 or negative rake angles employed on carbide, ceramic and similar “hard” tools

– Increases tool forces, but keeps the tool in compression and provides added support to the cutting edge

- Particularly important in making intermittent cuts and in absorbing impact during initial tool-workpiece contact
- Rake angles: 5 – 15 degrees for HSS; Lower for harder materials.



Tool Angles



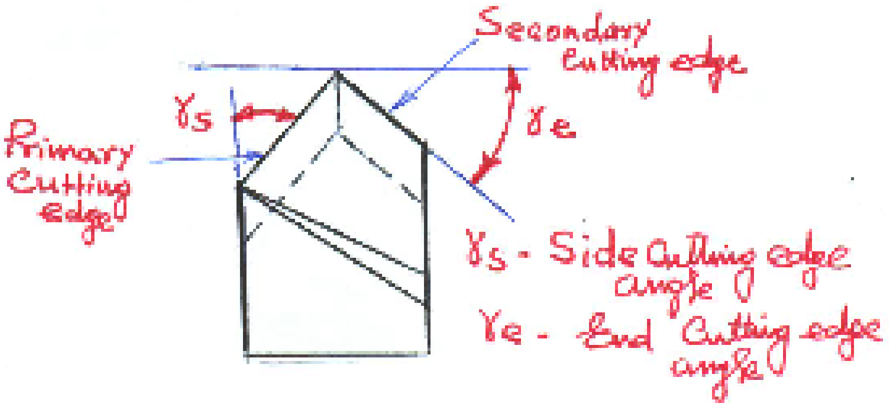
Flank Angle

- Minimizes rubbing of flank faces with the machined surface
- Higher values of flank angle will reduce rubbing but also weaken the tool
- Flank angles have no influence on cutting forces and power. So angles large enough to avoid rubbing is generally chosen
- Angle: 5 – 12 degrees for HSS; higher for softer and lower for brittle material

Tool Angles

Cutting Edge Angles:

- Provided to clear the cutting edge from the machined surface
- To Reduce tool chatter
- Affects tool life as well as surface finish



Tool Parameter

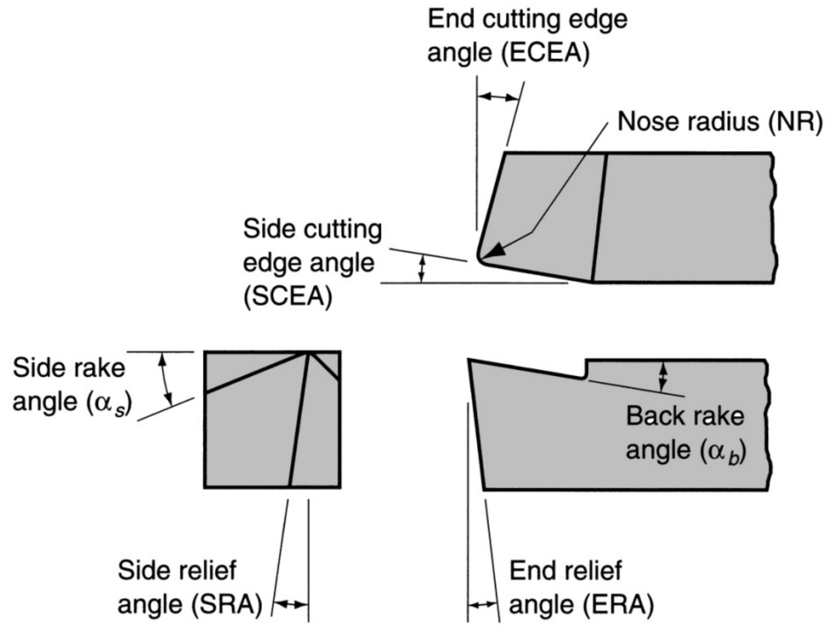
Nose radius

- Improves tool life and surface finish.

- Large nose radius
  - Increases cutting forces and power
  - Causes chatter (self-excited vibration)

- Recommended value: 1 – 3 mm

Single-Point Tool Geometry in Coordinate System (ASA)

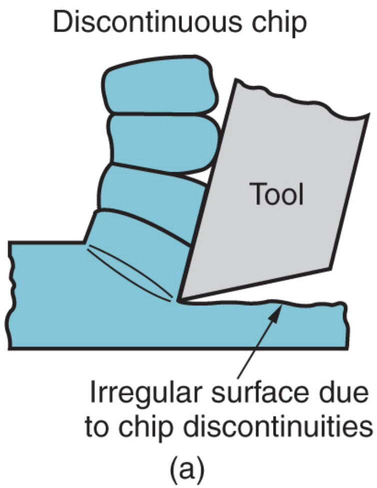


Tool specifications (all six angles, and nose radius) :7-8-5-6-9-4-1mm

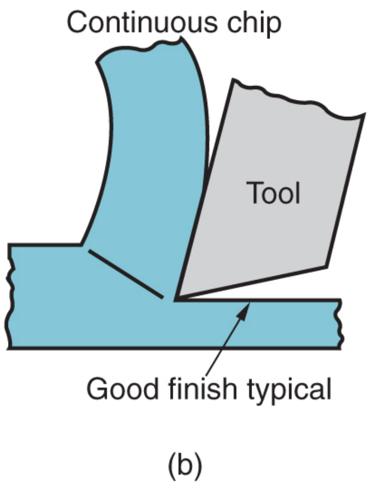
This specification indicates the following:

- Back rake angle (7^0)
- Side rake angle (8^0)
- End clearance (relief) angle (5^0)
- Side clearance (relief) angle (6^0)
- End cutting edge angle (9^0)
- Side cutting edge angle (4^0)
- Nose radius (1 mm)

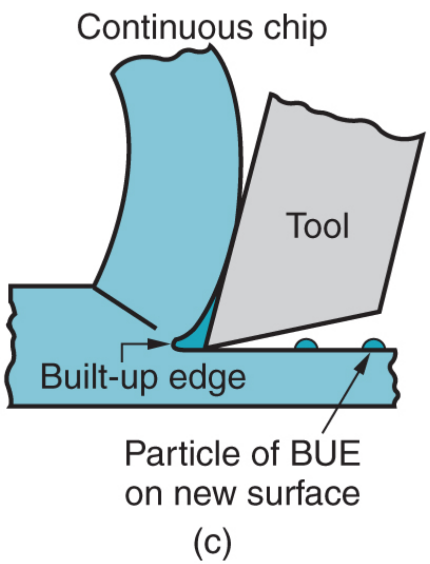
Types of Chips



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



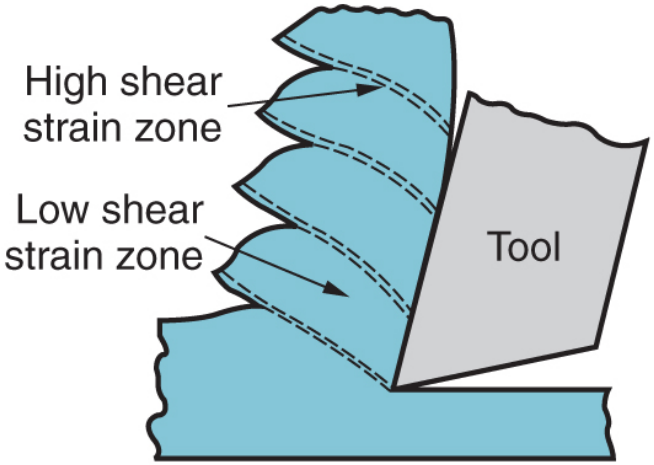
- •Ductile work materials
- •High cutting speeds
- •Small feeds and depths
- •Large rake angle
- •Sharp cutting edge
- •Low tool-chip friction



- •Ductile materials
- •Low-to-medium cutting speeds
- •Large feed
- •Small rake angle
- •Tool-chip friction causes portions of chip to adhere to rake face
- •Built up Edge (BUE) forms, then breaks off, cyclically

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



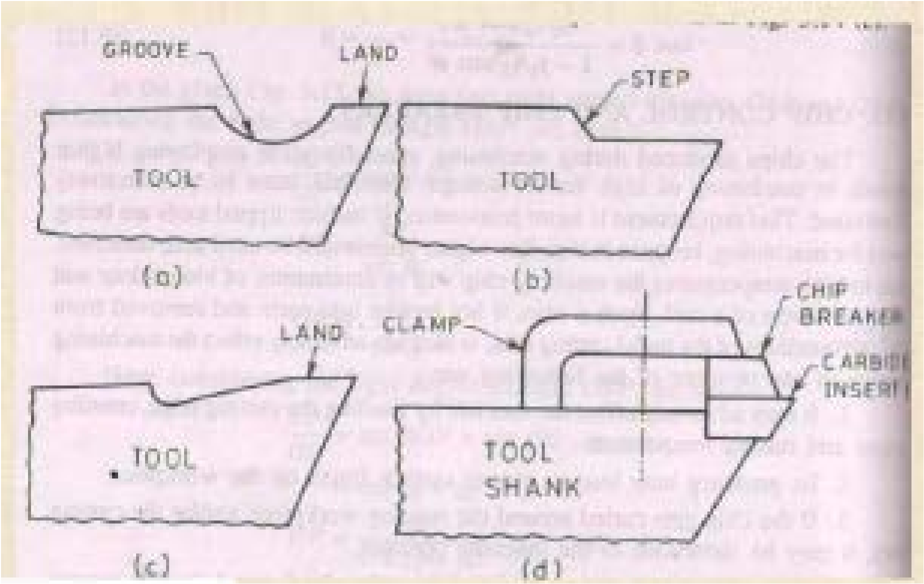
(d)

Chip-Breaking

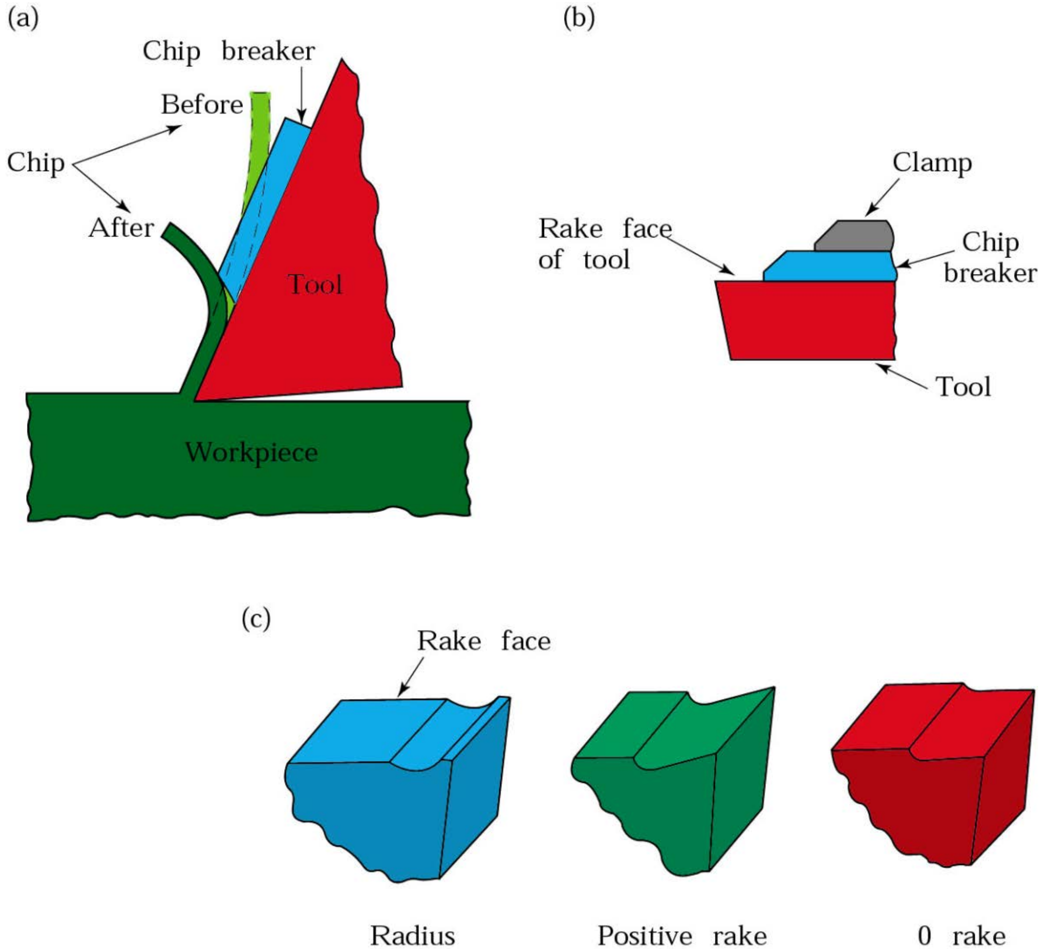
- The chip breaker breaks the produced chips into small pieces.
- The work hardening of the chip makes the work of the chip breakers easy.
- When a strict chip control is desired, some sort of chip breaker has to be employed.

➢ The following types of chip breakers are commonly used:

a) Groove type
b) Step type
c) Secondary Rake type
d) Clamp type



Chip-Breaking



(a) Schematic illustration of the action of a chip breaker. Note that the chip breaker decreases the radius of curvature of the chip. (b) Chip breaker clamped on the rake face of a cutting tool.

(c) Grooves in cutting tools acting as chip breakers.

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
  - <u>Roughing</u> - removes large amounts of material from starting workpart
    - Some material remains for finish cutting
    - High feeds and depths, low speeds
  - <u>Finishing</u> - completes part geometry
    - Final dimensions, tolerances, and finish
    - Low feeds and depths, high cutting speeds

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 Temperature is Important

High cutting temperature:

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

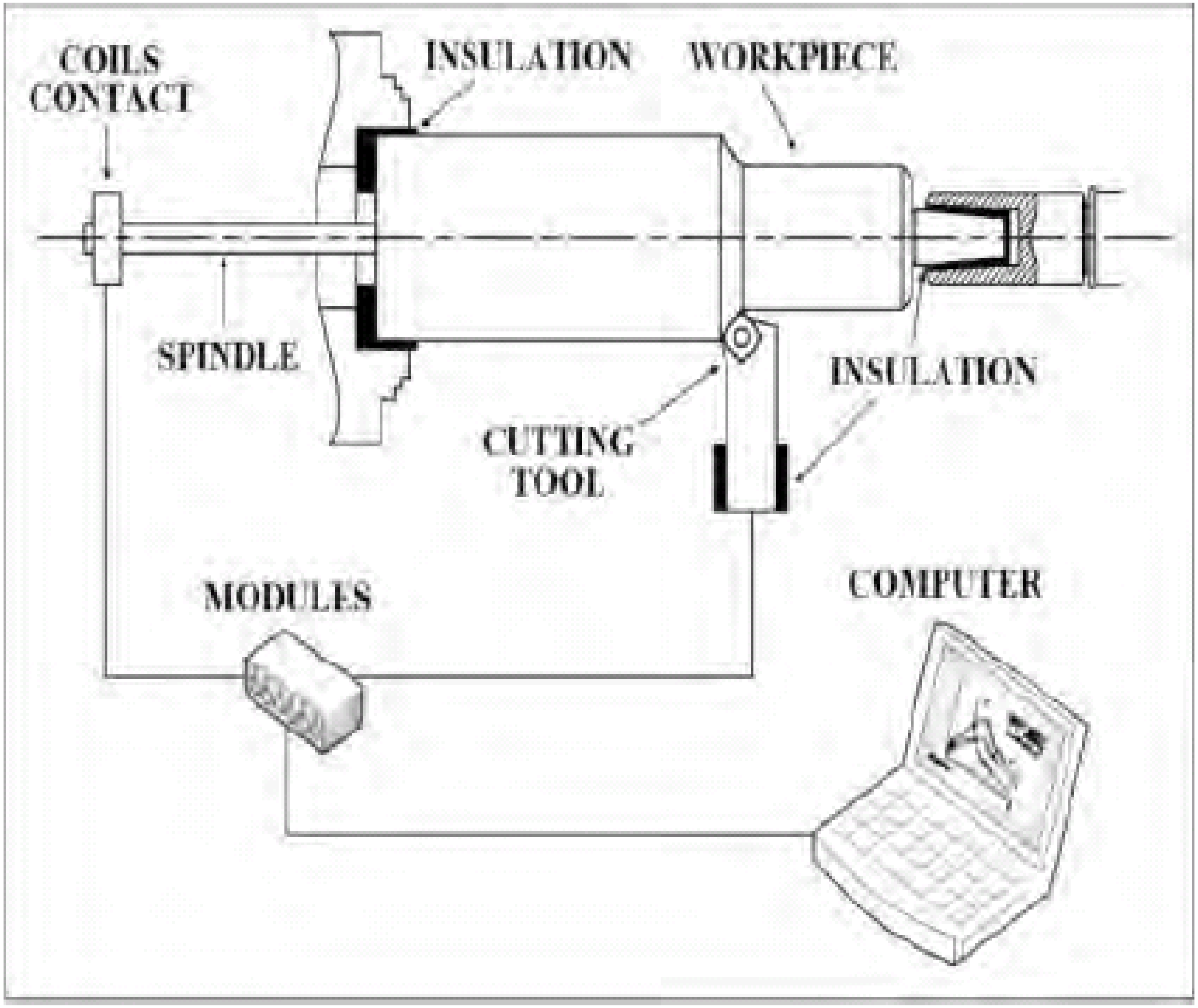
Cutting Temperature

- 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:

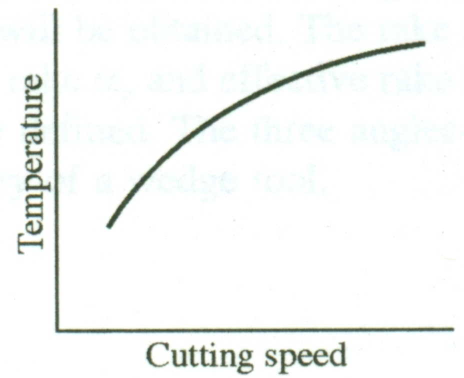
$$T = K\, v^{m}$$

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

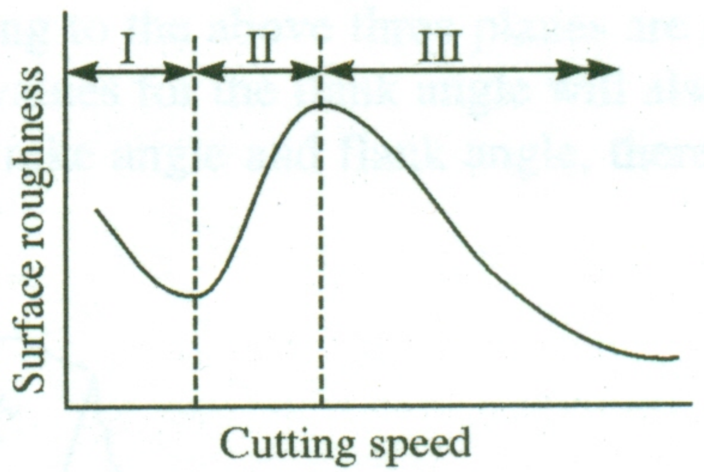
Tool-Chip Thermocouple



Temperature and Roughness

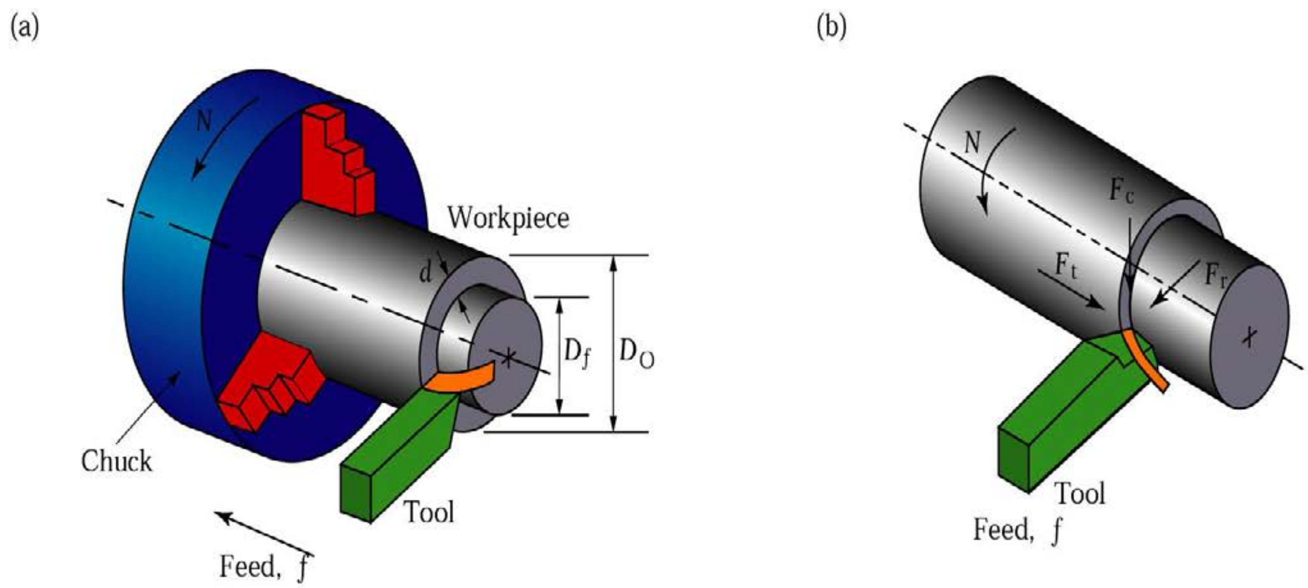


$$\theta \propto \sqrt{V_c}$$



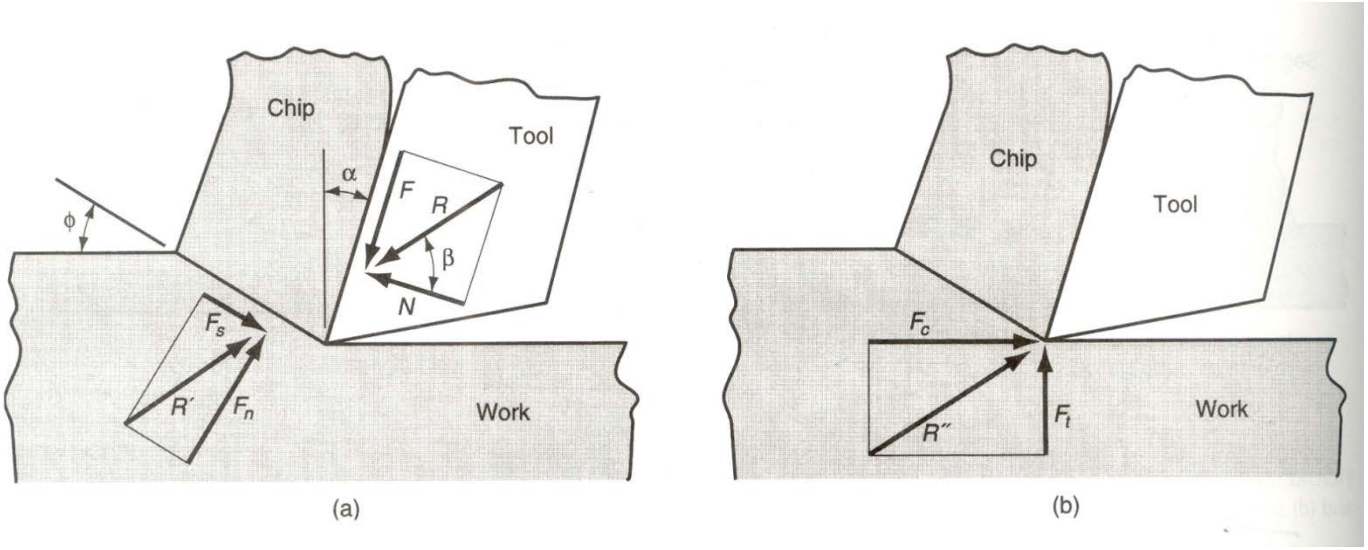
Zone I : Discontinuous chip. Initially poor surface finish. It improves as speed increases and the chip becomes semi-discontinuous.
Zone II : BUE is formed; continue till the recrystallization temperature is reached.
Zone III : Continuous chip without BUE.

Turning Operation



(a) Schematic illustration of a turning operation showing depth of cut, *d, and feed, f. Cutting* speed is the surface speed of the workpiece at the *Fc, is the cutting force, Ft is the thrust or feed force (in* the direction of feed, *Fr is the radial force that tends to push the tool away from the workpiece being* machined. Compare this figure with Fig. 20.11 for a two-dimensional cutting operation.

Forces in Machining



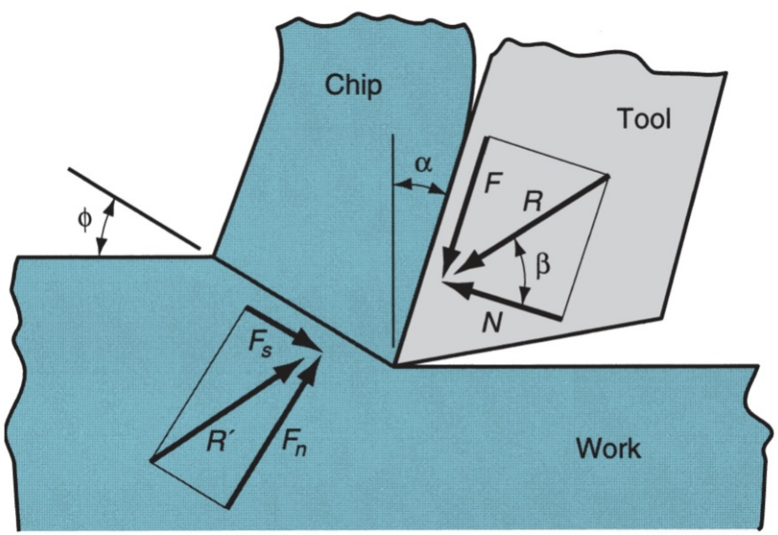
F - Frictional force between the tool and chip
N - Normal force
β - Friction angle;
Fs - Shear force
Fn - Normal force to shear
Fc - Cutting force
Ft - Thrust force
ϕ – Shear plane angle
α – Rake angle

- *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

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

$$\mu = \tan \beta$$

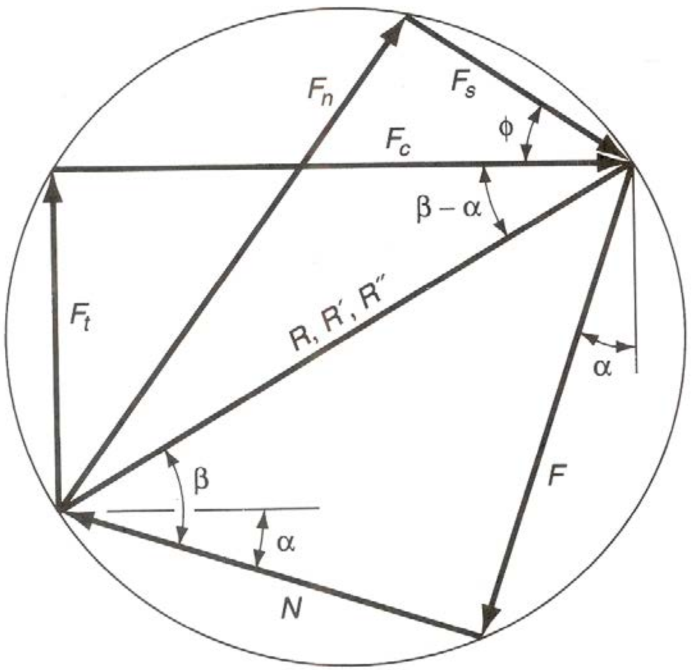
- Shear stress acting along the shear plane

$$S = \frac{F_s}{A_s}$$

where A_s = area of the shear plane

$$A_s = \frac{t_o w}{\sin \phi}$$

Merchant's Circle Diagram



$$F_s = R\,Cos(\emptyset + \beta - \alpha)$$

$$F_n = R\,Sin(\emptyset + \beta - \alpha)$$

$$F_c = R\,Cos(\beta - \alpha)$$

$$F_T = R\sin(\beta - \alpha)$$

$$F = R\sin\beta$$

$$N = R\cos\beta$$

Expressing through F_c,

$$F_S = F_C\,Cos\,\emptyset - F_T\,Sin\emptyset$$

$$F_n = F_C Sin\emptyset + F_T Cos\emptyset$$

$$F = F_C\,Sin \propto + F_T\,Cos \propto$$

$$N = F_C\,Cos \propto - F_T\,Sin \propto$$

$$R = \frac{F_C}{\cos(\beta - \alpha)} = \frac{F_S}{\cos(\emptyset + \beta - \alpha)}$$

$$F_C = \frac{F_S \cos(\beta - \alpha)}{\cos(\emptyset + \beta - \alpha)}$$

Merchant's First Equation

,

Shear force, F_S along the shear plane can be written as:

$$F_S = \frac{\omega t_1}{\sin \emptyset} \tau_S$$

Where, ω is the width of the workpiece under cutting, t_1 is the uncut thickness, and τ_S is the shear strength of the work material

$$F_C = \frac{\omega t_1 \tau_S \cos(\beta - \alpha)}{\sin \emptyset \cos(\emptyset + \beta - \alpha)}$$

$$Power, P = F_C V_C$$

ϕ is the Shear Plane Angle, which is the angle between the shear plane and the velocity vector.

As per nature of taking path of least resistance, during cutting φ takes a value such that least amount of energy is consumed, or P = Min.

$$P(\emptyset) = \frac{Const.}{\sin \emptyset \cos(\emptyset + \beta - \alpha)} = \frac{N_m}{D_n}$$

For least energy,

$$\frac{dD_n(\emptyset)}{d\emptyset} = 0$$

$$2\emptyset + \beta - \alpha = \frac{\pi}{2}$$

Known as Merchant's FIRST EQUATION

Assumptions:

- Tool tip is sharp
- Orthogonal case
- Continuous chip without BUE
- μ along chip-tool contact is constant

Shear Stress and Normal Stress

Shear Stress, $\boxed{\tau = \frac{F_S}{A_S}}$ Where, A_S is the area of shear plane

$$\boxed{A_S = \frac{\omega t_1}{\sin \emptyset}}$$

$$\boxed{\tau = \frac{(F_C \cos \emptyset - F_t \sin \emptyset) \sin \emptyset}{\omega t_1}}$$

Normal Stress:

$$\boxed{\sigma = \frac{F_n}{A_S}}$$

$$\boxed{\sigma = \frac{(F_C \sin \emptyset + F_t \cos \emptyset) \sin \emptyset}{\omega t_1}}$$

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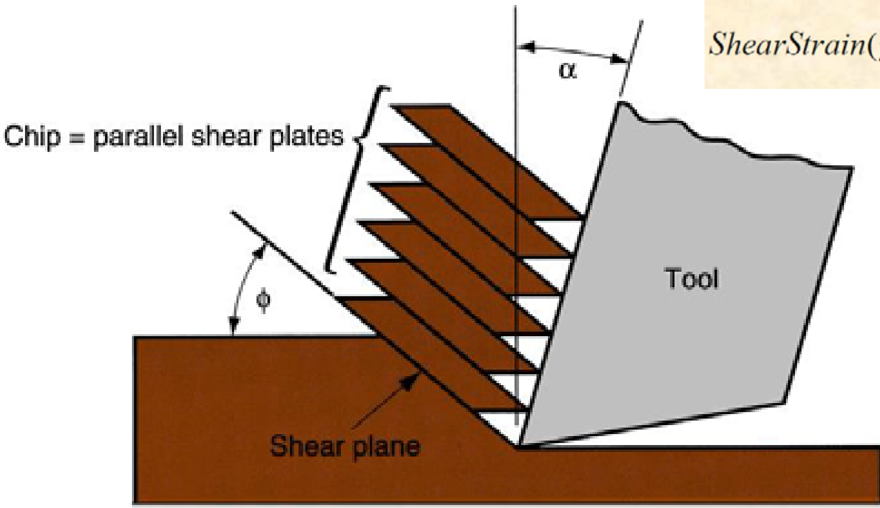
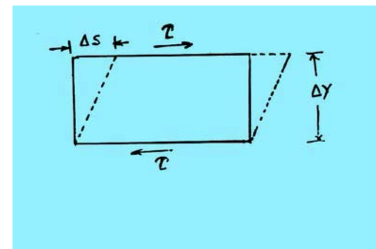
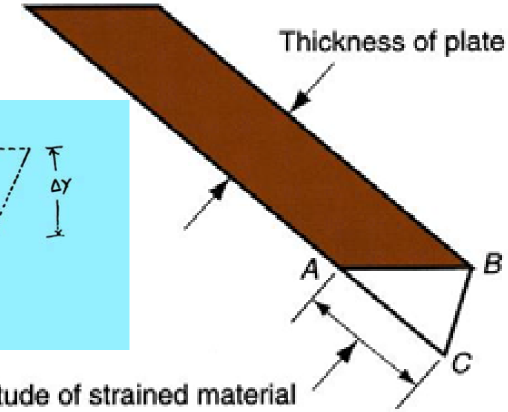
Shear Strain in Chip Formation

$$ShearStrain(\gamma) = \frac{deformation}{Length}$$



(a)

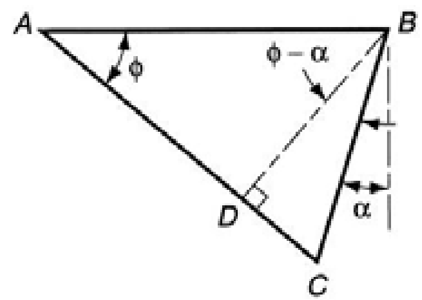




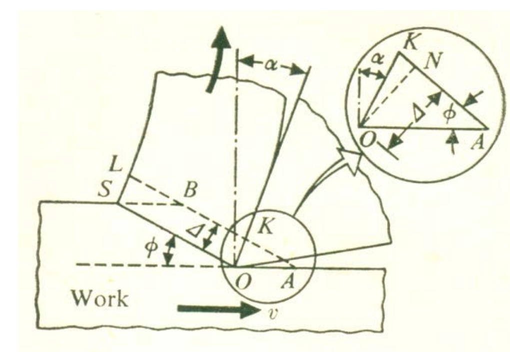
(b)

$$\gamma = \frac{AC}{BD} = \frac{AD + DC}{BD} = \frac{AD}{BD} + \frac{DC}{BD}$$

$$\gamma = \tan(\emptyset - \alpha) + Cot\emptyset$$



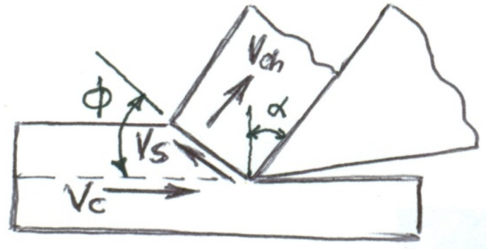
(c)

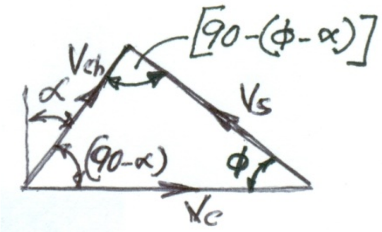


where γ= *shear strain,* ϕ= *shear plane angle, and*
α= *rake angle of cutting tool*

Strain Rate

$$\dot{\gamma} = \frac{\Delta S}{\Delta Y} \cdot \frac{1}{\Delta t}$$





- $\dot{\gamma}$ Can also be obtained in terms of shear velocity from the velocity diagram

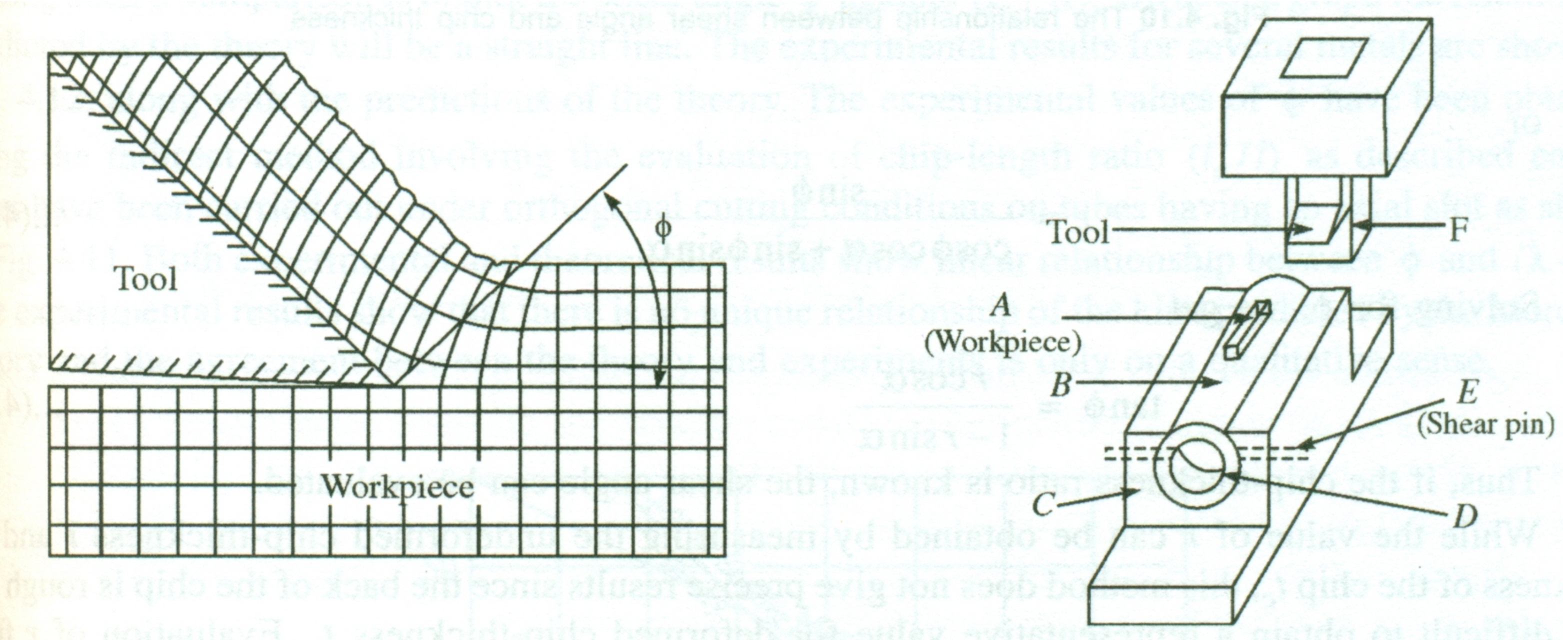
$$\frac{V_s}{\sin(90-\alpha)} = \frac{V_c}{\sin[90-(\Phi-\alpha)]} = \frac{V_{ch}}{\sin\Phi}$$

Therefore, Shear Velocity,

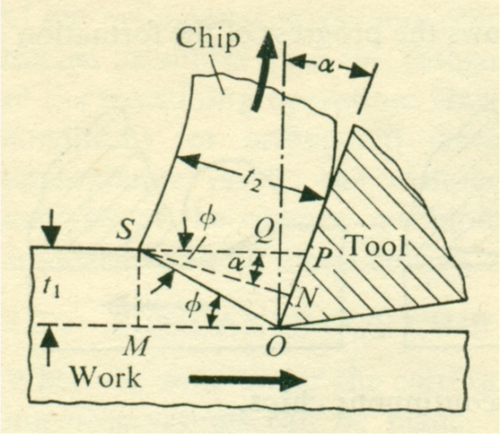
$$V_s = \frac{\cos\alpha}{\cos(\Phi-\alpha)} \cdot V_c$$

$$\dot{\gamma} = \frac{V_s}{\Delta t}$$

Measurement of Shear Plane Angle



Shear Plane Angle



$$Chip\ Thickness\ Ratio(\gamma) = \frac{Undeformed\ Chip\ Thickness\ (t_1)}{Chip\ Thickness\ (t_2)}$$

$$t_1 = OS\ \sin\emptyset$$

$$t_2 = OS\ \cos(\emptyset - \propto)$$

$$Therefore, \gamma = \frac{OS\ \sin\emptyset}{OS\ \cos(\emptyset - \propto)} = \frac{\sin\emptyset}{\cos(\emptyset - \propto)}$$

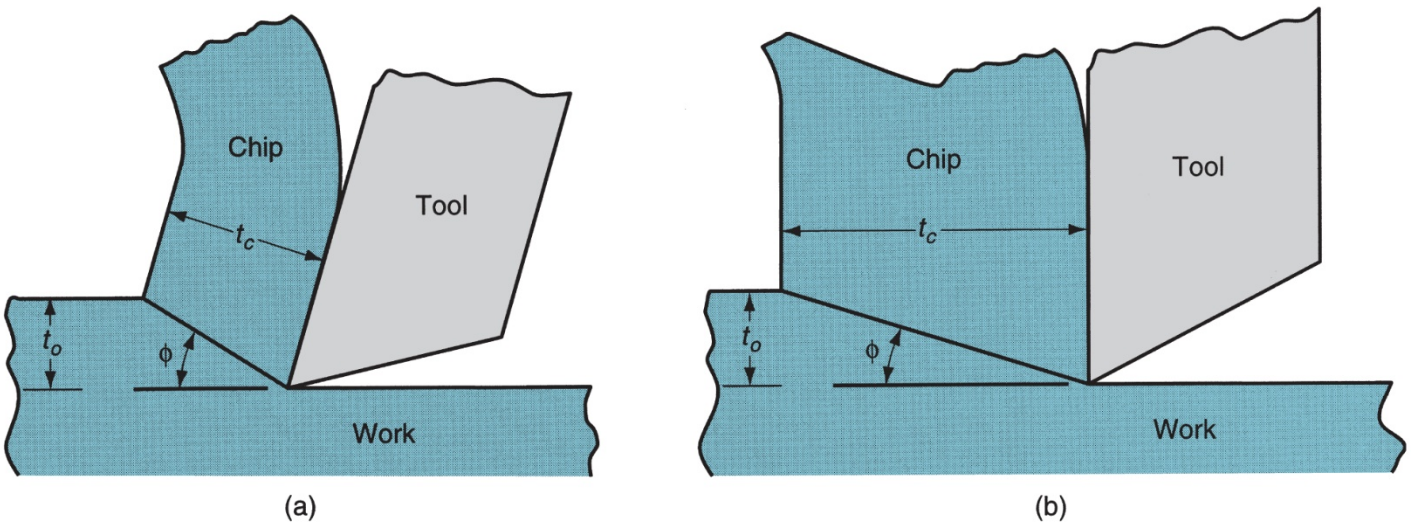
$$\frac{1}{\gamma} = \frac{\cos\emptyset\ \cos\propto\ + \sin\emptyset\ \sin\propto}{\sin\emptyset} = \frac{\cos\propto}{\tan\emptyset} + \sin\propto$$

$$or, \tan\emptyset = \frac{\gamma\ \cos\propto}{1 - \gamma\ \sin\propto}$$

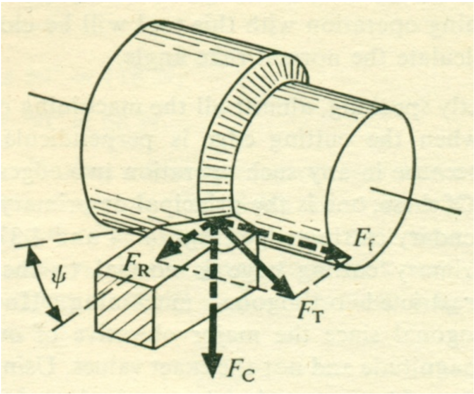
Normally, Chip Thickness Ratio = 0.5 – 0.6

Effect of Higher Shear Plane Angle

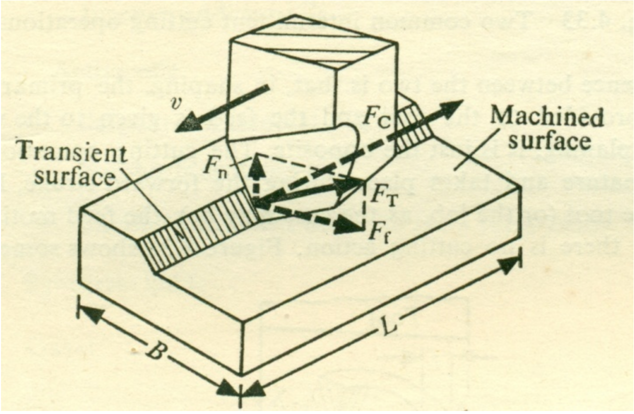
- Higher shear plane angle means smaller shear plane which means lower shear force, cutting forces, power, and temperature



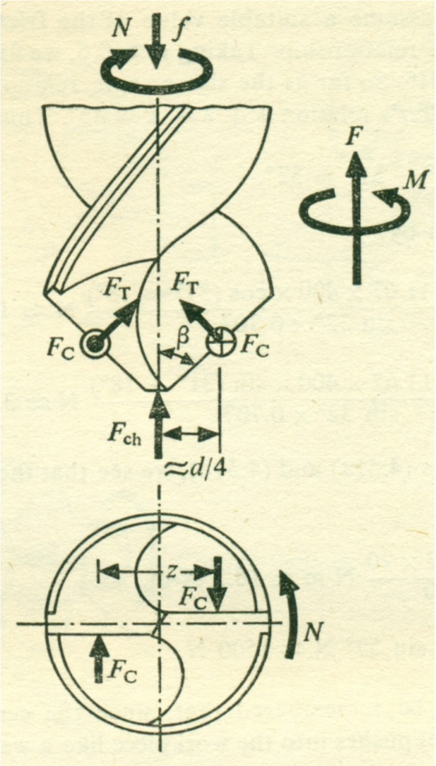
Forces in Machining



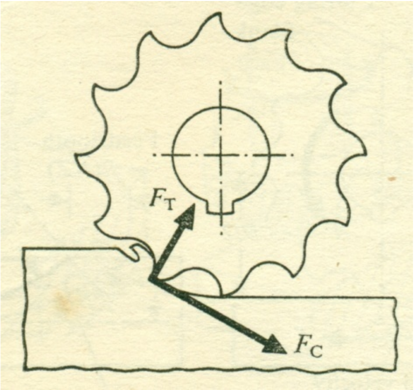
Forces in Turning



Forces in shaping/planing



Forces in Drilling



Forces in Milling

Practical Machining Processes

TURNING :

The power required in turning,

$$P_w = F_c.V_c + F_f.V_f = F_c.V_c \ (For\ V_f \ll V_c)$$

Power can also be expressed as:

$$P_w = U_c\ .\ MRR,$$

U_c – Specific energy = Energy required to remove a unit volume of material [Joules/mm^3]

$$U_c = U_0(t_1)^{-0.4}$$

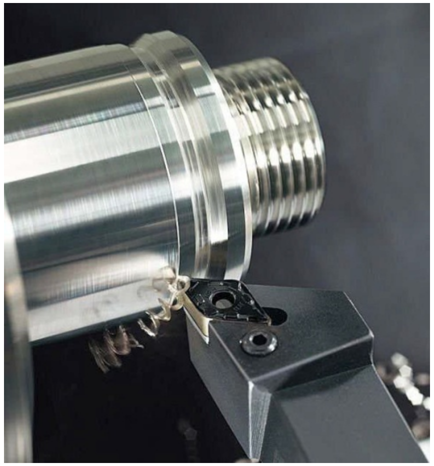
U_0 – Specific energy to remove 1 mm of uncut thickness

Material Removal Rate, MRR = $f.d.\frac{\pi.D.N}{60}\left[\frac{mm^3}{sec}\right]$

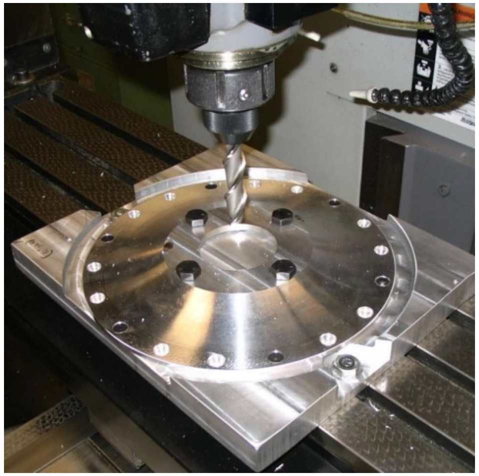
When a cylinder of length L is being turned at a spindle speed, N with a feed, f, then,

Total time to machine the part, $T = \frac{L}{f.N}.n$

Machining Operations



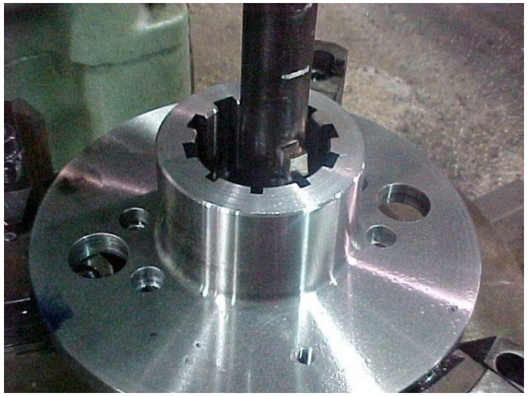
TURNING



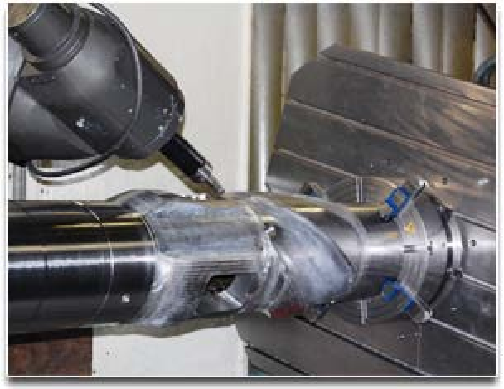
MILLING

DRILLING

SAWING



BROACHING



PLANING

Tool Wear & Tool Life

Modes of Tool Failure

- ***Fracture failure***

Cutting force becomes excessive and/or dynamic, leading to brittle fracture

- **Temperature failure**

Cutting temperature is too high for the tool material

- **Gradual wear**

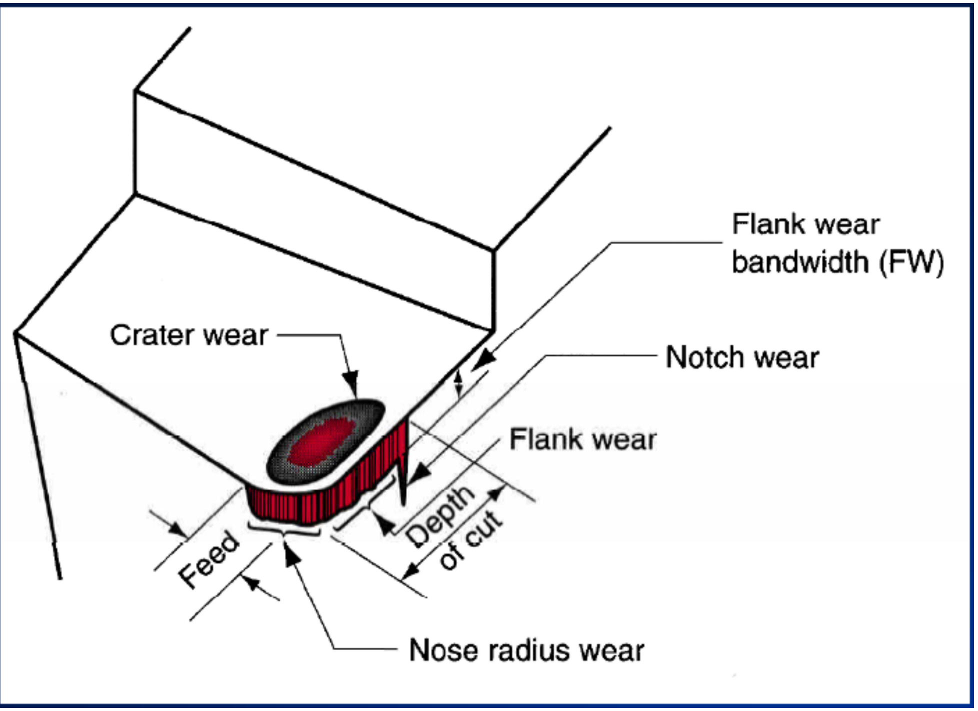
Gradual wearing of the cutting tool

Tool Wear & Tool Life

Mechanisms of Tool Wear:

- **Abrasion:** If one of the surfaces contains very hard particles, then these during the process of sliding may dislodge material from other surfaces by Ploughing action.
- **Adhesion:** When bodies of similar nature are in contact, the asperities tend to get welded. Sliding causes fracture of these welded junctions and material is lost from both the surfaces.
- **Diffusion:** Atoms in a metallic crystal lattice always move from higher concentration to that of low concentration. The process is known as Diffusion.

Tool Wear & Tool Life

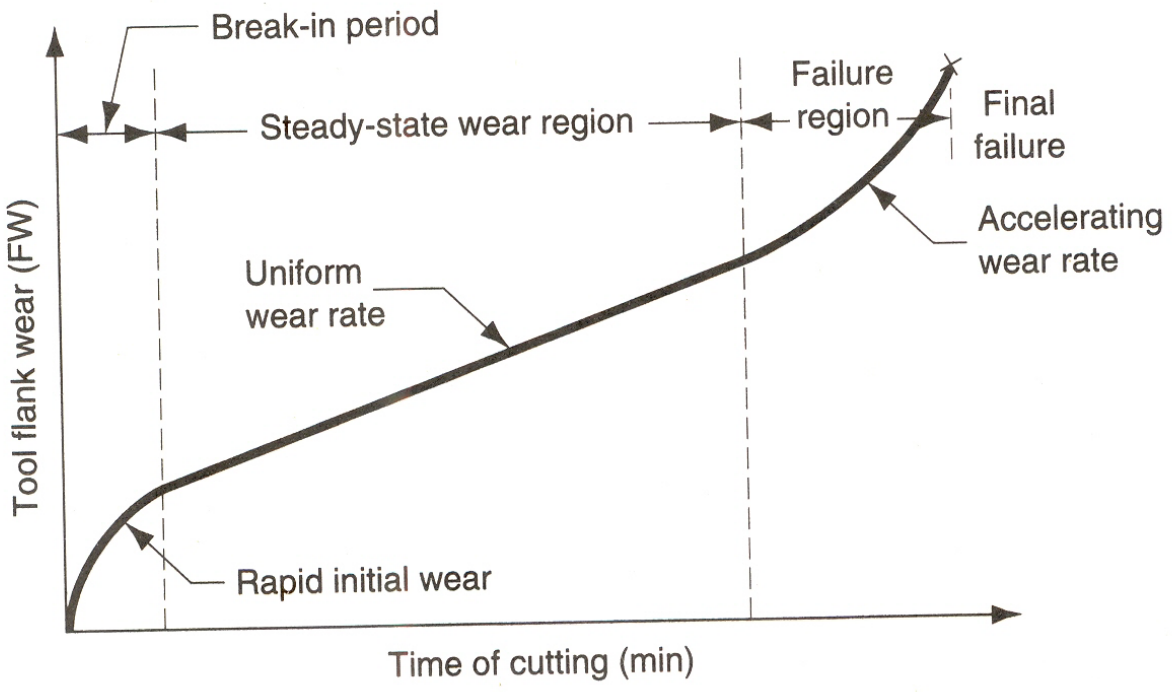


- The progressive wear of a cutting tool first occurs on the flank face in the form of a wear land due to rubbing against the newly machined surface known as FLANK WEAR.

- As a result of chip flowing over the rake face, wear also takes place on the rake surface in the form of a crater known as CRATER WEAR.

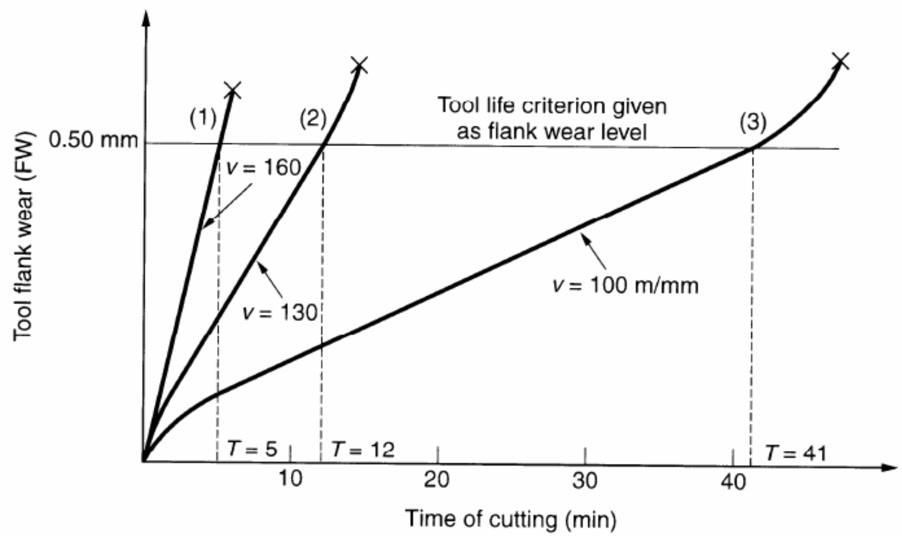
- Flank wear is measured by means of a measuring microscope.
- Crater wear can be evaluated by means of a surface analyser.
- Crater wear is formed at higher speeds, when diffusion has been considered to play a major role.

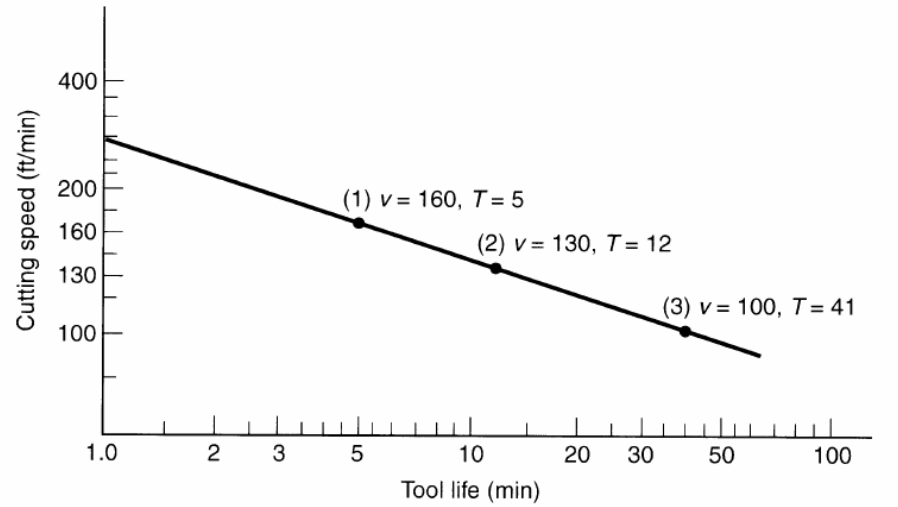
Tool Wear & Tool Life



A tool that no longer performs the desired function (and not unable to cut at all) is said to be reached the end of its usual life or failed. At this point the tool is resharpened and used again.

Tool Wear & Tool Life





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

n is the slope of the plot

C is the intercept on the speed axis

Tool Wear & Tool Life

- The variables, Speed, Feed and Depth of cut affect the material removal rate and hence have a direct effect on the production cost.

$$T = \frac{C^{\frac{1}{n}}}{V^{\frac{1}{n}}}$$

T can also be expresses as:

$$T = \frac{C_1}{V^{\frac{1}{n}} f^{\frac{1}{n_1}} d^{\frac{1}{n_2}}}$$

Where, $\frac{1}{n} > \frac{1}{n_1} > \frac{1}{n_2}$, indicates that the cutting speed has greatest effect on tool life followed by feed and then depth of cut.

Tool Wear & Tool Life

Variables Affecting Tool Life:

- The Cutting Conditions
- The Tool Geometry
- The Tool Material
- The Work Material
- The Cutting Fluid

Tool Wear & Tool Life

Effect of Tool Geometry: Rake angle

- Increasing the Rake Angle reduces the cutting force and the cutting temperature resulting in increased tool life.
- However, for large rake angle, tool edge is weakened resulting in increased wear due to chipping of the cutting edge.
- Increased wear is also due to larger temperature since the tool becomes thinner and the area available for heat conduction reduces.
- These conditions give an optimum rake angle which gives the maximum tool life.
- Higher is the strength of workpiece material, lower is the value of optimum rake angle.

Tool Wear & Tool Life

Effect of Tool Geometry: Flank angle

- Increasing the Flank Angle reduces rubbing between tool and the workpiece and hence improves the tool life.
- However, too high a value of flank angle weakens the tool and reduces its life.
- Optimum value of flank angles is also affected by the feed rates. Higher is the feed rate, lower is the optimum value. The flank angle, therefore, should be low if higher feed values are to be used.

Tool Wear & Tool Life

Tool and Work Material

- Tool material must be at least 35% to 58% harder than the work material.
- High strain rate of deformation and elevated temperature of the work material further complicate the situation.
- With the increase in machining speed, the temperature of both the tool and the work material increases, resulting in a lowered effective hardness of the tool. Unfortunately, the expected fall in the hardness in the work material is neutralized by the higher rate of deformation.
- In general, harder the work material, higher will be the tool wear rate and lower will be the tool life.

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

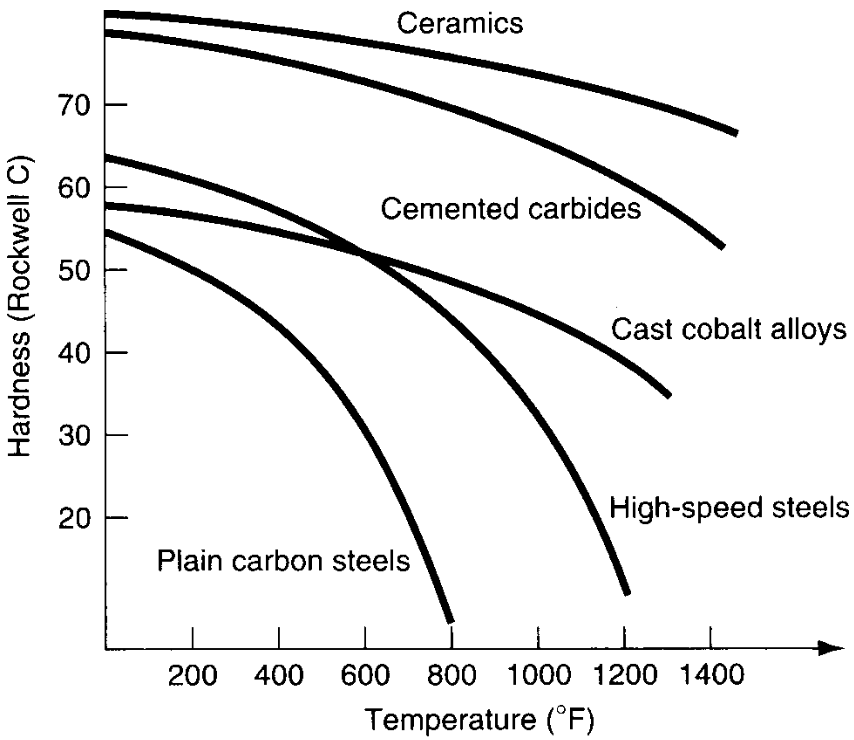


Figure - Typical hot hardness relationships for selected tool materials. Plain carbon steel shows a rapid loss of hardness as temperature increases. High speed steel is substantially better, while cemented carbides and ceramics are significantly harder at elevated temperatures.

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
- 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 semi-finishing 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
- 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

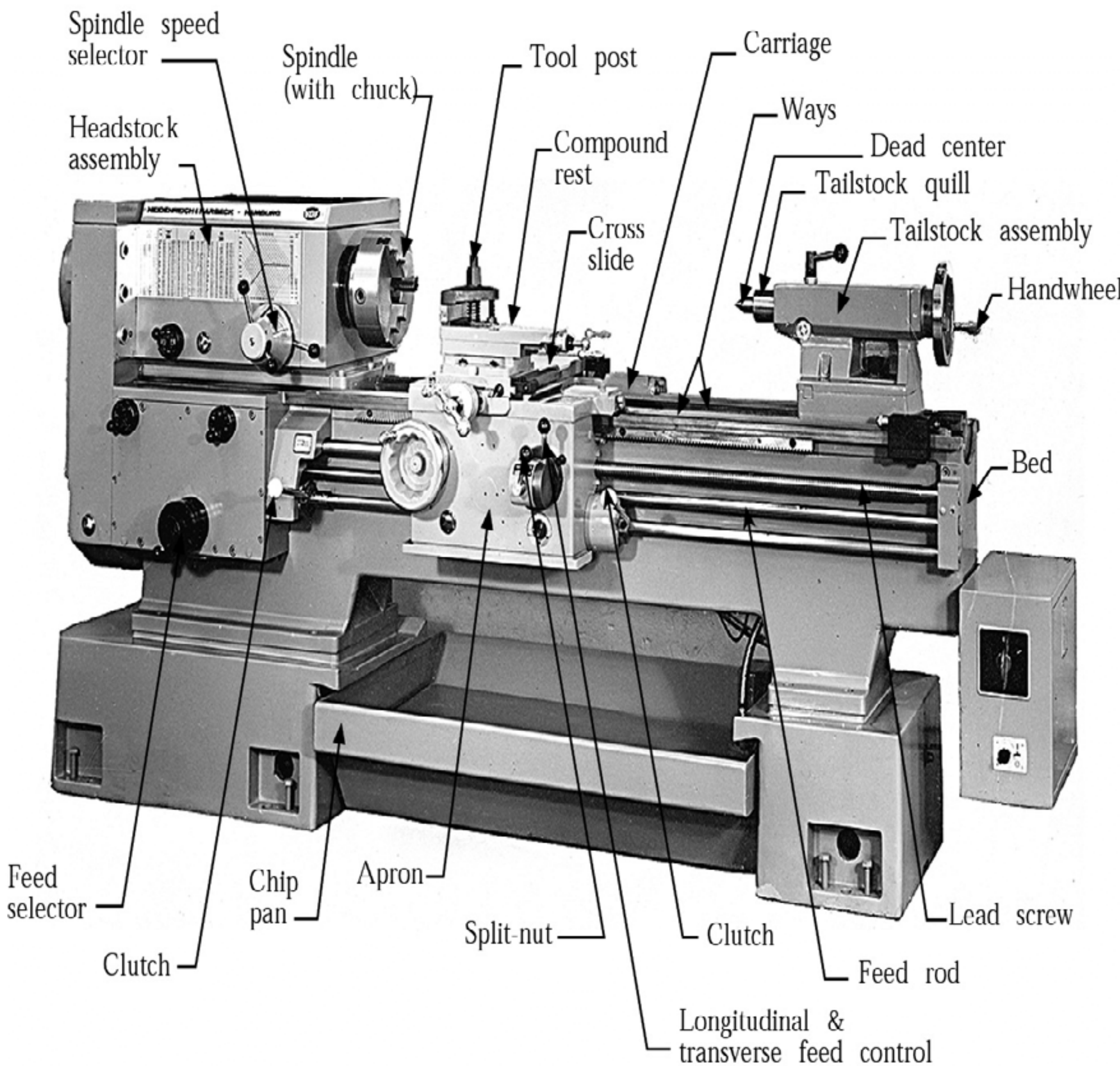
- Next to diamond, *cubic boron nitride* (cBN) is hardest material known
- Fabrication into cutting tool inserts same as SPD: coatings on WC-Co inserts
- Applications: machining steel and nickel-based alloys
- SPD and cBN tools are expensive

Tool Wear & Tool Life

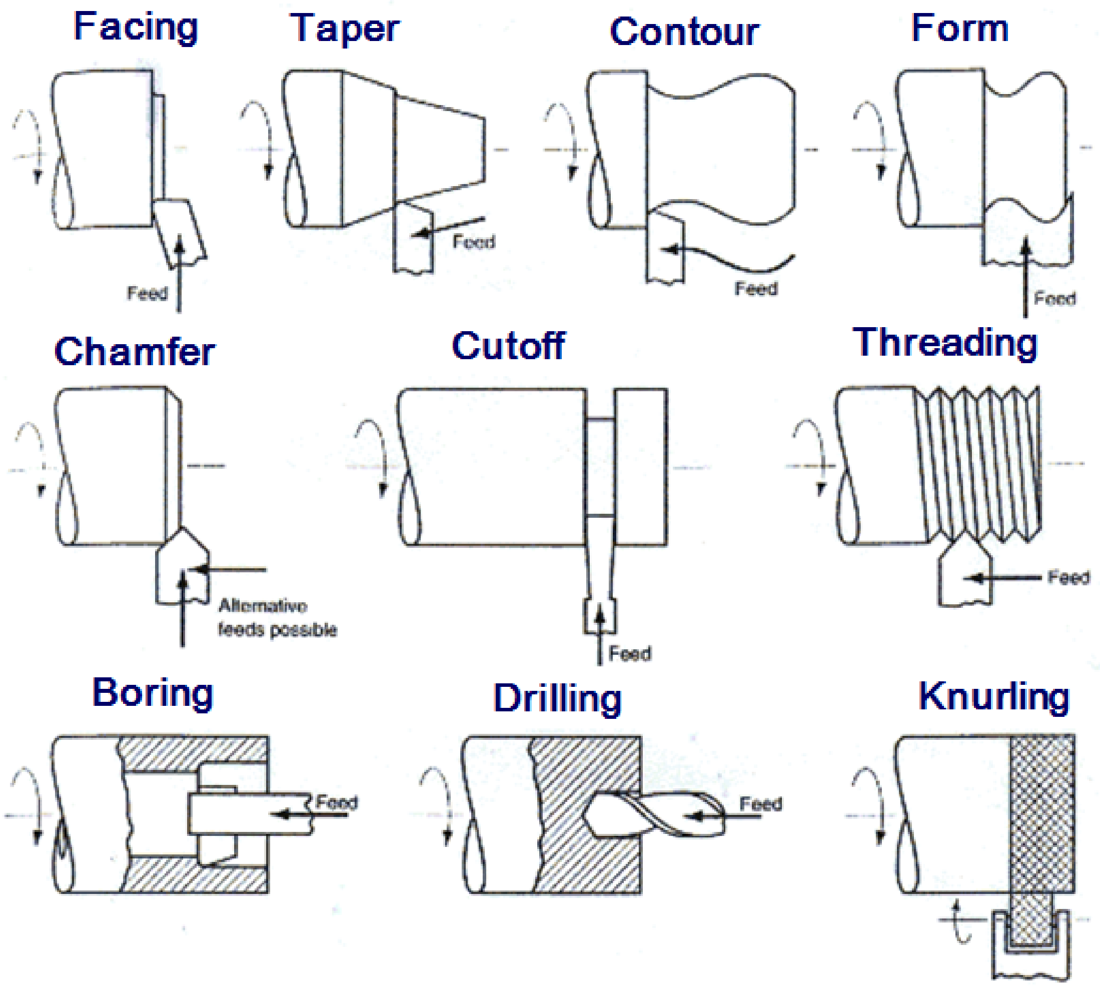
Cutting Fluid

- Cutting fluids are primarily used for decreasing the cutting temperature and the chip-tool interface friction.
- They also serve to keep the workpiece cool to avoid thermal expansion, provide a rust-proof layer on the finished surface and remove chips from the machining area.
- Cutting fluids should have high specific heat and good thermal conductivity, a chemical constituent to form weak junctions, should have a low viscosity and small molecular size, non corrosive and inexpensive.
- At a very high speed, coolant is ineffective.

Lathe Machine



Tool-work interaction



Operations Performed on Lathe (Other than Turning)

Facing: Tool is fed radially inward to create a flat surface

Taper turning: The tool is fed at an angle instead of feeding parallel to the axis of rotation of work

Contour turning: Instead of feeding the tool parallel to the axis of rotation, tool follows a contour that is other than straight, thus creating a contoured form

Form turning: The tool has a shape that is imparted to the work by plunging the tool radially into work

Chamfering: Cutting edge cuts an angle on the corner of the cylinder, forming a "chamfer"

Operations Performed on Lathe (Other than Turning)

Cutoff: Tool is fed radially into rotating work at some location to cut off end of part

Threading: Pointed form tool is fed linearly across surface of rotating workpart parallel to axis of rotation at a large feed rate, thus creating threads

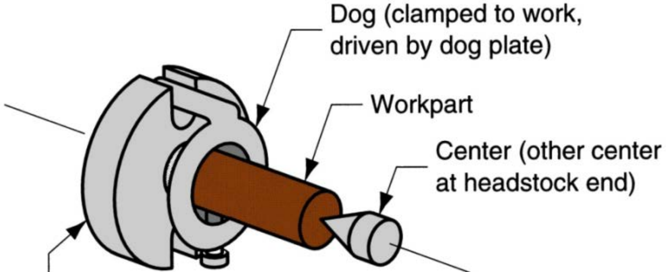
Boring: The tool is fed parallel to the axis of rotation on the inside diameter of an existing hole

Drilling: Drill is fed into the rotating work along its axis

Knurling: Used to produce a regular cross-hatched pattern in the work surface. Not a machining operation.

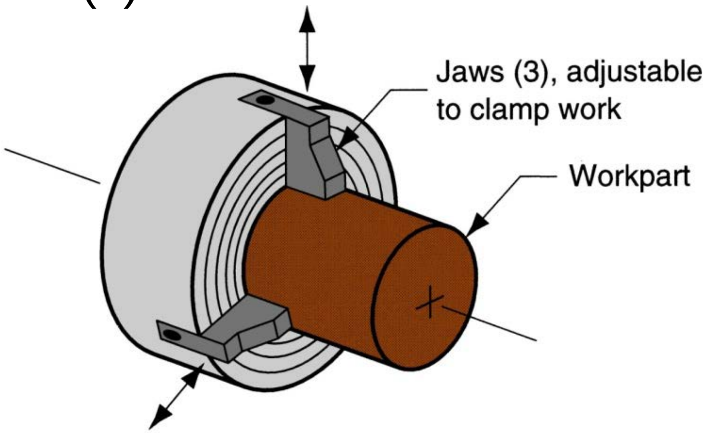
Methods of Holding the Work in a Lathe

(a)Holding the work between centers



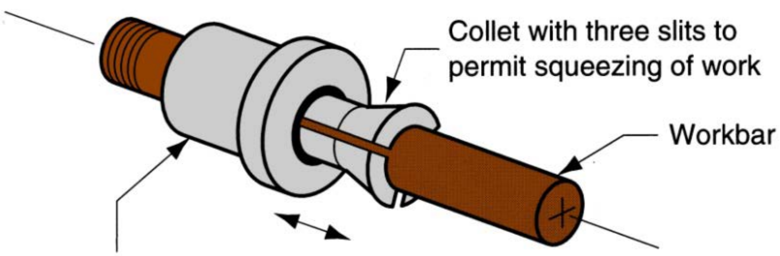
(a)

(b)Chuck



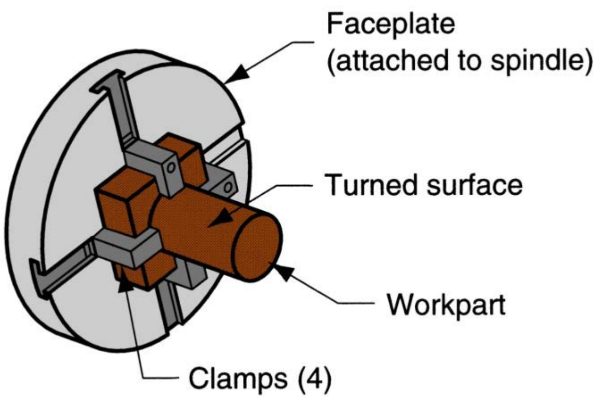
(b)

(c)Collet



(c)

(d)Face plate



(d)

Boring

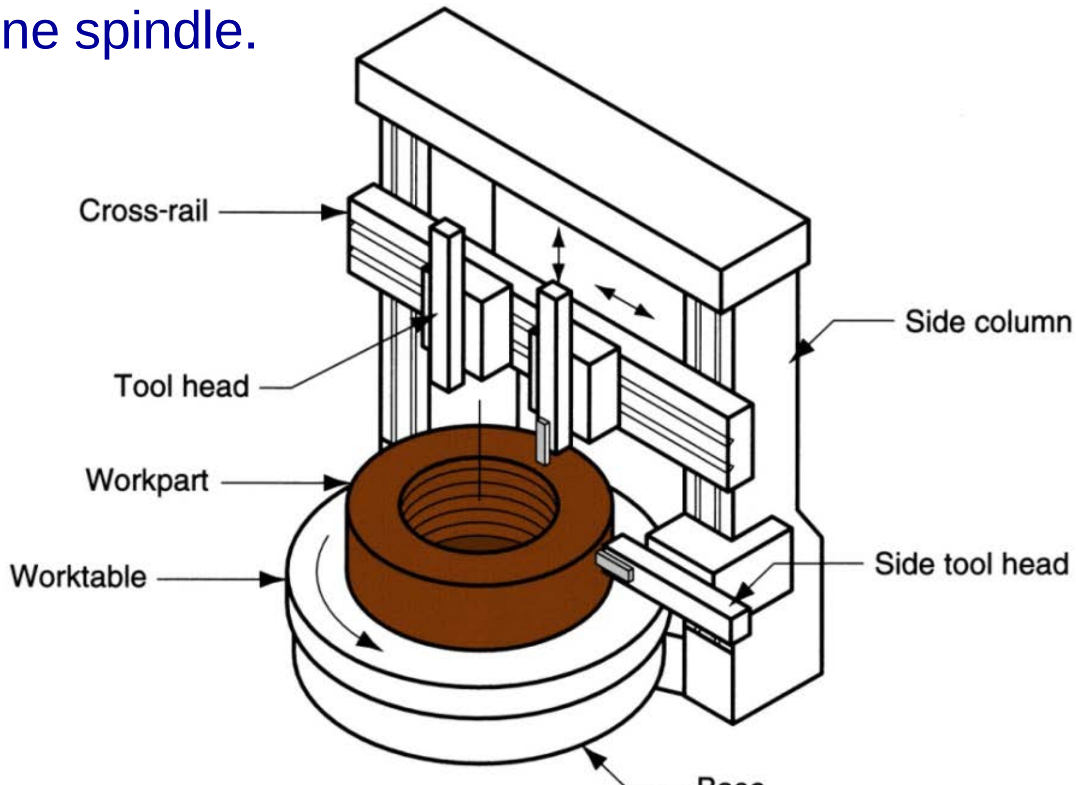
Difference between boring and turning:

➢*Boring is performed on the inside diameter of an existing hole.*

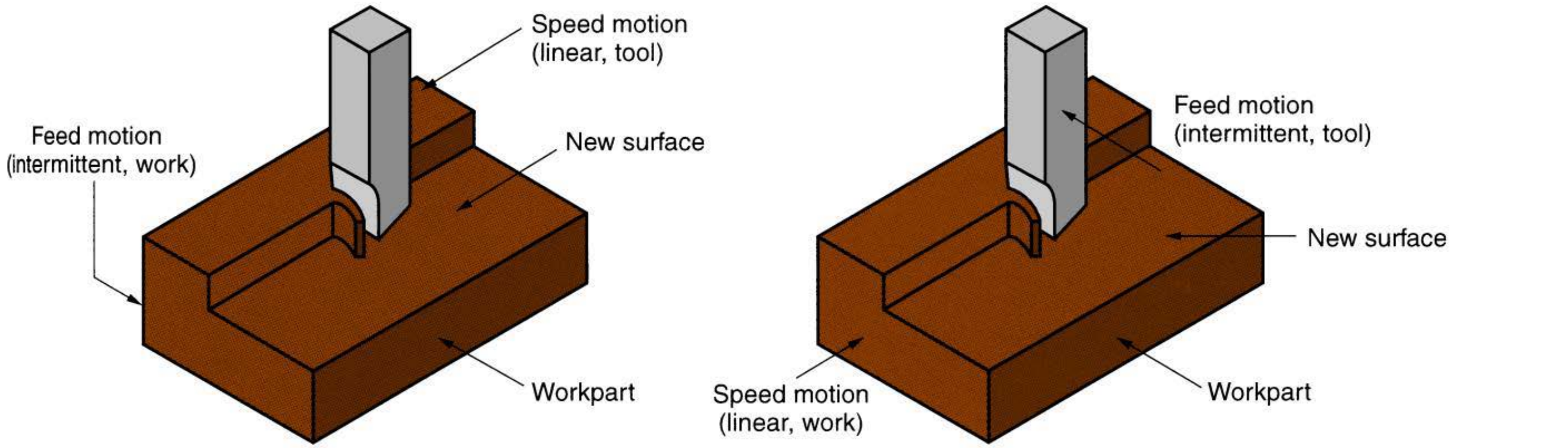
➢*Turning is performed on the outside diameter of an existing cylinder*

➢In effect, boring is an internal turning operation

Boring machines Horizontal or vertical - refers to the orientation of the axis of rotation of machine spindle.



Shaping and Planing



(a) Shaping (b) Planing

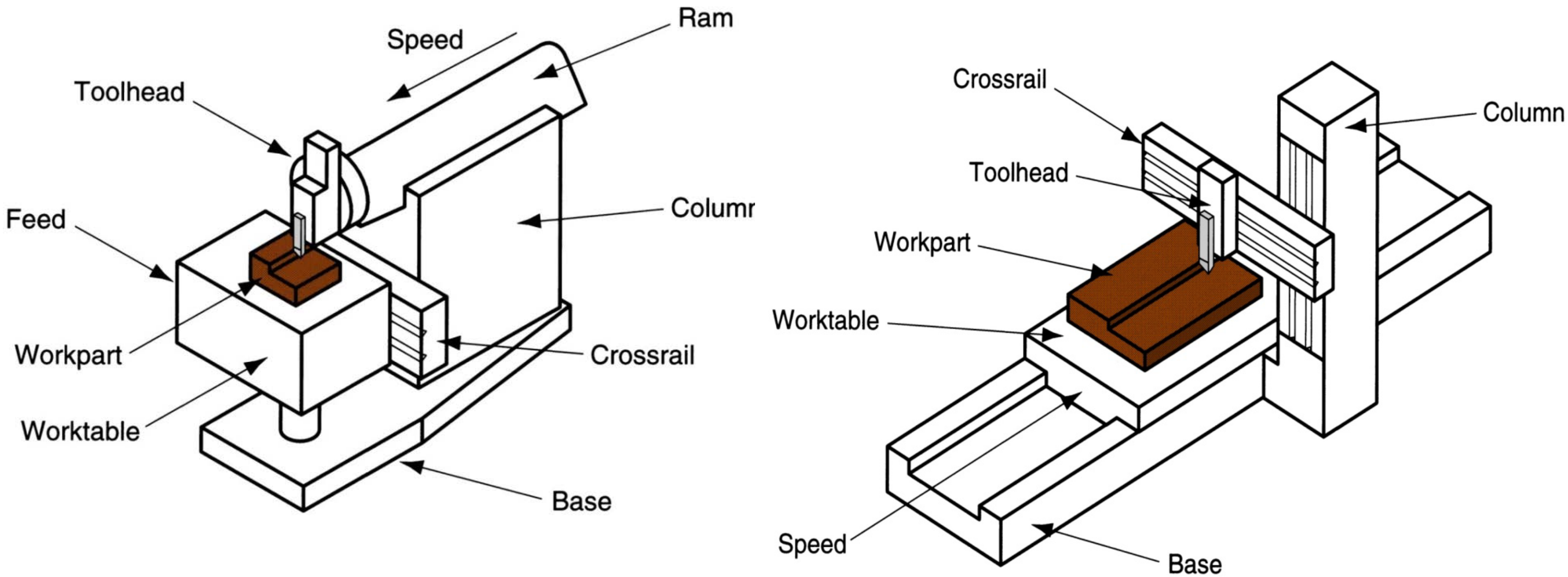
➢Both use a single point cutting tool moved linearly relative to the workpart

➢A straight, flat surface is created in both operations

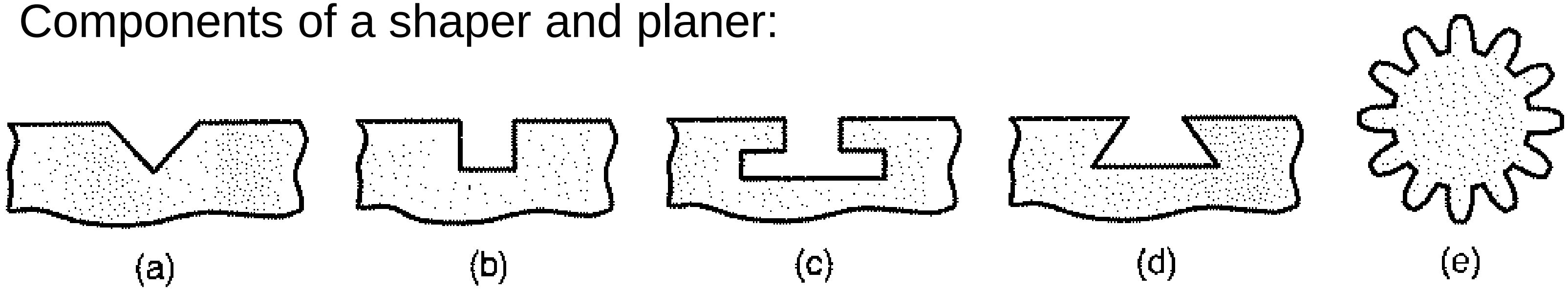
➢Interrupted cutting ; Subjects tool to impact loading when entering work

➢Low cutting speeds due to start-and-stop motion

Shaping and Planing Machines

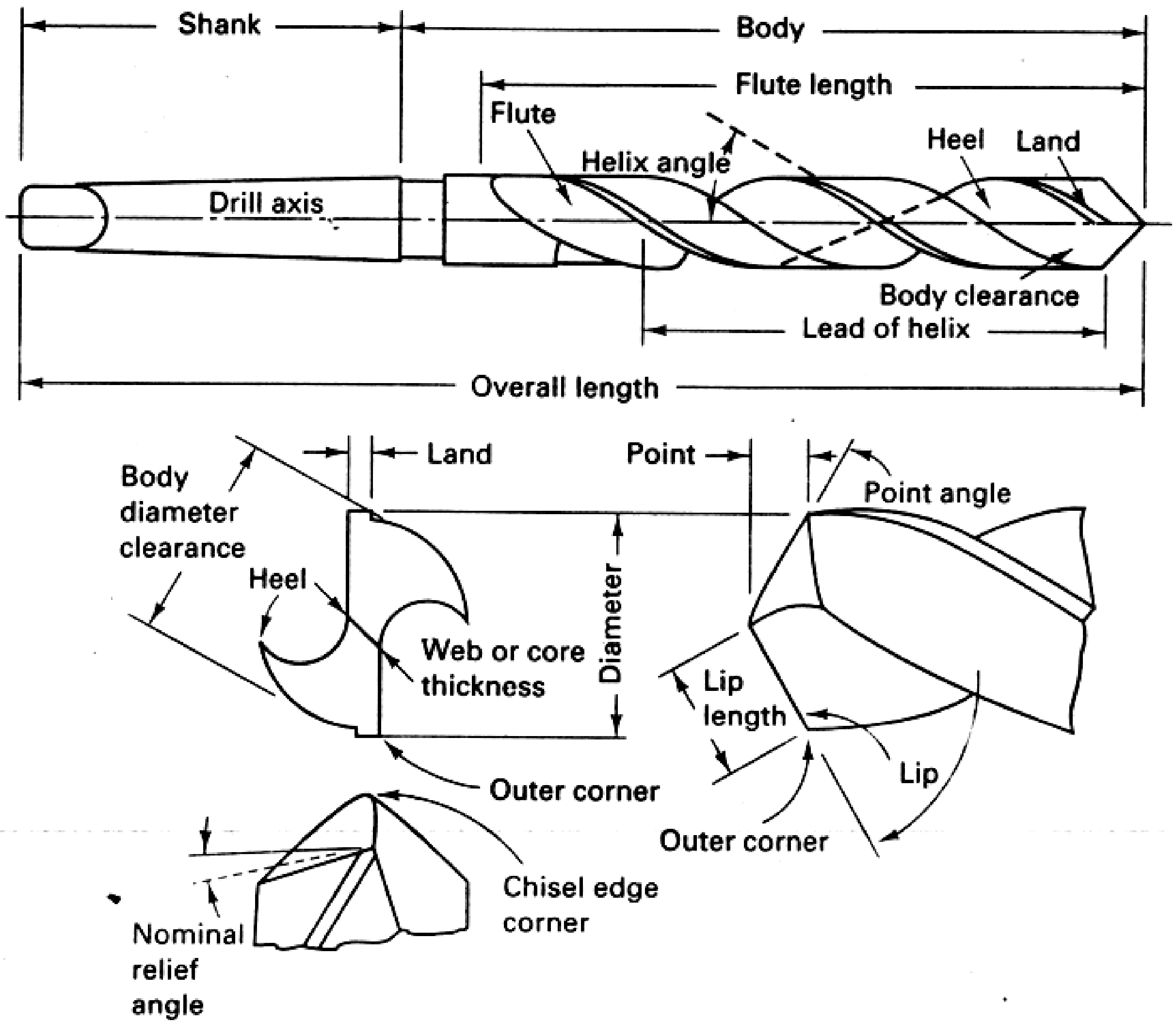


Components of a shaper and planer:

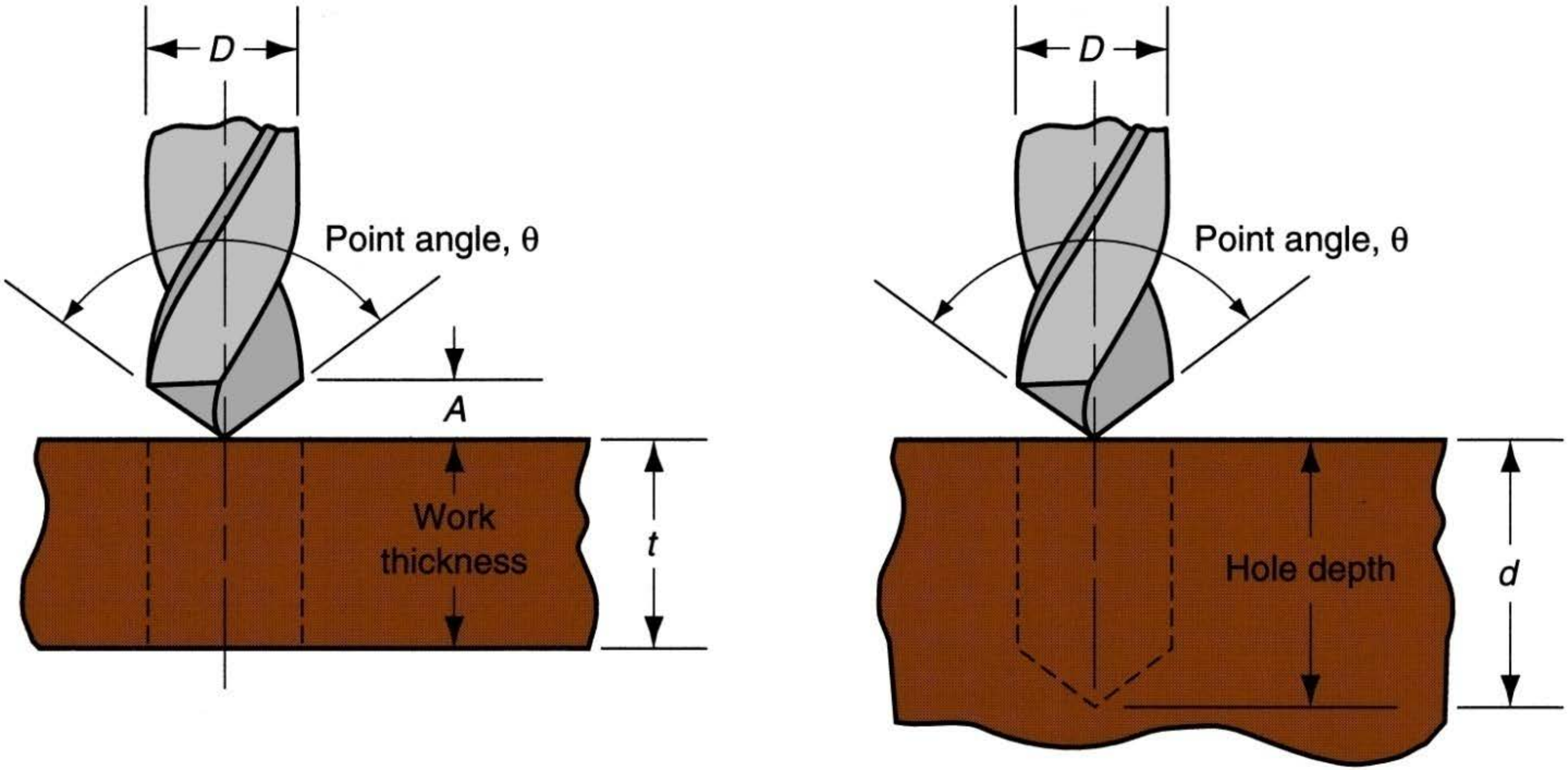


Drilling

➢Used for making (drilling) internal holes

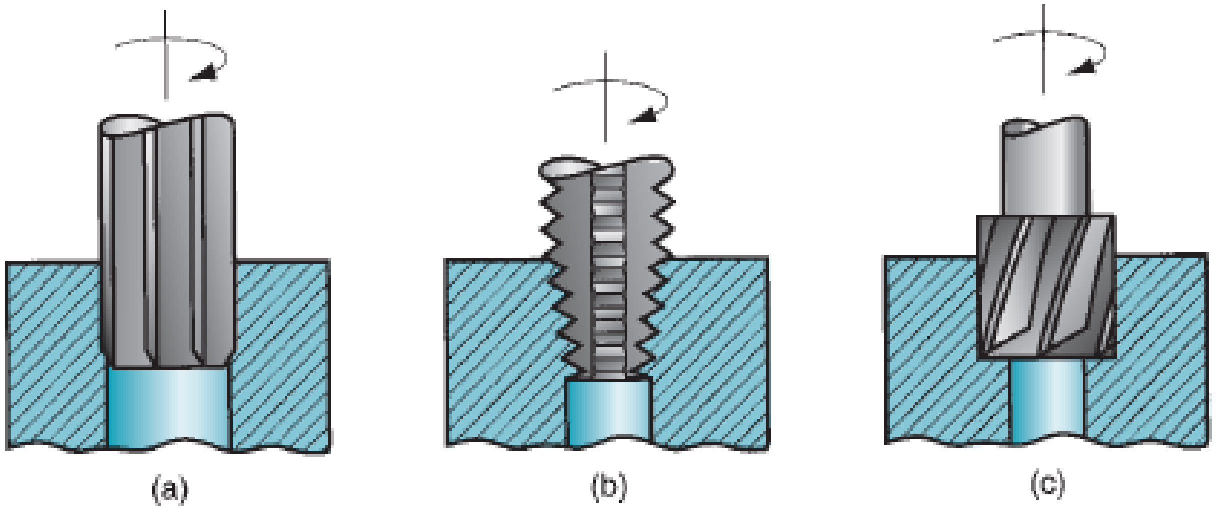


Drilling – Through or Blind Holes



(a) (b)

Machining Operations Related to Drilling



(a) Reaming (b) Tapping (c) Counterboring

Reaming: Used to slightly enlarge a hole, provide better tolerance on diameter, and improve surface finish

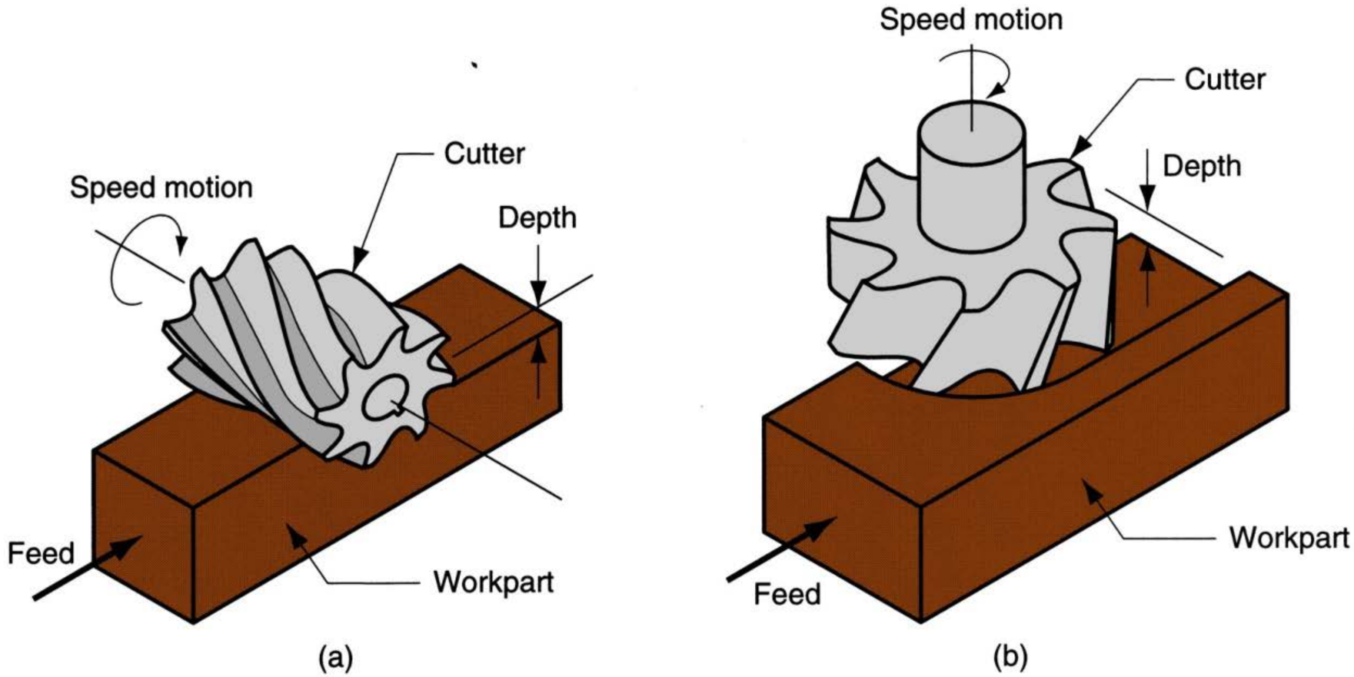
Tapping: Used to provide internal screw threads on an existing hole. Tool called a *tap*

Countreboring: Provides a stepped hole, in which a larger diameter follows a smaller diameter partially into the hole

Milling

- Machining operation in which work is fed past a rotating tool with multiple cutting edges
- Axis of tool rotation is perpendicular to feed direction
- Creates a planar surface; other geometries possible either by cutter path or shape
- Other factors and terms:
  - Milling is an *interrupted cutting* operation
  - Cutting tool called a *milling cutter,* cutting edges called "teeth"
  - Machine tool called a *milling machine*

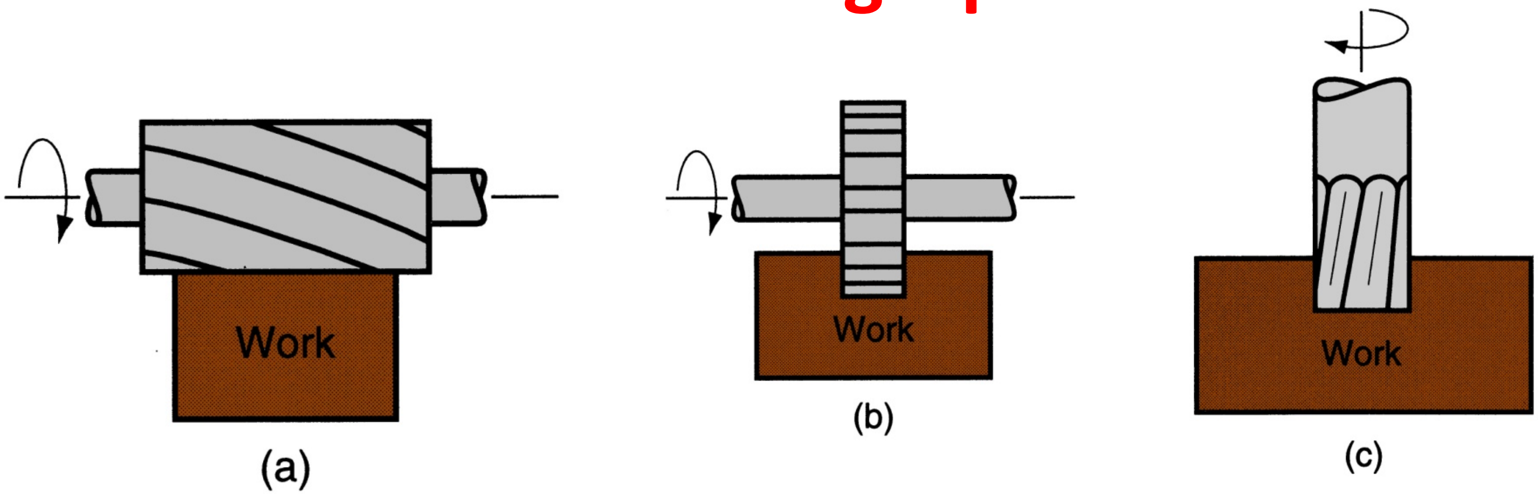
Milling



(a) Peripheral milling: Cutter axis is parallel to surface being machined Cutting edges on outside periphery of cutter

(b) Face milling: Cutter axis is perpendicular to surface being milled Cutting edges on both the end and outside periphery of the cutter

Various Milling Operations



(a) Slab Milling: The basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides

(b) Slotting: Width of cutter is less than workpiece width, creating a slot in the work

(c) End Milling: Cutter diameter is less than work width, so a slot is cut into part

Various Milling Operations

Profile Milling

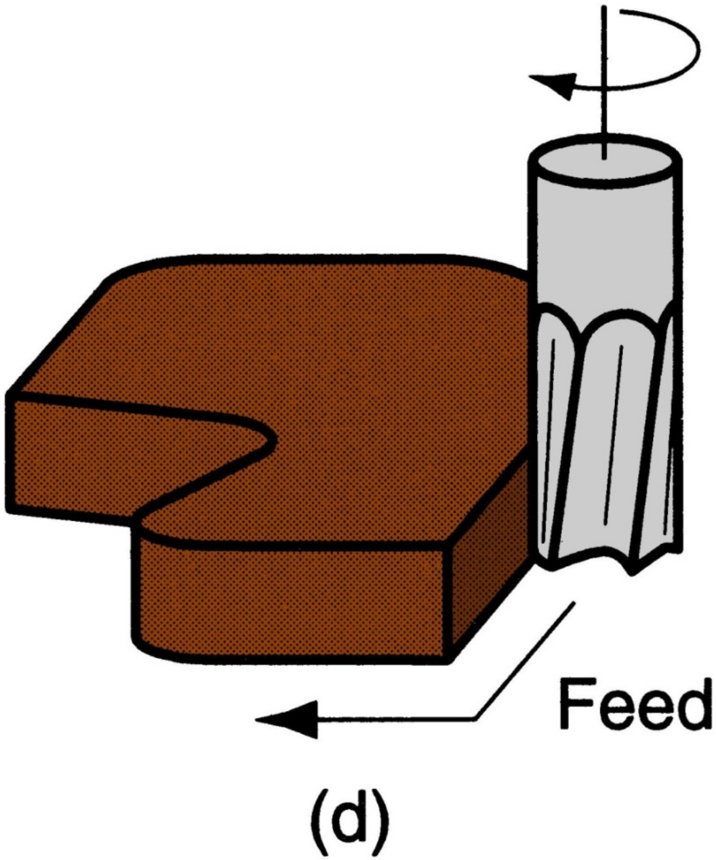
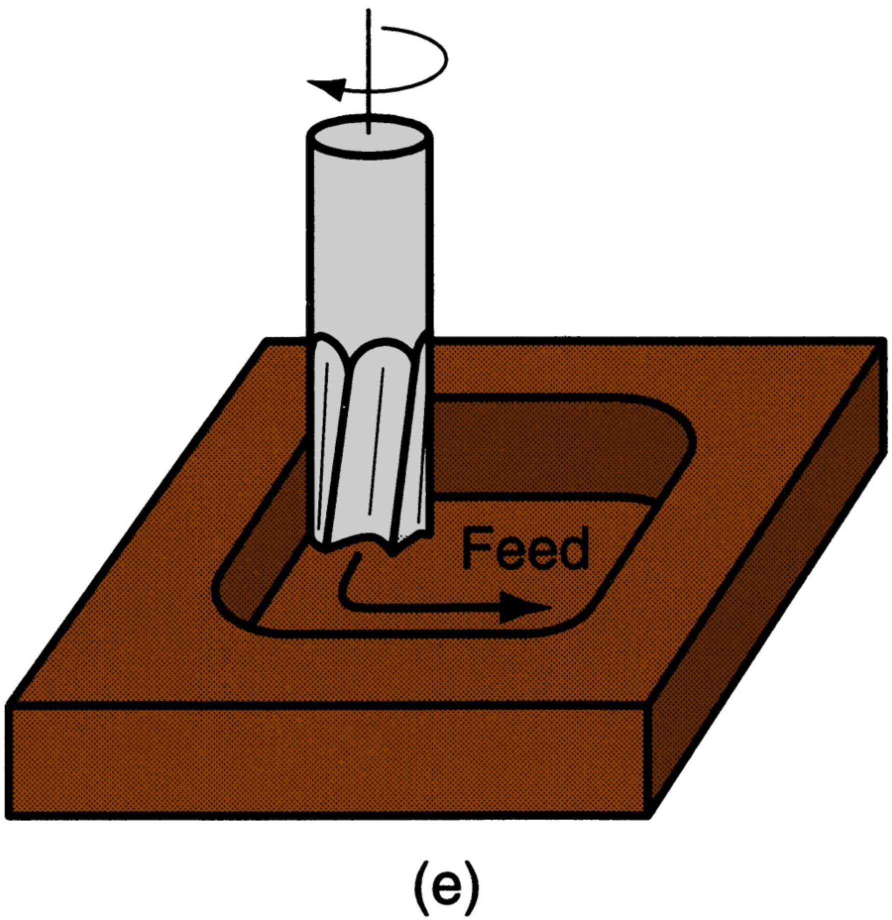


Figure (d) profile milling

Form of end milling in which the outside periphery of a flat part is cut

Various Milling Operations

Pocket Milling



Another form of end milling used to mill shallow pockets into flat parts

Figure (e) pocket milling

Various Milling Operations

Surface Contouring

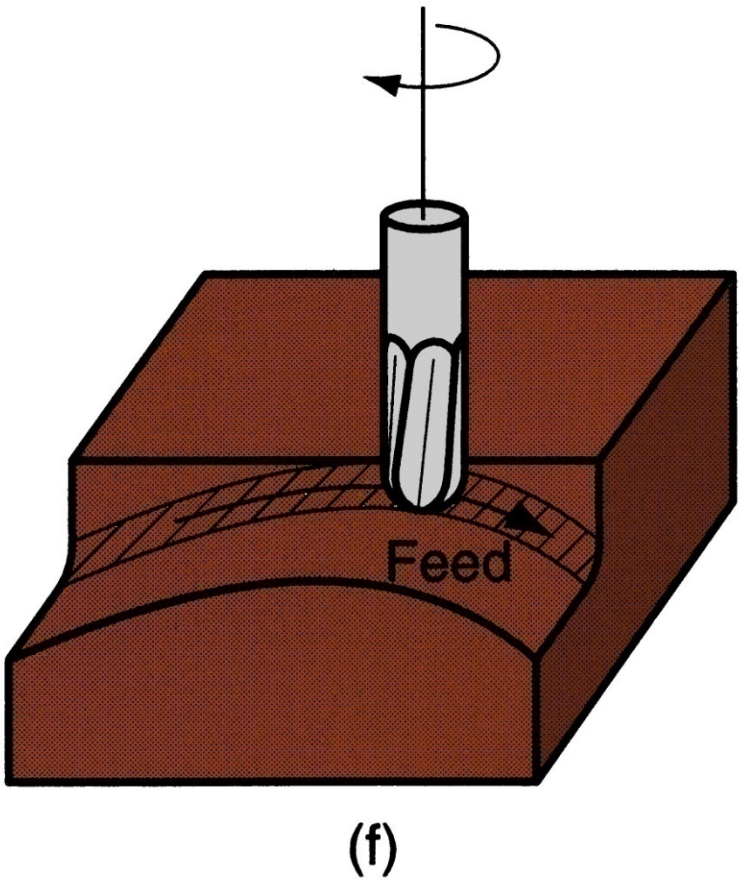
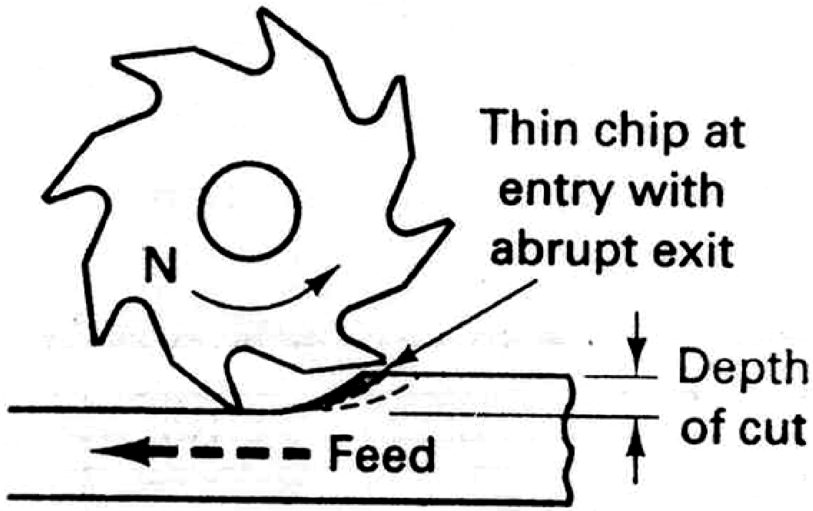


Figure (f) surface contouring

Ball-nose cutter is fed back and forth across the work along a curvilinear path at close intervals to create a three dimensional surface form

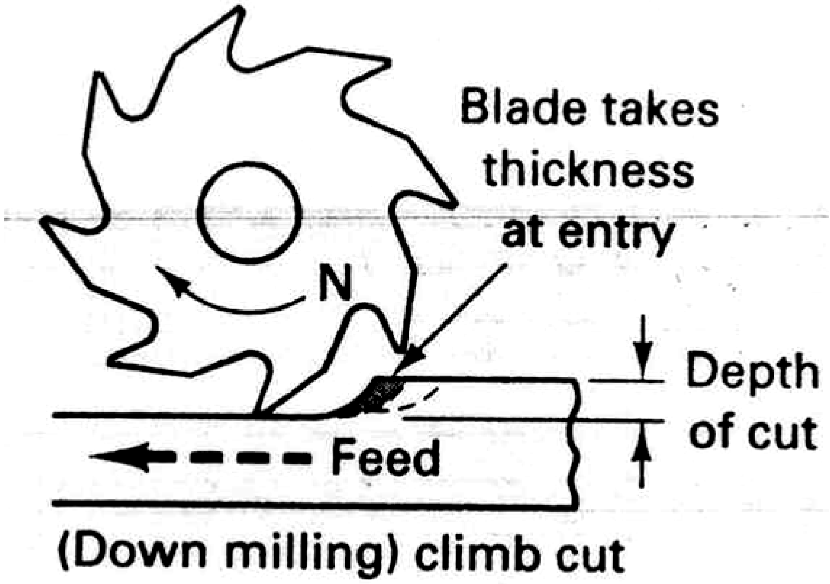
Up Milling



(Up milling) conventional cut

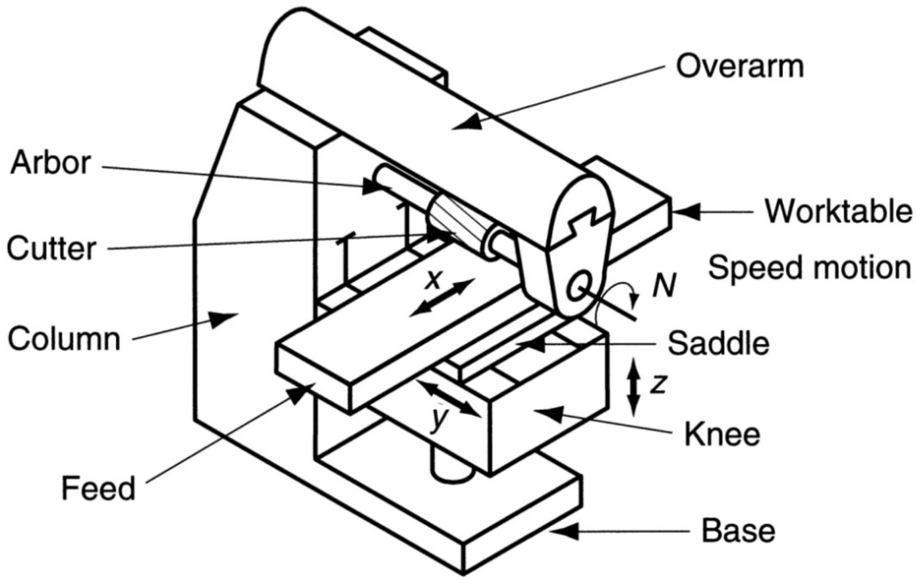
- Common method of milling
- Chip thin in the beginning and increases in thickness
- Work piece has a tendency to be pulled up. Needs clamping
- Tool engagement is not affected by surface characteristics, surface scales
- Chips can be carried into the newly machined surface leading to poor surface finish

Down Milling



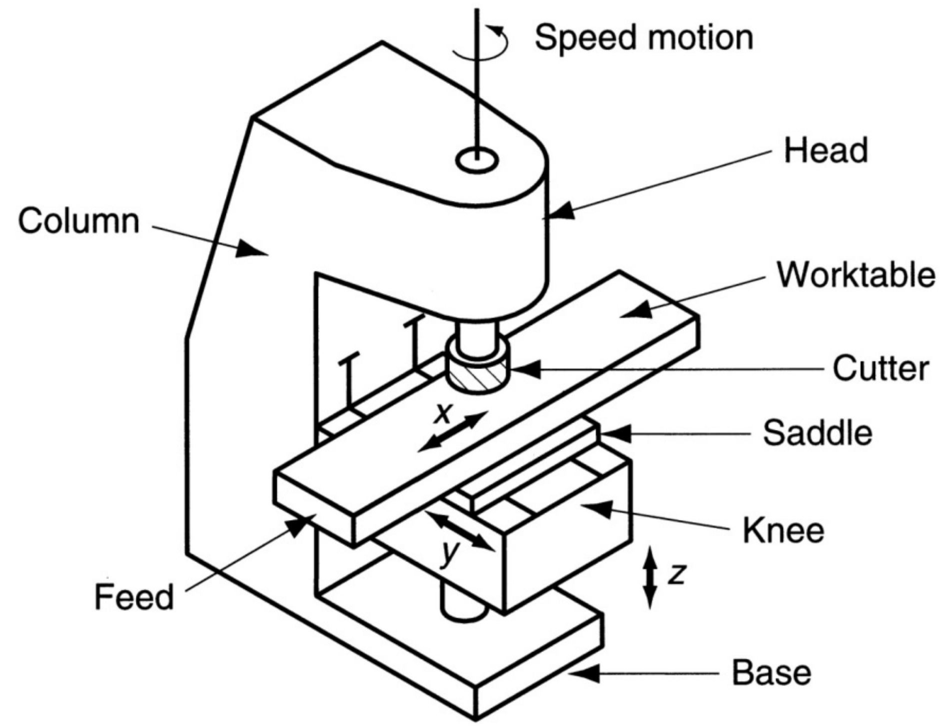
- Cutting starts at the surface where the chip is at its thickest.
- High impact forces require rigid setup
- Cutting force tends to push the work piece down reducing clamping requirements
- Less chatter
- Not suitable for work piece with hard, abrasive scales, as in hot worked metals, forgings and castings.
- Excessive tool wear

Milling Machines



(a)

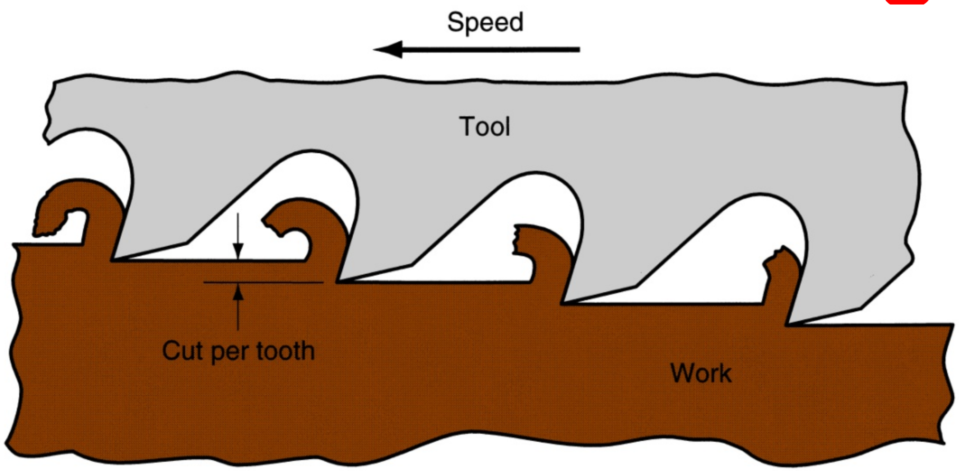
(a) Horizontal Milling Machine



(b)

(b) Vertical Milling Machine

Broaching



Moves a multiple tooth cutting tool linearly relative to work in direction of tool axis

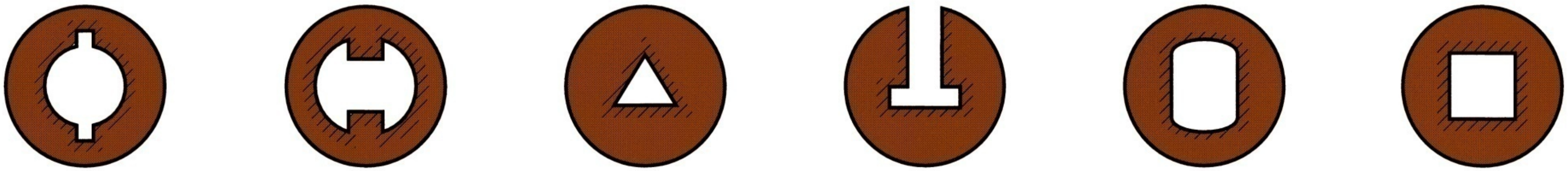
Advantages:

- ❑ Good surface finish
- ❑ Close tolerances
- ❑ Variety of work shapes possible

Cutting tool called a *broach*

➢Owing to complicated and often custom-shaped geometry, tooling is expensive

Internal Broaching

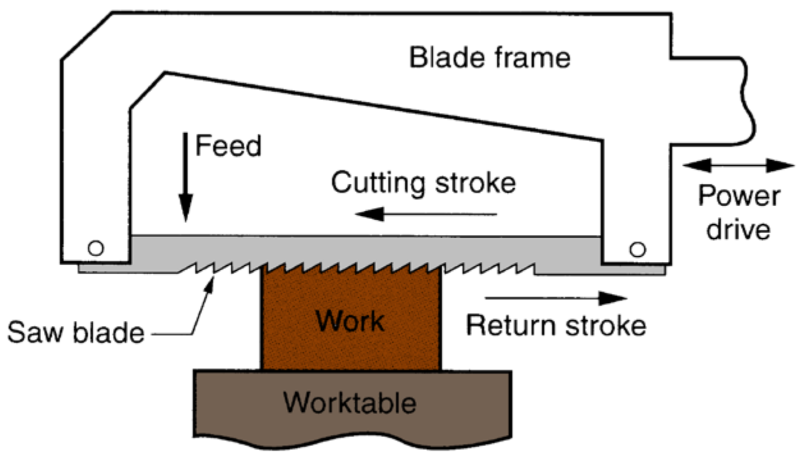


(b)

- Performed on internal surface of a hole
- A starting hole must be present in the part to insert broach at beginning of stroke

Sawing

- Cuts narrow slit in work by a tool consisting of a series of narrowly spaced teeth
- Tool called a *saw blade*
- Typical functions:
  – Separate a workpart into two pieces
  – Cut off unwanted portions of part



(a)

Figure power hacksaw –linear reciprocating motion of hacksaw blade against work

Abrasive Machining Processes

- Hard particles like Al_2O_3, B_4C, SiC etc. abrade the softer materials. Machining processes that use such particles are called Abrasive Machining Processes.
- Material removal by action of hard, abrasive particles usually in the form of a bonded wheel
- Generally used as finishing operations after part geometry has been established conventional machining
- Grinding is most important abrasive processes
- Material removal process in which abrasive particles are contained in a bonded grinding wheel that operates at very high surface speeds
- Other abrasive processes: honing, lapping, super finishing, polishing, and buffing

Abrasive Machining Processes

- The Grinding Wheel consists of abrasive particles and bonding material
- Abrasive particles accomplish cutting
- Bonding material holds particles in place and establishes shape and structure of wheel
- Grinding Wheel Parameters
  - Type of Abrasive material
  - Grain size
  - Wheel grade
  - Wheel structure
  - Bonding material

Abrasive material

Commonly used abrasives in abrasive machining are:

Conventional Abrasives:

- **Aluminum Oxide (A):** Used for grinding Steels, Fe-Alloys, Bronze and other high-strength materials.
- **Silicon Carbide (C):** Used for grinding Cast Iron, Brass, Al, Hard alloys and Carbides.

Superabrasives: Used for very hard materials like Glass, Carbides and Ceramics.

- Cubic boron nitride (CBN)
- Diamond (D)

Grain Size

- Grain Size is expressed in terms of a SIEVE NUMBER , S_n which corresponds to the number of openings per linear inch.
- The diameter of an abrasive grain, $D_g = \frac{0.6}{S_n}$ inch
- The larger the size of the grains, the more will be material removal, but surface finish will be worse.

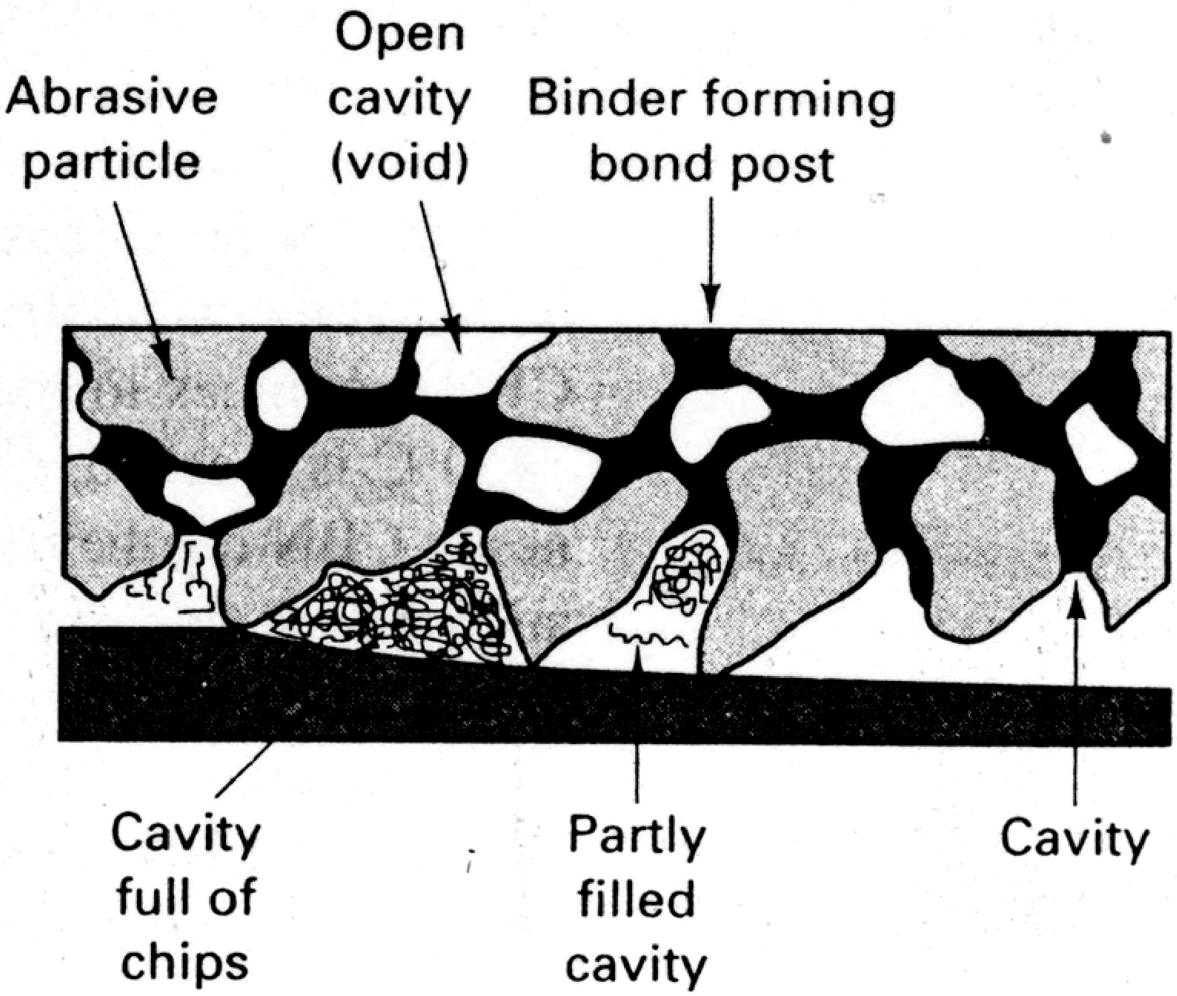
Sieve No.	Type of Grain
10-24	Coarse
30-60	Medium
70-180	Fine
220-600	Very Fine

Grade

- Indicates the strength of the binding material.
- When the work material is hard, the grains wear out easily and the sharpness of the cutting edges is quickly lost. This is known as WHEEL GLAZING.
- To avoid this problem, a soft wheel should be used.

- ❑ **A-H – Soft Wheel**
- ❑ **J-P – Medium Wheel**
- ❑ **Q-Z – Hard Wheel**

Structure



Abrasive particle
Open cavity (void)
Binder forming bond post
Cavity full of chips
Partly filled cavity
Cavity

Structure

- If the voids are too small for the chips, the chips stay in the wheels blocking the voids. This is known as **LOADING** of the wheel.
- **0…..16 – Dense (Closed) to Open structures**

Recommendations:

- For Hard work material – Closed Structure

- Open structure means *voids are* relatively large and *grains are* relatively small - recommended when clearance for chips must be provided
- Dense structure means *voids are* relatively small and *grains are* larger - recommended to obtain better surface finish and dimensional control

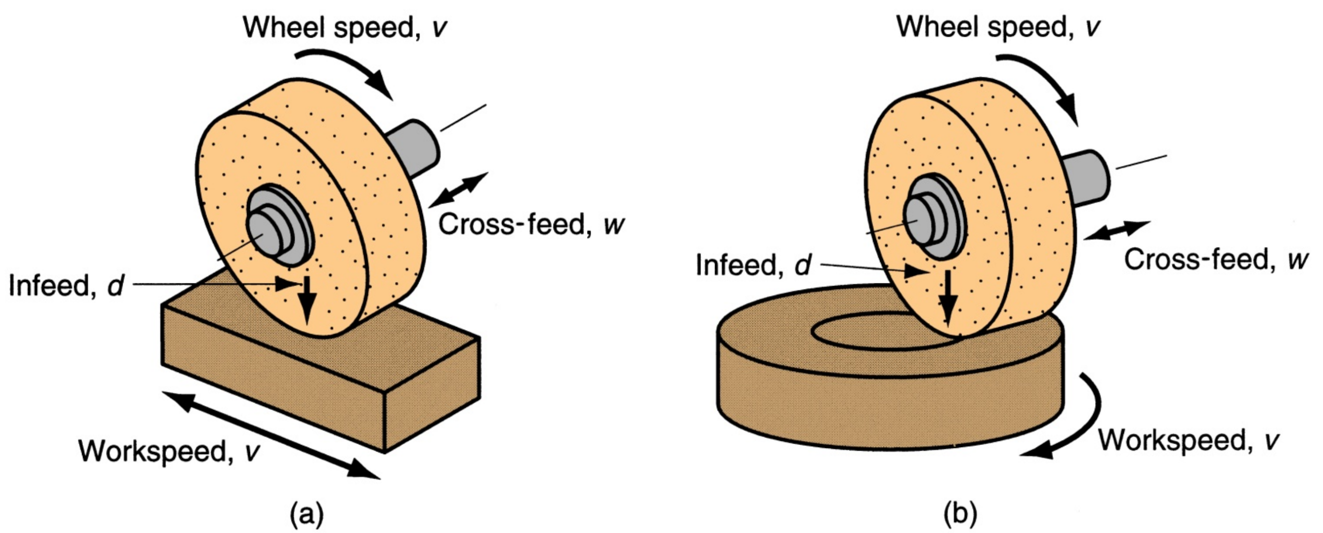
Bonding Material

- Vitrified Bond (V) – Strong and Rigid, commonly used.
- Resinoid (B) – Provides shock absorption and elasticity. They are Strong enough.
- Silicate (S) – Provides softness (grains dislodge quickly)
- Shellac (E) – Used for making thin but strong wheels possessing some elasticity.
- Rubber Bonds (R) – For making flexible wheels
- Metallic Bond (M) – For diamond wheels only.

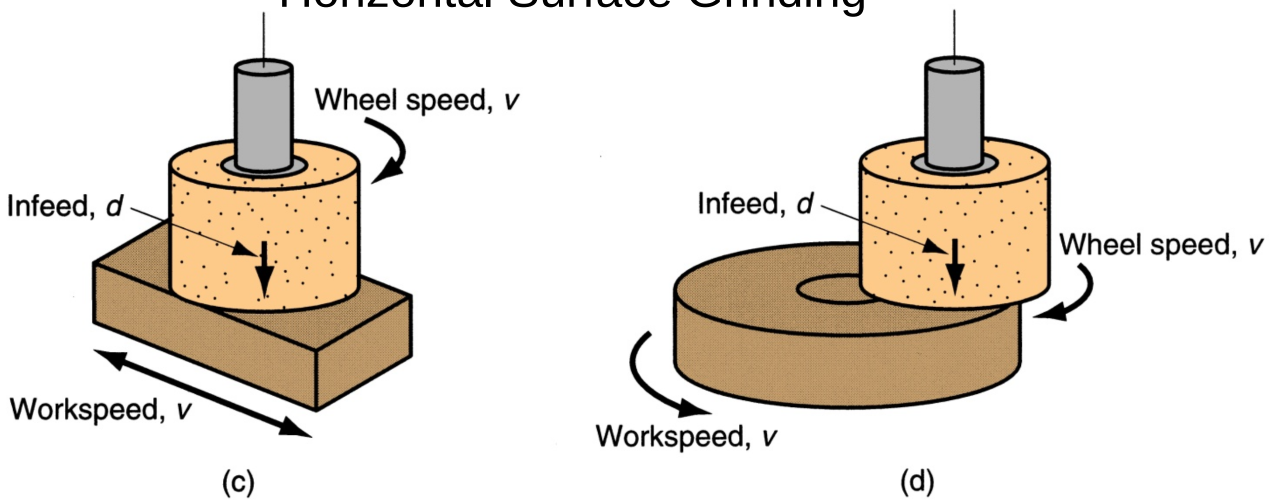
Grinding Wheel Specification

- Standard grinding wheel marking system used to designate abrasive type, grit size, grade, structure, and bond material
  - Example: **A-46-H-6-V**
- Also provides for additional identifications for use by grinding wheel manufacturers

Grinding Processes

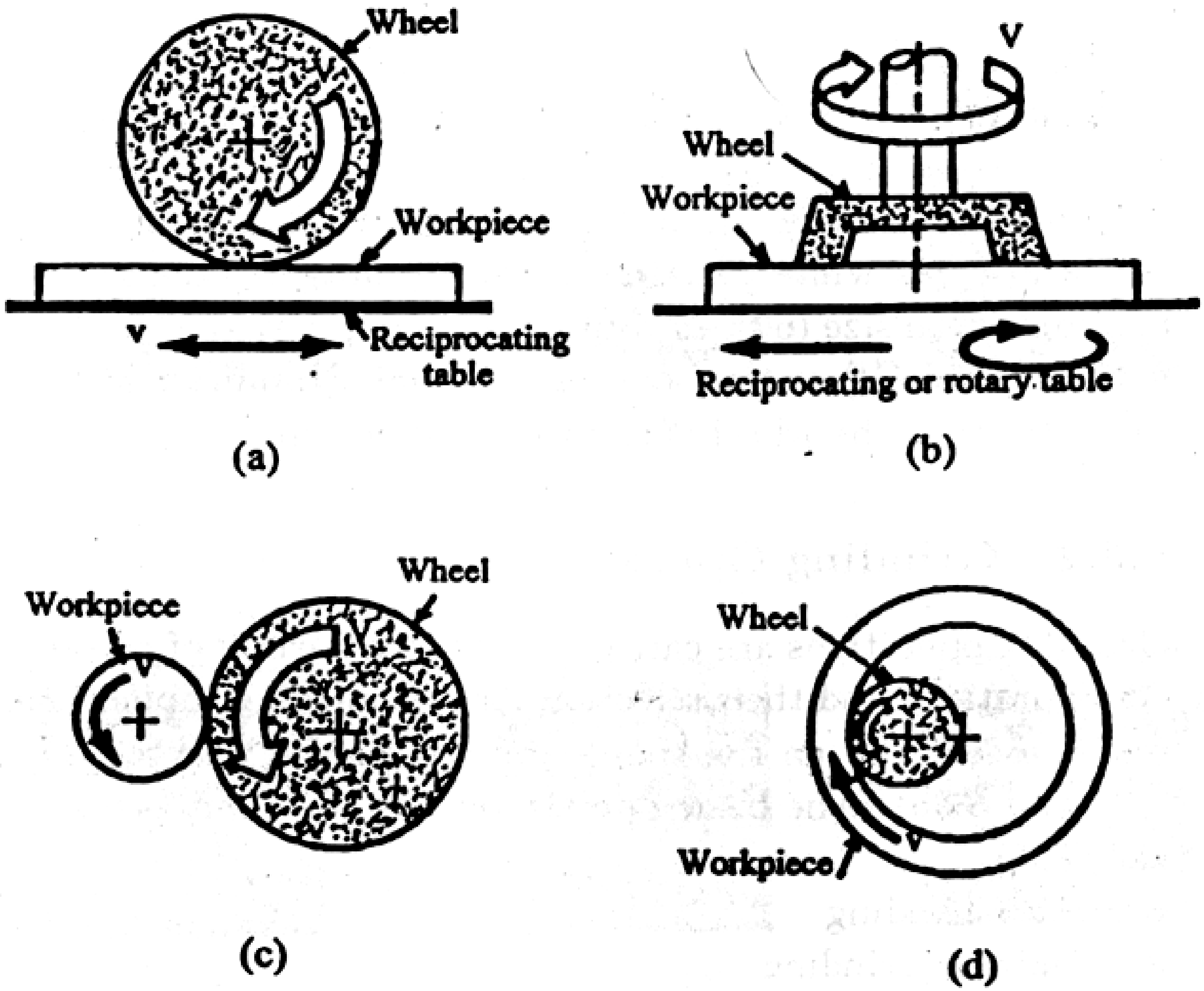


Horizontal Surface Grinding

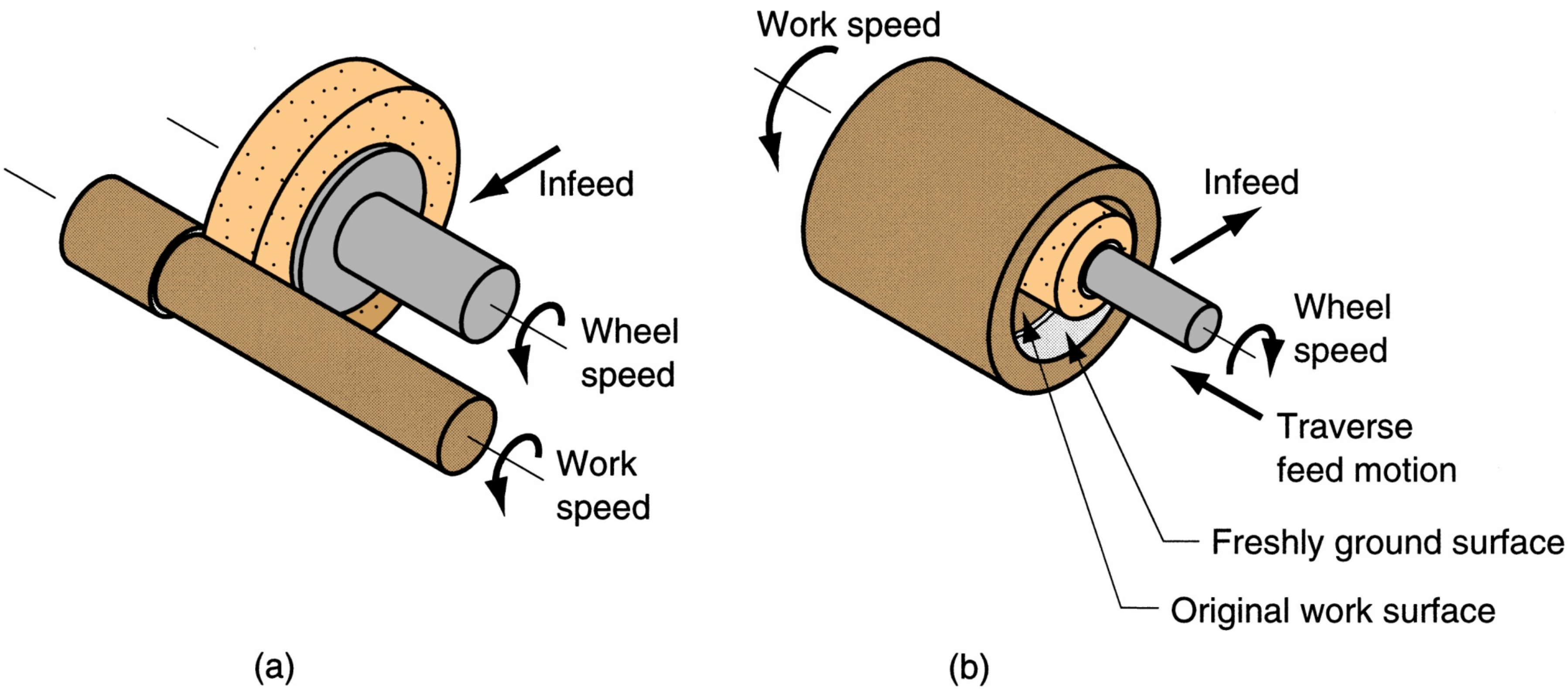


Vertical Surface Grinding

Grinding Processes

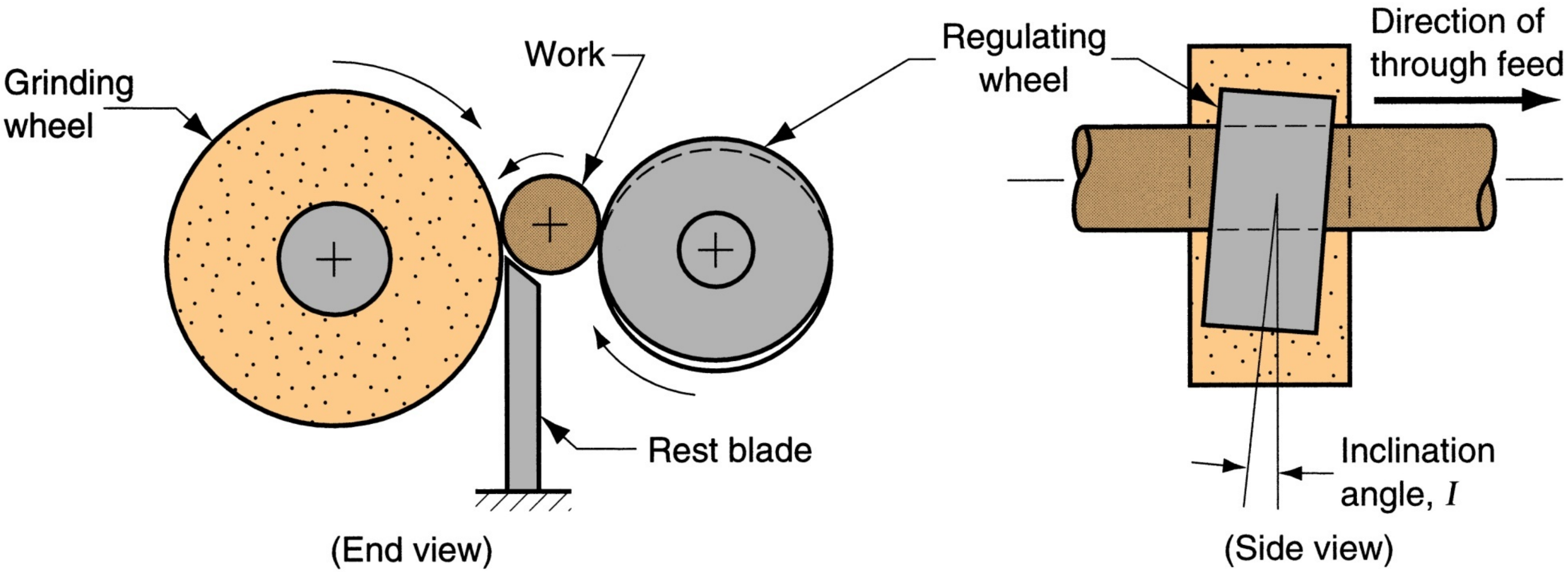


Grinding Processes



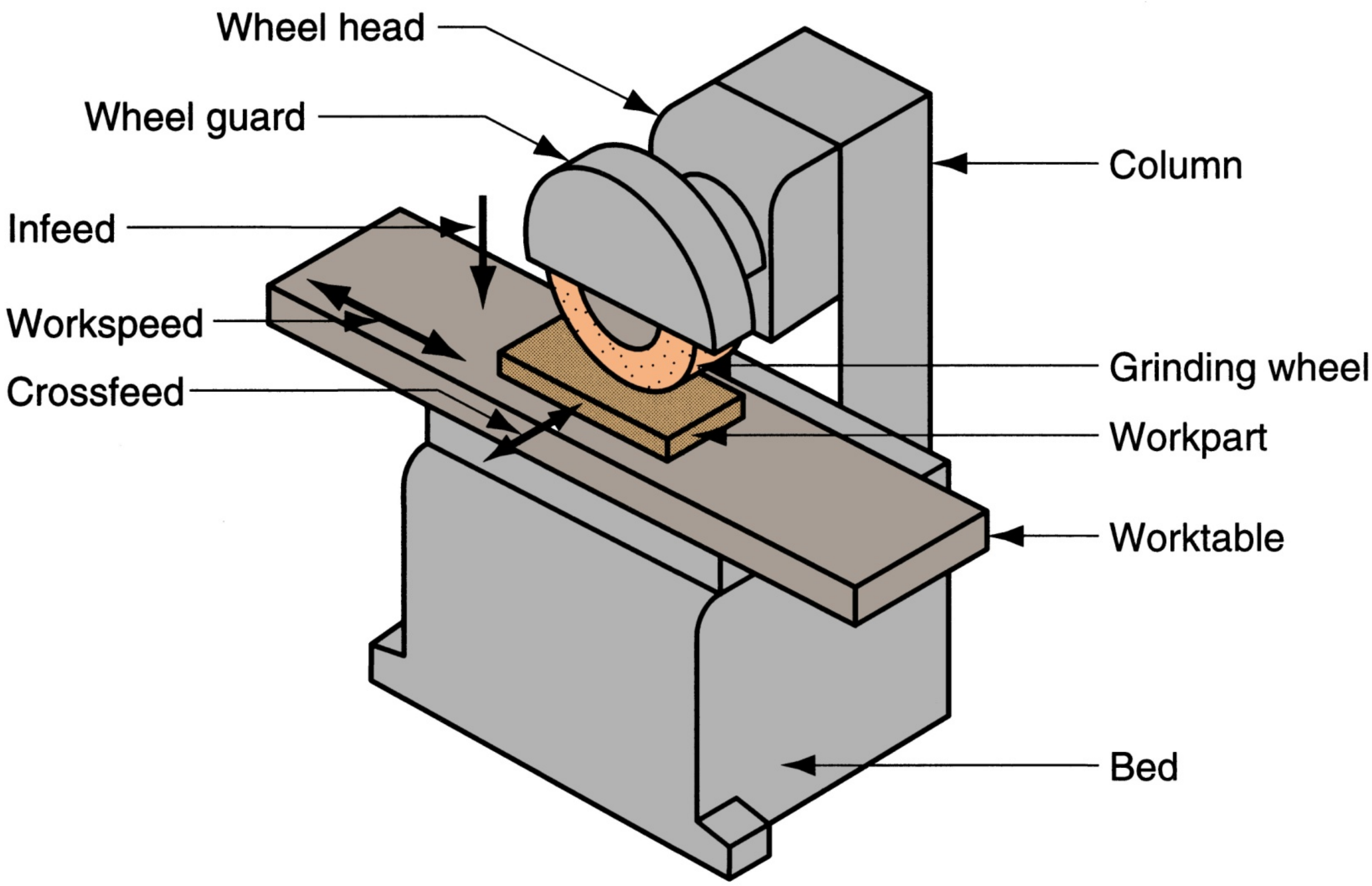
Two types of cylindrical grinding:
(a) external, and (b) internal

Grinding Processes



External centerless grinding

Grinding Processes



Horizontal Grinding Machine