JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE

Year & Sem – Third Year & Fifth Semester
Subject – Manufacturing Technology
Unit – Second
Presented by – Ms.Palak Jindal, Assistant Professor, Mechanical Engineering Department

VISSION AND MISSION OF INSTITUTE

VISSION - To become a renowned centre of outcome based learning, and work towards academic, professional, cultural and social enrichment of the lives of individuals and communities.

MISSION –

- Focus on evaluation of learning outcomes and motivate students to inculcate research aptitude by project based learning.
- Identify, based on informed perception of Indian, regional and global needs, areas of focus and provide platform to gain knowledge and solutions.
- Offer opportunities for interaction between academia and industry.
- Develop human potential to its fullest extent so that intellectually capable and imaginatively gifted leaders can emerge in a range of professions.

VISSION AND MISSION OF DEPARTMENT

VISSION –

The Mechanical Engineering Department strives to be recognized globally for outcome based technical knowledge and to produce quality human resource, who can manage the advance technologies and contribute to society.

MISSION –

- To impart quality technical knowledge to the learners to make them globally competitive mechanical engineers.
- To provide the learners ethical guidelines along with excellent academic environment for a long productive career.
- To promote industry-institute relationship.

CONTENTS (TO BE COVERED)

Classification of metal removal process and machines: Geometry of single point cutting tool and tool angles, tool nomenclature in ASA, ORS. Concept of orthogonal and oblique cutting.Type of chips, Mechanics of metal cutting; interrelationships between cutting force, shear angle, strain and strain rate. Thermal aspects of machining and measurement of chip tool interfacetemperature.

- Many components produced by primary manufacturing processes need machining to get their final shape, accurate size and good surface finish.

- The term machining is used to describe various processes which involve removal of material from the workpiece

Definition of Machining (or Metal cutting)

"Machining is an essential process of finishing by which jobs are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool(s) moved past the work surface(s)"

Importance of machining

- The ever increasing importance of machining operations is gaining new dimensions in the present industrial age.

- Competition towards the economical manufacture of machined parts.

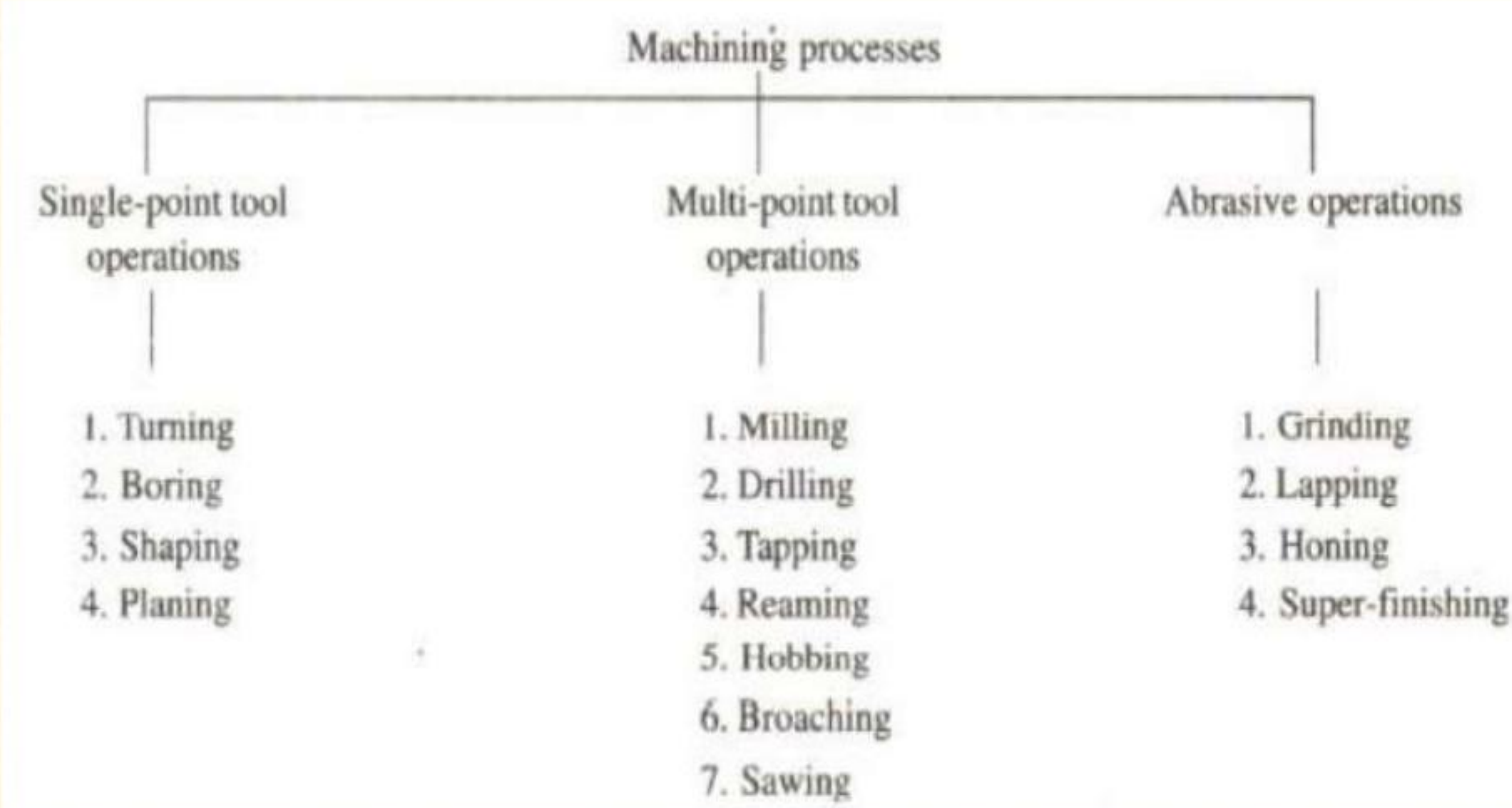
- Basic *objectives* of the economical and efficient manufacturing practice are:

- 1.Quick Metal Removal or MRR(Material Removal Rate)
- 2.High class surface finish
- 3.Economy in tool cost
- 4.Less power consumption
- 5.Economy in cost of replacement and sharpening of tools
- 6.Minimum lead time of machine tools

What is machine tool?

- A machine tool is a machine for shaping or machining metal or other rigid materials, usually by cutting, boring, grinding, shearing, or other forms of deformation.

- Machine tools employ some sort of tool that does the cutting or shaping.



CLASIFICATION OF CUTTING TOOLS

- The cutting tools used in metal cutting can be broadly classified as:

  1. Single point tools :

     Those having only one cutting edge.

     Ex: Lathe tools, shaper tools, planer tools, boring tools, etc.

  2. Multi-point tools:

     Those having more than one cutting edge.

     Ex: milling cutters, drills, broaches, grinding wheels, etc.

- The cutting tools can be classified according to the motion as:

  1. Linear motion tools:

     Ex: Lathe, boring, broaching, planing, shaping tools, etc.

  2. Rotary Motion tools:

     Ex: milling cutters, grinding wheels, etc.

  3. Linear and Rotary Motion tools:

     Ex: drills, honing tools, boring heads, etc.

How cutting takes place?

- **For providing cutting action a relative motion between the tool and work-piece is necessary.**
- **This relative motion can be provided by:**

1. **Either keeping the workpiece stationary and moving the tool**

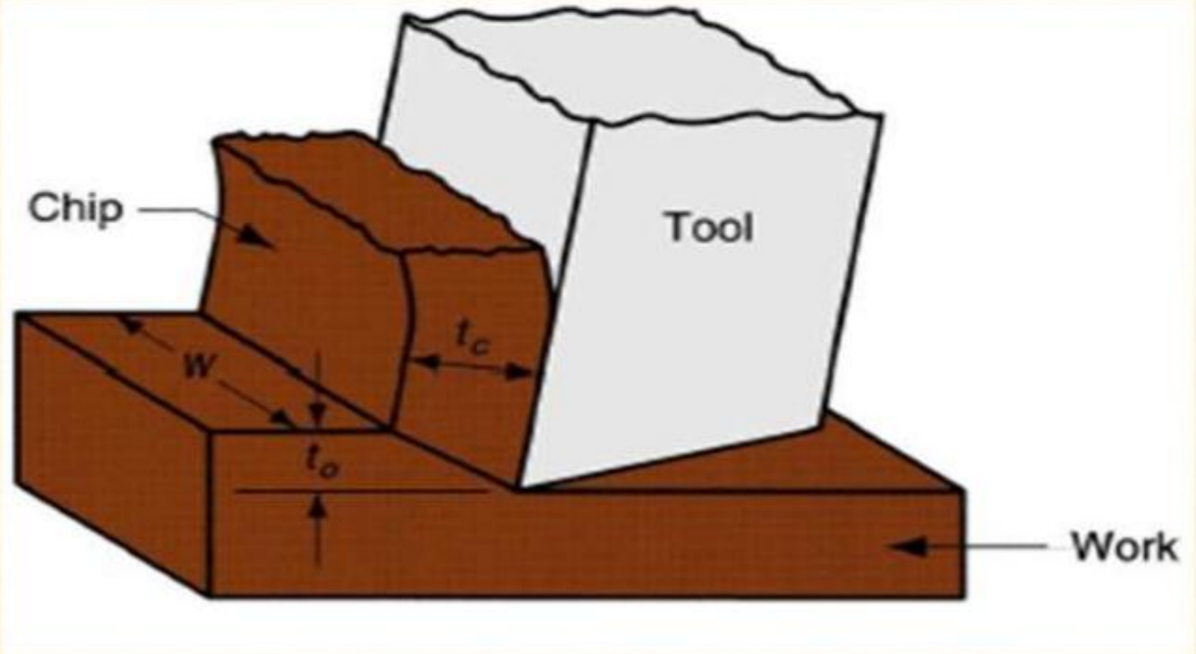
Ex. Shaper, Slotter, Broaching machine etc.

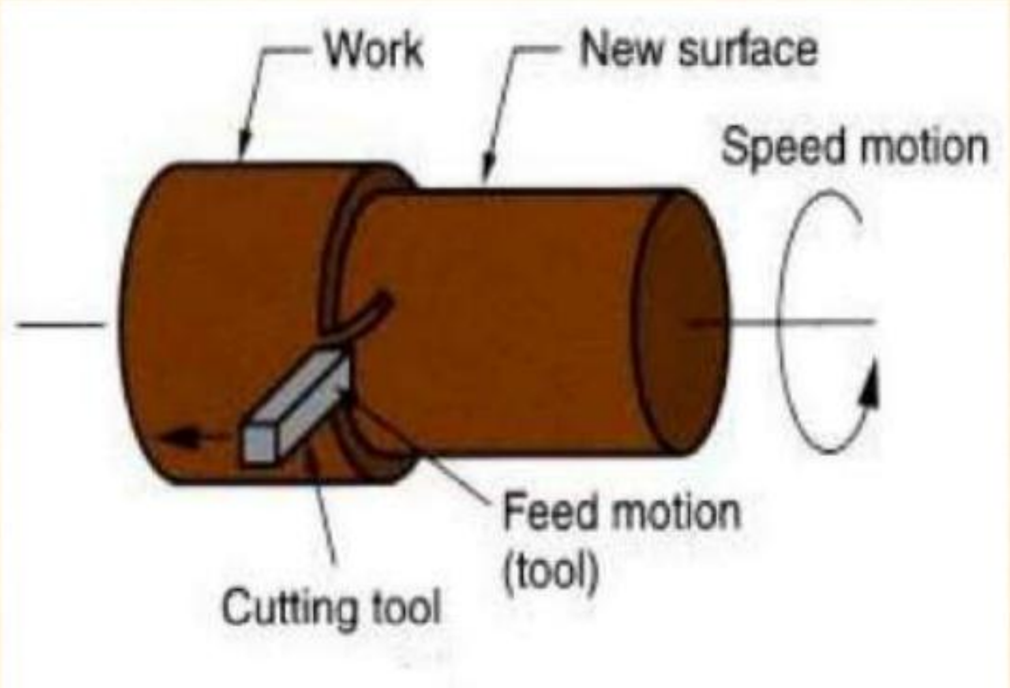
2. By keeping the tool stationary and moving the work

Ex. Planer

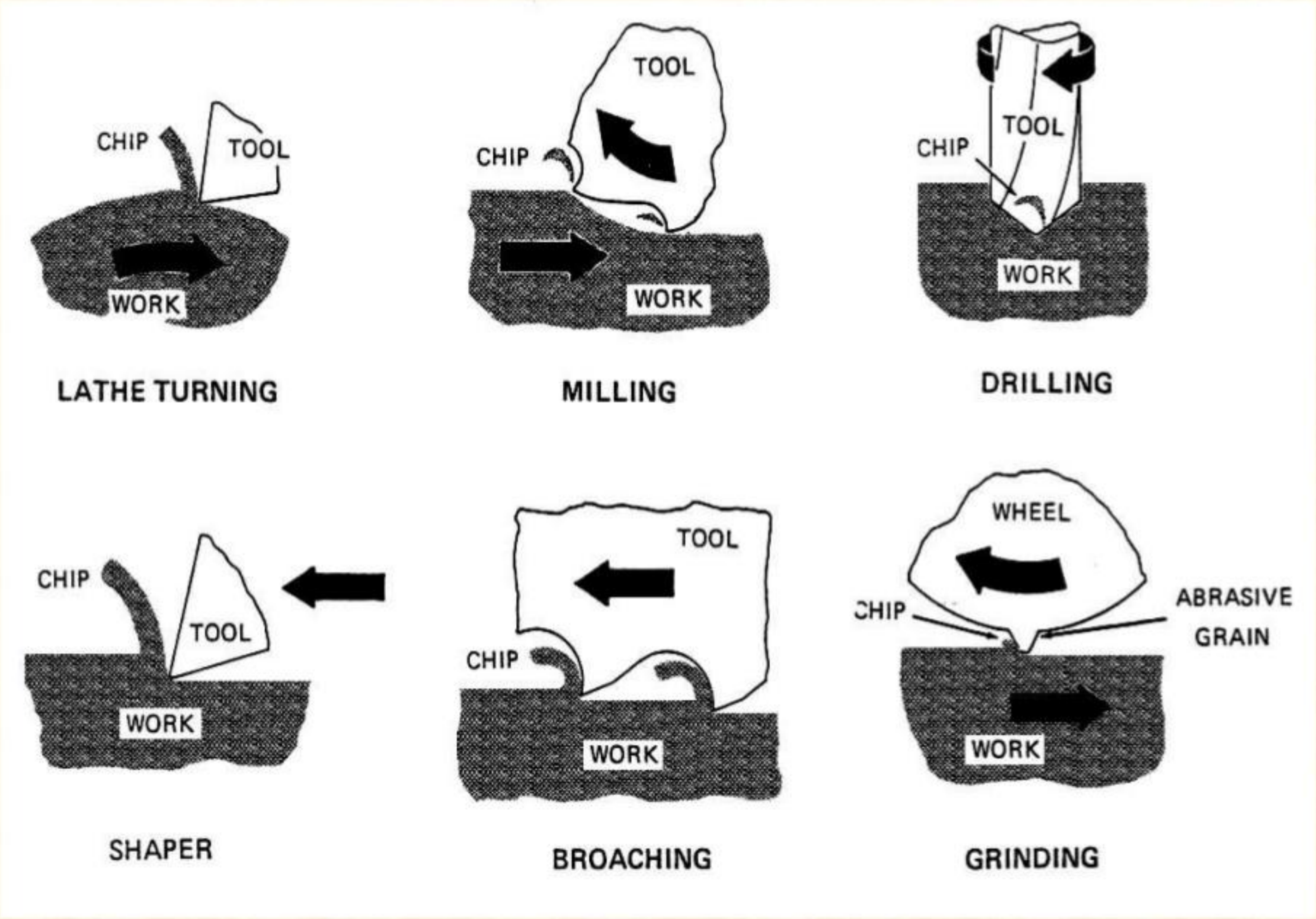
3. By moving both in relation to one another.

Ex. Grinding and Milling

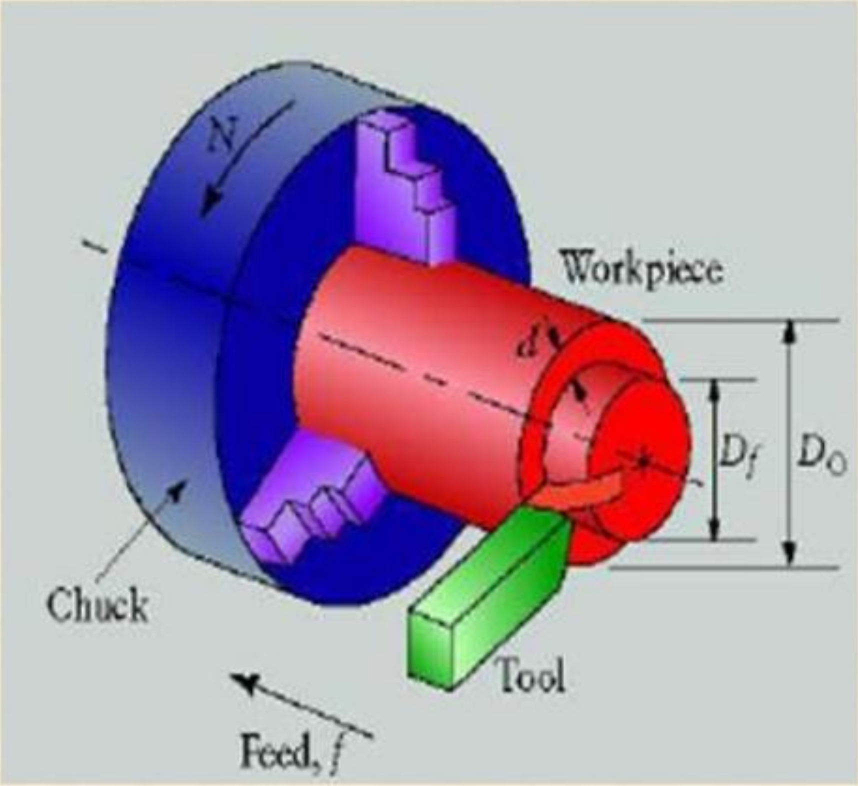

Chip
Tool
t_c
w
t_o
Work

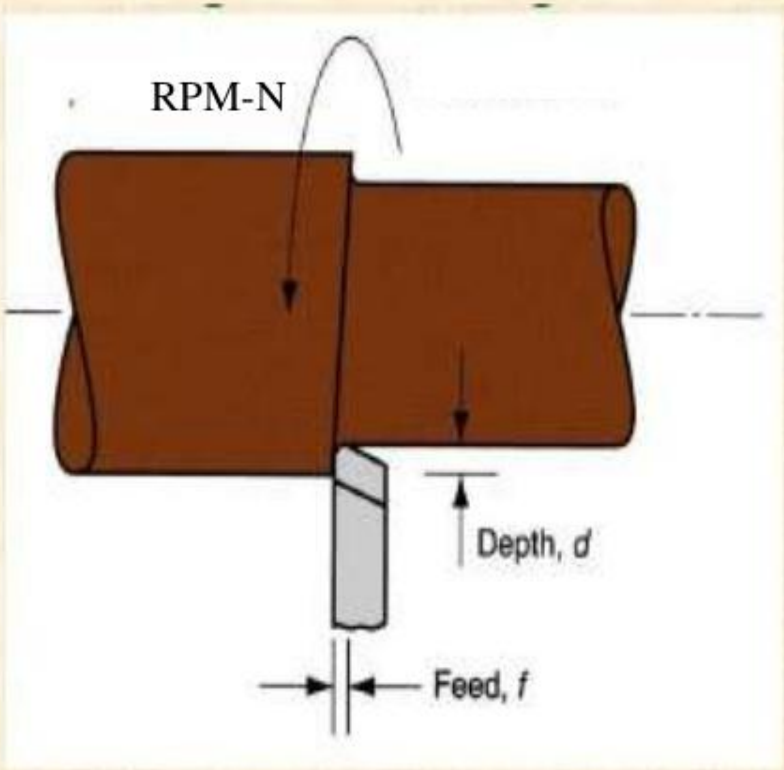

Work
New surface
Speed motion
Feed motion
(tool)
Cutting tool

Diagrammatic Representation of Material Removal Operations



Cutting Parameters





Cutting Parameters

Cutting speed (V) is the largest of the relative velocities of cutting tool or workpiece. In turning, it is the speed of the workpiece while in drilling and milling, it is the speed of the cutting tool.

Cutting speed is the distance traveled by the work surface in unit time with reference to the cutting edge of the tool.

Cutting speed of a cutting tool can be defined as the rate at which its cutting edge passes over the surface of the workpiece in unit time.

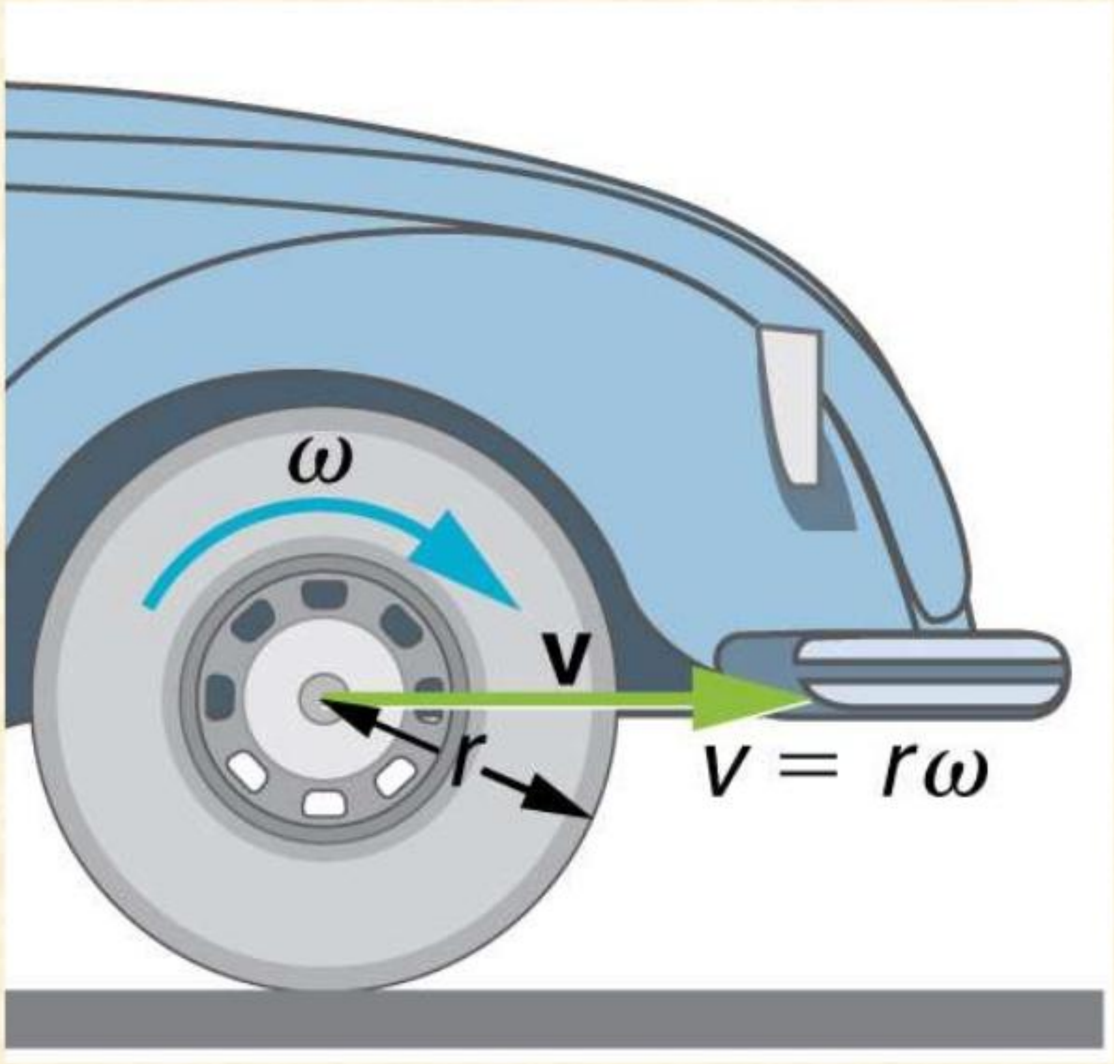
It is normally expressed in terms of surface speed, referred to as speed(v) and expressed in meters per minute (m/min)

In turning, it is given by the surface speed of the workpiece

$V = r\omega = r * (2 \pi N)/60 = \pi DN/1000$ m/min   D in mm, N in rpm

D= Dia. of w/p
N=rpm of spindle

V=linear velocity
ω = angular velocity = rad/sec


ω
v
r
v = rω

Feed: The feed is the distance advanced by the tool into or along the workpiece each time the tool point passes a certain position in its travel over the surface.
In case of turning, feed is the distance that the tool advances in one revolution of the workpiece.

Feed **f** is usually expressed in mm/rev.
Feed in mm/min = Feed in mm/rev x N

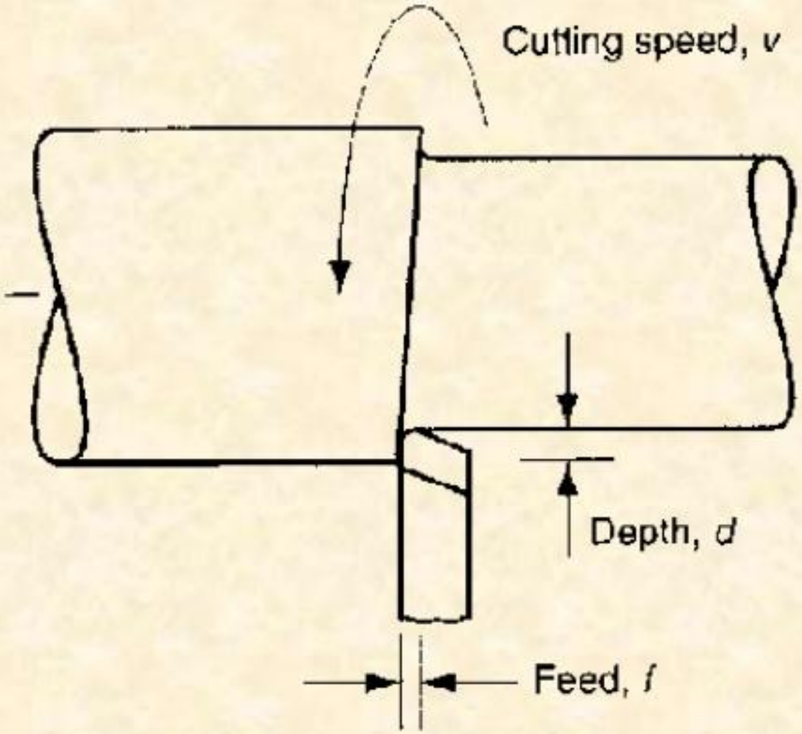
Depth of cut : It is the distance through which the cutting tool is plunged into the workpiece surface.

Thus it is the distance measured perpendicularly between the machined surface and the unmachined (uncut) surface or the previously machined surface of the workpiece.

The depth of cut ***d*** is expressed in mm.=(d1-d2)/2 for turning

Material Removal Rate

➢Volume of material removed per unit time(1 min) or volume of material removed divided by the machining time



$$MRR = vfd$$

m/min * mm/rev * mm

$$Roughing(R)$$

$$f = 0.4 - 1.25 mm / rev$$

$$d = 2.5 - 20 mm$$

$$Finishing(F)$$

$$f = 0.125 - 0.4 mm / rev$$

$$d = 0.75 - 2.0 mm$$

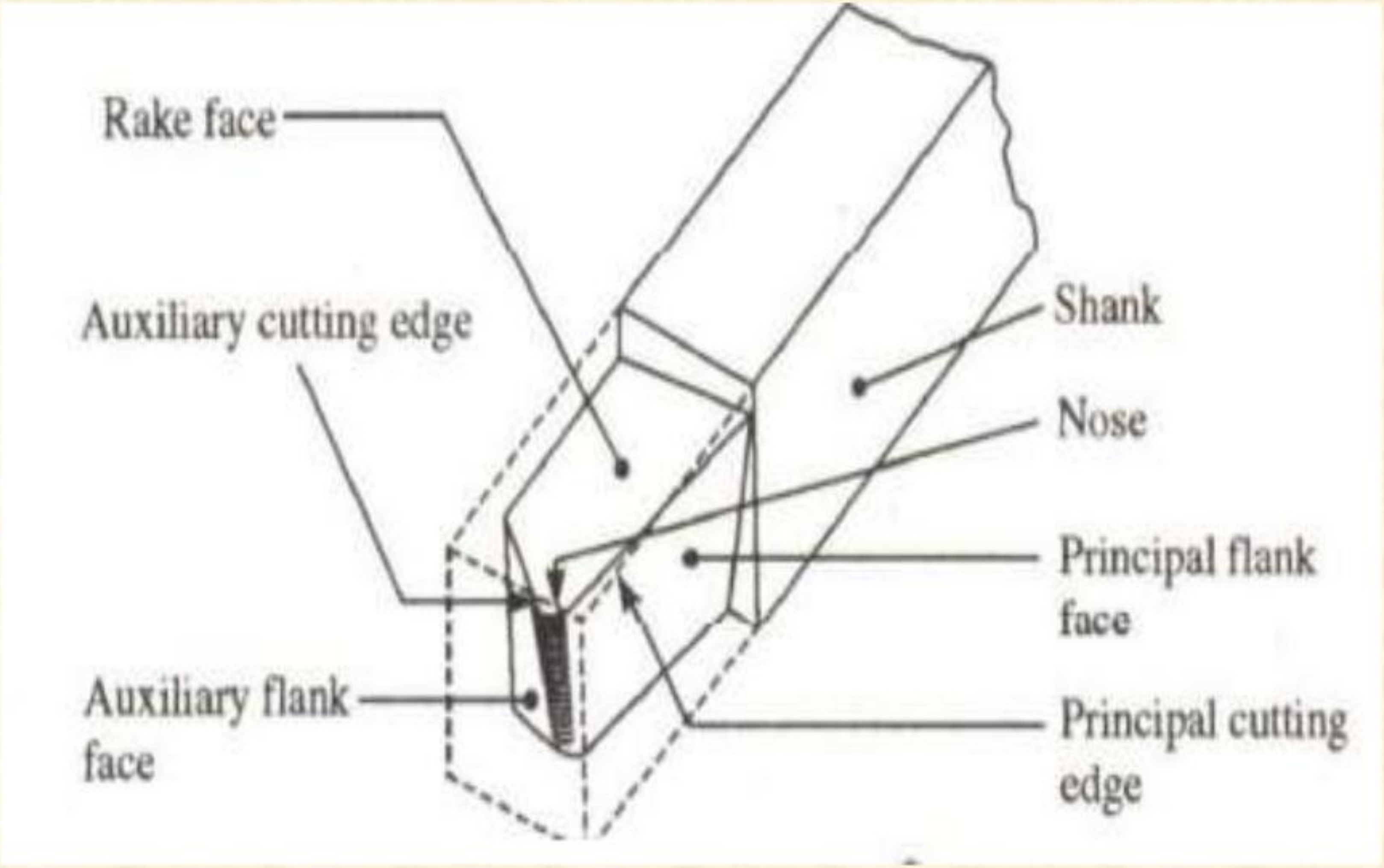
MRR= (Initial weight – Final weight)/Machining time

$$v_R << v_F$$

MRR= Volume removed/cutting time=mm^3/min or mm^3/sec

Power required = MRR x Specific cutting energy (Watts/mm^3/sec)

Single point cutting tool



2 parts of the cutting tool: 1.Shank 2.Flank

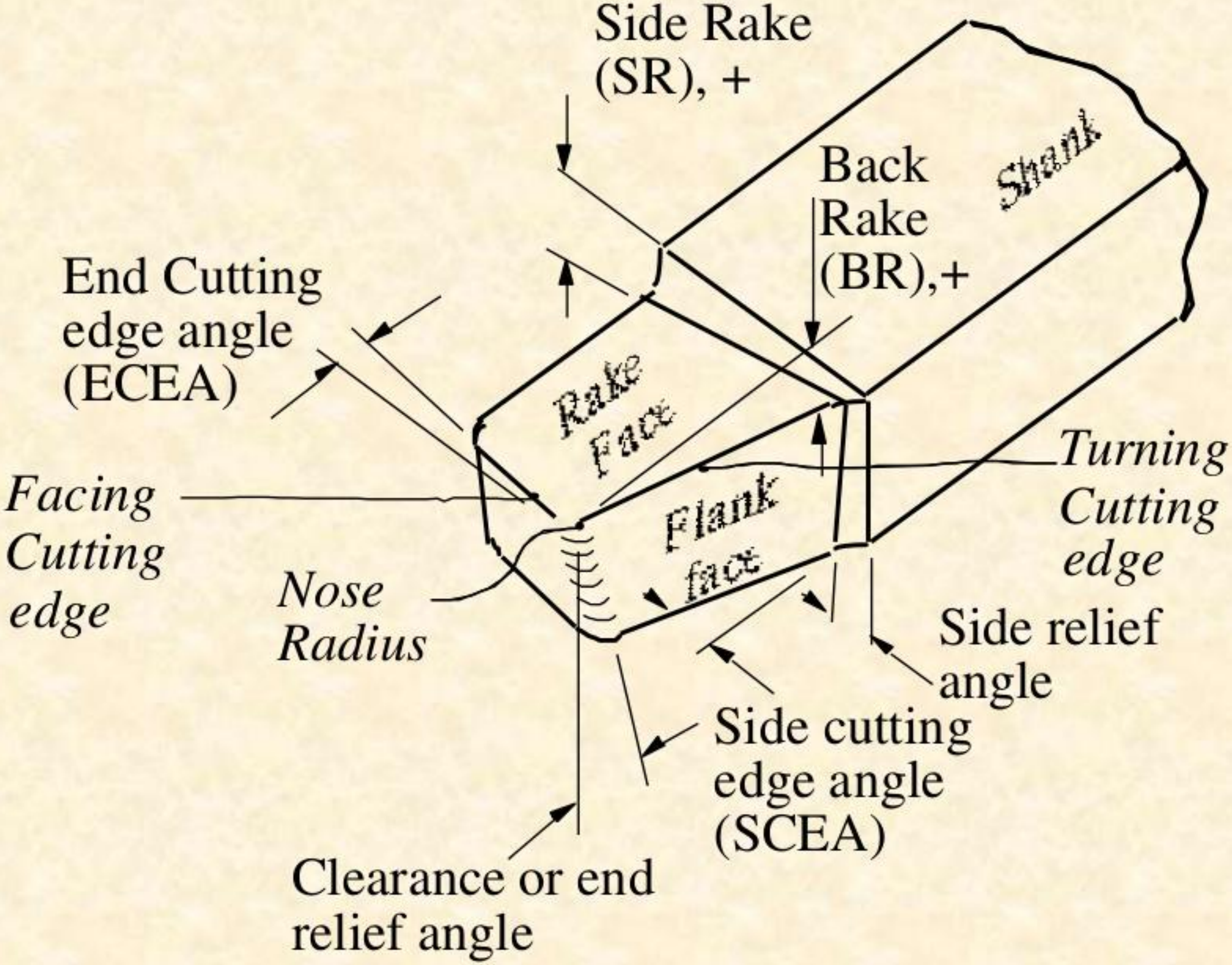
3 Faces of shank: 1. Rake face 2.Principle flank face 3. Auxiliary flank face

2 cutting edges: 1. Principle cutting edge 2.Auxiliary cutting edge

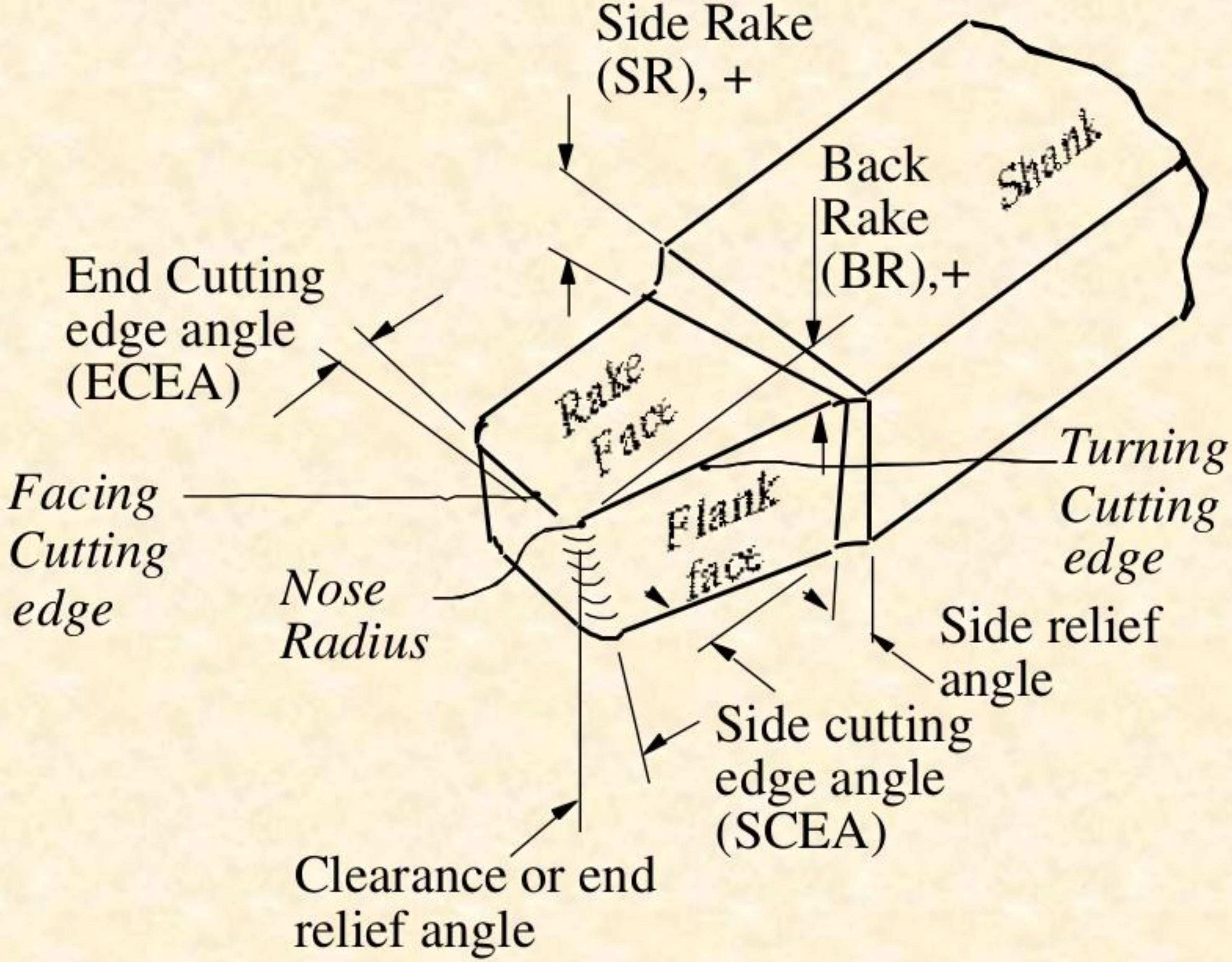
- **Shank:** *Main body of tool, it is part of tool which is gripped in tool holder*
- **Face:** *Top surface of tool b/w shank and point of tool. Chips flow along this surface*
- **Flank:** *Portion of tool which faces the work. It is surface adjacent to & below the cutting edge when tool lies in a horizontal position*
- **Point:** *Wedge shaped portion where face & flank of tool meet.*
- **Base:** *Bearing surface of tool on which it is held in a tool holder.*
- **Nose radius:** *Cutting tip, which carries a sharp cutting point. Nose provided with radius to enable greater strength, increase tool life & surface life.*

Typical Value : 0.4 mm – 1.6 mm

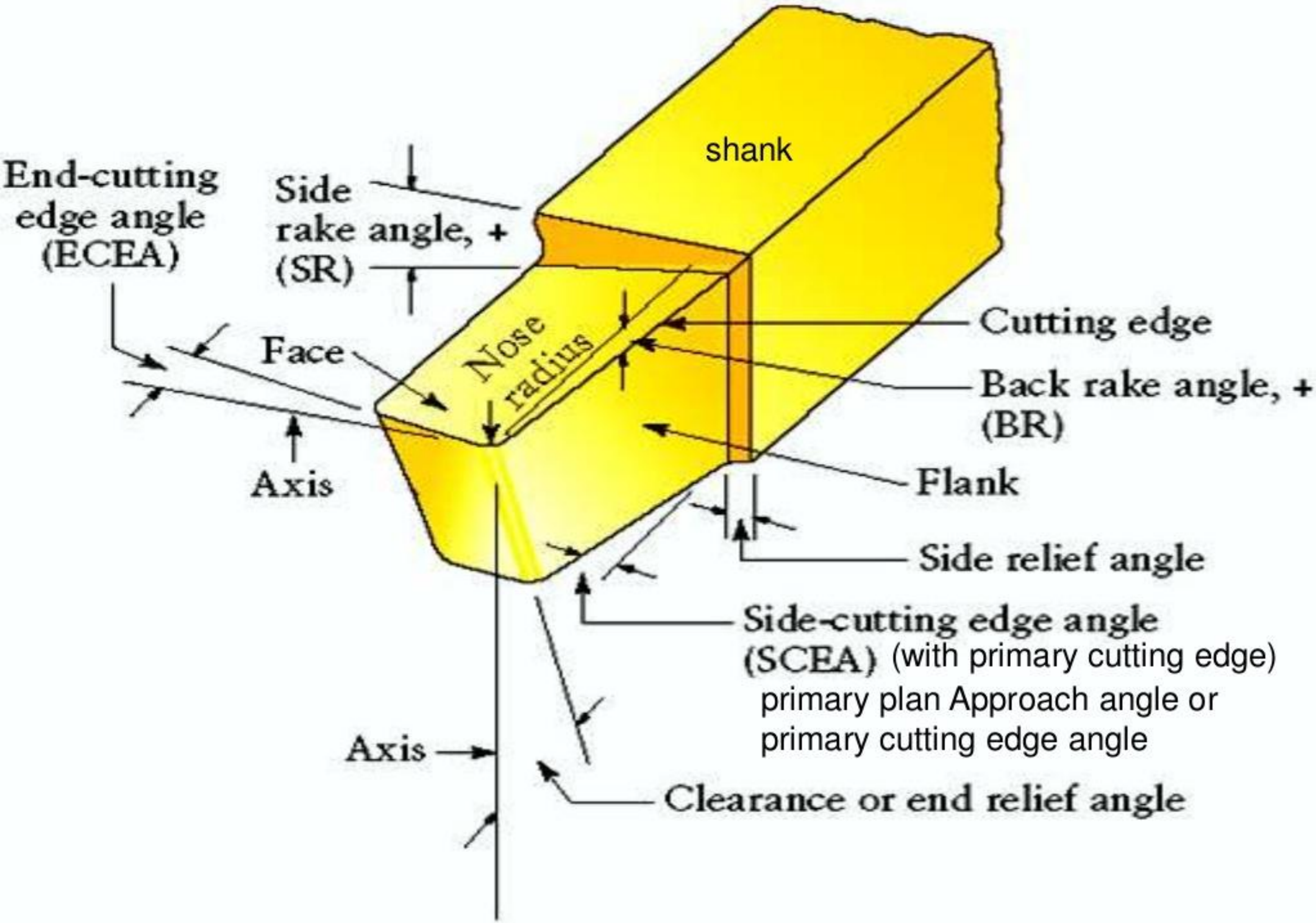
Tool Terminology



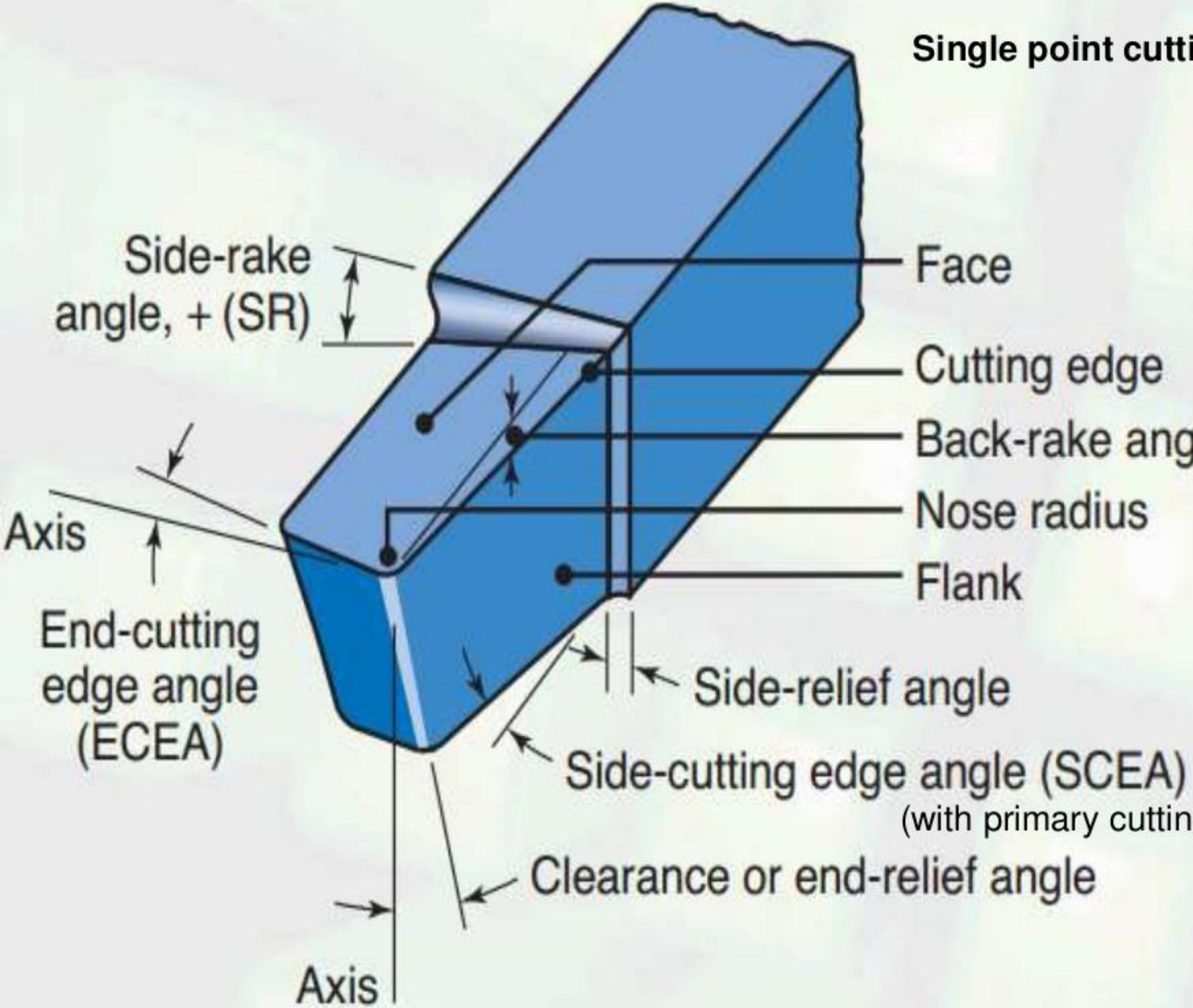
Tool Terminology



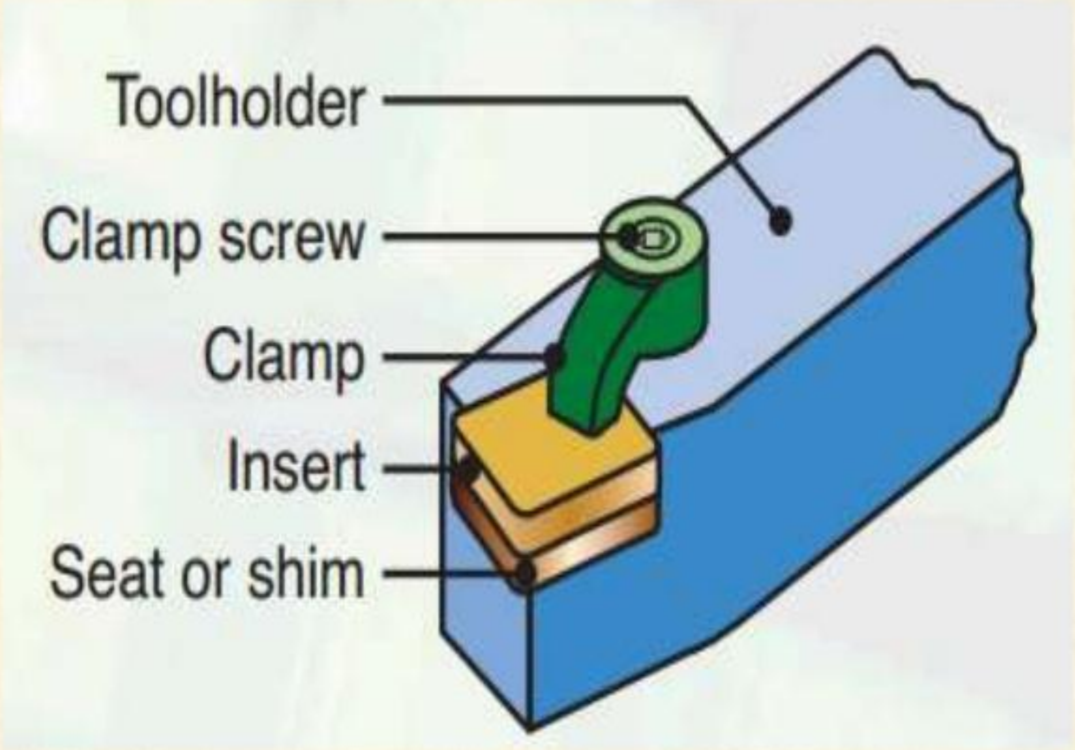
Single point cutting tool Terminology



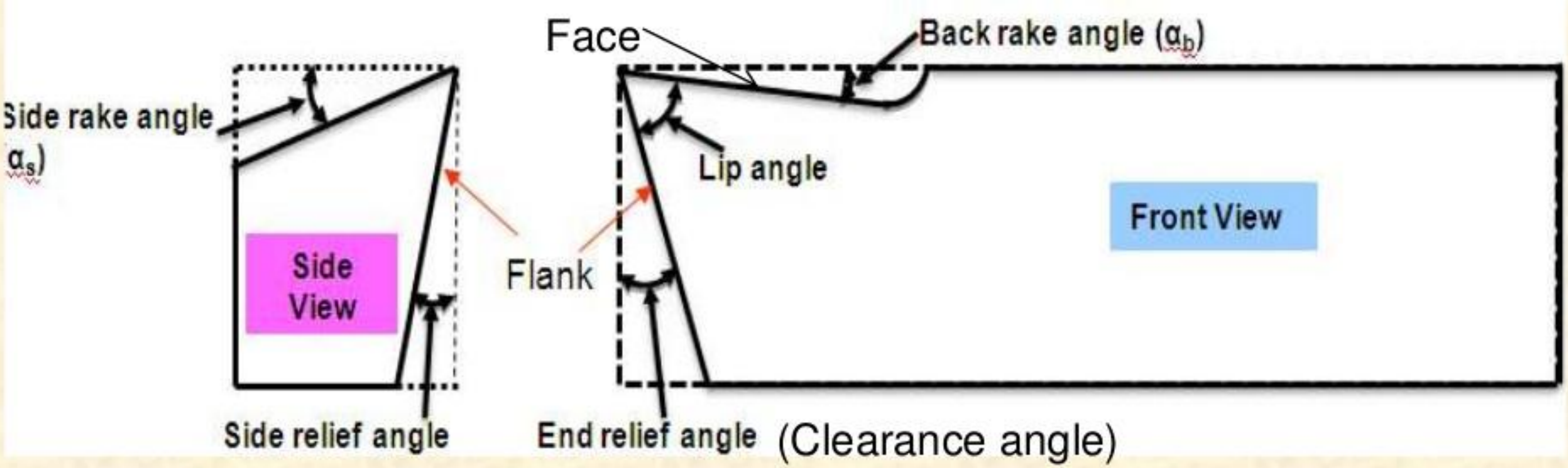
Single point cutting tool

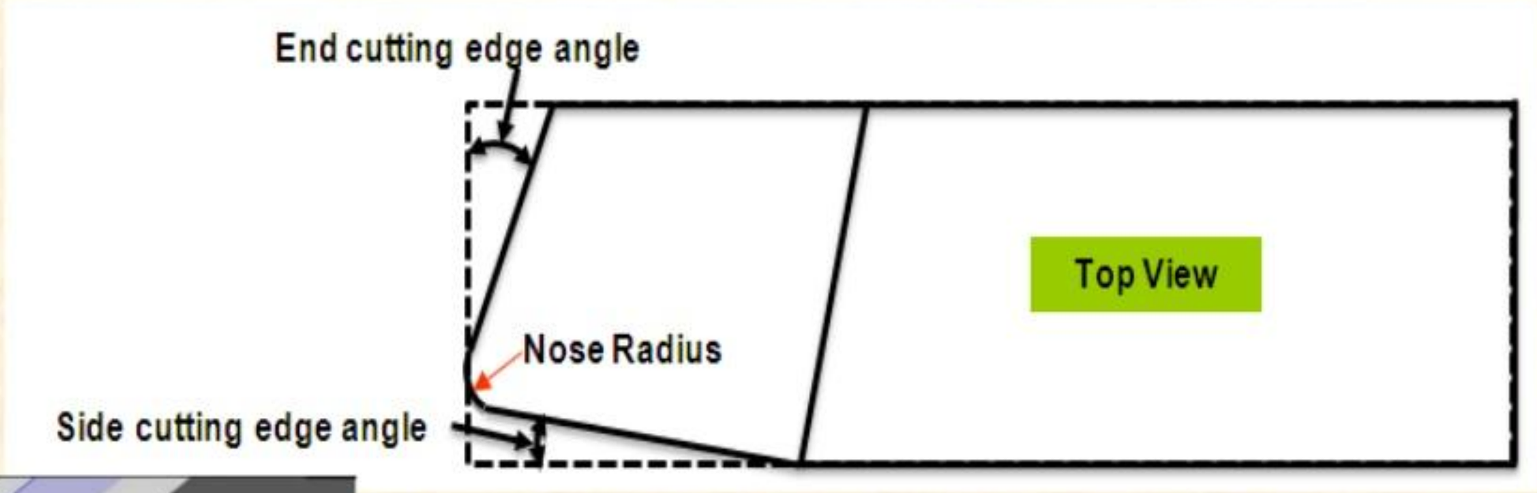


(with primary cutting edge at top)

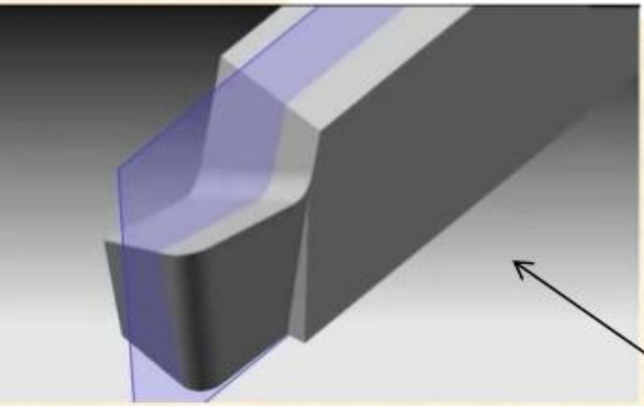


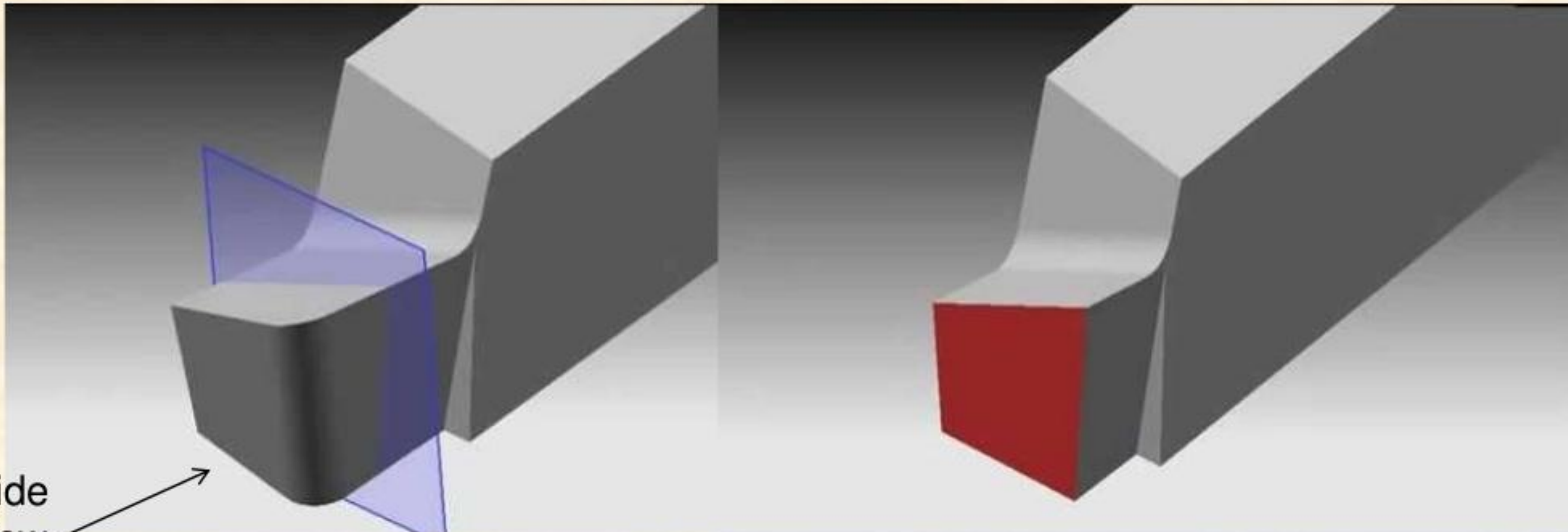
- Traditional tool replaced by inserts of carbide or other tool materials of various shapes and sizes



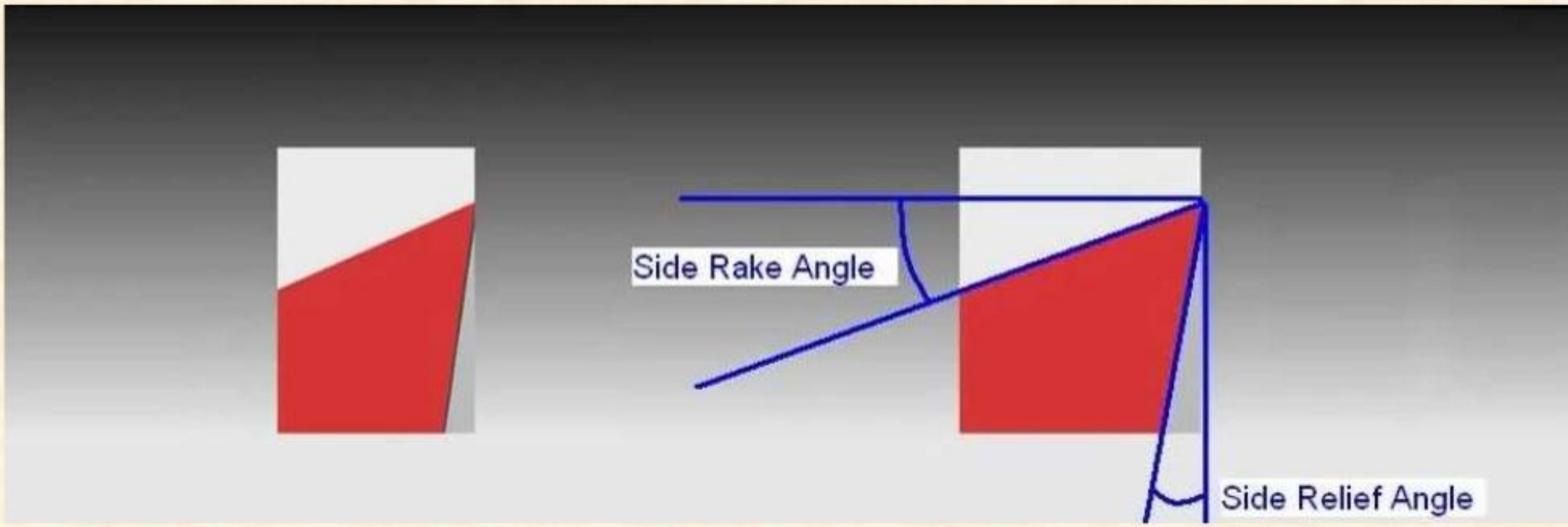


Geometry of Positive rake single point cutting tool

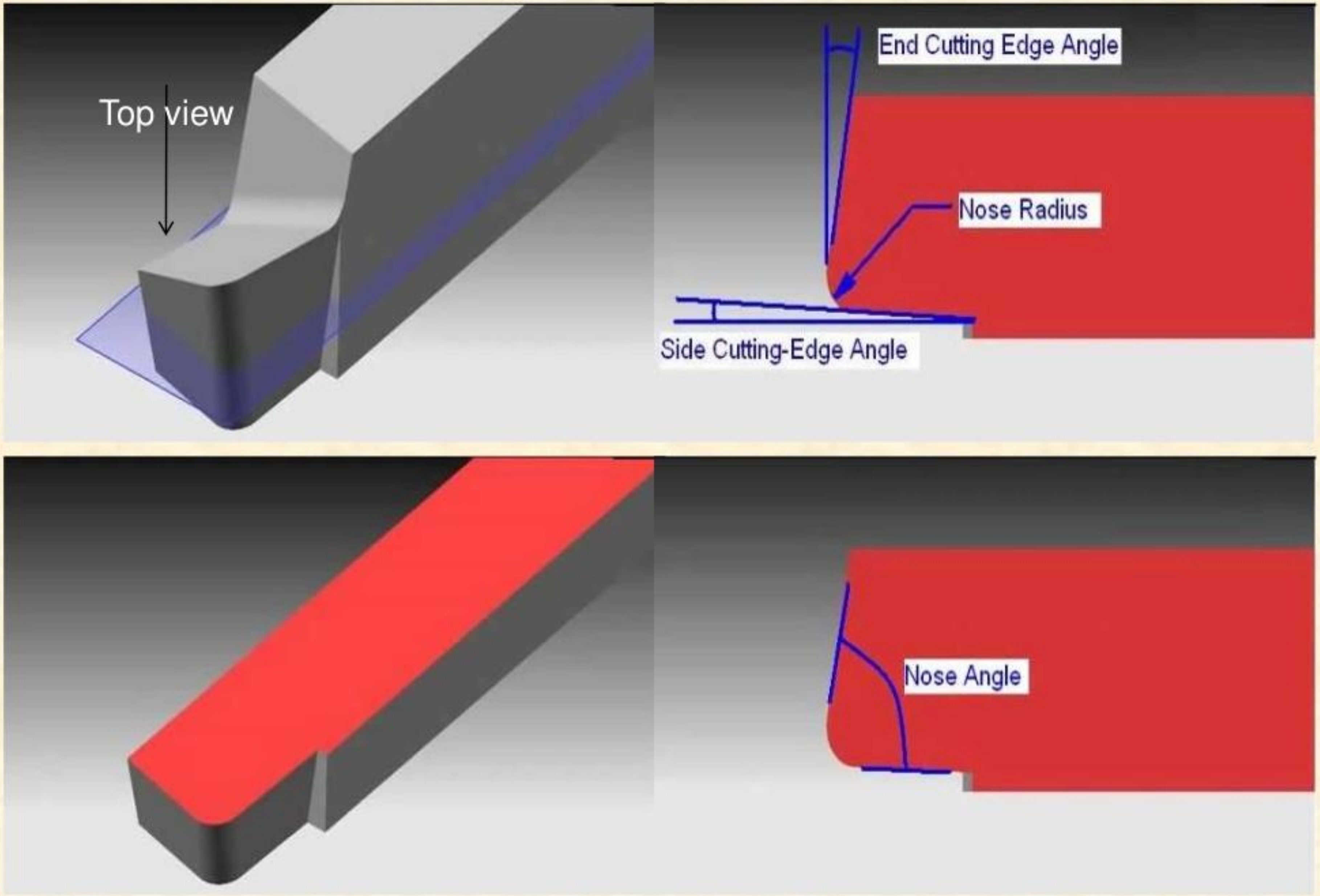




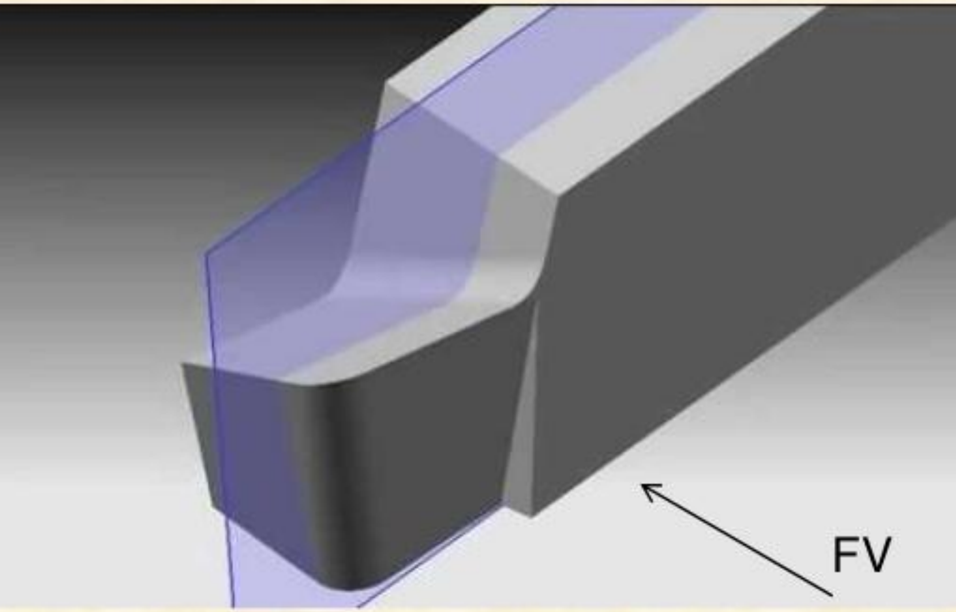
Side view

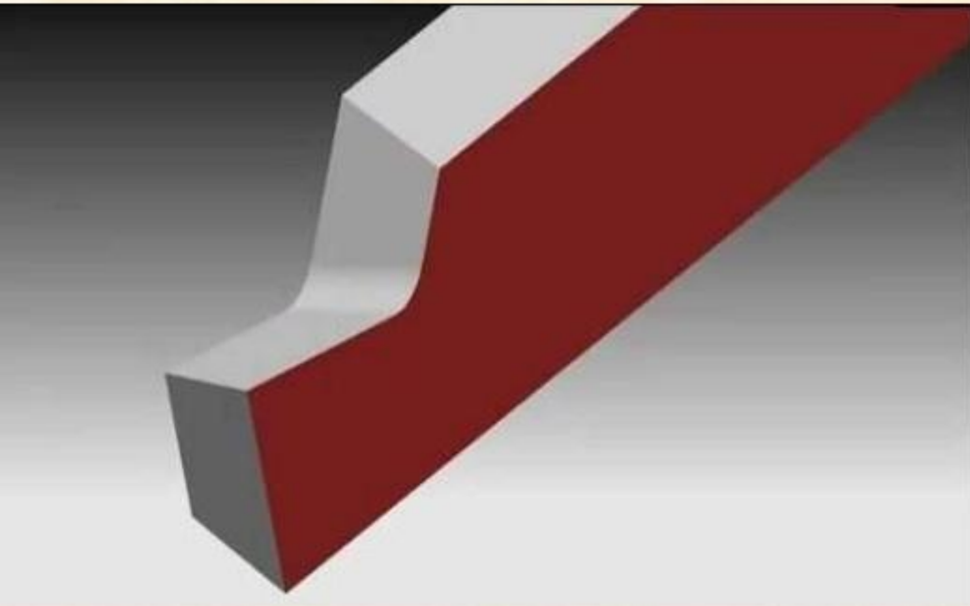


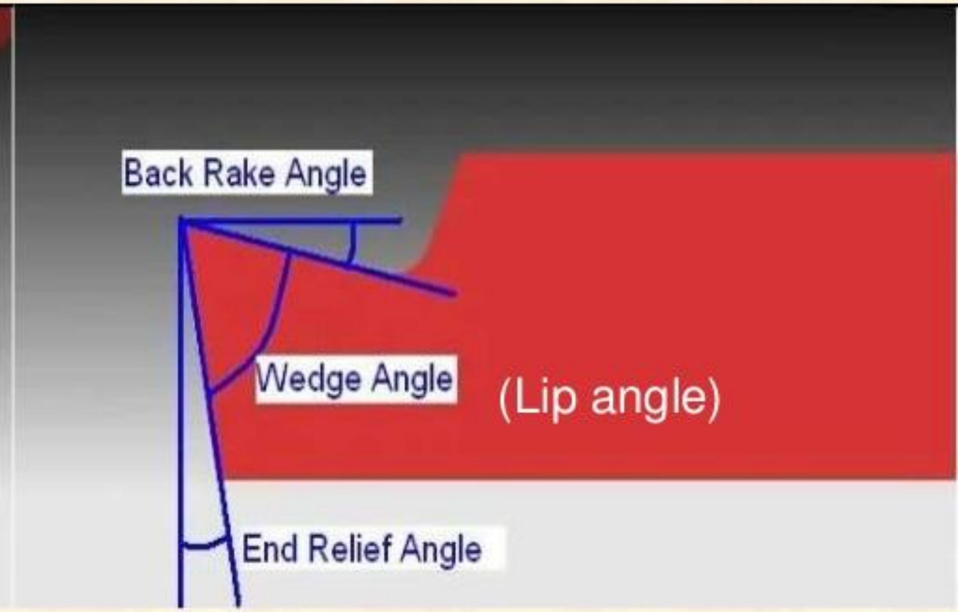
(side clearance angle)



Top view
End Cutting Edge Angle
Nose Radius
Side Cutting-Edge Angle
Nose Angle


FV

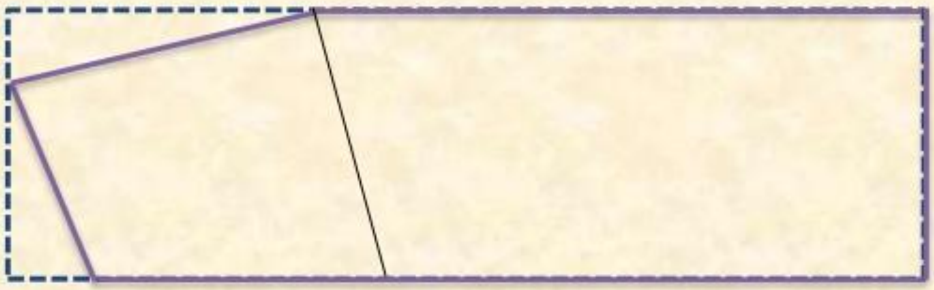



Back Rake Angle
Wedge Angle
(Lip angle)
End Relief Angle

Rake Angles

Positive Rake

Top face slopes downward away from point



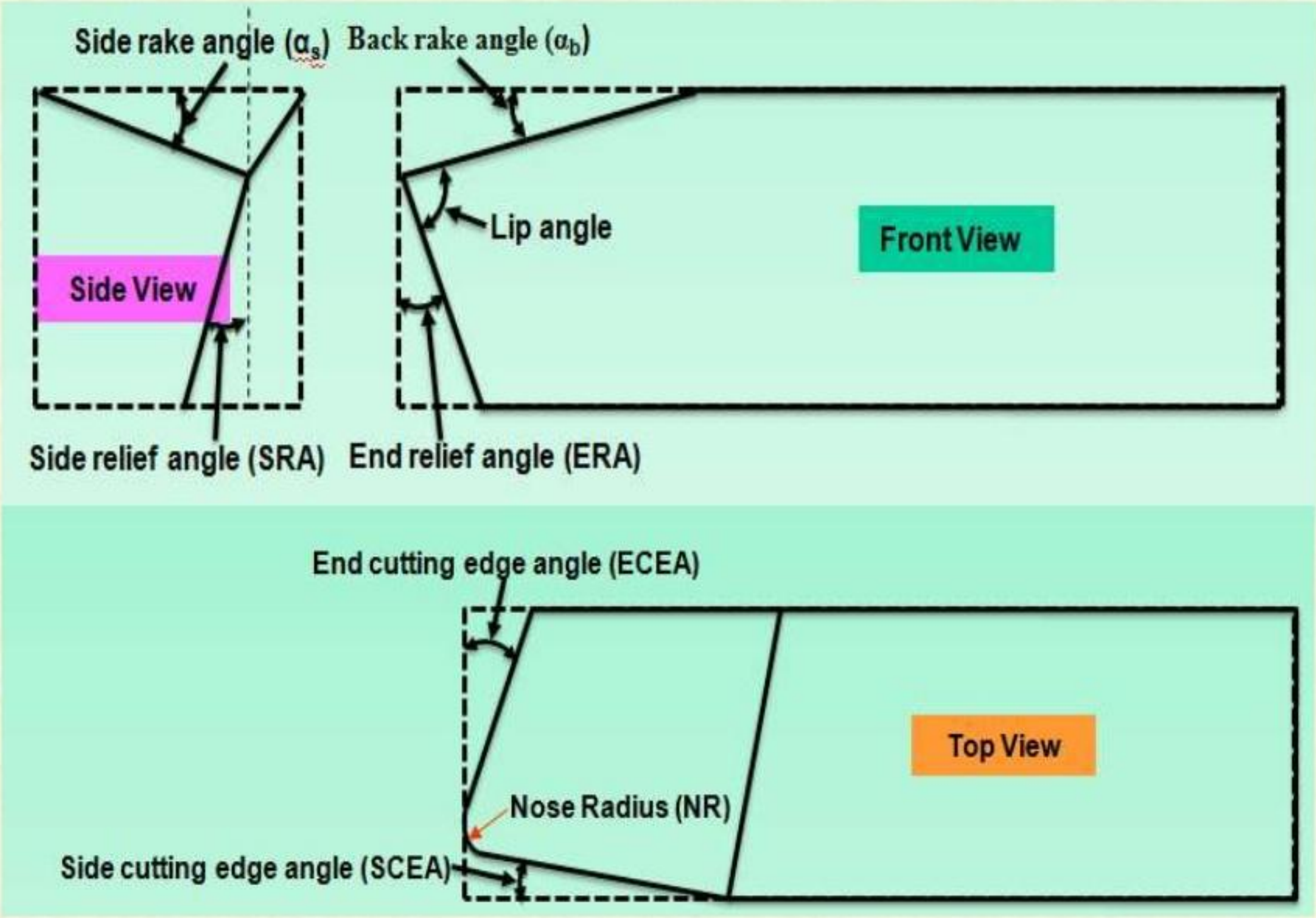
Negative Rake

Top face slopes upward away from point

For carbide tipped tools-Extra hard

Zero Rake

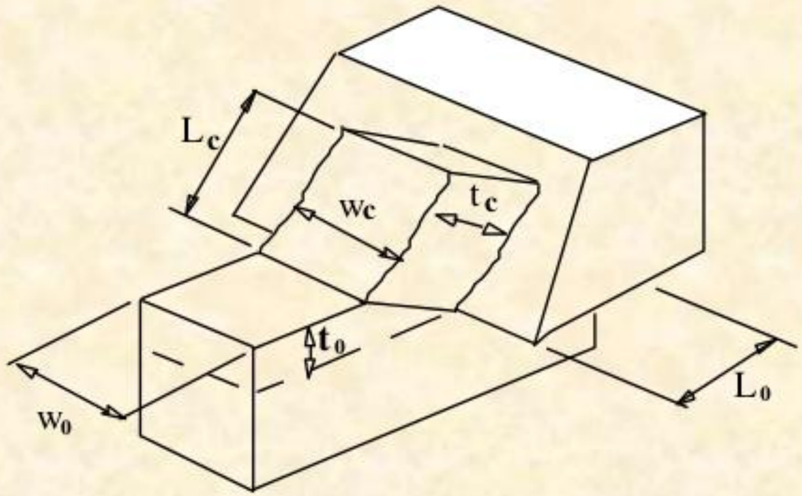
Geometry of Negative rake single point cutting tool



Cutting Ratio(Chip thickness ratio)

- Shear angle ϕ may be obtained either from photo-micrographs (or) assume volume continuity (no chip density change):

Shaping



In turning,
Length of uncut chip $L_0 = \pi D = \pi(D1+D2)/2$
Where D = Diameter of workpiece
D1=original dia., D2= final dia.

Since $t_0 w_0 L_0 = t_c w_c L_c$ and $w_0 = w_c$ (exp. evidence)

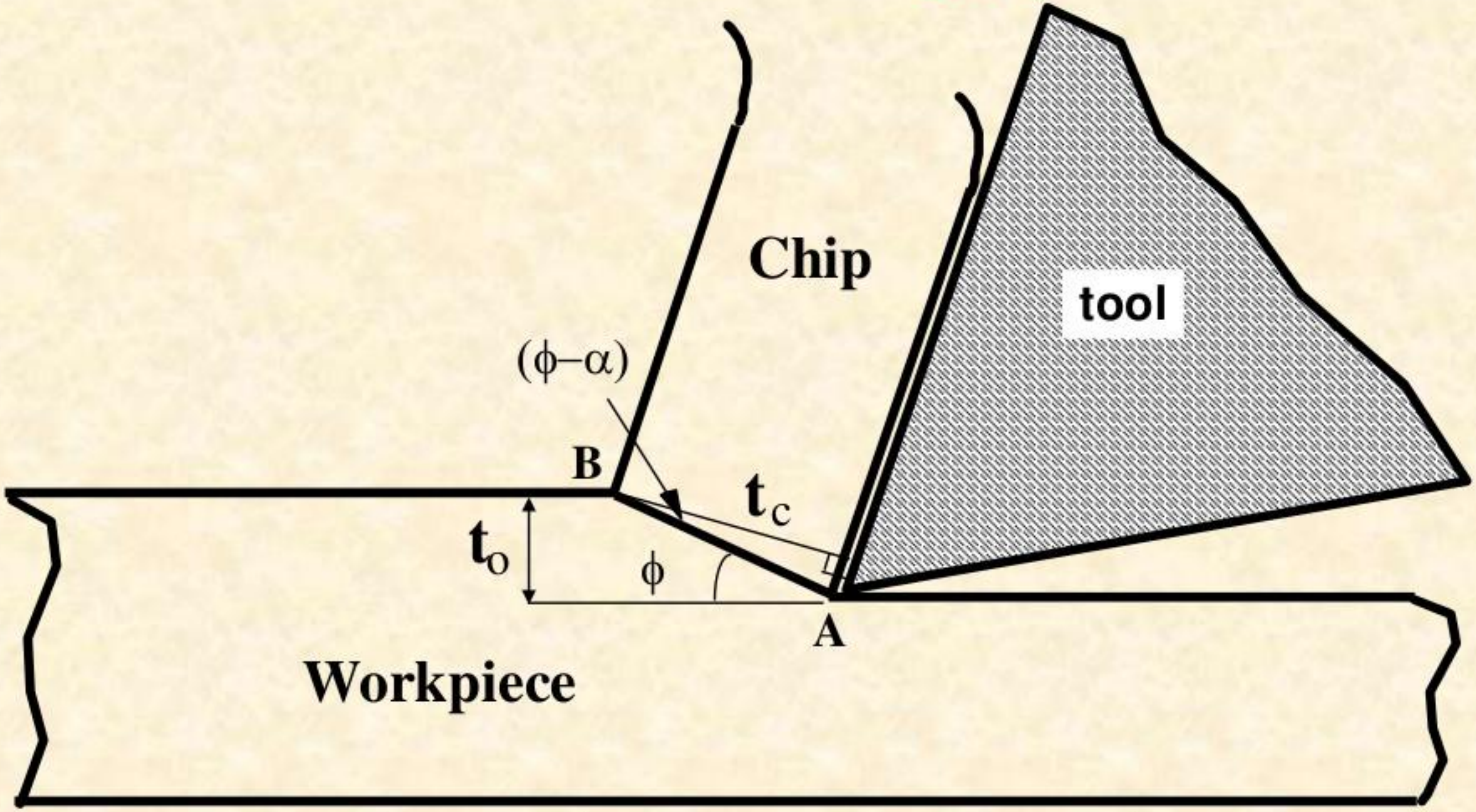
$$\textbf{Cutting ratio}, \quad r = \frac{t_0}{t_c} = \frac{L_c}{L_0}$$

Chip reduction coefficient = $1/r = t_c/t_o$

i.e. Measure length of chips (easier than thickness)

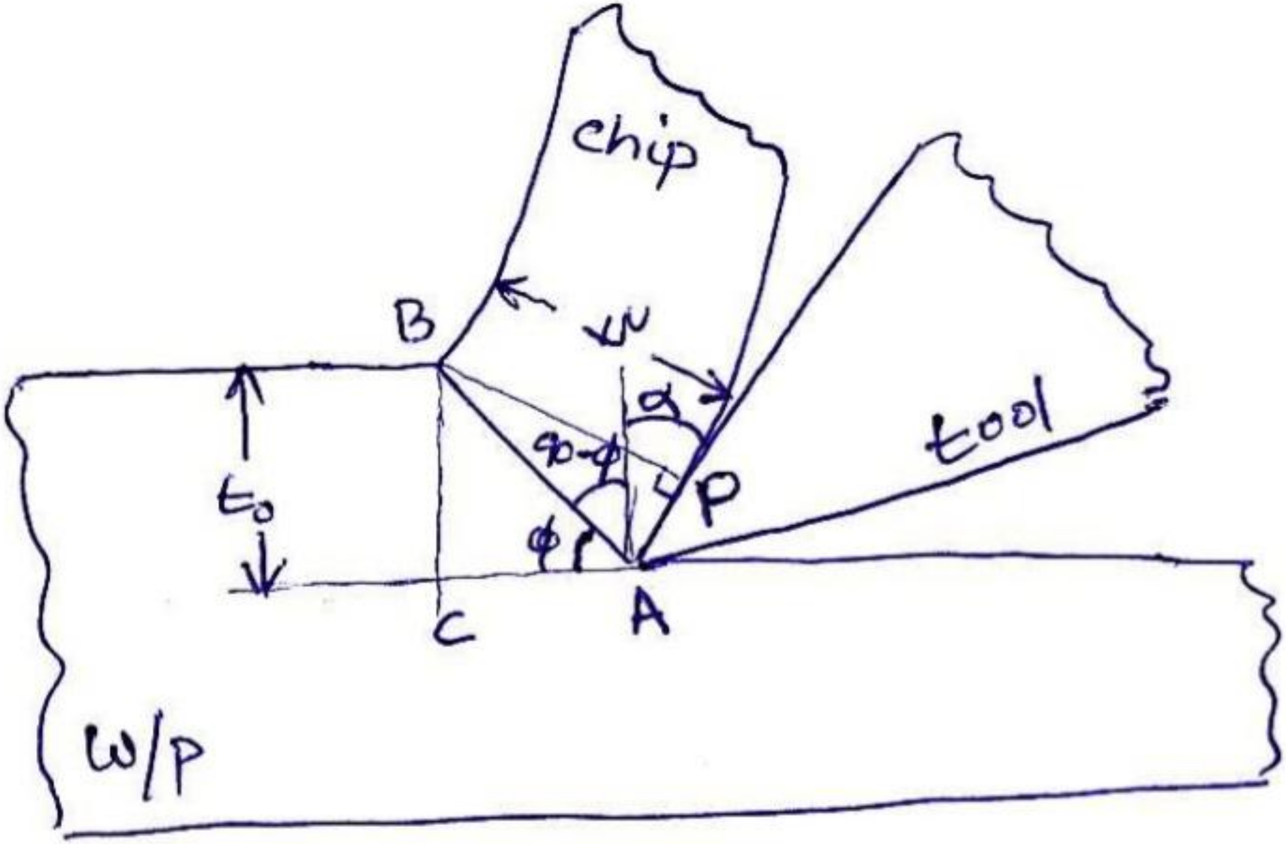
Area of chip = Depth of cut × feed/rev

Cutting Ratio (or chip thickness ratio) Contd..



$$\text{As } \sin\phi = \frac{t_o}{AB} \text{ and } \cos(\phi-\alpha) = \frac{t_c}{AB}$$

$$\text{Chip thickness ratio } (r) = \frac{t_0}{t_c} = \frac{\sin\phi}{\cos(\phi-\alpha)}$$



$\angle BAP = (90-\phi) + \alpha$

$\angle ABP = 90 - [(90-\phi) + \alpha] = \phi - \alpha$

Shear Angle ϕ or θ

How (ϕ - α)?

At A, let the angle between AB and vertical is x= 90 - ϕ
From triangle APB, angle A = 90 - ϕ + α
So at B, 90-(90 - ϕ + α)= ϕ - α

Chip thickness ration r = $\frac{t_1}{t_2}$

$$t_1 = h\sin\theta, \qquad t_2 = h\cos(\theta-\alpha)$$

$$r = \frac{t_1}{t_2} = \frac{h\sin\theta}{h\cos(\theta-\alpha)} = \frac{\sin\theta}{\cos\theta\cos\alpha+\sin\theta\sin\alpha}$$

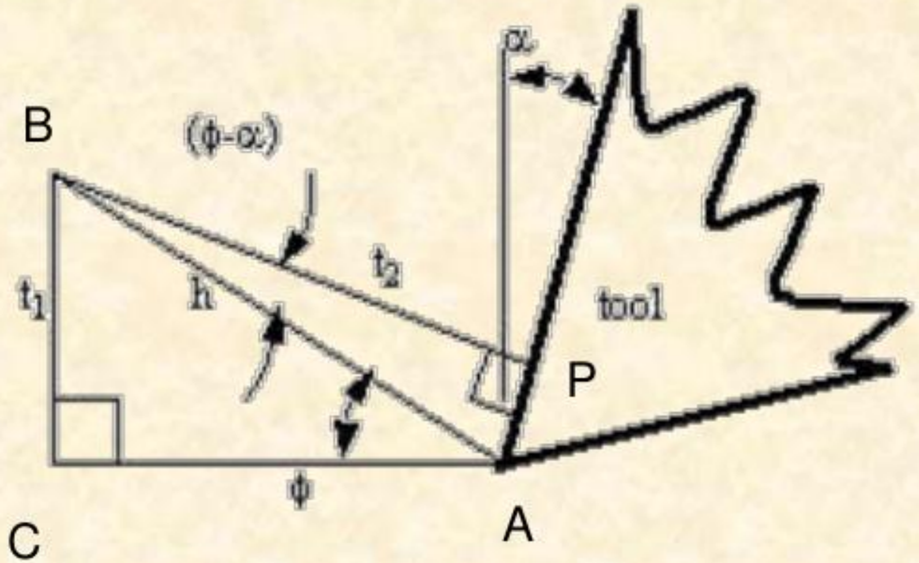
$$\left[r = \frac{\sin\phi}{\cos(\phi-\alpha)} \right]$$

$$r\cos\theta\cos\alpha + r\sin\theta\sin\alpha = \sin\theta$$

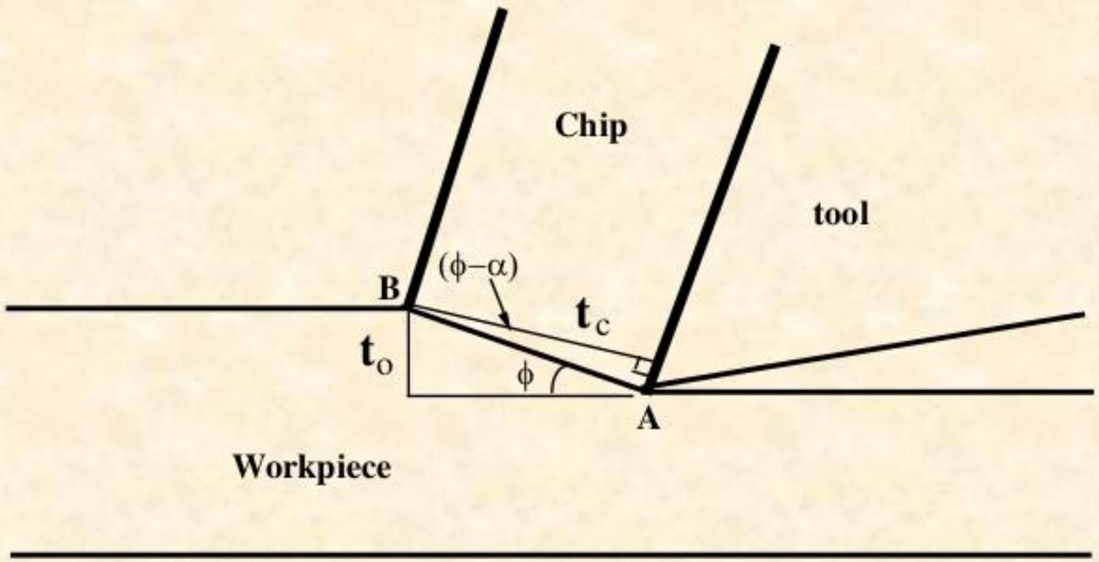
$$\frac{r\cos\theta\cos\alpha}{\sin\theta} + \frac{r\sin\theta\sin\alpha}{\sin\theta} = 1$$

$$\frac{r\cos\alpha}{\tan\theta} + r\sin\alpha = 1$$

$$\tan\theta = \frac{r\cos\alpha}{1 - r\sin\alpha}$$



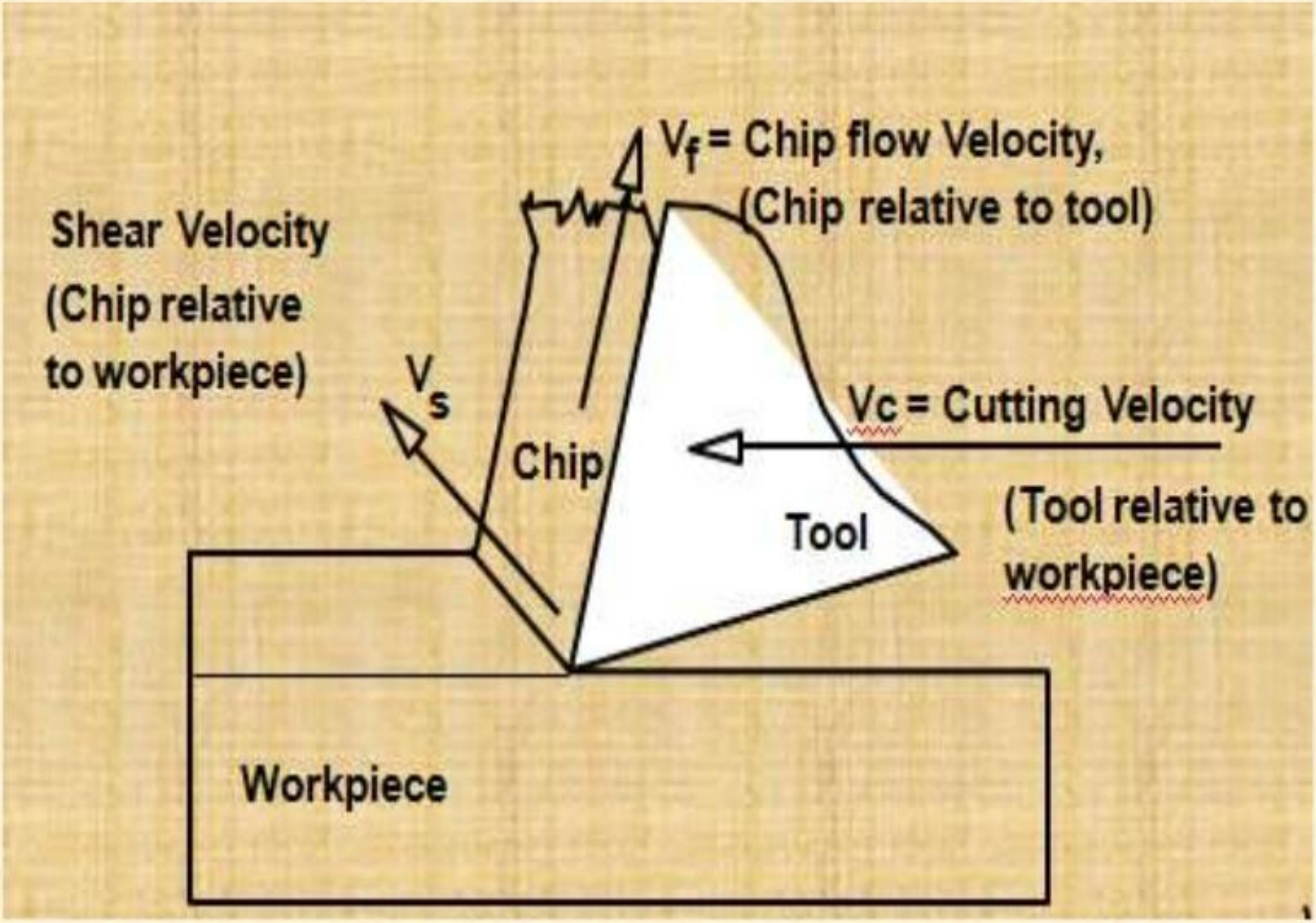
Shear Plane Length and Angle ϕ



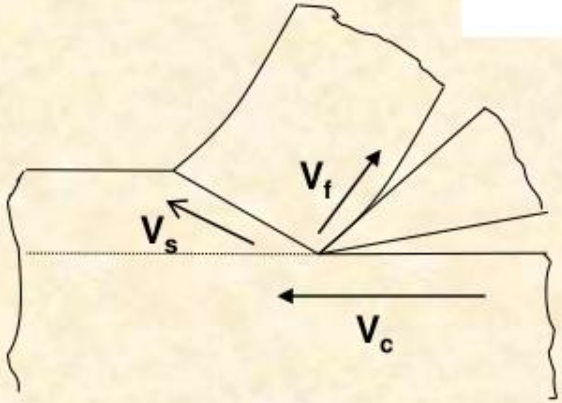
$$\textbf{Shear plane length AB} = \frac{t_0}{\sin\phi}$$

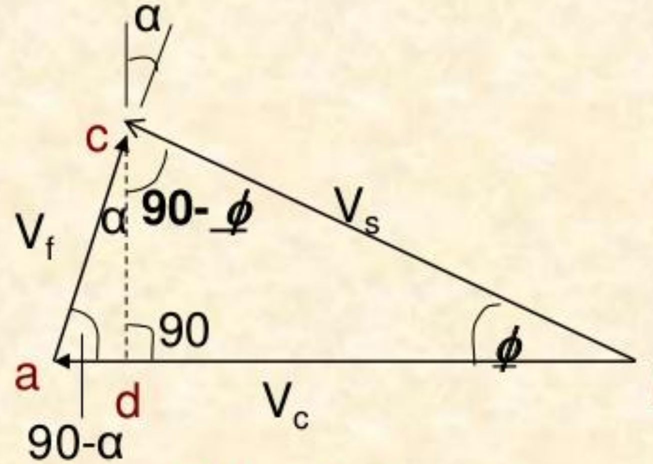
$$\textbf{Shear plane angle } (\phi) = \mathrm{Tan}^{-1}\left[\frac{r\cos\alpha}{1 - r\sin\alpha}\right]$$

Velocity Relationships



Velocity Relationships Contd..





Velocity diagram

Analytically,

$$\frac{v_c}{\sin(90-(\phi-\alpha))}=\frac{v_f}{\sin\phi}=\frac{v_s}{\sin(90-\alpha)}$$

$$\frac{v_c}{\cos(\phi-\alpha)}=\frac{v_f}{\sin\phi}=\frac{v_s}{\cos\alpha}$$

$$\boxed{v_f=\frac{v_c\sin\phi}{\cos(\phi-\alpha)}} \qquad \left[r=\frac{\sin\phi}{\cos(\phi-\alpha)}\right]$$

$$v_f=v_c\times r$$

$$\boxed{v_s=\frac{v_c\cos\alpha}{\cos(\phi-\alpha)}}$$

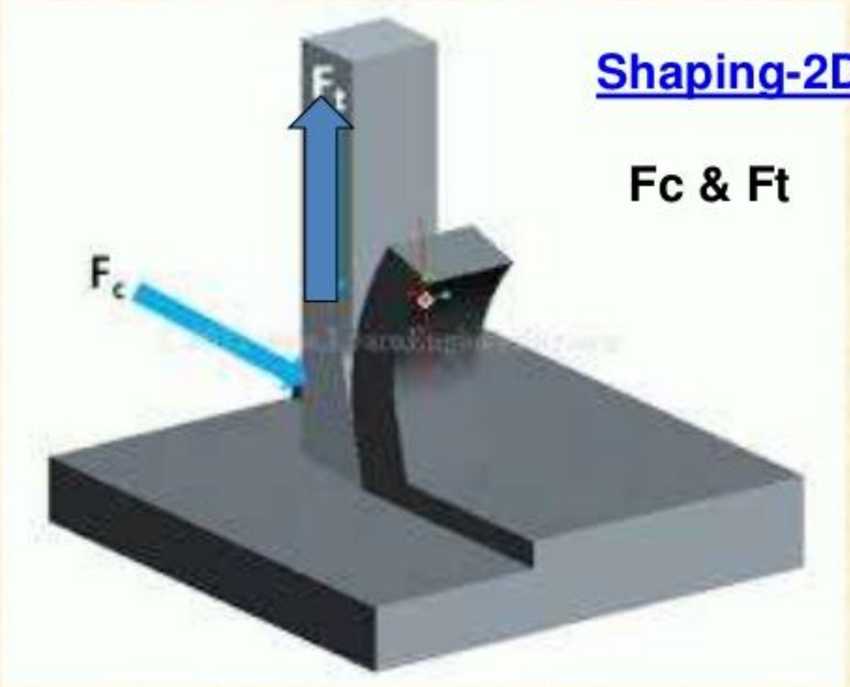
V_s= Velocity of shear along shear plane

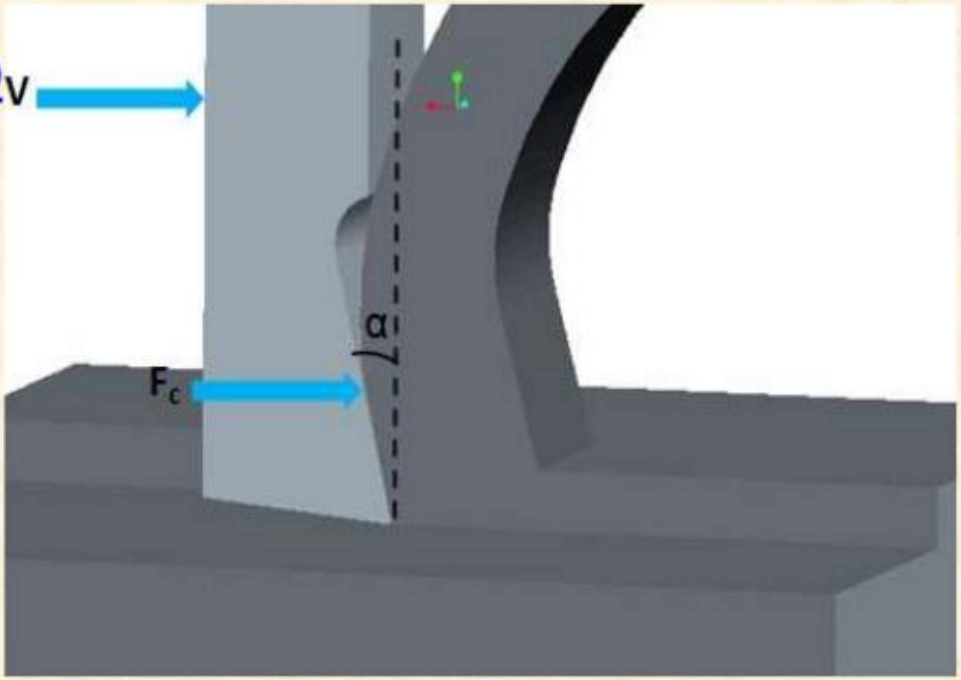
V_f= Chip flow velocity along the tool face
(frictional velocity)
parallel to face of the tool

V_c=Cutting velocity

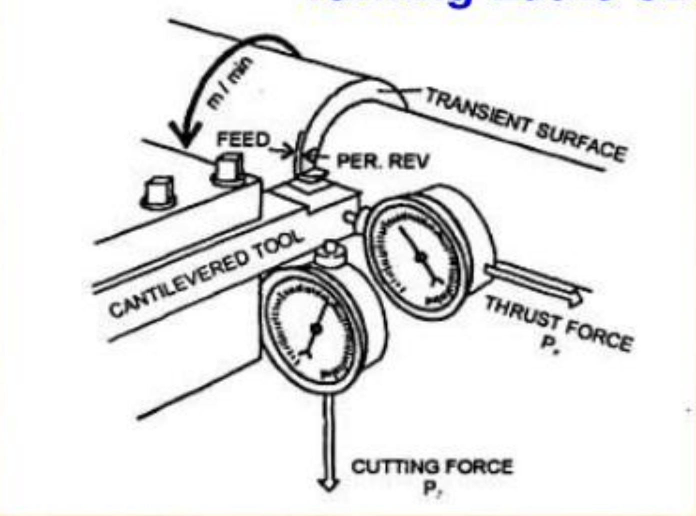
Cutting Forces

Shaping-2D





Turning-Lathe-3D



F_c= In the direction of cutting velocity

F_c = Tangential to the rotation of shaft(cutting speed)

F_t = Thrust force or feed force
=opposite to the direction of feed

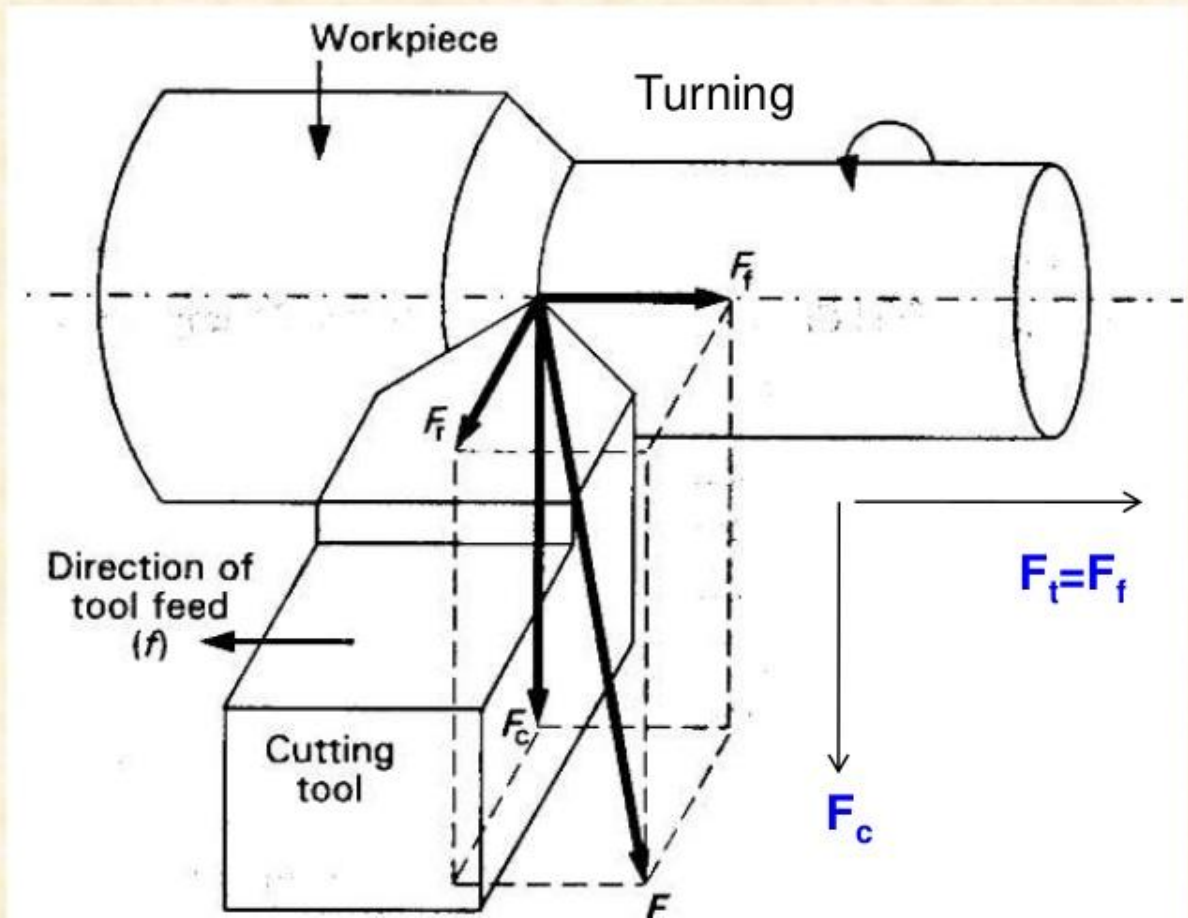
F_r = Radial force
= will tend to push the tool away from the work, which may cause chatter

F_c=Cutting force, acting in vertical plane and is tangential to the work surface, Also called tangential force or tangential feed force (67%)

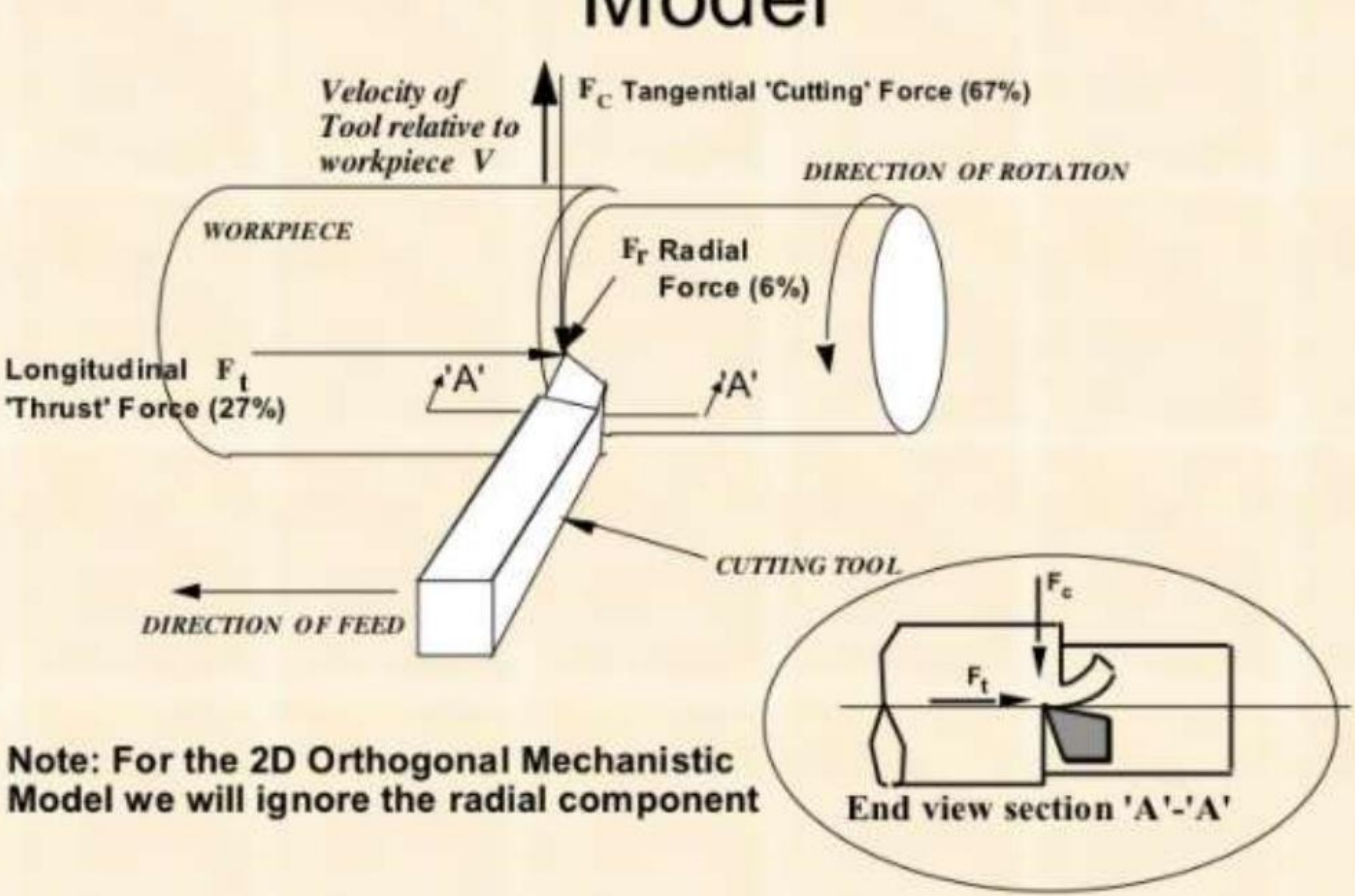
F_t=F_f = Feed force or thrust force or axial feed force, acting in horizontal plane parallel to the work axis (opposite to the direction of feed) (27%)

F_r= Radial force or radial feed force, also acting in the horizontal plane but along the radius of the work piece i.e along the axis of the tool, which will push away from the work(6%)

F = Resultant cutting force
F_f = Axial feed force
F_r = Radial feed force
F_c = Tangential feed force



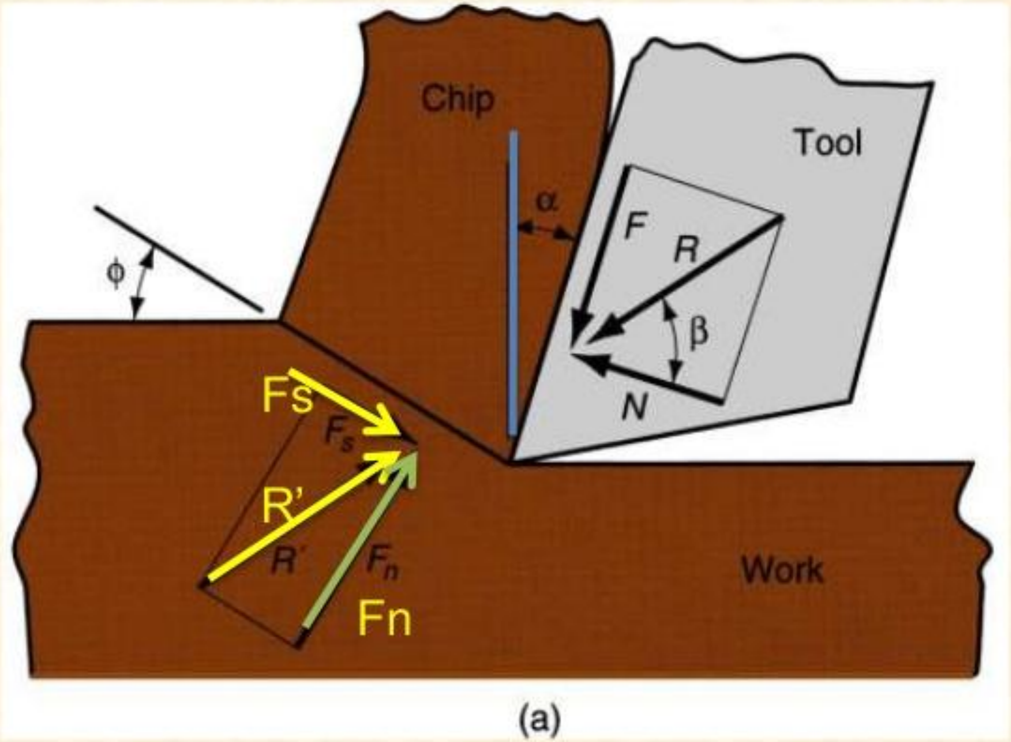
‘Turning’ Forces For Orthogonal Model



Note: For the 2D Orthogonal Mechanistic Model we will ignore the radial component

Mechanics of chip formation: Forces acting on chip(2D- orthogonal)

- Friction force *F* and Normal force to friction *N*
- Shear force *Fs* and Normal force to shear *Fn*



Equilibrium of Chip

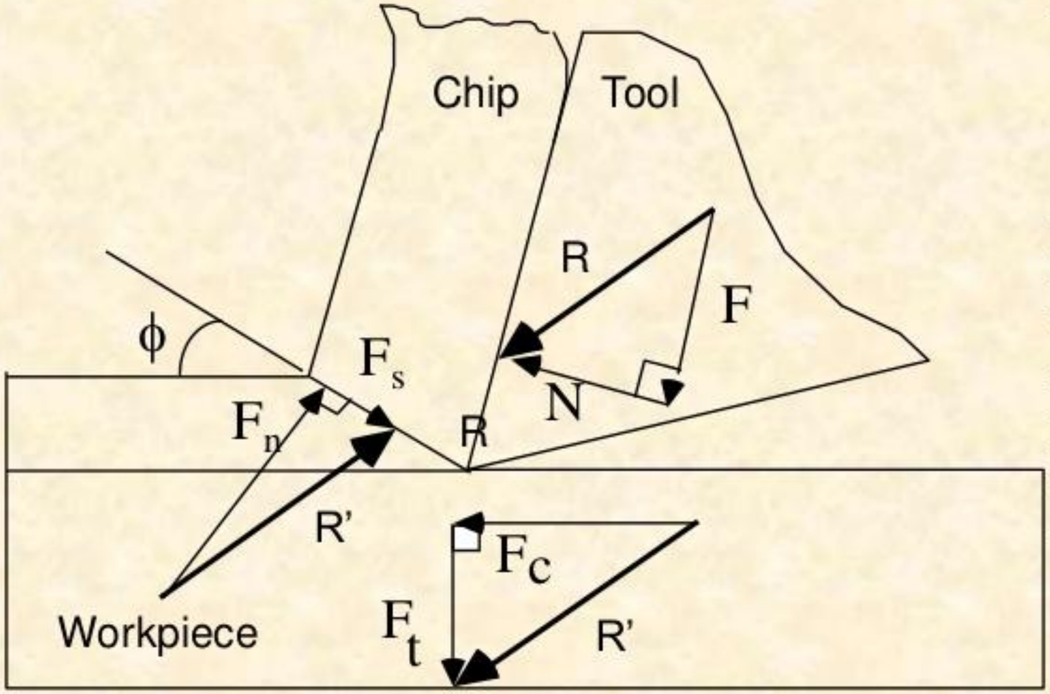
➢It is assumed that the resultant forces R & R' are equal and opposite in magnitude and direction and are collinear.

➢For the purpose of analysis, the chip is regarded as an independent body held in mechanical equilibrium by the action of two equal and opposite forces

➢R - the tool exerts upon the chip.

➢R' - the work piece exerts upon the chip

Cutting Forces
(2D Orthogonal Cutting)-Shaping



Free Body Diagram

we know:
Tool geometry & type of Workpiece material

and we wish to know:

F_c = Cutting Force
F_t = Thrust Force
F = Friction Force
N = Normal Force
F_s = Shear Force
F_n = Force Normal to Shear

Angle between R and N is **β**

Resultant Forces

- Vector addition of *F* and *N* = resultant *R*
- Vector addition of *Fs* and *Fn* = resultant *R'*
- Forces acting on the chip must be in balance:
  - *R'* must be equal in magnitude to *R*
  - *R'* must be opposite in direction to *R*
  - *R'* must be collinear with *R*

$$R' = -R$$

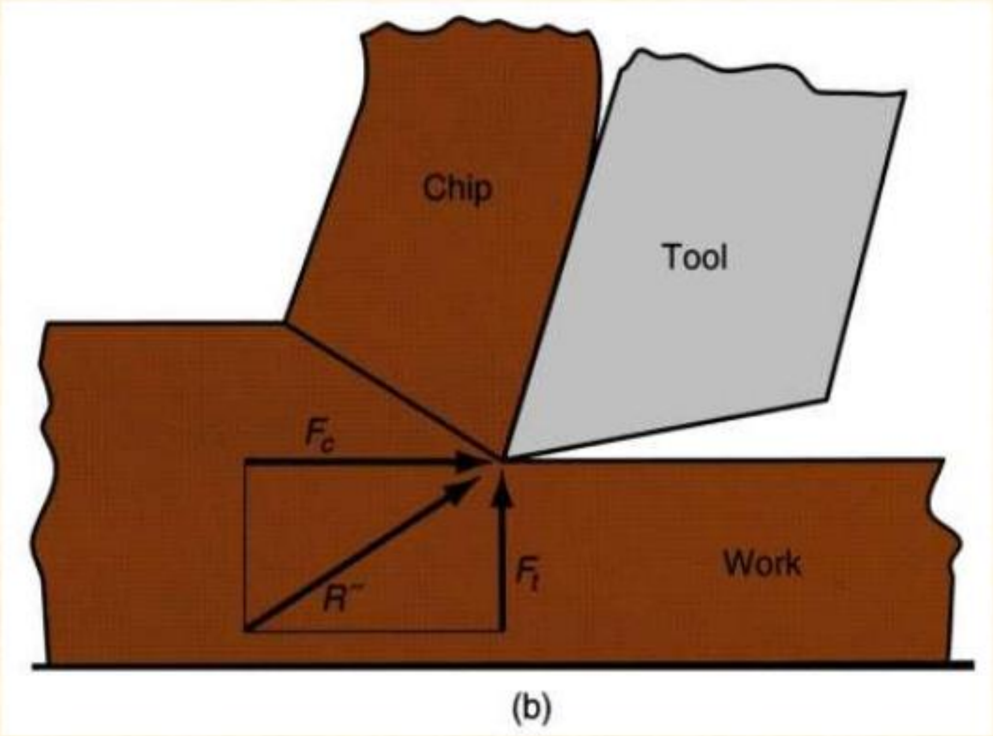
Coefficient of Friction

- Coefficient of friction between tool and chip: $\mu = \frac{F}{N}$
- Friction angle related to coefficient of friction as follows:

$$\mu = \tan \beta$$

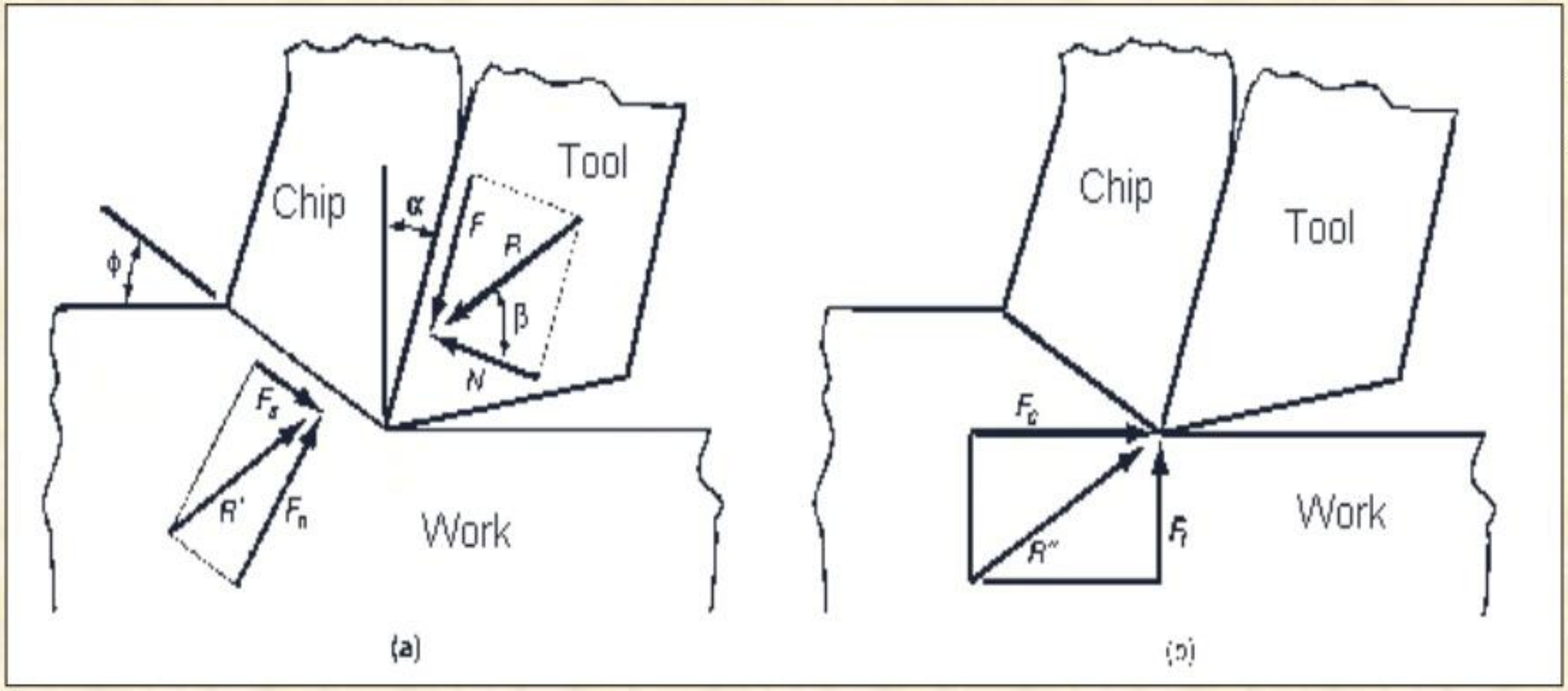
Cutting Force and Thrust Force

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



Forces acting on the tool that can be measured

The forces acting on the chip in orthogonal cutting



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

$$\vec{R} = \vec{F_S} + \vec{F_N}$$

F_s = Shear Force, which acts along the shear plane, is the resistance to shear of the metal in forming the chip.

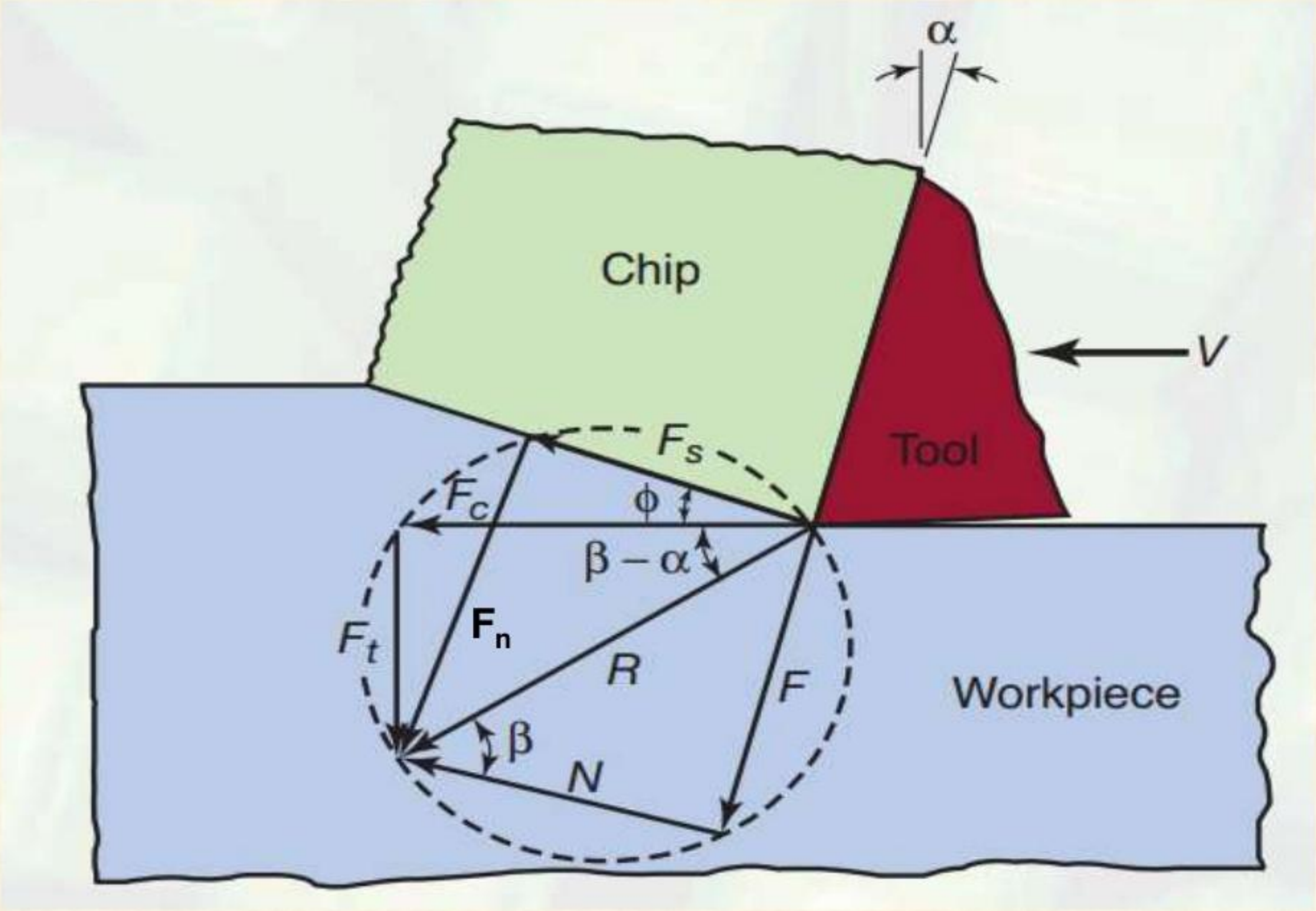
F_n = Force acting normal to the shear plane, is the backing up force on the chip provided by the workpiece.

F = Frictional resistance of the tool acting against the motion of the chip as it moves upward along the tool.

N = Normal to the chip force, is provided by the tool.

Merchant's Circle Diagram

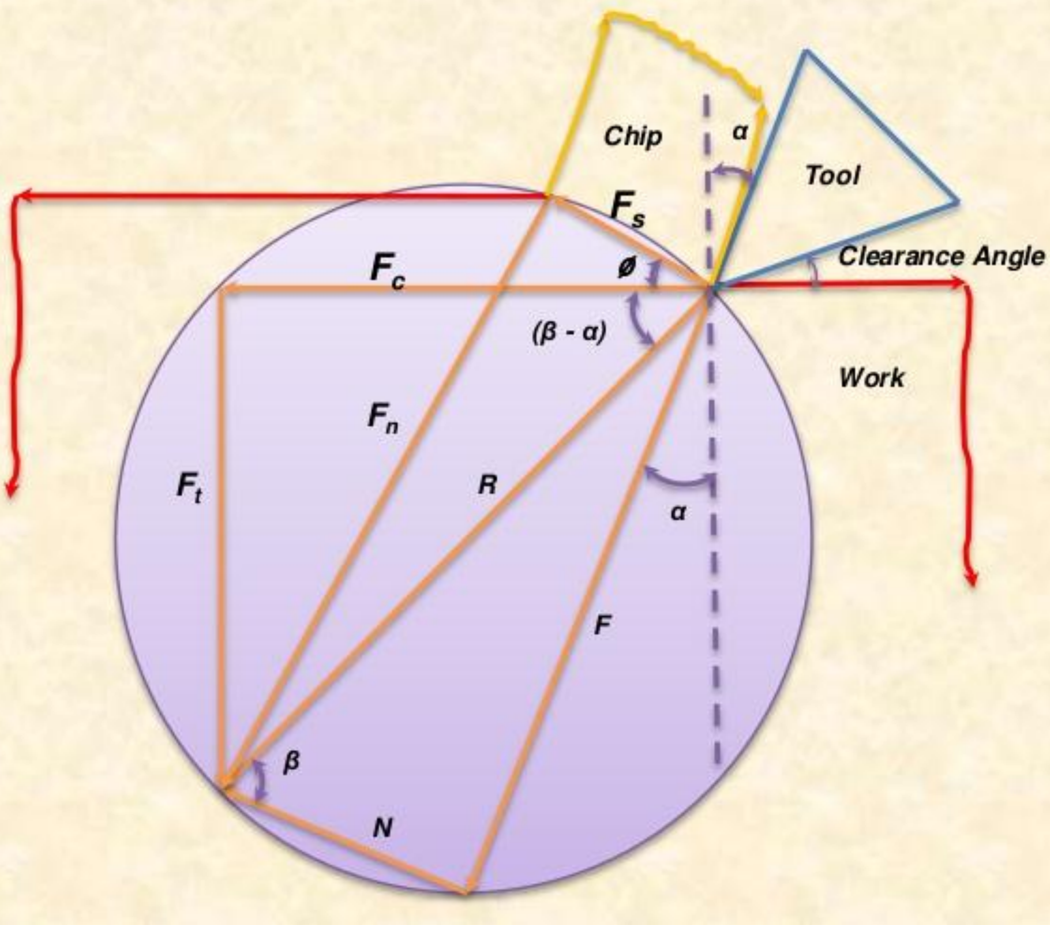
- Merchant's circle diagram is convenient to determine the relation between the various forces and angles.
- In the diagram two force triangles have been combined and R and R' together have been replaced by R.
- The force R can be resolved into two components F_c and F_t.
- F_c and F_t can be determined by force dynamometers.



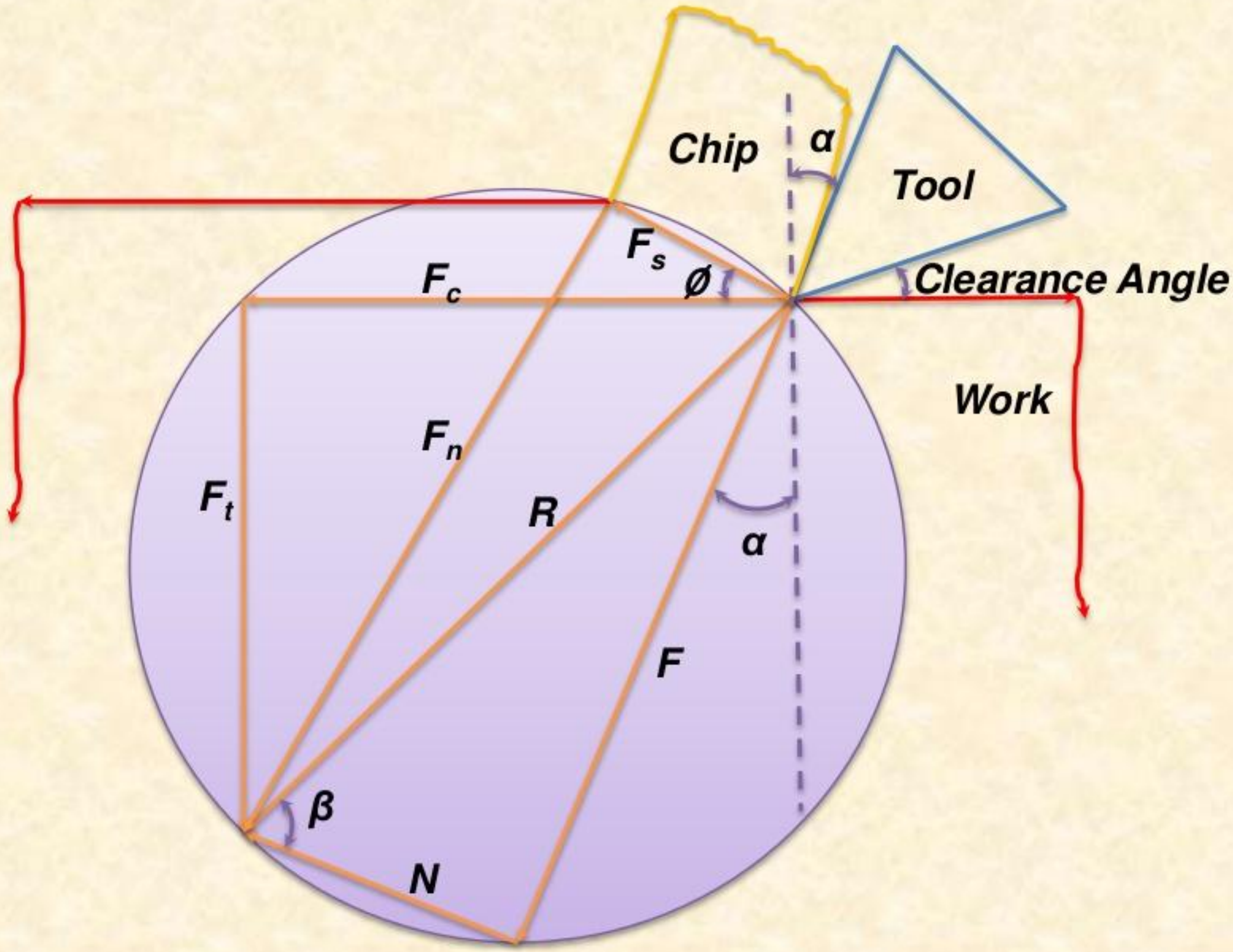
Force circle to determine various forces acting in the cutting zone.

➢The rake angle (α) can be measured from the tool, and forces F and N can then be determined.

➢The shear angle (ϕ) can be obtained from it's relation with chip reduction coefficient. Now Fs & Fn can also be determined.

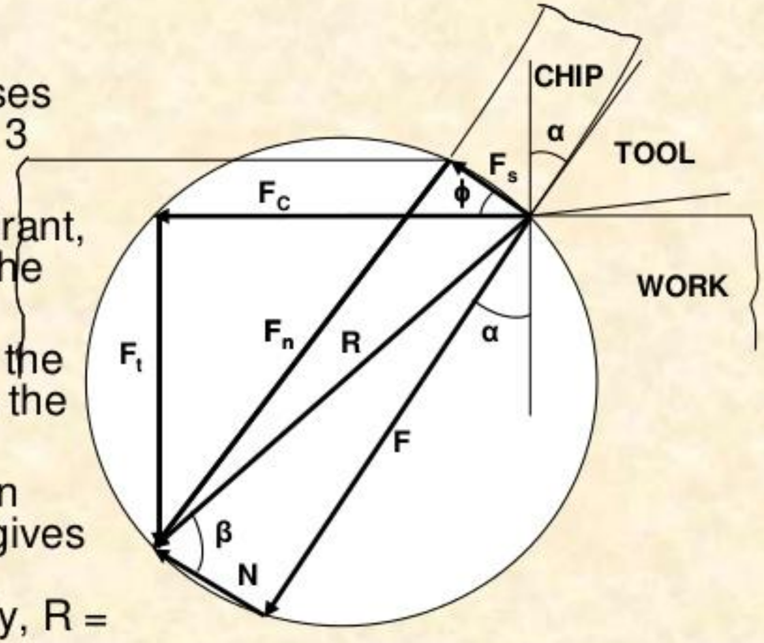


Procedure to construct a merchants circle diagram



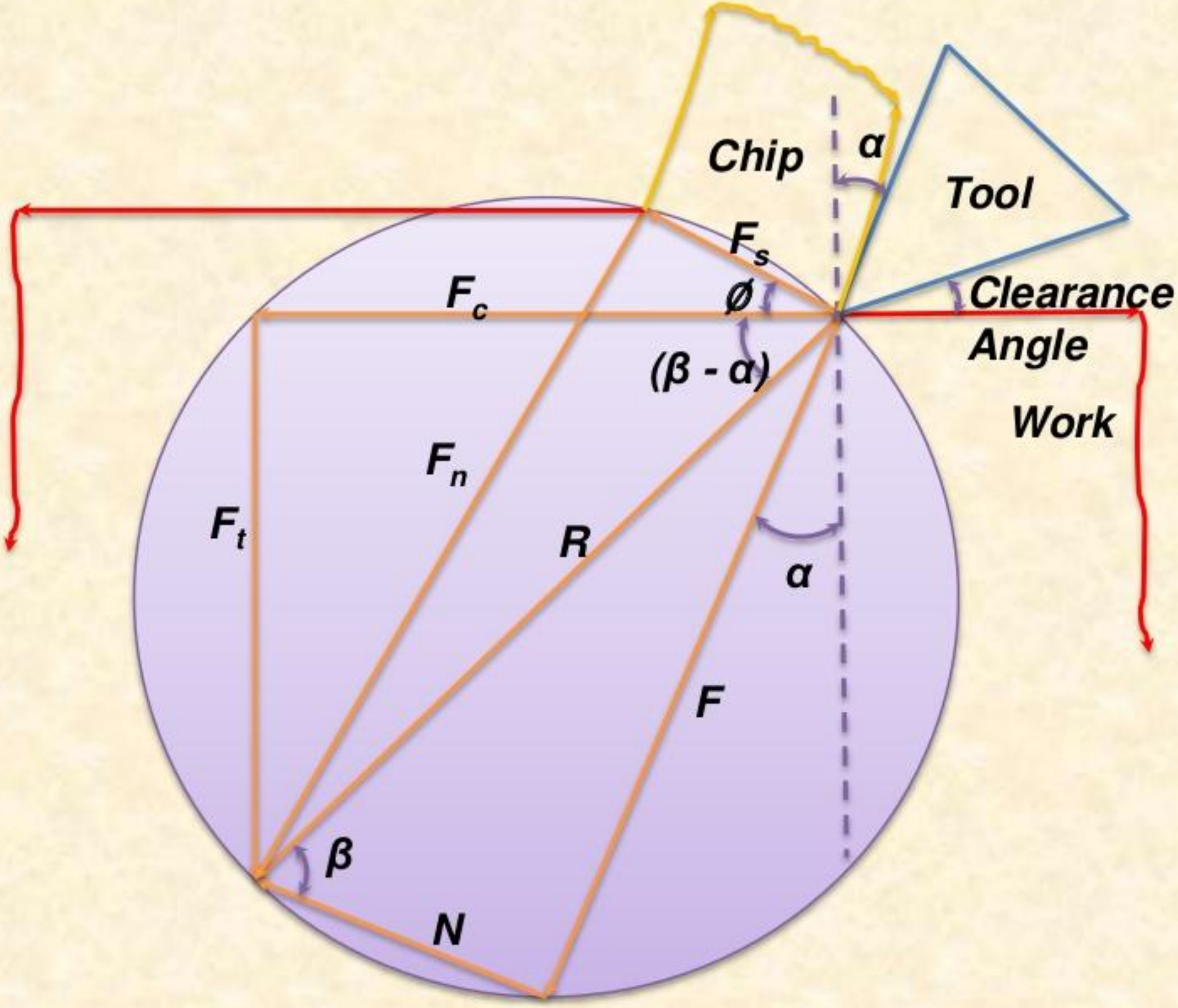
Procedure to construct a merchants circle diagram

- Set up x-y axis labeled with forces, and the origin in the centre of the page. The cutting force (**Fc**) is drawn horizontally, and the tangential force (**Ft**) is drawn vertically. (Draw in the resultant (R) of Fc and Ft.
- Locate the centre of R, and draw a circle that encloses vector R. If done correctly, the heads and tails of all 3 vectors will lie on this circle.
- Draw in the cutting tool in the upper right hand quadrant, taking care to draw the correct rake angle (**α)** from the vertical axis.
- Extend the line that is the cutting face of the tool (at the same rake angle) through the circle. This now gives the friction vector (F).
- A line can now be drawn from the head of the friction vector, to the head of the resultant vector (R). This gives the normal vector (N). Also add a friction angle (**β**) between vectors R and N. Therefore, mathematically, R = Fc + Ft = F + N.
- Draw a feed thickness line(**t1**) parallel to the horizontal axis. Next draw a chip thickness line(**t2**) parallel to the tool cutting face.
- Draw a vector from the origin (tool point) towards the intersection of the two chip lines, stopping at the circle. The result will be a shear force vector (Fs). Also measure the shear force angle between Fs and Fc.
- Finally add the shear force normal (Fn) from the head of Fs to the head of R.
- Use a scale and protractor to measure off all distances (forces) and angles.



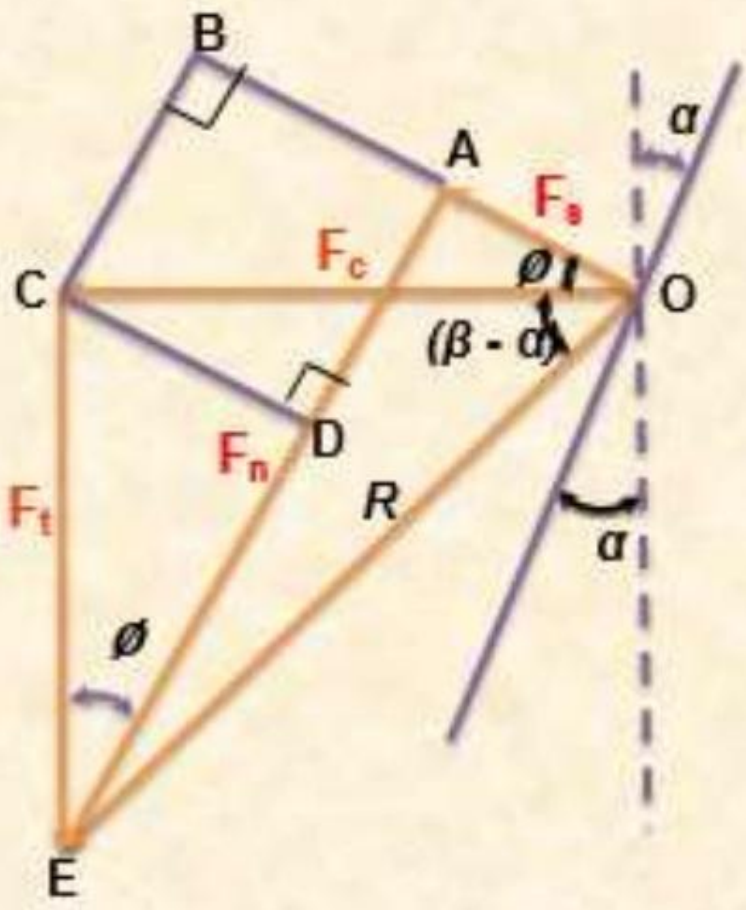
Known: t_1 or t_2, α , F_c, F_t

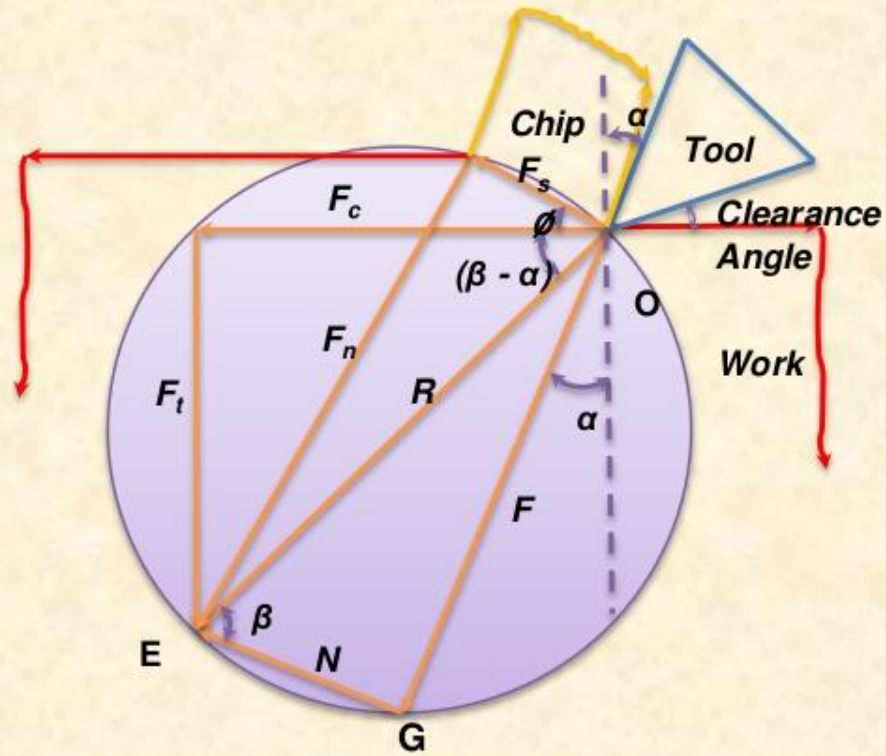
Merchant's Circle Diagram



Relationship of various forces acting on the chip with the horizontal and vertical cutting forces from Merchant circle diagram

Shear Force System –Fs & Fn

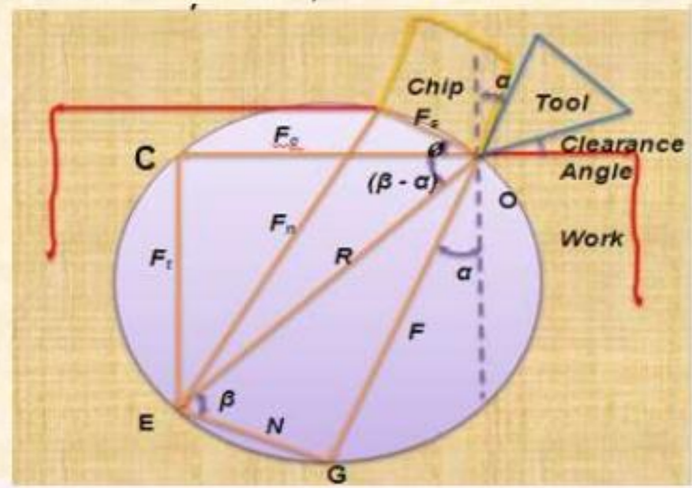




Shear Force System –Fs & Fn

From Triangle OEG, angle E= β (Angle between R & N)

Angle at G= 90^0 , So angle at O = 90 – β (Angle between R & F)

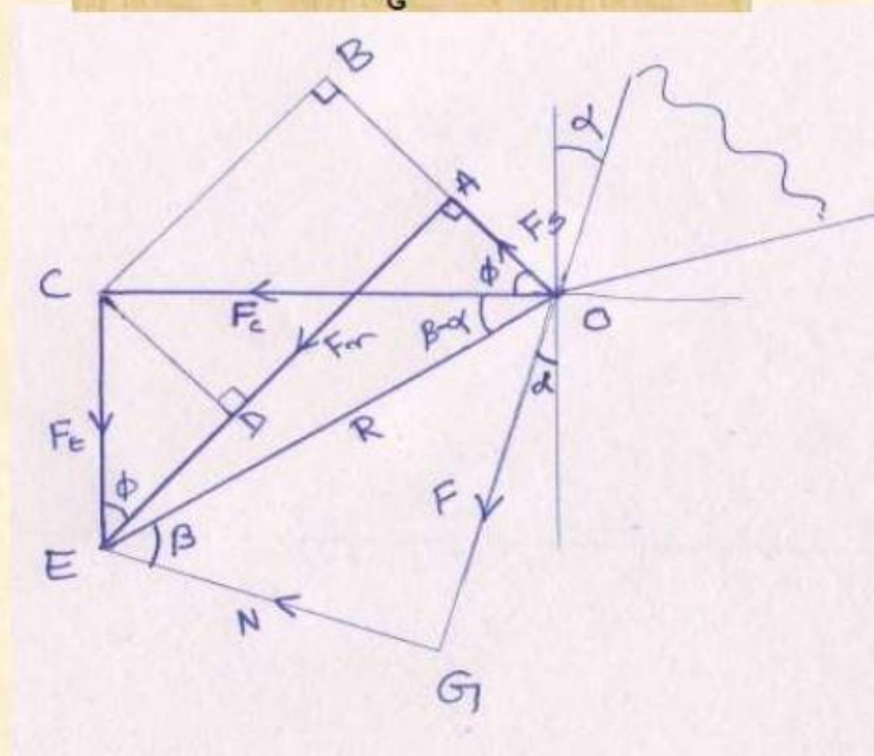


From Triangle ECO,
Angle at O = 90 – (90- β) – α = β – α
Angle at E = 90 – (β – α) = 90 - β+ α

From Triangle EAO,
Angle at E = 90 - (φ + β –α)

So angle CED = (90- β+ α) – (90-(φ + β –α)) = φ

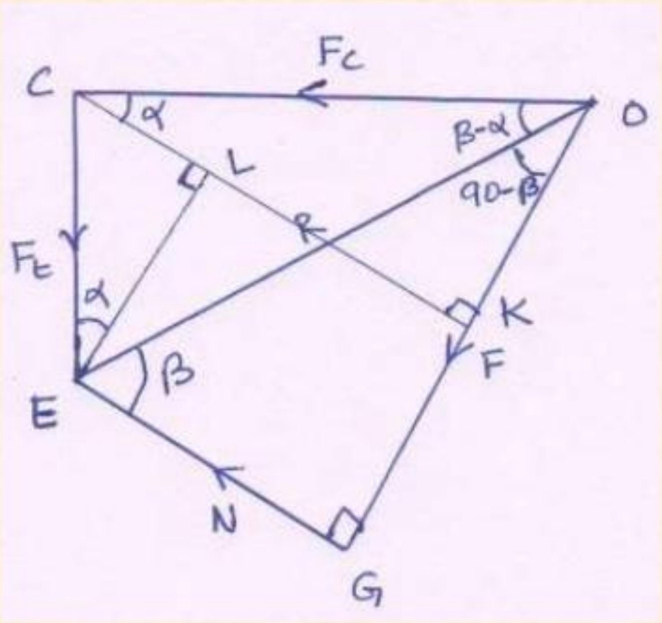
$$F_S = OA = OB - AB = OB - CD$$
$$\Rightarrow F_S = F_C \cos\phi - F_t \sin\phi$$
$$F_N = AE = AD + DE = BC + DE$$
$$\Rightarrow F_N = F_C \sin\phi + F_t \cos\phi$$



Also:

$$F_N = F_S \tan(\phi + \beta - \alpha)$$

Frictional Force System: F & N



Draw a perpendicular from C to OG, meeting at K

Draw a perpendicular from E to CK, meeting at L

Angle between R & N is β

So, in triangle GOE, angle O = 90- β

We already know in triangle ECO, angle O= β - α

Consider triangle COK, angle at O =(90-β) +(β-α)
= 90- α

There fore, In triangle KCO, angle C = 90-(90- α) = α

In triangle CEL, angle at C= 90 - α (As angle between F_c and F_t is 90)
So, angle at E = 90 -(90 - α) = α

F= OK + KG = OK + EL = $\mathbf{F_c}$ **(Sinα) +** $\mathbf{F_t}$ **(Cos α)**

N = CK - CL = $\mathbf{F_c}$**(Cos α) –** $\mathbf{F_t}$ **(Sin α)**

$$\mu = \frac{F}{N} = \text{Tan}\beta = \frac{Fc\,Tan\alpha + Ft}{Fc - Ft\,Tan\alpha}$$

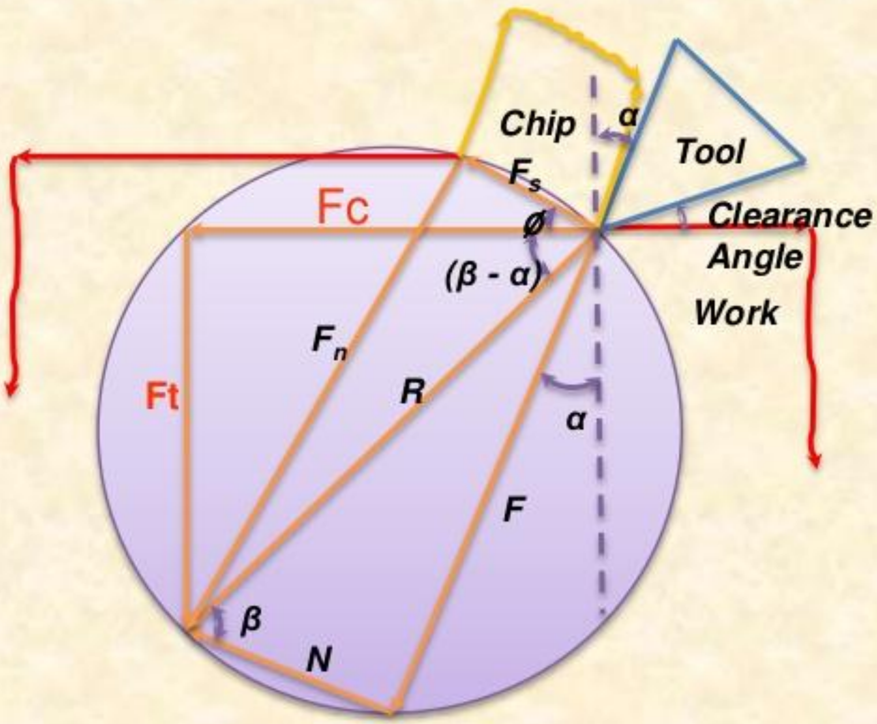
From Triangle ECO, $\text{Tan}(\beta-\alpha) = \frac{Ft}{Fc}$

The coefficient of friction

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

Where $\beta = Friction\ angle$

Relationship of various forces acting on the chip with the horizontal and vertical cutting force, from Merchant circle diagram



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

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

$$F_S = F_C \cos\phi - F_t \sin\phi$$

$$F_N = F_C \sin\phi + F_t \cos\phi$$

$$= F_S \tan(\phi + \beta - \alpha)$$

$$Also, F_s = R\cos(\phi + \beta - \alpha)$$

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

$$F_s = R\cos(\phi + \beta - \alpha)$$

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

$$R = \sqrt{F_c^2 + F_t^2} = \sqrt{F_s^2 + F_n^2} = \sqrt{F^2 + N^2}$$

Shear area in orthogonal turning

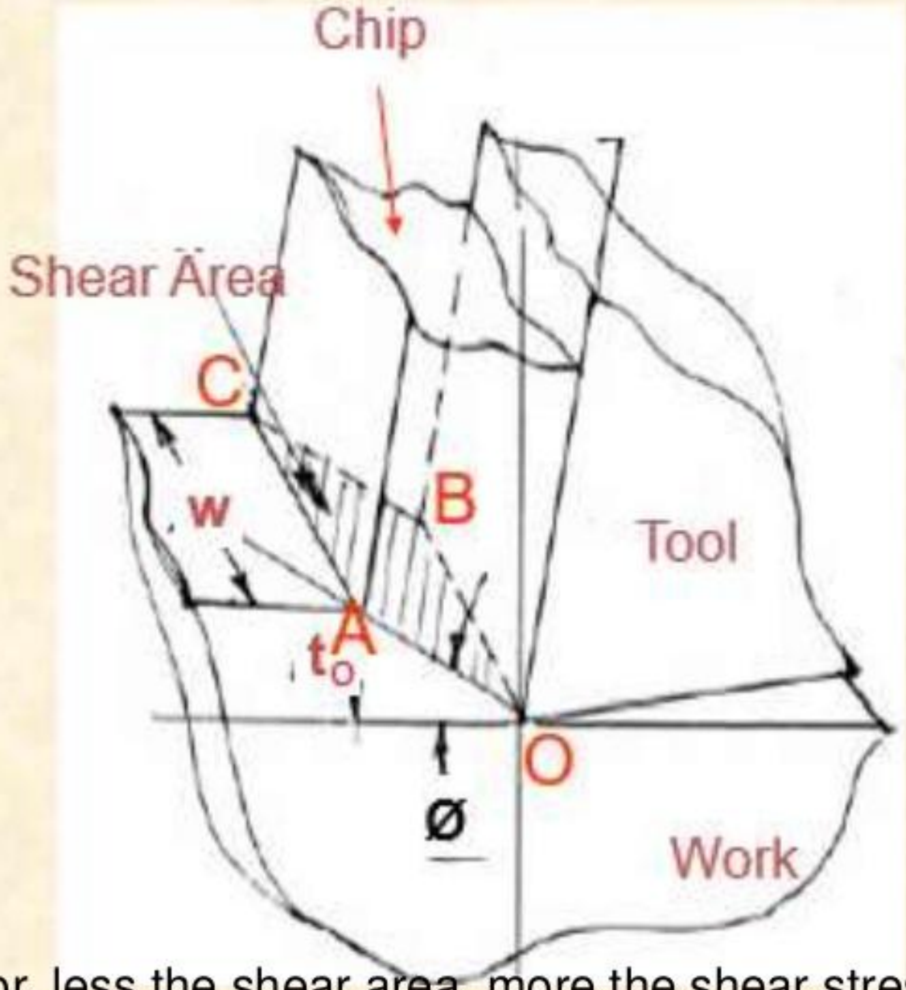
$Sin\varnothing = t_o/OA$

Shear Area (A_s) = OA × AC

$= (t_o / Sin\varnothing) \times w$

$= w\, t_o / Sin\varnothing$

Where w= width of chip



More the shear angle, more the denominator, less the shear area, more the shear stress

Stresses

On the Shear plane:

Normal Stress = σ_s = Normal Force / Area = $\dfrac{F_n \sin\phi}{t_o w}$

Shear Stress = τ_s = Shear Force / Area = $\dfrac{F_s \sin\phi}{t_0 w}$

Note: $\tau_s = \tau_y$ = yield strength of the material in shear

On the tool rake face:

σ = Normal Force / Area = $\dfrac{N}{t_c w}$ (often assume t_c = contact length)

τ = Shear Force / Area = $\dfrac{F}{t_c w}$

Theory of Ernst and Merchant (1944)-Shear Stress

We can express F_s and R as

$$F_s = R\cos(\phi + \beta - \alpha)$$

$$R = F_c \sec(\beta - \alpha) \qquad F_c = R\cos(\beta - \alpha)$$

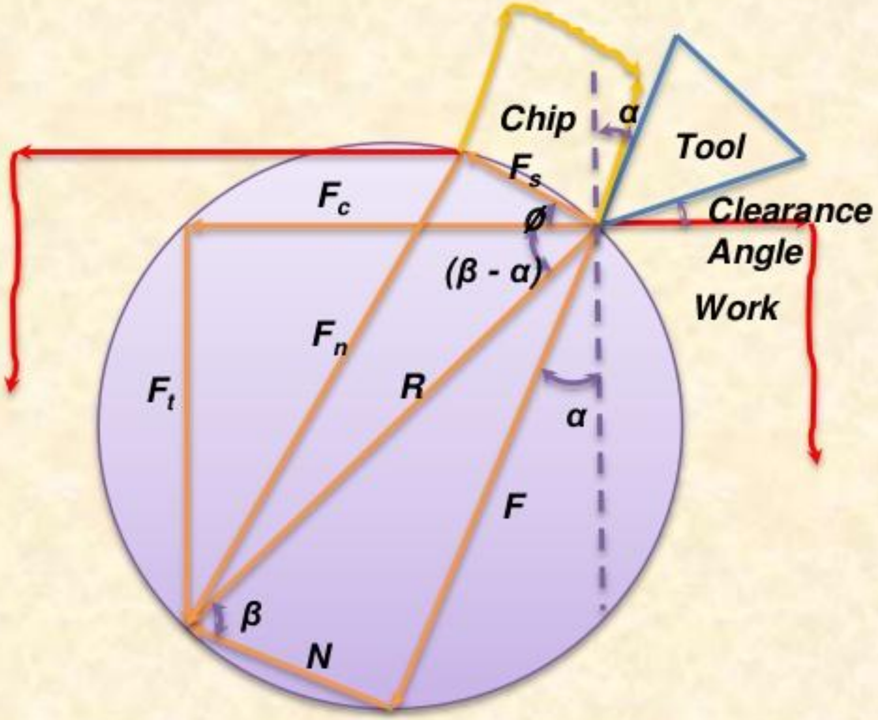
$$\Rightarrow F_s = F_c \sec(\beta - \alpha)\cos(\phi + \beta - \alpha)$$

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

$$where,\ A_s = \frac{wt_0}{\sin\phi}$$

$$\Rightarrow \tau_s = \frac{F_c \sec(\beta - \alpha)\cos(\phi + \beta - \alpha)}{\dfrac{wt_0}{\sin\phi}}$$

$$\Rightarrow \tau_s = \frac{F_c \sec(\beta - \alpha)\cos(\phi + \beta - \alpha)\sin\phi}{wt_0}$$



- ➢It is assumed that ϕ adjusts itself to give minimum work.
- ➢For a given set of cutting condition, t_o, w and α are all constants.
- ➢It is also assumed that β is independent of ϕ.

As $R = F_s / \cos(\varphi + \beta - \alpha)$ we know $F_s = T \times A_s$ and $A_s = \frac{wt_0}{\sin\phi}$ Substituting in F_c

Cutting force

$$F_c = R\cos(\beta - \alpha) = \frac{wt_o \tau \cos(\beta - \alpha)}{\sin\phi \cos(\phi + \beta - \alpha)}$$

Friction coefficient

$$\mu = \tan\beta = \frac{F_t + F_c \tan\alpha}{F_c - F_t \tan\alpha}$$

Earnst-Merchant
(Principle of Minimum Energy Consumption)

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

(Over estimate)

$2\phi + \beta - \alpha = C$ - 2nd solution

Where C=Machining constant

Lee & Shaffer
(slip line field theory)

$$\phi = 45^\circ + \alpha - \beta$$

Mizuno

$$\phi = \alpha \quad \text{for} \quad \alpha > 15^\circ$$

$$\phi = 15^\circ \quad \text{for} \quad \alpha < 15^\circ$$

$$Mean\ \text{shear stress}\ \tau_s = \frac{F_s}{A_s}$$

$$Mean\ \text{normal stress}\ \sigma_s = \frac{F_n}{A_s}$$

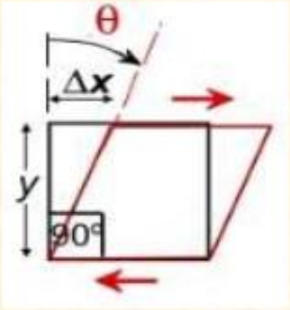
Shear Strain $\gamma = \dfrac{\cos\alpha}{\cos(\phi-\alpha)\sin\phi}$ = $\dfrac{V_s}{V_c Sin\phi}$

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

where γ = shear strain,

φ = shear angle, and

α = rake angle of cutting tool



$\gamma = \Delta x / y = \tan\theta$

Power required in Metal cutting

The Power consumed or work done per sec *in cutting*: $P_C = F_C \times v_C$ Watts

F_c= Cutting force in N
V_c=Cutting speed in m/sec

Power = $(F_c \times V_c)/1000$ KW

If F_c is in Kg, V_c is in m/min

Power = $(F_c \times V_c)/4500$ HP

= $(F_c \times V_c)/(4500 \times 1.36)$ KW

Material Removal Rate(MRR)

$$\text{Material Removal Rate (MRR)} = \frac{\text{Volume Removed}}{\text{Time}}$$

$$\text{Volume Removed} = Lwt_o$$

$$\text{Time to move a distance L} = L/V$$

$$\text{Therefore, MRR} = \frac{Lwt_o}{L/V} = Vwt_o$$

MRR = Cutting velocity x width of cut x depth of cut

Specific cutting Energy

- To get better picture of the efficiency of the metal-cutting operation, it is necessary to have a new parameter which does not depend upon the cutting process parameters.

- The specific cutting energy is such a parameter which can be obtained by dividing the total work done with the material removal rate(MRR)

- The material removal rate(MRR) = $V_c w t_0$

- Specific cutting Energy, u_t, is defined as the total energy per unit volume of material removed, or ratio of work done to MRR

$$u_t = \frac{F_C v_c}{w t_0 v_c} = \frac{F_C}{w t_0}$$

Approximate specific-energy requirements in cutting operations.

MATERIAL	SPECIFIC ENERGY*	
	W-s/mm^3	hp-min/in^3
Aluminum alloys	0.4-1.1	0.15-0.4
Cast irons	1.6-5.5	0.6-2.0
Copper alloys	1.4-3.3	0.5-1.2
High-temperature alloys	3.3-8.5	1.2-3.1
Magnesium alloys	0.4-0.6	0.15-0.2
Nickel alloys	4.9-6.8	1.8-2.5
Refractory alloys	3.8-9.6	1.1-3.5
Stainless steels	3.0-5.2	1.1-1.9
Steels	2.7-9.3	1.0-3.4
Titanium alloys	3.0-4.1	1.1-1.5

* At drive motor, corrected for 80% efficiency; multiply the energy by 1.25 for dull tools.

Source " Manufacturing Processes for Engineering Materials", 4th edition, Kalpakjian, Schmid, Prentice Hall 2003

$$\text{Cutting ratio}\quad, \mathbf{r} = \frac{t_0}{t_c} = \frac{L_c}{L_0}$$

$$\text{Chip thickness ratio } (r) = \frac{t_0}{t_c} = \frac{\sin\phi}{\cos(\phi-\alpha)}$$

$$\tan\phi = \frac{r\cos\alpha}{1-r\sin\alpha}$$

$$\text{Shear plane angle } (\phi) = \mathrm{Tan}^{-1}\left[\frac{r\cos\alpha}{1-r\sin\alpha}\right]$$

$$v_f = \frac{v_c \sin\phi}{\cos(\phi-\alpha)}$$

$$v_f = v_c \times r$$

$$v_s = \frac{v_c \cos\alpha}{\cos(\phi-\alpha)}$$

V_s= Velocity of shear along shear plane

V_f= Chip flow velocity along the tool face
(frictional velocity)
parallel to face of the tool

V_c=Cutting velocity

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

Friction coefficient

$$\mu = \tan\beta = \frac{F_t + F_c \tan\alpha}{F_c - F_t \tan\alpha}$$

$$\mu = \tan\beta$$

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

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

$$F_S = F_C \cos\phi - F_t \sin\phi$$

$$F_N = F_C \sin\phi + F_t \cos\phi$$

$$= F_S \tan(\phi + \beta - \alpha)$$

$$Also, F_s = R\cos(\phi + \beta - \alpha)$$

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

F_c= Cutting force in N

V_c=Cutting speed in m/sec

Power(Pc) = (F_c x V_c)/1000 KW

If F_c is in Kg, V_c is in m/min

Power = (F_c x V_c)/4500 HP

= (F_c x V_c)/(4500x1.36) KW

$$P_C = F_C \times v_C$$

- The material removal rate(MRR) = V_c (w t_0)

Problem1.

In orthogonal turning of a 50mm dia. mild steel bar on a lathe, the following data were obtained:

Rake angle= 15 deg, cutting speed=100 m/min, feed= 0.2 mm/rev

Cutting force=180 kg, feed force=60kg.

Calculate the shear plane angle, coefficient of friction, cutting power, chip flow velocity and shear force, if the chip thickness =0.3 mm

$r = t_1/t_2 = 0.2/0.3 = 0.667$

$$\textbf{Shear plane angle } (\phi) = \textbf{Tan}^{-1}\left[\frac{r\cos\alpha}{1 - r\sin\alpha}\right]$$

Shear plane angle = $37^0\ 55'$

Coefficient of friction = 0.66

Cutting power = (cutting force in Kg x cutting speed in m/min)/4500 HP = 4 HP

Chip flow velocity = cutting velocity x r = 66.7 m/min

Shear force =105.2 Kg

$$\textbf{Cutting ratio}\ , \ r = \frac{t_0}{t_c} = \frac{L_c}{L_0}$$

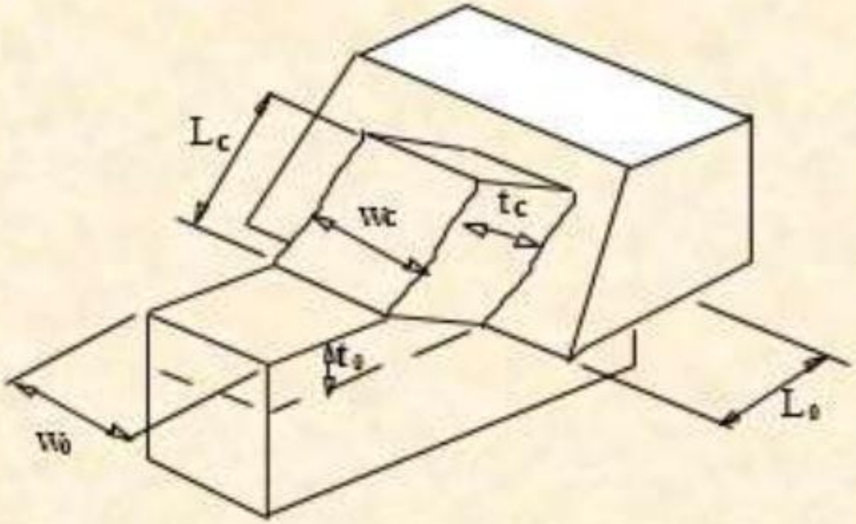
In turning, feed is the distance that the tool advances in one revolution of the workpiece, So, assume feed=t_0

Problem2. A bar of 75mm diameter is reduced to 73 mm by a cutting tool while cutting orthogonally. If the mean length of the chip is 73.9 mm, find the cutting ratio. If the rake angle is 15 degrees, what is the shear angle?

Length of uncut chip $L_1 = \pi(d1+d2)/2 = \pi(75+73)/2 = 232.4779$ mm

Cutting ratio $r = t_1/t_2 = L_c/L_o = 73.9/232.4779 = 0.3179$

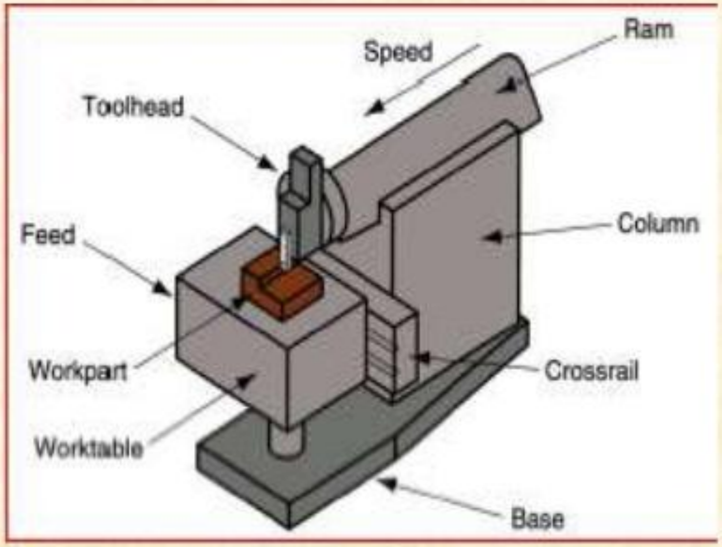
Shear angle $\varphi = \mathrm{Tan}^{-1} \dfrac{r\cos\alpha}{1 - r\sin\alpha} = 19^0$

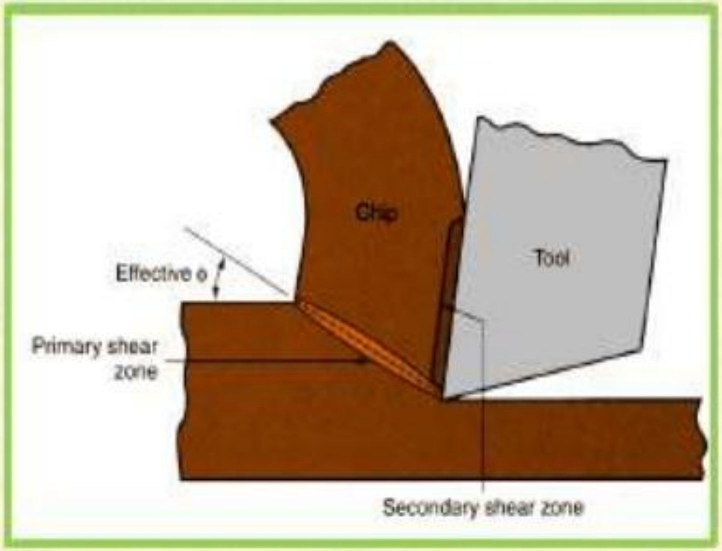


$$\text{Cutting ratio} \quad , \; r = \frac{t_0}{t_c} = \frac{L_c}{L_0}$$

MECHANISM OF CHIP FORMATION

- The fig. represents the *shaping operation*, 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 workpiece is *ductile*, the material *flows plastically* along the shear plane, forming *chip*, which flows upwards along the face of the tool.





- When the cutting tool is forced against the work, the metal layer which is just ahead of tool is compressed.

- If the tool is forced further, a condition will be reached, in which the stress exceeds ultimate shear strength of the given work material.

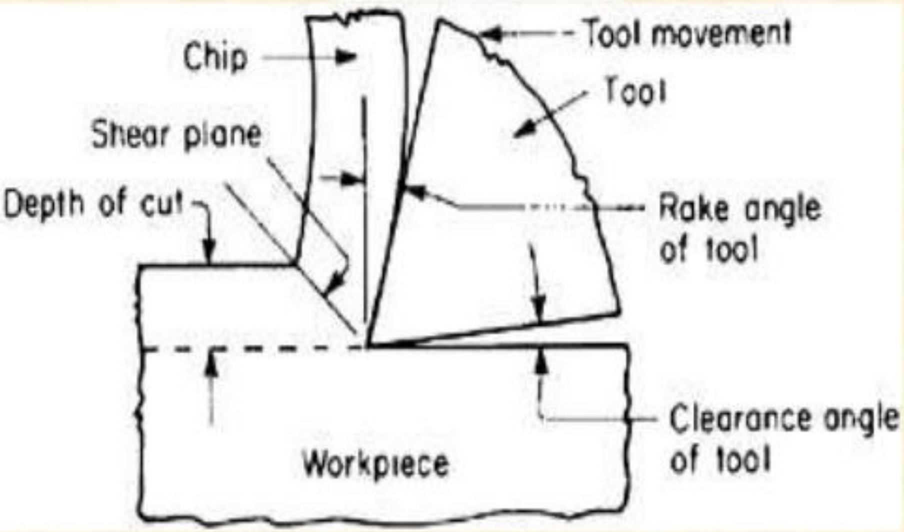
- This leads shear along the shear plane and cutting off the chip from the workpiece.

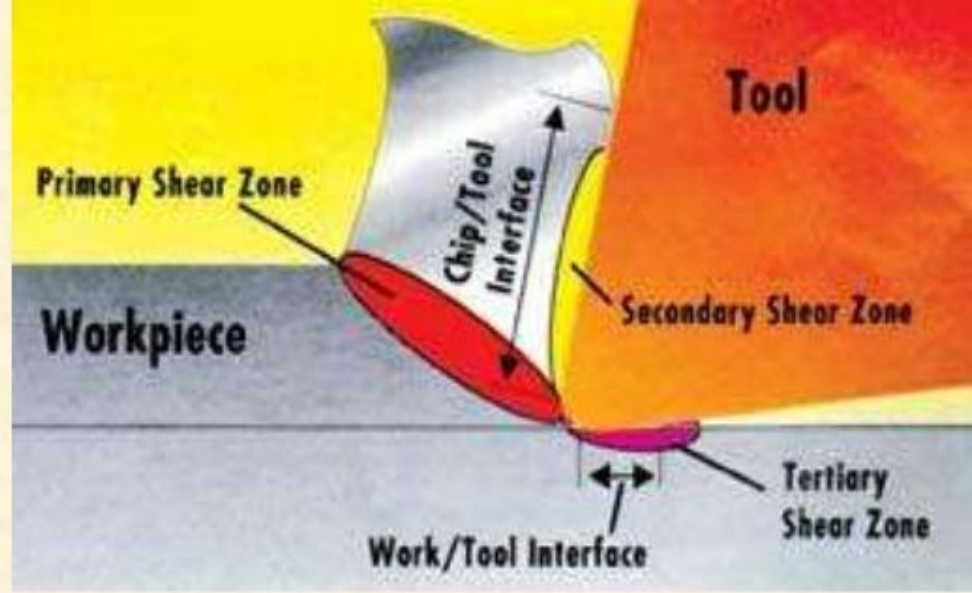
- With further movement of the tool, the new layer is compressed and the cycle is repeated.

- The chip formed in the metal cutting operations, undergoes plastic deformation, it becomes shorter (chip contraction) and cross-section increases.

- Due to contraction, the length of chip is shorter than the length of the tool travel, along the surface of the work.

Shear zone



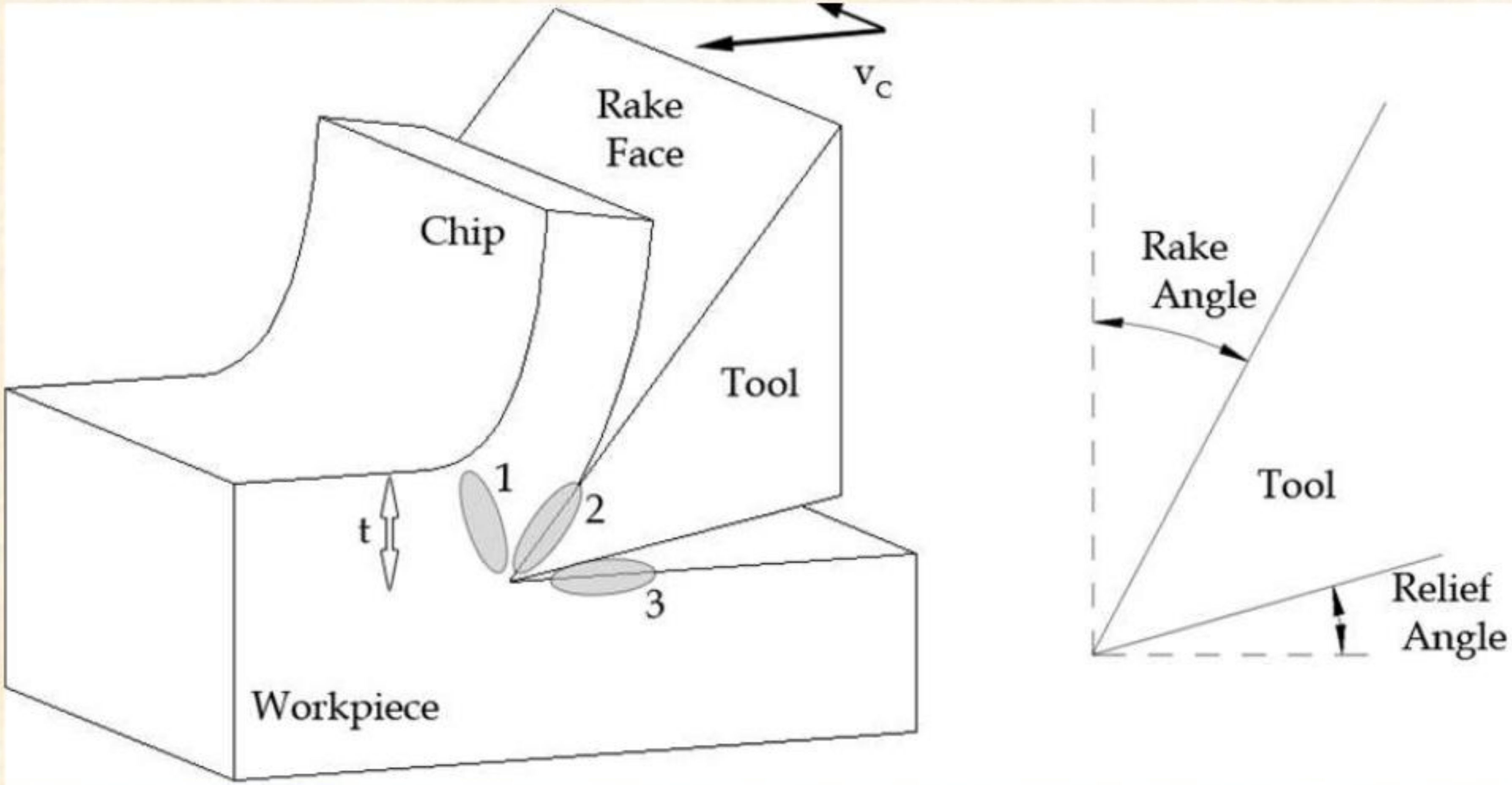


- Deformation of metal occurs along shear plane. However, in realistic model the shear deformation occurs within a shear zone(Primary shear zone).

- An other shear occurs due to friction between the chip and tool as the chip slides along the rake face of the tool. This is referred as secondary shear zone.

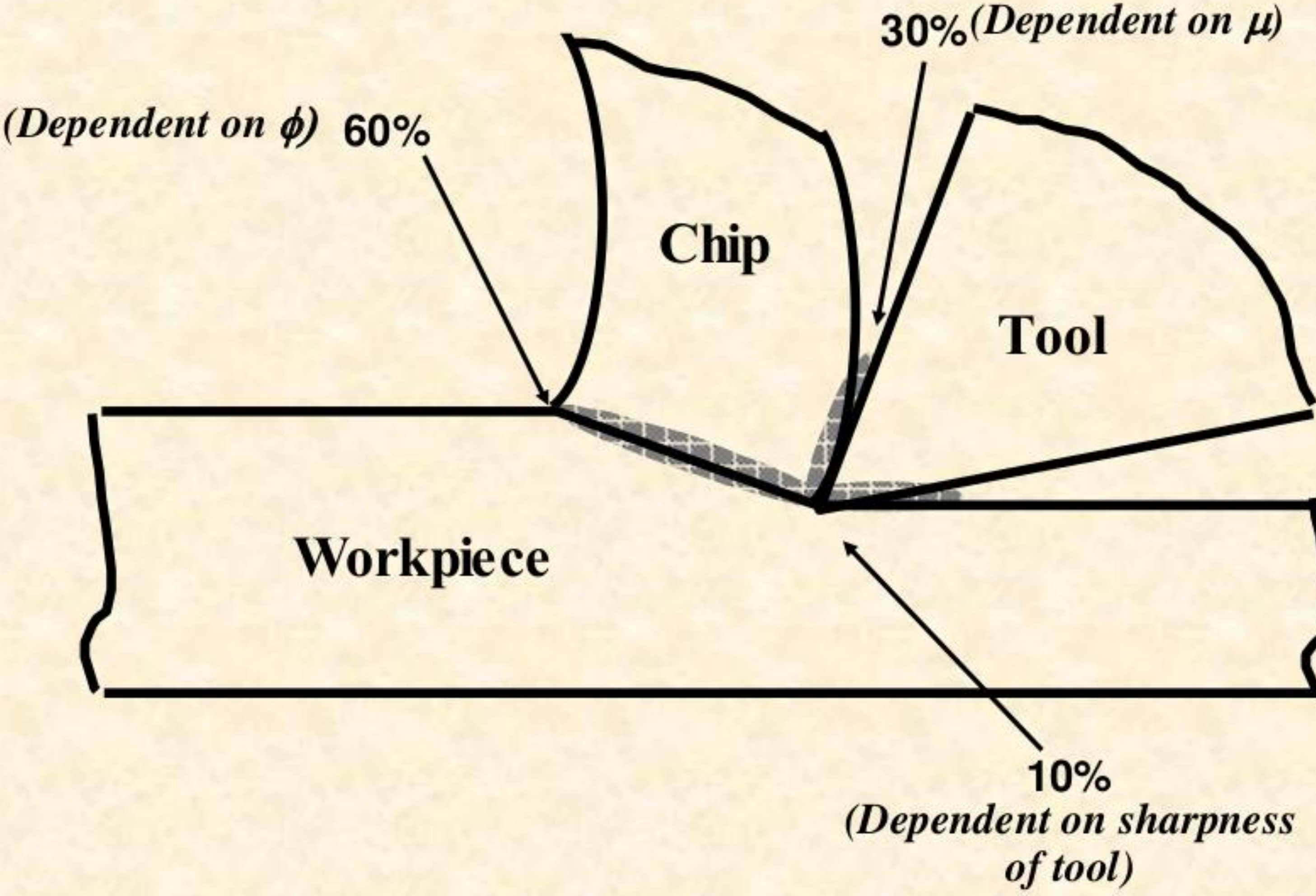
- Another shear occurs between work and tool interface, which is called as tertiary shear zone.

- If machined at low cutting speed → Shear zone is thick
- If machined at high cutting speed →Shear zone is thin



v_C
Rake
Face
Chip
Tool
1
2
3
t
Workpiece
Rake
Angle
Tool
Relief
Angle

Heat Generation Zones



CHIP FORMATION

Tool will cut or shear off the metal, provided

1. Tool is harder than the work metal.

2. Tool is properly shaped so that its edge can be effective in cutting the metal.

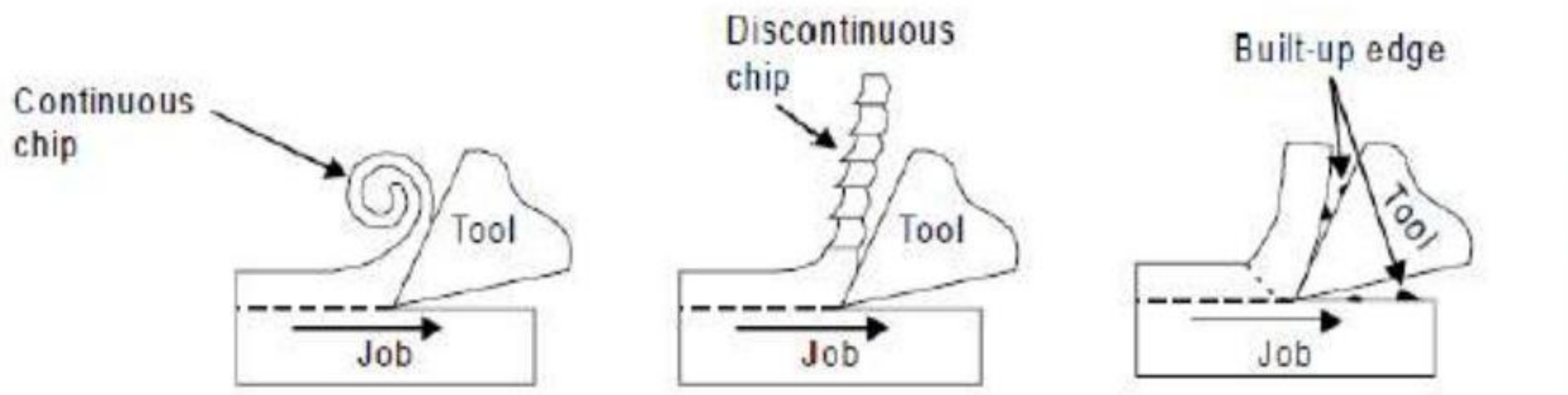
3. The tool is strong enough to resist the cutting pressures.

4. Movement of the tool relative to the material or vice versa, so as to make cutting action possible.

TYPES OF CHIPS

The chips produced during machining can be broadly classified as 3 types:

1.Continuous chips
2.Discontinuos chips or Segmental chips
3.Continuous chips with build-up edge



(a) Continuous chips (b) Discontinuous chips (c) Chips with built-up edge

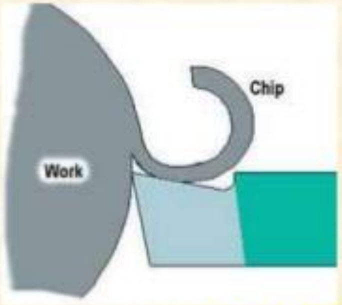
Continuous chips

➢Continuous chips are formed when machining ductile materials(low carbon steel, mild steel, copper, aluminium etc) with a cutting tool of large rake angle and sharp cutting edge.

➢Chip flows off the tool face in the form of a ribbon

➢The other favorable conditions which give rise to this type of chips are

- High cutting speed
- Small feeds and depth of cut
- Low friction



➢Formation of continuous chips are desirable because a smooth surface will be obtained. They also help in providing higher tool life and lower power consumption

➢Long continuous chips can cause problems of chip disposal

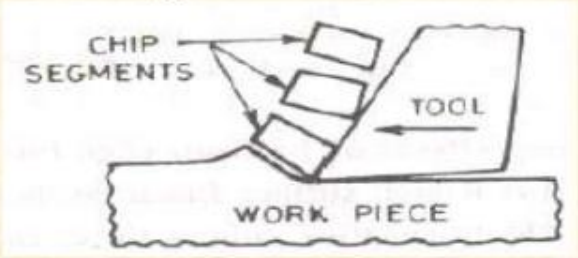
➢These problem can be solved by providing chip breakers(step or groove in the tool rake face) which allow the chips to be broken into small pieces so they can be removed easily

Discontinuous Chips

➢This type of chip is produced when machining brittle material, such as cast iron and bronze, with a cutting tool having low rake angle.

➢The following factors favours the formation of discontinuous chips

1. Low to medium cutting speed
2. Large feeds and depth of cut
3. Absence of cutting fluid

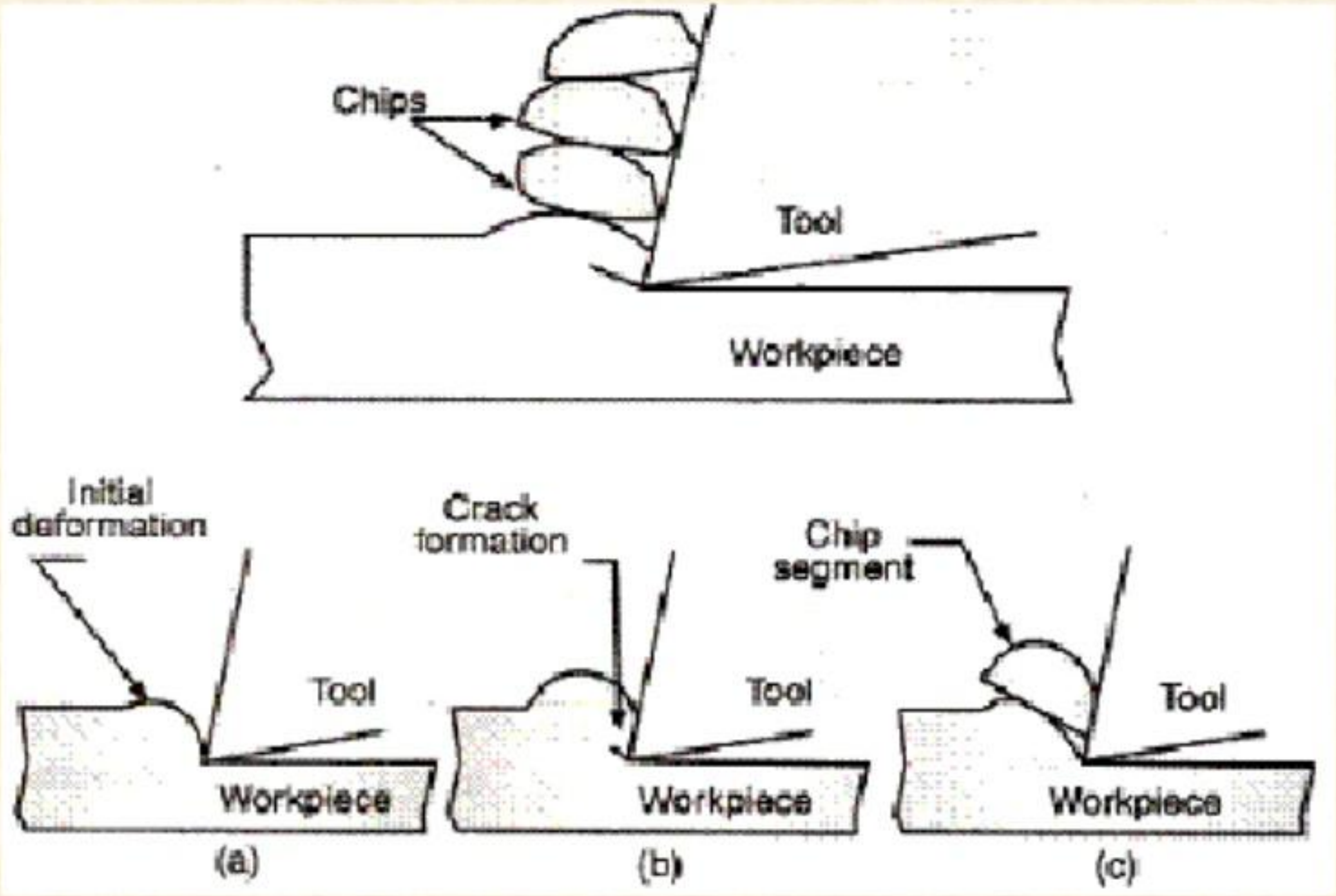


➢Chips are broken into small segments instead of plastic flow of chip along tool face.

➢The discontinuous chips may also result if the material is ductile and the coefficient of friction between chip and tool is very high.

➢The most of the heat generated is carried by the chip and hence the tool is heated to a lower temperature. Thus the tool life is longer

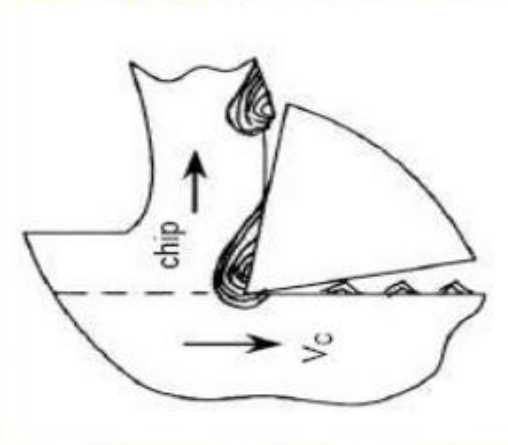
Discontinuous Chips Contd..



Stages of formation of Discontinous chips

Continuous chips with BUE

➢Continuous chips with BUE are formed when machining ductile metals with a cutting tool of smaller rake angle at lower cutting speed. The other conditions which give rise to BUE are:



1. Higher values of feed and depth of cut
2. High friction
3. Poor lubrication
4. High cutting pressure and temperature in shear zone

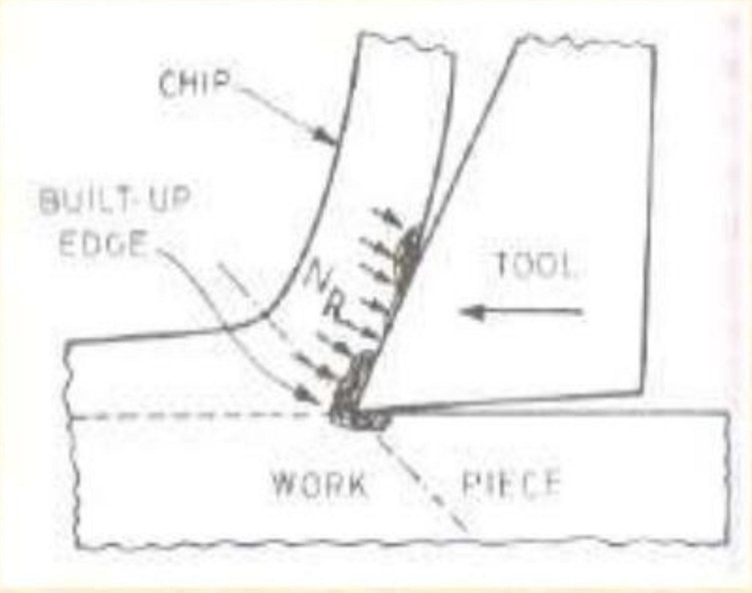
➢These BUE eventually swept from the tool and remain attached to the machined surface.

➢This causes poor surface finish of work surface.

➢Presence of build up edge increases power consumption.

Continuous chips with BUE

- In machining ductile metals like steels with long chip-tool contact length(small rake angle), lot of stress and temperature develops in the secondary deformation zone at the chip-tool interface.
- Under such high stress and temperature in between two clean surfaces of metals, strong bonding may locally take place due to adhesion similar to welding.
- In ductile materials, with lower cutting speeds
- small particles of cut chip adheres, under the action of pressure and temperature, to the face of the tool.



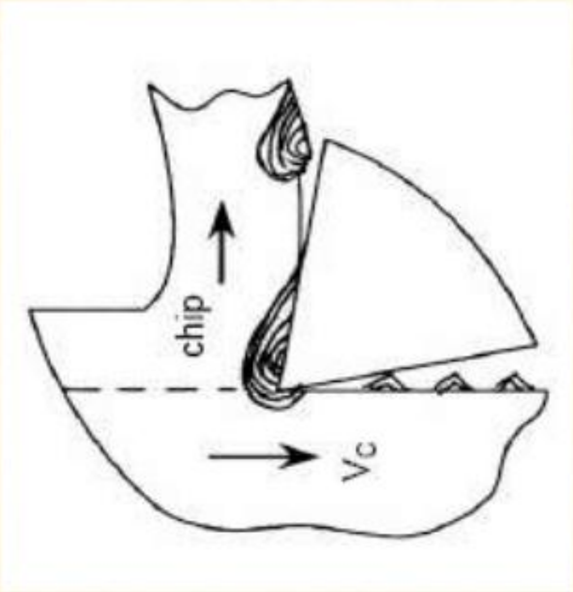
HOW BUE DEVELOPED?

✓ Such bonding will be encouraged and accelerated if the chip-tool materials have mutual affinity or solubility. The weldment starts forming as an embryo at the most favourable location and thus gradually grows

✓ With the growth of the BUE, the force, F also gradually increases due to wedging action of the tool tip along with the BUE formed on it.

✓ Whenever the force, F exceeds the bonding force of the BUE, the BUE is broken or sheared off and taken away by the flowing chip.

✓Then again BUE starts forming and growing. This goes on repeatedly.



Overgrowing and overflowing of BUE causing surface roughness

Effects of BUE

Effects of BUE formation

Formation of BUE causes several harmful effects, such as:

1. It unfavourably changes the rake angle at the tool tip causing increase in cutting forces and power consumption
2. Repeated formation and dislodgement of the BUE causes fluctuation in cutting forces and thus induces vibration which is harmful for the tool, job and the machine tool.
3. Surface finish gets deteriorated
4. May reduce tool life by accelerating tool-wear at its rake surface by adhesion

Type of chip	Work material	Cutting speed	Feed	Rake Angle
Continuous	Ductile	High	Small	Large
Continuous with BUE	Ductile	Medium	High	Small
Discontinuous	Brittle	Low	High	Small

Why Chip Breakers ?

- When carbide tipped tools are used for machining, because of higher cutting speeds, due to high temperatures, the resulting chip will be continuous, blue in colour and take the shape of a coil.

- Such a chip, if not broken into parts and removed from the surroundings of the metal cutting area, is likely to adversely effect the machining results.

1. It may adversely effect the tool life by spoiling the cutting edge, creating crater and raising temperature

2. Its presence may lead to a poor surface finish on the workpiece

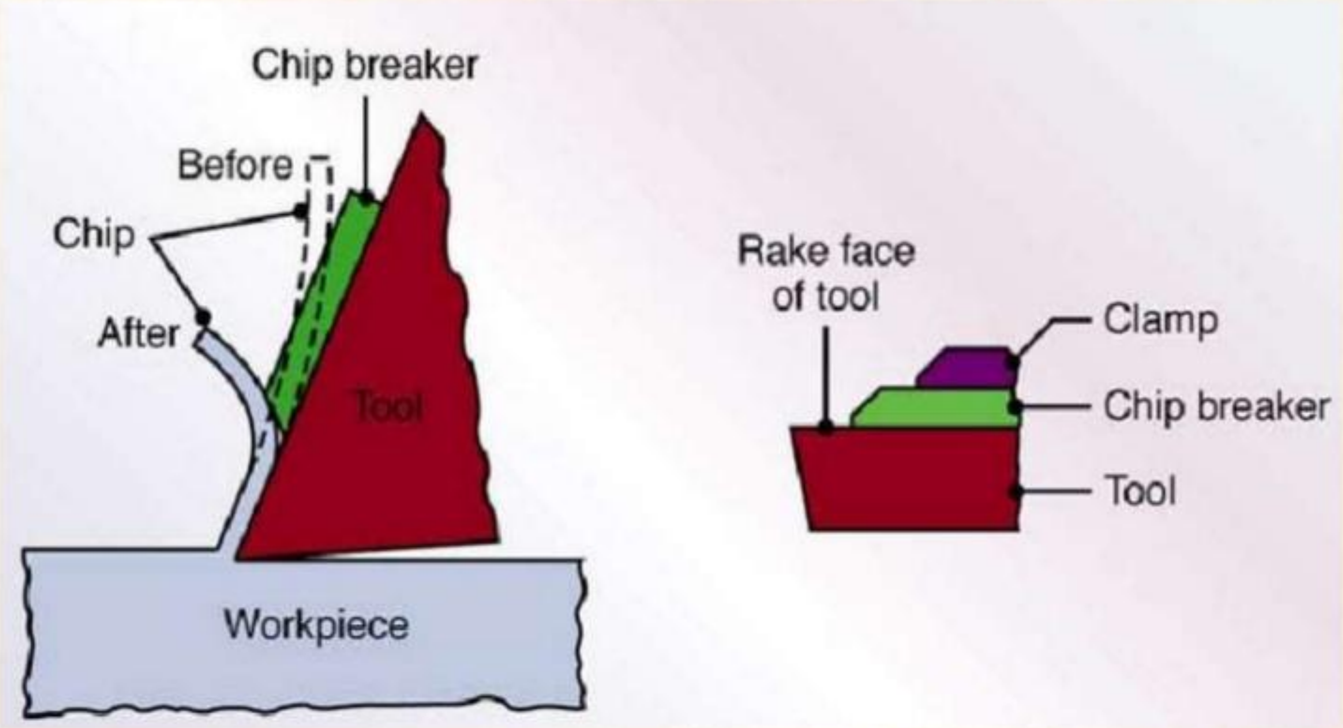
3. If the chip gets curled around the rotating workpiece and/or cutting tool, it may be hazardous to the machine operator

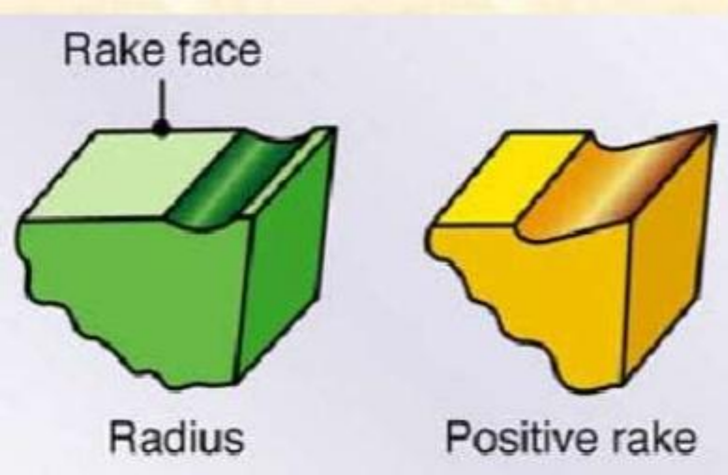
4. Very large coils offer a lot of difficulty in their removal

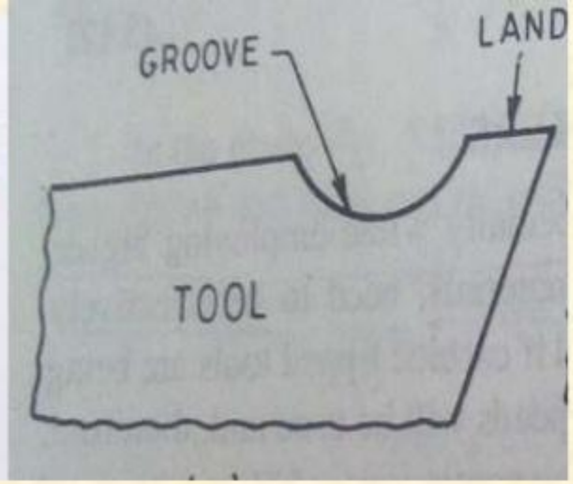
- To prevent the adverse effects, chip breakers are used. These will break the produced chips into small pieces. Chip breakers reduces the radius of curvature of the chip

1.By control of tool geometry: Grinding proper back rake and side rake according to the feeds and speeds to be used.

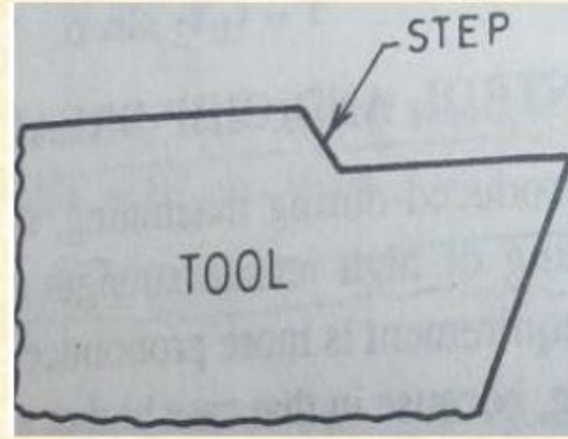
2.By obstruction method: By interposing a metallic obstruction in the path of the coil.







1.Groove type



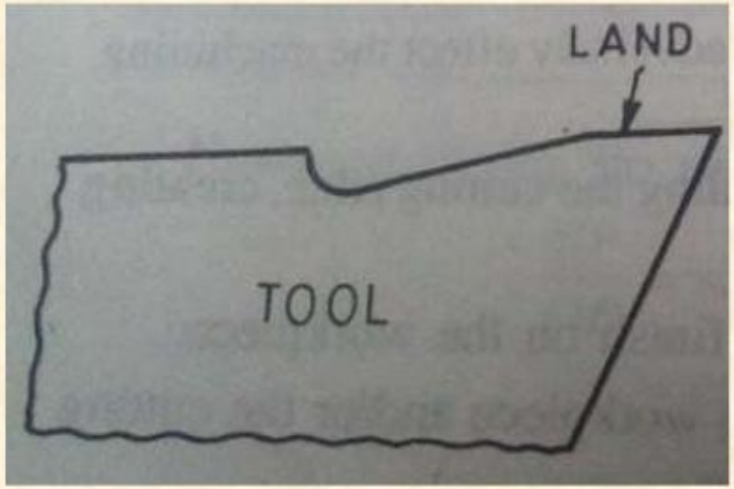
2.Step type

1.Groove type: Grinding a groove on the face of the tool, leaving small land near the tip

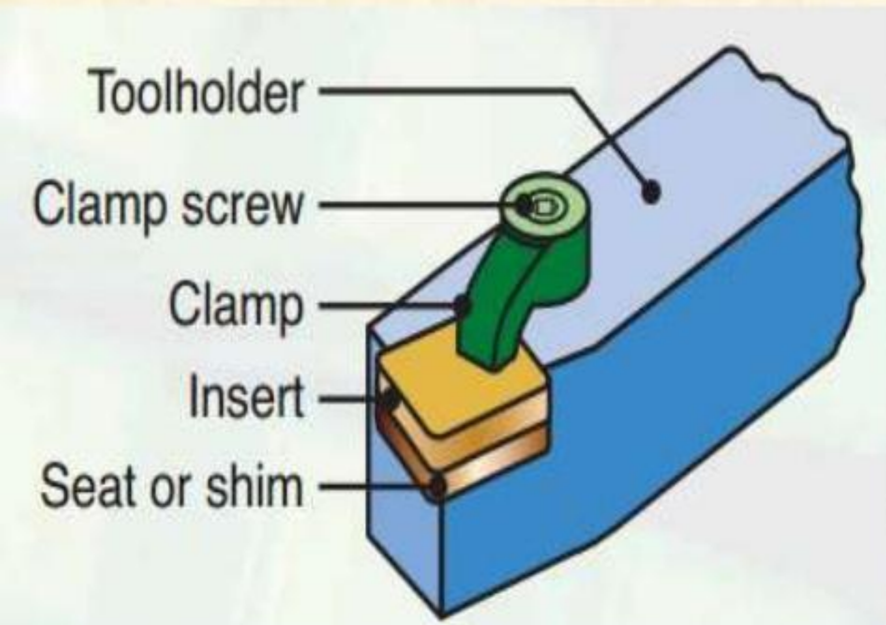
2.Step type: Grinding a step on the face of the tool, adjacent to the cutting edge

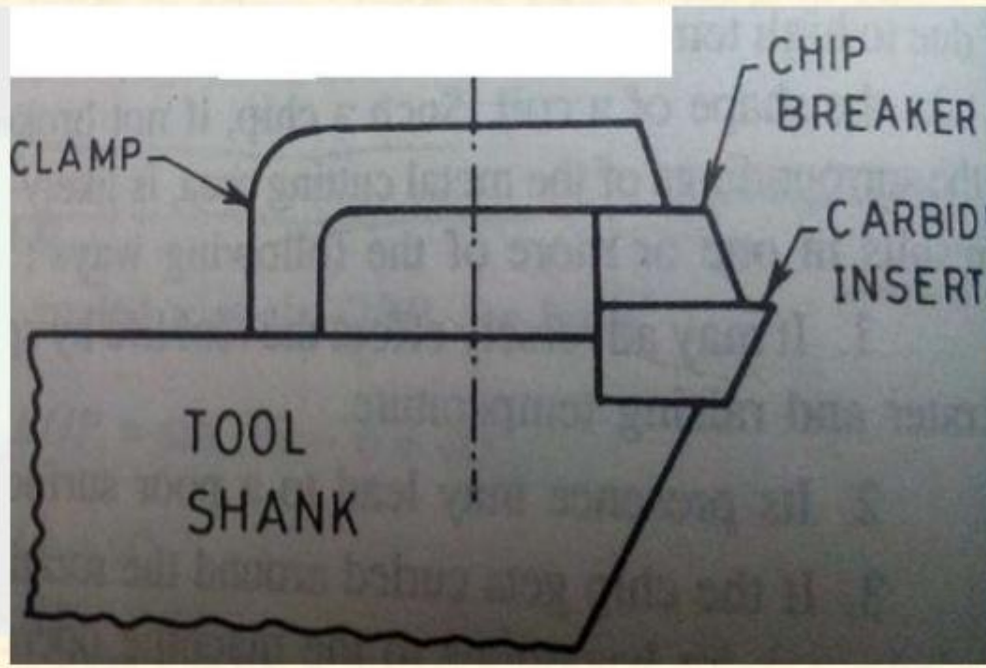
3.Secondary rake: Providing a secondary rake on the tool through grinding, together with a small step

4.Clamp type: Very common with carbide tipped tools. Chip breaker is a thin and small plate which is either brazed to or held mechanically on the tool face



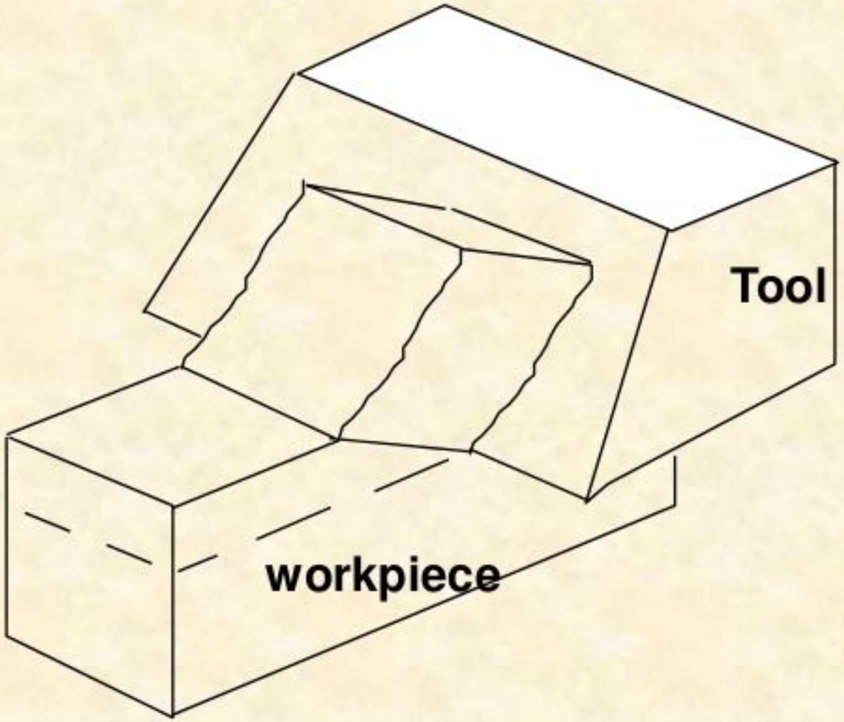
3.Secondary rake



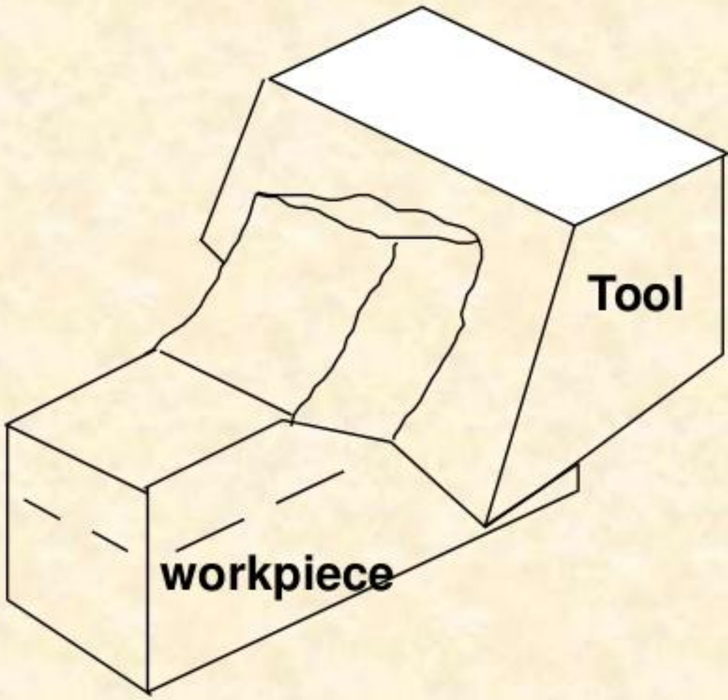


4.Clamp type

Cutting Models



ORTHOGONAL GEOMETRY



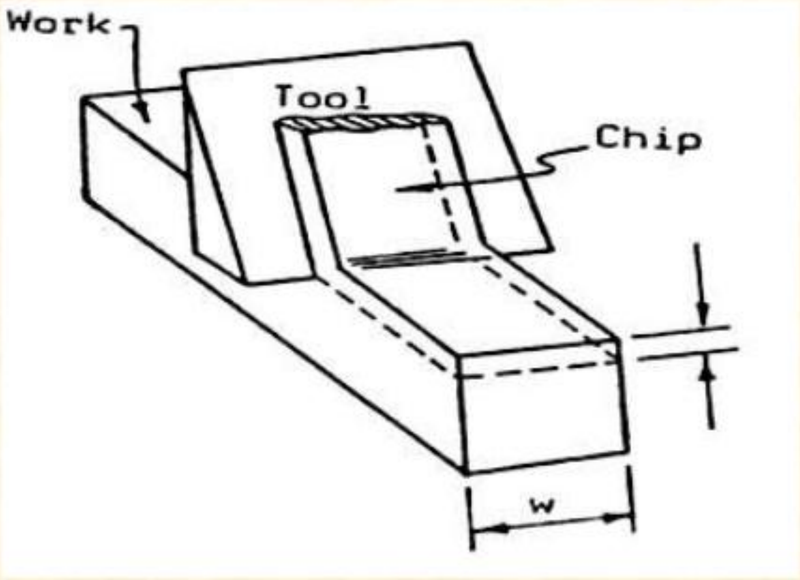
OBLIQUE GEOMETRY

Orthogonal and Oblique Cutting

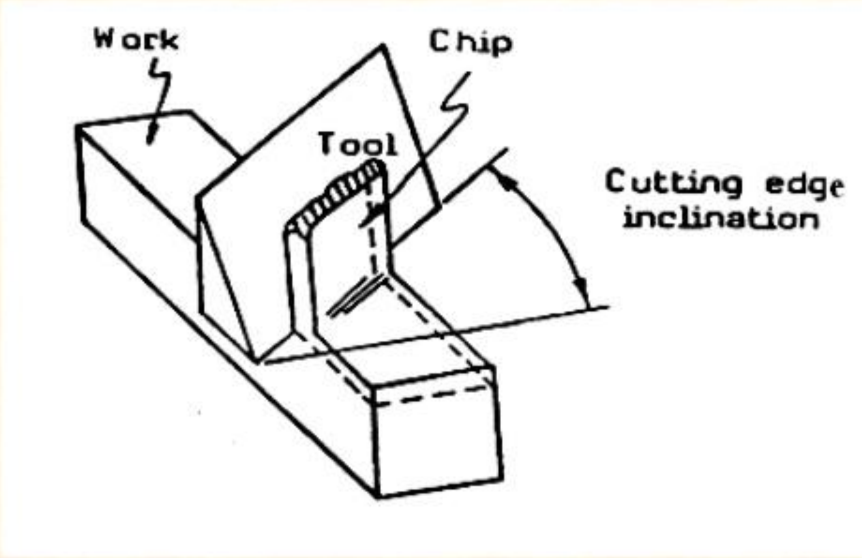
➢The two basic methods of metal cutting using a single point tool are the orthogonal (2D) and oblique (3D).

➢Orthogonal cutting takes place when the cutting edge is straight and perpendicular to the direction of cutting(90 degree).
Ex: lathe cut-off operation, straight milling etc.

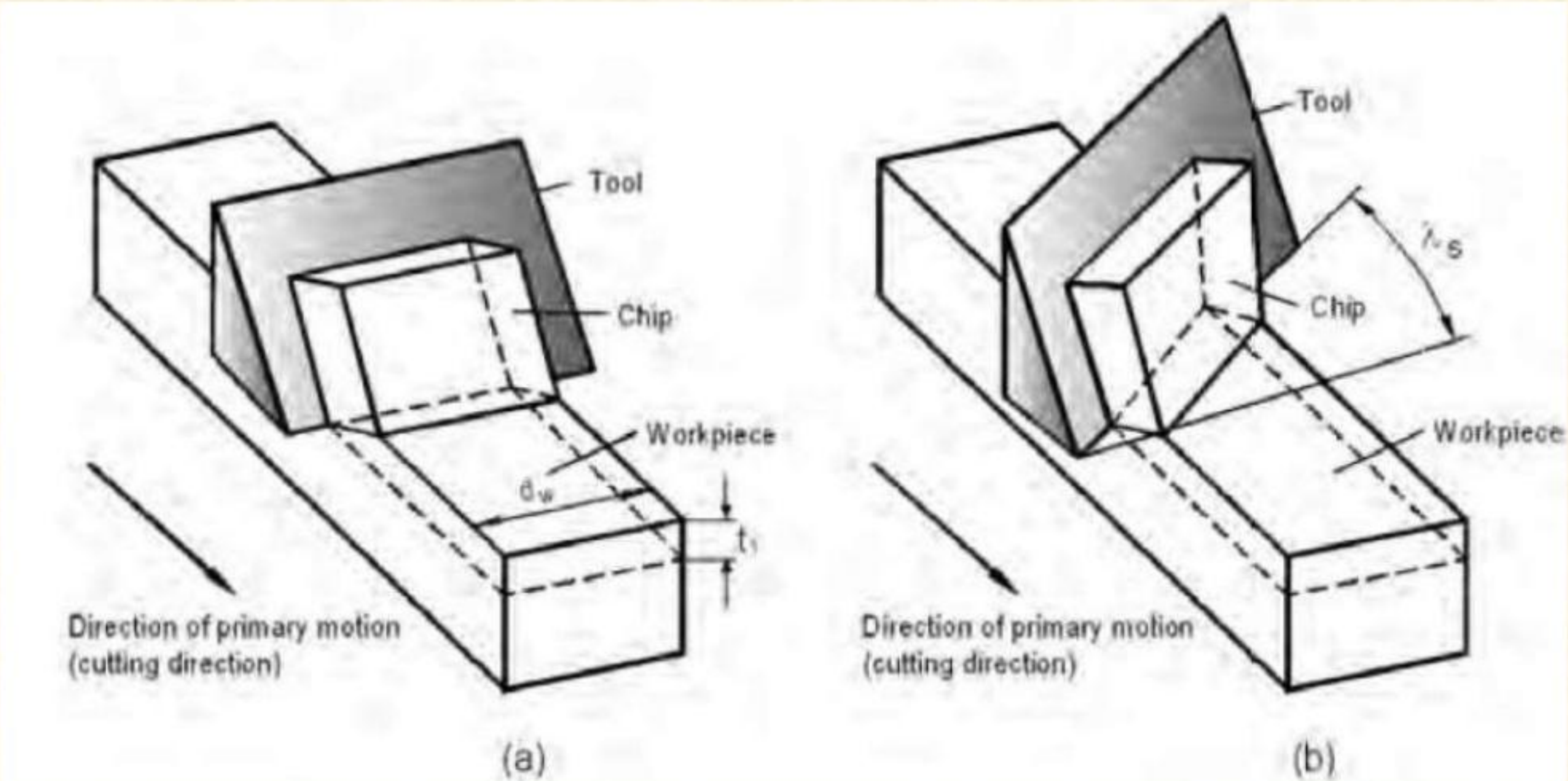
➢If the cutting edge of the tool is inclined(less than 90 degree) to the line normal to the cutting direction, the cutting action is known as oblique.
➢Ex: Turning, Milling



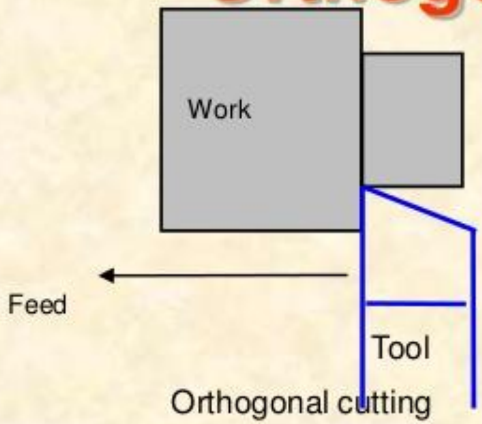
Orthogonal



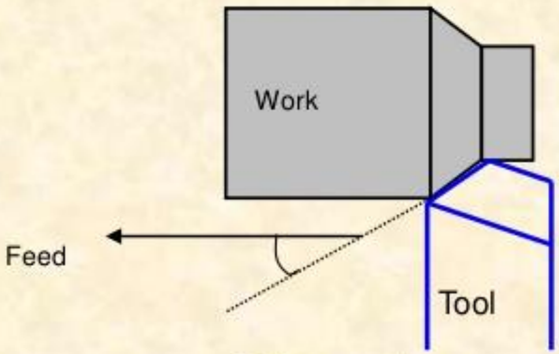
Oblique


Tool
Chip
Workpiece
d_w
t_1
Direction of primary motion
(cutting direction)
(a)
Tool
λ_s
Chip
Workpiece
Direction of primary motion
(cutting direction)
(b)

Orthogonal and Oblique Cutting



Orthogonal cutting



Oblique cutting

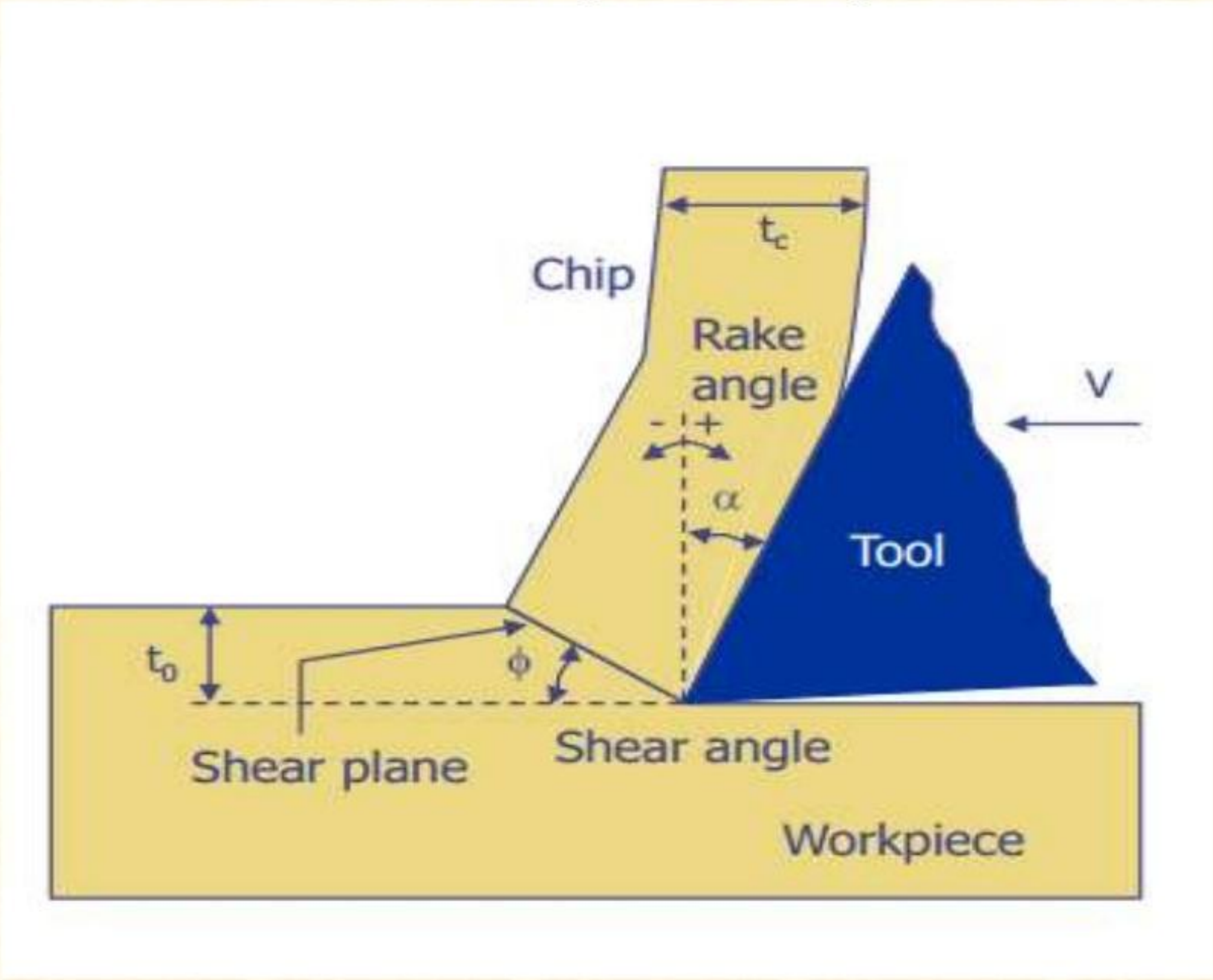
Orthogonal Cutting:

- The cutting edge of the tool remains normal to the direction of tool feed or work feed.
- The direction of the chip flow velocity is normal to the cutting edge of the tool.
- Here only two components of forces are acting: Cutting Force and Thrust Force. So the metal cutting may be considered as a two dimensional cutting.
- Examples are: Parting off operation, Broaching, Sawing, straight milling
- **Shear force acts on smaller area.**

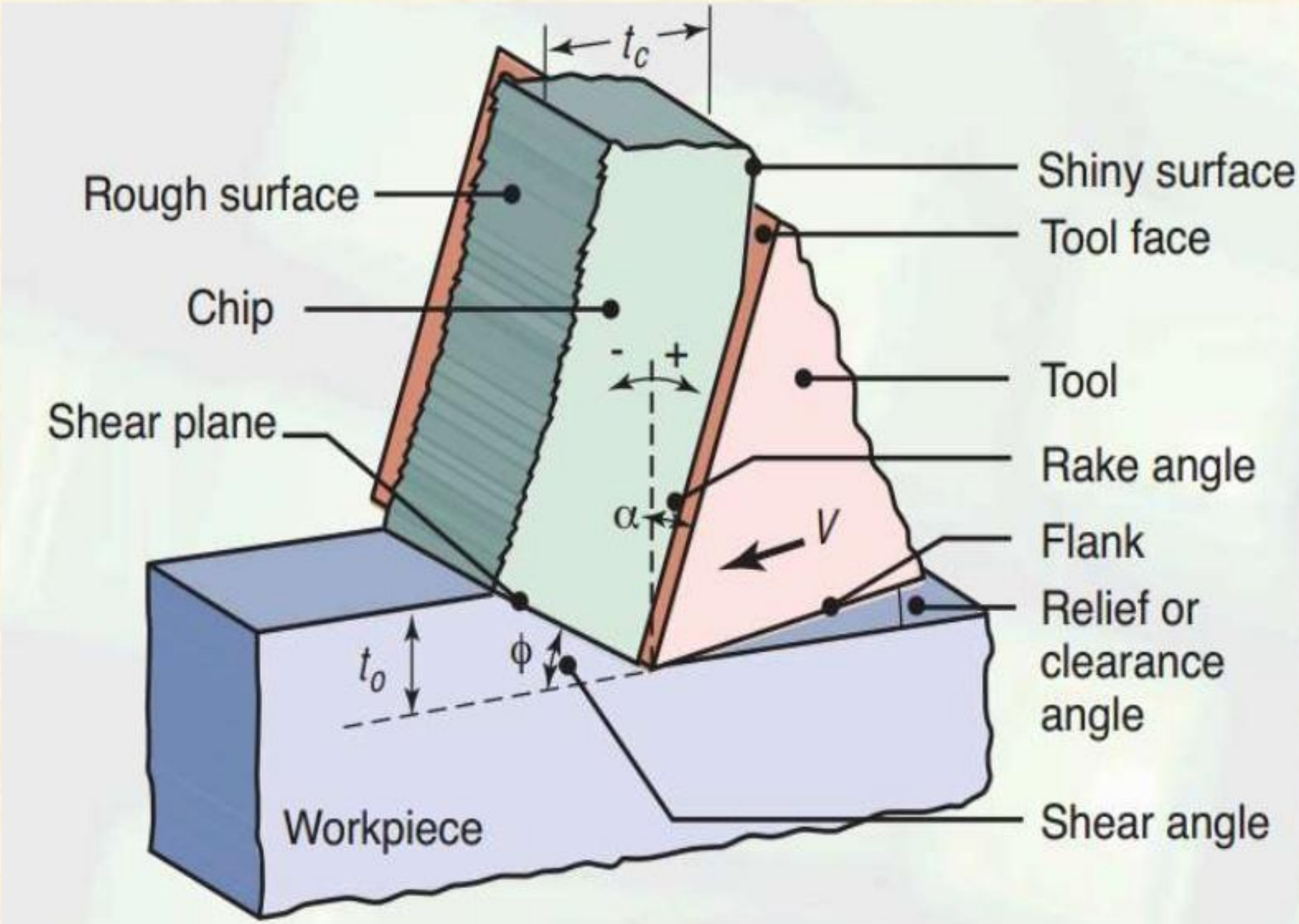
Oblique Cutting:

- The cutting edge of the tool remains inclined at an acute angle to the direction of tool feed or work feed.
- The direction of the chip flow velocity is at an angle with the normal to the cutting edge of the tool. The angle is known as chip flow angle.
- Here three components of forces are acting: Cutting Force, Radial force and Thrust Force or feed force. So the metal cutting may be considered as a three dimensional cutting.
- The cutting edge being oblique, the shear force acts on a larger area and thus tool life is increased.
- Examples are: lathe turning, drilling etc.,
- **Shear force acts on larger area**

Orthogonal cutting

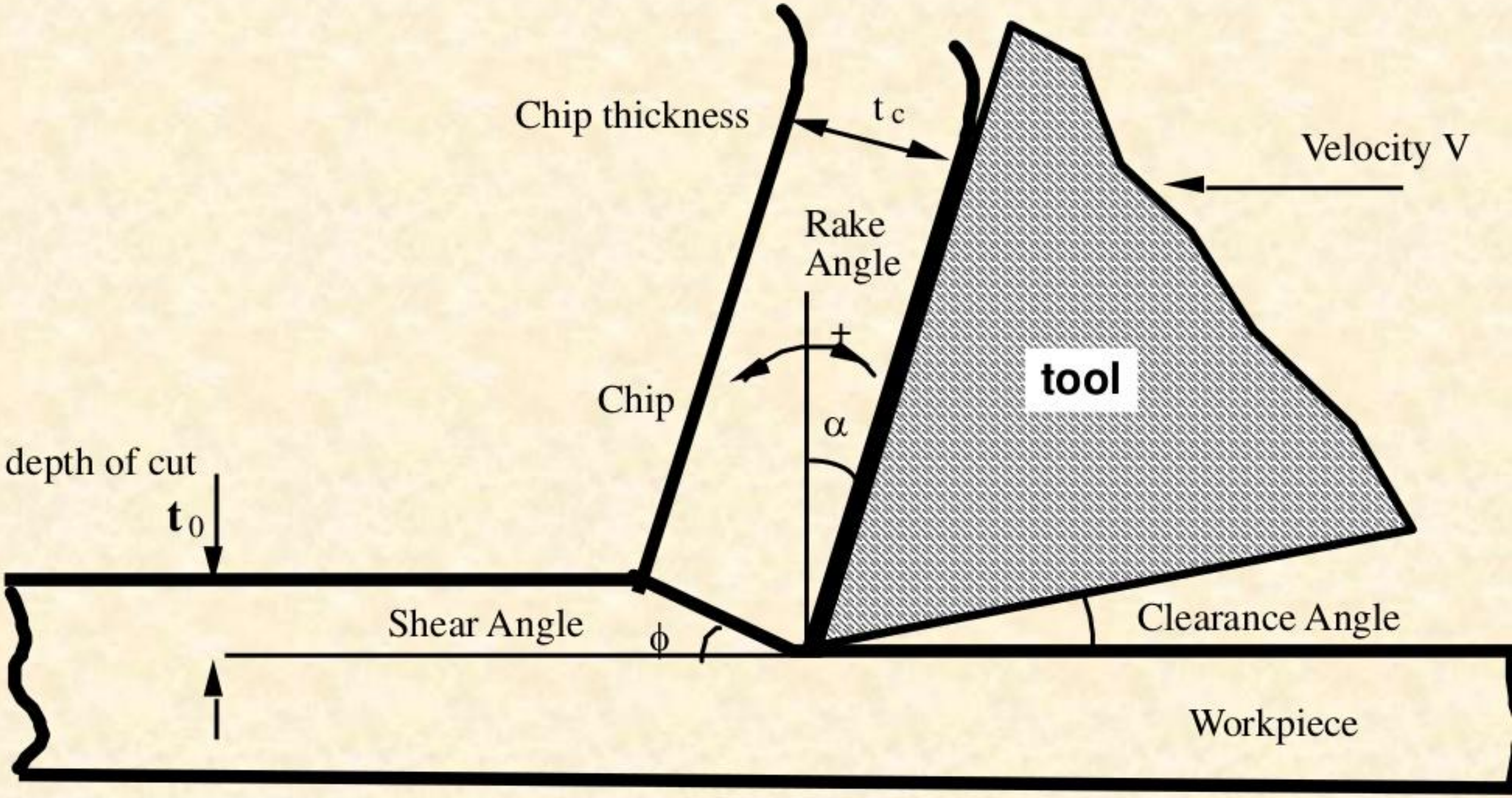


Schematic illustration of a two dimensional cutting process (or) orthogonal cutting



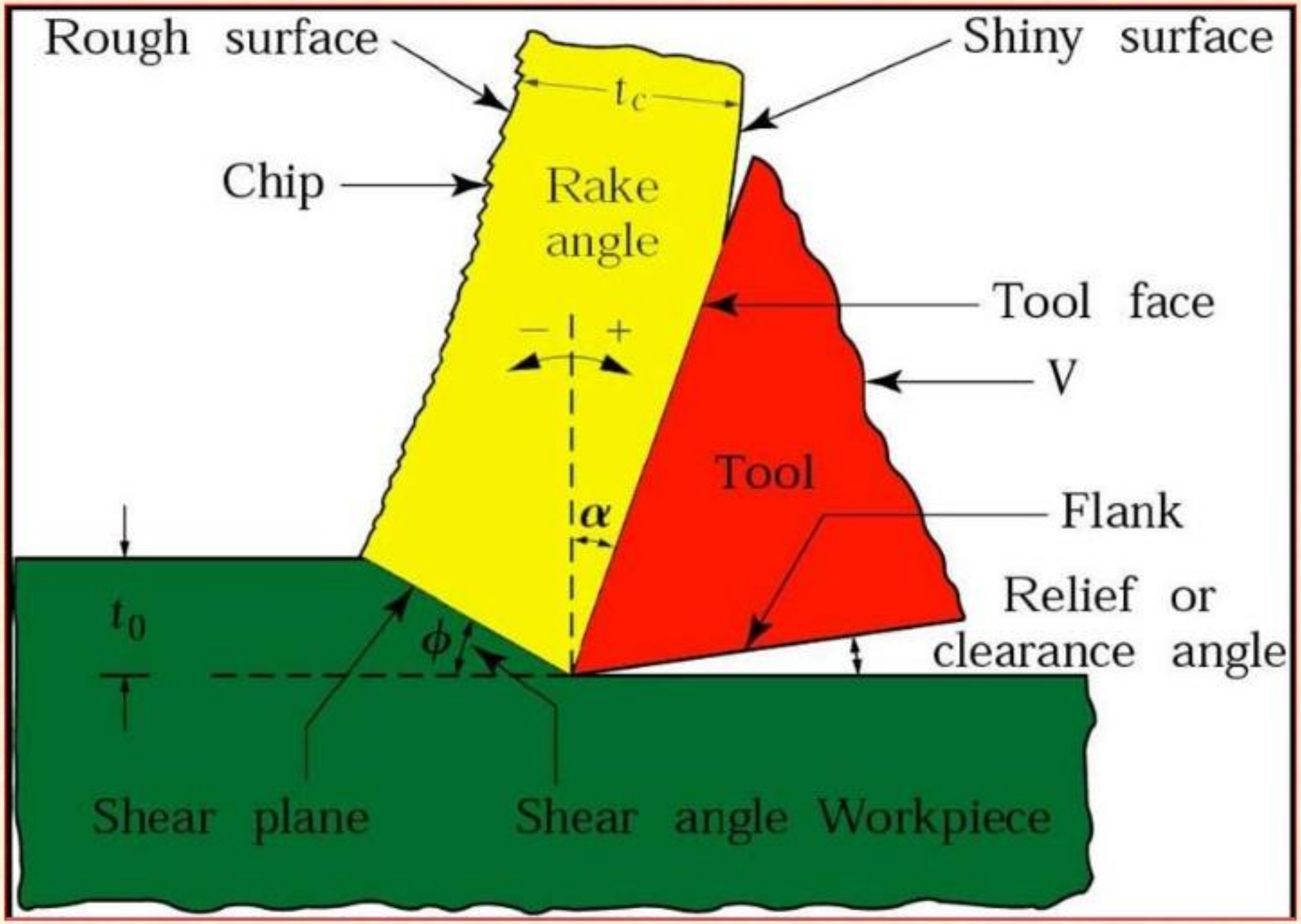
Orthogonal cutting with a well-defined shear plane, also known as the Merchant Model

Orthogonal Cutting Model
(Simple 2D model)



Mechanism: Chips produced by the shearing process along the shear plane

Elements of Metal Cutting



- ✓ The outward flow of the metal causes the chip to be thicker after the separation from the parent metal.
- ✓ That is the chip produced is thicker than the depth of cut.