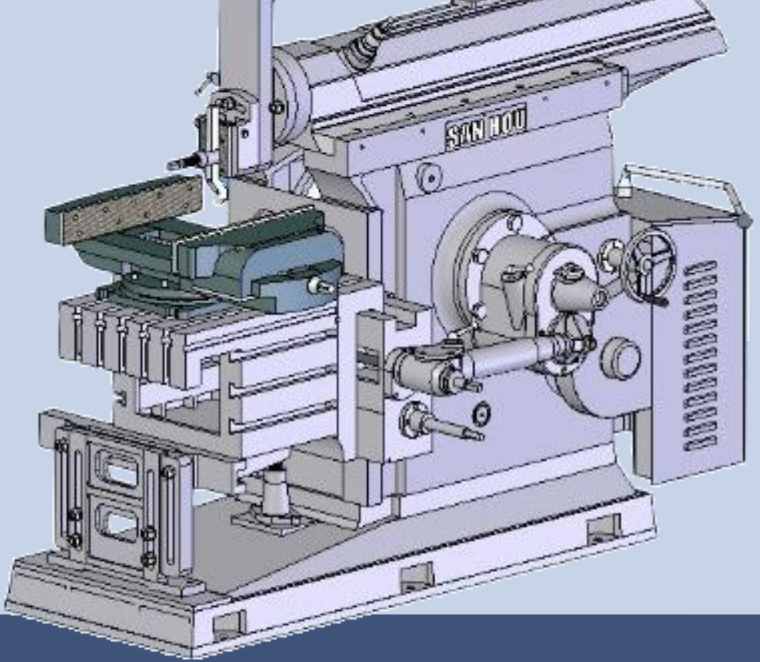
DEPARTMENT OF MECHANICAL ENGINEERING
PARALA MAHARAJA ENGINEERING COLLEGE, SITALAPALLI, BERHAMPUR

MACHINING SCIENCE & TECHNOLOGY

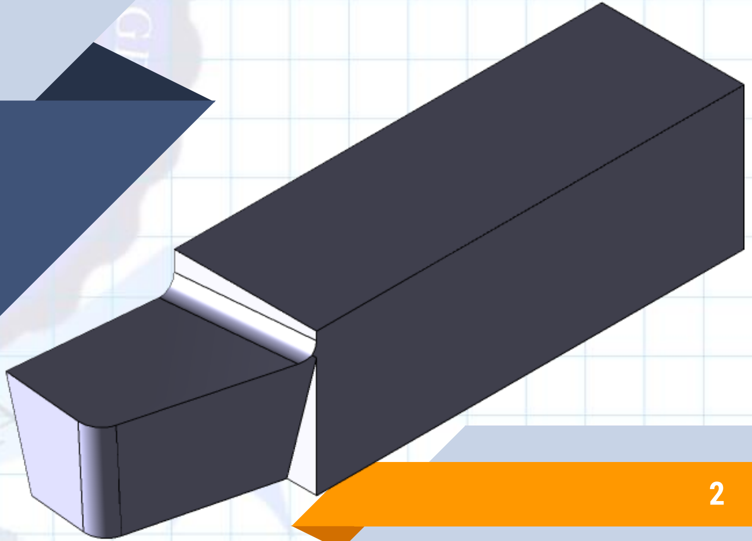
By :Asst.Prof. A.K. Mishra



1

Metal Cutting

Let’s Begin



It is a process of producing a work piece by removing unwanted material from a block of metal in the form of chips.
It is the process of analysing the material removal process for determining
1.Forces induced during machining.
2.Toollife
3. Temperature induced in the machining and power consumption.

Manufacturing Vs Production

- **Manufacturing** Manufacturing is a process of converting converting raw material material into finished product by using various processes, machines and energy, it is a narrow term.
- **Production** is a process of converting inputs in to outputs it is a broader term.

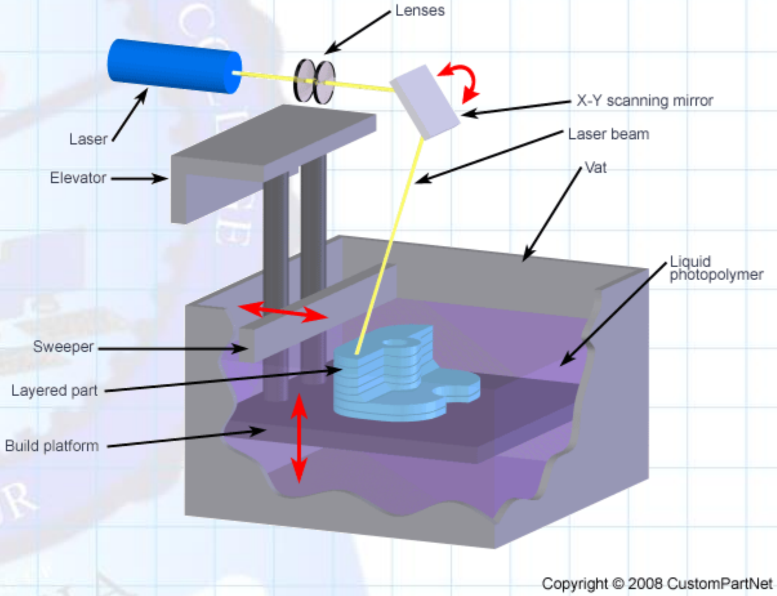
  Eg. ‘crude oil production production’ not ‘crude oil manufacturing
  ‘movie production production’ not ‘movie manufacturing manufacturing’

*** Manufacturing and production are often used interchangeably.**

Classification of Manufacturing Process

- ❑Shaping or forming
- ❑Joining process
- ❑Removal process
- ❑Regenerative manufacturing

Production of solid products products in layer by layer from raw materials in different forms.
liquid – e.g., stereo lithography
powder – e.g., selective sintering
sheet – e.g., LOM (laminated object manufacturing)
wire – e.g., FDM. (Fused Deposition Modeling)
Very rapid, accurate and used for Rapid prototiyping and tooling.

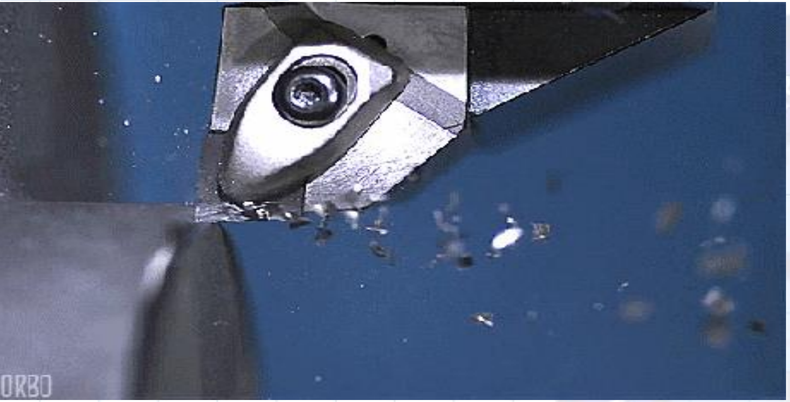


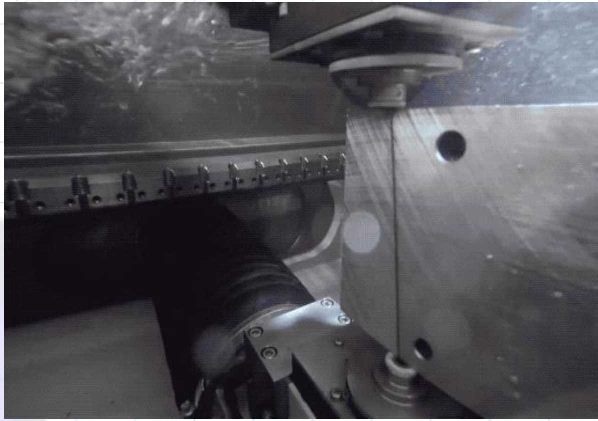
Machining/Metal Cutting

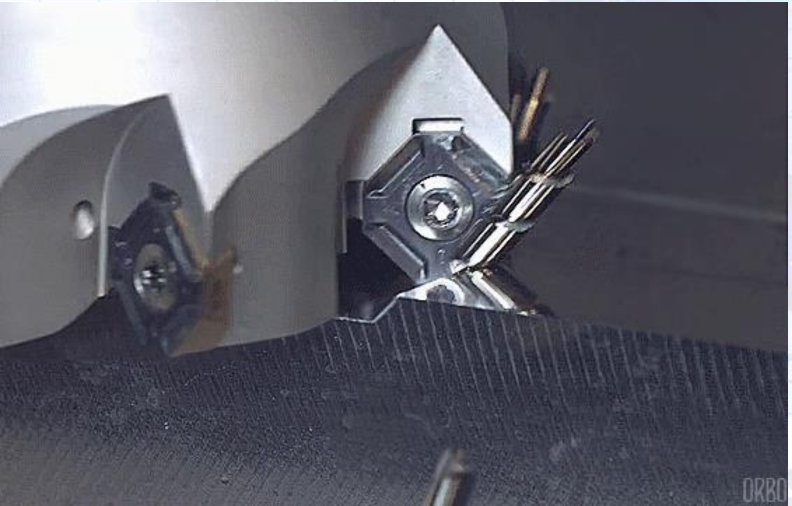
- Machining is an essential process of finishing by which jobs are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting cutting tools moved past the work surface.
- Machining is a removal process.

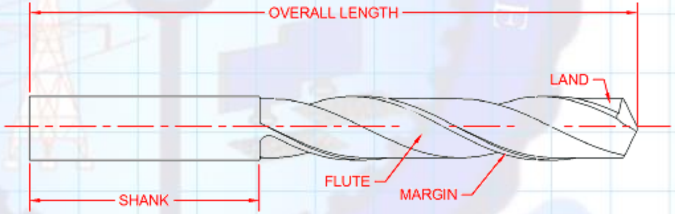
Machining

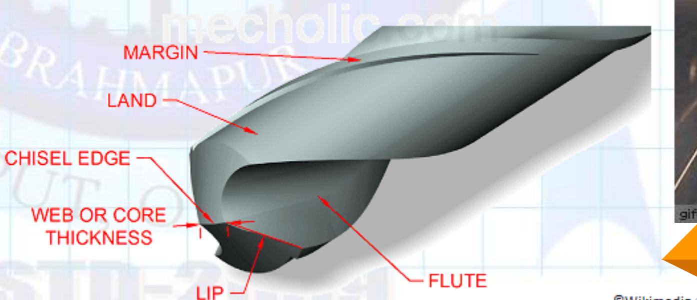
- Conventional
  - Single point cutting
  - Double point cutting
  - Multipoint cutting
- Non-Conventional
  - mehanical
  - Thermal
  - Chemical & Electrochemical


ORBO




ORBO


OVERALL LENGTH
LAND
SHANK
FLUTE
MARGIN


mecholic.com
MARGIN
LAND
CHISEL EDGE
WEB OR CORE
THICKNESS
LIP
FLUTE


gif-finder.com

Pros and cons of single point and multi-point cutting tools	
Single point cutting tool	**Multi-point cutting tool**
1. Easy to design and fabrication.	1. Small chip load per tooth.
2. Comparatively cheaper.	2. Facilitates higher speed, feed, DOC.
3. High tool wear rate.	3. High MRR and productivity.
4. Shorter tool life.	4. Reduced tool wear.
5. High cutting temperature.	5. Lower cutting temperature.
6. Thermal damage.	6. Longer tool life.
7. Low material removal rate (MRR).	7. Complicated design & fabrication.
8. Low productivity.	8. Costlier.
	9. Inherently intermittent cutting.

Machining Tool

A machine tool is a non-portable portable power operated and reasonably valued device or system of device in which energy is expended to produce jobs of desired size, shape and surface finish by removing excess material from the preformed blanks in the form of chips with the help of cutting tools moved past the work surface.

Machining Tool Vs Machine

Machine	Machine Tool
• It is used to complete an **action** or **process** the things.	• It is used to **cut** and **remove the materials** to give a particular shape to the workpiece.
• Examples of Machine are Printing Machine, Laminating Machine, Packing Machine, Food Processing Machine, etc.	• Examples of Machine tools are Lathe, Shaper, Planer, Grinder, Miller, etc.
• They are **fixed** at one place and even can be moved to other place with lots of effort according to the importance to perform the required actions.	• They can be **carry** to everywhere and perform the required actions. They may Hand Saw, Hand Cutter, Hand Grinder, Hand Driller, etc.

Generatrix & Directrix

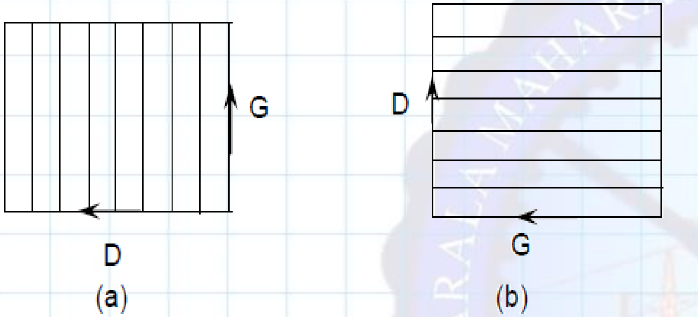
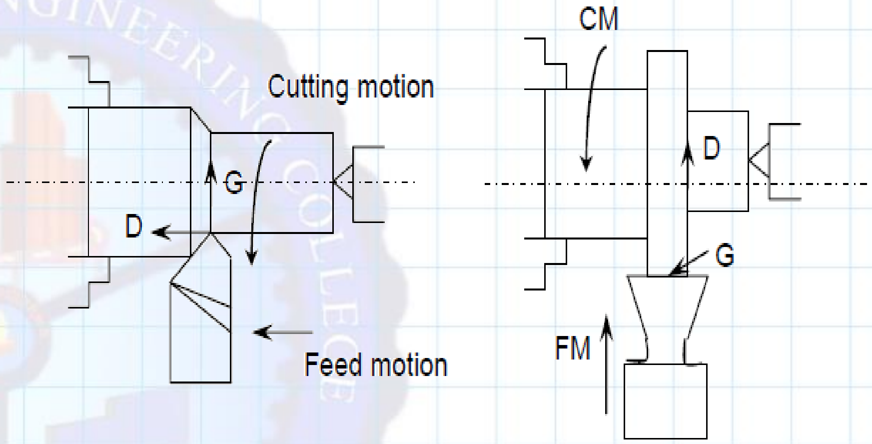


Fig. Generation of flat surfaces by Generatrix and Directrix.



(a) longitudinal turning (b) transverse turning

Fig. 2.3 Principle of turning (cylindrical surface)

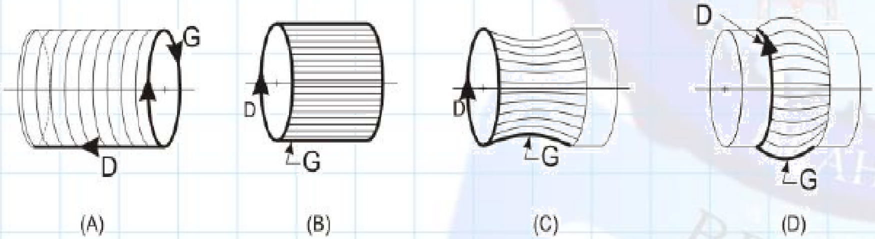


Fig. Generation of cylindrical surfaces (of revolution)

The connections in case of straight longitudinal turning shown in Fig. 2.3 (a) are:

Generatrix (G) – Cutting motion (CM) – Work (W)
Directrix (D) – Feed motion (FM) – Tool (T)

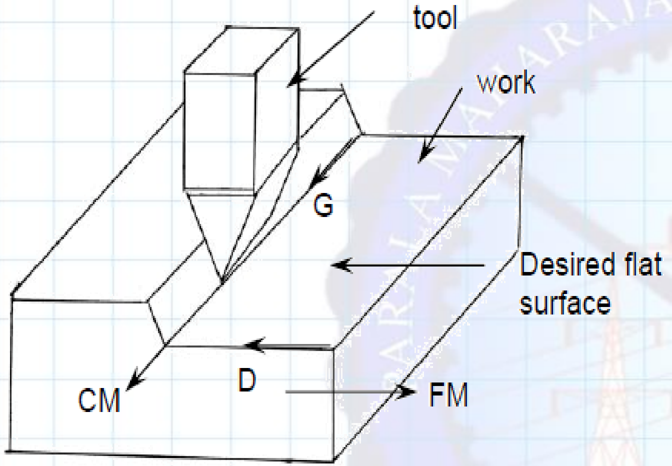


Fig. Principle of producing flat surface in shaping machine

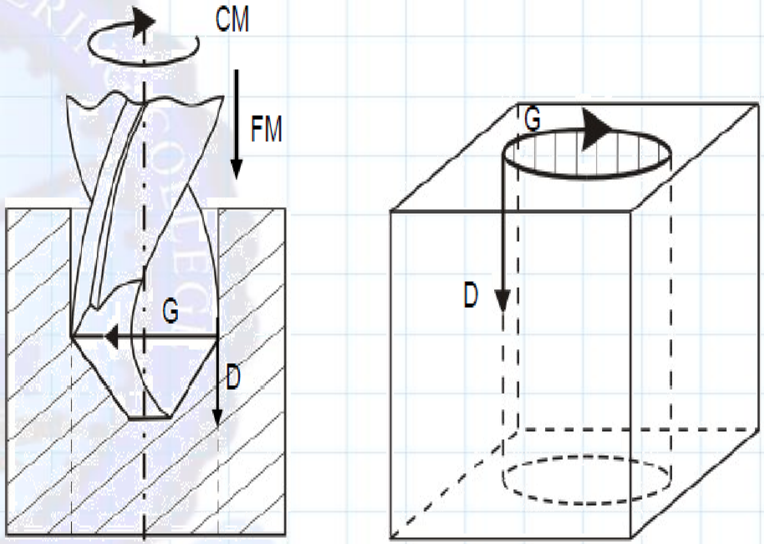
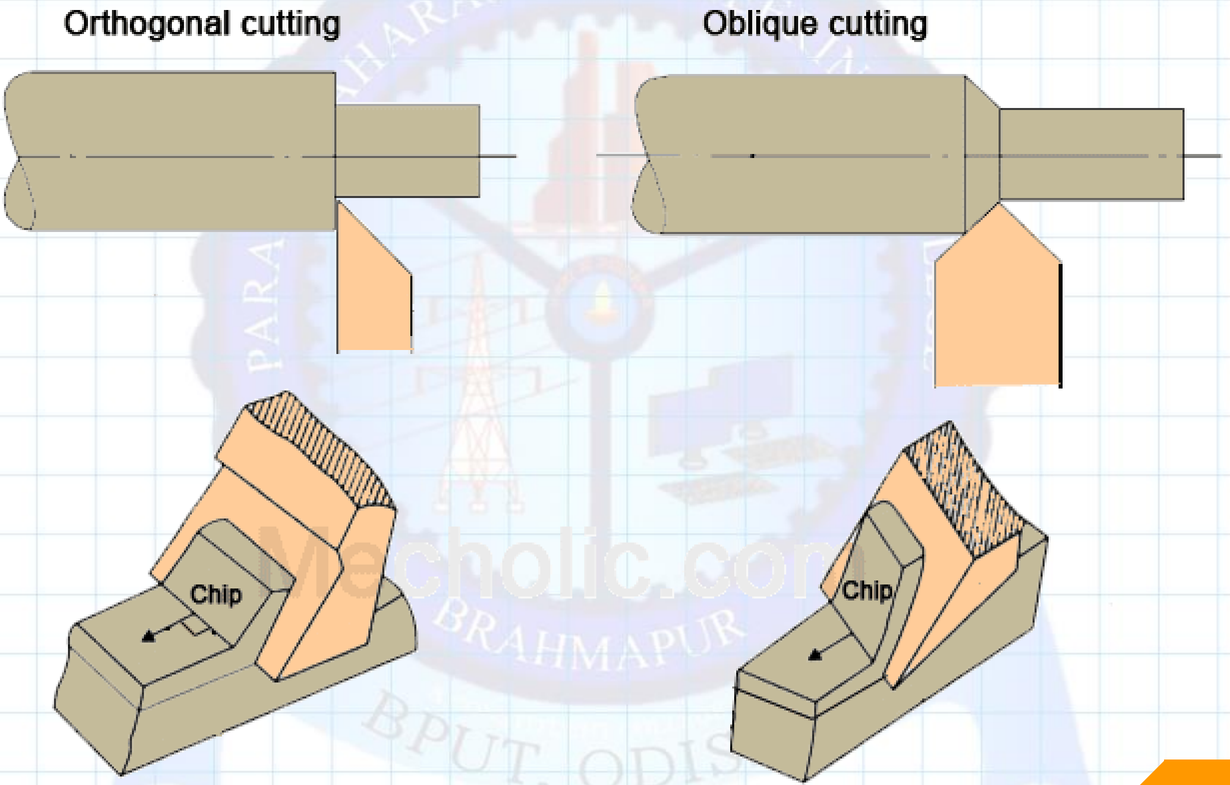


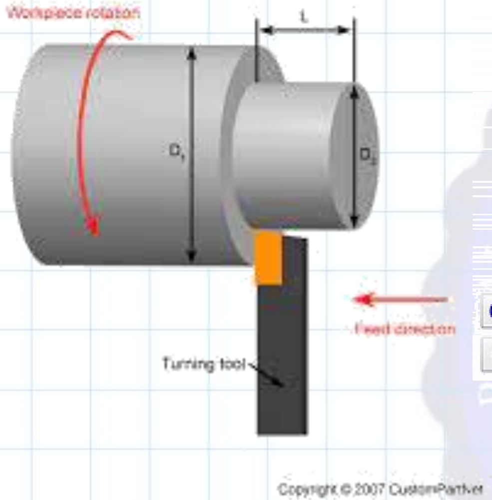
Fig. 2.8 Tool-work motions and G & D in drilling.

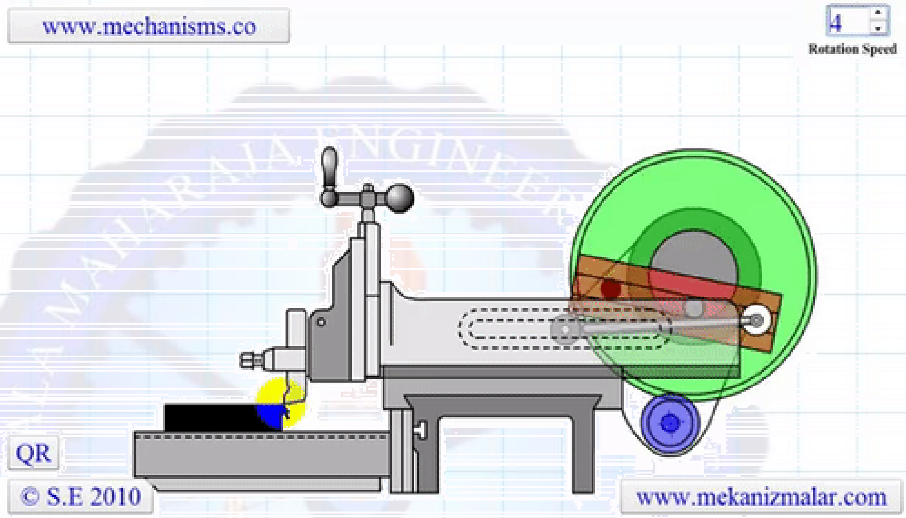
In case of making flat surface in a shaping machine as shown in Fig. the connections are:

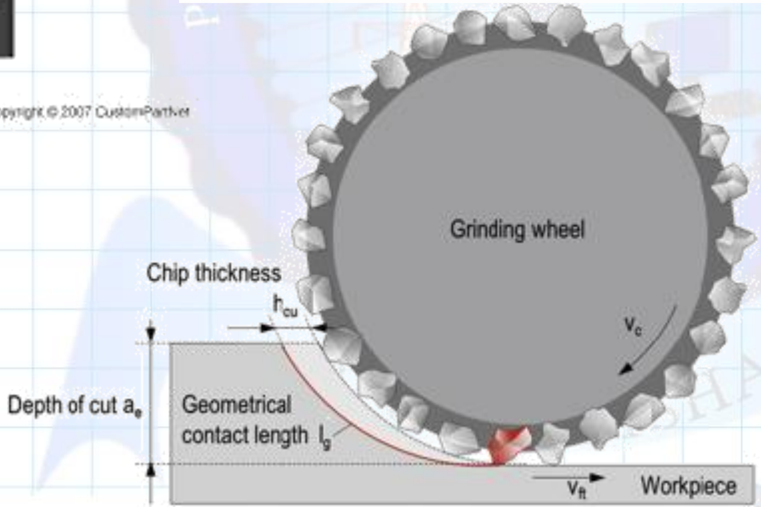
G – CM – T
D – FM – W

Machining Technique




Workpiece rotation
L
Feed direction
Turning tool
Copyright © 2007 CustomPartNet


www.mechanisms.co
4
Rotation Speed
QR
© S.E 2010
www.mekanizmalar.com


Grinding wheel
Chip thickness
Depth of cut a
Geometrical
contact length
Workpiece

Tool Geometry

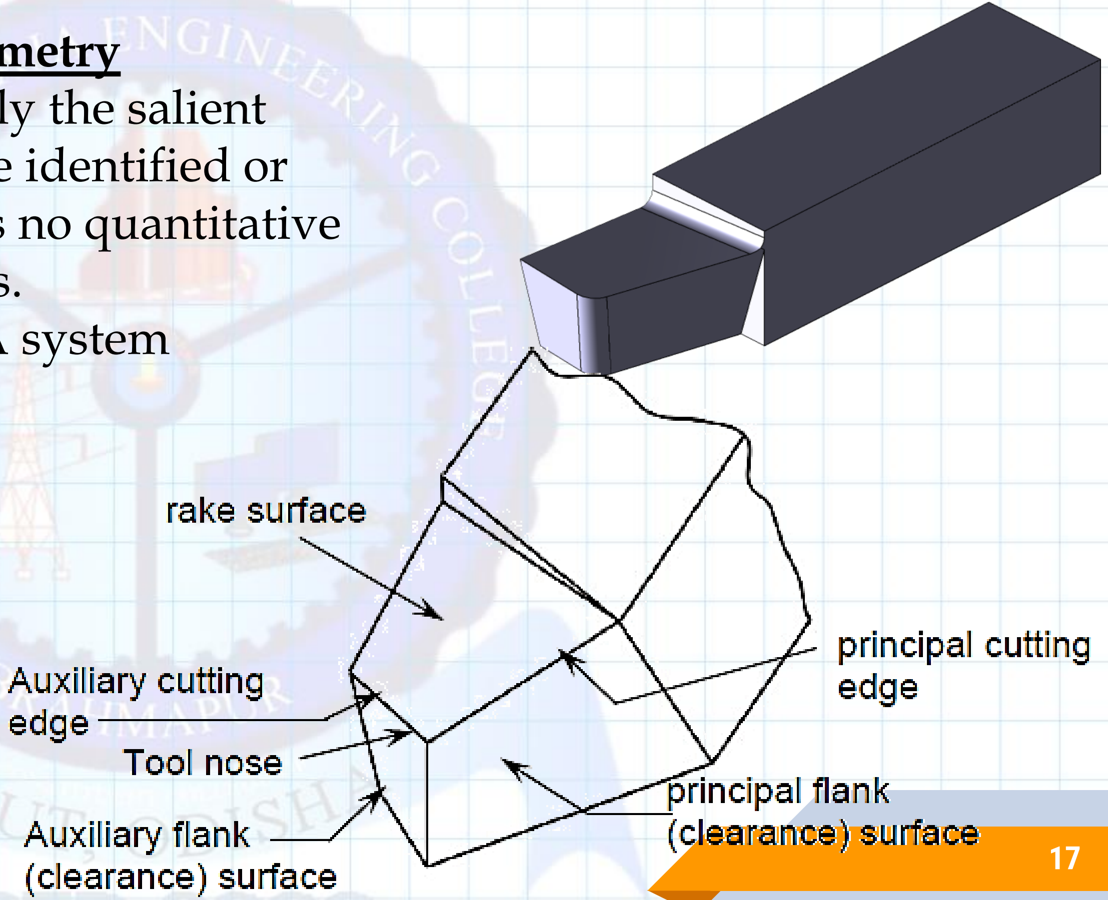
<u>Systems of description of tool geometry</u>

- Tool-in-Hand System – where only the salient features of the cutting tool point are identified or visualized as shown in Fig. There is no quantitative information, i.e., value of the angles.
- Machine Reference System – ASA system
- Tool Reference Systems

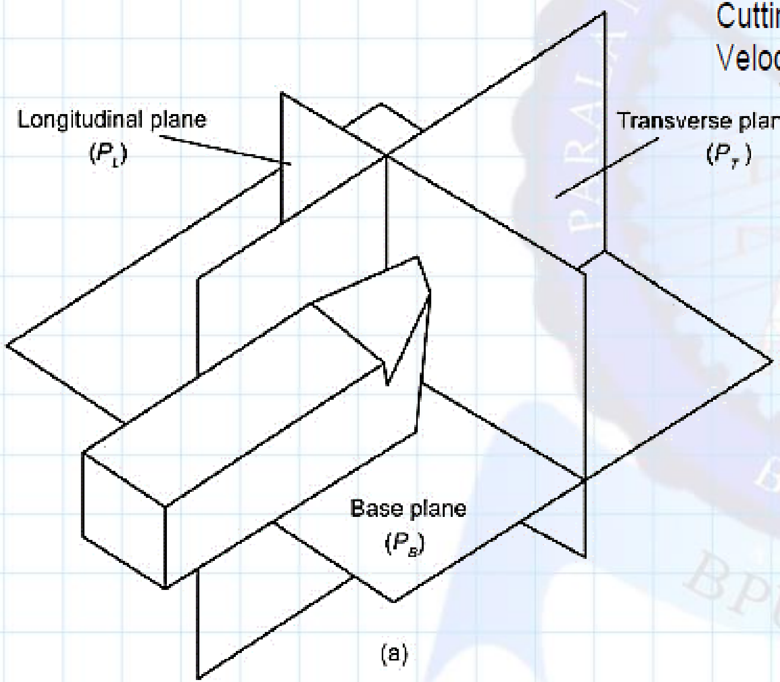
∗ Orthogonal Rake System – ORS

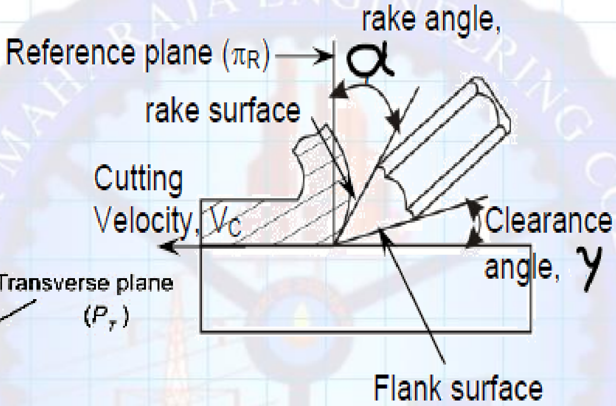
∗ Normal Rake System – NRS

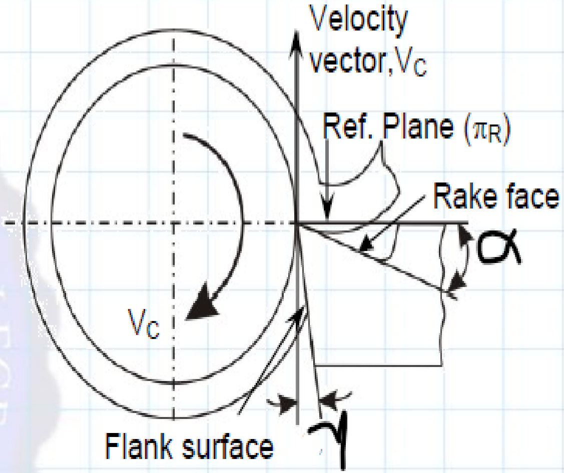
- Work Reference System – WRS

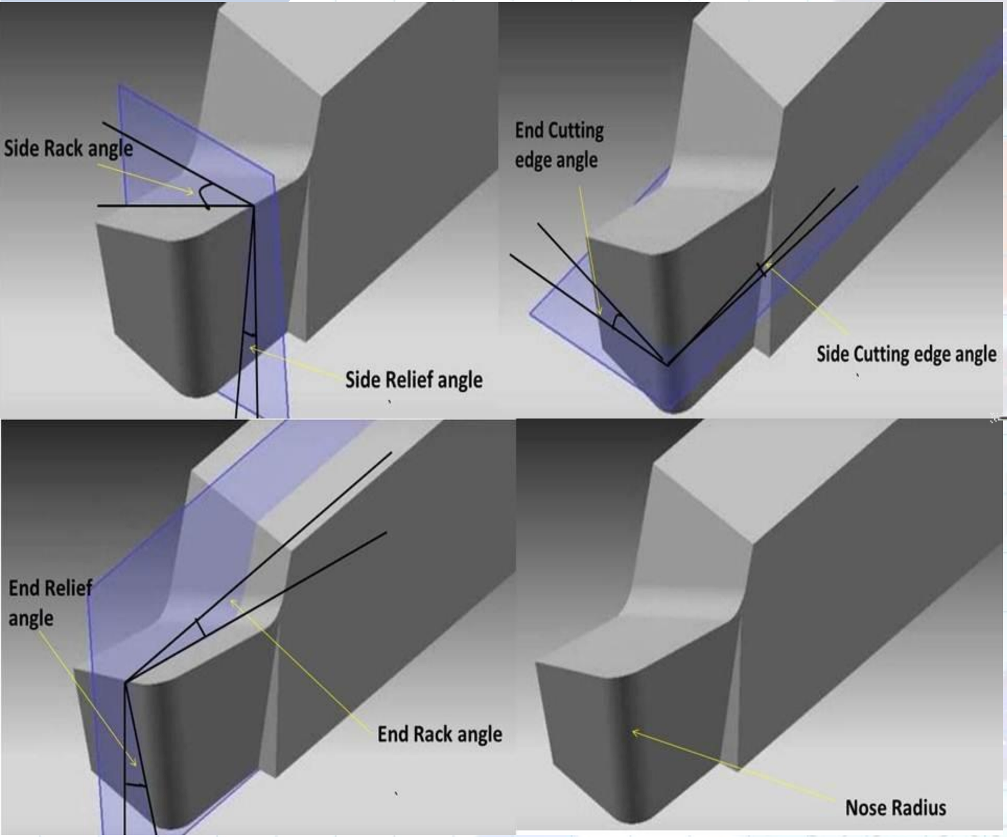


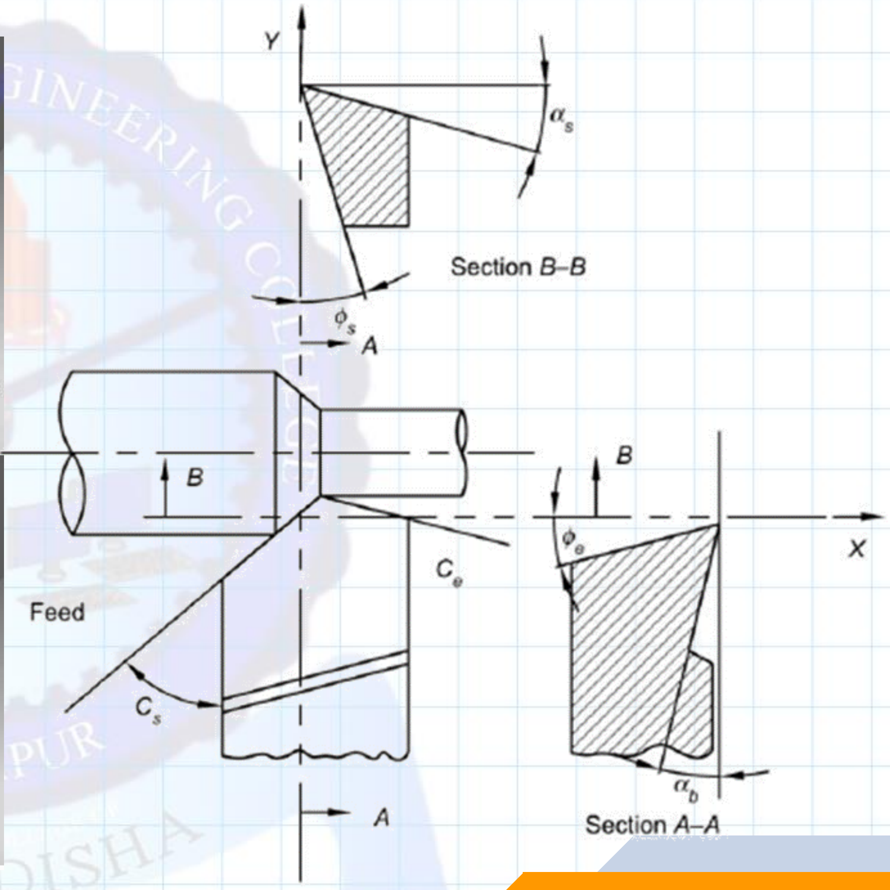
Tool Geometry: Machine reference system








Side Rack angle
End Cutting edge angle
Side Cutting edge angle
Side Relief angle
End Relief angle
End Rack angle
Nose Radius

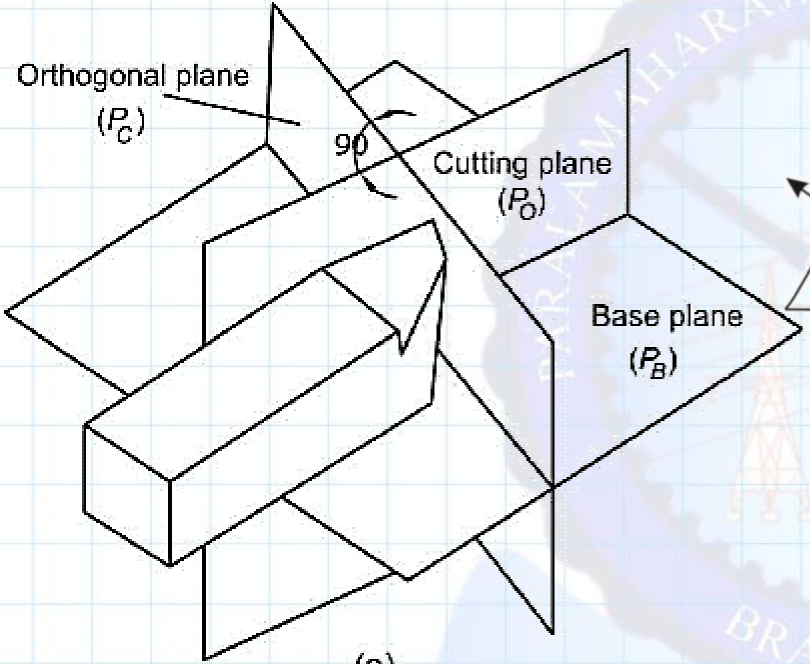

Y
α_s
Section B–B
ϕ_s
A
B
B
X
ϕ_e
C_e
Feed
C_s
α_b
A
Section A–A

(b)

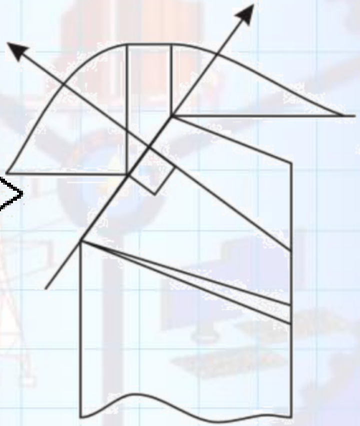
- *Back rake angle* (α_b)—Angle of inclination of the rake surface from the base plane (P_B) and measured on machine transverse plane, P_T.
- *Side rake angle* (α_s)—Angle of inclination of the rake surface from the base plane (P_B) and measured on machine longitudinal plane, P_L.
- *End relief angle* (φ_e)—Angle of inclination of the principal flank from the machined surface and measured on P_T plane.
- *Side relief angle* (φ_s)—Angle of inclination of the principal flank from the machined surface and measured on P_L plane.
- *End cutting-edge angle* (C_e)—Angle between the end cutting edge (its projection on P_B) from P_L and measured on P_T.
- *Side cutting-edge angle* (C_s)—Angle between the principal cutting edge (its projection on P_B) and P_T and measured on P_B.

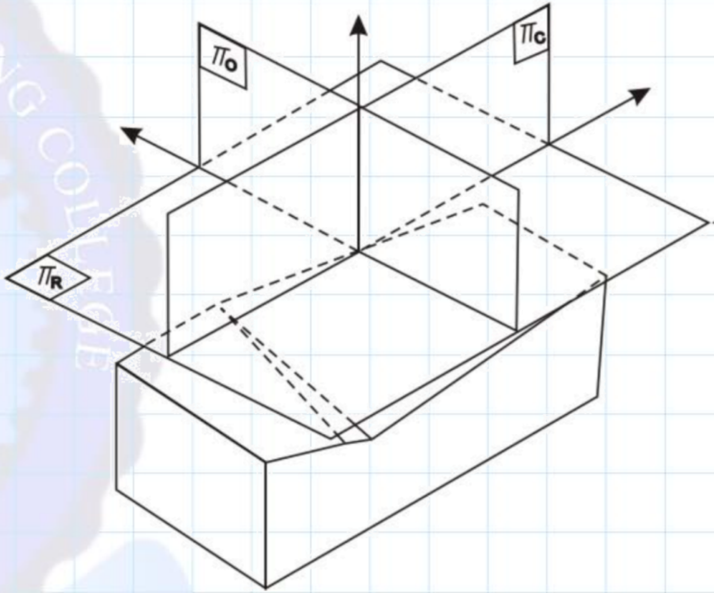
Tool signature: $\alpha_b - \alpha_s - \gamma_e - \gamma_s - \psi_e - \psi_s - R$

Tool Geometry: Tool reference system

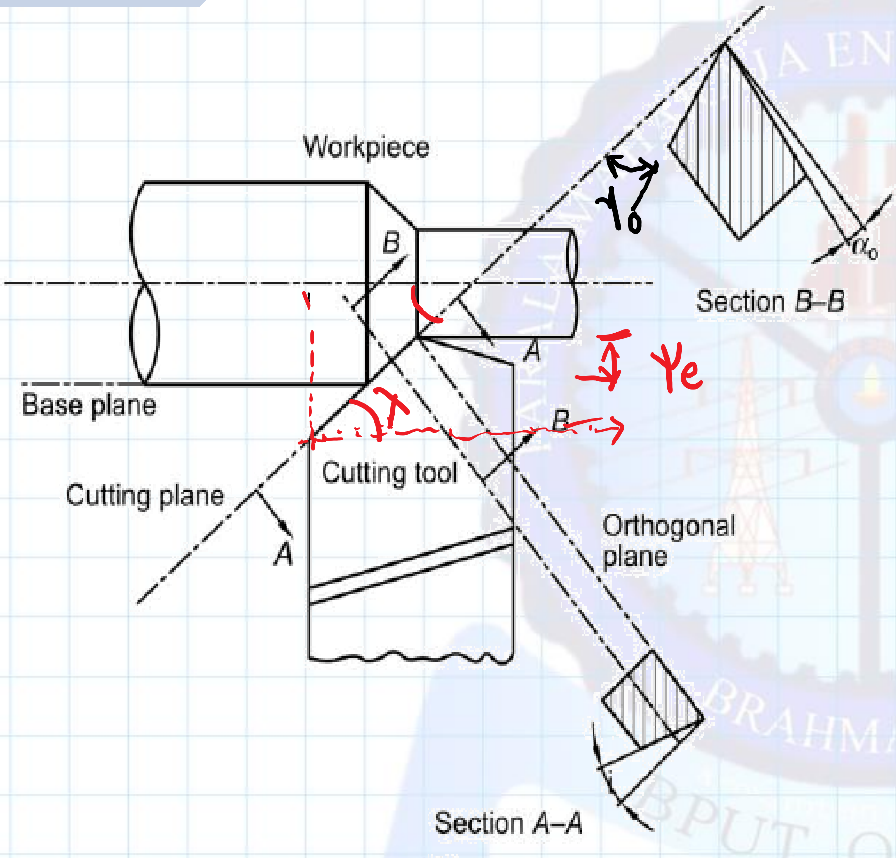


(a)





Tool Geometry: ORS



(b)

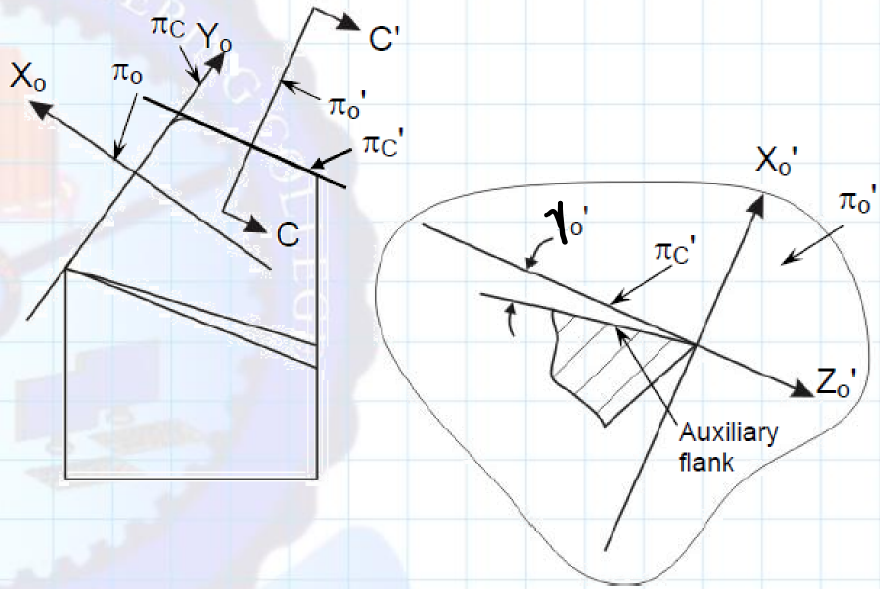


Fig. Auxiliary orthogonal clearance angle

ORS: Tool Angles

- **αo = orthogonal rake**: angle of inclination of the rake surface from Reference plane, πR and measured on the orthogonal plane, π**o.**
- **i = inclination angle**; angle between πC from the direction of assumed longitudinal feed [πL] and measured on πC.
- **γo = orthogonal clearance of the principal flank**: angle of inclination of the principal flank from πC and measured on πo.
- **γo′ = auxiliary orthogonal clearance**: angle of inclination of the auxiliary flank from auxiliary cutting plane, πc′ and measured on auxiliary orthogonal plane, πo′.
- **λ = principal cutting edge angle**: angle between πc and the direction of assumed longitudinal feed or πL and measured on πR
- **ψe = auxiliary cutting angle**: angle between πc′ and πL and measured on πR.
- **Nose radius**, r (mm) r = radius of curvature of tool tip.

* $i - \alpha_o - \gamma_o - \gamma_o' - \psi_e - \lambda$ - R(in mm)

Conversion of tool angles from one system to another

- **Conversion of tool rake angles from ASA to ORS**

$$\tan i = \tan\alpha_b . \cos\psi_s - \tan\alpha_s . \sin\psi_s$$

$$\tan\alpha_o = \tan\alpha_s . \cos\psi_s + \tan\alpha_b . \sin\psi_s$$

ASA → $\alpha_b - \alpha_s - \gamma_e - \gamma_s - \psi_e - \psi_s - R$ (in inch)

ORS → $i - \alpha_o - \gamma_o - \gamma_o' - \psi_e - \lambda - R$ (in mm)

- **Conversion of rake angles from ORS to ASA system**

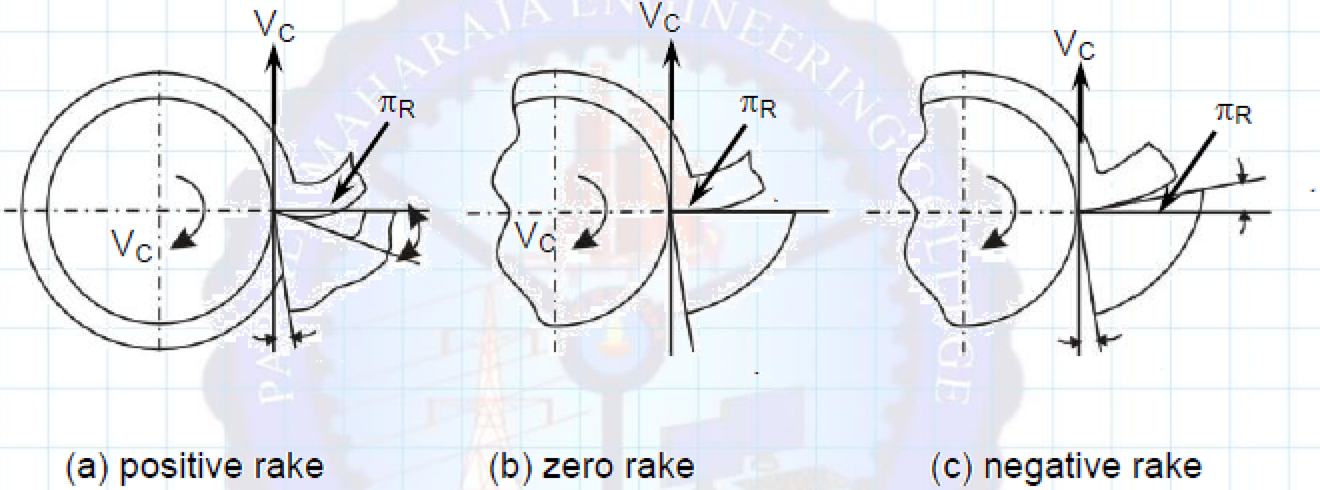
$$\tan\alpha_b = \tan\alpha_o . \sin\psi_s + \tan i . \cos\psi_s$$

$$\tan\alpha_s = \tan\alpha_o . \cos\psi_s - \tan i . \sin\psi_s$$

Purpose :-

- To understand the actual tool geometry in any system of choice or convenience from the geometry of a tool expressed in any other systems
- To derive the benefits of the various systems of tool designation as and when required
- Communication of the same tool geometry between people following different tool designation systems.

Tool Geometry: Significance of Tool Angles



- ❑ Positive rake – helps reduce cutting force and thus cutting power requirement.
- ❑ Negative rake – to increase edge-strength and life of the tool
- ❑ Zero rake – to simplify design and manufacture of the form tools.

Tool Geometry: Significance of Tool Angles

- **Side Rake Angle α_s (5˚-15˚)**

I. Guides the direction of the chip away from the job.

II. Chip bending depends upon α_s - **Chip bending ↓; αs ↑**

- **Clearance/Relief Angle**

I. Clearance angle is essentially provided to avoid rubbing of the tool (flank) with the machined surface which causes loss of energy and damages of both the tool and the job surface. Hence, clearance angle is a must and must be positive (3˚ ~ 15˚) depending upon tool-work materials and type of the machining operations like turning, drilling, boring etc.)

II. Side relief angle: this angle permits the tool to be fed side ways in to the job so that it can cut without rubbing.

III. If very large: cutting edge will breaks with out getting enough support.

IV. If very small: the tool can not be fed in to the job, and it will rub against the job , will get over heated and become blunt . Surface finish will be rough.

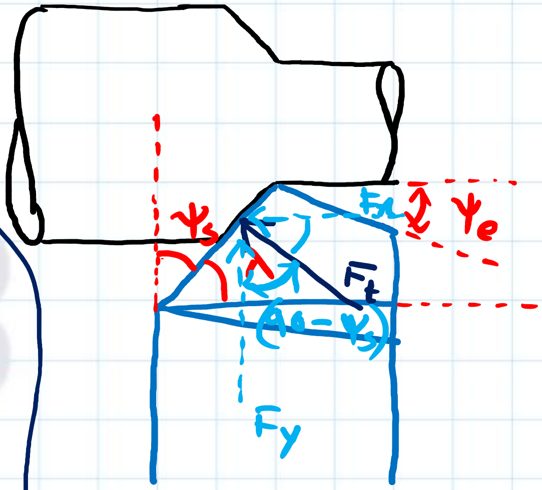
Tool Geometry: Significance of Tool Angles

❑ Cutting Edge Angles:

1. **Side Cutting/Principal Cutting edge angle:**

This component of force try to separate tool & workpiece which may introduce self exciting vibration (Chatter).

$$F_y = F_t \sin(\psi_s) \quad \text{(Thrust Force)}$$



$$F_y = F_t \cos(90 - \psi_s) = F_t \sin \psi_s$$

$$F_x = F_t \cos \psi_s$$

2. **End Cutting/Auxiliary Cutting Edge:**

It acts as relief angle that allows only small section of the cutting edge to contact with the machined surface And prevents chatter and vibration.

Tool Geometry: Significance of Tool Angles

❑ **Nose Radius (R):(0.2mm -1.2 mm)**

I. It is provided to increase the surface finish and strength of cutting tip of the tool.
II. Small radii produce smooth surface finish and are used on thin cross section of the work.
III. Large radii strengthen the tool and are used on cast iron and casting.
IV. Too large nose radius will induce chatter.
V. With increase in nose radius the surface finish increases first then it decreases.

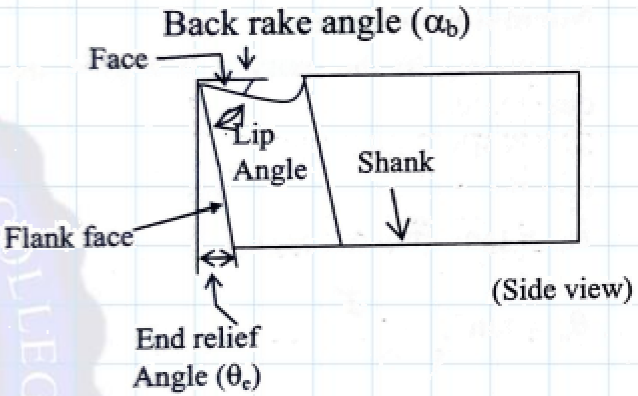
❑ Lip Angle

I. The angle between face and flank of the tool.

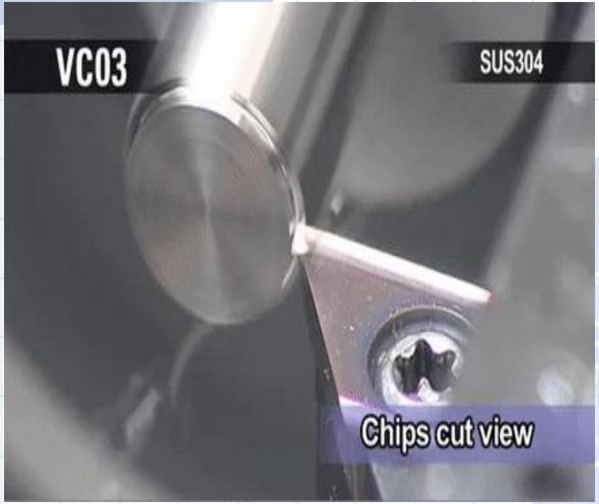
II. Strength of cutting edge or tip of the tool is directly affected by this.

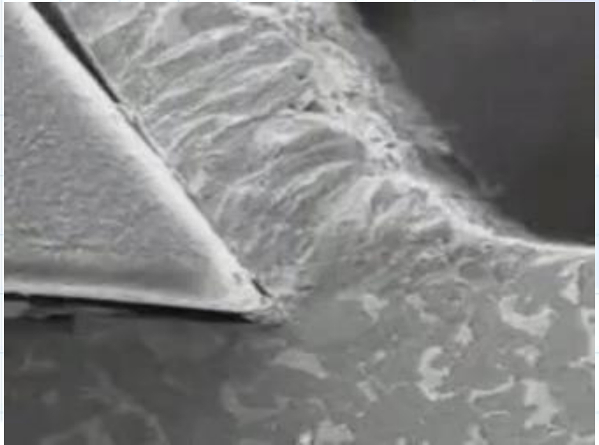
III. Larger the lip angle stronger will be the cutting edge.

IV. Since the clearance angle remains constant lip angle varies inversely with the rake angle.



Mechanism of chip formation





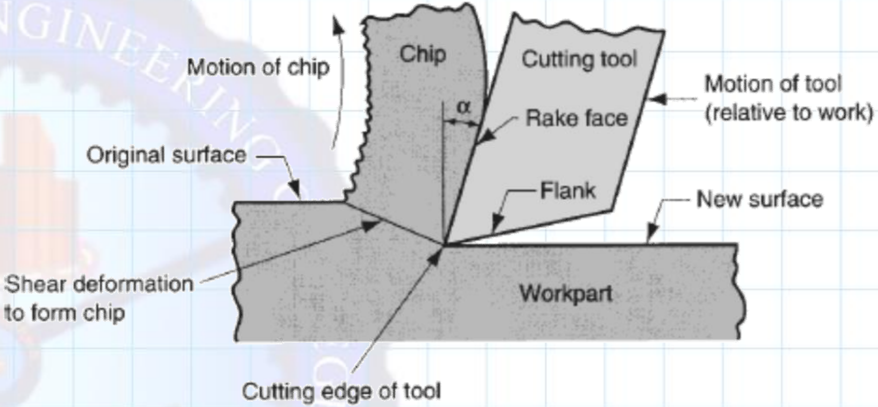
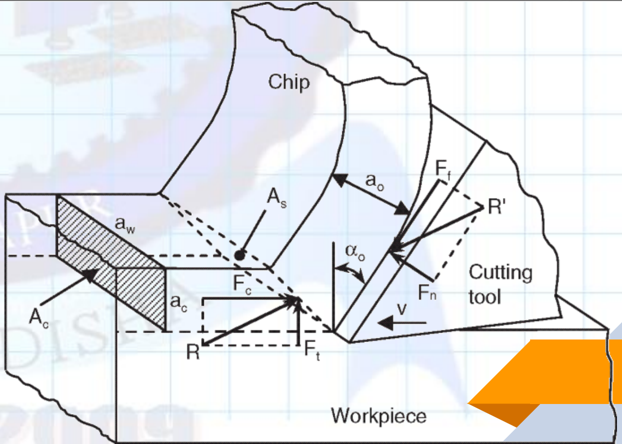


Figure :- Mechanism of chip formation



- In any machining material from the work is removed in the form of chip.
- Chips are formed due to shearing and tearing.
- When a force is applied by using tip up tool on to the layer of work piece material, the material is started deforming plastically and sliding over the rake face of tool inducing shear stresses on the layer of work piece material.
- On further application of the force using the tool, the shear stresses induced in the layer of work material are increasing continuously.
- At some point, the shear stresses induced will become greater than or equal to the ultimate shear stresses of work material.
- Then the shearing or cracking is taking place at the tip of the tool and it is propagating towards the surface of the workpiece producing shear plane.
- From the mechanism by which chip formation taking place is shearing and tearing action.

Piispanen Theory of Chip formation

- Plastic deformation can be caused by yielding, in which case strained layers of material would get displaced over other layers along the slip-planes which coincide with the direction of maximum shear stress.
- Piispanen presented an interesting mechanism to account for the deformation process taking place at the cutting edge. He considers the undeformed metal as a stack of cards which would slide over one another as the wedge-shaped tools move under these cards as shown in Fig..
- Though this idea is an oversimplified one, it would generally account for a number of features that are found to be in practice. A practical example is when paraffin is cut; block wise slip is clearly evident.

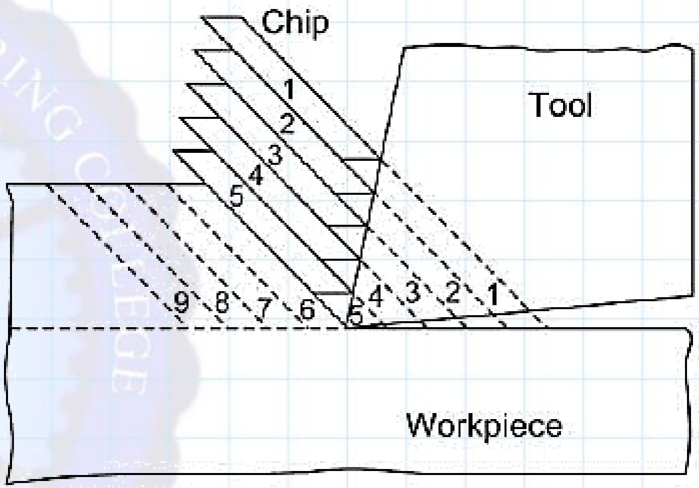
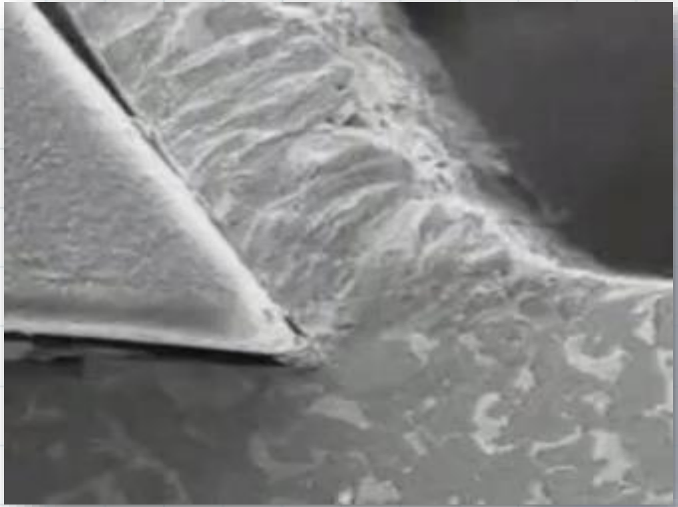
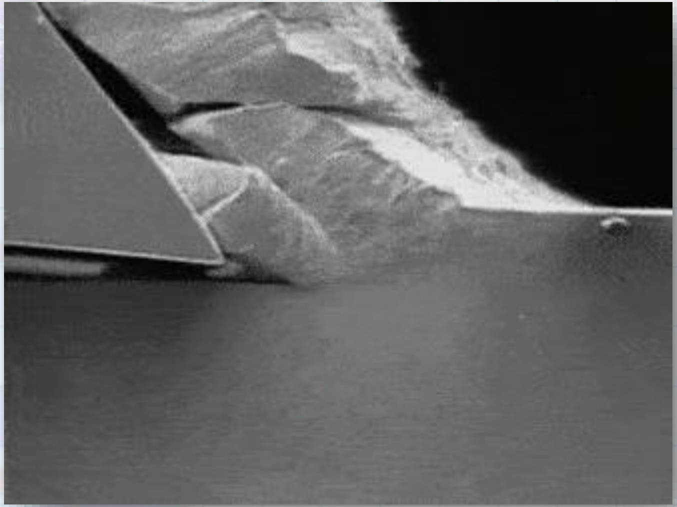


Fig. *Piispanen's model of metal cutting*

Built up edge(BUE)



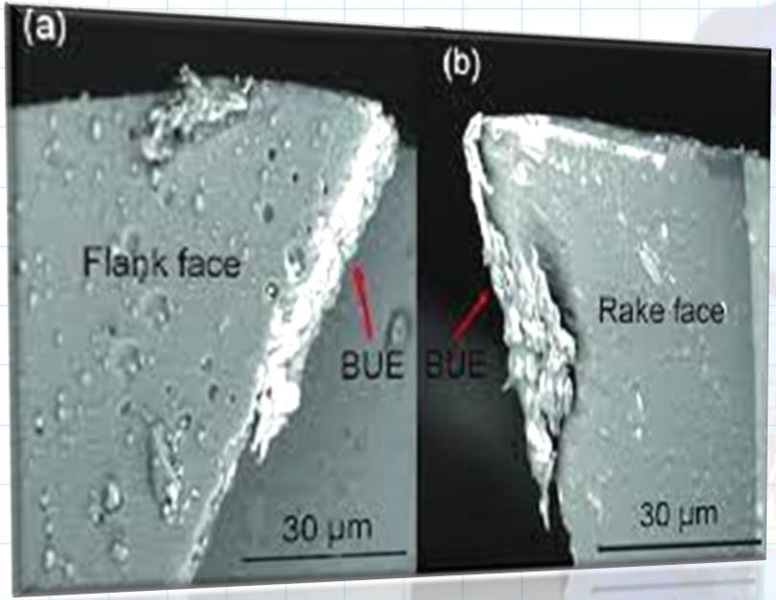


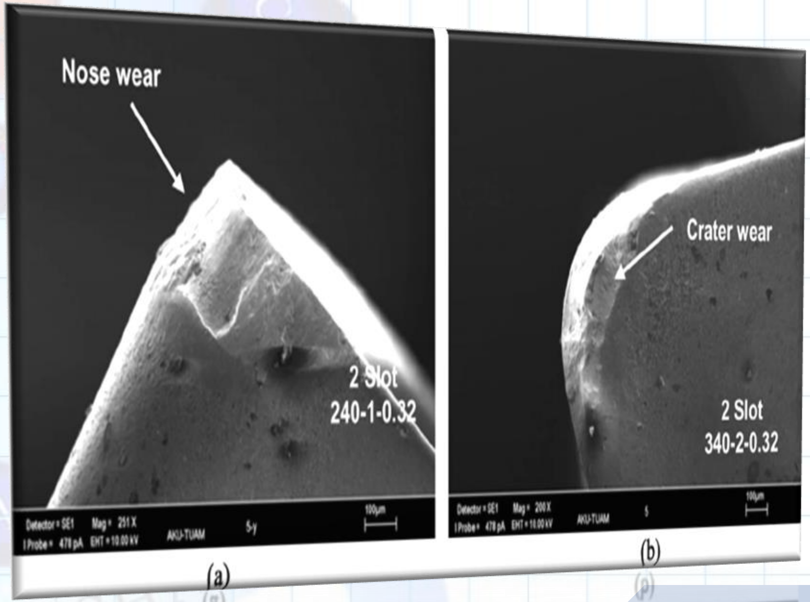
- Built of Edge formation: When machining ductile materials, conditions of high local temperature and extreme pressure in the cutting zone and also high friction in the tool chip interface amy cause the work material to adhere or weld to the cutting edge of the tool forming the BUE.

- ❑ BUE formation takes place only with continuous chip.
- ❑ As in case of discontinuous chips the chips are simply thrown away from the machining zone so there is no chance of adhering micro chips to the rake face of the tool. So no BUE will form.
- ❑ Formation of BUE increases the tool life.

❑ **Disadvantages:**

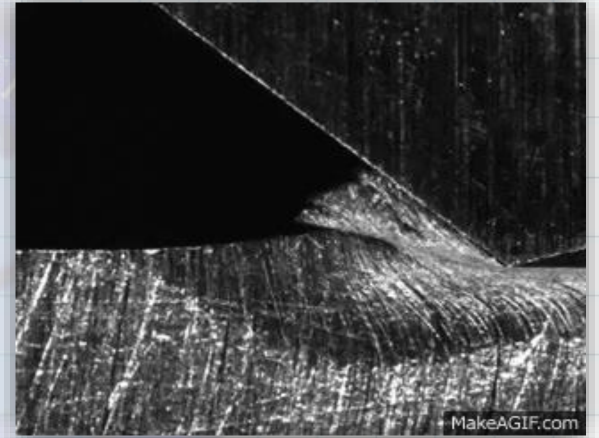
1. Rough surface finish on the work piece.
2. Fluctuating cutting force causing vibration on the cutting tool.
3. Chances of carrying away some material from the tool by built up surface , producing ***Crater** on the tool face causing tool wear.


(a)
(b)
Flank face
BUE
BUE
Rake face
30 µm
30 µm


Nose wear
2 Slot
240-1-0.32
Crater wear
2 Slot
340-2-0.32
(a)
(b)

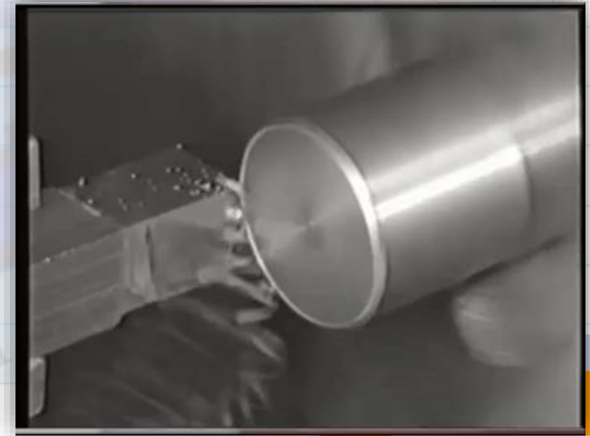
Types of Chip Formation

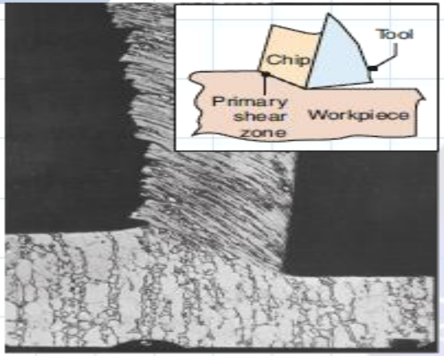
1.Discontinuous Chip



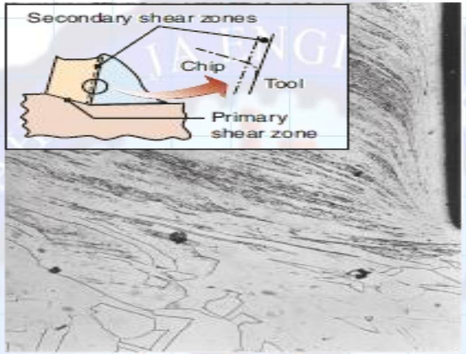
2.Continuous Chip

- With out BUE
- With BUE

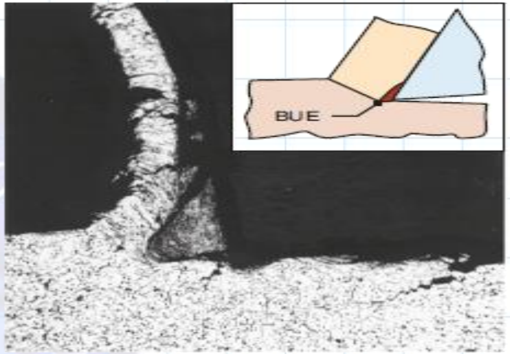



Tool
Chip
Primary
shear
zone
Workpiece

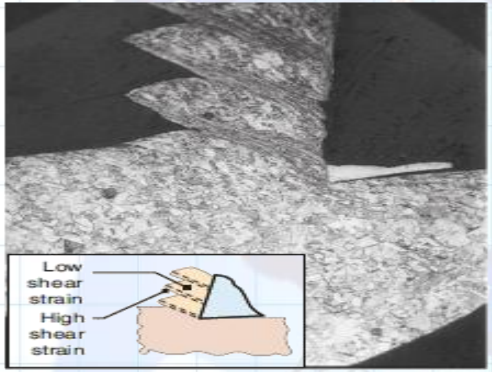
(a)


Secondary shear zones
Chip
Tool
Primary
shear zone

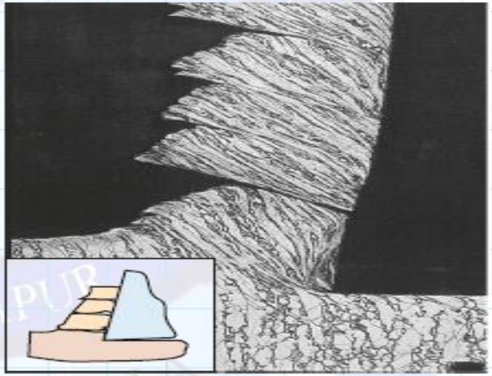
(b)


BUE

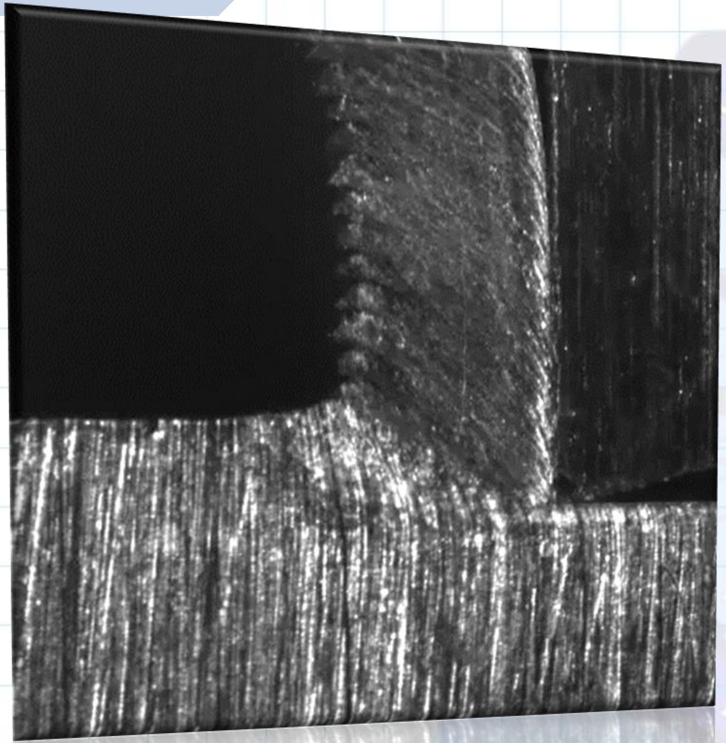
(c)


Low
shear
strain
High
shear
strain

(d)



(e)



Types of Chip Formation

- **Discontinuous Chip**

I. Generally produced when cutting of brittle materials like grey cast iron, bronze, hard brass.

II. Due to lack of ductility for plastic chip formation material ahead of tool edge fails in a brittle fracture manner along the shear zone. This produces small fragments of discontinuous chip.

III. As a result friction between the chip tool interface decreases resulting in better surface finish.

Types of Chip Formation

❑ **Conditions of producing Discontinuous Chip from Ductile material**

I. **Small Rake Angle:** As rake angle is small, force on machining will increase. Therefore the magnitude of energy wave will increase . The energy wave will propagate te surface easily to form discontinuous chip.

II. **Low Cutting Velocity:** Due to low cutting velocity the chip velocity will also low. Hence the time available for curling is more. So the chips will get curled into small radius and it gives large amount of welding so that the cracks are already present in chip will propagate very easily and converted into discontinuous chip.

III. **Large Uncut chip thickness:** As uncut chip thickness is high , higher force is to be applied by using the tool. Hence the magnitude of energy wave is high. So the chances of propagation of energy wave up to the surface is high.

❑ **Conditions of producing Discontinuous Chip from Ductile material**

IV. **Use of Cutting fluid:** By using cutting fluid the heat available in chip will be carried away by cutting fluid and the chip will contract. Within a sort period of time chip is getting expanding and contracting. So any crack which is already present in the ci will get propagated and converting the chip in to discontinuous form.

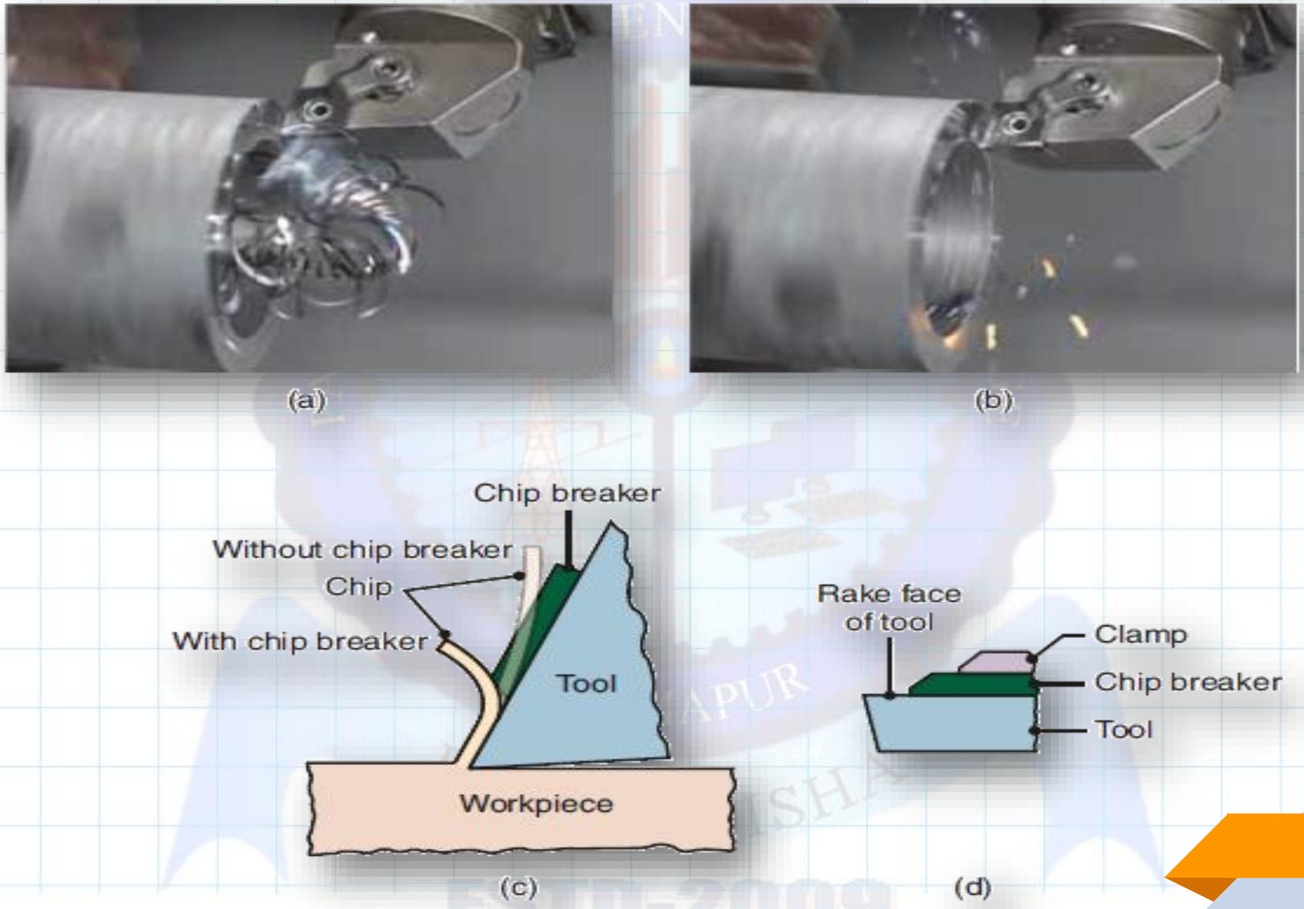
❑ **Continuous Chips**

I. Cutting ductile material.

II. This type of chip remains in contact with the tool face for a long period, resulting in more frictional heat.

III. Also the chips may curl around the work and the tool and may injure the operator when breaks loose.

IV. These can be avoided by the attaching the chip breaker.


(a)
(b)
Chip breaker
Without chip breaker
Chip
With chip breaker
Tool
Workpiece
(c)
Rake face of tool
Clamp
Chip breaker
Tool
(d)

❑ **Continuous Chip with BUE**

I. Soft and ductile workpiece
II. Small rake angle
III. Low speed machining
IV. Large uncut chip thickness
V. With out use of cutting fluid.

Vs

❑ **Continuous Chip with out BUE**

I. Soft and ductile workpiece
II. Large rake angle
III. High speed machining
IV. Small uncut chip thickness
V. With use of cutting fluid.

Question????

- **During face turning of a ductile material with optimum cutting velocity from surface towards centre the types of chips produced are**

I. Continuous through out
II. Discontinuous through out
III. Continuous in beginning , discontinuous at the end
IV. Discontinuous in beginning , continuous at the end

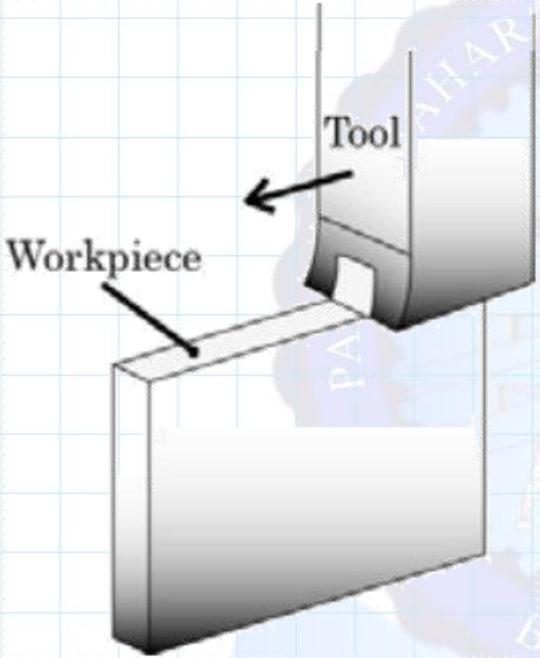
- **Ans: III**

I. As the dia decreases , V decreases from the surface to the centre. So Continuous chip will form in the beginning and discontinuous at the end.

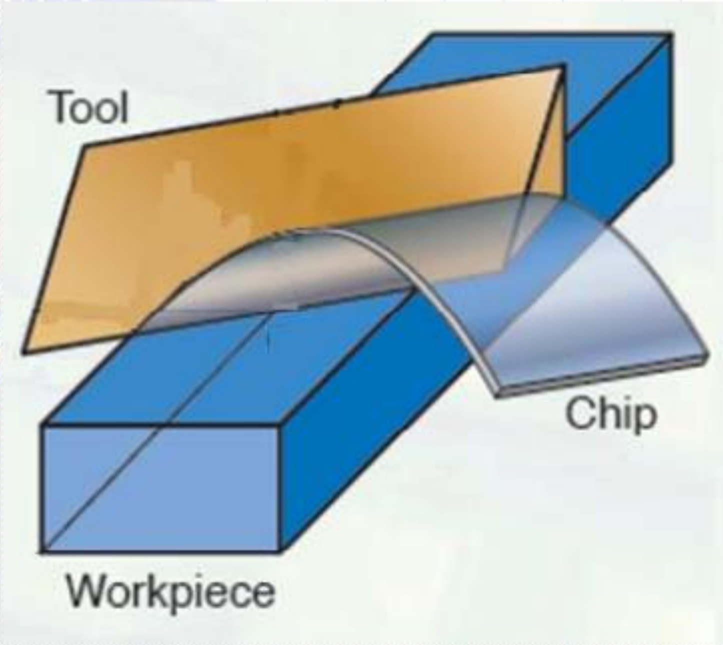
$$V = \frac{\Pi D N}{1000}$$

Orthogonal Cutting Vs Oblique Cutting

Orthogonal cutting	Oblique cutting
1. The cutting edge of the tool remains the direction of tool feed.	1. The cutting edge of the tool is inclined normal to at an acute angle to the direction of tool feed.
2. The direction of chip flow velocity is normal to the cutting edge of the tool	2. The direction of chip flow velocity is at an angle with the normal to the cutting edge of the tool.
3. The cutting edge clears the width of the workpiece on either ends.	3. The cutting edge may or may not clear the width of work.
4. Only two components of cutting forces act on the tool. These two components are perpendicular to each other.	4. Three mutually perpendicular components of cutting forces act at the cutting edge of the tool.
5. Examples are jack plane, broaching sawing etc.	5. Examples are lathe turning, drilling, milling, shaping, planning etc.



Orthogonal Cutting



Oblique Cutting

38

Orthogonal Cutting Vs Oblique Cutting

Orthogonal Cutting	Oblique Cutting
I. Cutting edge of the tool is perpendicular to the direction of cutting velocity.	I. Cutting edge of the tool is inclined at an angle to the direction of cutting velocity.
II. The cutting edge is wider than the workpiece width and extends beyond the workpiece on either side. Also the width of the workpiece is much greater than the depth of cut.	II. The cutting edge may or may not wider than the workpiece width.
III. The chip generated flows on the rake face of the tool with chip velocity perpendicular to the cutting edge.	III. The chip generated flows on the rake face of the tool with chip velocity at an angle to the cutting edge.
IV. The cutting force acts along two directions only.	IV. The cutting force acts along three directions.
V. Tool life is less	V. Tool life is more.

Analysis Of Orthogonal Machining

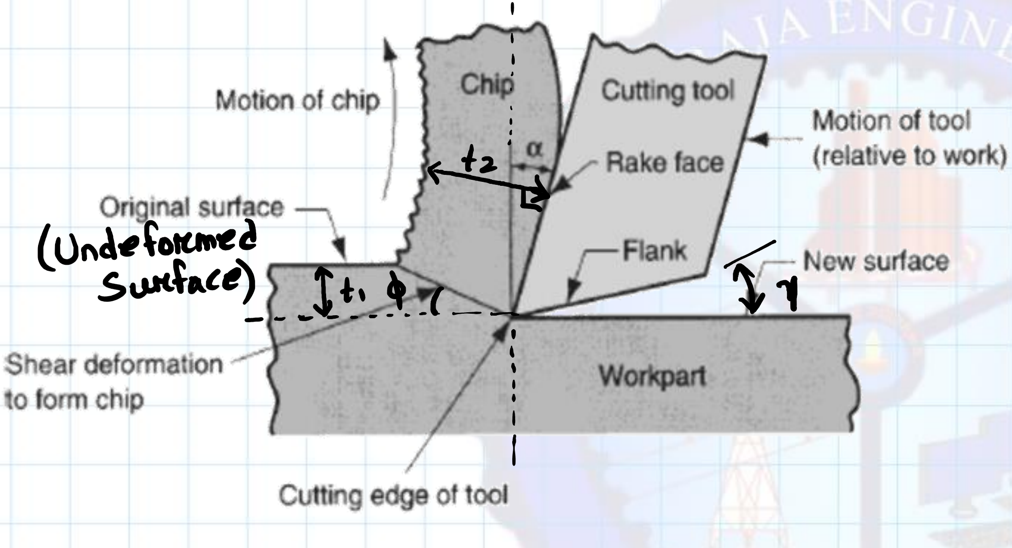
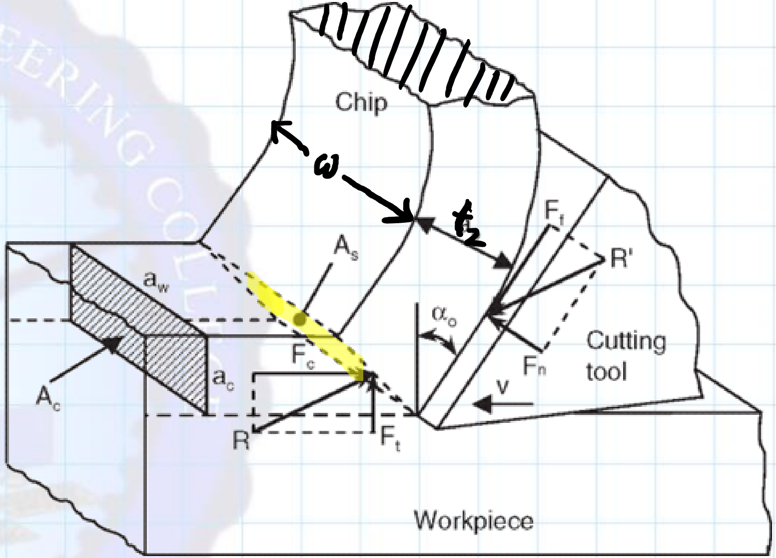


Figure :- Mechanism of chip formation



t_1 = Uncut chip thickness / Undeformed thickness

t_2 = Chip thickness / Deformed thickness

α = Rake Angle

γ = Relief angle / Clearance Angle

d = depth of Cut / (= Uncut chip thickness)

w = width of cut

Cross Sectional area of chip $= (t_2 \times w)$

L_2 = Length of Chip / Length after cut.

L_1 = Length of Chip before machining.

Shear Angle : (ϕ).

It is the angle made by shear plane with Velocity of Cutting.

* Use of proper cutting fluid can increase the shear angle.
* For a given DOC and shear strength of the work material, the reduction in shear plane area reduces the forces required to produce sufficient shearing stress to cut the work.

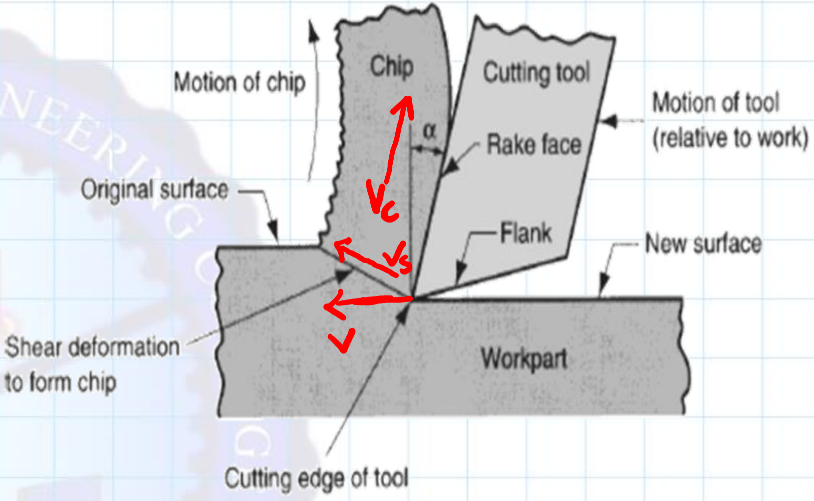


Figure :- Mechanism of chip formation

V = Cutting Velocity / Velocity of tool w.r.t w/p.

V_c = Chip Velocity / Velocity of Chip w.r.t tool.

V_s = Shear Velocity / Velocity of chip w.r.t w/p.

Assumption

- The tool is perfectly sharp and has no contact along the clearance face.
- The surface where shear is occurring is a plane.
- The cutting edge is a straight line extending perpendicular to the direction of motion and generates a plane surface as the work moves past it.
- The chip does not flow to either side or there is no side spread.
- Uncut chip thickness is constant.
- Width of the tool is greater than the width of the work.
- A continuous chip is produced without any BUE.
- Work moves with a uniform velocity.
- The stresses on the shear plane are uniformly distributed.

* Imp. Assumption

Every metal which is undergoing m/cing operation will be considered as incompressible i.e. Volumetric changes of material during machining is zero.

ie. Volume before machining = Volume after machining.

$$t_1 b_1 L_1 = t_2 b_2 L_2$$

or $$t_1 b_1 V = t_2 b_2 V_c$$

* Width of the chip is assumed to be const and there is no side way flow of metal

$$b_1 = b_2 = b$$

→ During machining the force applied by the tool is compressive in nature in the length direction.

→ Therefore Volume of chip is reducing in the length direction but as material is considered to be incompressible, whatever the volume reduction taking place in the length direction has to be increased in thickness or width direction of the chip.

→ As the thickness direction is weak Vol. of chip is only increasing on thickness direction. by keeping the width constant.

So $t_1 b_1 L_1 = t_2 b_2 L_2$

$$\Rightarrow \boxed{\frac{t_1}{t_2} = \frac{L_2}{L_1} = r_c}$$

or $t_1 b_1 V = t_2 b_2 V_c$

$$\boxed{\frac{t_1}{t_2} = \frac{V_c}{V} = r_c}$$

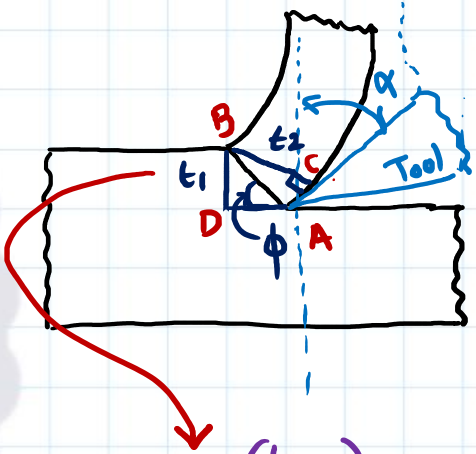
* As compressive force acting along the length direction of the chip, the length of chip after machining must be less than the length of chip before machining.

So $\frac{t_1}{t_2} < 1$

Chip Thickness Ratio(r)

$r = \dfrac{t_1}{t_2}$ (where $t_2 > t_1$ for ductile material with continous chip)

$\therefore r < 1$



* For Brittle material $t_2 \approx t_1$ So $r \approx 1$

Chip Reduction Ratio (ξ)

$$\xi = \frac{1}{r} = \frac{t_2}{t_1}$$

$\xi > 1$

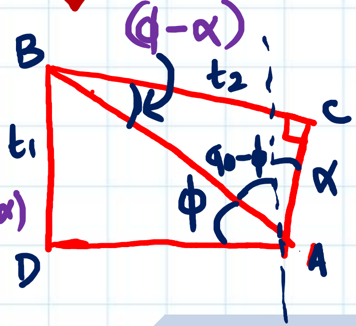
In ΔABD $\sin\phi = \dfrac{BD}{AB}$

$\Rightarrow AB = \dfrac{BD}{\sin\phi} = \dfrac{t_1}{\sin\phi}$ —(i)

In ΔABC

$\cos(\phi-\alpha) = \dfrac{BC}{AB}$

$AB = \dfrac{BC}{\cos(\phi-\alpha)} = \dfrac{t_2}{\cos(\phi-\alpha)}$ —(ii)



From eq^n (i) & (ii)

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

$$\Rightarrow \frac{t_1}{t_2} = \frac{\sin\phi}{\cos(\phi-\alpha)} = r$$

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

$$\text{Eq} = \frac{1}{r} = \frac{\cos(\phi-\alpha)}{\sin\phi}$$

$$\Rightarrow \frac{1}{r} = \frac{\cos\phi.\cos\alpha + \sin\phi.\sin\alpha}{\sin\phi}$$

$$\Rightarrow \frac{1}{r} = \cot\phi.\cos\alpha + \sin\alpha$$

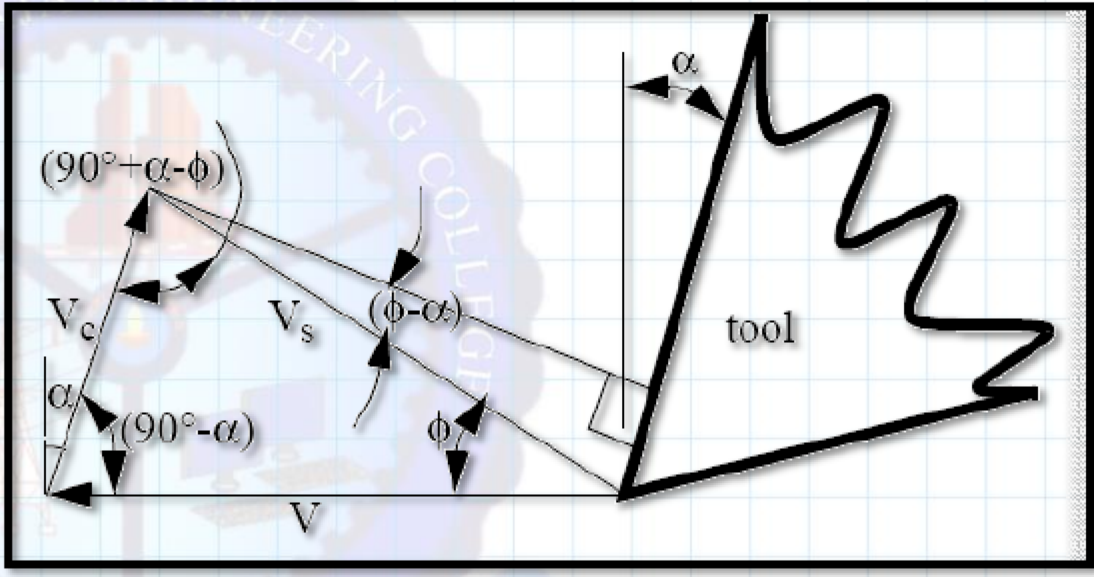
$$\Rightarrow \frac{1}{r} - \sin\alpha = \cot\phi\cdot\cos\alpha$$

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

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

Velocity Analysis

(i) The velocity of the tool relative to the work piece (V) is called the **cutting speed**.
(ii) The velocity of the chip relative to the work, V_s is called the **shear velocity**.
(iii) The velocity of the chip relative to the tool, V_c, is called **chip velocity**.

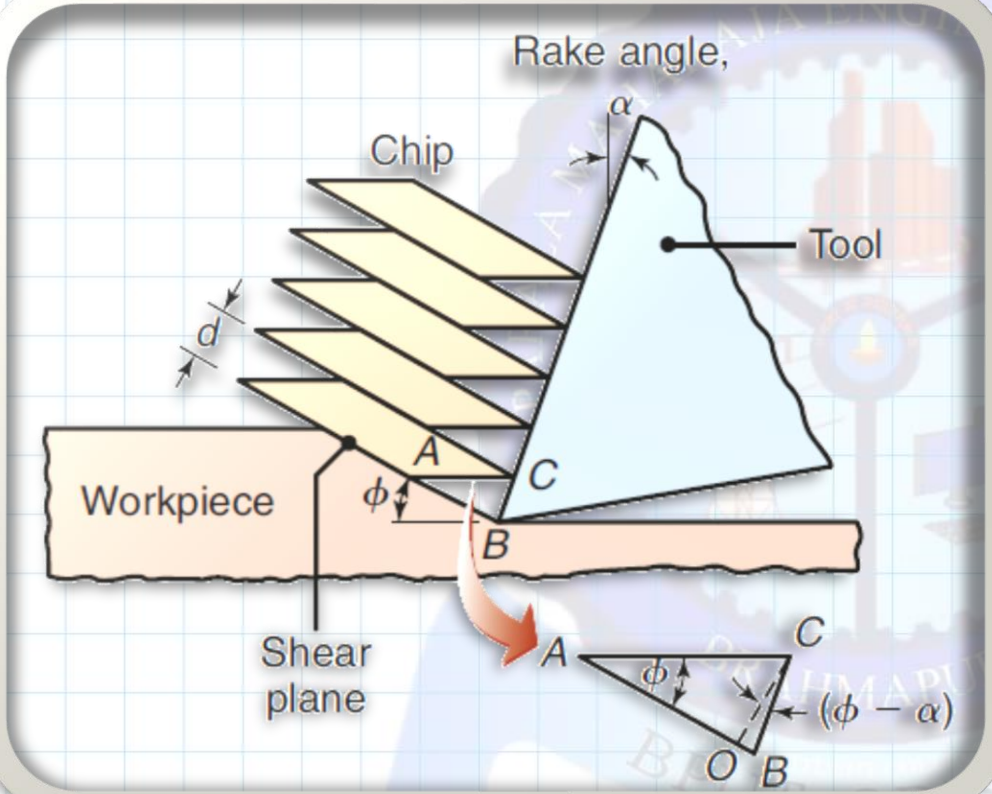


$$\frac{V}{\sin\{90° - (\varphi - \alpha)\}} = \frac{V_S}{\sin(90° - \alpha)} = \frac{V_C}{\sin\varphi}$$

$$V_C = \frac{V \sin\varphi}{\cos(\varphi - \alpha)}$$

$$V_S = \frac{V \cos\alpha}{\cos(\varphi - \alpha)}$$

Shear Stress(τ) and Strain(ε)

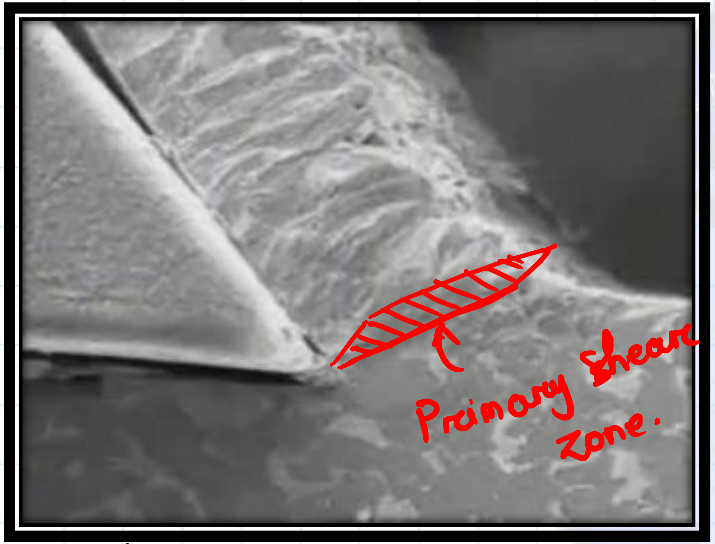


$$\varepsilon = \frac{AB}{OC} = \frac{AO}{OC} + \frac{OB}{OC},$$

$$\varepsilon = \cot\phi + \tan(\phi - \alpha).$$

$$\tau = \frac{F_s \sin\phi}{w t_1} = \frac{F_s \sin\phi}{A_o}$$

Shear Strain Rate(ε')



$\tau = \mu \frac{du}{dy}$ or μ shear strain rate (ϵ')

$\tau \propto \epsilon$ or γ — Solid Mechanics

$$\epsilon' = \frac{\text{Shear Velocity}}{\text{Mean thickness of Primary Shear Zone}} = \frac{V_s}{T}$$

* If T is not given (= 25 μm)

Shear Zone

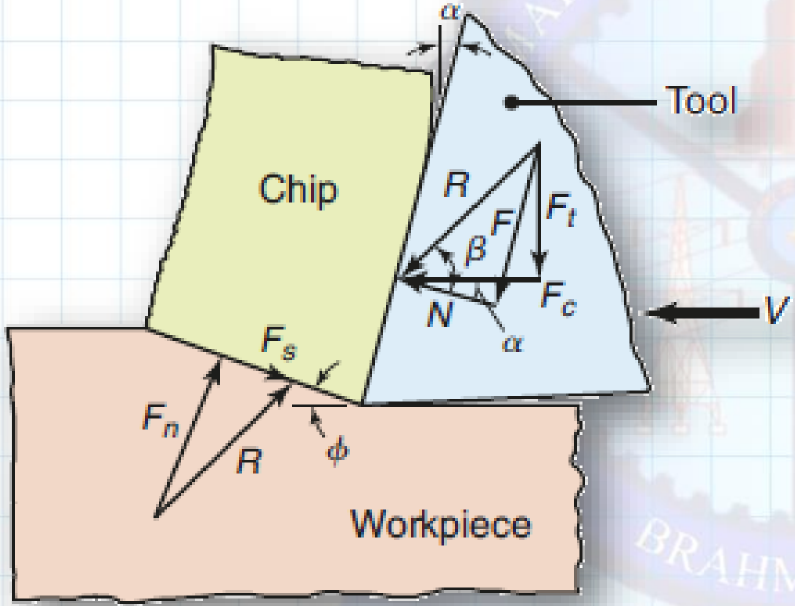
1. Primary Shear Zone
2. Secondary Shear Zone (Friction Zone)
3. Tertiary Zone (Work tool interface)

* Maximum heat is generated in this zone. (because of the Plastic deformation).
  - 90% → Chip
  - 10% → w/p

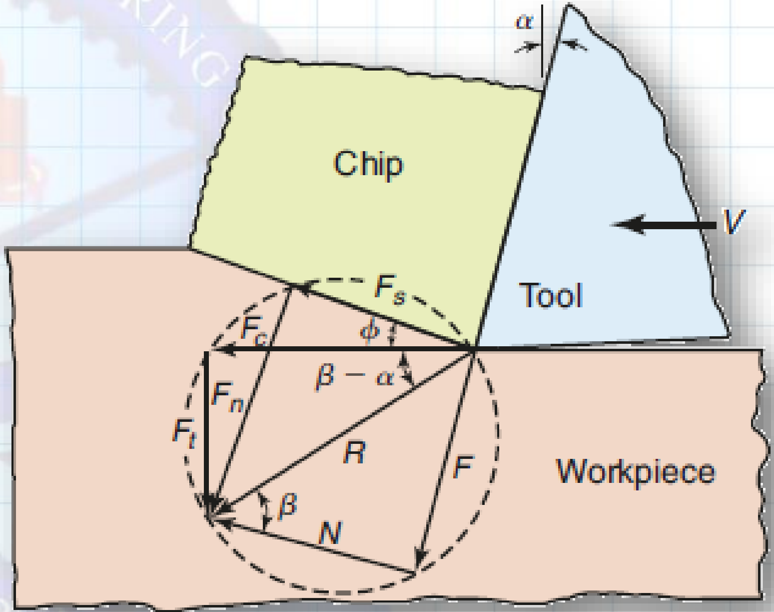
Note: If rake angle of tool is zero then the minimum shear strain =2

- Shear strain rate(∈) =Vs/(thickness of primary shear zone)

Forces in Metal Cutting



(a)



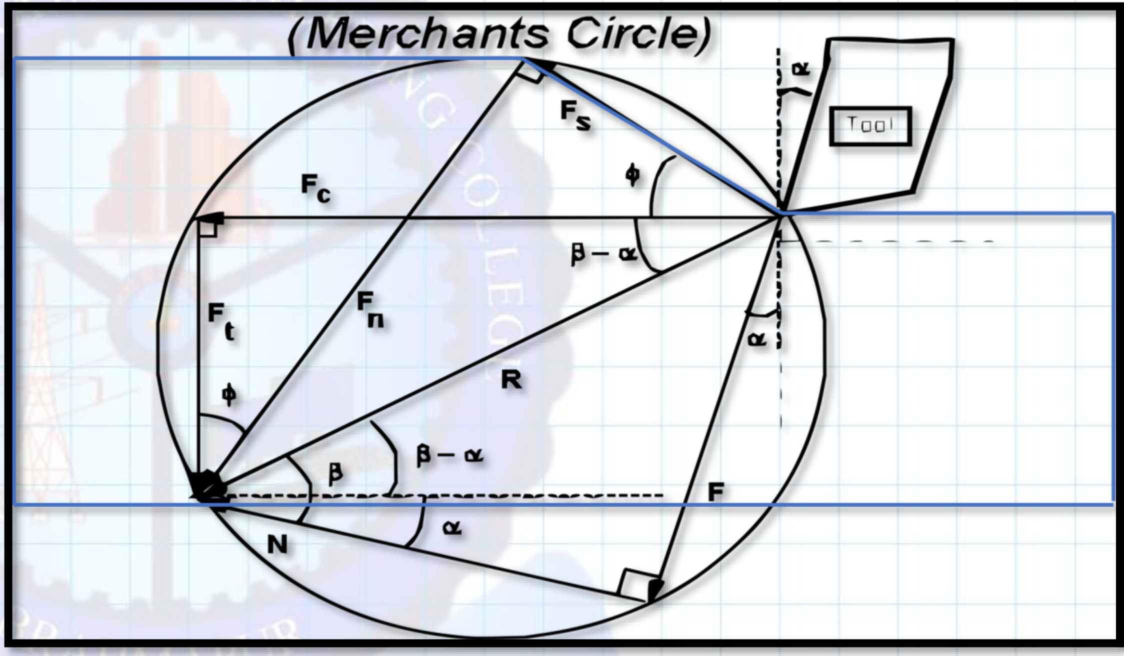
(b)

Merchant's Circle: Forces in Metal Cutting

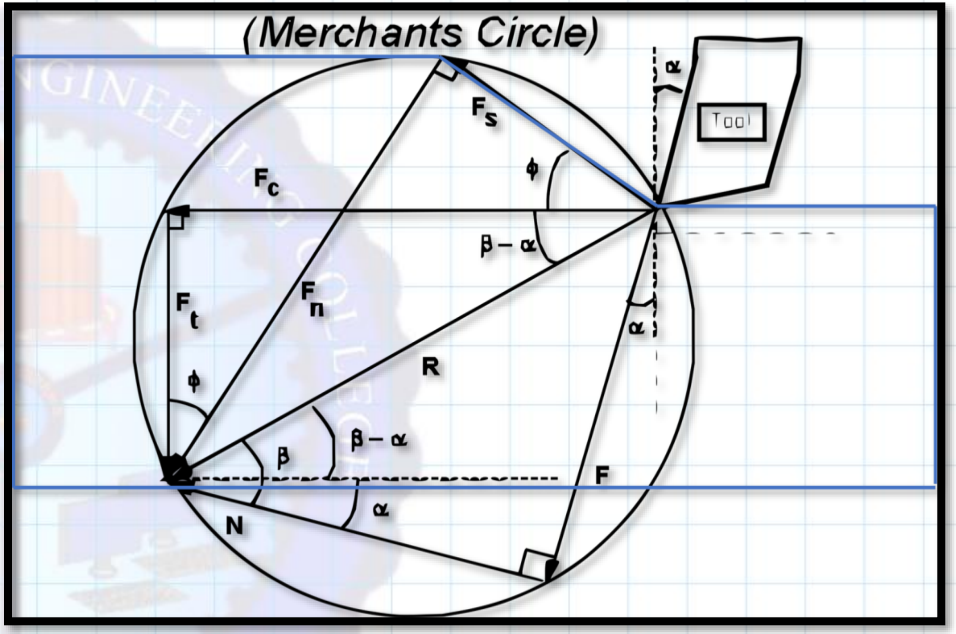
❑ ***Assumptions made in drawing Merchant's Circle***

1. Shear surface is a plane extending upwards from the cutting edge.
2. The tool is perfectly sharp and there is no contact along the clearance face.
3. The cutting edge is a straight line extending perpendicular to the direction of motion and generates a plane surface as the work moves past it.
4. The chip does not flow to either side, that is chip width is constant.
5. The depth of cut remains constant.
6. Width of the tool is greater than that of the work)
7. Work moves with uniform velocity relative tool tip.
8. No BUE is formed.

- Merchant circle is used to analyze the forces acting in metal cutting. :
- The analysis three forces system, which balance each other for cutting to occur. Each system is a triangle of forces.



- The three triangles are .
  a) a triangle of forces for the cutting forces
  b) a triangle of forces for the shear forces
  c) a triangle of forces for the friction a forces
- Let Ff = frictional force
  N = normal to frictional force
  Fs= Shear force
  Fsn = normal to shear force
  Fc = cutting force
  Ft= thrust force or feed force
  β = friction angle
  μ = coefficient of friction = tan β
- Fc and Ft are along and normal to the direction of velocity



- Let R – Resultant force

  $R = \sqrt{Fc^2 + Ft^2}$ = Diameter of Merchant circle
- Ft, Fc defined based on actual machining conditions
- From the above merchants circle found that there are three right angled triangles are present and all the three right angled triangles are possessing common hypotenuse.
- This is used for establishing relationship between measurable and actual forces.

$$\sin\beta = \frac{Ff}{R}$$

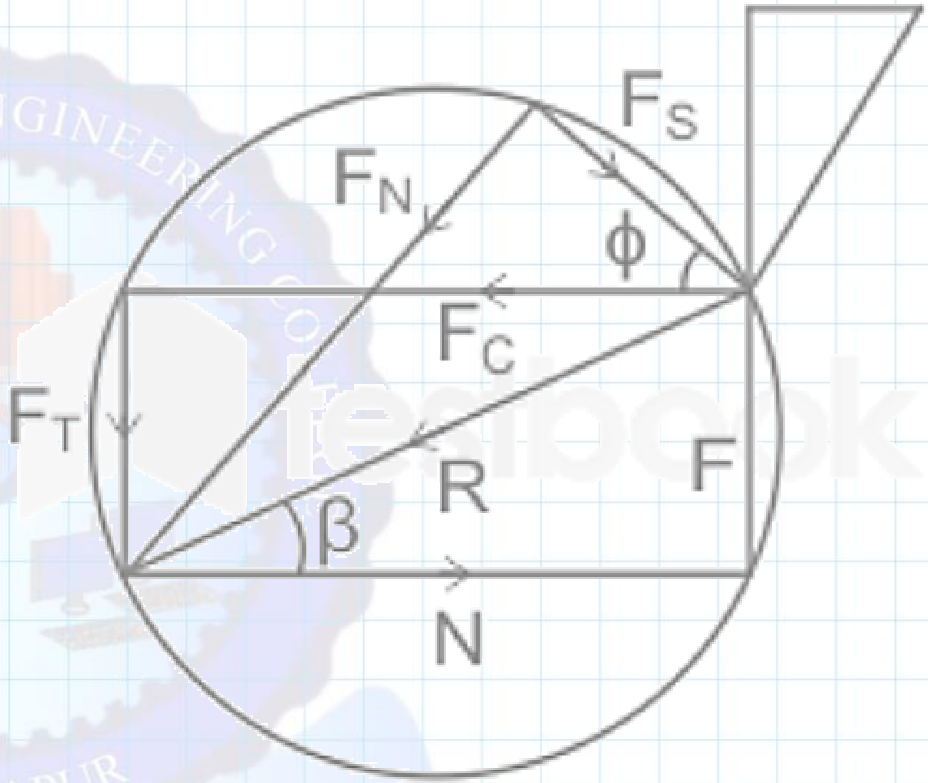
$$R = \frac{Ff}{\sin\beta} = \frac{N}{\cos\beta} = \frac{Fs}{\cos(\phi+\beta-\alpha)} = \frac{Fsn}{\sin(\phi+\beta-\alpha)} = \frac{Fc}{\cos(\beta-\alpha)} = \frac{Ft}{\sin(\beta-\alpha)}$$

- In general $F_C > F_T$
- But in some cases $F_C < F_T$ like face turning operation, broaching, grinding .etc.
- $$\frac{F_T}{F_C} = 2.5 \text{(Grinding)}$$
- In machining operations where $F_T > F_C$. the value of β is becoming greater than 45°. So the coefficient of friction will become greater than 1.
- But in general the coefficient of friction must be less than 1.
- So in cases where μ is becoming greater than 1, in such cases use Classical friction theorem for determining the coefficient of friction in machining

$$\mu = \frac{\ln\left(\frac{1}{r}\right)}{\frac{\pi}{2} - \alpha}$$

According to Classical frictional theorem

$$\mu = \frac{\ln(\frac{1}{r})}{\frac{\pi}{2} - \alpha}$$



NOTE

- Case I: If α = 0 & μ ≠ 1

»FC ⊥ F and FT ⊥ N »FC, FT , F & N form a rectangle

»FC = N & FT = F

- Case II: If α = 0 & μ = 1

»FC ⊥ F and FT ⊥ N »FC, FT , F & N for a square

»FC = N = FT = F

Power in Metal Cutting

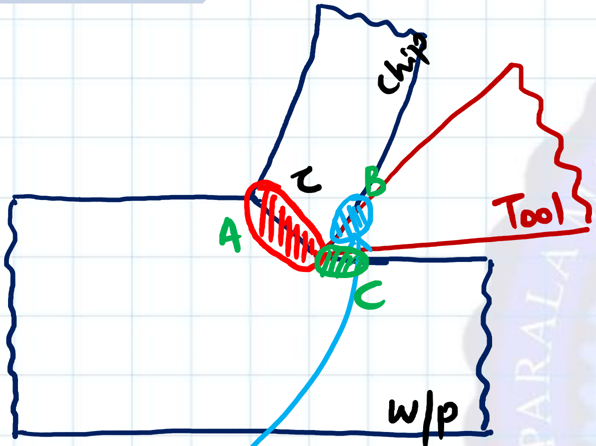
1. Cutting power = Fc.V

2. Friction power = F.Vc

3. Shear power =Fs.Vs

∴ Cutting power = Friction power + shear power

Fc.V = F.Vc + Fs.Vs



$\tau \geq \tau_u$

Power in Metal Cutting -

P = Force × Velocity J/sec or W

Cutting Power = $F_c \times V$

↳ Shear Power = $F_s \times V_s$

↳ Friction Power = $F_f \times V_c$

⇒ CP = SP + FP

$$F_c \times V = F_s V_s + F_f \times V_c$$

Energy required / Work done = $F_c \times V$

* A part of heat goes to the tool.

3rd Zone - Work Tool interface

* Condⁿ for minⁿ energy requirement $= F_c \times V$

∵ $\tau = \tau_u$

* By varying the shear angle (ϕ) it is possible to vary the shear stresses. So to ensure τ_u, it is required to determine optimum shear angle.

$$\tau = \frac{F_s}{A_0}\sin\phi$$

$$WD = F_c \times V = \frac{F_s \cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)} \times V$$

$$\Rightarrow WD = \frac{\tau A_0}{\sin\phi} \times \frac{\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)} \times V$$

For minimum energy requirement

$$\frac{d(WD)}{d\phi} = 0$$

$$\Rightarrow \boxed{2\phi+\beta-\alpha = 90^\circ}$$

↳ Cond^n for Min^m work done

$$\Rightarrow \left[\phi = \frac{90^\circ+\alpha-\beta}{2}\right] \rightarrow$$ Merchant's Shear Angle

Lee - Shaffer's Relation

$$\phi+\beta-\alpha = \frac{\pi}{4} \text{ or } 45^\circ$$

Stabler Relation

$$\phi+\beta-\frac{\alpha}{2} = \frac{\pi}{4}$$

Specific Cutting Energy

Energy required for removing unit volume of material from the work piece.

$$Sp.\,E = \frac{\text{Work done}}{\text{Material Removal Rate}}$$

$$= \frac{F_c \times V}{t_1 \times w \times V} = \frac{F_c}{A_0} \ N/mm^2$$

Q- In an Orthogonal operⁿ following observations were made :

$\alpha = 10^\circ$; $r = 0.4$ $t_1 = 0.5\,mm$ $w = 3\,mm$

$\mu = 0.65$ $\tau_s = 285\,N/mm^2$ Determine all forces in MCD ?

Solⁿ $R = ?$

$$r = \frac{t_1}{t_2} = \frac{0.5}{t_2} = 0.4 \Rightarrow t_2 = \frac{0.5}{0.4} = 1.25\,mm$$

$$\mu = \tan\beta = 0.65$$

$$\beta = \tan^{-1}(0.65) = 33.02^\circ$$

$$\phi = \tan^{-1}\left(\frac{r\cos\alpha}{1 - r\sin\alpha}\right) = 22.94^\circ$$

$$\tau = \frac{F_s \sin\phi}{w t_1} \Rightarrow F_s = \frac{\tau \times w \times t_1}{\sin\phi}$$

$$= \frac{285 \times 3 \times 0.5}{\sin 22.94^\circ}$$

$$F_s = 1096.8\,N$$

$$R = \frac{F_s}{\cos(\phi + \beta - \alpha)} = \frac{1096.8}{\cos(22.94^\circ + 33.02^\circ - 10^\circ)}$$

$$= 1577.76\,N$$

$$F_{sn} = R \times \sin(\phi + \beta - \alpha) = 1134.18\,N$$

$$F_f = R \sin\beta = 859.77\,N$$

$$N = R\cos\beta = 1322.92\,N$$

$$F_c = R\cos(\beta - \alpha) = 1452.1\,N$$

$$F_T = R\sin(\beta - \alpha) = 616.9\,N$$

Q. In an Orthogonal M/c following parameters are given:

$\alpha = 15^\circ$ $V = 200\ m/min$

$w = 5mm$ $t_1 = 0.5mm$

$t_2 = 0.7m$ $F_c = 1200N$

$F_T = 200N$

Calculate (i) - Shear Angle & Shear Strain

(ii) - Cutting power

(iii) - % of total power consumed in friction.

Sol^n (i) $r_c = \frac{t_1}{t_2} = \frac{0.5}{0.7} = 0.714 mm$

$\phi = \tan^{-1}\left(\frac{r_c \cos\alpha}{1 - r_c \sin\alpha}\right) = 40.23^\circ$ (Ans)

$\epsilon = \cot\phi + \tan(\phi - \alpha) = 1.65$

(ii) - Cutting Power $= F_c \times V$

$= \cancel{1200}\ 20 \times \frac{200}{\cancel{60}} = 4000W$

(iii) - Friction Power (F_F, V_c)

$r_c = \frac{t_1}{t_2} = \frac{V_c}{V} \Rightarrow V_c = 200 \times 0.714$

$= 142.8\ m/min$

$F_F = R \sin\beta$

$R = \sqrt{F_c^2 + F_T^2} = 1216.55 N$

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

$\Rightarrow \beta = 24.46^\circ$

$F_F = 1216.55 \times \sin 24.46^\circ$

$= 503.72 N$

$FP = F_F \times V_c = 503.72 \times \frac{142.8}{60}$

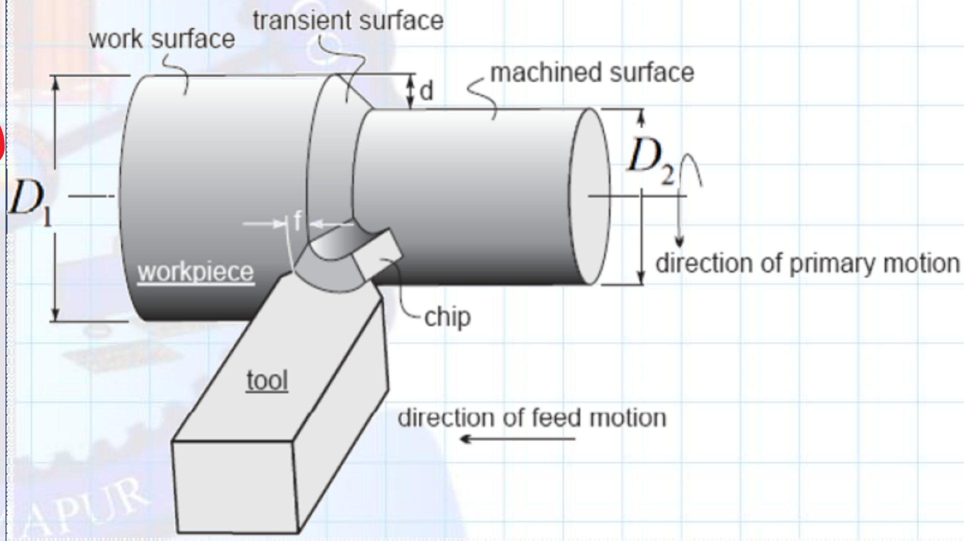
$= 1198.8$

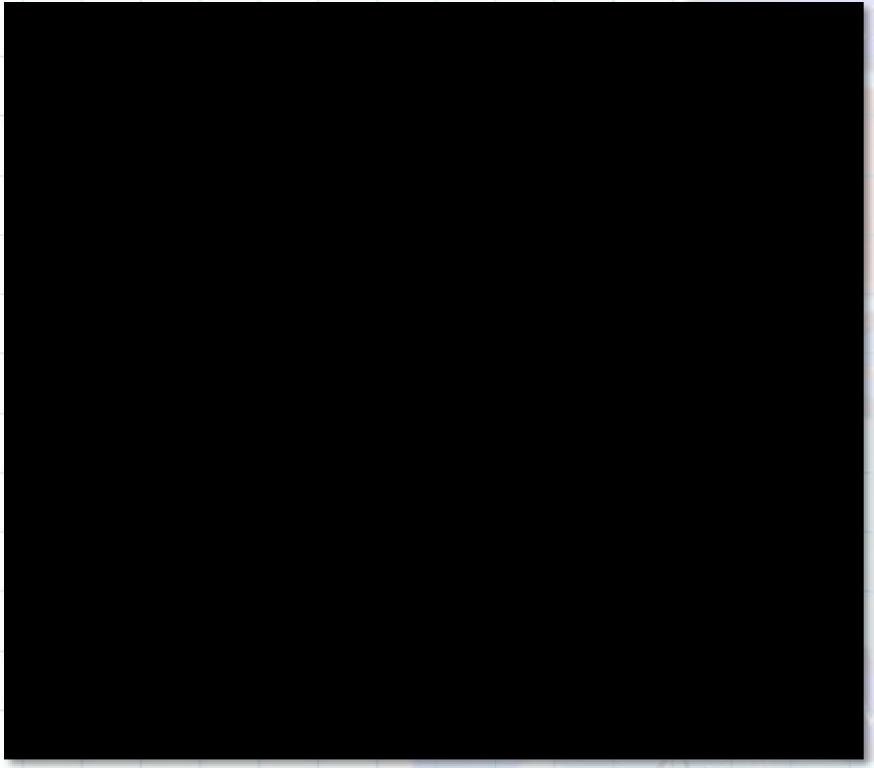
% of FP =

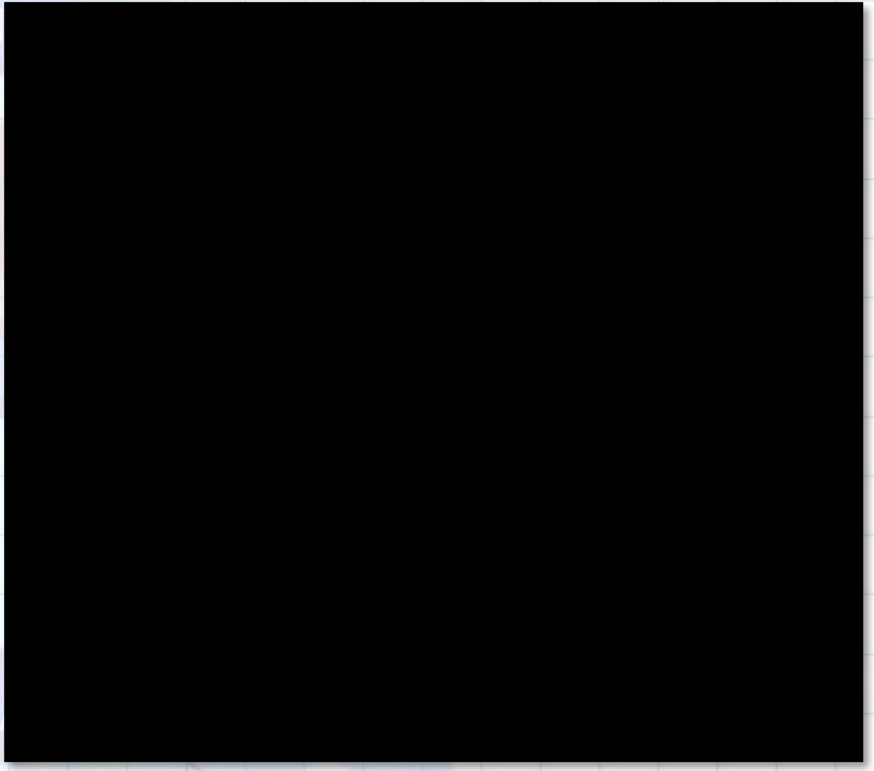
Merchant's Circle: Problems

- In an Orthogonal turning process chip thickness obtained as 1mm.Depth of cut is 2mm feed rate= 0.4mm/rev.cutting speed is 180m/min then determine the chip speed?

Uncut chip $t_1 = f$ (feed)
(* Refer to Slide 80)







Merchant's Circle: Problems

- In an Orthogonal machining cutting velocity =200m/min μ=0.5, uncut chip thickness is 2mm shear stress induced 400 N/mm^2 rake angle is 10° .Determine shear angle , cutting force, thrust force.

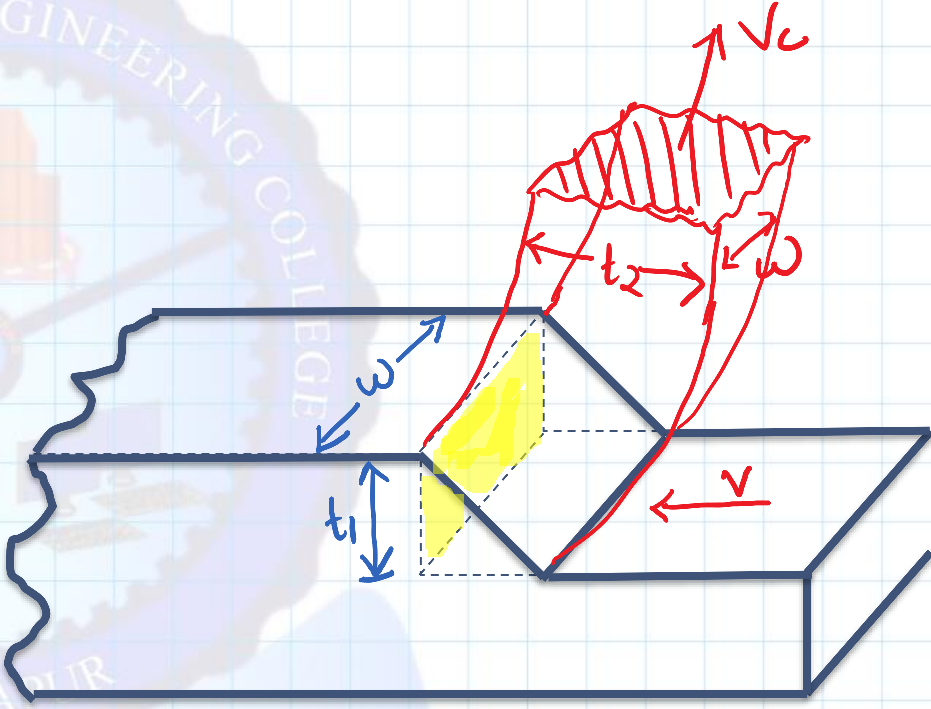
- In an Orthogonal machining DOC=0.1mm Chip thickness =0.2mm, width of cut =5mm rake angle= 10°.Component the force along and normal to cutting velocity are 500N and 200N respectively. Determine COF and Shear stress induced.

Material Removal Rate(MRR)

- MRR= Vx Area of Uncut chip plane
- = V.t_1.w
- But in case of Turning Process
  t_1w= f.d (* Refer to Slide 80)
- $MRR_{Turning}$ = V.f.d
- Unit = volume(m^3)/min
- Area of chip = w.t_2
- MRR_{chip} = Vc.w.t_2
- From volume constancy

  =>t_1.w.V = t_2.w.Vc

  $$=> \frac{t_1}{t_2} = \frac{v_c}{v} = r$$



Specific Power Consumption

- Power required per unit MRR.
- i. Specific Machining Power(SMP)

$$= \frac{\text{Machining Power}}{\text{MRR}}$$

$$SMP = \frac{F_c \times V}{t_1 w V} = \frac{F_c}{t_1 w}$$

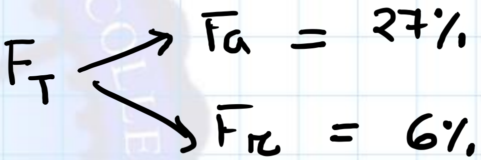
$$\Rightarrow \text{Unit} = \frac{J/sec}{m^3/sec} = \frac{J}{m^3} = \frac{\text{Energy}}{\text{Volume}}$$

- Used for indicating machinability of given workpiece material.
- Higher the SCE indicates lower machinability.
- At high cutting speed and large feed the SCE tends to be constant.
-

Factors Influencing Forces in Machining

- The tool forces does not change significantly by changing the cutting speed.
- As chip size increases, the cutting force increases.
- FT decreases if the nose radius is made large or if the side cutting edge angle increases
- Fc reduces as back rake angle increases, for every one degree of increase, the cutting force is reduced by 10%.
- Use of coolants reduce the forces required on the tool. Coolants also increase the tool life to a greater extent.

- IN Orthogonal cutting Fc = 67 %, F_T=33 %
- In Oblique cutting Fc = 67 %

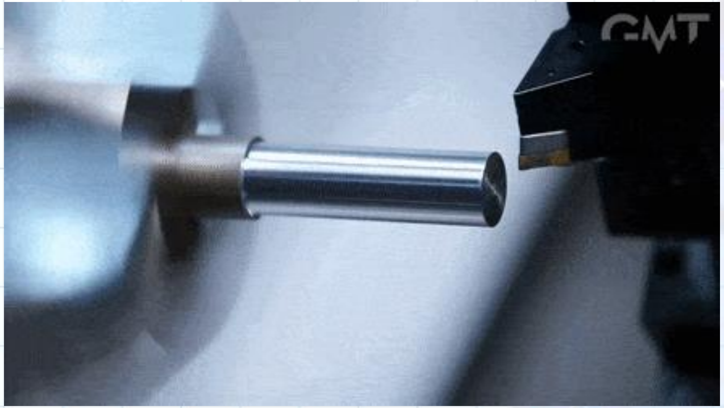
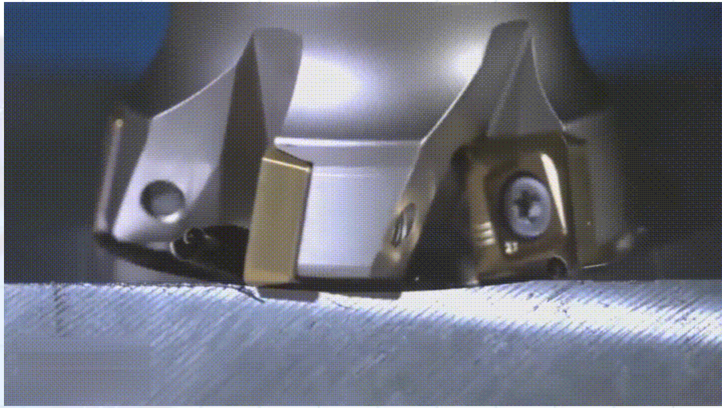


Cutting speed, feed and depth of cut:

- **Cutting Speed:**
- Cutting speed of a cutting tool can be defined as the rate at which its cutting edge passes over surface of the work piece in unit time.
- It is normally expressed as in terms of surface speed in meters per minute
- * It it is too high. the tool gets overheated and its cutting edge may fail.
- * If it is too low. too much time is consumed in machining and full cutting capacities of the tool and machine are not utilized., which results in lowering of productivity and increases the production cost.

Feed:

- * It is defined as distance travels along or into workpiece for each pass of its point through a particular position in unit time.
- * For example, in turning operation on a lathe it is equal to the advancement of the tool corresponding to each revolution of work.
- In planing. it is the work which is fed and not to the tool.
- In milling, the feed is basically considered per tooth of the cutter.

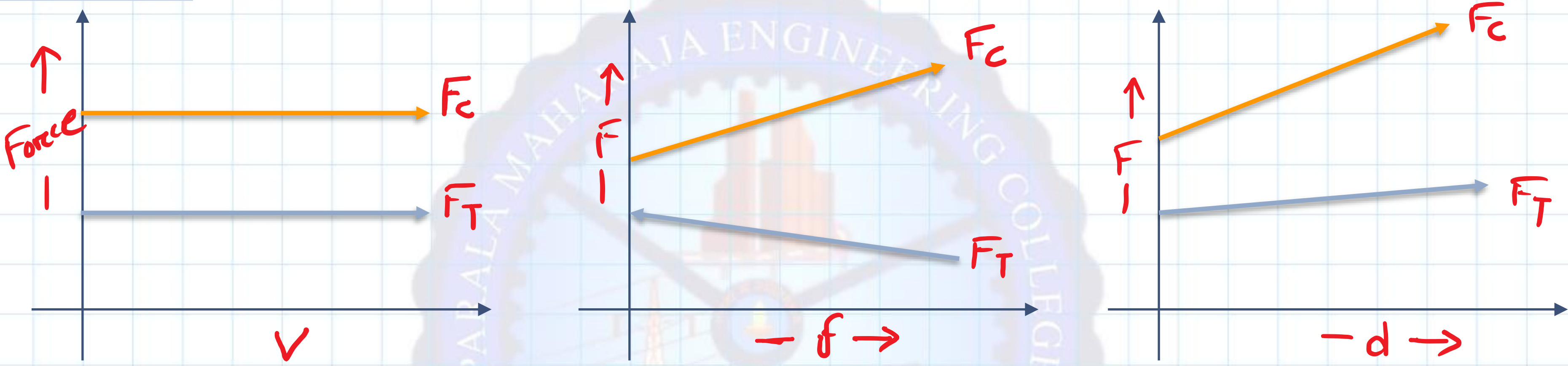

GMT


MakeAGIF.com

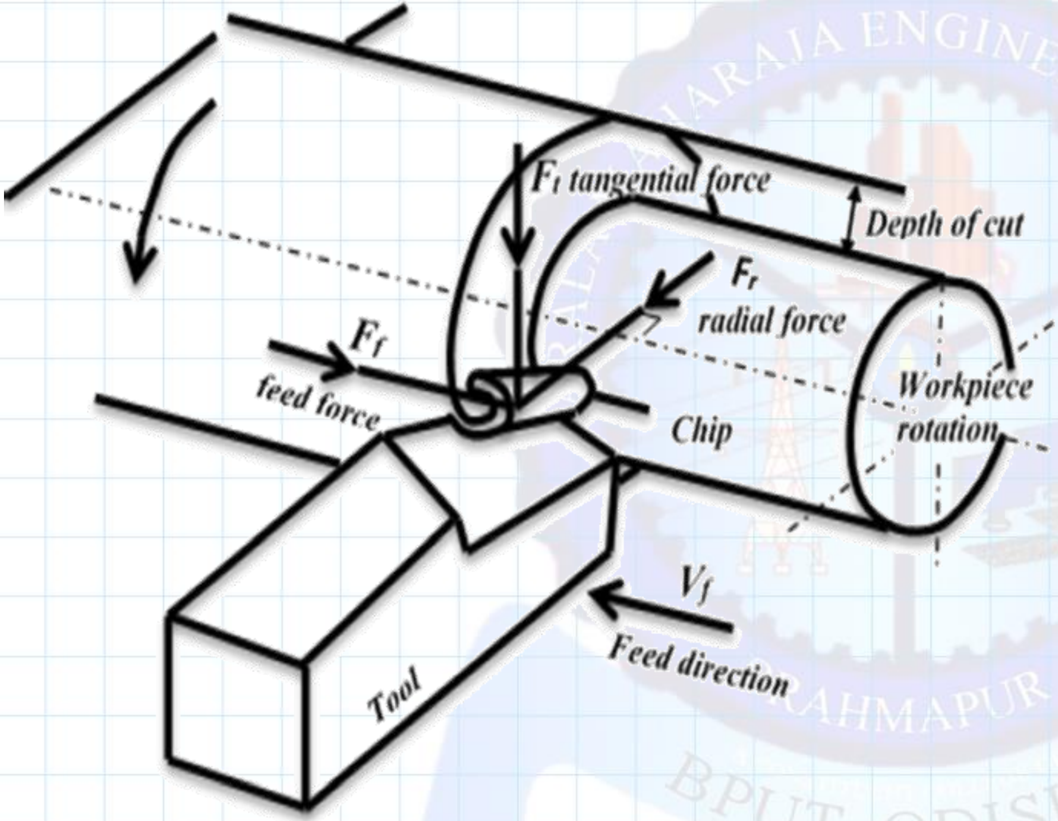
Cutting speed, feed and depth of cut:

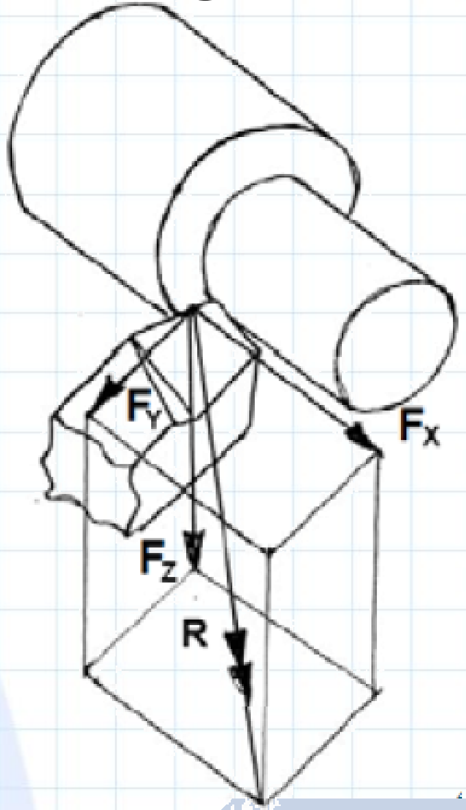
Depth of cut:

- It is penetration of the cutting edge of the tool into the workpiece material in each pass, measured perpendicular to the machined surface, i.e., it determines the thickness of metal layer removed by the cutting tool in one pass.


Force
F_c
F_T
V
F
F_c
F_T
f
F
F_c
F_T
d

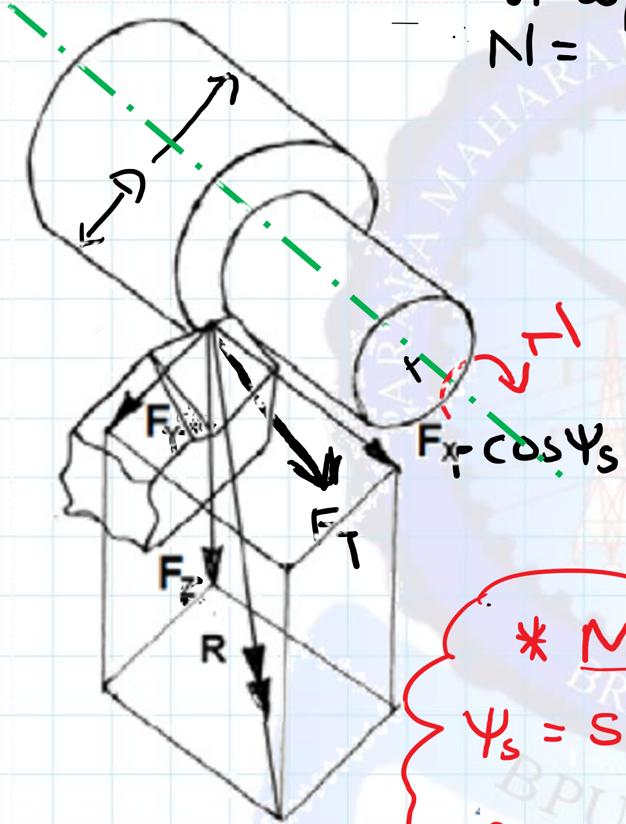
Turning Process



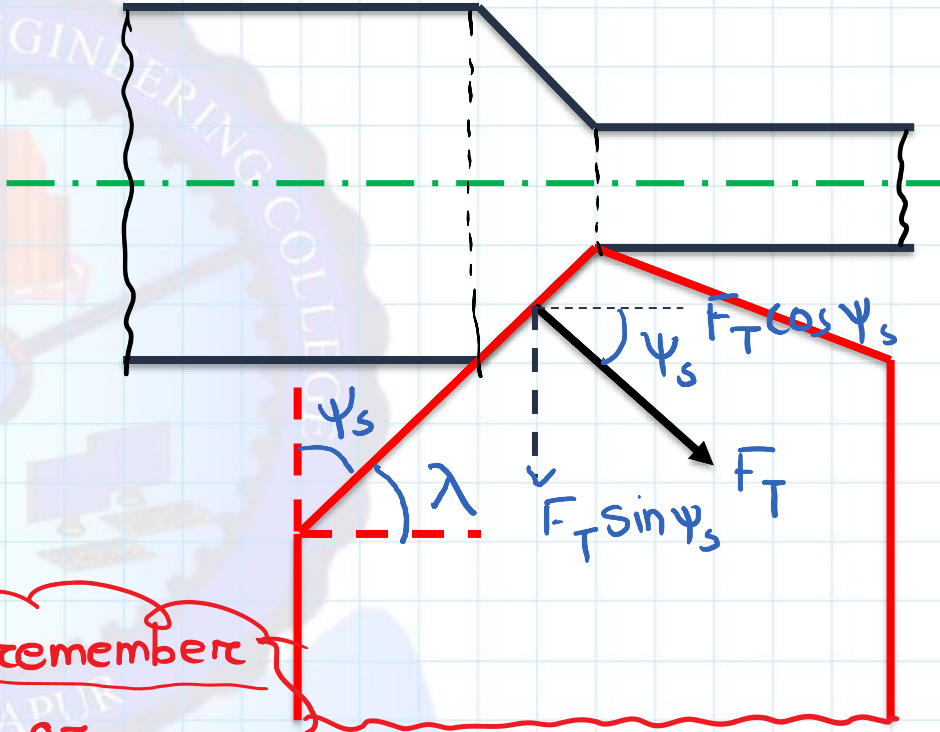


Let D = initial dia of w/p.

N = rpm



Top View



* Must remember

ψ_s = SCEA or Approach angle

λ = PCEA

Turning Parameters

(i). Cutting Speed : (V)

$$V = \frac{\pi D N}{60}$$ (Tangential Speed)

(ii). Feed (f)

$f =$ feed Rate (mm/rev)

(iii). Feed Velocity (V_f)

$$V_f = f \cdot N$$ (Unit : mm/min)

(iv). Machining Time

$$MT = \frac{\text{Distance}}{\text{Feed Speed}} = \frac{L}{f \cdot N}$$

Forces in Turning :-

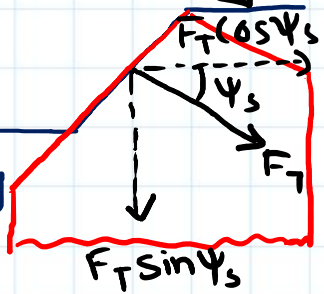
(i). Cutting Force (F_c) / Tangential force
(which is along the cutting velocity)

(ii). Axial Force (F_a)

$$F_a = F_T \cos \psi_s$$

(iii). Radial Force (F_R)

$$F_R = F_T \sin \psi_s$$



→ So there are 3 mutually perpendicular forces

(i). Cutting Force (F_c)
(ii) Axial Force (F_a)
(iii) - Radial Force (F_R)

} Component of Thrust Force.

Turning Parameters

Important

As we know practically value of SCEA (ψ_s) = $15^\circ - 30^\circ$

So

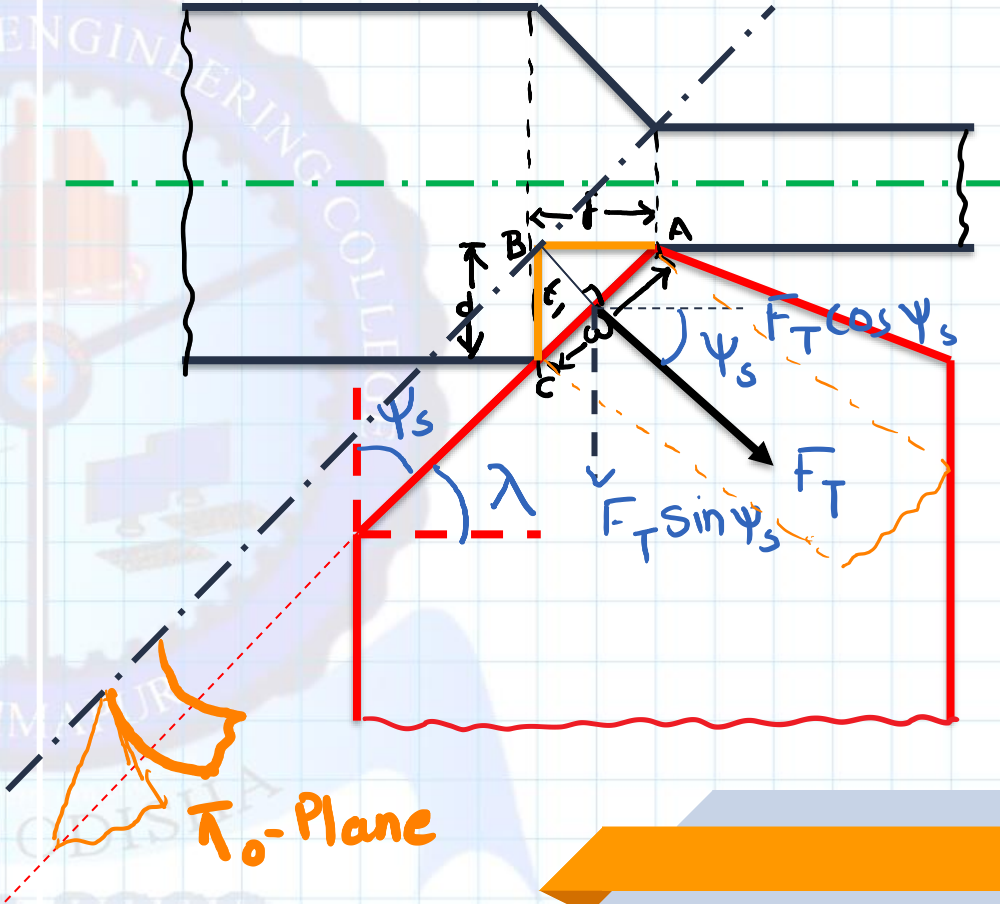
Function \ Angle →	0°	15°	30°
sin θ	0	0.25	0.5
cos θ	1	0.96	0.86

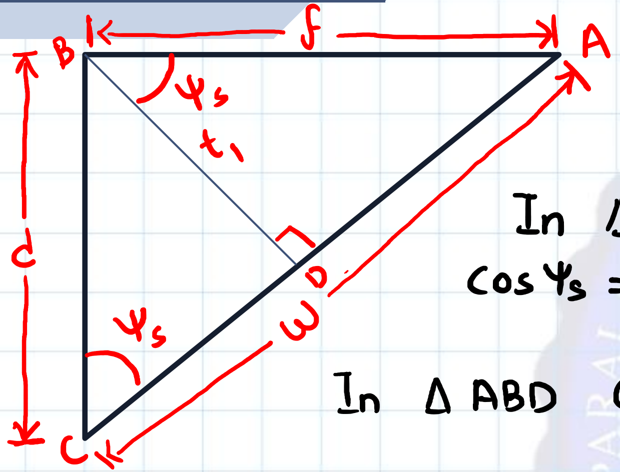
So, if $\theta = \psi_s$; $\cos\psi_s$ always has a greater values than $\sin\psi_s$

i.e $F_a > F_r$

* or $F_r < F_a < F_c$

50% 50% (In general)





In ΔABC

$$\cos\psi_s = \frac{BC}{AC} = \frac{d}{w} \quad \text{—(i)}$$

In ΔABD $\cos\psi_s = \frac{BD}{BA} = \frac{t_1}{f}$ —(ii)

From eq^n (i) & (ii) $\left[\frac{d}{w} = \frac{t_1}{f}\right]$ i.e. $t_1 w = d f$

From ΔABD $t_1 = f\cos\psi_s$

In Orthogonal Machining $\psi_s = 0°$

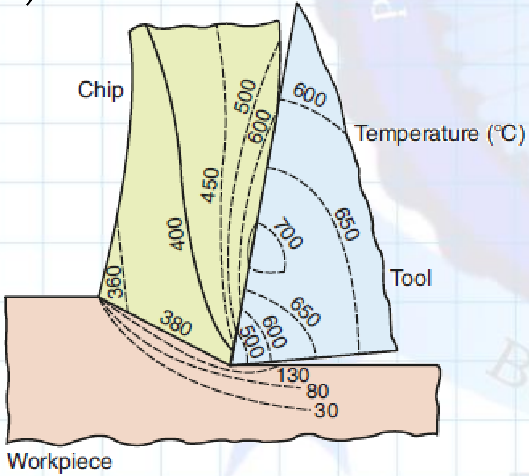
$t_1 = f\cos 0° = f$

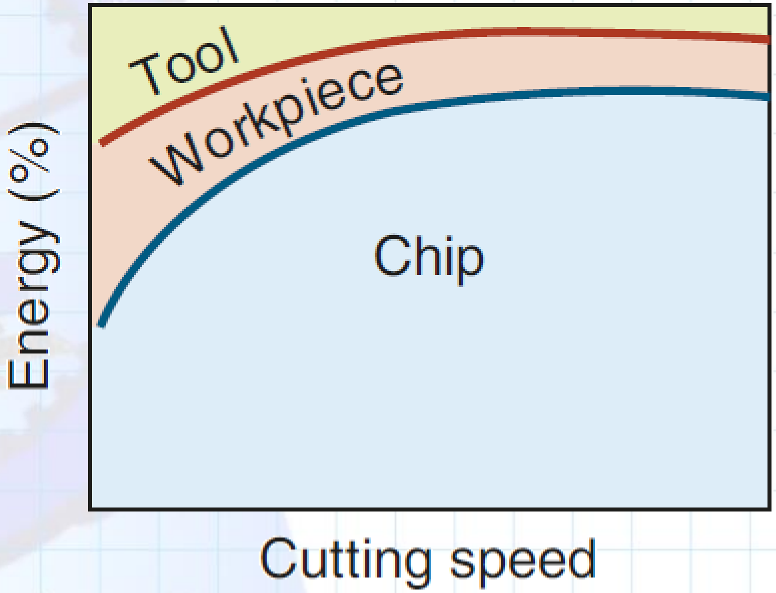
$t_1 = f$ → For Orthogonal M/c

$\Rightarrow d = w$

Heat Generation

- The power or the total energy given by an external source for cutting is spent in the form of shear energy, frictional energy, and momentum energy.
- Heat is generated a cutting
  - a) Shear zone
  - b) friction zone
  - c) Tool – work interface Shear zone:





- **Shear zone**:Maximum heat is generated in this zone due to the plastic deformation of the 3 zones during metal.
- The major heat generated in this zone is carried away by the chip and remaining (less than 10%) is taken by workpiece.
- The total heat generated in the shear zone comnsists of heat of deformation and the heat of distortion.
- **Friction zone (chip tool interface)** In this zone, as the chip moves upwards along the tool face, a good amount of heat is generated due to friction at the chip tool interface, which further rises the temp of chip.
- A part of the heat generated goes to the tool.
- **Work tool interface** Due to friction between work and tool, the heat is generated. This heat is carried away partly by the tool and partly by the workpiece.

A - Primary heat zone
B- Secondary heat zone
C - Tertiary heat zone

- ❑ In general tertiary heat zone is very less and so neglected.
- ❑ Heat generated = heat carried by chip + Heat carried by work
- ❑ Heat carried by chip = m.Cp.ΔT

  = ρ.Vol.Cp.ΔT = ρ(wt₁.V).Cp .ΔT

  ΔT = rise in temperature of chip
- ❑ let heat carried by work W = a W

  Where "a" is a fraction,

  W – Heat generated

. Heat carried by chip = HG-H.C.W

$$\rho \cdot Vol \cdot C_p \cdot \Delta T = W(1-a)$$

$$\Delta T = \frac{W(1-a)}{\rho \cdot Vol \cdot C_p}$$

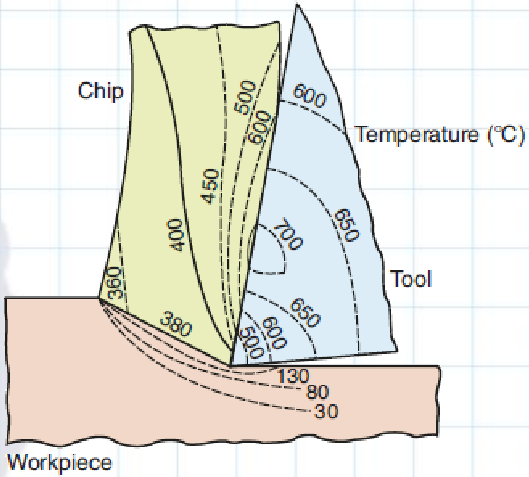
where Vol = Volume of metal being removed.

$$[w \cdot t_1 \cdot V = MRR]$$

- ❑ From the above figure all the three heat zones are meeting at one point known as Tip of tool
- ❑ Tip of tool may experience very high temperature. When the temperature of tip of tool goes beyond hot hardness temperature of tool material then the tool tip is loosing hardness considerably.

Temperature Measurement

- To avoid the plastic deformation failure of tool it is required to measure the temperature of tip of tool.
- If it goes beyond hot hardness temperature of tool material, adjust the process parameters (cutting velocity, feed and depth of cut) such that the temperature induced at the tip of tool is less than hot hardness temperature of tool material.



- **The temp of a chip tool interface can be measured by using following methods**
  - **a) Tool work thermocouple**
  - **b) Calorimetric set up**
  - **c) Optical pyrometer**

Tool Failure

The parameters used for measurement of satisfactoriness of machining is

- **Surface finish produced on workpiece:**

  i-At the beginning of machining operation it is found that excellence and mirror like finish is produced on work piece.

  ii-After sometimes when the lines are produced on machined surface. it is assumed that surface finish is reduced and tool is failed.

- **Forces induced during machining:**

  i-By connecting dynamometer to the work table. the forces in machining will be measured online.

  ii-Whenever the increase in forces is taking place more than 15% from the original forces it is assumed that tool has been failed.

- **Power consumption:**

  -By connecting Ammeter to the input of electrical motor, the current drawn by motor will be measured .

  -When ever the increase in current drawn by motor is greater than 15% from its original value it is assumed that tool has been failed.

<u>The parameters used for measurement of satisfactoriness of machining is</u>

- **Temperature of chip:**

  -The temperature of chip can measure by observing the color.

  -During normal satisfactory machining conditions the color of chip is light Blue or metallic color.

  -When the machining is done with failure tool, because of higher heat generation the color of chip is turned to black or burnt color.

  -From the above whenever the color of chip is observed to be black or burnt colour, tool is assumed to be failed.

  -During machining of high carbon work pieces, whenever white colored gases are observed. it is assumed that tool is failed.

Modes of Tool Failure

1. **Failure through plastic deformation**
2. **Failure through mechanical breakage**
3. **Failure through mechanical gradual wear**

- **Plastic Deformation Failure:**

Whenever the tip of tool is experiencing temperature greater than hot hardness temperature of tool material, it is losing its hardness considerably and the tip of tool is deforming plastically called as plastic deformation failure of the tool.

Reasons:

1. Wrong selection of tool material
2. Wrong selection of process parameters.

- **Mechanical Breakage:**

A cutting tool gets broken due to following factors:

a) Large cutting force.

b) By developing fatigue cracks under chatter conditions.

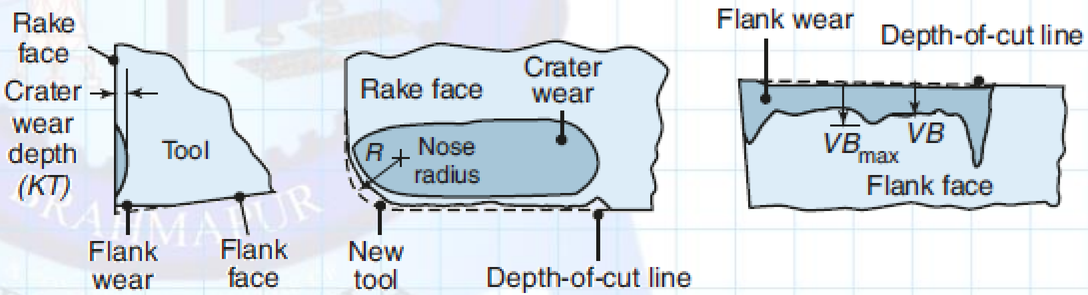
c) Weak tool material.

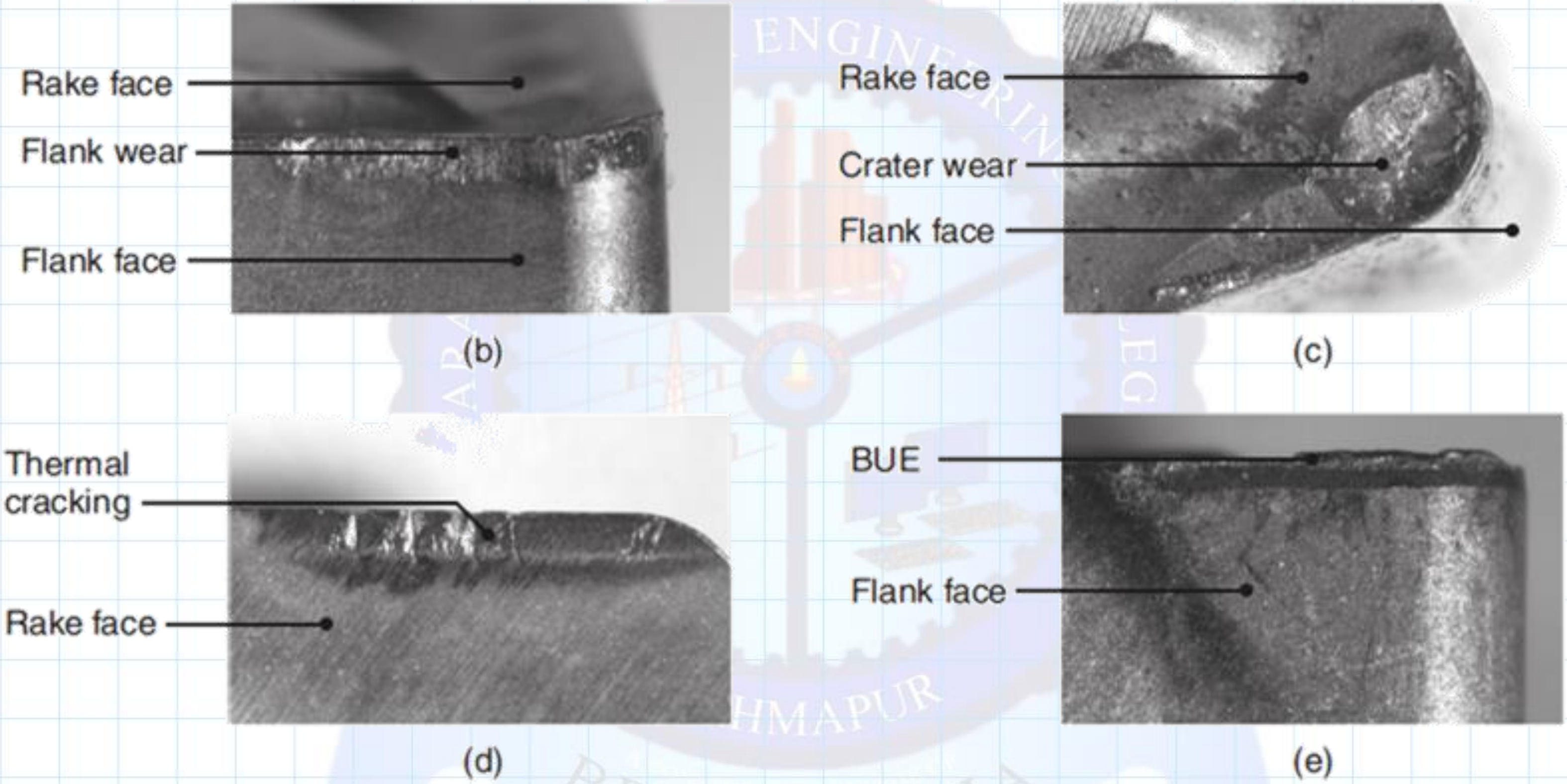
d) High temperature and High stress.

- In this also the failure duration is not repeatable.
- It is also considered as abnormal failure of tool

Modes of Tool Failure

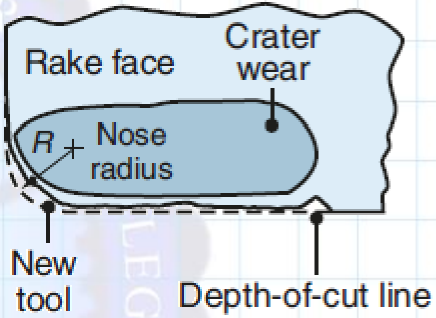
- **Gradual Wear failure:** During machining operation, the tool is wearing out slowly and whenever the wear become considerable, it can't perform the machining satisfactory called as gradual wear failure.
- The gradual wear is taking place due to crater and flank wear.
  1. Crater wear
  2. Flank wear

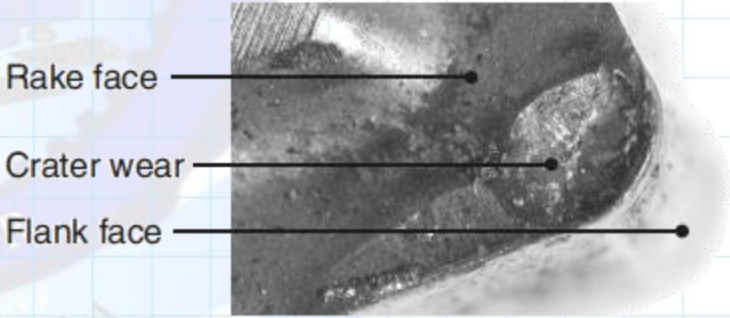



Rake face
Flank wear
Flank face
(b)
Rake face
Crater wear
Flank face
(c)
Thermal cracking
Rake face
(d)
BUE
Flank face
(e)

Crater Wear

- The major tendency for wear is due to the abrasion between the chip and the face of the tool, a short distance from the cutting edge.
- The crater (a shallow spherical depression present on surface) is formed on the surface of the tool by the action of chip particles flowing over it because of very high temperature.
- When Cratering becomes excessive. The cutting edge may break from the tool.
- Cratering is commonly observed while machining ductile materials, which produce continuous chips.





Reasons:

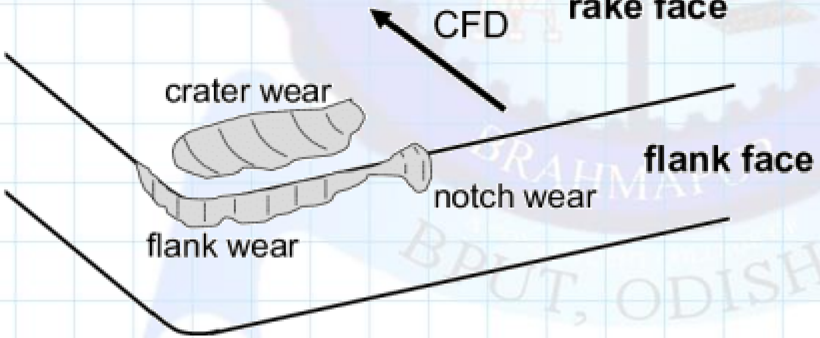
- Presence of friction between chip – tool interface
- Abrasive action of microchips present at chip – tool interface
- Abrasive action of fragments of built up edge present at chip-tool interface
- **During the machining operation the crater wear will take place at some distance away from tip of tool**

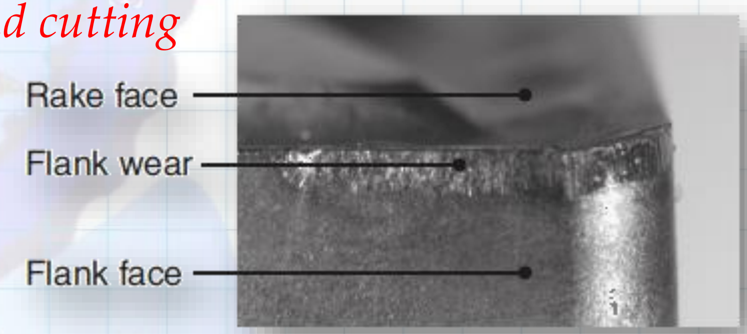
This is because of

- When the force is acting by the tool on the layer of work piece material, thechip will be directly lifting upward
- But because of self weight of chip, it will falling back on the rake face of tool.
- In process of lifting up and falling back the chips don’t have any contact with the rake face of tool.
- Hence no friction, no abrasive action, no diffusion will take place.
- When the chip is falling back on to rake face of tool, it is trying to penetrate into the tool material
- Hence it produces large amount of friction at some distance away from tip of tool which produces shape of wear like crater.

Flank Wear

- **Wear taking place on Flank face of tool is called flank wear.**
- **Reasons:**
  1. Presence of friction at tool interface
  2. Abrasive action of microchips present at tool work interface
  3. **Diffusion wear(***This is occurring mainly during machining of ferrous work pieces by using diamond cutting tool*.)





- **Stages in flank wear**

i. Primary wear:

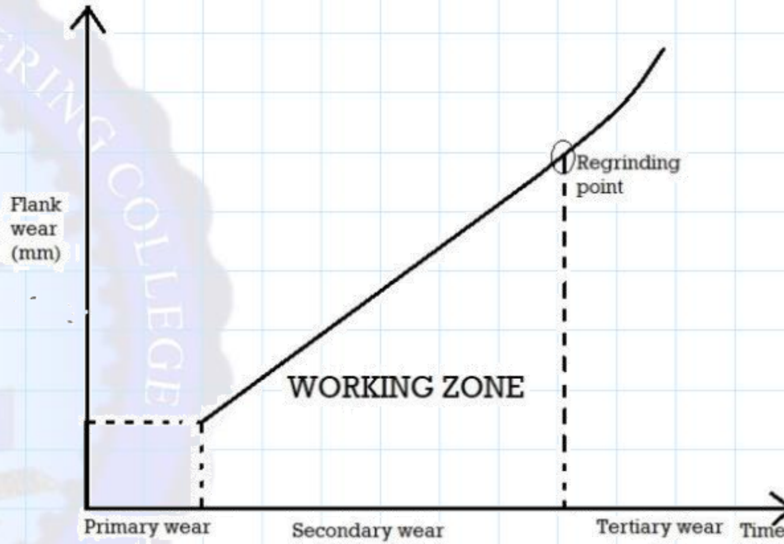
- Zone where sharp cutting edge is quickly broken
- Finite wear land is established

ii. Secondary wear:

- Zone where wear takes place at constant rate
- This is working zone of tool

iii. Tertiary wear:

- wear progresses at highly increasing rate because, area of contact is much larger
- Tool wear becomes more sensitive to increase temperature of machining zone
- Regrinding needed



Tool Life

- ***The actual machining time between TWO successive regrinding of a cutting tool is called tool life.***
- There are number of ways of expressing tool life such as:
  I. Volume of metal removed (rough machining)
  II. Number of work pieces machined in mass production)
  III. Time unit -It is most commonly expressed in minutes.

Taylor's tool life equation

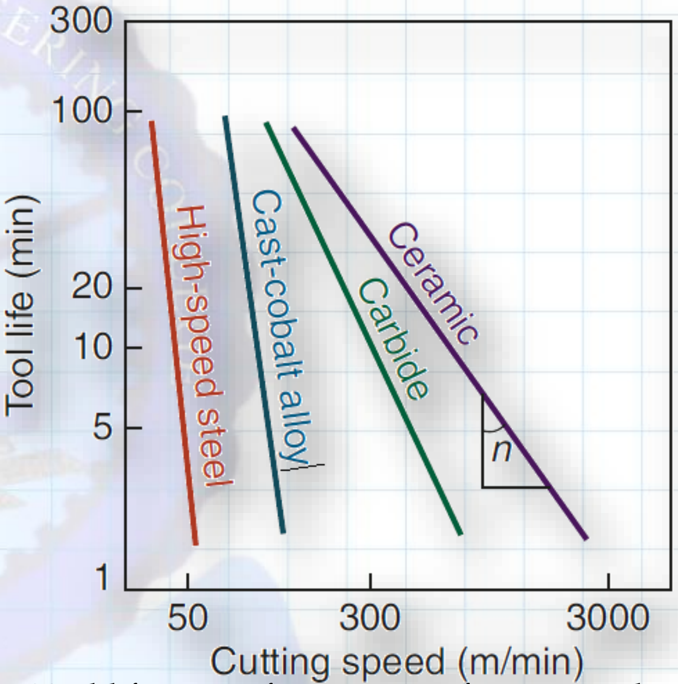
VT^n = constant = C
Where V = Cutting velocity in m/min
T = tool life in minutes
C = Taylor's constant = Cutting velocity for 1 minute tool life
n = Taylor's exponent depending mainly on cutting tool material
= 0.05 to 0.1 for H.C steels
= 0.1 10 0.2 for H.S.S
= 0.2 to 0.4 —> carbides
= 0.4 to 0.6 —> ceramics
= 0.7 to 0.9 —» diamond/ CBN

- **Factors Influencing tool life:**

1. Properties of work piece material
2. Tool Geometry
3. Use of Cutting Fluid
4. Process Parameters:

Modified Taylor's tool life equation

- $VT^n f^p d^q$ = C
  - f = Feed mm/rev
  - d = depth of cut in mm
  - p,q are constants <1
- q < p indicates that tool life is more sensitive to the uncut chip thickness than to the width of cut
- Effect of tool. life on cutting parameters is V>f>d.
- hard constituents in the material or on the workpiece surface, such as rust, scale, and slag, also are important factors, because their abrasive action reduces tool life.
- **Note that the smaller the value of *n*, the faster the tool life decreases with increasing cutting speed.**



Tool-life curves for a variety of cutting-tool materials

Machinability

- The ease with machining of a given material can be done is called Machinability.
- For a given workpiece, conduct a machining experiment and measure any one of the following below parameters and based on this which workpiece is easy in machining when compared to other workpiece can be determined.
- The parameters are :

1.Specific cutting energy

lower the specific cutting energy, better the machinability.

2. Tool life:

Under similar condition's of machining, the work piece on which higher tool life is taken as better machinability of work piece

3. **Surface finish**:

Under similar conditions of machining. the work piece on which better surface obtained is called as – better machinability work piece.

4. **Forces and power consumption:**

Under similar conditions of machining lower the forces and power consumption, better will be the machinability.

5. **SHEAR ANGLE:**

larger the shear angle, better the machinability.

6. **MRR:**

under the similar conditions of machining. higher the MRR, higher will be machinability.

7. Types of Chips:

- Under the similar condition of machining. the workpiece on which discontinuous chips are produced is considered as better machinability workpiece.
- The above method is used only used when more than one workpiece is given.

- Machinability Index (MI) = $\frac{V_T}{V_S}$

Where V_T = cutting speed on test piece for 60 min tool life.

Vs = cutting speed on standard material (***free cutting steel**) for 60 min tool life.

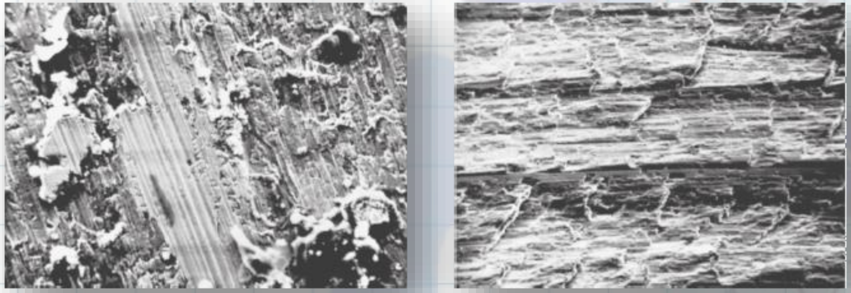
*Any steel with upto 0.5% of sulphur, upto 0.5% of phosphorus and 2-4% of lead is **free cutting steel.**

- **UMI (Universal Machinability Index)**

$$UMI = \frac{COS(\beta - \alpha)}{COS(\phi + \beta - \alpha)} = \frac{F_C}{F_S}$$

Surface Finish

- *Surface finish* influences not only the dimensional accuracy of machined parts but also their properties and performance in service.
- The term *surface finish* describes the *geometric features* of a surface.
- *surface integrity* pertains to *properties*, such as fatigue life and corrosion resistance, that are strongly influenced by the nature of the surface produced.



Machined surfaces produced on steel (highly magnified), as observed with a scanning electron microscope: (a) turned surface and (b) surface produced by shaping

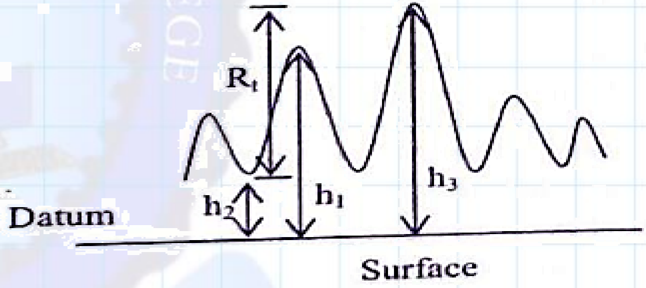
Let R_t = Maximum peak to valley height

$$= \frac{f}{\tan C_s + \cot C_e}$$

f = Feed in machining in mm/rev

C_e = end cutting edge angle

C_s = side cutting edge angle



$$R_t = \frac{f^2}{8r}$$

Case-I: When tool nose radius (R) = 0 (Ideal case)

$$H_{max} = \frac{f}{\cot \Psi_e + \tan \Psi_s}$$ where, f = feed rate

$$H_{avg} = \frac{H_{max}}{4}$$

Case-II: When tool nose radius (R) ≠ 0

$$H_{max} = \frac{f^2}{8R}$$

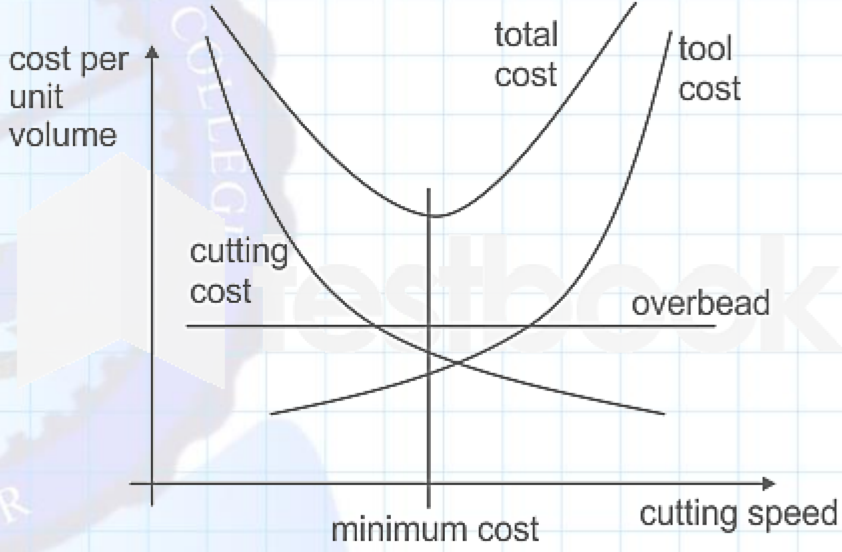
$$H_{avg} = \frac{f^2}{18\sqrt{3}.R}$$

- R ↑ ⟹ H_{max} ↓ ⟹ surface roughness ↓ ⟹ surface finish ↑

Eeconomics of Machining

- To obtain the required economic condition during machining. The optimum process parameter to be used is called economics of machining.
- Out of different process parameters. The cutting velocity has highest influence on machining.
- Therefore it is required to determine the optimum cutting velocity for a given economic condition of machining.
- Machining economics can be done based on the following criteria
  a) Minimum cost criteria
  b) Maximum production rate criteria
  c) Maximum profit criteria

a) Minimum cost criteria



Tool Materials

Basic properties which must be possessed by cutting tool material are

- Tool material must be at least 30 to 50% harder than the work piece material.
- Tool material must be have high hot hardness temperature.
- Higher toughness for withstanding the impact loads.
- High wear resistance to minimize the wear of the tool.
- High thermal conductivity for easy distribution of heat and avoid the high heat.
- Iower coefficient of friction.
- Easiness in fabrication and cheap.

Carbon Steels (HCS & HSS):

- composition C = O.8 to 1.3%, Si=0.1 t0 0.4% & Mn – 0.1 to 0.4%
- Used for machining soft metals like free cutting steels and brass and used as chisels etc.
- These tools loose hardness above 250°C.
- Hardness of tool is about Rc – 65
- Used at cutting speed of 5 m/min.

High Speed Steel

- General use of HSS is 18 4 1
  18 – Tungsten is used to increase hardness and stability
  4 – Chromium is used to increase strength
  1 – Vanadium is used to maintain keenness of cutting edge .
- In addition 2.5% to 10% cobalt is used to increase red hot hardness 0.8% carbon.
- H.S.S is used for drills, milling cutters, single point cutting tools, dies, reamers etc.)
- It looses hardness above 600°c.
- Some times tungsten is replaced by Molybdenum
- Molybdenum based H.S.S completely is cheaper than the Tungsten based H.S.S and also slightly greater toughness but less wear resistance.
- Used at cutting speeds 40 to 50 mv/min

Non – ferrous cast alloys (Stellite)

- It is an alloy of
  Cobalt – 40 to 50%,
  Chromium – 27 to 32%
  Tungsten – 14 to 29%,
  Carbon - 2 to 4%
- It can not heat treated and are used as cast form.
- It looses its hardness about 800°C.
- It will give better tool life than H.S.S and can be used at slightly higher cutting speeds.
- They are weak in tension and like all cast materials tend to shatter when subjected to shock load or when not properly supported.

Cemented Carbides

- Produced by powder metallurgy technique with sintering at 1500°C
- Speed can be used 6 to 10 times that of H.S.S
- Can withstand up to 1000°C.
- High compressive strength
- High wear resistance
- High modulus of elasticity
- Low coefficient of thermal expansion
- High thermal conductivity
- According to ISO the various grades of carbide tool materials grouped as for cutting CI and non ferrous metals are designated as K01 to K40
- for cutting steel are designated as P01 to P60
- for general purpose application are designated as M10 to M 30

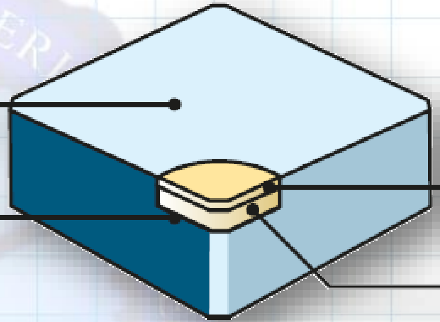
Ceramics and sintered oxides:

- It is basically Al_2O_3 containing additions like MgO, Al_2O_3, Cr_2O_3, TiO_2,FeO_3 etc to improve grain structuring. cutting properties, and sintering. These are made by Powder Metallurgy technique.
- Used for very high speed (4 times carbides, 500m/min to times H.S.S).
- Used for continuous cutting only .
- Can withstand up to 1200°C
- Have very high abrasion resistance
- Used for machining CI and plastics.
- Has less tendency to weld metals during machining
- Generally used ceramic is sintered carbides
- Another ceramic tool material is silicon nitride which is mainly used for CI
- The tool life of silicon nitride is effective over 1500 CI pieces, but for same work. tungsten carbide tool lasted only for 250 pieces.

Cermets

- It is the combination of ceramics and metals and produced by Powder Metallurgy process.
- When they combine ceramics give high refractoriness and metals will give toughness and thermal shock resistance.
- For cutting tools usual combination as Al_2O_3 + W + Mo + Boron + Ti etc.
- Usual combination 90% ceramic, 10% metals.
- Increase in %of metals reduces brittleness some extent and also reduces wear resistance.

Diamonds



It has

- ❑ Extreme hardness
- ❑ Low thermal expansion
- ❑ High thermal conductivity
- ❑ Very low coefficient of friction
- ❑ Work materials are Cu, brass, Zn, Al, Mn alloys etc.
- ❑ Cutting speeds are ranging from 200 to 500 m/min
- ❑ On ferrous metals diamonds are not suitable because of the diffusion of carbon atoms from diamond to Work piece.
- ❑ Can withstand up to 2000°C
- ❑ A synthetic (man made) diamond with polycrystalline structure is recently introduced and is called compacts and made by powder metallurgy process.
- ❑ Used as turning and boring tools, grinding wheel ,milling cutters, reamers, wheels, honing tools, grinding dressing etc.

CBN& UCON

- The trade name is **Borozone**
- Consists of atoms of Nitrogen and Boron and produced by Powder metallurgy process.
- Used as a substitute for diamond during machining of steel
- Used as a grinding wheel on H.S.S tools
- Excellent surface finish is obtained.

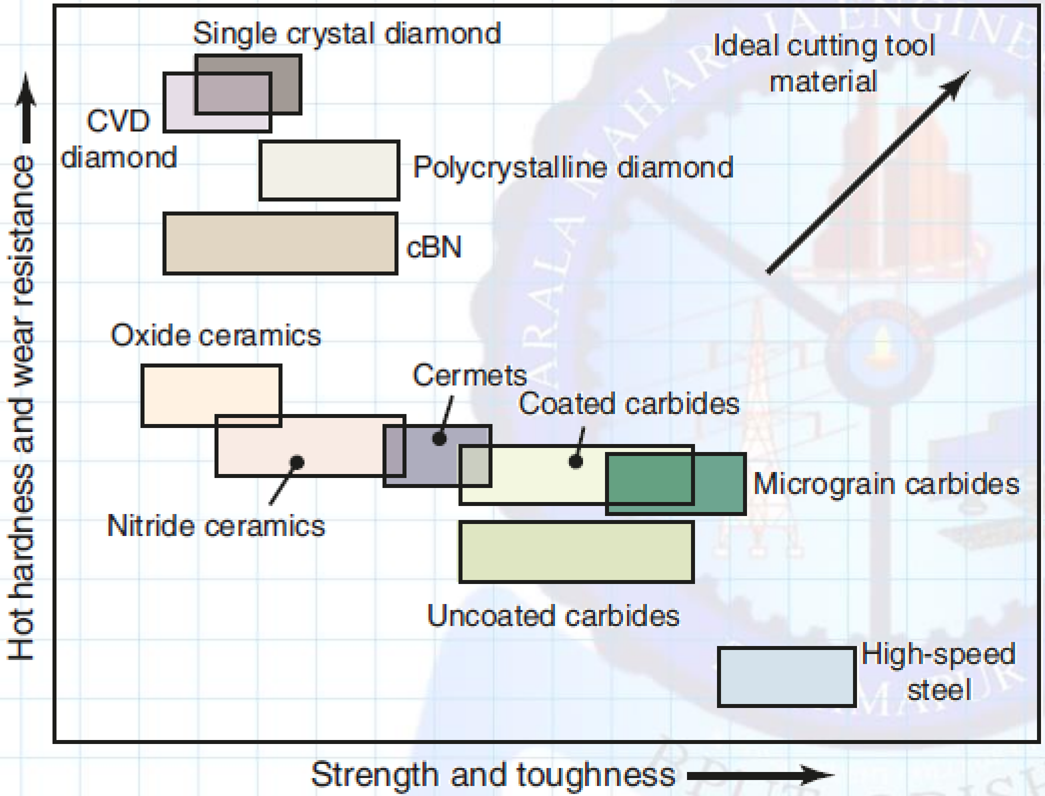
UCON:

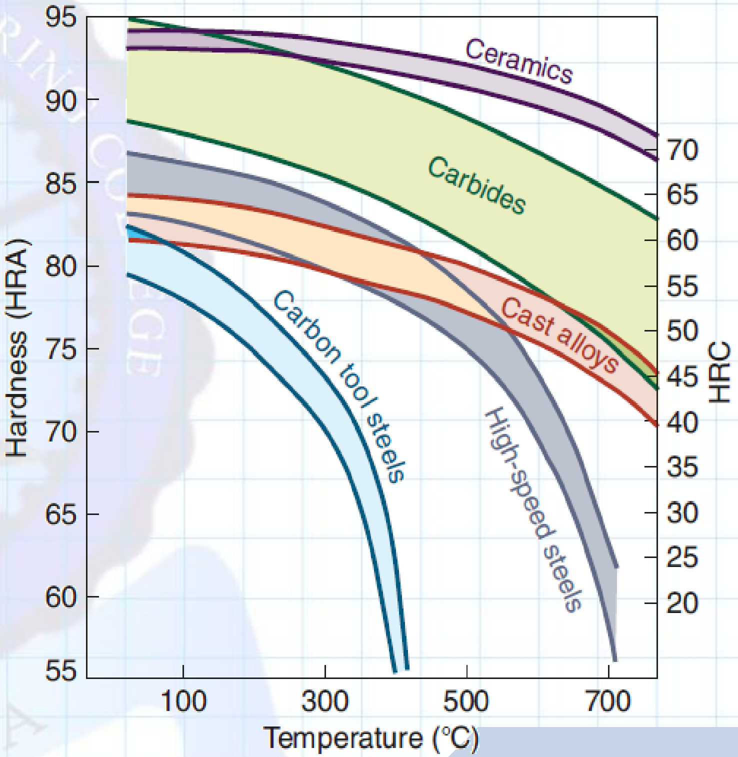
- Developed by Union Carbide in USA
- It consists of Columbium 50%Titanium 30 % and Tungsten 20%.
- This is a refractory metal alloy which is cast rolled into sheets and slit into blanks. Though its hardness is only 200BHN. it is hardened by _dlffusing nitrogen into surface producing very hard surface with soft core. It is not used because of its higher costs.

Sialon

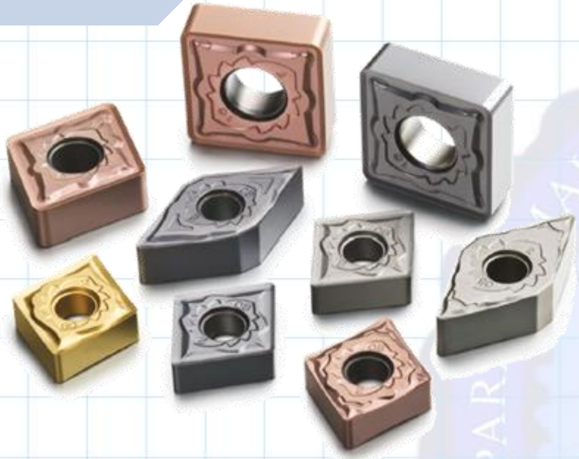
- Si-Al-O-N
- It is made by powder metallurgy with milled powders of Silicon, Nitrogen Aluminium and oxygen by sintering at 1800° C.
- This is tougher than ceramics and so it can be successfully used in interrupted cuts. Cutting speeds are 2 to 3 times of ceramics.
- At present this is used for machining of Nickel based gas aerospace alloys, Nickel based turbine blades with a cutting speed of 3 to 5 m/sec.

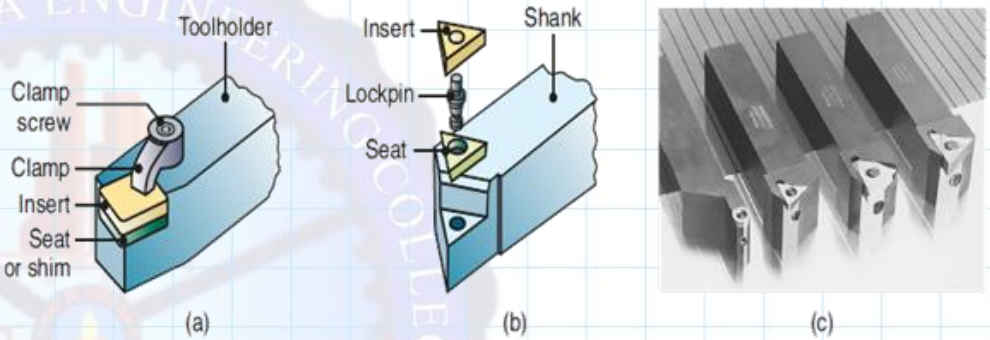
Mechanical Properties of various group of Tool Materials

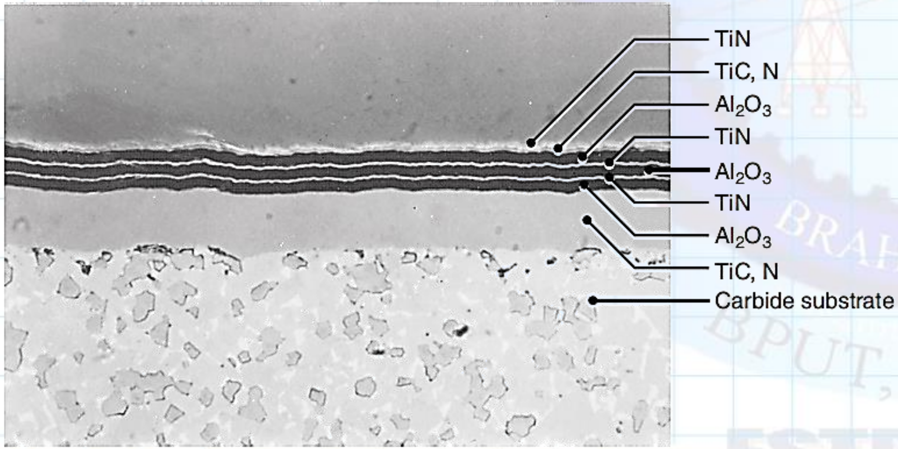


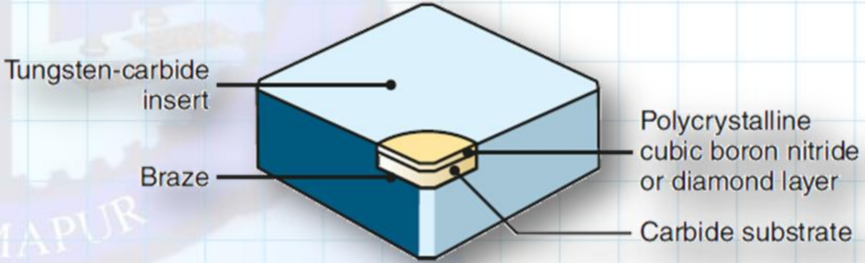


Inserts & Coated Inserts









Cutting Fluid

Cutting fluids are used in machining operations for the following purposes:

- ❑ Reduce friction and wear, thus improving the tool life and surface finish of the workpiece.
- ❑ Cool the cutting zone, thus improving tool life and reducing the temperature and thermal distortion of the workpiece.
- ❑ Reduce cutting forces and energy consumption.
- ❑ Flush away the chips from the cutting zone, preventing the chips from interfering with the cutting operation, particularly in drilling and tapping.
- ❑ Protect the machined surface from environmental corrosion.

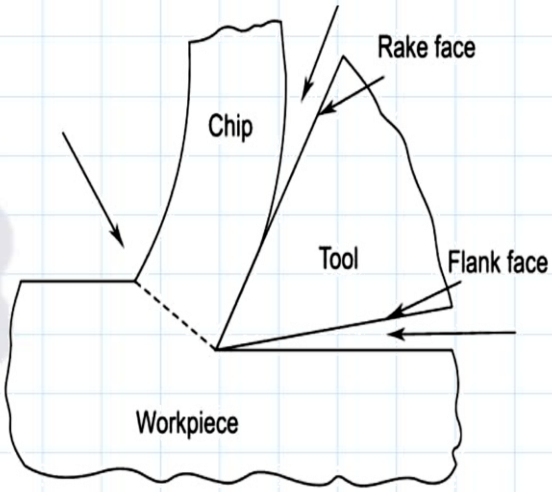
- ❑ Depending on the type of machining operation, the cutting fluid required may be a **coolant**, a **lubricant**, or both.
- ❑ The effectiveness of fluids depends on several factors, such as the type of machining operation, tool and workpiece materials, cutting speed, and the method of application.
- ❑ Water is an excellent coolant, and can effectively reduce the high temperatures developed in the cutting zone. However, it is not an effective lubricant and it does not reduce friction, and can cause corrosion of workpieces and machine-tool components.

Cutting Fluid

- The necessity for a cutting fluid depends on the *severity* of the particular machining operation, defined as
  (a)the level of temperatures and forces encountered and the ability of the tool materials to withstand them.
  (b) the tendency for built-up edge formation.
  (c) the ease with which chips produced can be removed from the cutting zone, and
  (d) how effectively the fluids can be supplied to the proper region at the tool–chip interface.
- The relative severities of specific machining processes, in increasing order of severity, are: sawing, turning, milling, drilling, gear cutting, thread cutting, tapping, and internal broaching.

Cutting Fluid Action

- Studies have shown that the cutting fluid gains access to the tool–chip interface by seeping
- from the *sides* of the chip (perpendicular to the page in Fig of chip removal mechanism), through the *capillary action* of the interlocking network of surface asperities in the interface.
- Because of the small size of this capillary network, the cutting fluid should have a *small molecular size* and possess *wetting* (*surface tension*) characteristics. Grease, for example, cannot be an effective lubricant in machining, whereas low-molecular-weight oils suspended in water, known as *emulsions*, are very effective.
- Note also that in discontinuous machining operations, cutting fluids have more access to tool–chip-workpiece interfaces.

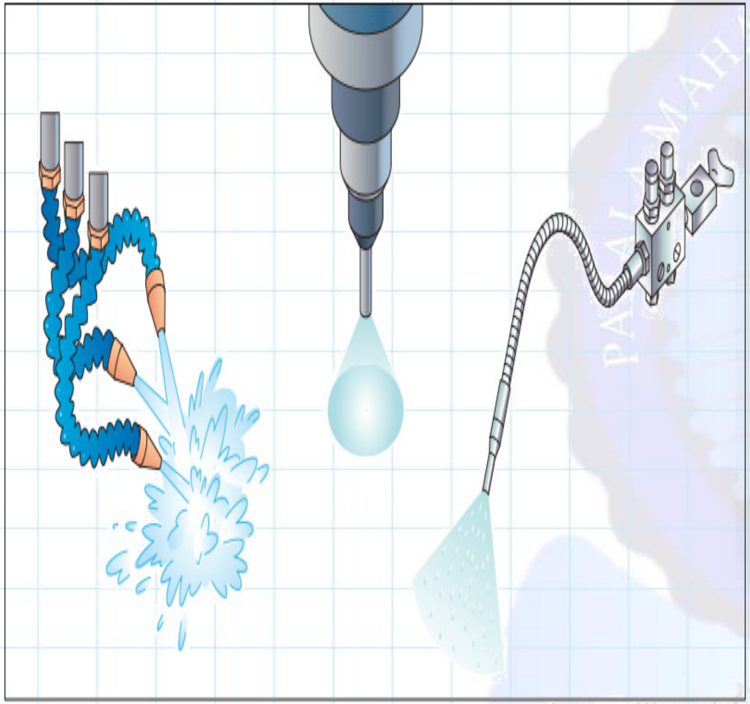


Types of Cutting Fluids

1. **Oils** include mineral, animal, vegetable, compounded, and, more recently, synthetic oils. They typically are used for low-speed operations where temperature rise is not significant.
2. **Emulsions**, also called *soluble oils*, are a mixture of oil, water, and additives. They generally are used for high-speed machining operations where the temperature rise is significant. The presence of water makes emulsions highly effective coolants, and the presence of oil reduces or eliminates the tendency of water to cause oxidation of workpiece surfaces.
3. **Semi synthetics** are chemical emulsions containing some mineral oil diluted in water, and additives that reduce the size of the oil particles, thus making them more effective.
4. **Synthetics** are chemicals with additives, diluted in water; they contain no oil.

Methods of Cutting-fluid Application

1. **Flooding.** This is the most common method,as shown in the next slide. Fluid flow rates typically range from 10 L/min for single-point tools to 225 L/min per cutter for multiple-tooth cutters, as in milling. In some operations, such as drilling and milling, fluid pressures in the range from 700 to 14,000 kPa are used to flush away the chips produced to prevent their interfering with the operation.
2. **Mist.** This type of cooling supplies fluid to inaccessible areas, in a manner similar to using an aerosol can, and provides better visibility of the workpiece being machined. This method is particularly effective with water-based fluids and at air pressures ranging from 70 to 600 kPa. However, it has limited cooling capacity, and requires venting to prevent the inhalation of airborne fluid particles by the operator and other personnel nearby.
3. **High-pressure systems.** Heat generation in machining can be a significant factor. Particularly effective is the use of high-pressure *refrigerated coolant systems* to increase the rate of heat removal. High pressures are also used to deliver the cutting fluid via specially designed nozzles; they aim a powerful jet of fluid to the cutting zone, particularly into the *clearance* or *relief face* of the tool . The pressures are usually in the range from 5.5 to 35 MPa, and also act as a chip breaker in situations where the chips produced would otherwise be long and continuous, interfering with the cutting operation. Proper cycling and continuous filtering of the fluid is essential to maintain workpiece surface quality



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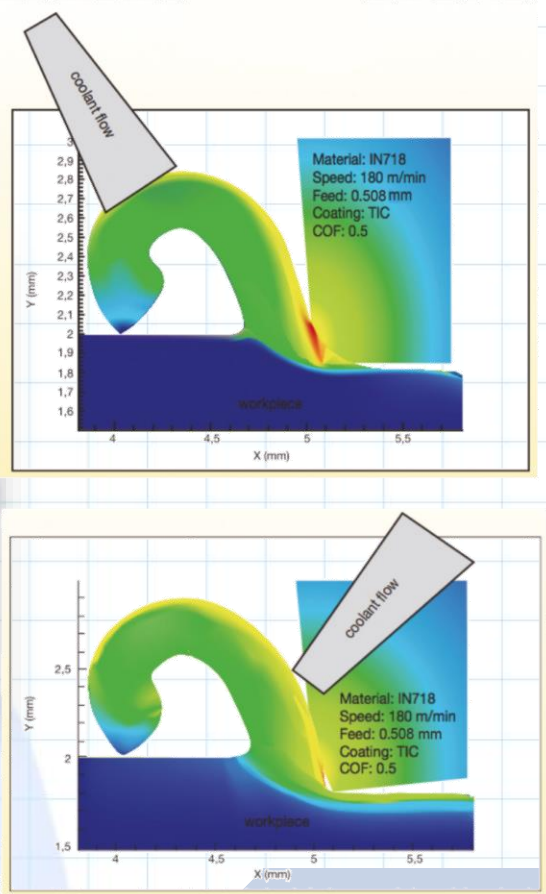


(a) A turning insert with coolant applied through the tool; (b) comparison of temperature distributions for conventional and through-the-tool application. *Source:* Courtesy of Kennametal, Inc.

Lathe Tool Dynamometer

- Cutting forces can be measured using a **force transducer** (typically with quartz piezoelectric sensors), a **dynamometer**, or a **load cell** (with resistance-wire strain gages placed on octagonal rings) mounted on the cutting-tool holder. It is also possible to *calculate* the cutting force from the **power consumption** during cutting.
- The measuring equipment that is used to measure the cutting force is called a **dynamometer.**
- The measurement of cutting force can be accomplished by a number of approaches. They are
  1. By measuring the deflection of a body that is directly influenced by the acting cutting forces,
  2. By measuring the strain induced in the body that is directly influenced by the acting cutting forces, and
  3. By measuring the pressure exerted on a medium that is directly influenced by the acting cutting forces.

- Any typical set-up for measuring the cutting force consists of the following two components:
  1. A medium that experiences the cutting force, and
  2. A sensor that measures and converts it to a measurable quantity such as a strain gauge.
- The sensor output is then normally amplified and measured using any of the traditional measuring equipment used in the laboratory.

Lathe Tool Dynamometer: Design Requirements

While designing a dynamometer, it is important to consider a number of design requirements. They are the followings:

- **Sensitivity**—It should provide sufficient sensitivity for different ranges of measurements.
- **Rigidity**—It should have high stiffness and rigidity.
- **Cross sensitivity**—In the case of multichannel dynamometer, it should separate the individual force components without them having any cross-sensitivity
- **Stability**—The dynamometer measuring component should not be affected by cutting fluids, humidity or temperature.
- **Solid construction**—It is preferable that the dynamometer be manufactured from a single block of material in place of an assembly of number of parts in the force transmission as they may cause loss of accuracy.
- **Ease of calibration**—The dynamometer should be calibrated with simple procedures, and the calibration curve should remain linear in the operating range.

Sensing Technologies used in Dynamometers

1. Measuring deflection (relatively simple)

- Potentiometers
- Capacitance pick-up
- Inductance pick-up
- LVDT

2. Measuring the strain (more common for low-cost equipment)

- Strain gauges in full-bridge, half-bridge and quarter bridge configurations

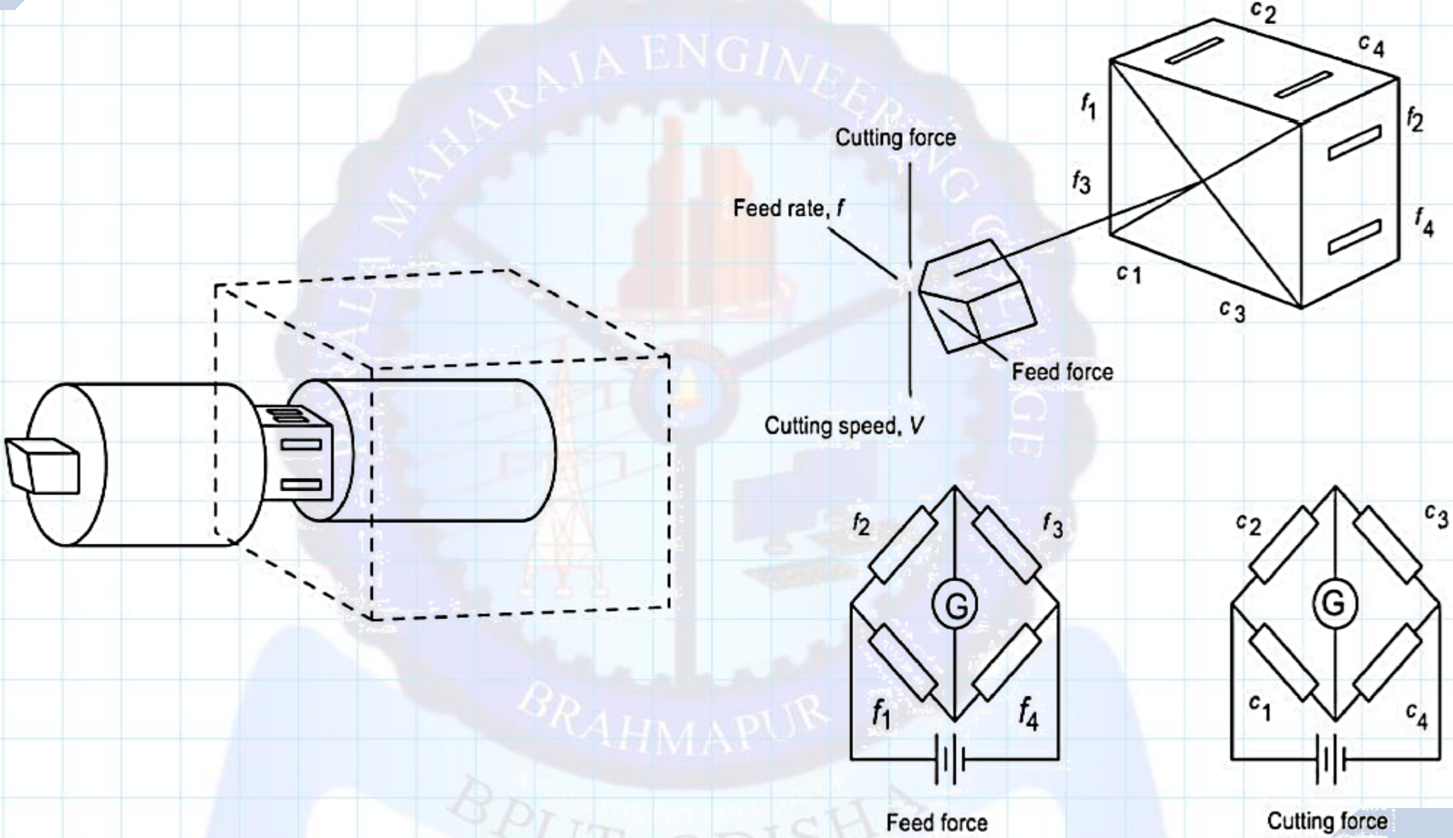
3. Measuring the pressure (more rugged and expensive)

- Piezoelectric crystals

Two-component Dynamometer Design

- It utilises strain gauges to measure the force. A strain gauge system actually measures strain and not force.
- Therefore, a strain-gauge transducer is designed in such a way that the force to be measured develops a suitable stress level in the sensing element.
- The strain gauge then measures the strain in one or more locations of the sensing element, Strain is measured only locally on several points on the surface of the sensing element to compensate for the temperature variations.

- The dynamometer structure consists of a rod of suitable diameter to provide the necessary rigidity. A part of the rod in the middle portion is reduced in size and machined flat which will act as the sensing structure.
- The strain gauges are then fixed at the flat portions in appropriate locations as shown in Fig. to measure both the horizontal and vertical components of the cutting forces.
- The strain gauges are then formed into a full Wheatstone bridge structure as shown to measure the change in the resistance which corresponds to the acting cutting forces.



c2
c4
f1
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Cutting force
Feed rate, f
Feed force
Cutting speed, V
f2
f3
G
f1
f4
Feed force
c2
c3
G
c1
c4
Cutting force

THANKS!

Any questions?

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