TA202A: Introduction to Manufacturing Processes

Lectures 2-5
Conventional Machining Processes

Dr. J. Ramkumar
Department of Mechanical Engineering
IIT Kanpur

Link for course information and Lectures: http://home.iitk.ac.in/~jrkumar/ta202a.php

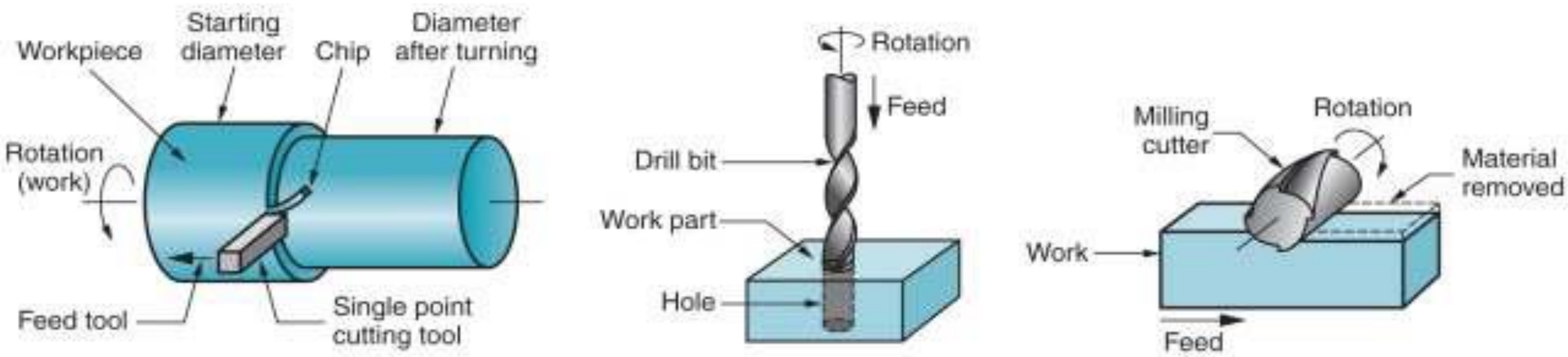
Material Removal Processes

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

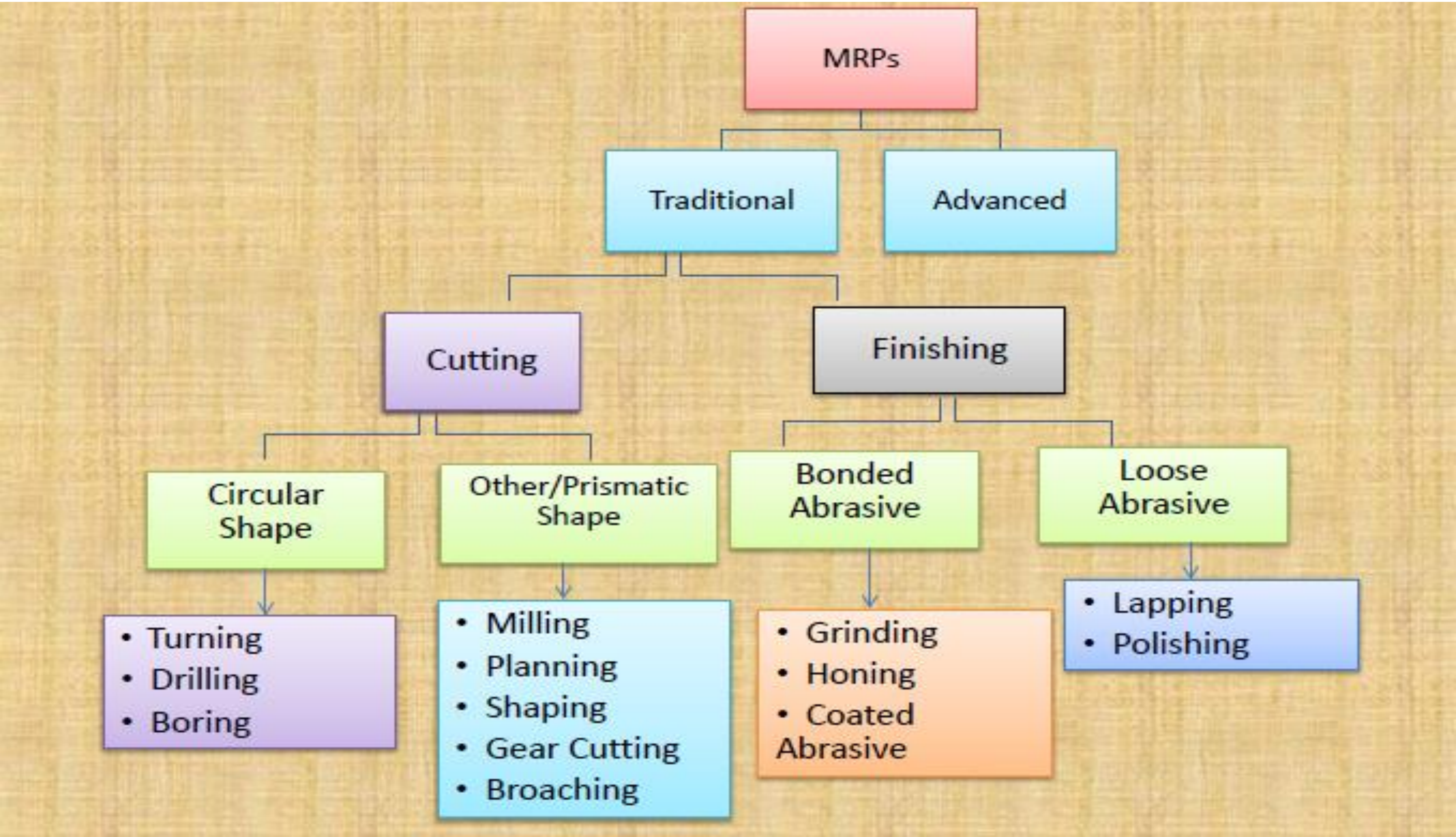
Machining

- Excess material removed from the starting piece so what remains is the desired geometry
- Examples: (a) Turning, (b) Drilling, and (c) Milling

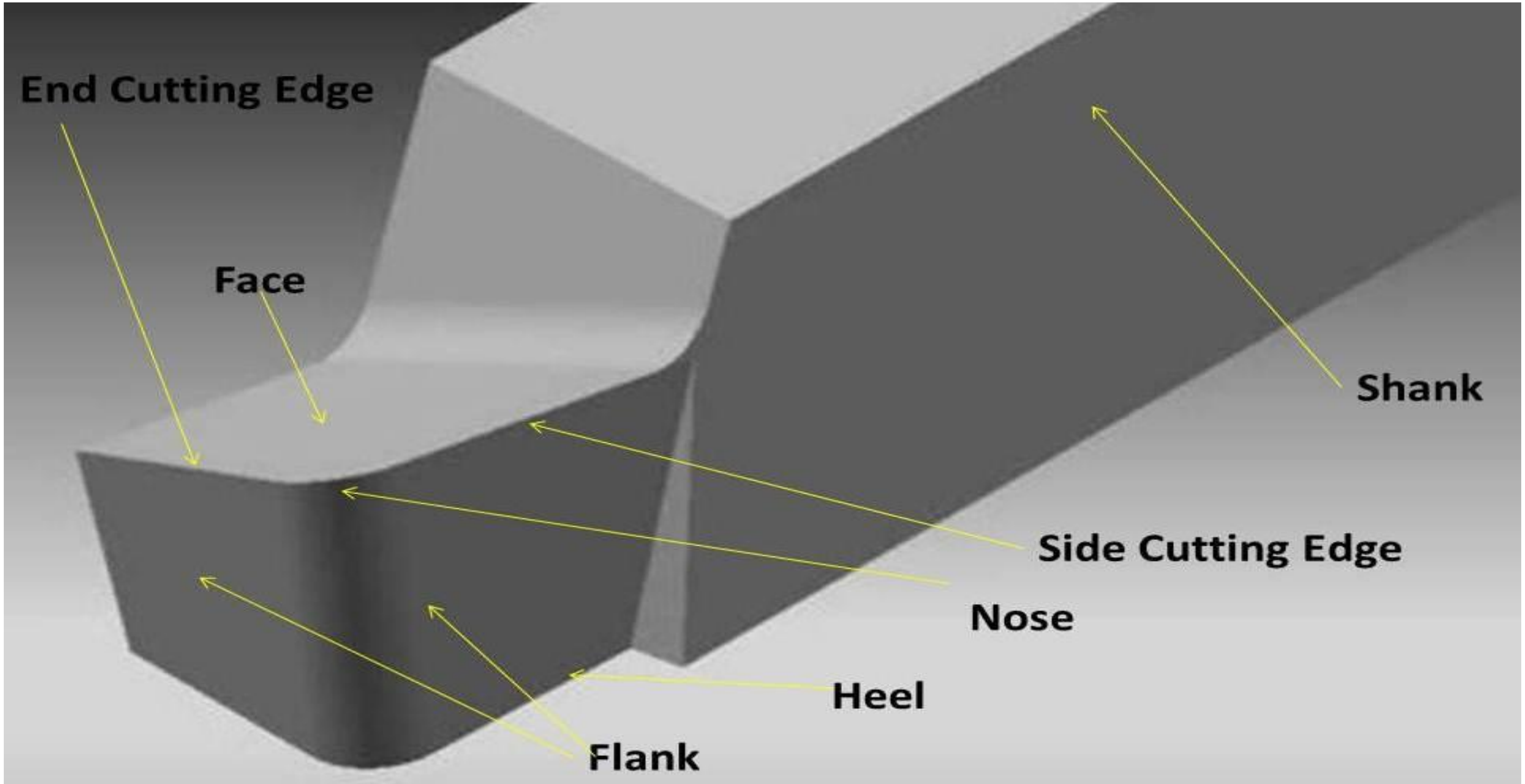


(a) (b) (c)

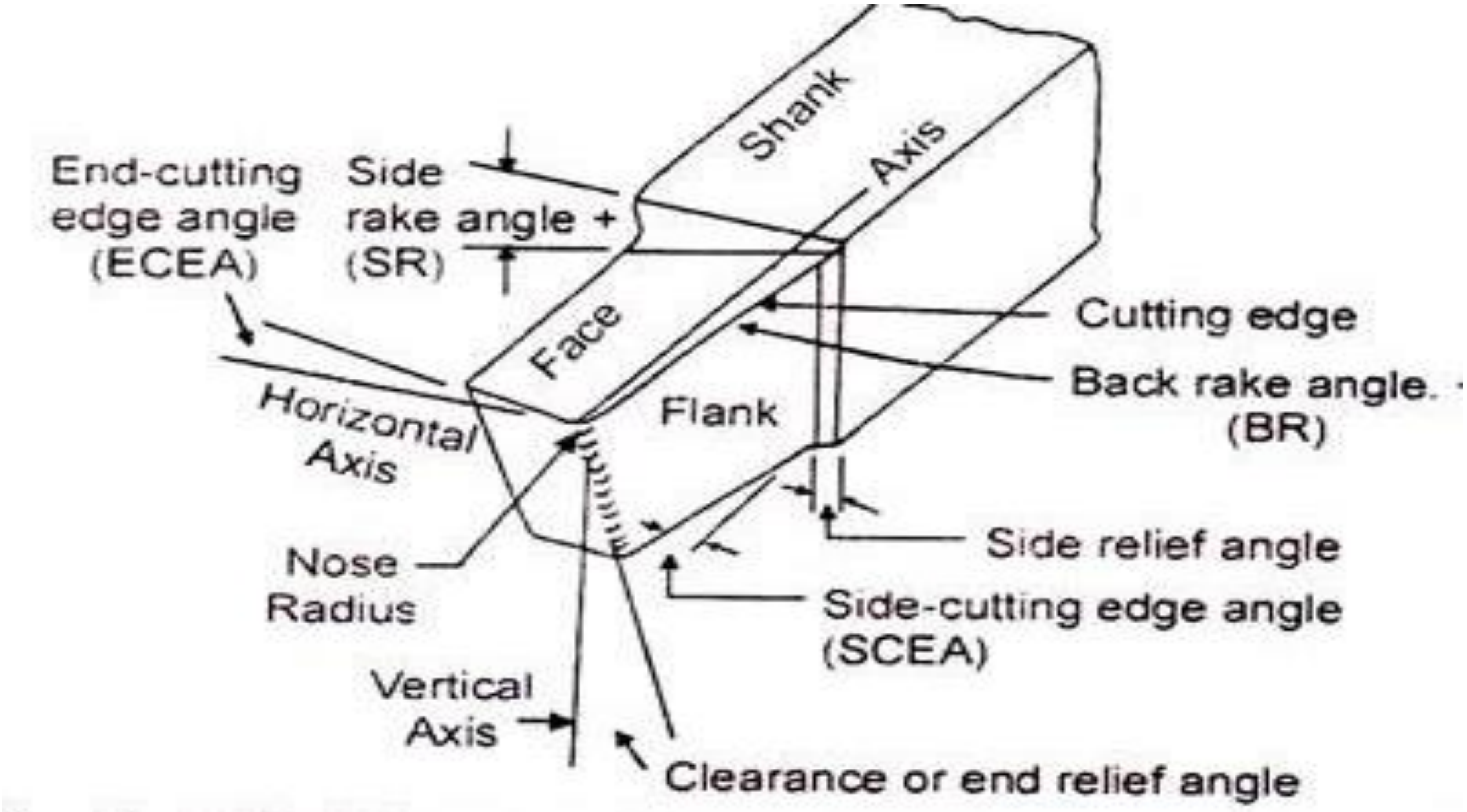
Material Removal Processes



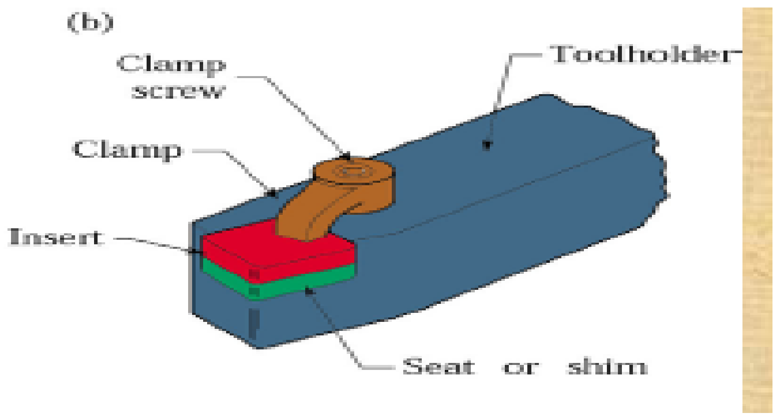
Geometry of single point cutting tool



Geometry of right hand single point cutting tool



Schematic illustration of a right-hand cutting tool



Turning tool with tool insert

Tool Nomenclature/Angles

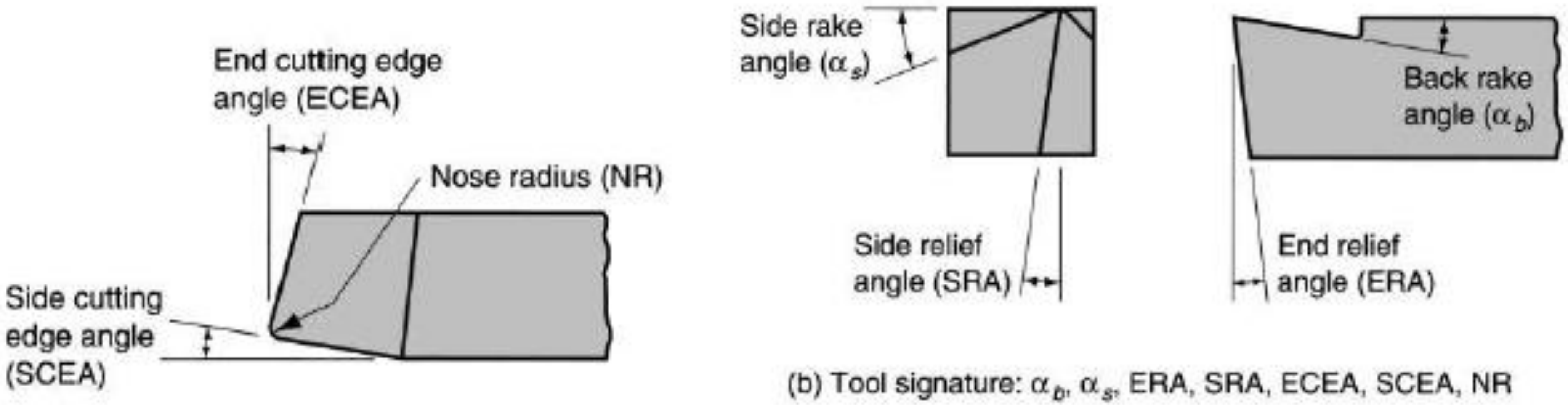
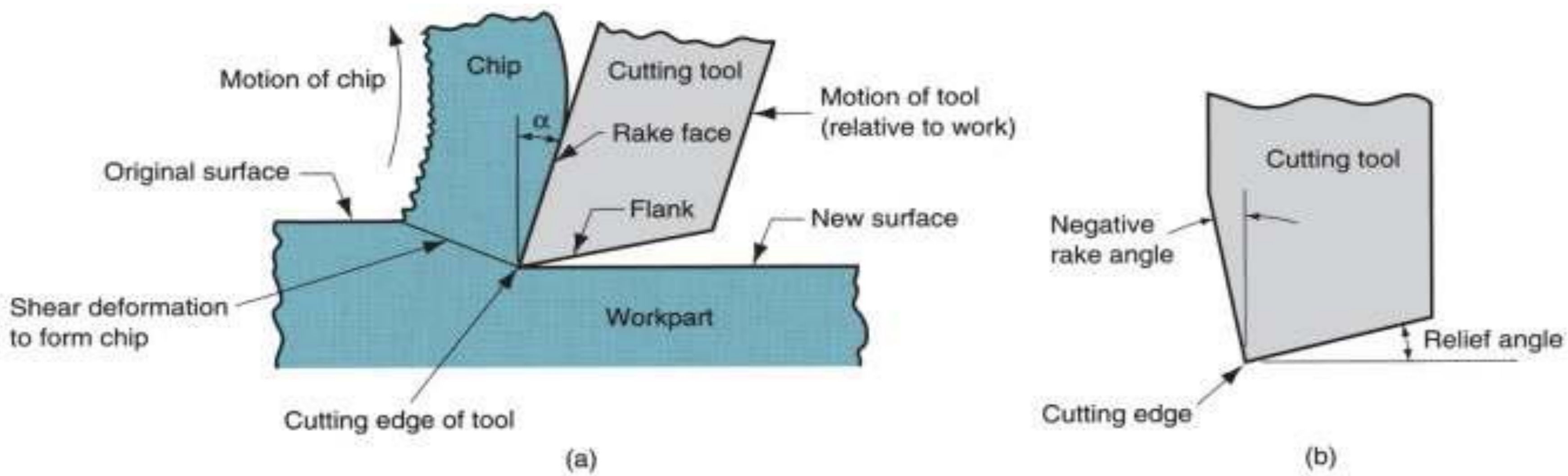
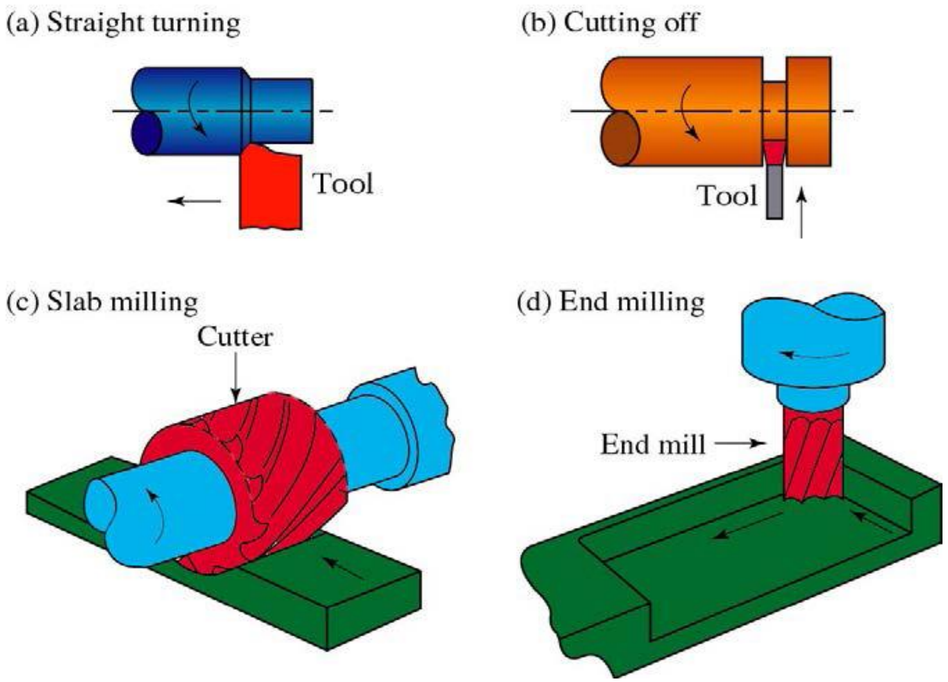
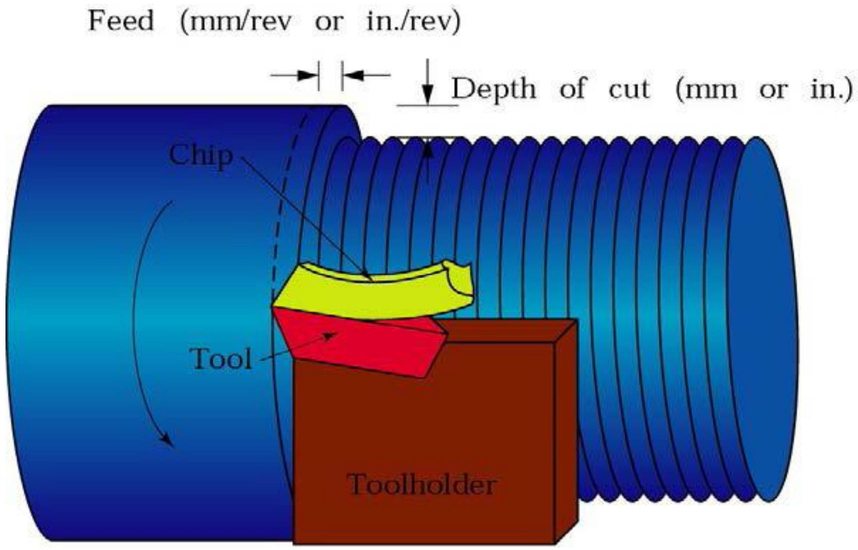


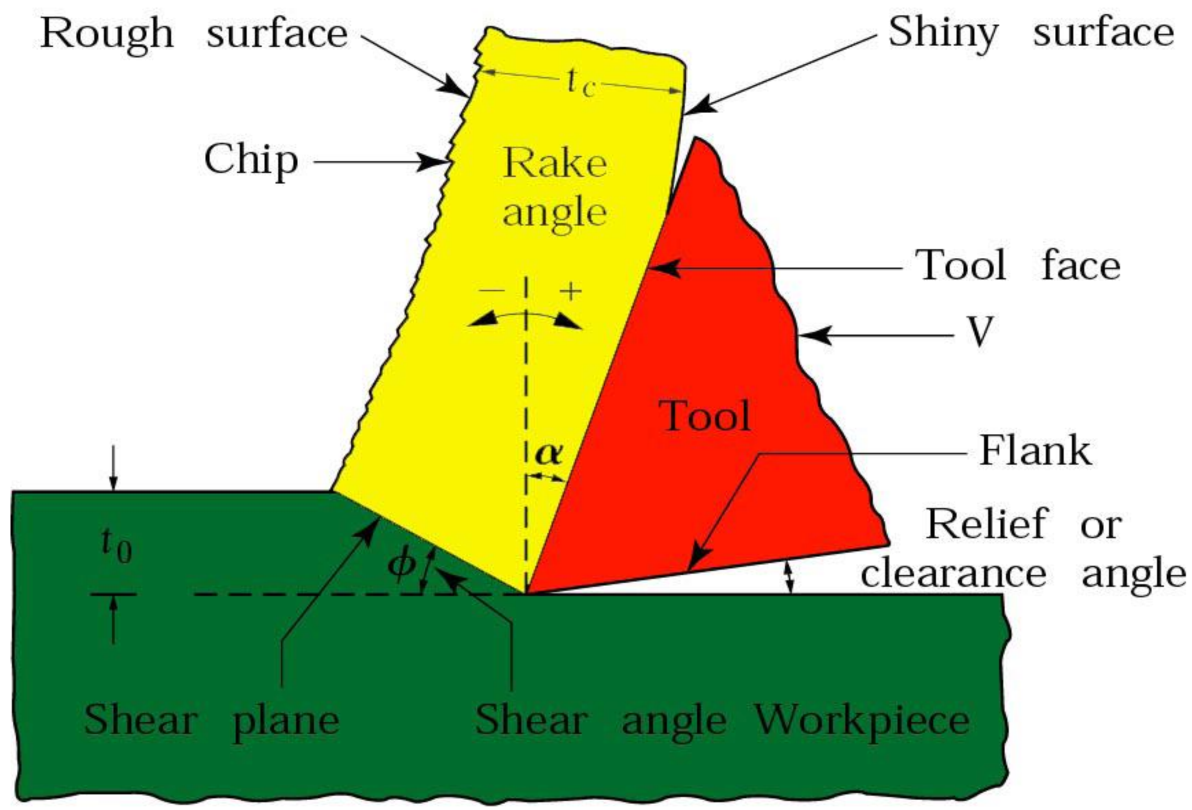
Figure: (a) Seven elements of single-point tool geometry; and (b) the tool signature convention that defines the seven elements



Examples of cutting processes



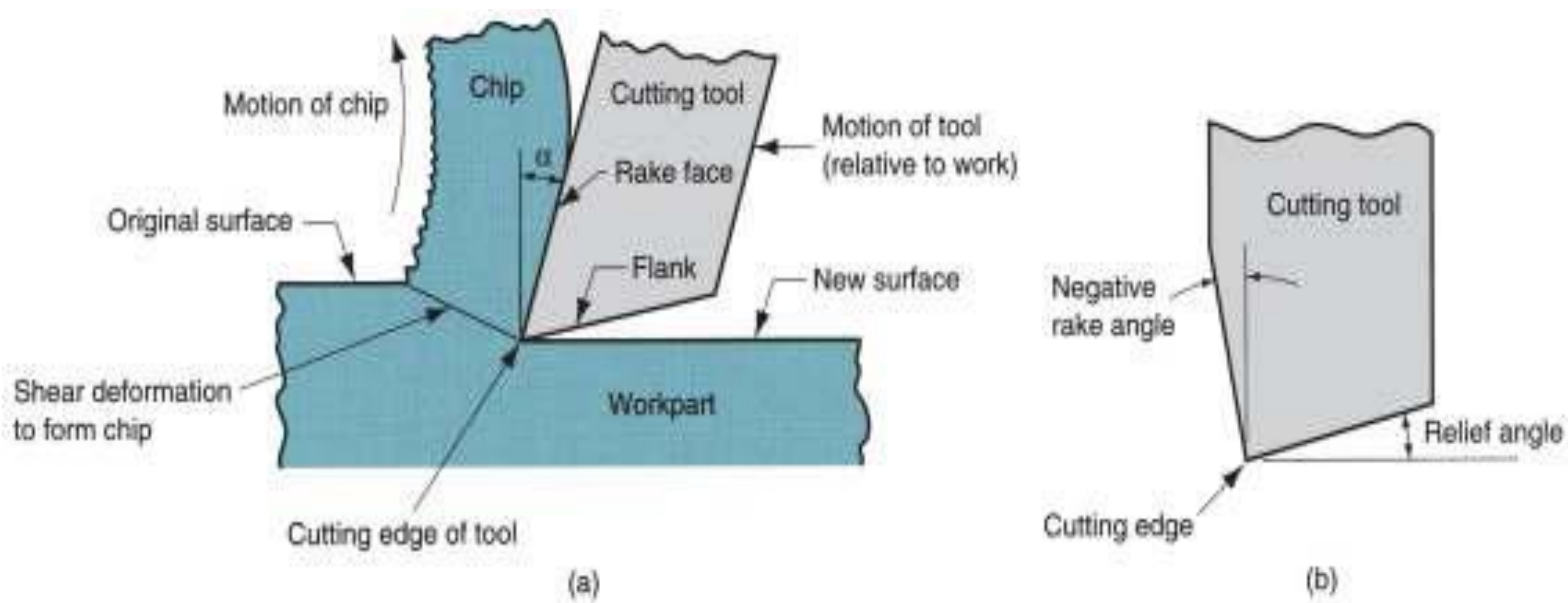




Two-dimensional cutting process, also called orthogonal cutting.
Note that the tool shape and its angles, depth of cut, to, and the cutting speed, V, are all independent variables.

Traditional material removal process :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



Cutting Conditions in Machining

The three dimensions of a machining process:

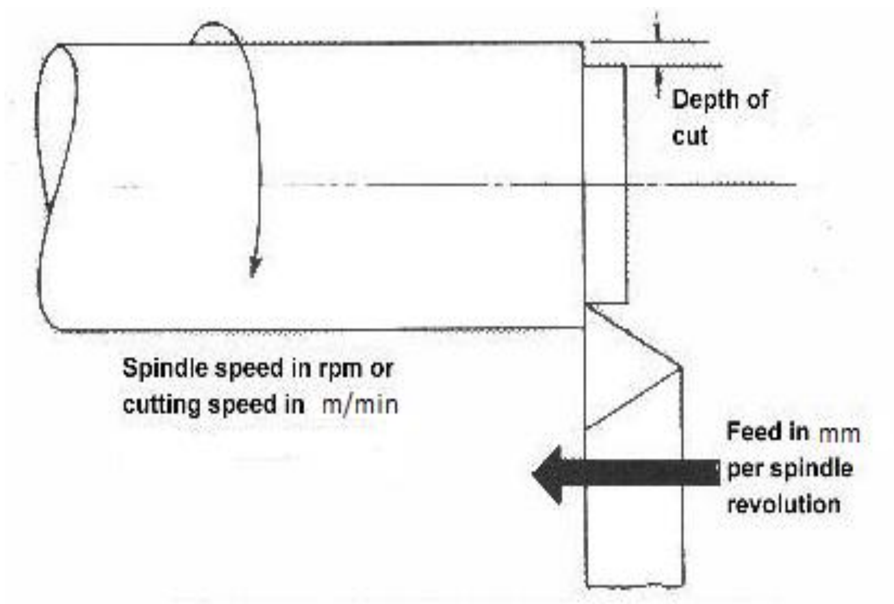
- ❖ Cutting speed (v) :Primary motion
- ❖ Feed (f) :Secondary motion
- ❖ Depth of cut (d) :Penetration of tool below original work surface

For certain operations, material removal rate can be found as:

$$MRR = v \times f \times d$$

Where,

v = Cutting speed; f = Feed; d = Depth of cut



Types of cutting

❖ **Orthogonal Cutting (2-D Cutting):**

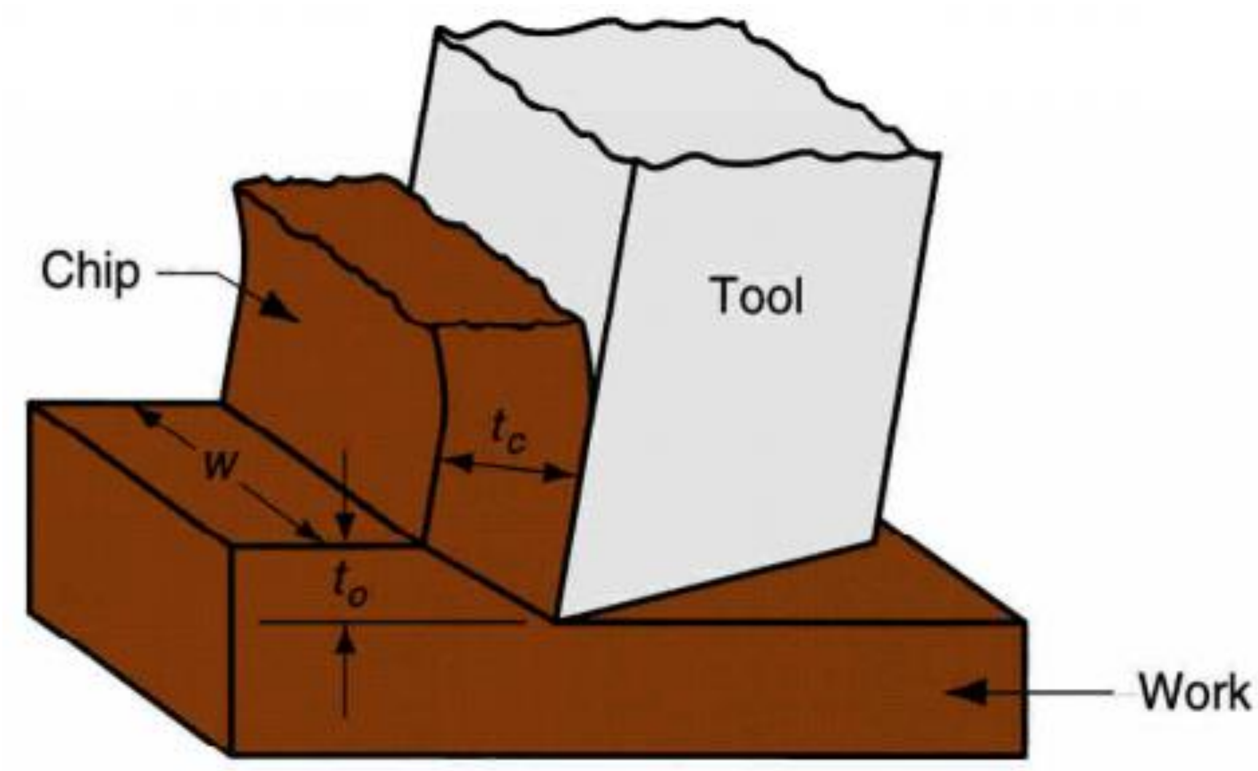
In Orthogonal Cutting, Cutting edge is

(1) Straight,

(2) Parallel to the original plane surface on the work-piece and

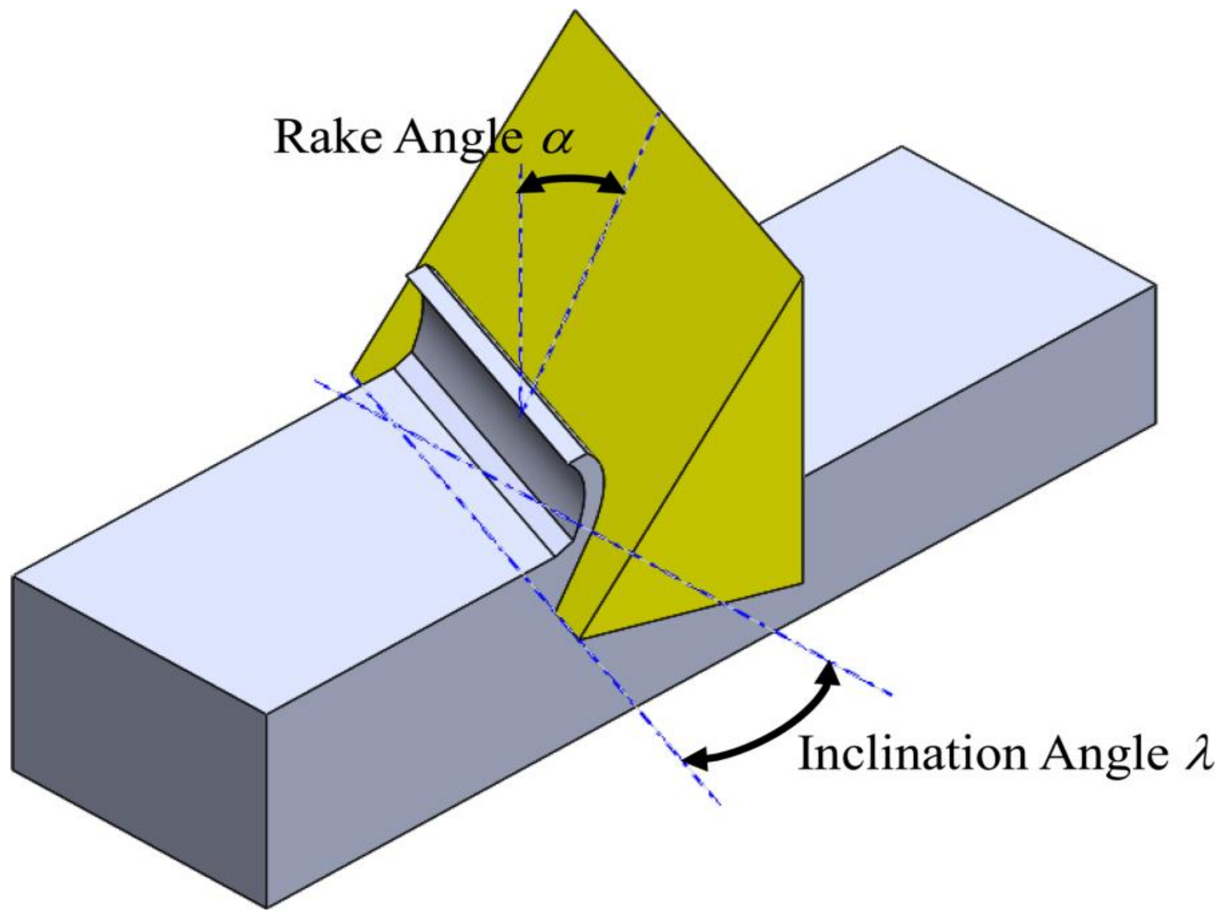
(3) Perpendicular to the direction of cutting.

For example: Operations: Lathe cut-off operation, Straight milling, etc.



Oblique Cutting

- ❖ **Oblique Cutting (3-D 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(3-D)

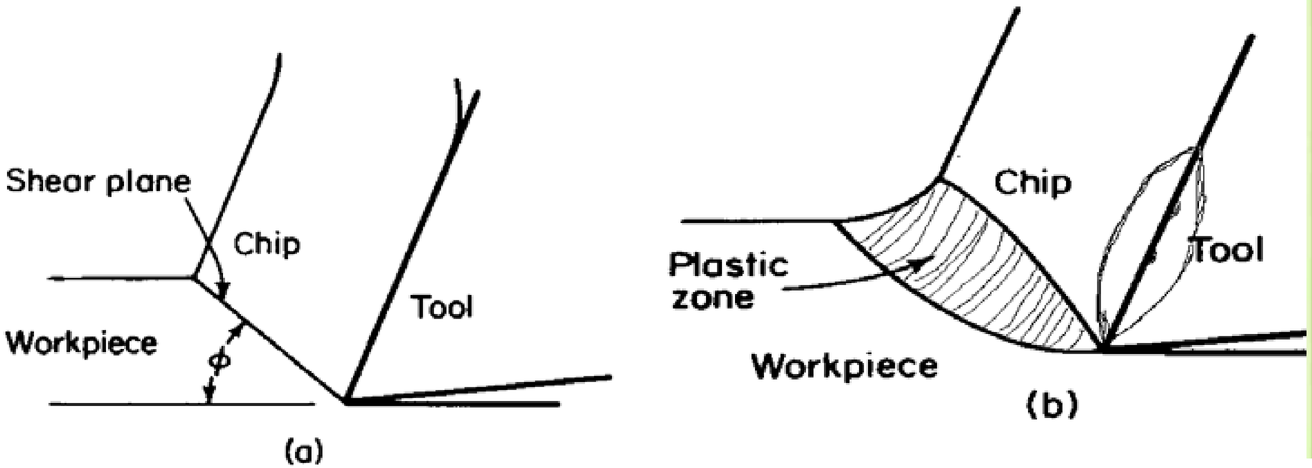


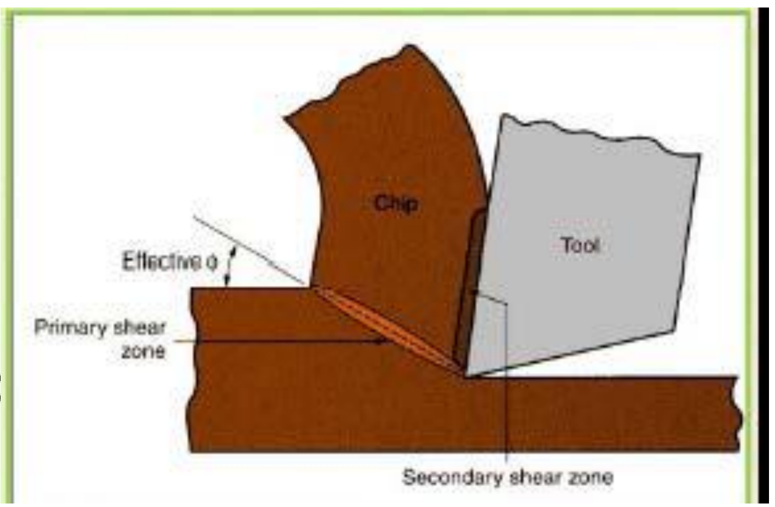
Mechanics of chip formation

- Plastic deformation along shear plane (Merchant)
- The figure, where the work piece remains stationary and the tool advances in to the work piece towards left. Thus the metal gets compressed very severely, causing shear stress.
- This stress is maximum along the plane is called shear plane.
- If the material of the work-piece is ductile, the material flows plastically along the shear plane, forming chip, which flows upwards along the face of the tool.

The tool will cut or shear off the metal, provided by:

- The tool is harder than the work metal
- The tool is properly shaped so that its edge can be effective in cutting the metal.
- Provided there is movement of tool relative to the material or vice-versa, so as to make cutting action possible.





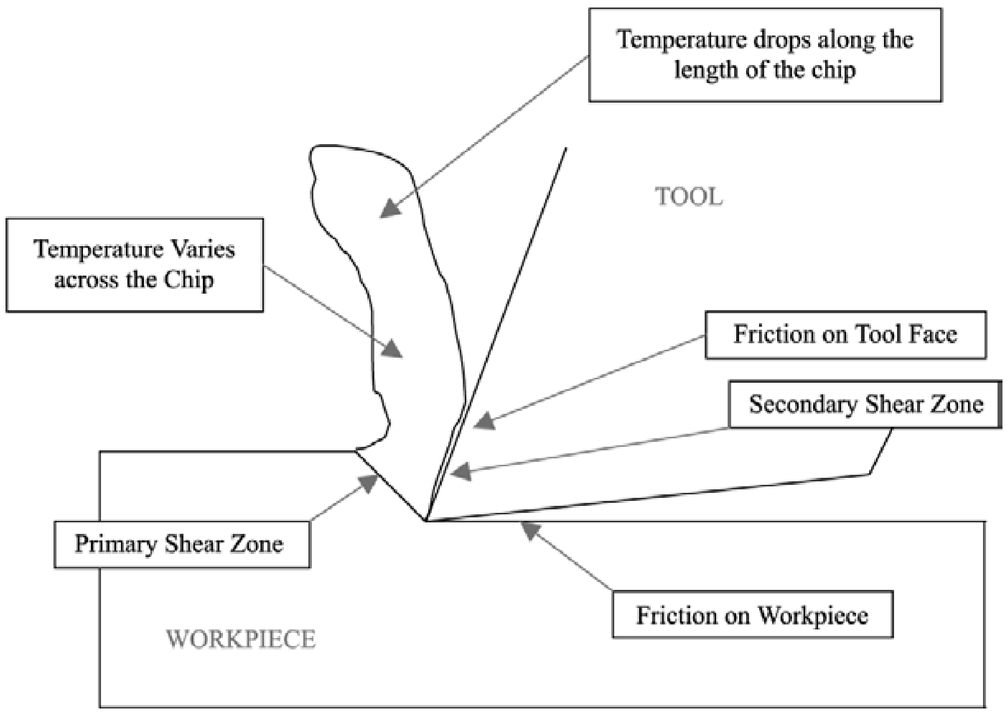
Types of Chips

Types of Chips

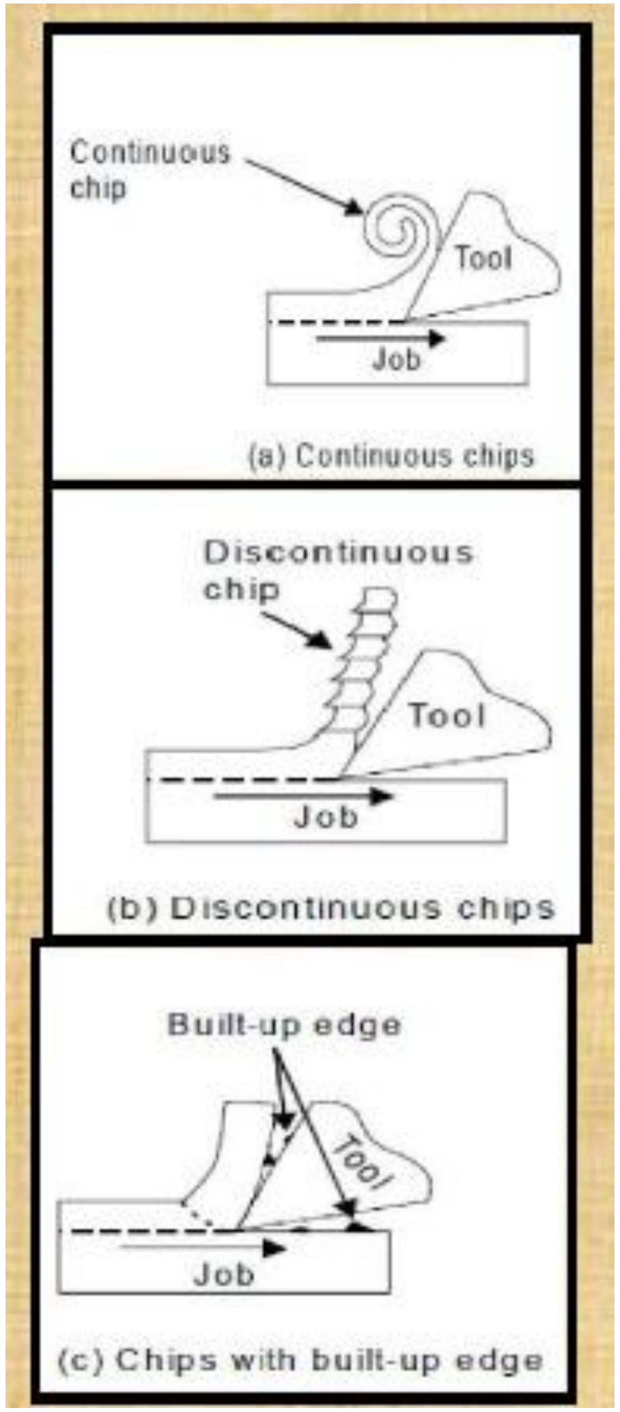
1. Continues Chips
2. Discontinues Chips
3. Continuous Chips with Built up Edge (BUE)

Conditions for Continuous Chips:

- Sharp cutting edges
- Low feed rate (f)
- Large rake angle (α)
- Ductile work material
- High cutting speed (v)
- Low friction at Chip-Tool interface



Schematic of chip formation

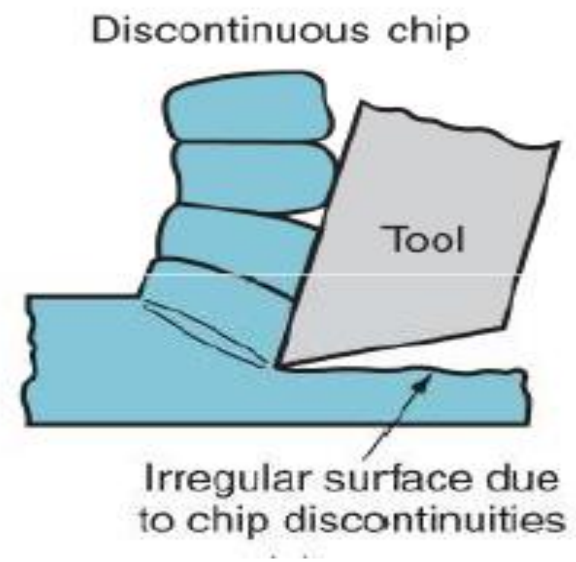


Schematic of different types of chip

Types of Chips

Conditions for discontinuous chips:

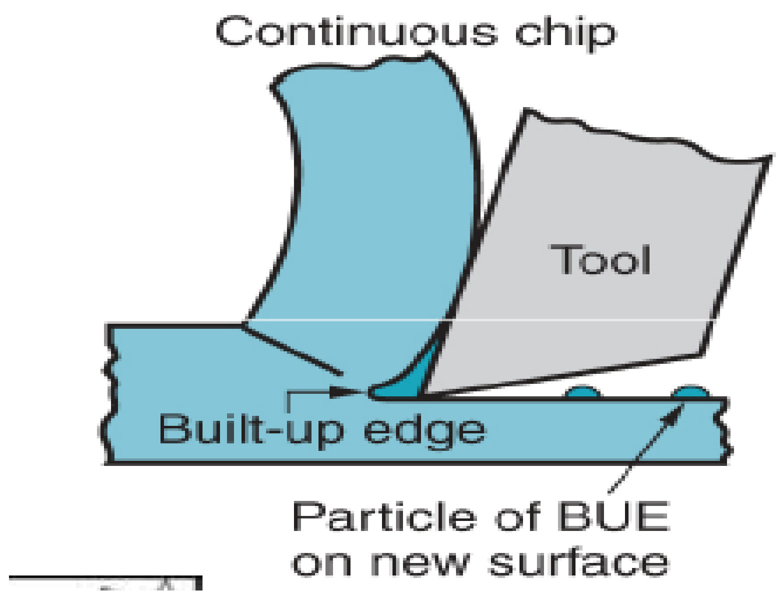
- Brittle Material
- Low cutting speed
- Small rake angle



Built up Edge:

Continuous Chips with Built up Edge (BUE)

- High friction between Tool & chip
- Ductile material
- Particles of chip adhere to the rake face of the tool near cutting edge



Chip breaking

- ❖ The chip breaker break 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.

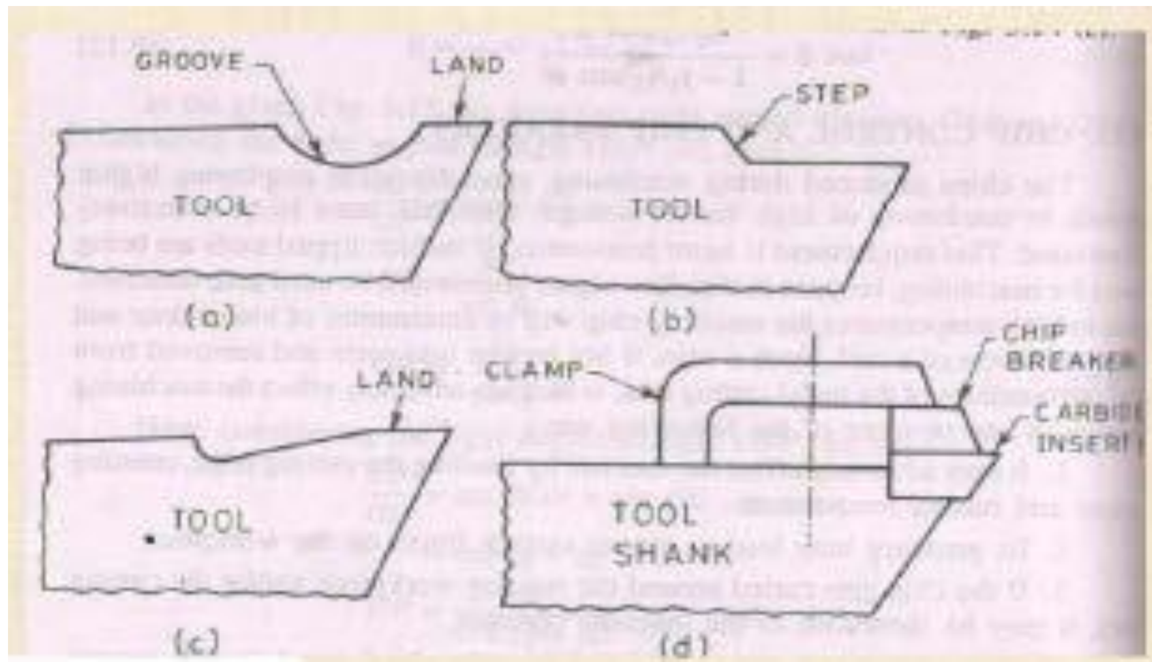
The following types of chip breakers are commonly used:

(a) Groove type

(b) Step type

(c) Secondary Rake type

(d) Clamp type



Schematics of different types of chip barkers

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 work-part
- 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

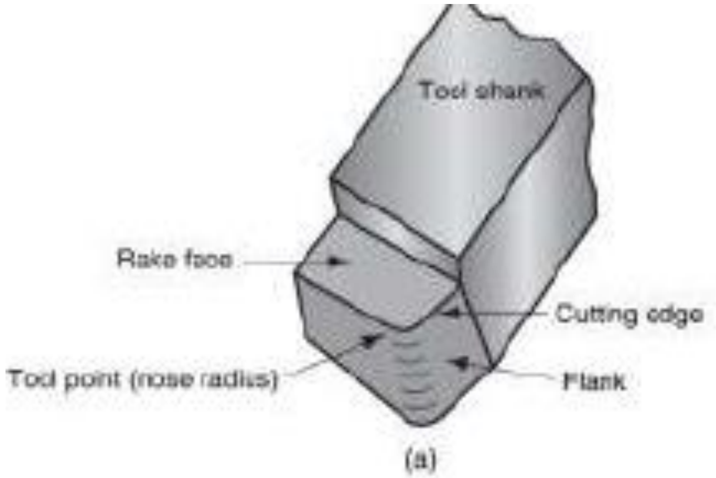
Cutting Tool Classification

1. Single-Point Tools

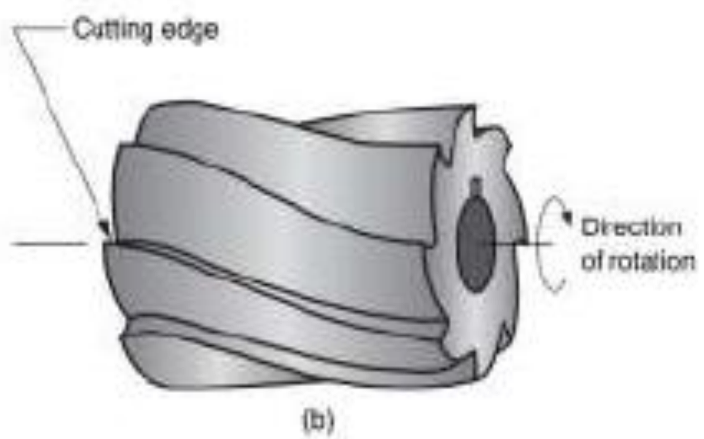
- ❖ One dominant cutting edge
- ❖ Point is usually rounded to form a nose radius
- ❖ Turning uses single point tools

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



Single-Point Tool

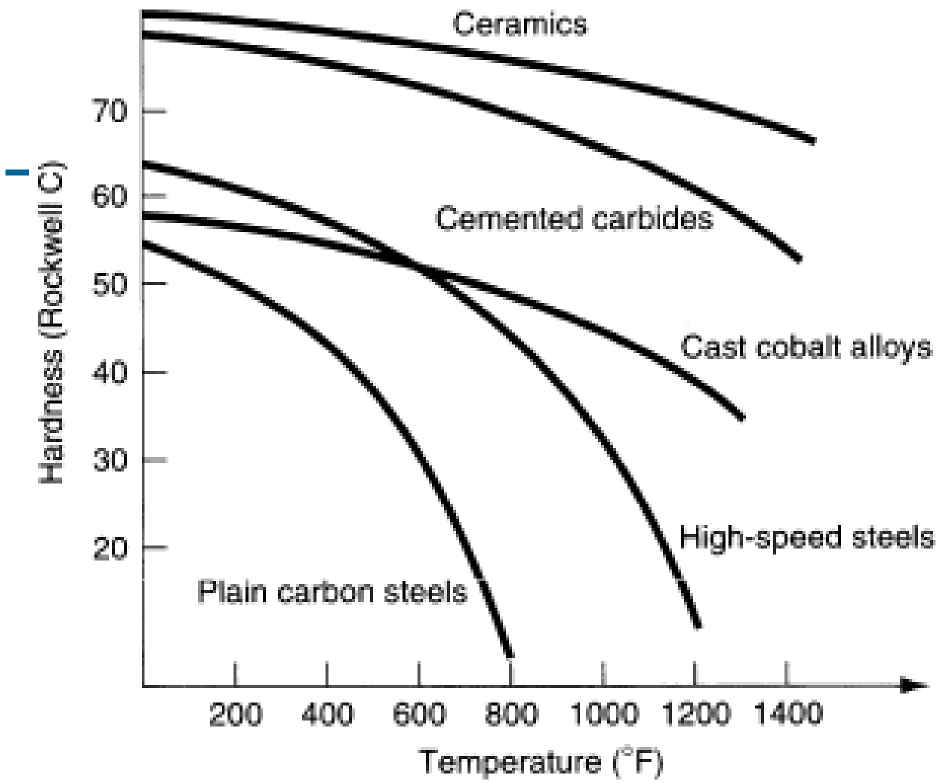


Multiple Cutting Edge Tool

Cutting Tool Materials

Tool failure modes identify the important properties that a tool material should possess:

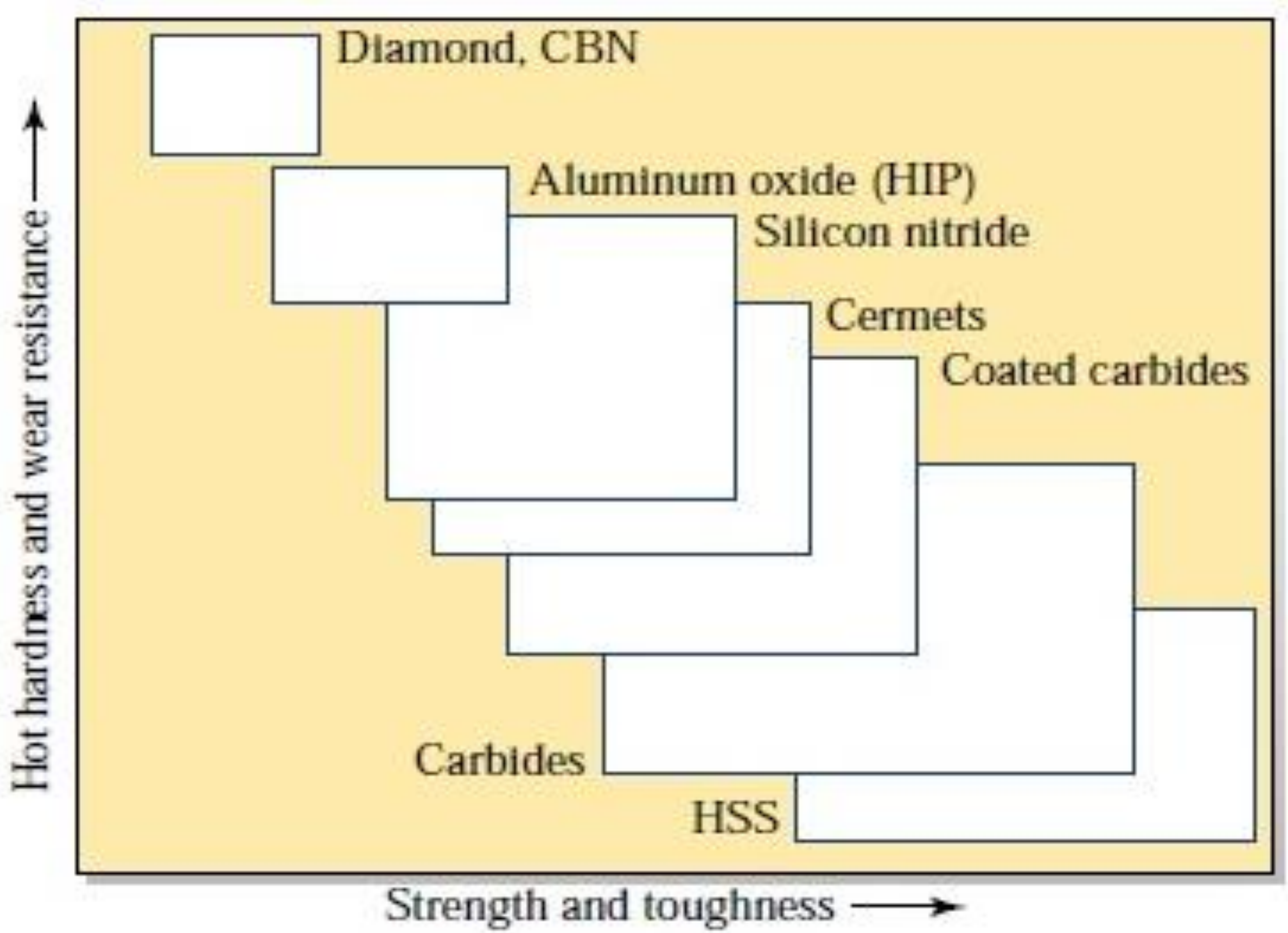
- Toughness - To avoid fracture failure
- Hot Hardness - Ability to retain hardness at high temperatures
- Wear Resistance - Hardness is the most important property to resist abrasive wear



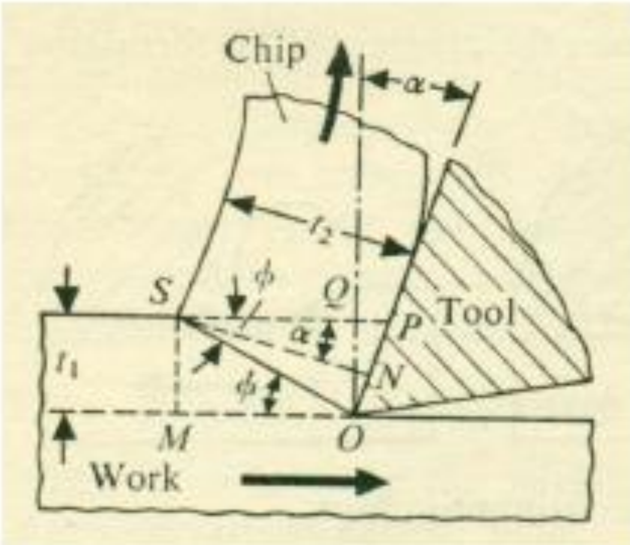
Typical hot hardness relationships for selected tool materials. Plain carbon steel shows a rapid loss of hardness as temperature increases.

High speed steel is substantially better, while cemented carbides and ceramics are significantly harder at elevated temperatures.

Hardness vs. Toughness for different tool Materials



Mechanics of Cutting
(Shear plane angle)



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

$$t_1 = OS\ \sin\emptyset \qquad t_2 = OS\ \cos(\emptyset - \propto)$$

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

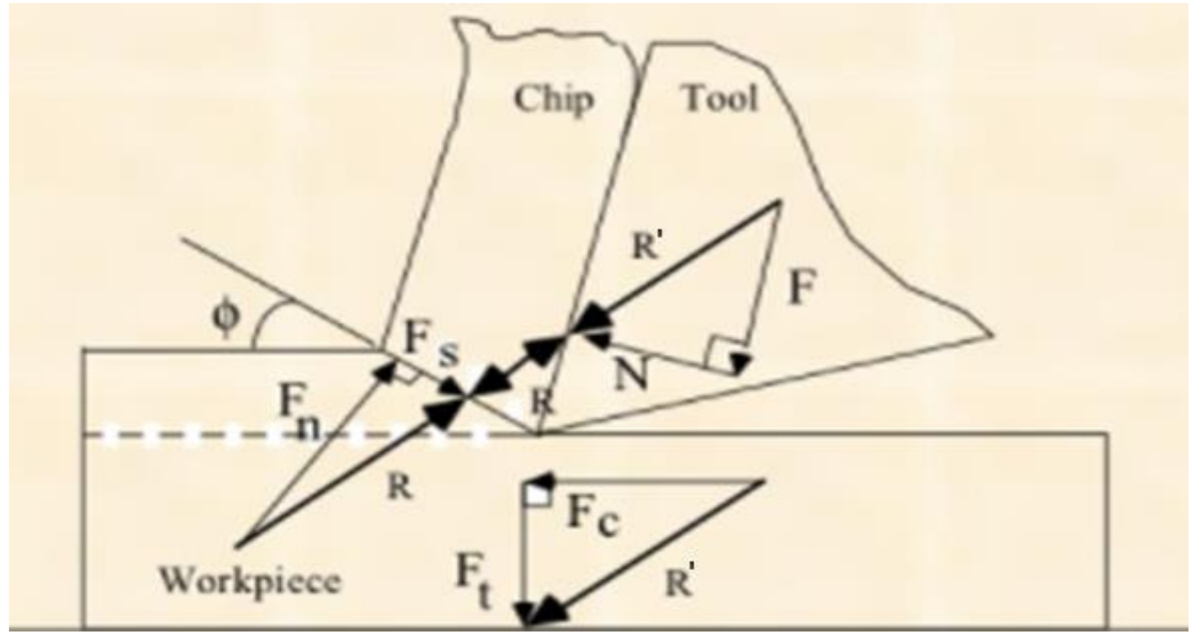
$$\frac{1}{\gamma} = \frac{\cos\emptyset\ \cos\propto\ + \sin\emptyset\ \sin\propto}{\sin\emptyset} = \frac{\cos\propto}{\tan\emptyset} + \sin\propto$$

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

Normally, Chip Thickness Ratio = 0.5 – 0.6

Forces in Orthogonal Cutting:

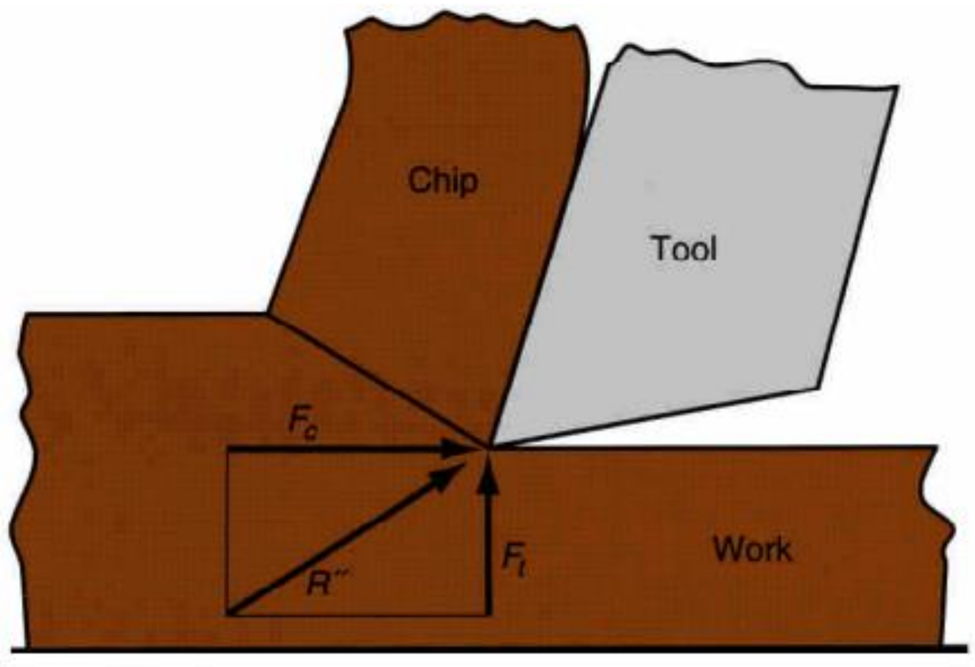
- Friction force, F
- Force normal to Friction force, N
- Cutting Force, F_c
- Thrust force, F_t
- Shear Force, F_s
- Force Normal to shear force, F_n
- Resultant force, R



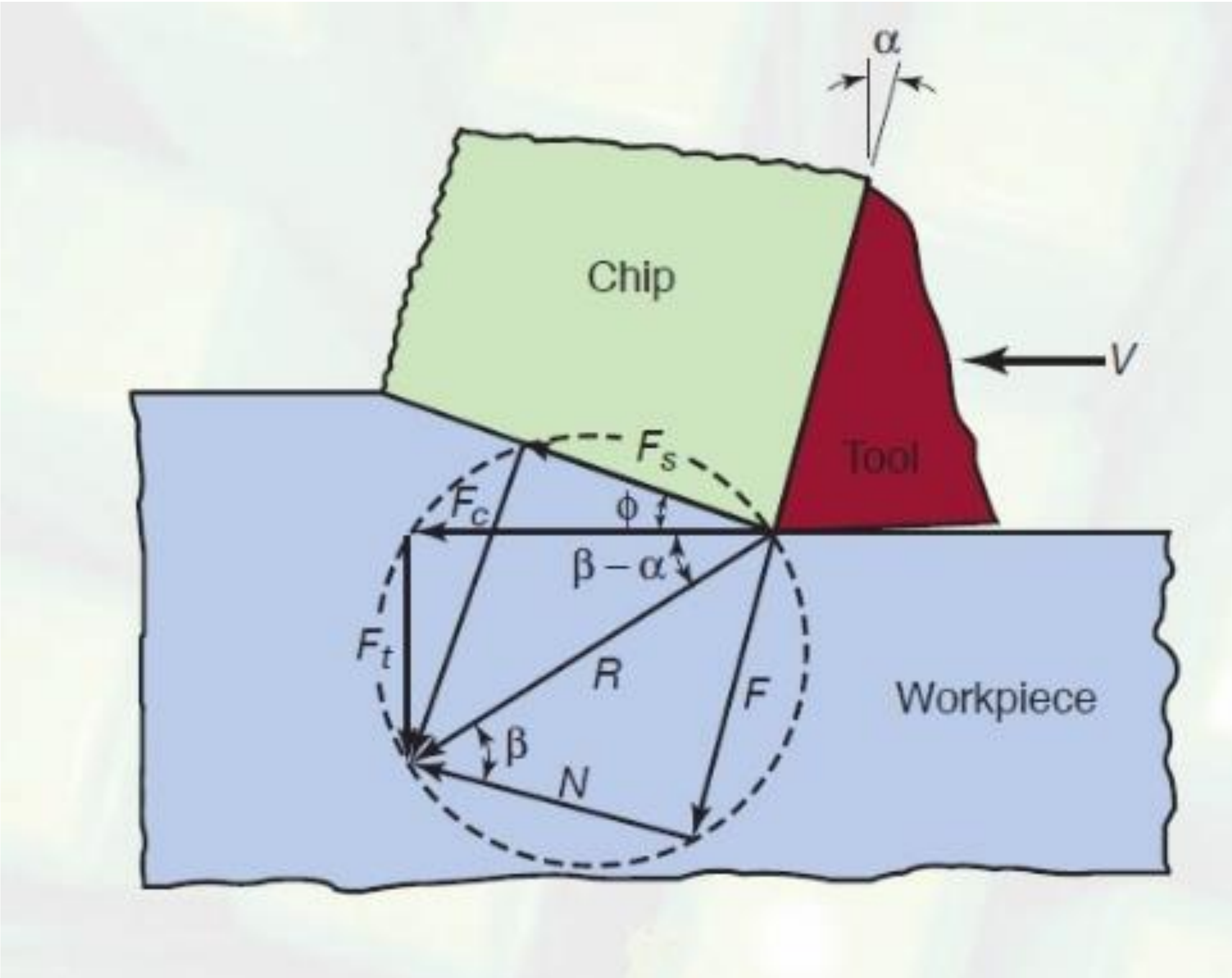
F, N, F_s, and F_n cannot be directly measured
Forces acting on the tool that can be measured:
Cutting force F_c and Thrust force F_t using tool Dynamometer

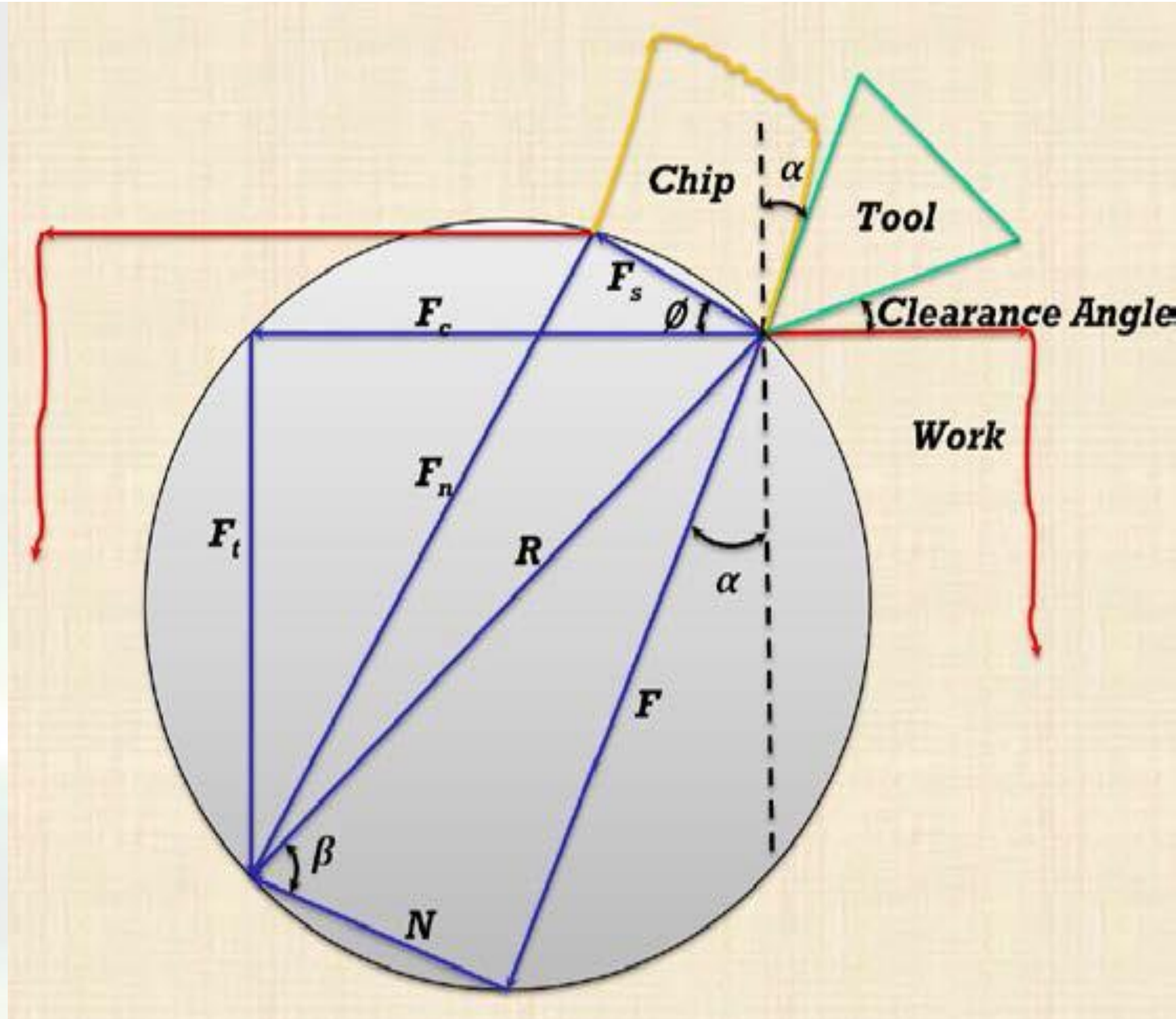
$$R' = \vec{F} + \vec{N}$$

$$R = \vec{F}_s + \vec{F}_N = \vec{F}_c + \vec{F}_t = \vec{R}'$$

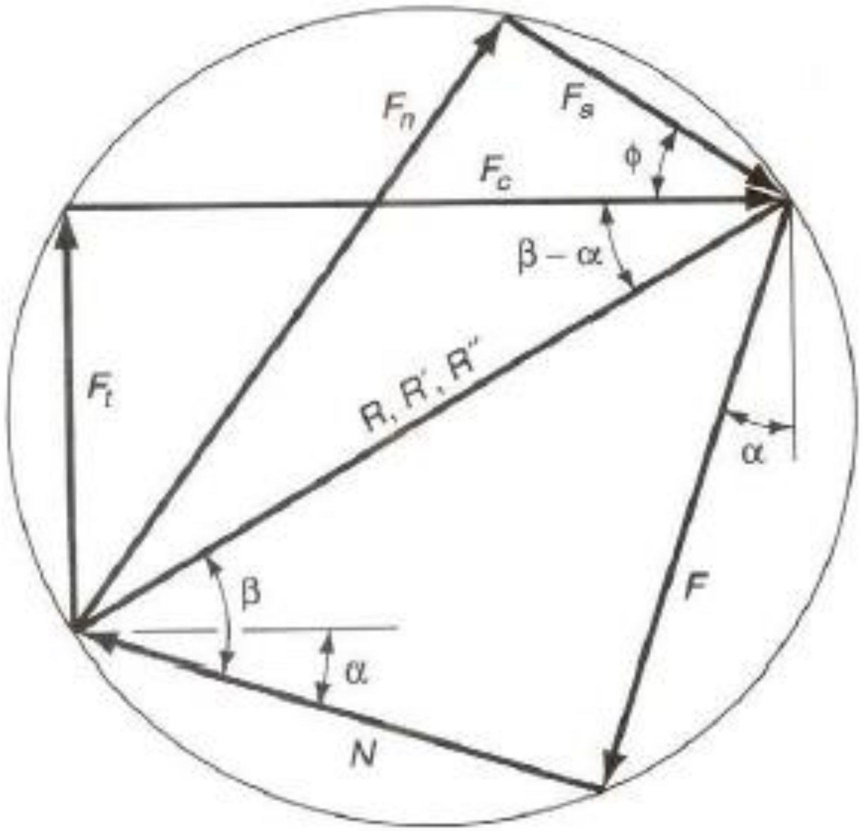


Force circle diagram (Merchant Circle Diagram)





Merchant Circle Analysis



$$Fs = RCos(\varnothing + \beta - \alpha)$$

$$Fn = RSin(\varnothing + \beta - \alpha)$$

From the Circle

$$Fc = RCos(\beta - \alpha)$$

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

$$F = R\sin\beta$$

$$N = R\cos\beta$$

Expressing through F_c,

Expending F_s,F_n,F and N

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

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

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

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

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

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

Merchant's First Solution

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

Force analysis

Let τ be the strength of the work piece material, b is the width of cut and t_u uncut chip thickness

Then F_c and F_t in terms of material properties (Strength)

$$F_S = A_S \tau = \frac{t_u b}{sin\phi}\tau$$

$$F_C = \left(\frac{t_u b\tau}{sin\phi}\right)\left(\frac{cos(\beta-\alpha)}{cos(\phi+\beta-\alpha)}\right) \quad and, \quad R = \left(\frac{t_u b\tau}{sin\phi}\right)\times\left(\frac{1}{cos(\phi+\beta-\alpha)}\right)$$

$$F_t = R\ sin(\beta-\alpha) = \frac{t_u b\tau}{sin\phi}\times\frac{sin(\beta-\alpha)}{cos(\phi+\beta-\alpha)}$$

$$\underset{(On\ Chip)}{Mean\ Shear\ Stress}\ (t_{chip}) = \frac{F_S}{A_S}$$

$$= \frac{(F_c\ cos\phi - F_t\ sin\phi)\sin\phi}{b\ t_u}$$

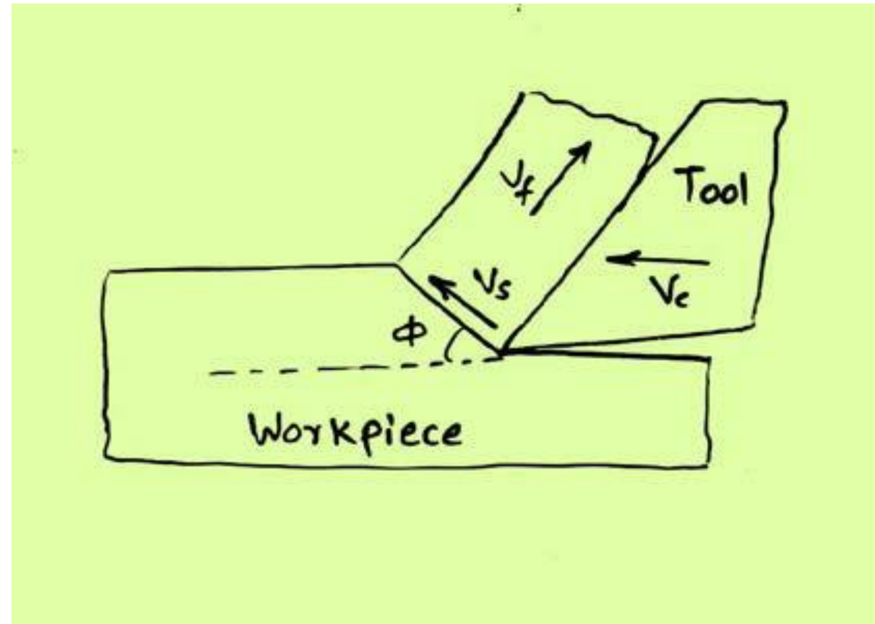
$$\underset{(On\ Chip)}{Mean\ Normal\ Stress}\ (\sigma_{chip}) = \frac{F_N}{A_S}$$

$$= \frac{(F_t\ cos\phi + F_c\ sin\phi)\sin\phi}{b\ t_u}$$

$$\boxed{\frac{F_t}{F_c} = \tan(\beta-\alpha)}$$

Velocity Analysis

V_c: Cutting velocity of tool relative to work-piece
V_f : Chip flow velocity
V_s: Shear velocity

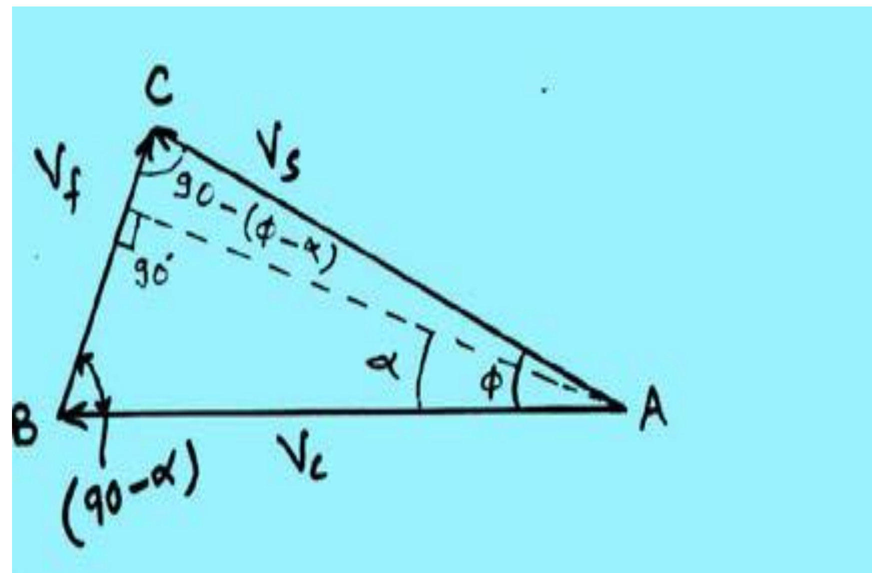


Using Sine Rule

$$\frac{V_c}{\sin(90-(\phi-\alpha))}=\frac{V_f}{\sin\phi}=\frac{V_s}{\sin(90-\alpha)}$$

$$\frac{V_c}{\cos(\phi-\alpha)}=\frac{V_f}{\sin\phi}=\frac{V_s}{\cos\alpha} \qquad and \quad V_f=\frac{V_c\sin\phi}{\cos(\phi-\alpha)}=V_c\cdot r_c$$

$$\boxed{V_s=\frac{V_c\cos\alpha}{\cos(\phi-\alpha)}\Rightarrow\frac{V_s}{V_c}=\frac{\cos\alpha}{\cos(\phi-\alpha)}}$$



Shear Strain and Strain Rate

- Characteristic of the metal cutting process is that the work-piece material is being deformed at extremely intense conditions in a small volume. The extreme deformation conditions make metal cutting a remarkable process if compared to other production processes.
- Strain rates in machining are in the order of 10^3–10^6 s^{-1}. In conventional material tests the strain rates are in the order of 10^{-3}–10^{-1} s^{-1}, i.e. up to a million times smaller than in machining.
- Plastic strain rate can be divided in three zones: the low strain rate region (<1 s^{-1}), the medium rate region (comprehended between the low and high strain rate region values) and the high strain rate region (above 10^3 or 10^4 s^{-1}).

Shear Strain & Strain Rate

Two approaches of analysis:

1.Thin Plane Model:- Merchant, PiisPanen, Kobayashi & Thomson

2. Thick Deformation Region:- Palmer, (At very low speeds) Oxley, kushina,Hitoni

Thin Zone Model: Merchant

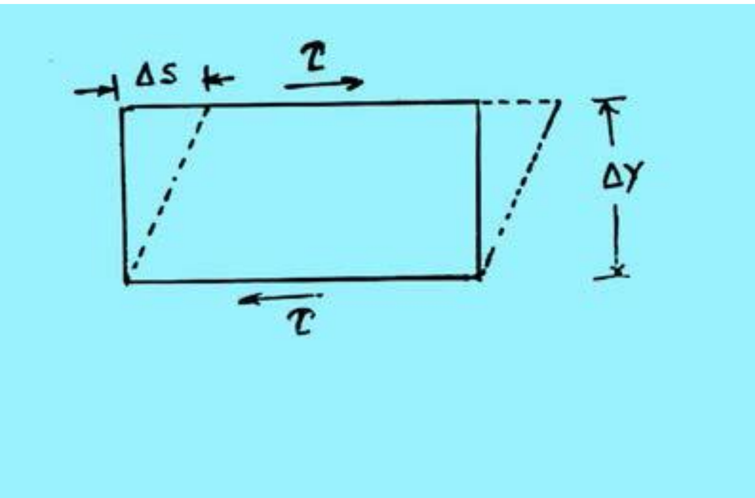
Assumptions:-

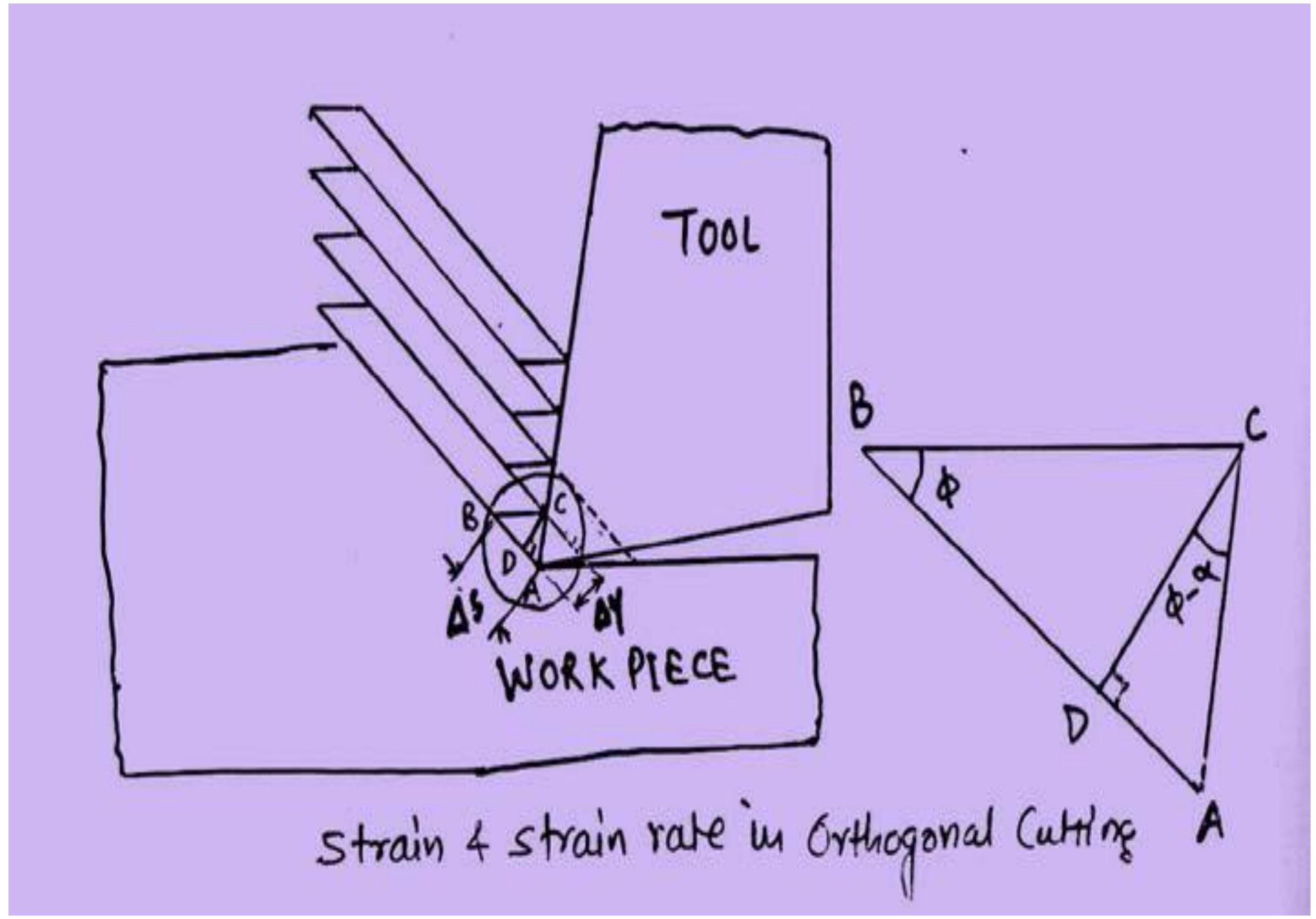
- ❖ Tool tip is sharp, No Rubbing, No Ploughing
- ❖ 2-D deformation.
- ❖ Stress on shear plane is uniformly distributed.
- ❖ Resultant force R on chip applied at shear plane is equal, opposite and collinear to force R’ applied to the chip at tool-chip interface.

Expression for Shear Strain

The deformation can be idealized as a process of block slip (or preferred slip planes)

Shear Strain= deformation/Length





$$\gamma = \frac{\Delta s}{\Delta y} = \frac{AB}{CD} = \frac{AD}{CD} + \frac{DB}{CD} \qquad = \tan(\phi - \alpha) + \cot\phi$$

$$\frac{\sin(\phi-\alpha)\sin\phi + \cos\varphi\cos(\phi-\alpha)}{\sin\phi\cos(\phi-\alpha)}, \qquad \boxed{\therefore \gamma = \frac{\cos\alpha}{\sin\phi\cos(\phi-\alpha)}}$$

Expending tan and cot angles in terms of sin and cosine angles, we get

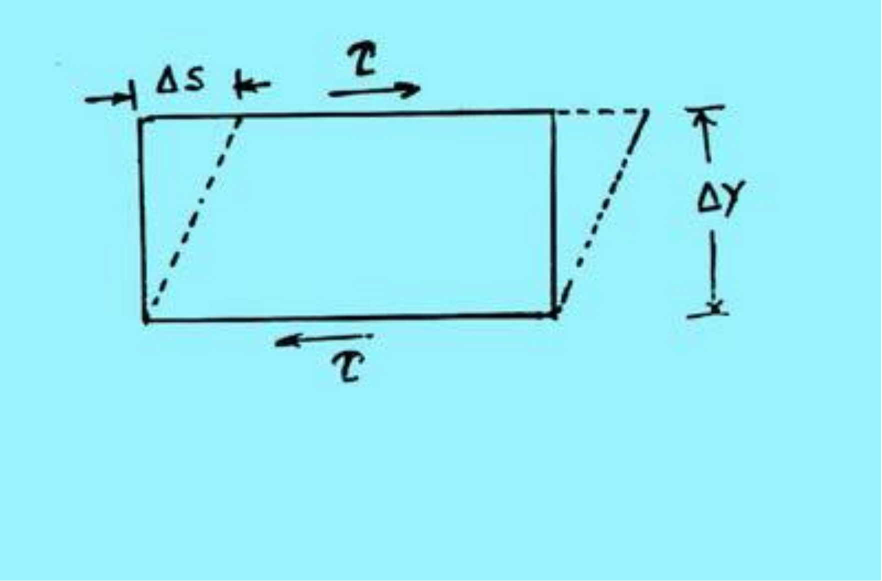
Expression for Shear Strain rate

In terms of shear strain, the Shear Strain can be written as:

Shear Strain Rate:

$$\dot{\gamma} = \frac{d\gamma}{dt} = \frac{\left(\frac{\Delta s}{\Delta y}\right)}{dt} = \left(\frac{\Delta s}{\Delta y}\right)\frac{1}{\Delta y}$$

$$= \frac{V_s}{\Delta y} = \frac{V_c \cos\alpha}{\cos(\phi-\alpha)\Delta y}$$



Where, Δy :Mean thickness of PSDZ

From velocity analysis V_s in terms of V_c, $V_s = \frac{V_c \cos\alpha}{\cos(\phi-\alpha)}$

Power and Energy Relationships

❖ A machining operation requires power as a input source.

The power to perform machining can be computed from:

$$\mathbf{P = F_c \times v}$$

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

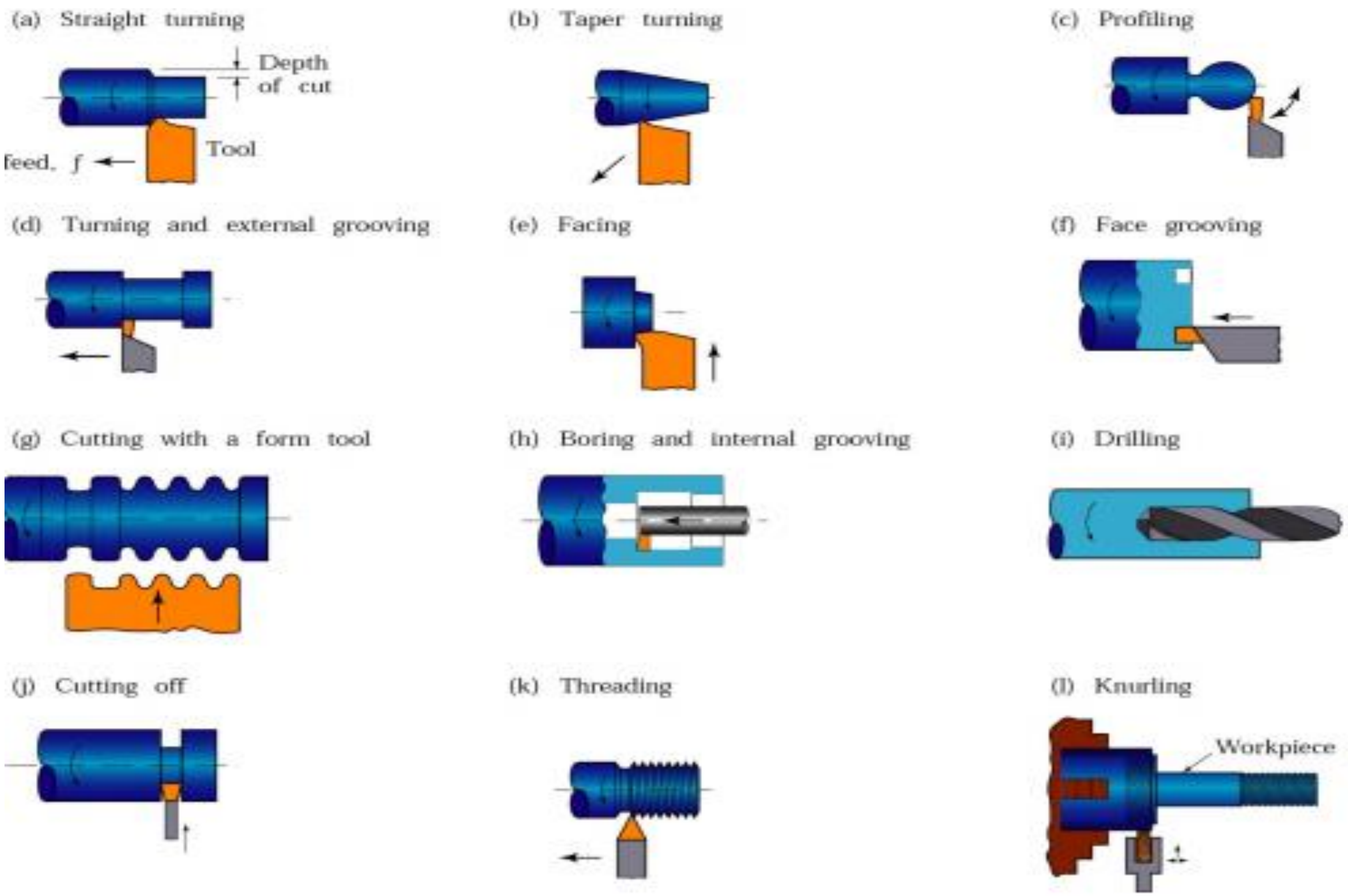
Specific Energy in Machining: Power required to remove unit volume of material. Given in W/mm^3

$$\mathbf{P = U_c \times MRR}$$

$$\mathbf{U_c = P/MRR}$$

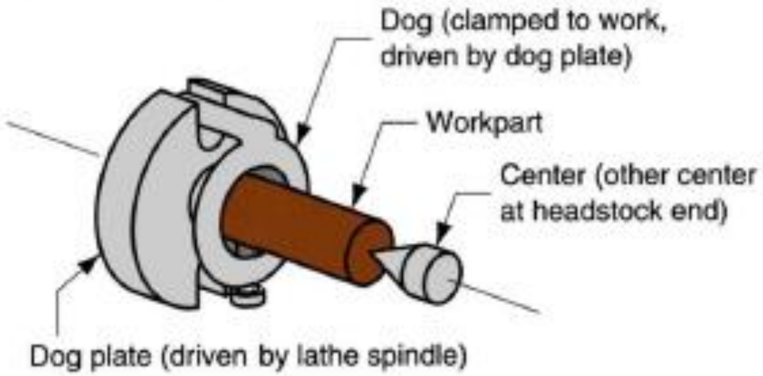
U_c = specific power, MRR = Volumetric material removal rate

Common Late Operations



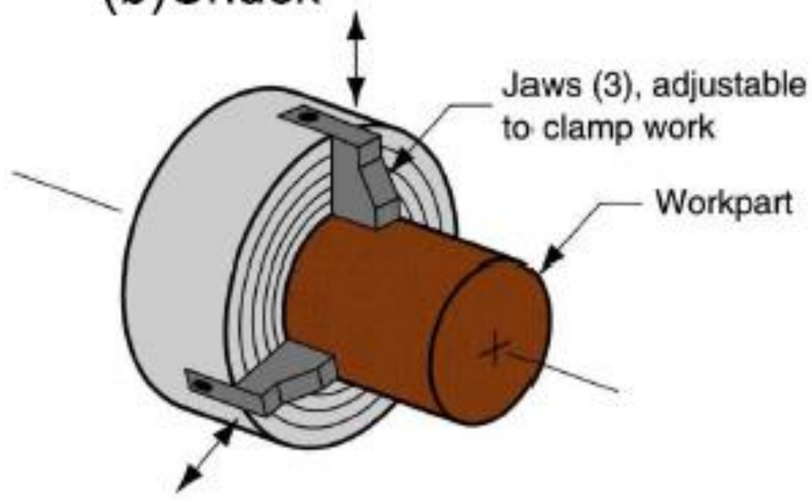
Methods of holding job in Lathe

(a)Holding the work between centers



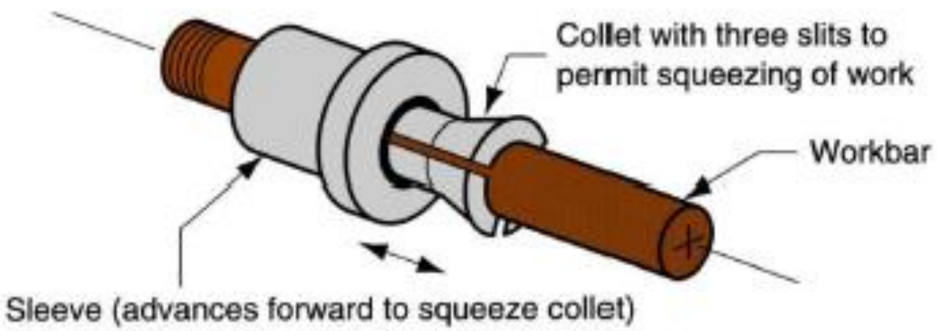
(a)

(b)Chuck



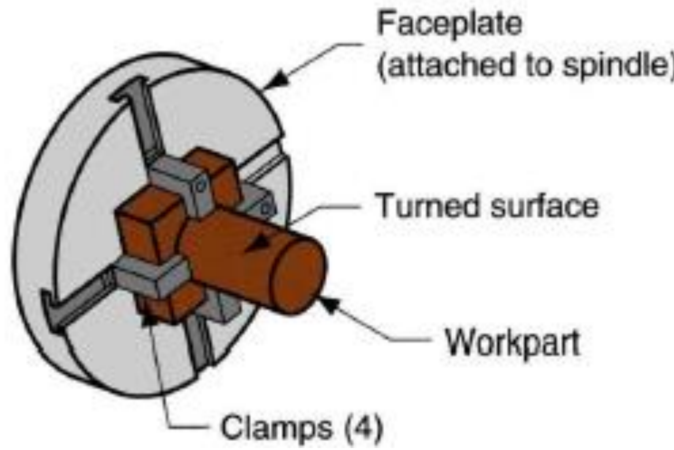
(b)

(c)Collet



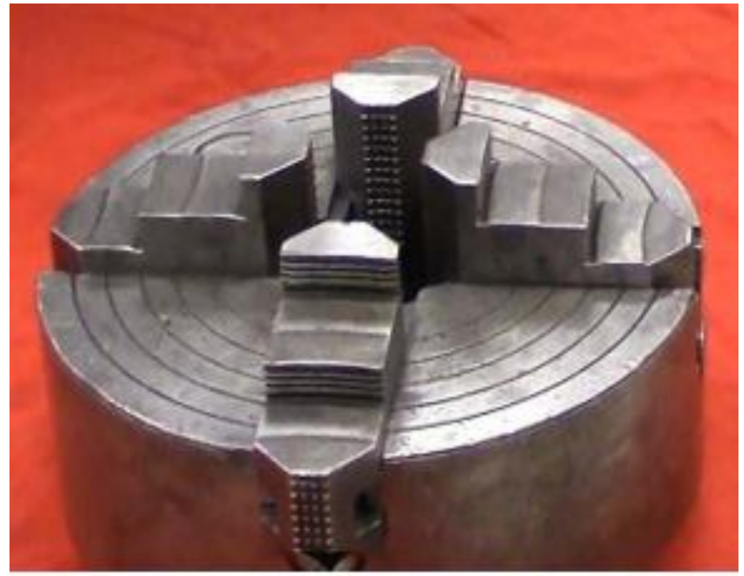
(c)

(d)Face plate



Lathe Chucks

3-Jaw chuck



4-Jaw chuck

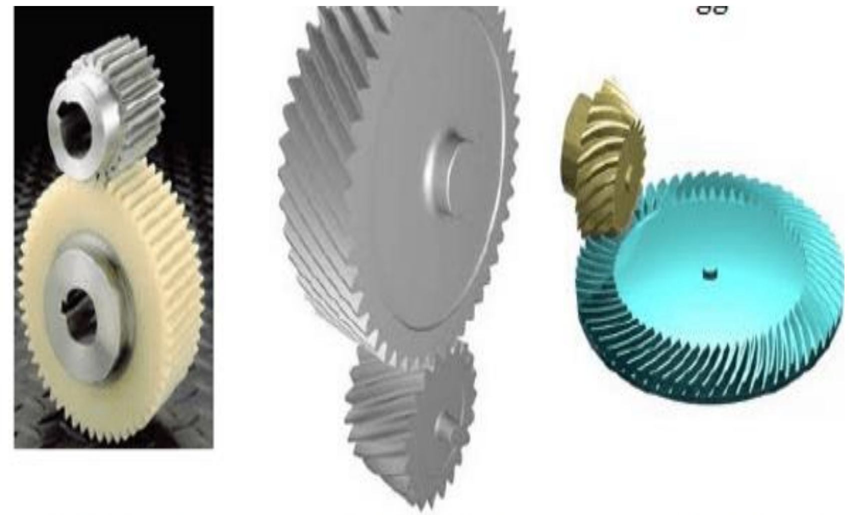
The jaws on the 3-jaw chuck move all at the same time. Accuracy level is about 0.010. 3-Jaw chuck has one hole for the chuck key/wrench to tighten or release the jaws' grip.

The jaws on the 4-jaw chuck move independently. 4-Jaw chuck has four holes for the chuck key/wrench to control each jaw, one at a time. Accuracy level is between 0 and 0.001

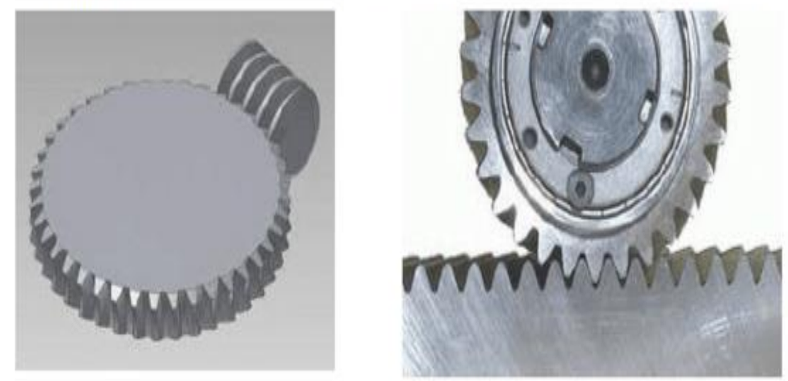
Different Mechanical Drives

Belt Drive

Rope Drives

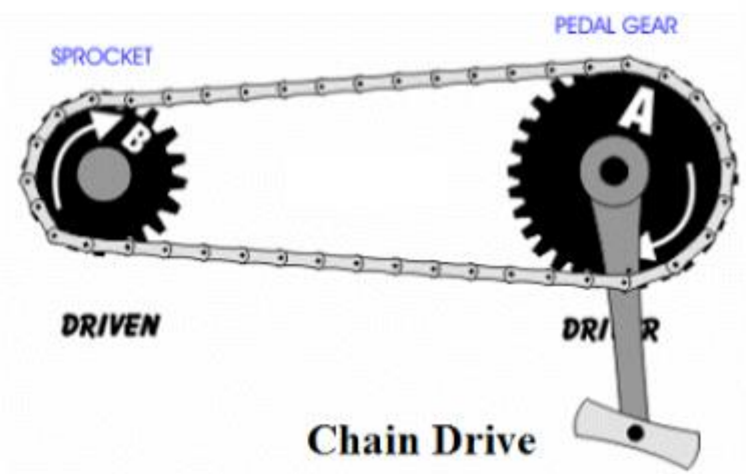


(a) Spur gear (b) Helical gear (c) Bevel gear



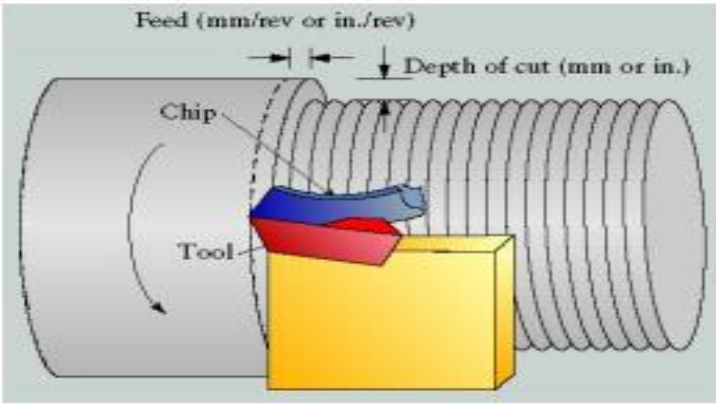
(d) Worm & worm gear (e) Rack & pinion gear

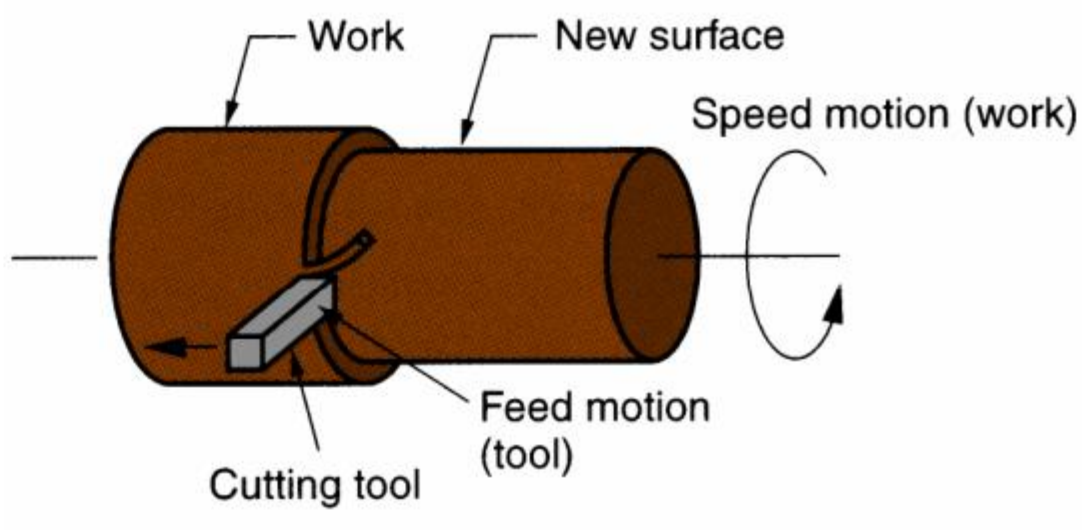
Gear Drives



Chain Drive

Turning Calculation





Average cutting speed: $V_{avg} = \pi \times D_{avg} \times N$

D_{avg} is the average diameter of work piece and N is the spindle speed in rpm

Material removal rate (MRR)= $V_{avg} \times d \times f$

d is the depth of cut, f is the feed (units: mm/rev or in/rev)

Cutting Power, $P_c = U_c \times MRR = F_c \times V$

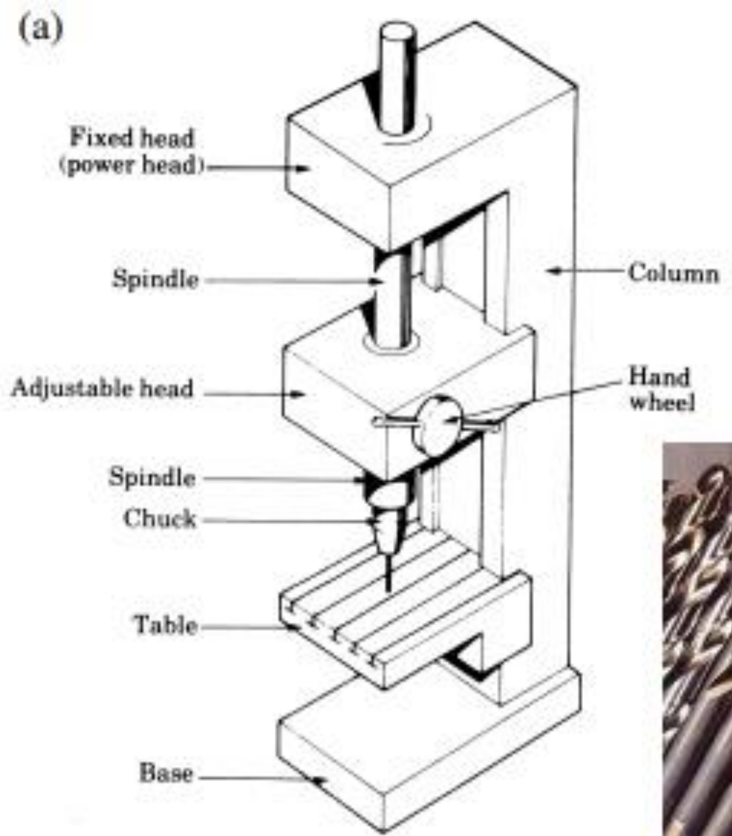
U_c=Specific energy consumption (W/mm^3)

F_c=Cutting force, V = Cutting speed

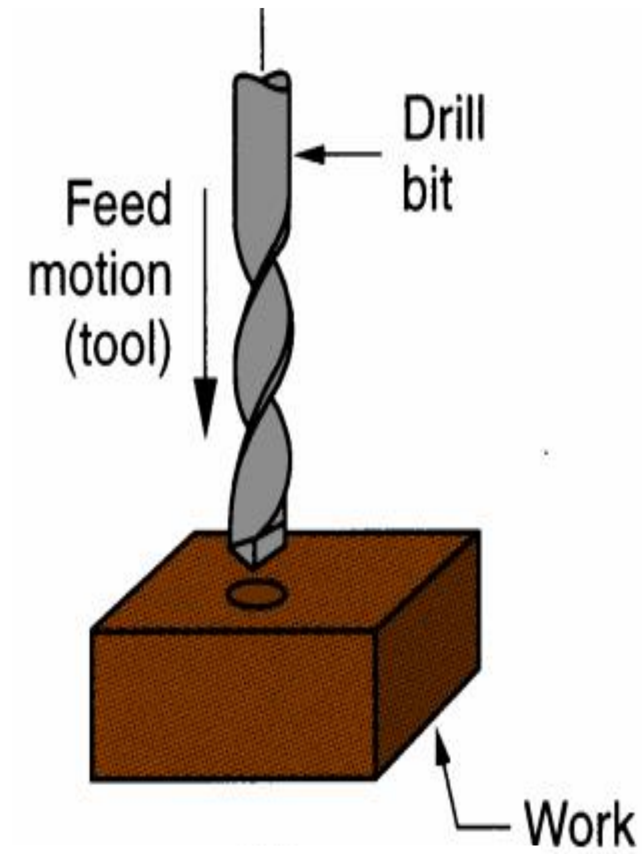
Machining time, $t_m = L/(f \times N) = L/f$

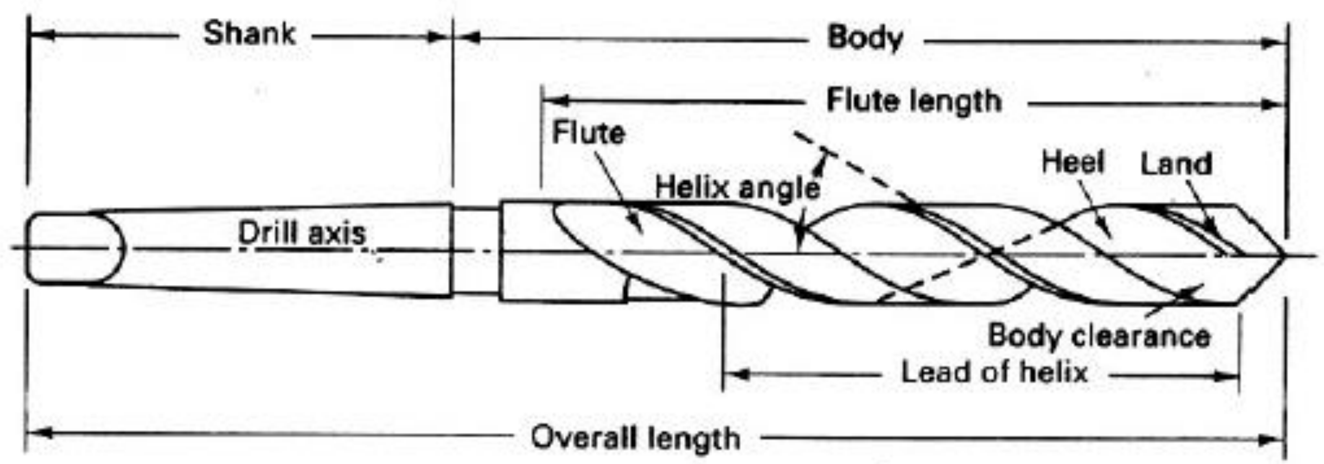
f is the feed rate (units: mm/min or in/min), L= Length of the job

Drilling

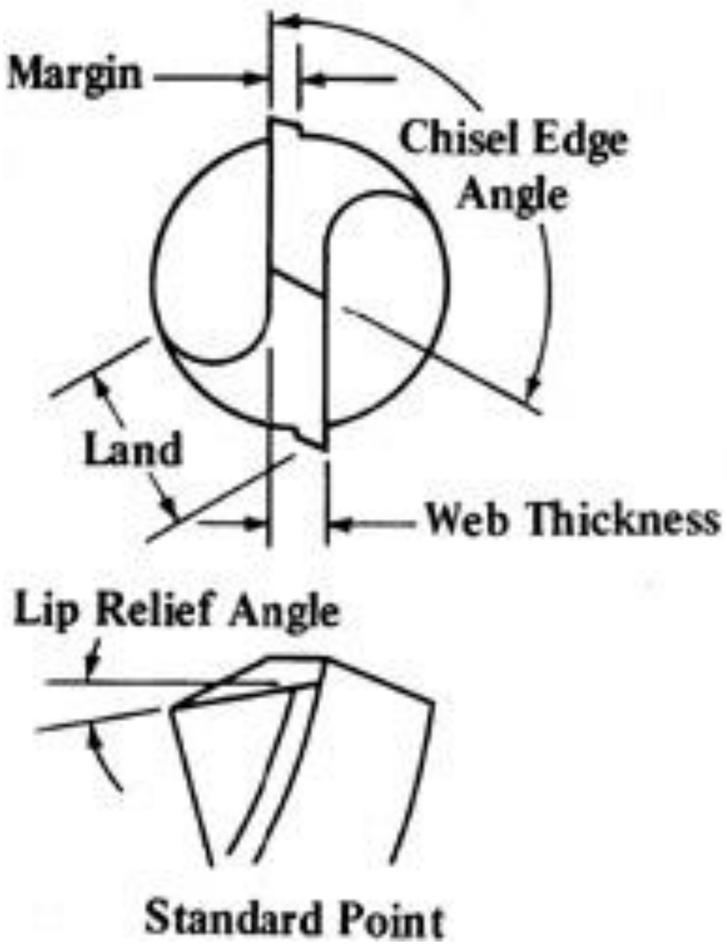

(a)
Fixed head
(power head)
Spindle
Column
Adjustable head
Hand
wheel
Spindle
Chuck
Table
Base

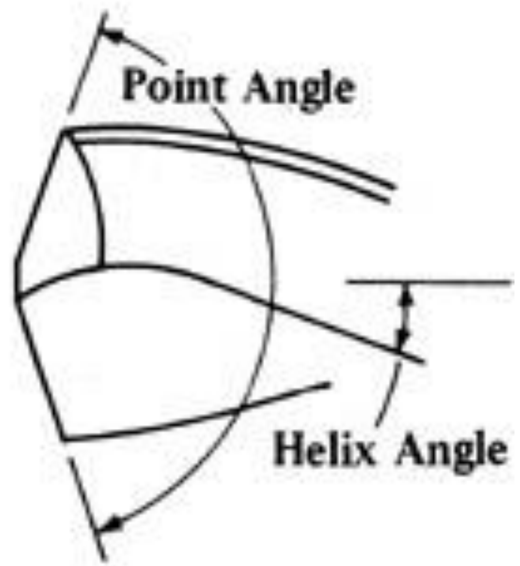

DRILL BITS

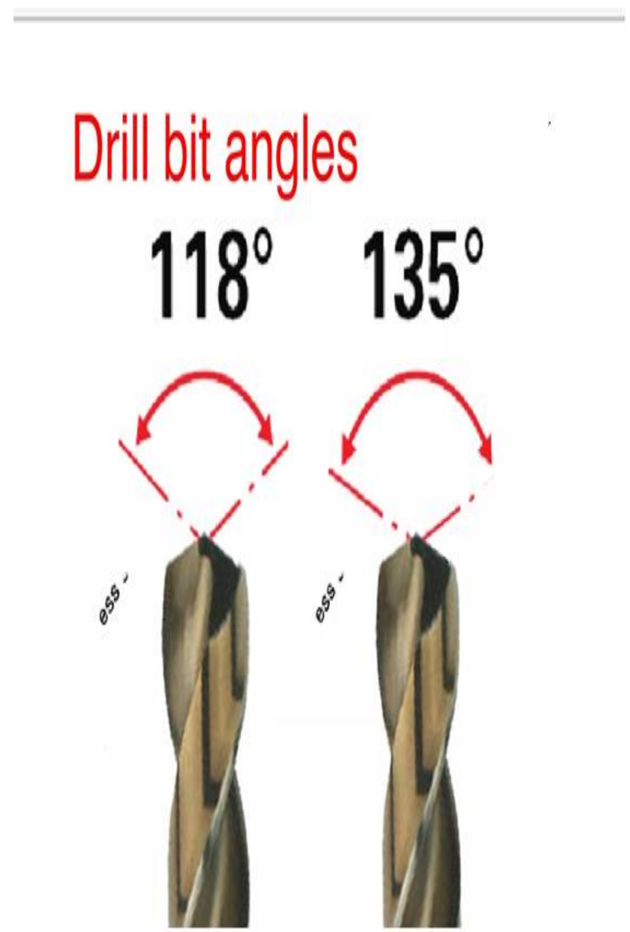

Drill
bit
Feed
motion
(tool)
Work


Shank
Body
Flute length
Flute
Helix angle
Heel
Land
Drill axis
Body clearance
Lead of helix
Overall length

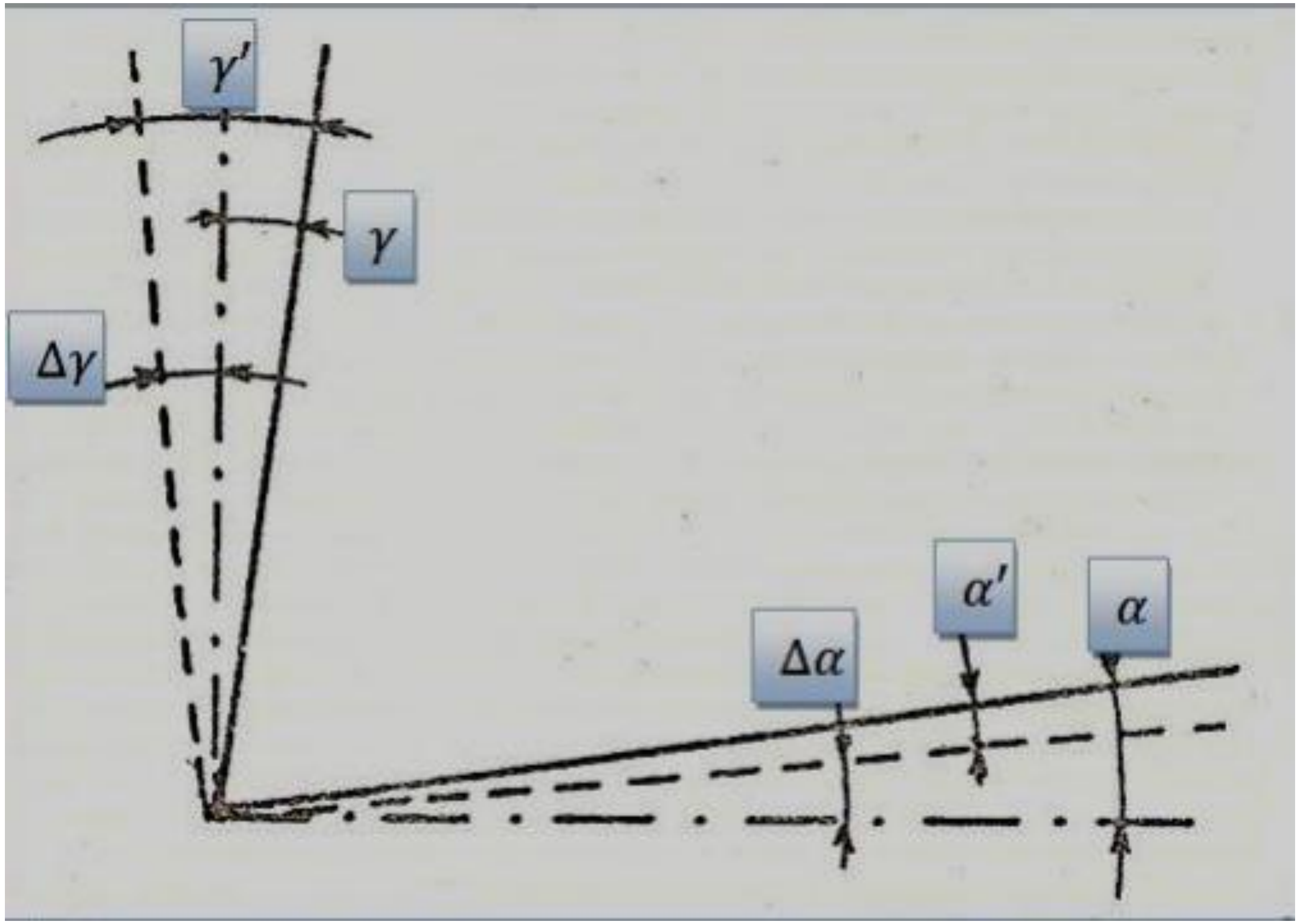
Drill geometry





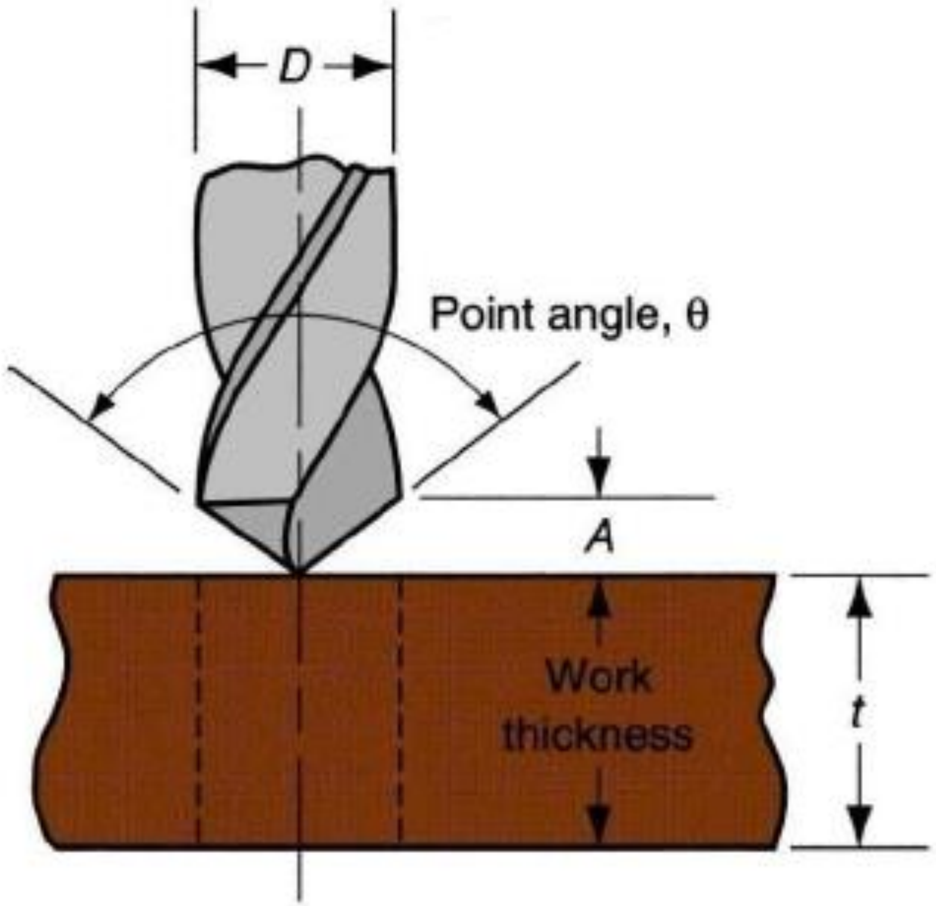


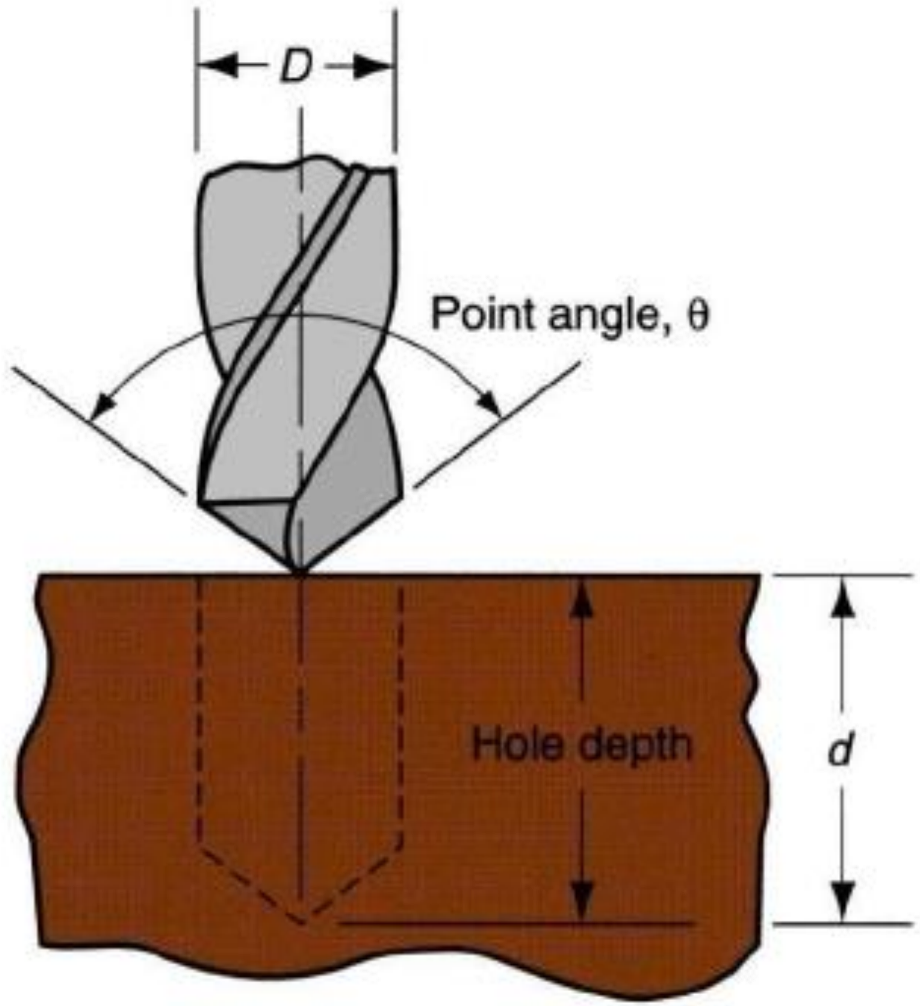
Variation of upper and lower rake angles due to the feed



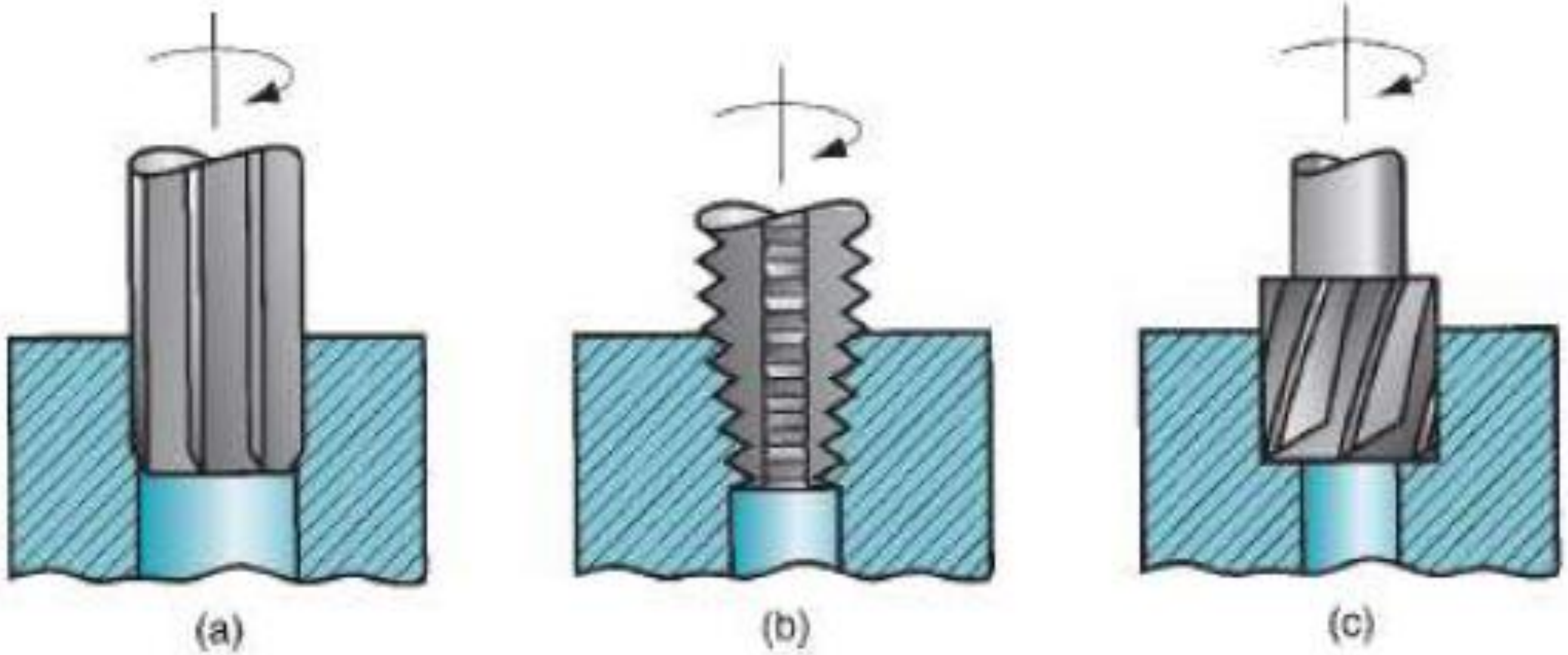
- ❖ From the inclination of helix the nominal upper rake angle, which decreases if they are considered smaller diameters.
- ❖ The upper rake angle determined by the helix suffers a slight variation due to the feed of the drill.
- ❖ In fact the cutting edge moves along a trajectory inclined at an angle Δα, which is equal to Δγ, compared to the reference surface.

Drilling through and Blind holes



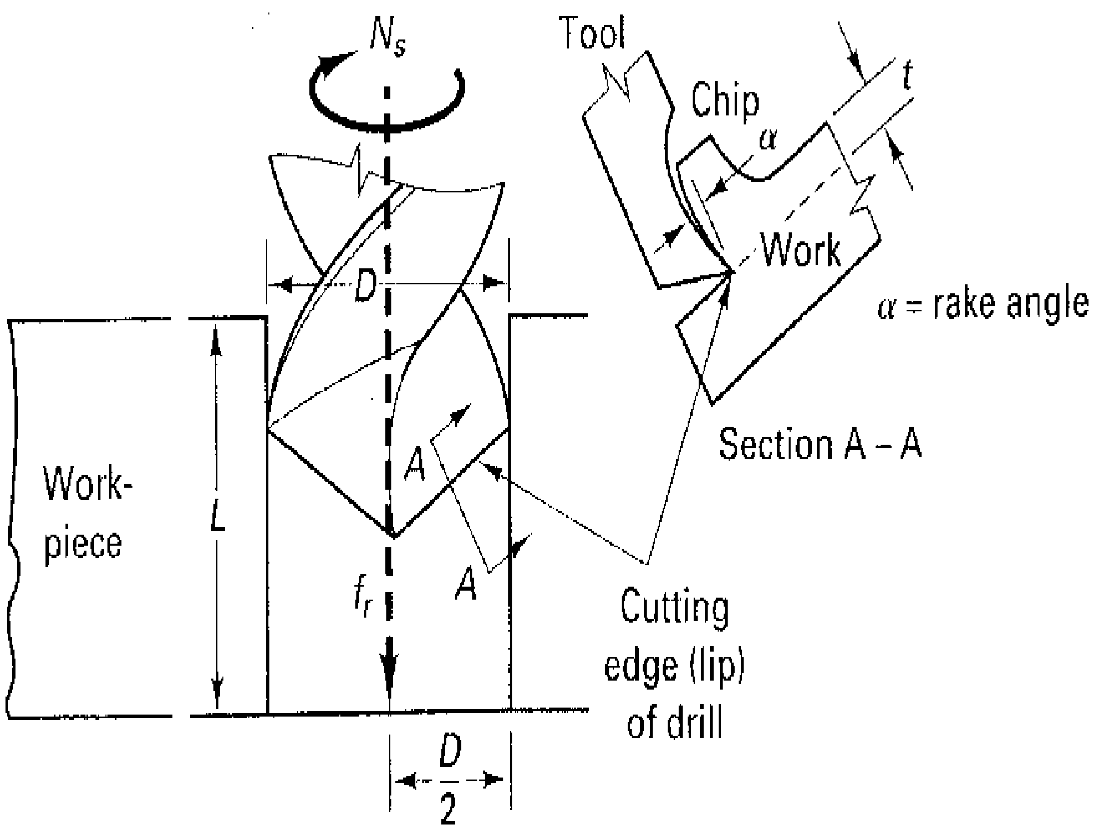


Operation related to Drilling



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

Drilling Calculations



Drilling-multiple edge tool

Drill Speed, RPM:

$$N = \frac{kV}{\pi D}$$

k is a Units Constant

D is Drill Diameter

V is cutting speed

V = πND/k

Cutting Time (min):

$$CT = \frac{(L + A)}{f_r * N}$$

A is allowance; usually $\frac{D}{2}$

f_r is drill feedrate

L is length of Hole

$$MRR = \frac{\text{Vol.Removed}}{CT} = \frac{\pi D^2 L f_r N}{4L} = \frac{\pi D^2 f_r N}{4}$$

Milling

Machining operation in which work is fed past a rotating tool with multiple cutting edges

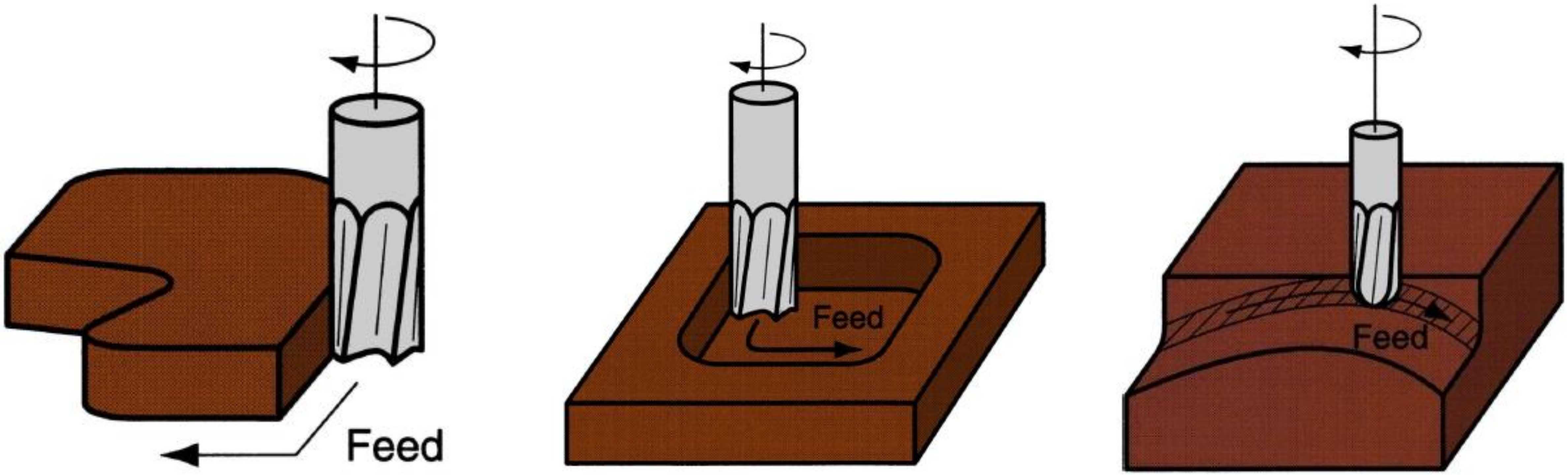
Axis of tool rotation is perpendicular to feed direction

Creates a planar surface; other geometries possible either by cutter path or shape

Other factors and terms:

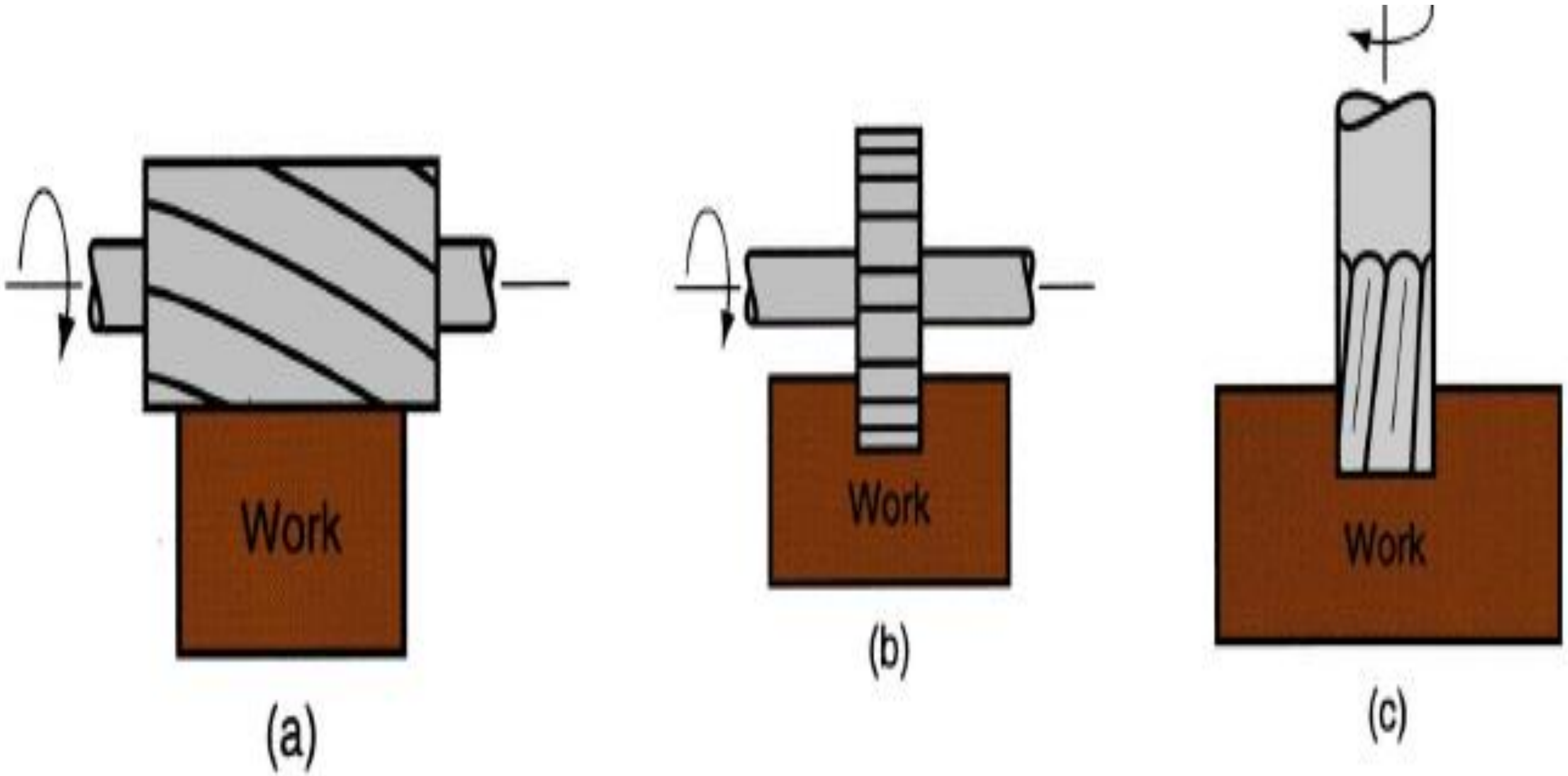
- Milling is an *interrupted cutting* operation
- Cutting tool called a *milling cutter,* cutting edges called "teeth"
- Machine tool called a *milling machine*

Different Milling Operation



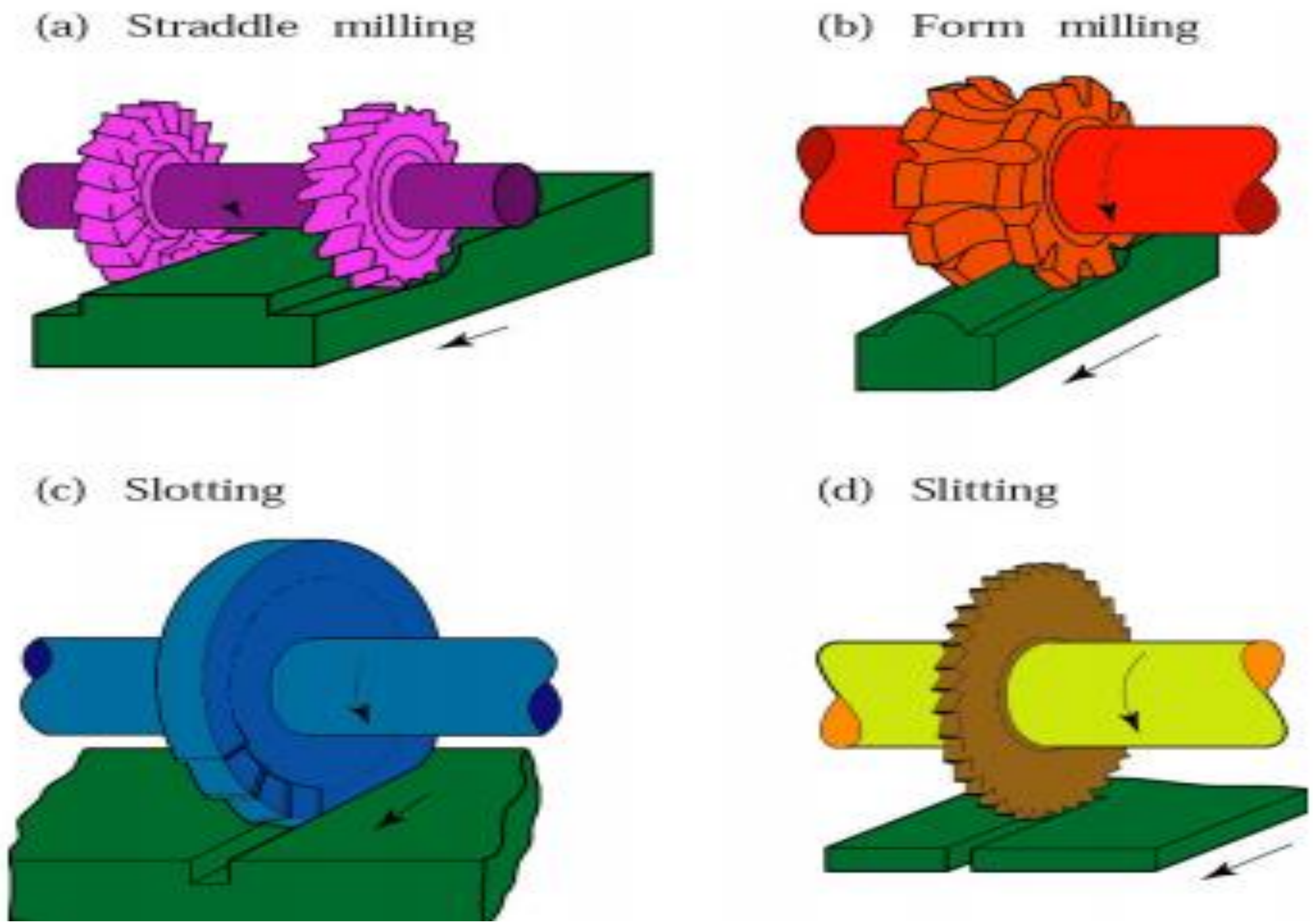
Profile Milling, Pocket Milling and Surface Contouring operations

Milling Operations

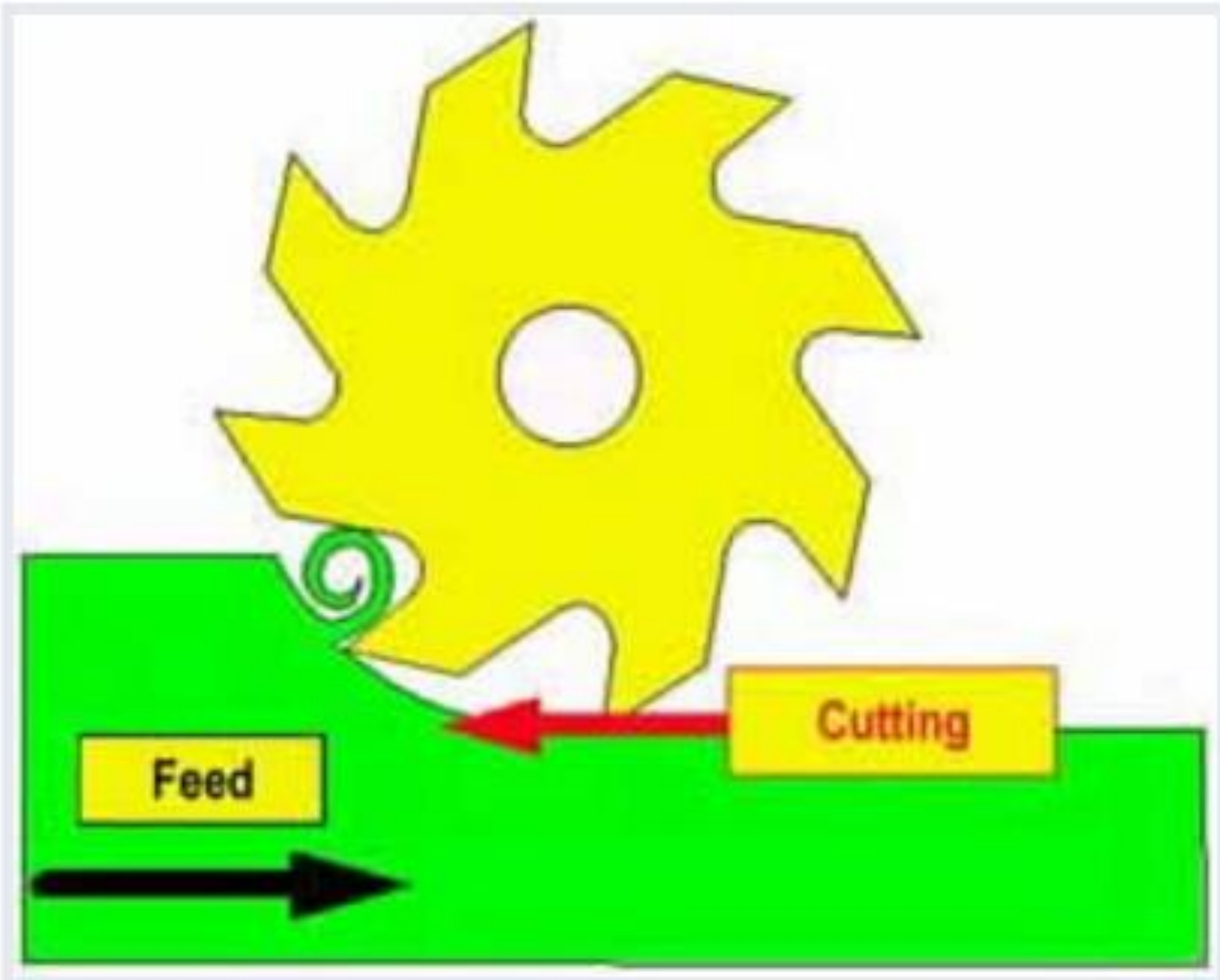


(a) Slab Milling, (b) Slotting, (c) End Milling

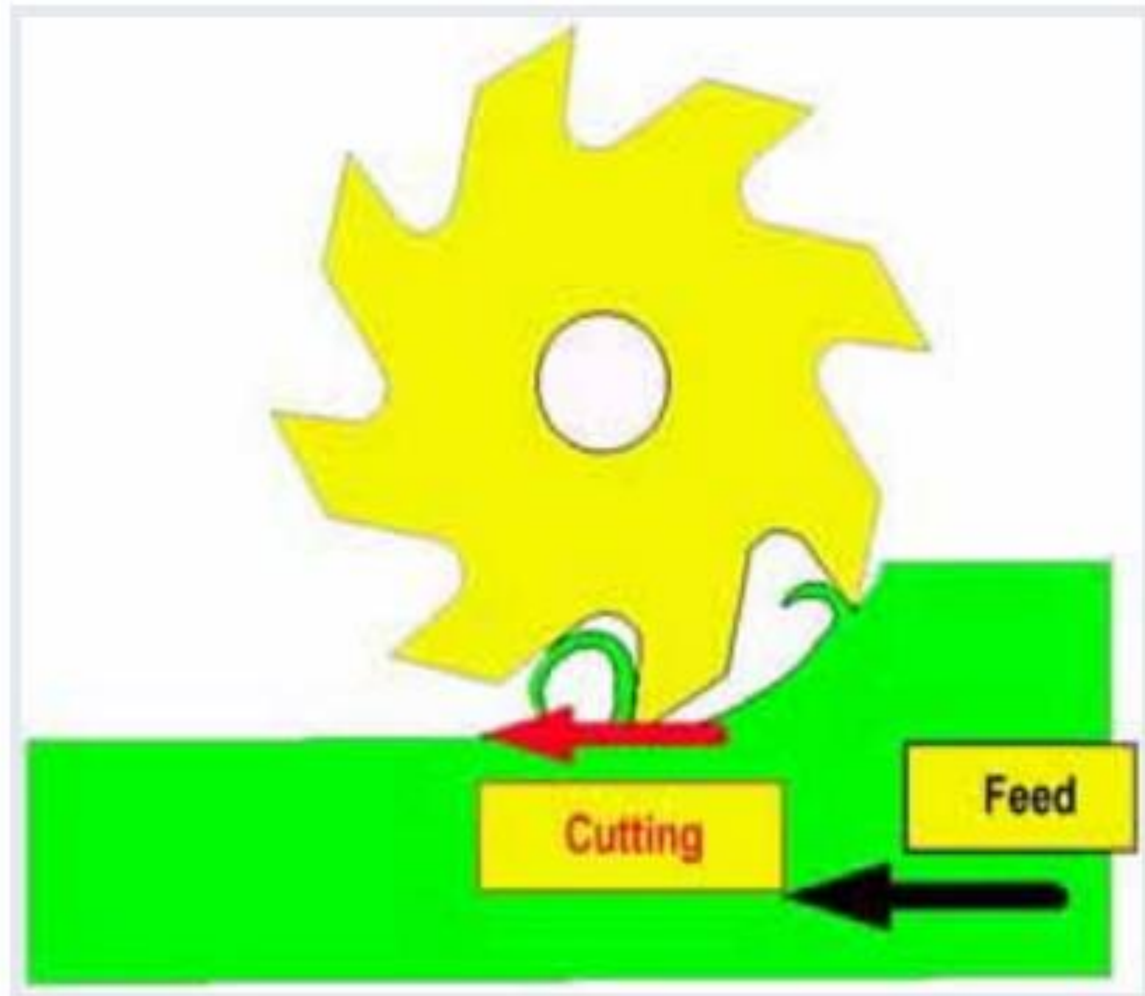
Milling Types



Up Milling & Down Milling



Up Milling

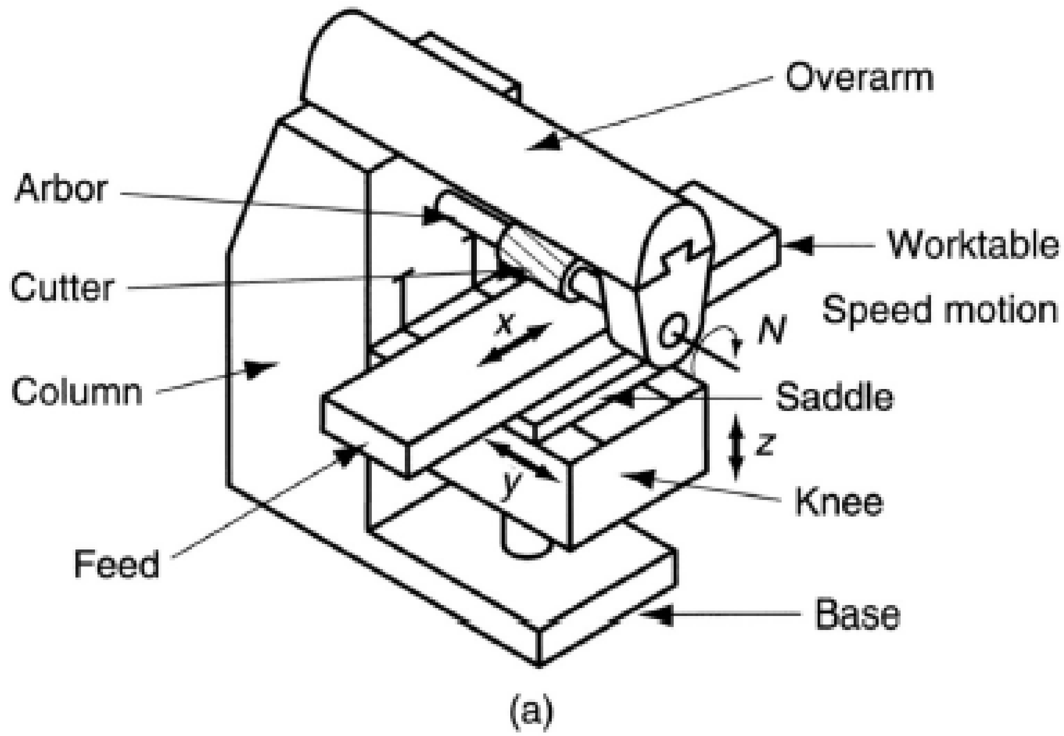


Down Milling

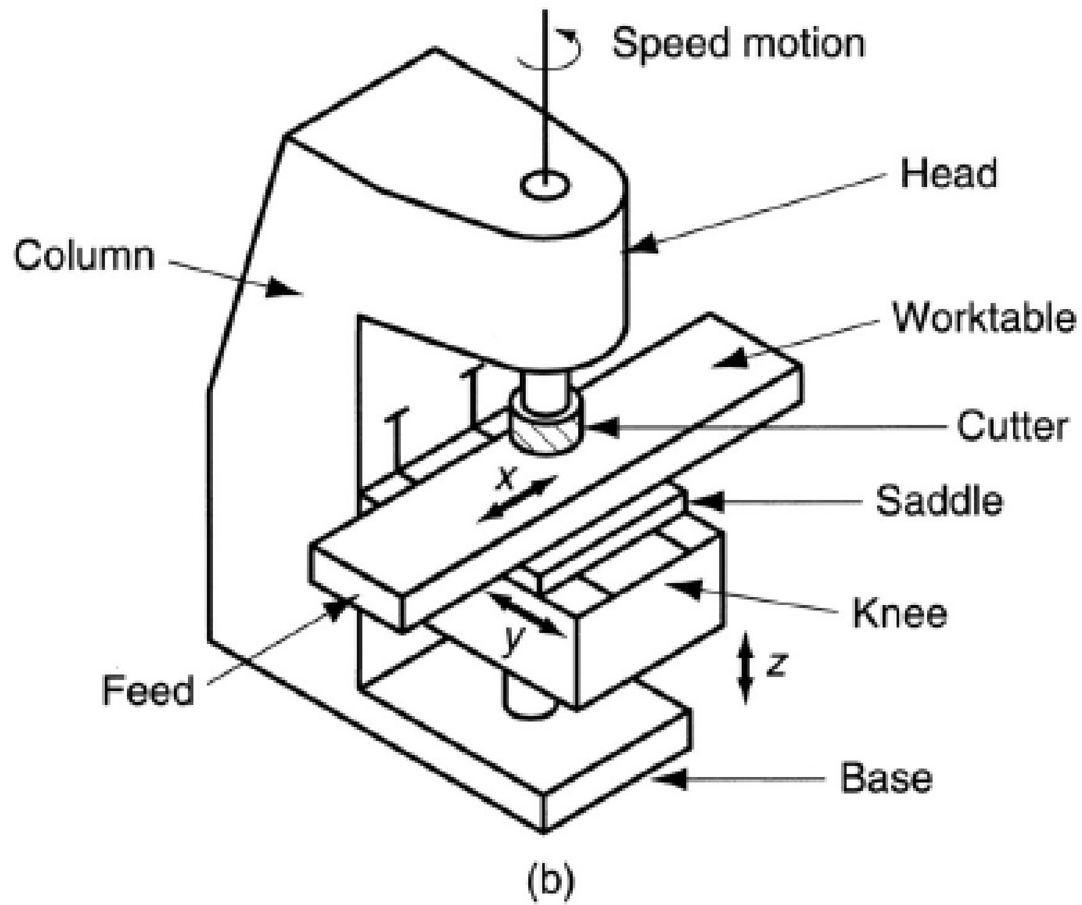
Comparison between Up Milling and Down Milling

SL. NO.	UP MILLING (CONVENTIONAL MILLING)	DOWN MILLING (CLIMB MILLING)
01	Work piece fed in the opposite direction that of the cutter.	Work piece fed in the same direction that of the cutter.
02	Chips are progressively thicker.	Chips are progressively thinner.
03	Strong clamping is required since the cutting force is directed upwards & tends to lift the work piece.	Strong clamping is not required since the cutting force is directed downwards & keep the work piece pressed to the table.
04	Gives poor surface finish, since chips gets accumulated at the cutting zone.	Gives good surface finish, since the chips are thrown away during cutting.
05	Used for hard materials.	Used for soft materials and finishing operations.

Milling Machines

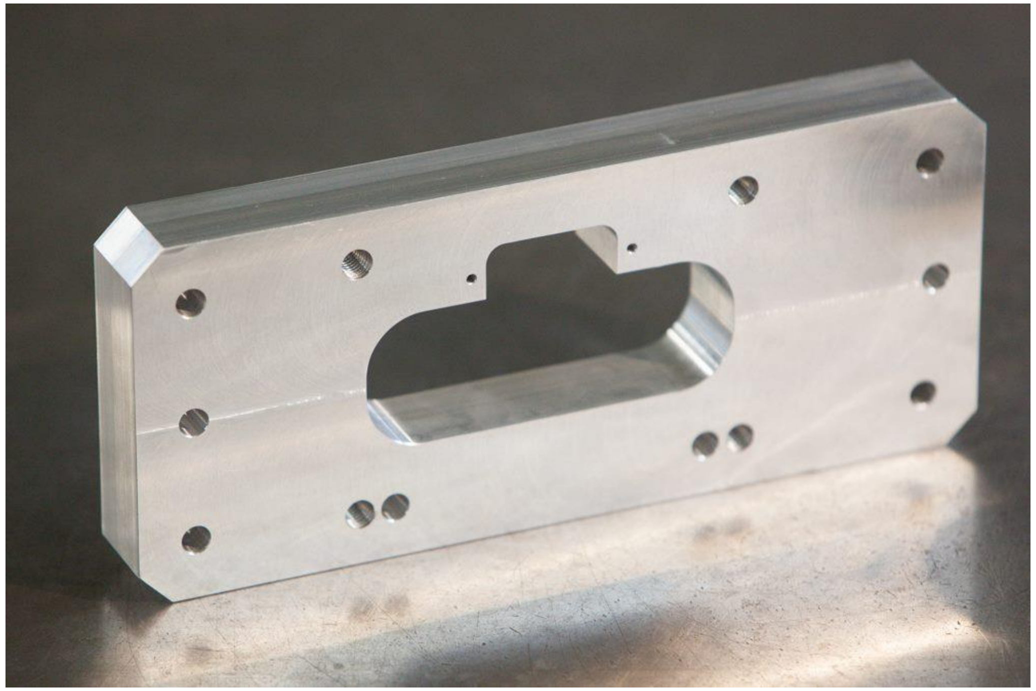


(a) Horizontal Milling Machine

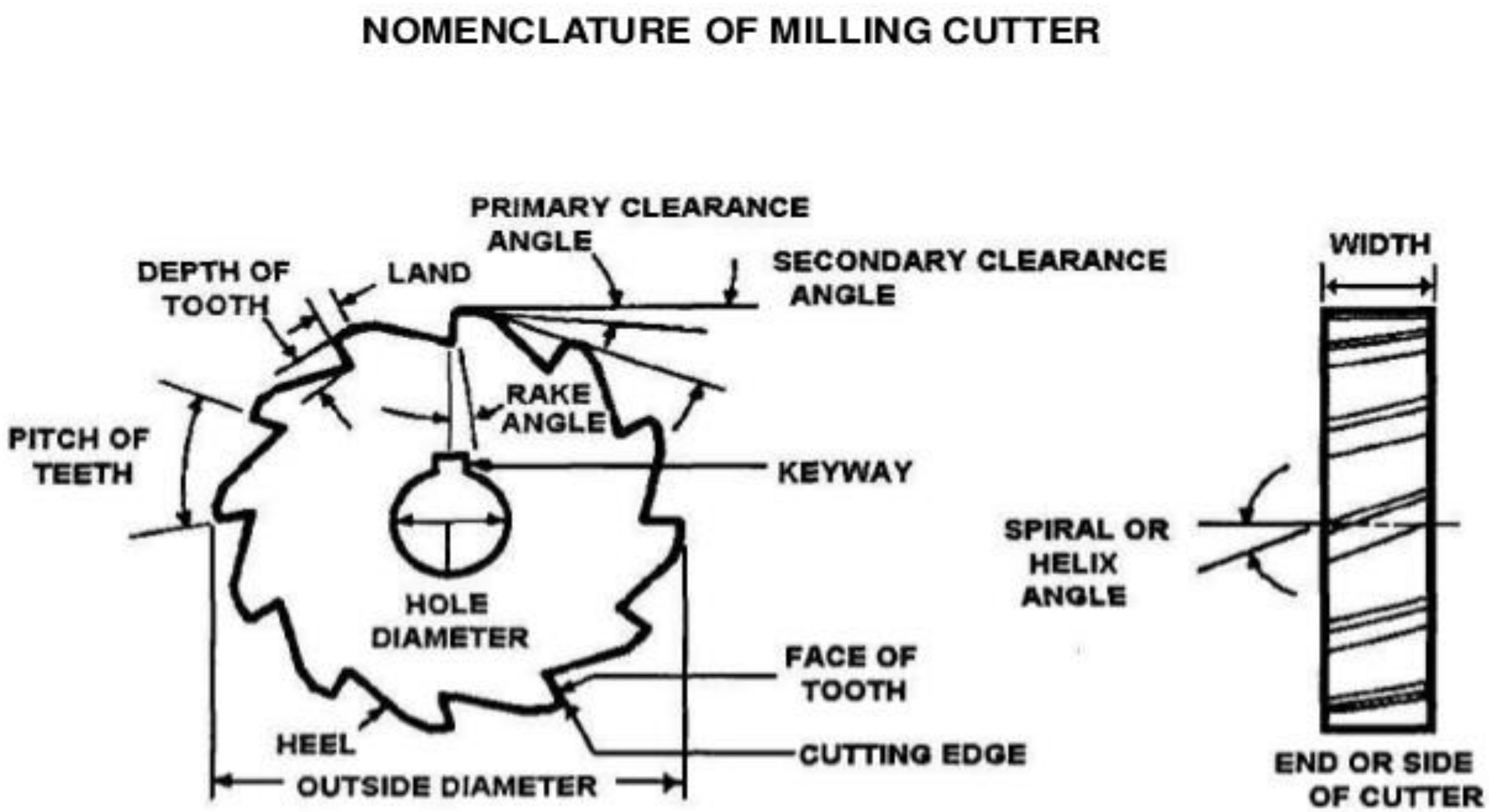


(b) Vertical Milling Machine

Milling Products



Milling cutter nomenclature



Milling Calculation

Cutting speed, $V = \pi \times D \times N$

D is the cutter diameter

Material removal rate is given as:

$MRR = f \times N \times d_a \times d_r = F \times d_a \times d_r$

d_a is the axial depth of cut

d_r is the radial depth of cut

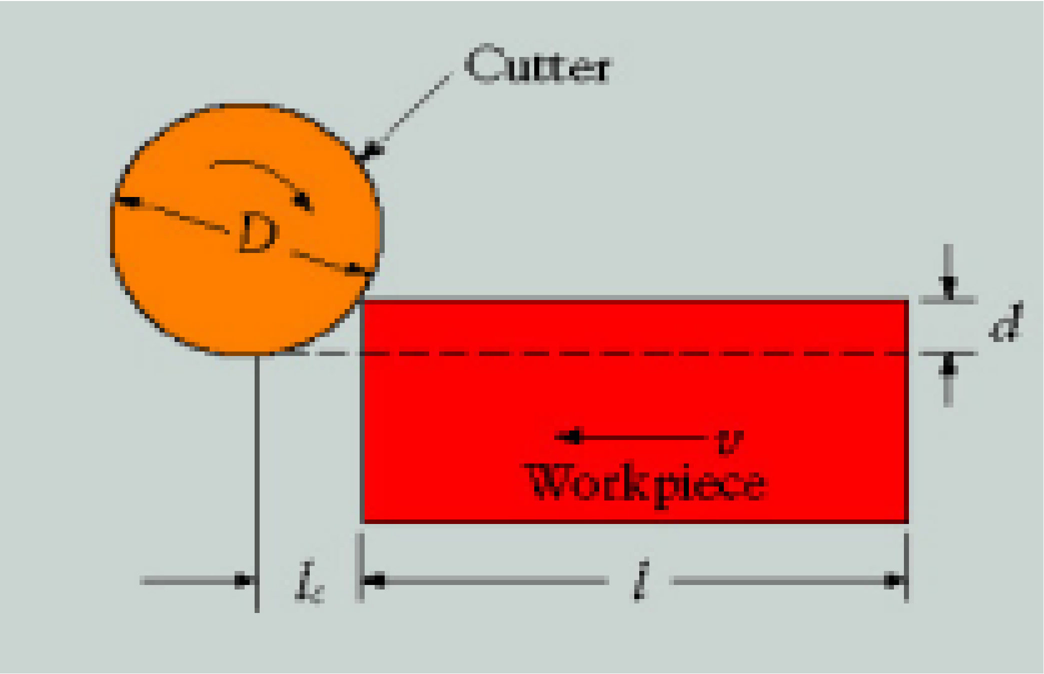
f is the feed per revolution

F is the feed rate (in/min or mm/min)

Cutting power, $P_c = U_c \times MRR$

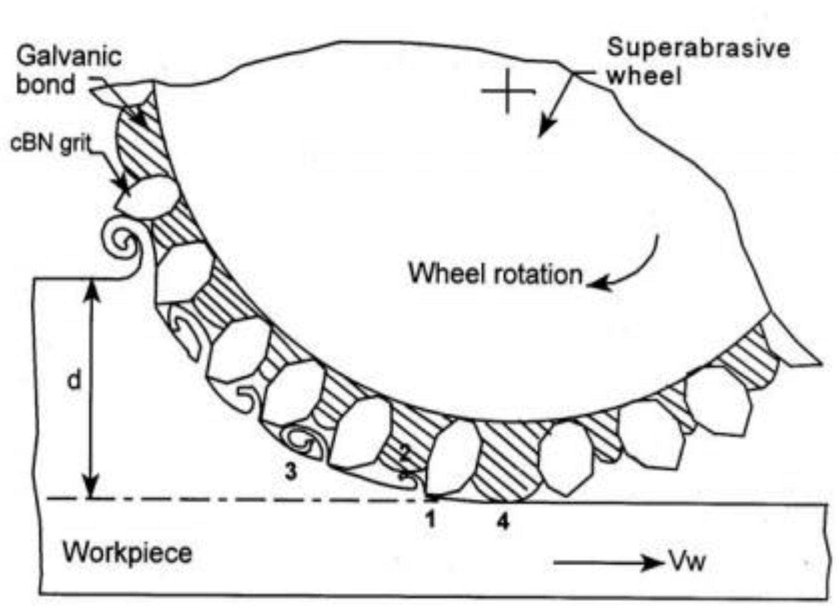
Machining time, $tm = (L + l_c)/F$

l_c is the length of the cutter's first contact with the work-piece



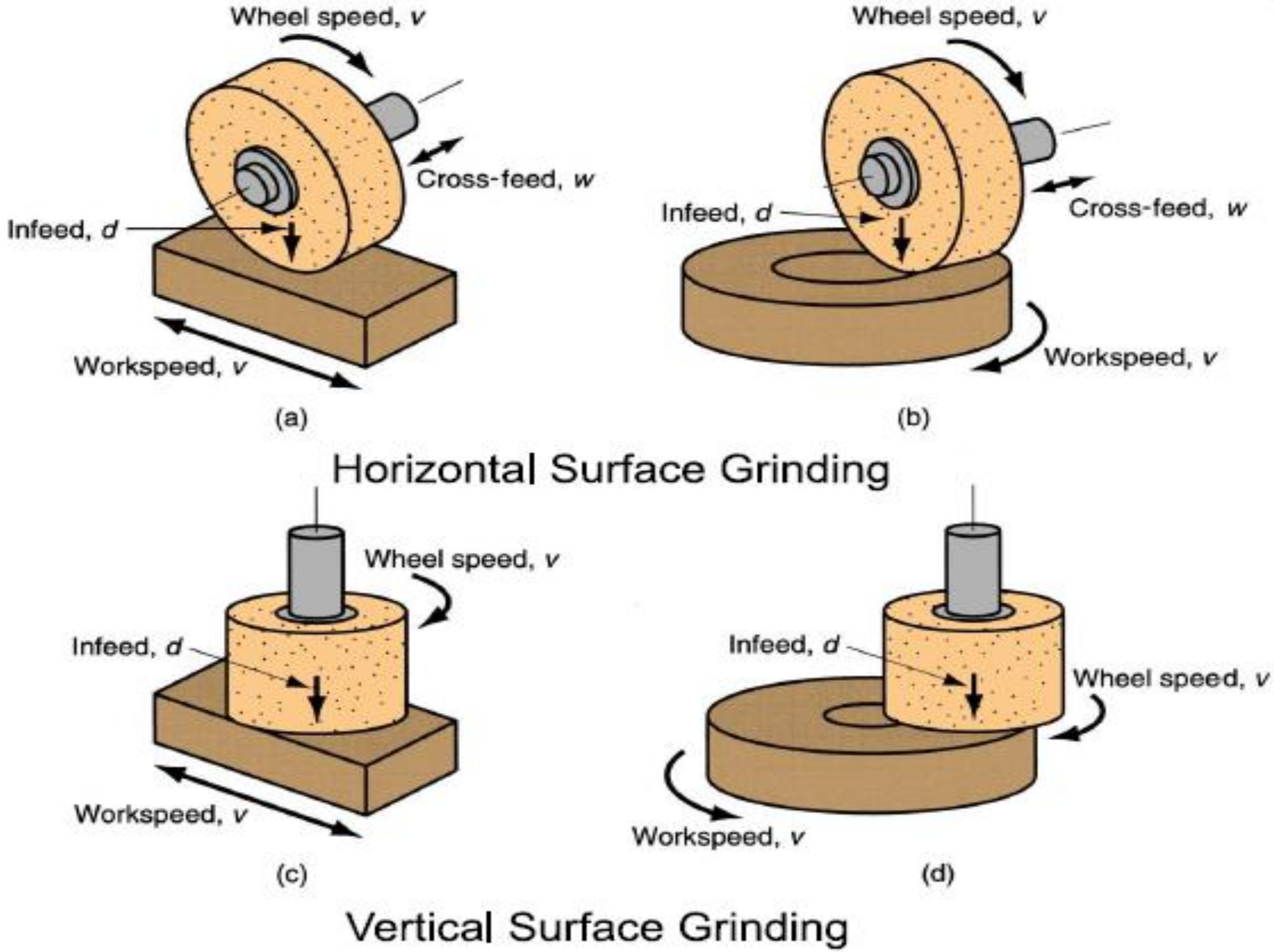
Grinding Operation

Grinding is the most common form of abrasive machining. It is a material cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as grit. These grits are characterized by sharp cutting points, high hot hardness, chemical stability and wear resistance. The grits are held together by a suitable bonding material to give shape of an abrasive tool.

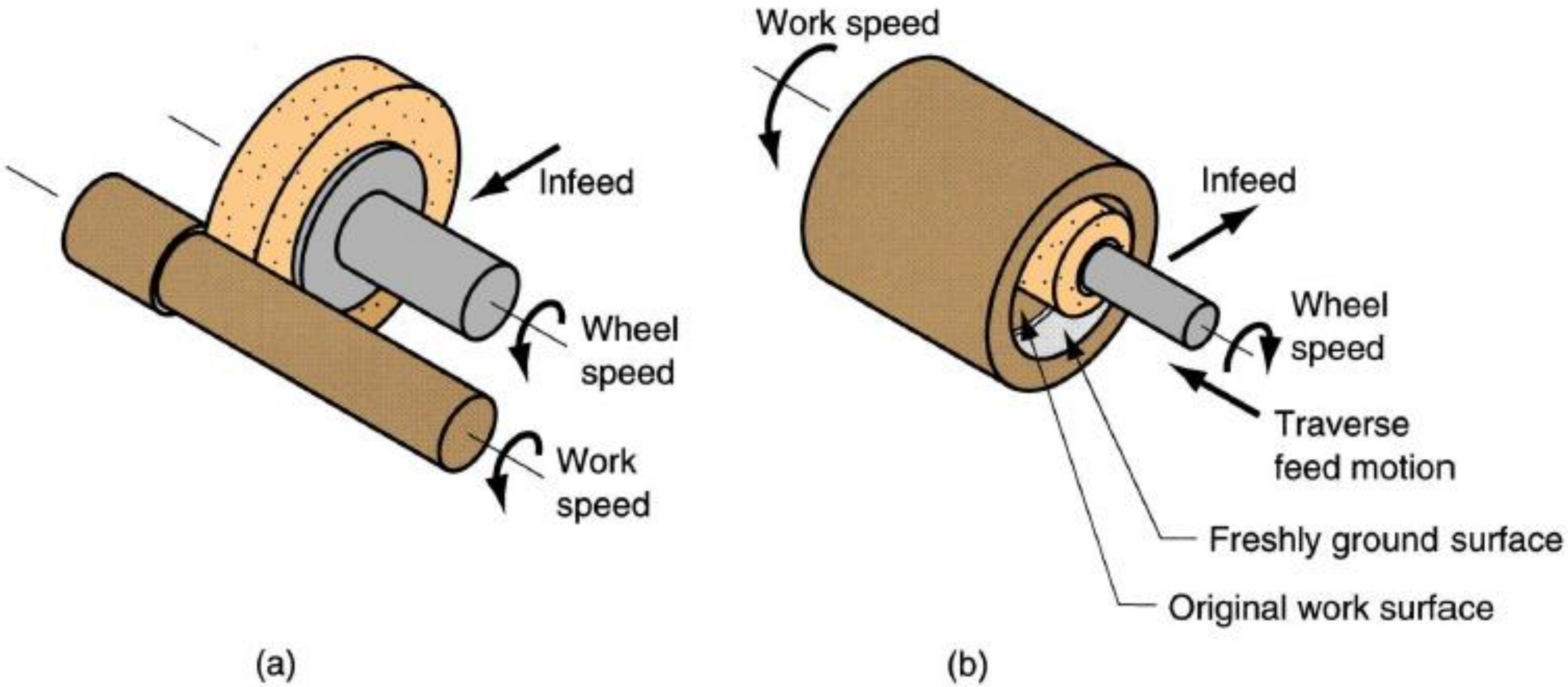


Grinding wheel and work-piece interaction

Grinding operations

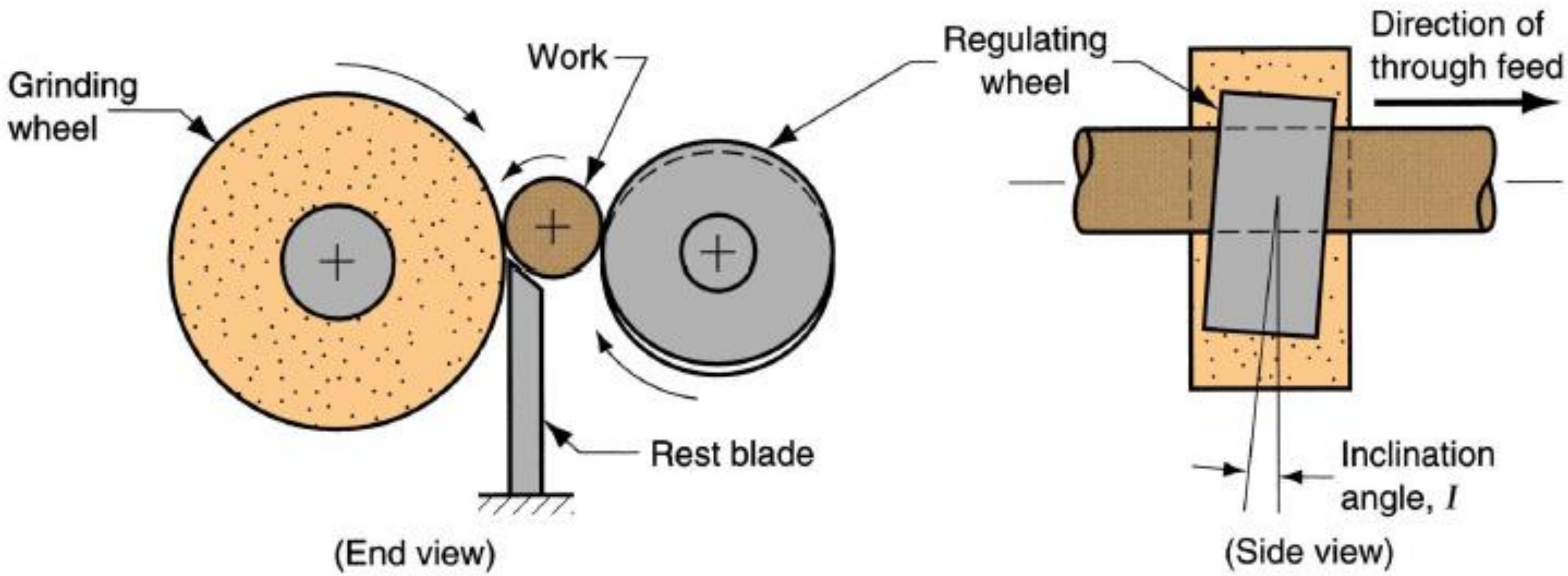


Cylindrical Grinding

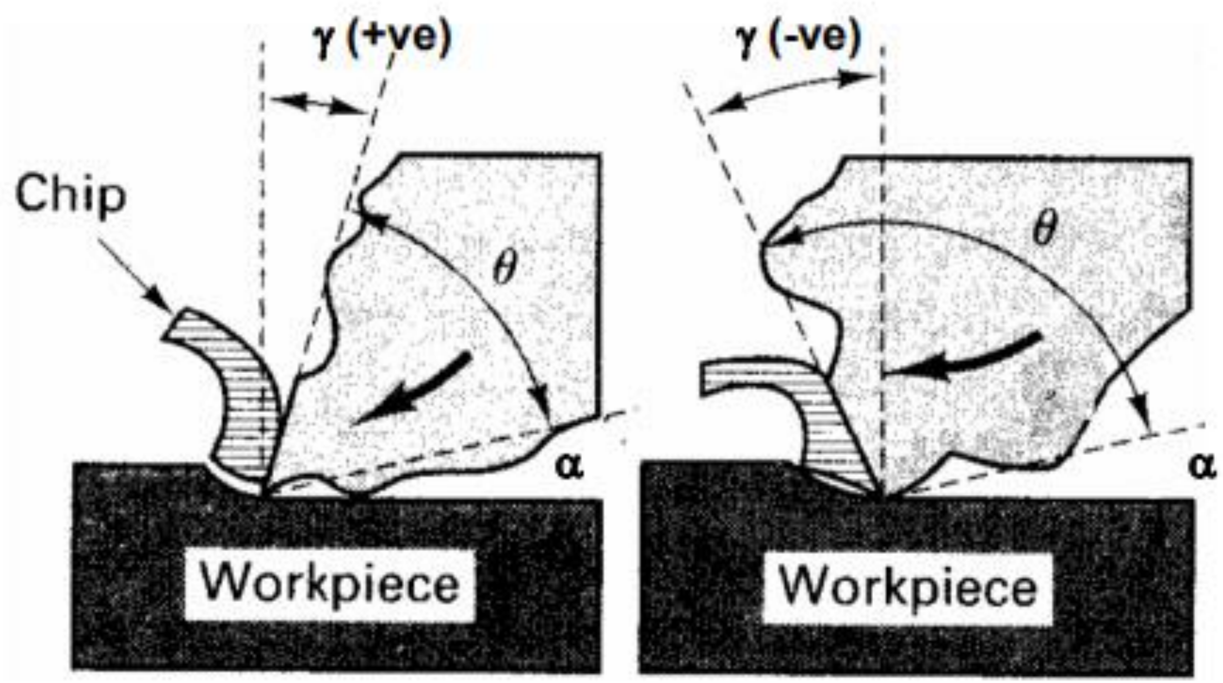


(a) External cylindrical Grinding(b) Internal cylindrical Grinding

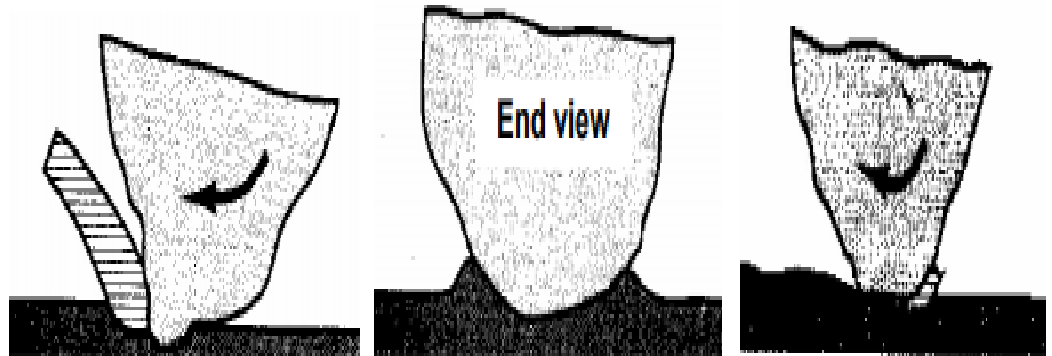
Centreless Grinding



Interaction of the grit with the work-piece



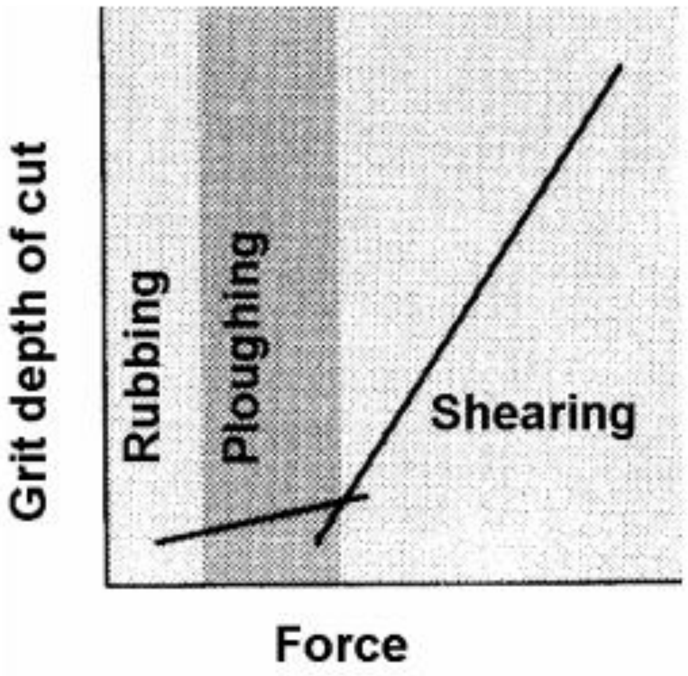
Variation in rake angle with grits of different shape



Grits engage shearing, ploughing and rubbing

Grit with favourable geometry can produce chip in shear mode. However, grits having large negative rake angle or rounded cutting edge do not form chips but may rub or make a groove by ploughing leading to lateral flow of the workpiece material as shown in fig.

Various stages of grinding with grit depth of cut



Various stages of grinding with grit depth of cut

At a small grit penetration only sliding of the grit occurs against the workpiece. In this zone rise of force with increase penetration is quite high. With further increase of grit penetration, grit starts ploughing causing plastic flow of the material associated with high grinding force.

It can be seen that with further increase of penetration, the grits start cutting and the rate of rise of force with increase of grit depth of cut is much less than what can be seen in the sliding or ploughing zone

Compositional specifications of Grinding Wheel

Specification of a grinding wheel ordinarily means compositional specification. Conventional Abrasive grinding wheels are specified encompassing the following parameters.

(1) The type of grit material

(2) The grit size

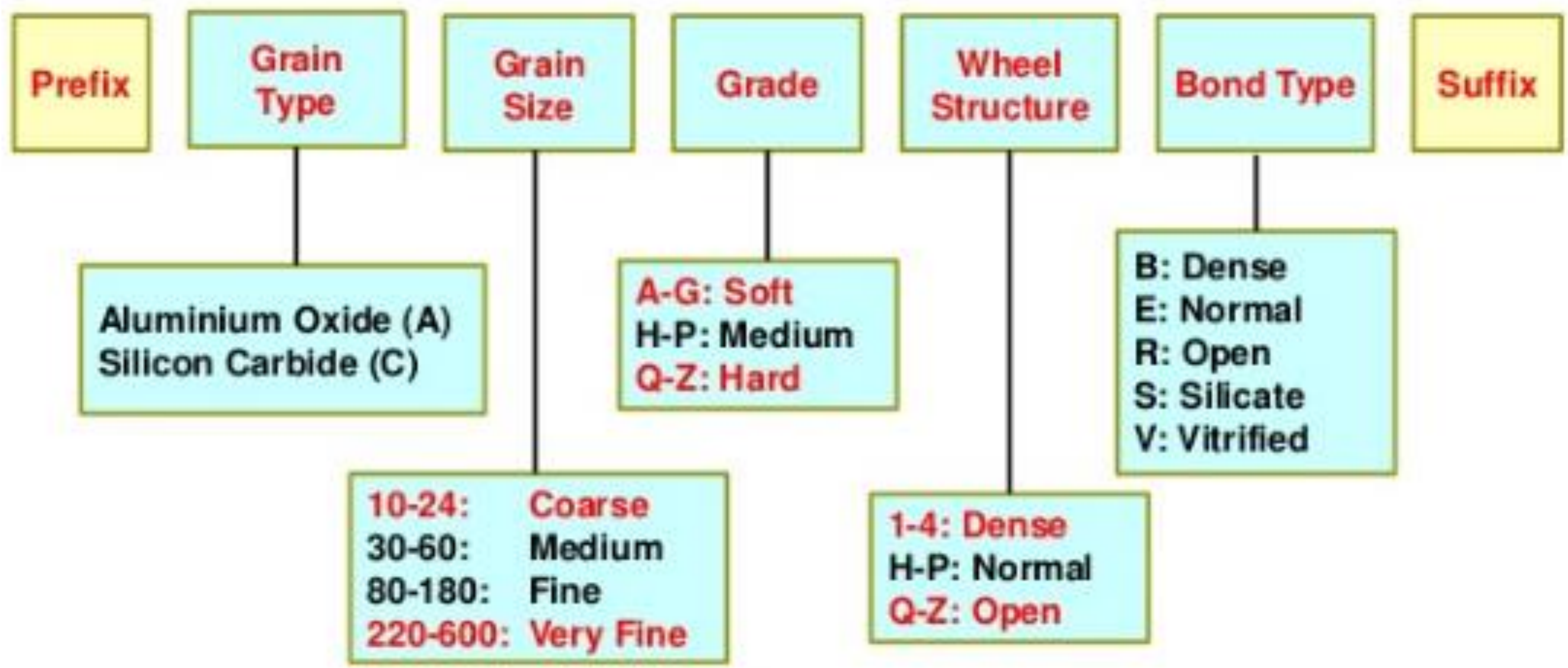
(3) The bond strength of the wheel, commonly known as wheel hardness

(4) The structure of the wheel denoting the porosity i.e. the amount of inter grit spacing

(5) The type of bond material

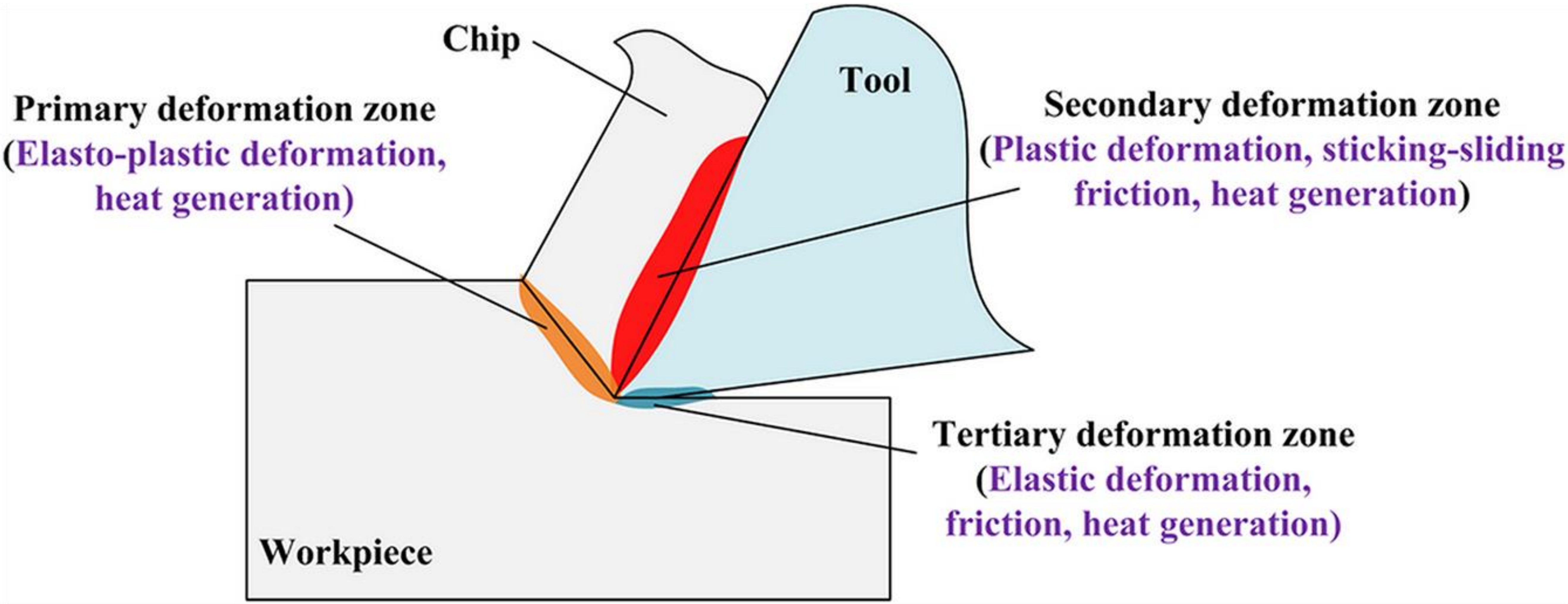
(6) Other than these parameters, the wheel manufacturer may add their own identification code prefixing or suffixing (or both) the standard code.

Specifications of Grinding Wheel



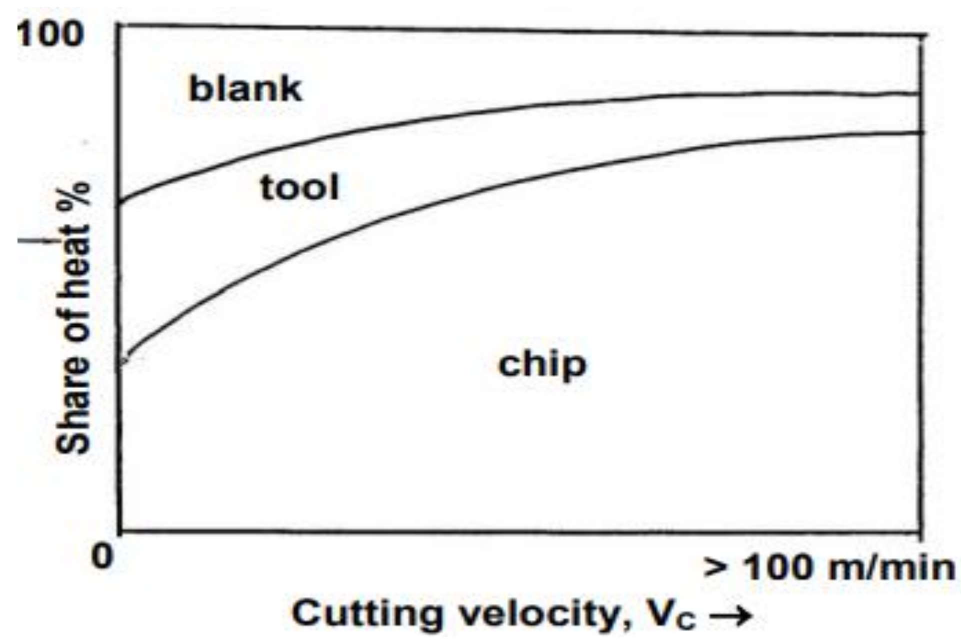
Heat generation in Metal cutting

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

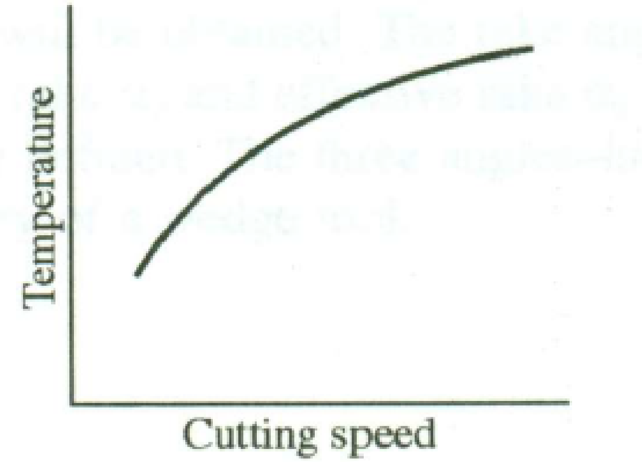


Heat distribution

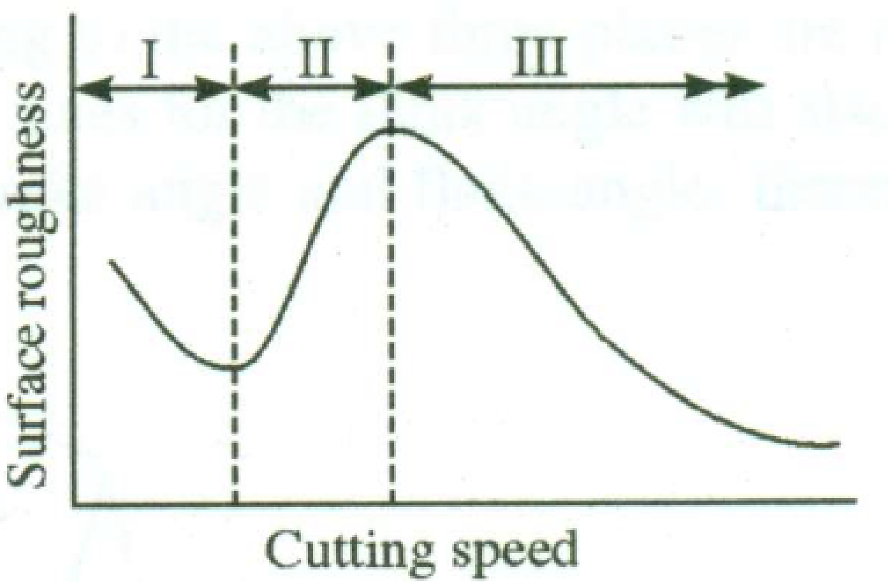
- Primary shear zone where the major part of the energy is converted into heat
- Secondary deformation zone at the chip – tool interface where further heat is generated due to rubbing and / or shear
- At the worn out flanks due to rubbing between the tool and the finished surfaces.
- The heat generated is shared by the chip, cutting tool and the blank.
- About 80% of total heat is carried away by the chip.
- From 10 to 20% of the total heat goes into the tool and some heat is absorbed in the blank. With the increase in cutting velocity, the chip shares heat increasingly.



Cutting Speed and Temperature



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



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.

Process of cutting tool failure

Tool that no longer performs the desired function can be declared as "failed"

Cutting tools generally fail by :

(i) Mechanical breakage: Due to excessive forces and shocks. Such kind of tool failure is random and catastrophic in nature and hence are extremely detrimental.

(ii) Rapid dulling :By plastic deformation due to intensive stresses and temperature. This type of failure also occurs rapidly and are quite detrimental and unwanted.

(iii) Gradual wear of the cutting tool at its flanks and rake surface.

Edge chipping/breakage

Thermal cracks

Gradual Wear of Cutting Tool

Tool Wear Mechanisms:

Abrasion wear: The hard inclusion having sharp edges comes in contact with a cutting tool and removes material from the tool surface by abrasion action. This wears are more predictable and give a stable tool life.

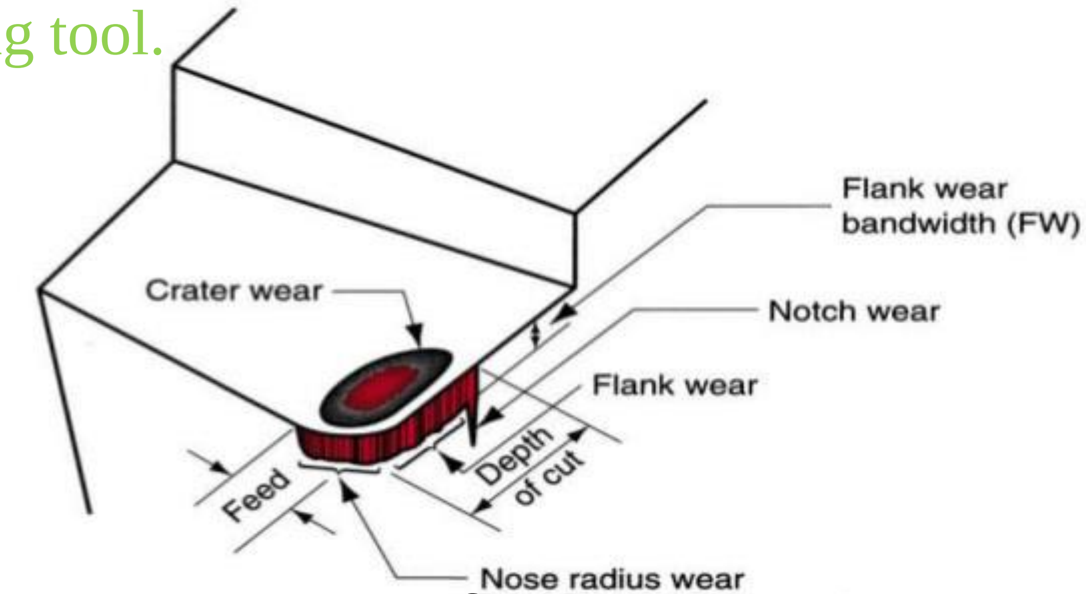
Adhesion wear: Adhesion wear occurred when chip material plucked out the microscopic fragment from the tool. At high temperature and pressure at cutting edge, the tool-chip interface forms a metallic bond in the form of spot welds.

Diffusion wear: This type of wear occurs due to the diffusion process, where atoms in a crystal lattice move from a region of high concentration to low concentration (Ficks law).

Flank wear and Crater wear are two common wear of cutting tool.

Flank wear

Crater wear

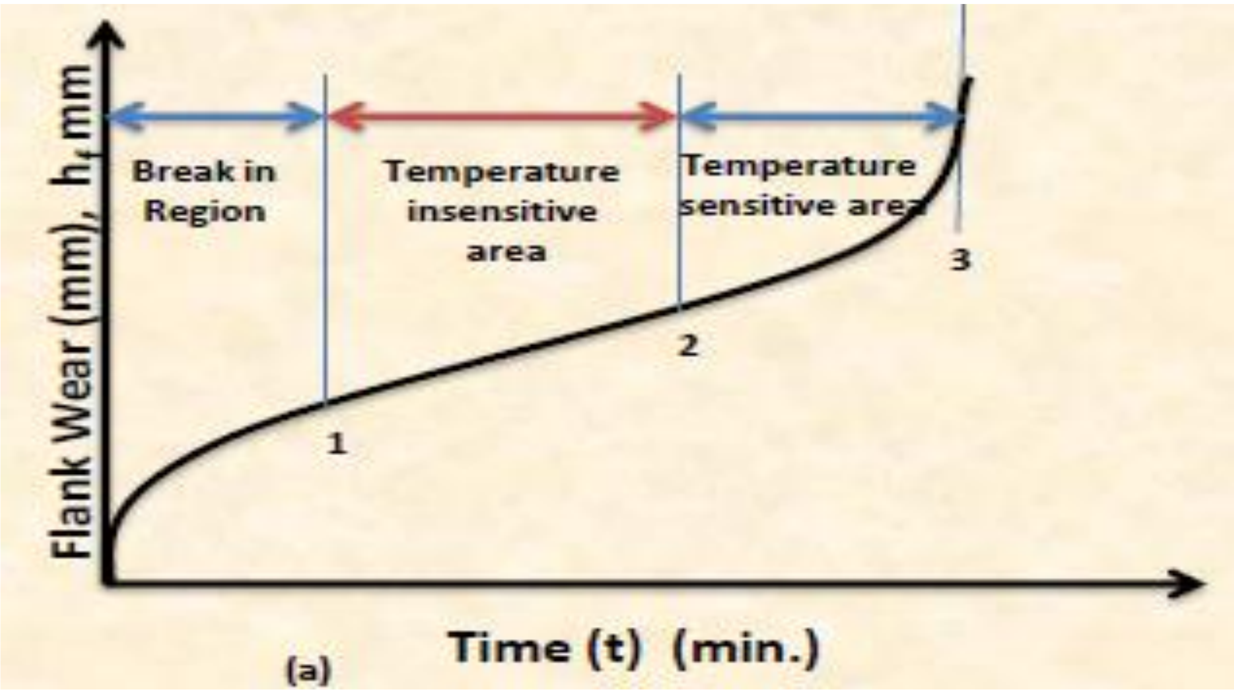


Create wear & flank wear

Flank wear and time relationship

Three stages of flank wear:

1. Rapid growth region (Break in region)
2. Steady state region (Temperature Insensitive region)
3. Catastrophe failure (Temperature sensitive region)



Flank wear characterized by wear land (or Height) h_f of wear band

Flank wear formation depends on

* Cutting Conditions (f, d, V, tool angles)

* Properties of work material and tool material

Tool Wear Index, Feed Marks and Surface finish

Type of wear depends MAINLY on cutting speed

- If cutting speed increases, predominant wear may be "CRATER" wear else "FLANK" wear.
- Failure by crater takes place when index h_k reaches 0.4 value, before flank wear limit of h_f=1mm for carbide tools is attained.

$$h_k = \frac{C}{(l/2)+f}$$

$Where, C = \text{Depth}$

$l = Width$

$f = Distance$

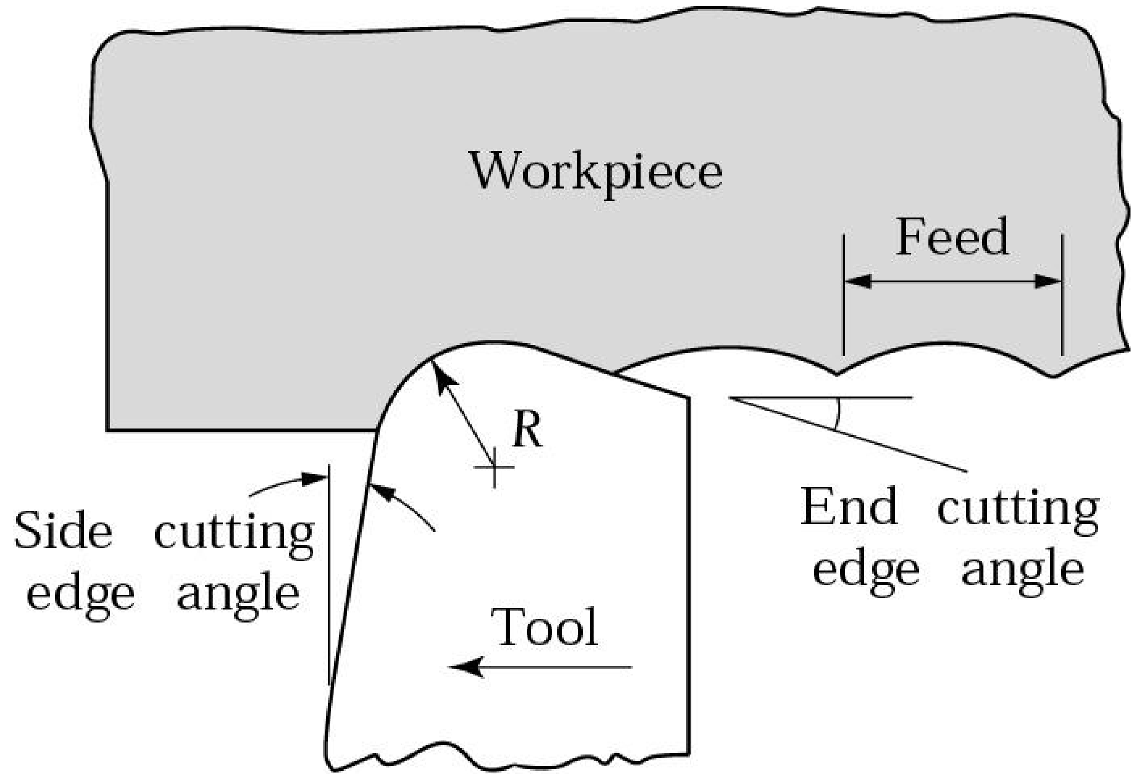
$for\ HSS\ h_k = 0.6$

$$R_{CLA} = \frac{8f^2}{R18\sqrt{3}}$$

$$R_{max} = 4R_{CLA}$$

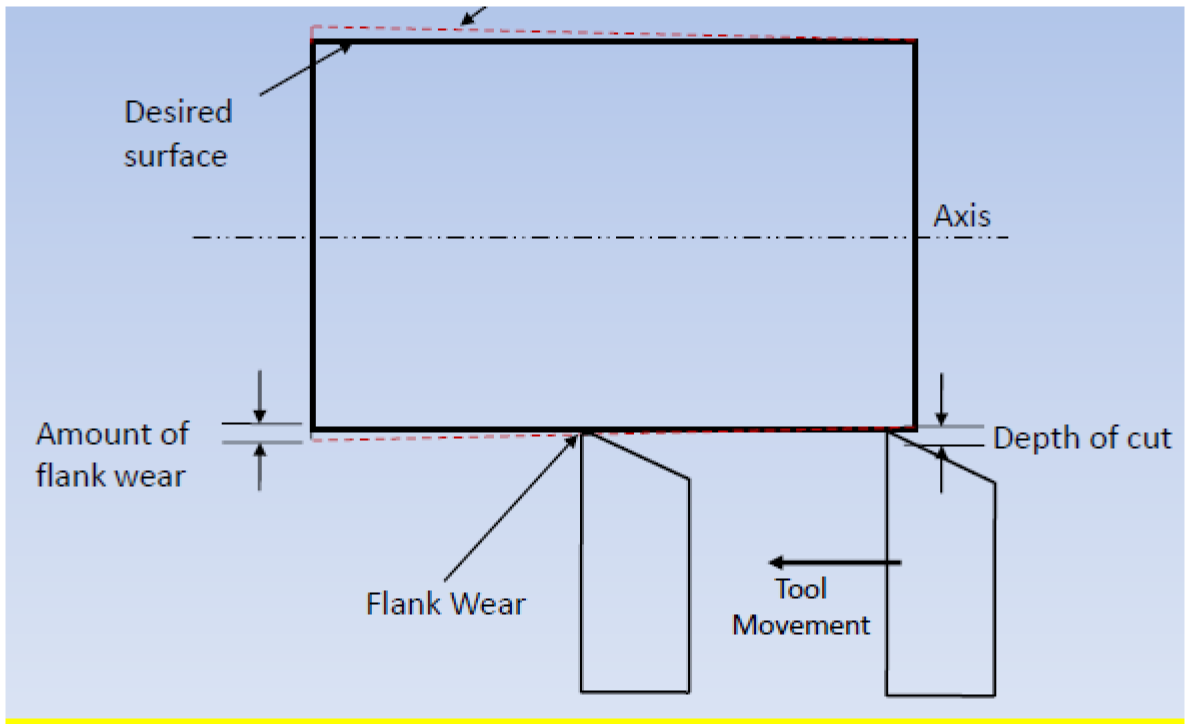
$Where, f = Feed$

$R = Tool\ \text{Nose Radius}$



Effect of tool wear on machined surface

- Dimensional accuracy
- Process stability
- Surface finish



Effect of tool wear on machined component dimensions (Exaggerated view)

Tool life & Machinability

Tool no longer performs desired function: failed

Re-sharpen and use it again.

Tool life:

Useful life of a tool expressed in terms of time from start of a cut to termination point (defined by failure criterion).

Sometimes also expressed in terms of number of the parts machined.

Machinability

Mainly concerned with work piece material properties not the tool properties.
It depends on work piece material properties and good Machinability means:

1. Ease of machining
2. Low tool wear
3. Good surface finish produced
4. Low cutting forces

Taylor's tool life equation

$$\boxed{VT^n = C}$$ ← After 12 Years of Experiments

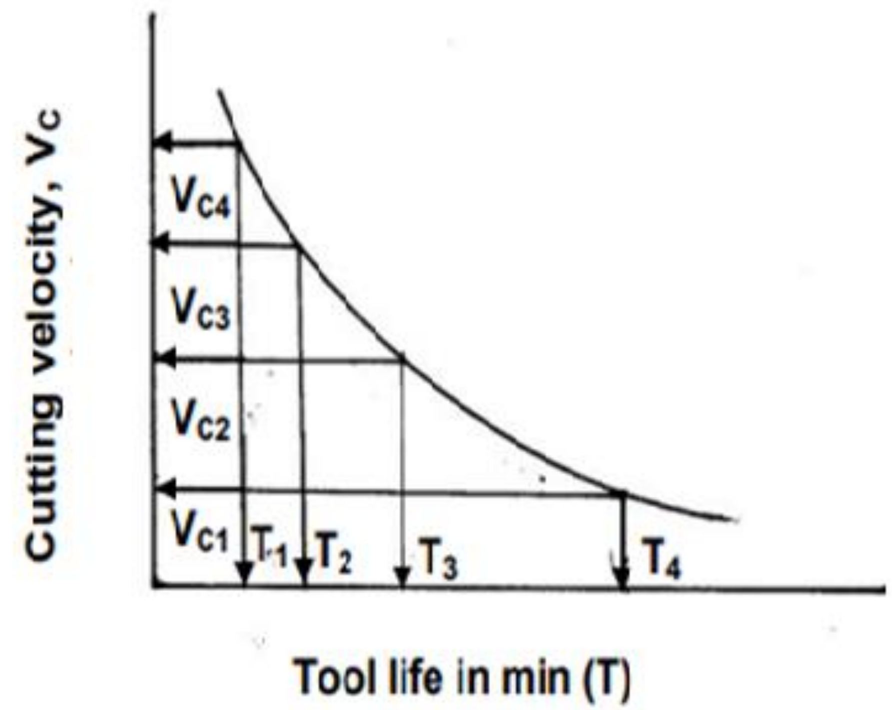
$Where, V = Cutting Speed$

$T = Tool\ life\ (Minutes)$

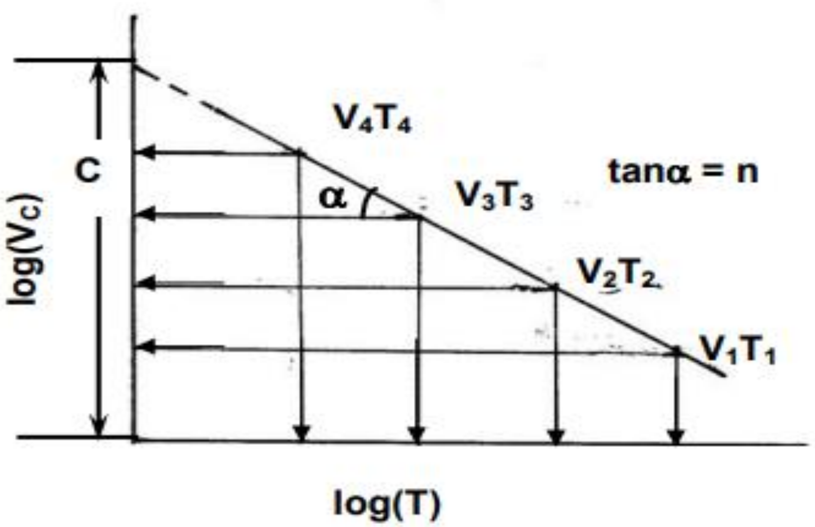
$n =$ Exponent for conditions tested

$C_t =$ Taylor's constant

$C_t \rightarrow$ represents cutting speed for 1 minute as tool life



Cutting velocity- tool life relationship



Cutting velocity vs tool life on a log-log scale

Tool life

Does not account for:

Feed (f)

Depth of cut (d)

Tool geometry (Rake Angle α)

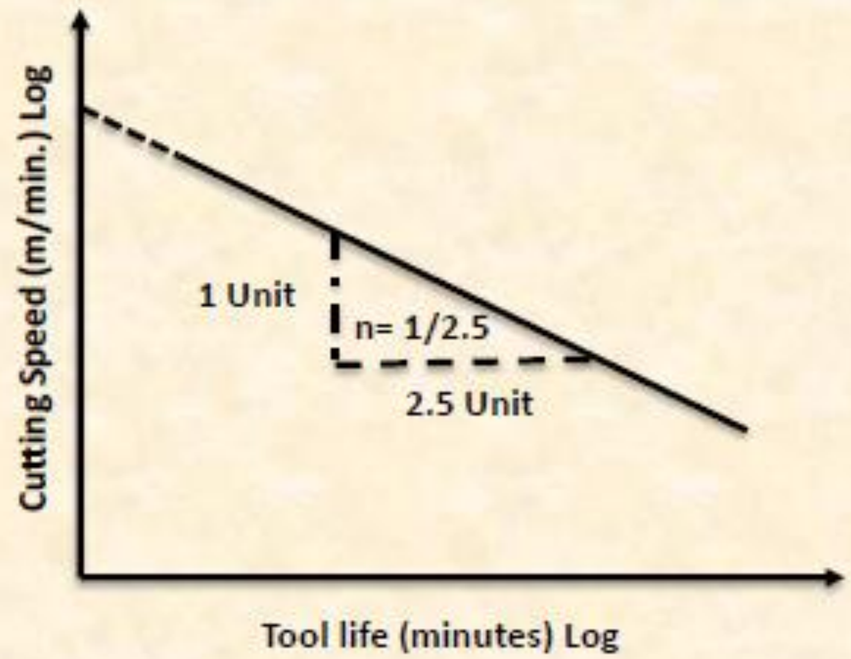
$$\boxed{VT^n = C}$$

(n<1), C_t is very large

Taking logarithm on both sides

$\text{LogV} + n\log T = \text{LogC}_t$

This becomes a straight line on the log-log scale



$VT^n f^{n1} d^{n2} = C$

N, n1, n2: Constants depending upon tool material (=0.1 to 0.4).

C: constant that depends on tool-work material combination and tool geometry (>100)

Variables affecting tool life

- Cutting Conditions (V, d, f)
- Tool Geometry (all six angles, and nose radius)
- Work piece Material
- Cutting fluid
- Machine tool and Work piece region
- Tool Material

Cutting fluids and Lubrication

The basic purposes of cutting fluid application are :

- ❖ Cooling of the job and the tool to reduce the detrimental effects of cutting temperature on the job and the tool.
- ❖ Lubrication at the chip–tool interface and the tool flanks to reduce cutting forces and friction and thus the amount of heat generation.
- ❖ Cleaning the machining zone by washing away the chip – particles and debris which, if present, spoils the finished surface and accelerates damage of the cutting edges
- ❖ Protection of the nascent finished surface – a thin layer of the cutting fluid sticks to the machined surface and thus prevents its harmful contamination by the gases like SO_2, O_2, H_2S, N_xO_y present in the atmosphere.

Essential Properties of Cutting Fluids

For cooling :

- High specific heat, thermal conductivity and film coefficient for heat transfer
- Spreading and wetting ability

For lubrication :

- High lubricity without gumming and foaming
- Wetting and spreading
- High film boiling point
- Friction reduction at extreme pressure (EP) and temperature

Other properties:

- Chemical stability, non-corrosive to the materials
- Less volatile and high flash point
- High resistance to bacterial growth
- Odourless and also preferably colourless
- Non toxic in both liquid and gaseous stage
- Easily available and low cost

Recap

- Material Removal processes and their Classifications
- Conventional Machining processes
- Single point and multipoint cutting tools
- Chips formation
- Mechanics of Cutting
- Cutting tool materials
- Heat Generation in cutting
- Tool life & Tool Wear
- Calculations of Turning, Drilling and Milling operations
- Grinding operation
- Classification of Grinding operations
- Grinding Wheel Specifications