



**DEPT. OF MECHANICAL ENGINEERING**

**TRIDENT ACADEMY OF TECHNOLOGY,  
BHUBANESWAR**

**LECTURE NOTES**

**ON**

**METAL CUTTING & MACHINING**

**B. Tech**

**5<sup>th</sup> Semester**

**By**

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## MEPC3003 METAL CUTTING & MACHINING (3-0-0)

### Course Objectives:

This course explores metal cutting principles, tool geometry, and machining processes (conventional and non-traditional). Students will analyze tool wear, cutting forces, and machinability criteria, and apply Taylor's tool life equation. Emphasis is placed on machine tool operations, CNC technology, and advanced processes like EDM, laser machining, and ultrasonic machining.

### Module – I: (06 Hours)

Geometry of cutting tools in ASA and ORS, Effect of Geometrical parameters on cutting force and surface finish, Mechanics of chip formation, Merchant's theory, Force relationship and velocity relationship, Cutting tool materials. Types of Tool Wear: Flank wear, Crater wear, Wear measurement, Temperature in metal Cutting, Cutting fluid and its effect.

### Module – II: (06 Hours)

Machinability Criteria, Tool life and Taylor's equation, Effect of variables on tool life and surface finish, Measurement of cutting force, Lathe tool dynamometer, and Drill tool dynamometer. Economics of machining: Minimum cost, Maximum production and Maximum profit rate.

### Module – III: (06 Hours)

Conventional machining process and machine tools: Turning, Drilling, Shaping, Planning, Milling, Grinding. Machine tools used for these processes, their specifications and various techniques used.

### Module – IV: (06 Hours)

Tool holding and job holding methods in different Machine tools, Types of surface generated. Production Machine tools: Capstan and turret lathes, single spindle and multi spindle semiautomatics, CNC Machine tools.

### Module – V: (06 Hours)

Non-traditional Machining processes: Ultrasonic Machining, Electro Chemical Machining, EDM, Wire EDM, Abrasive Jet Machining, Plasma Arc Machining and Laser Beam Machining.

### Course Outcomes:

- CO1: Remembering (Knowledge): Recall tool geometry systems (ASA, ORS), types of tool wear, and fundamentals of chip formation.
- CO2: Understanding (Comprehension): Explain the impact of tool geometry, cutting fluids, and variables on tool life and surface finish.
- CO3: Applying (Application): Calculate tool life using Taylor's equation and analyze cutting forces using dynamometers.
- CO4: Analyzing (Analysis): Compare conventional and non-traditional machining processes (e.g., EDM, laser) based on efficiency, precision, and applications.
- CO5: Creating (Synthesis): Design machining strategies for cost-effective production, integrating CNC and advanced processes for complex geometries.

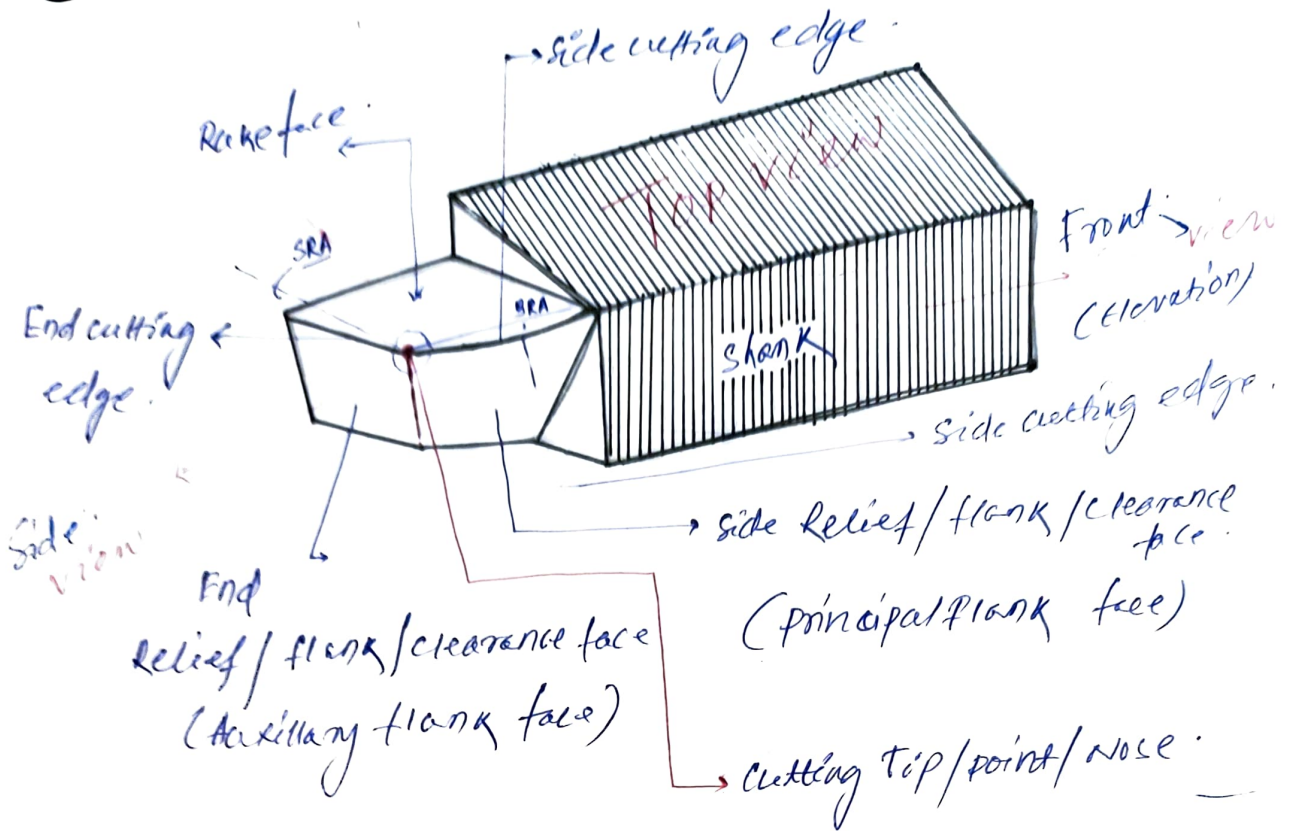
### Reference Books

1. A Bhattacharyya, Metal Cutting, Theory and Practice, New Central Book Agency (p) Ltd, 1st Edition, 2022.
2. A B Chattopadhyay, Machining and Machining tool, Wiley Publisher, 2nd. Edition, 2021.
3. Sreeramulu Moinikunta, Production Technology, Volume 2, Wiley Publisher, 1st. Edition 2019.
4. P. K. Mishra, Nonconventional Machining, Narosa Publishing House, 2007.
5. Production Technology HMT, Tata McGraw Hill, 2001.
6. M. C. Shaw, Metal Cutting Principles, Second Edition, Oxford University Press, 2005.

01

# Metal Cutting:

1



## → Single Point Cutting Tool ←

### Cutting Tool

- 1) Single pt. cutting Tool → (1) Turning  
 (2) Broad cutting tool.  
 (3) Shaper / planer / Boring Tool

- (2) Two point cutting tool → (1) Drilling bit

- (3) M.P.T. cutting tool → (1) Milling cutter  
 (2) Reamers  
 (3) Taps  
 (4) Grinding wheel.  
 (5) Hobs etc.

Different view of Tool.

# Carriage movement gives - feed.  $\leftarrow \rightarrow$

# cross-slide movement gives  $\rightarrow$  depth of cut  $\updownarrow$

Cutting Tool

# Tool is made of HSS, HCS, carbide bar

# Cutting edge is prepared by Grinding.

# Metal cutting

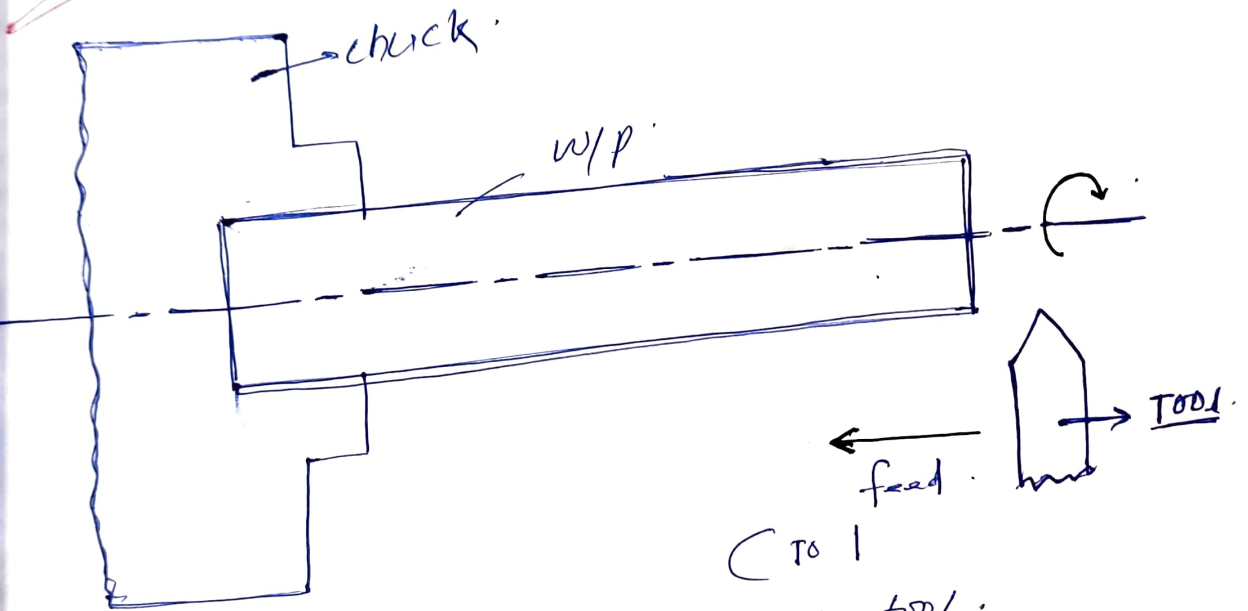
Generatrix and Director.

for successful m/ing process there are 2 motion.

1. Primary motion (cutting motion)  $\uparrow$

2. Secondary motion (Feed motion)  $\leftarrow$

Turning  $\rightarrow$  reduce the diameter of cylindrical objects.



feed - To provide correct area to tool.

Cutting motion  $\rightarrow$  W/P is responsible for cutting motion.  $\rightarrow$  ex

feed motion  $\rightarrow$  Tool is responsible for feed motion.

$\rightarrow$  If  $W/P = 0$  for W/P then tool may make a mark on W/P but not produced any chip.

(It depends upon m/ing operation)

(9c)

Generatrix

A line generated along <sup>by</sup> cutting motion is called generatrix.

Directrix

A line generated from feed motion is called directrix.

(Feed) (D)

# TOOL SIGNATURE:

(1)

It is basically referred to some specific angles and Surface of cutting tool.

## Systems of Description of Tool Geometry:

1. Tool in hand system
2. M/C Reference system (ASA) → American Standard Association
3. Tool Reference system (ORS) → Orthogonal rake system.  
Normal or orthogonal system

### 1. Tool in hand system:

Here only salient features of tool are described, there is not quantitative values.

(only fig and name)

### 2. ASA (Here M/C is considered as Reference)

$\alpha_b - \alpha_s - \gamma_e - \gamma_s - \psi_e - \psi_s - R$  (Inch)

BSES ES N

B → back rake angle →  $\alpha_b$

S → side rake angle →  $\alpha_s$

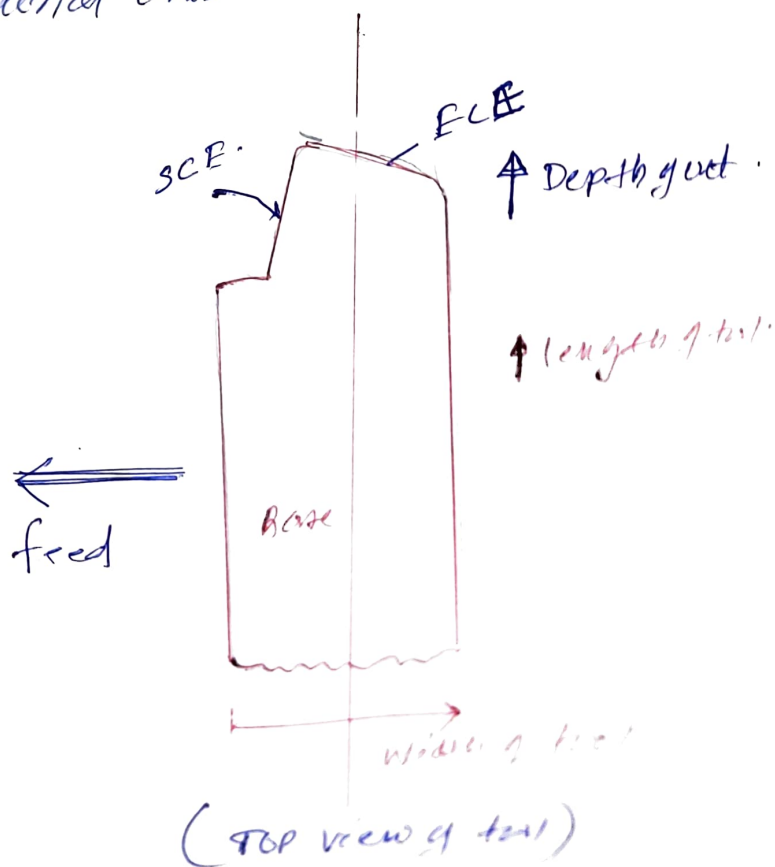
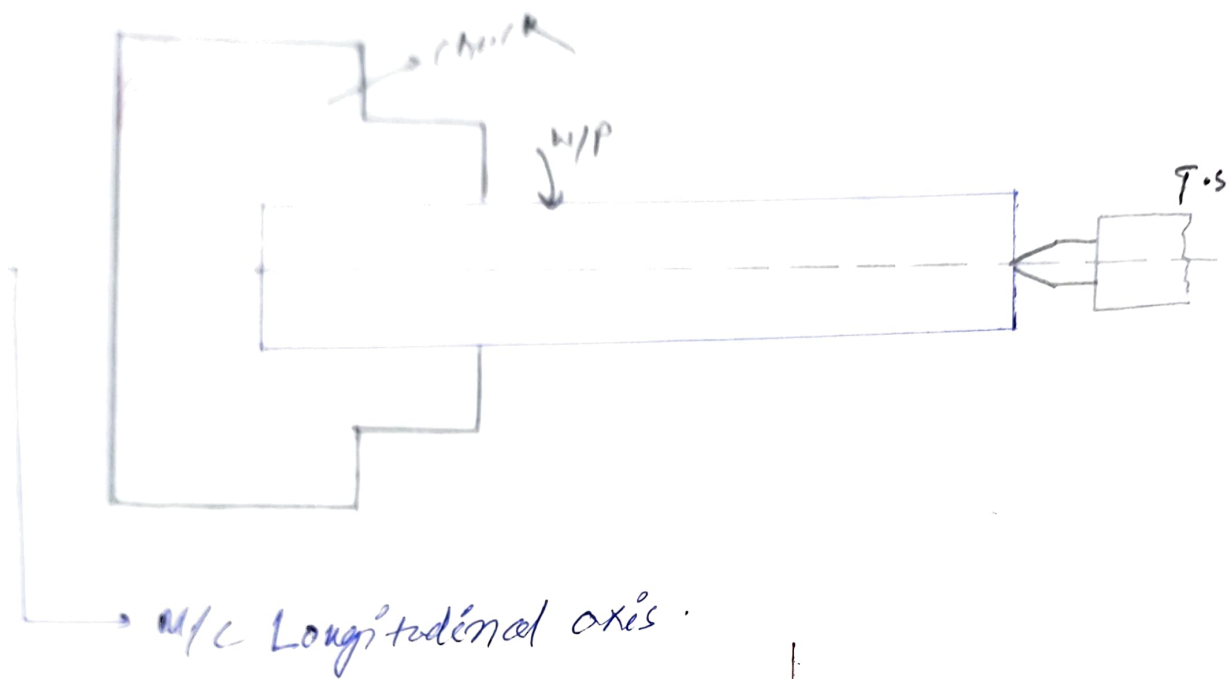
E → End Relief angle →  $\gamma_e$  (Clearance Angle)

S → side Relief →  $\gamma_s$

E → ECEA →  $\psi_e$

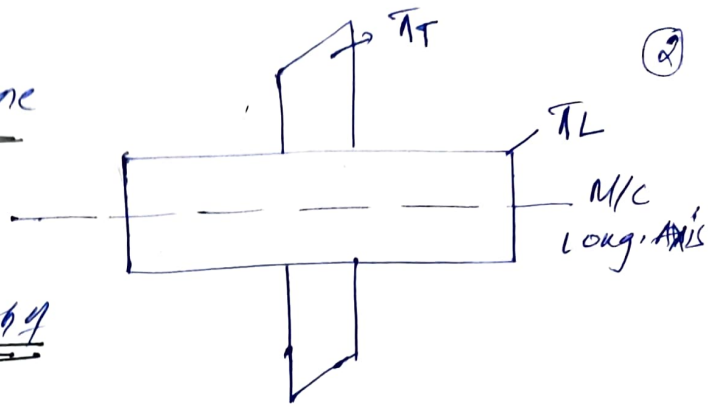
S → SCEA →  $\psi_s$

R → nose Radius (Inch)



- ① # Let us consider a vertical plane (consider with the M/C longitudinal axis) called M/C Longitudinal Plane (T.L)
- # T.L is  $\perp$  to Tool Base and  $\parallel$  to width.

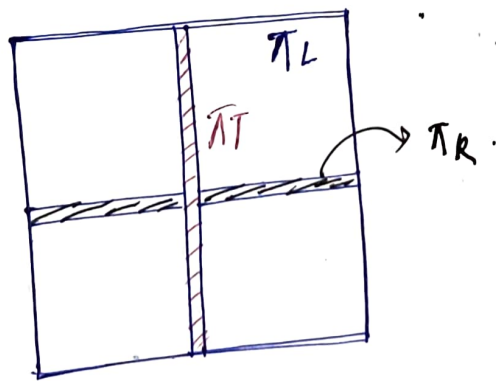
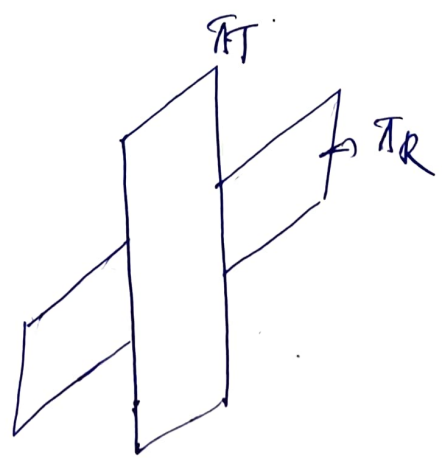
(2) M/C Transverse plane  
( $\pi_T$ )



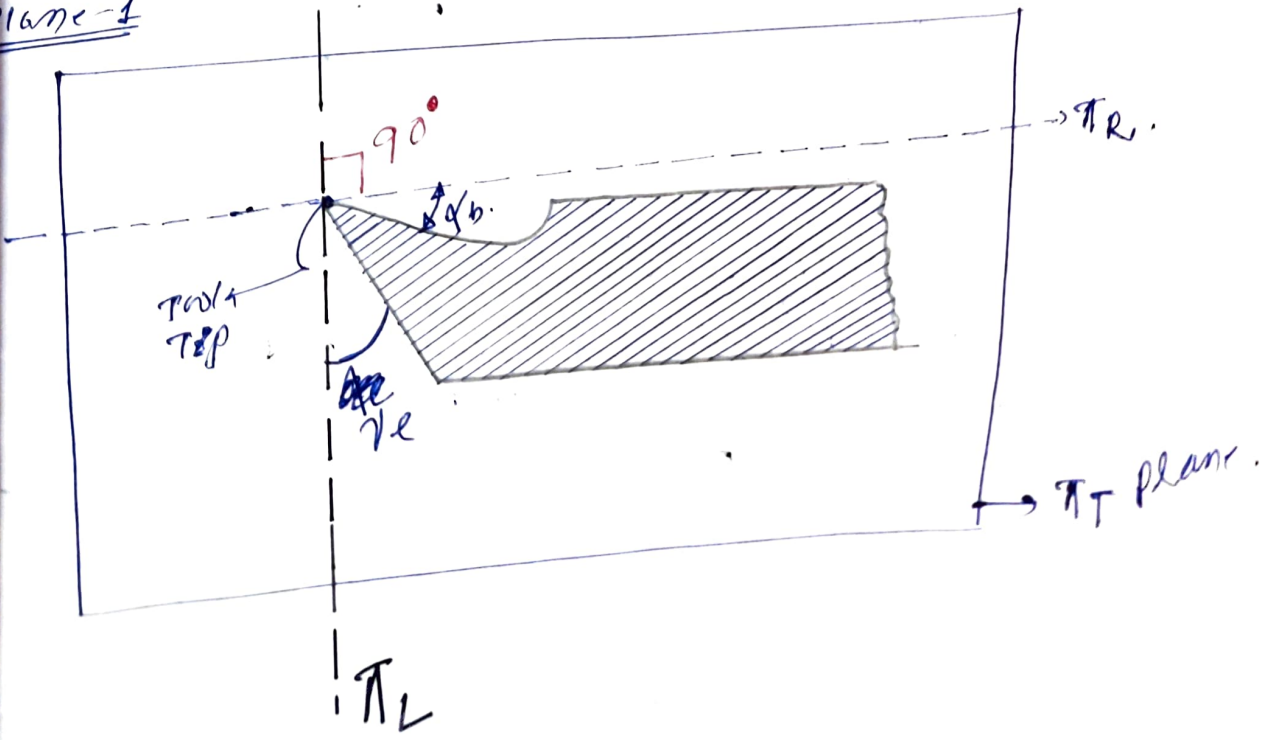
(It's base is || to Length)  
(Top)

(3) Another plane is ~~is~~ to  $\pi_T$   
( $\pi_R$ )

It's parallel to Base.



Plane-1

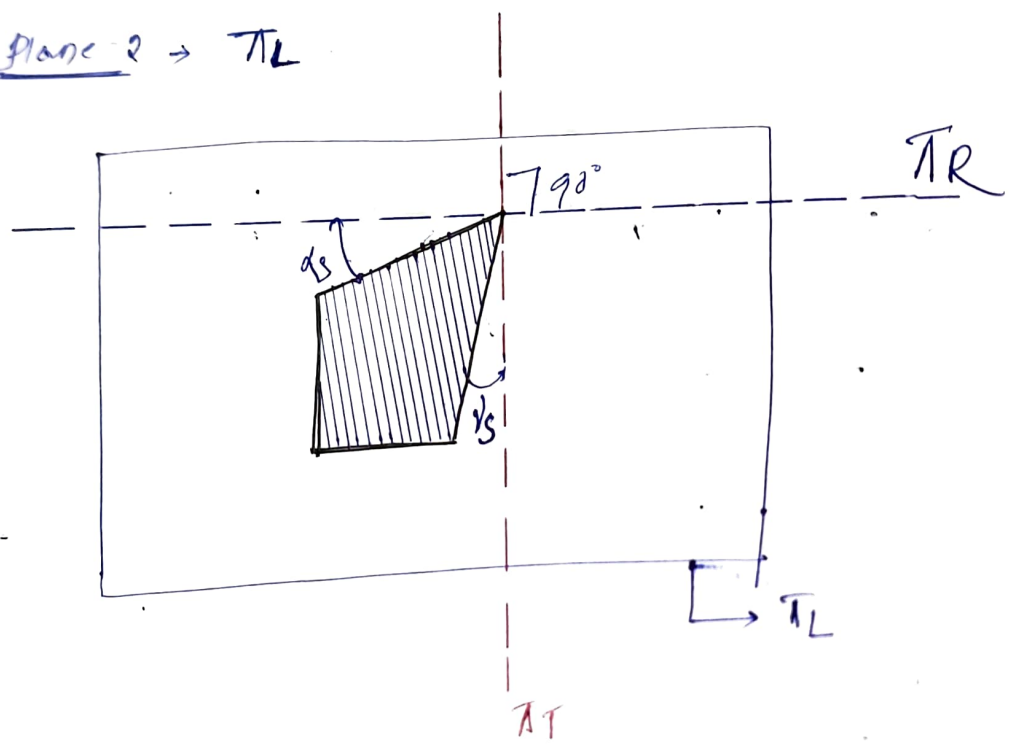


$\alpha_b$  = Angle of Inclination of Rake surface from Reference plane and measured in transverse plane  $\rightarrow$  Main Rake angle.

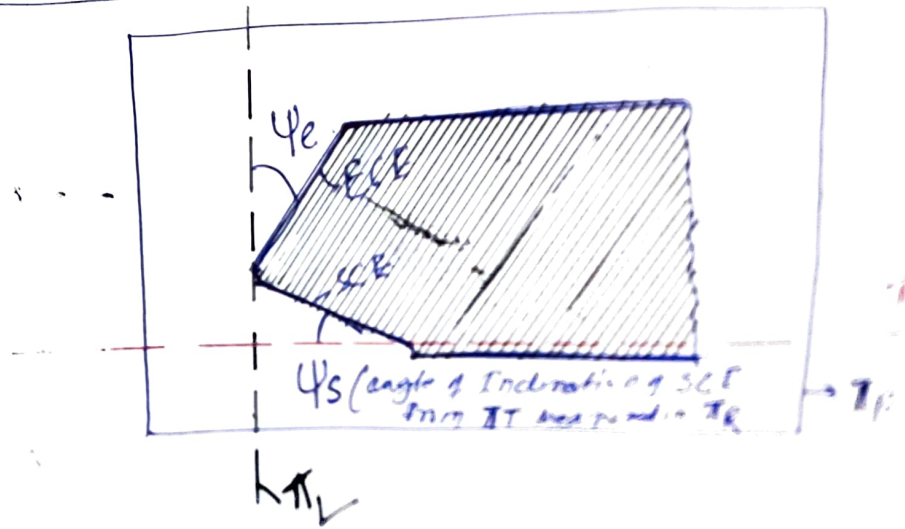
$\psi_e$  = end Relief angle

Angle of Inclination of End flank from ~~Reference~~ Longitudinal plane and measured in  $\pi\pi_0$ .

② Plane 2  $\rightarrow$   $\pi\pi_L$

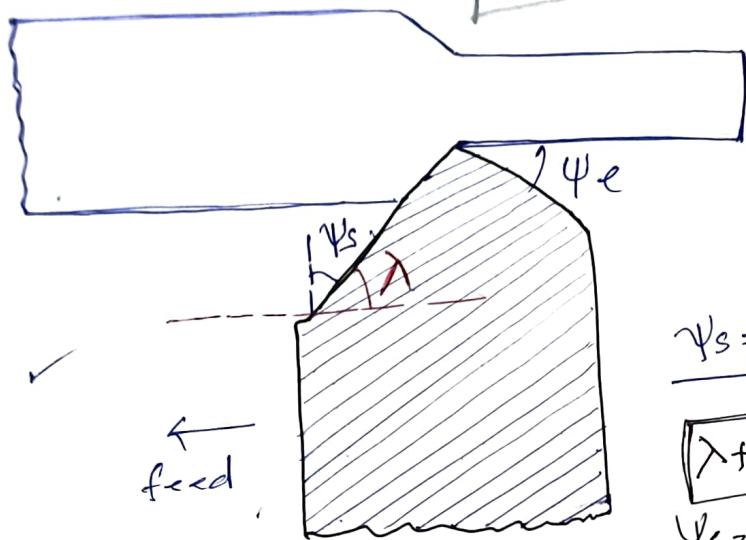


③ Plane 3  $\rightarrow$   $\pi\pi_R$



oblique turning

inclination ( $i$ )  $\neq 0$



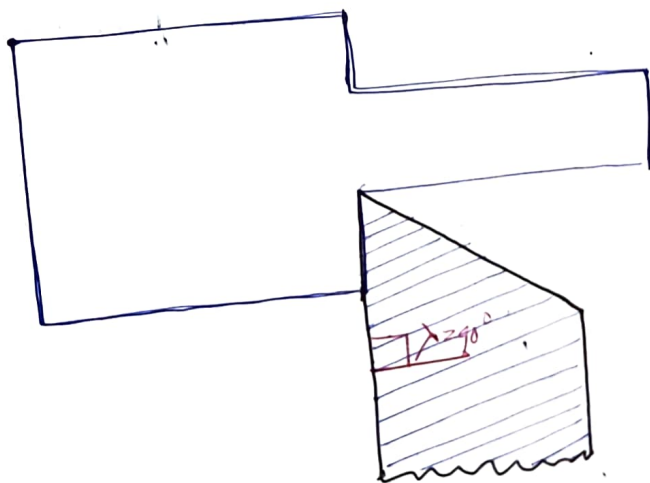
$\psi_s \neq 0$

$\lambda + \psi_s = 90^\circ$

$\psi_s =$  approach angle.

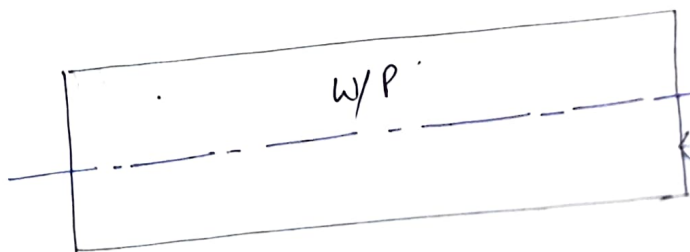


Orthogonal turning



$\psi_s = 0$   
 $\lambda = 90^\circ$

position of cutting edge with



AL = Approach length

feed



# ORTHOGONAL RAKE System

(ORS)

(Tool Reference system) (TRS)

Imp

$$i - \phi_0 - \psi_s - \psi_e - \lambda - R(\text{in mm})$$

$i$  = inclination angle.

$i$

5

$\phi_0$  = orthogonal rake angle.

0

S

$\psi_s$  = side relief angle (Auxiliary clearance angle)

E

$\psi_e$  = end relief angle (Auxiliary orthogonal clearance angle)

E

Not included

$\psi_e$  = end cutting edge angle (Auxiliary cutting edge)

$\lambda$  = principal cutting edge angle / Approach angle

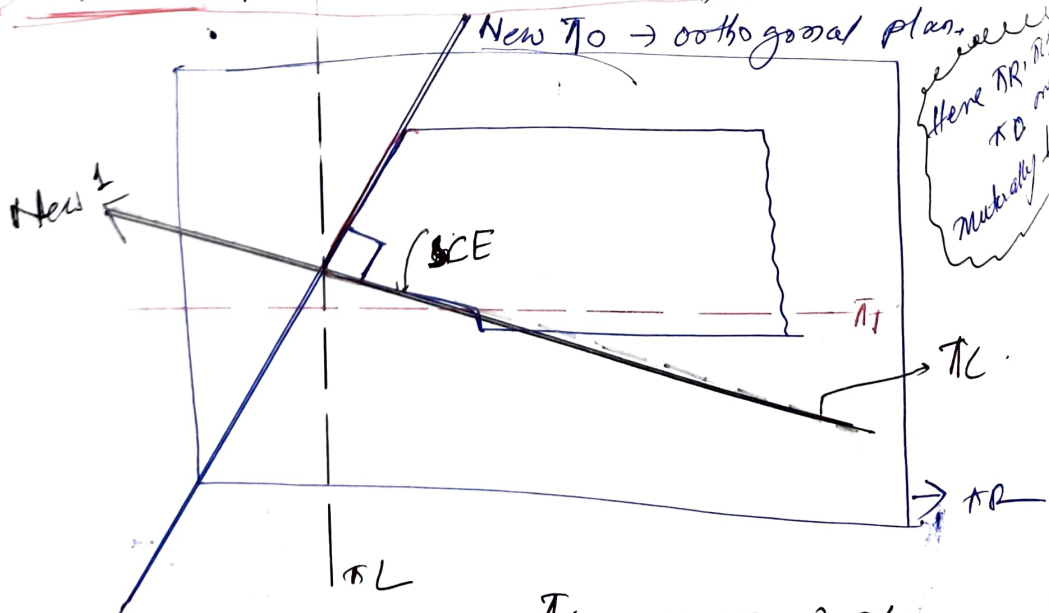
→ nose Radius (mm)

NOT Auxiliary angle.

Inclination Angle

$$90 - \psi_s = \lambda$$

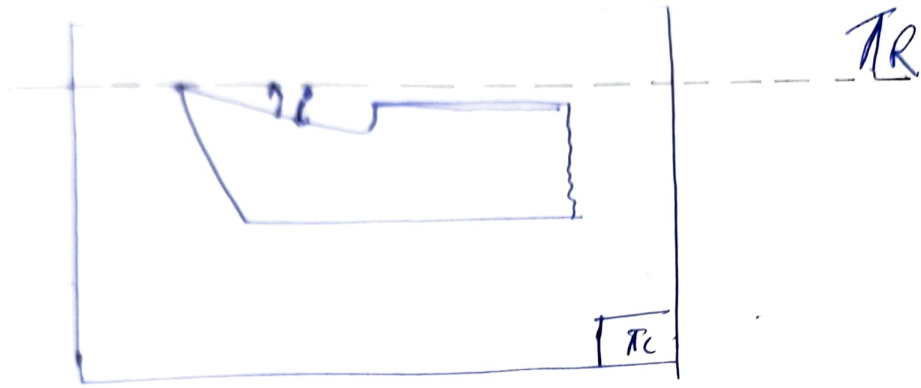
Reference plane is same as that of ASA.



TC = cutting plane

$T_0 \perp TC$  → All plane passing through cutting edge.

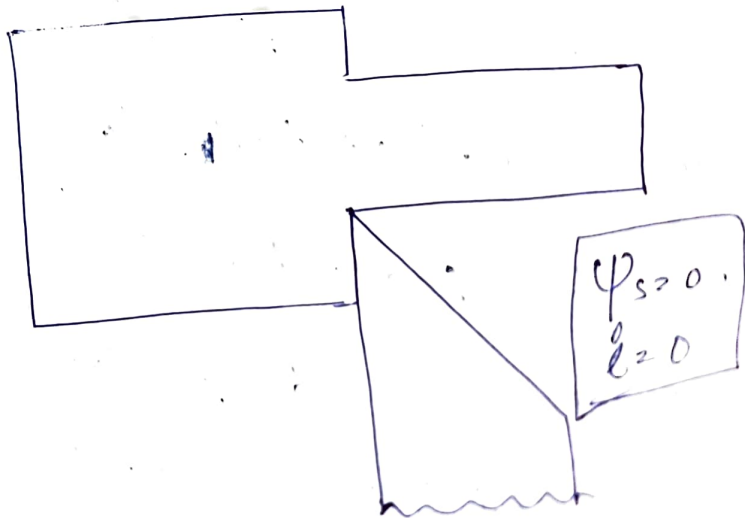
Q.1 cutting plane (1)



is inclination angle of cutting edge.

Q.2 (orthogonal plane)

Pure orthogonal turning



Back rake angle

Steady Greatly affects  $\rightarrow$  chip thickness & force of cutting

Compression

Asa. OR  
 $\alpha_b$  i  
 $\alpha_s$   $\alpha_o$

$\lambda \rightarrow$  approach angle

N. 8<sup>th</sup>

(4)

principal cutting edge angle

straight  $\rightarrow \sin \lambda$

(cross)  $\rightarrow \cos \lambda$

ASA  $\rightarrow$  O.R.S  $\rightarrow$  Tan.

ISIS  $\rightarrow$   $\alpha_b$   $\alpha_s$   $\alpha_o$  comes then (-) i.e.,

Relation b/w  $\alpha_b$  &  $i$ :  $\alpha_b \rightarrow i$

$\tan \alpha_b = \tan \alpha_o \sin \lambda + \tan \alpha_s \cos \lambda$  — (1)

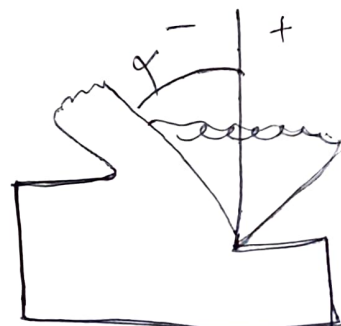
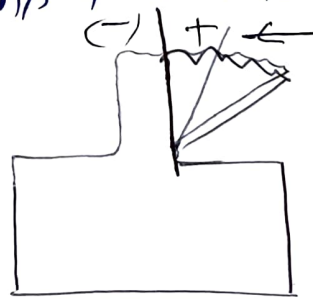
$\tan \alpha_s = \tan \alpha_b \sin \lambda - \tan \alpha_o \cos \lambda$  — (2)

$\tan i = \tan \alpha_b \sin \lambda - \tan \alpha_s \cos \lambda$  — (3)

$\tan \alpha_o = \tan \alpha_s \sin \lambda + \tan \alpha_b \cos \lambda$  — (4)



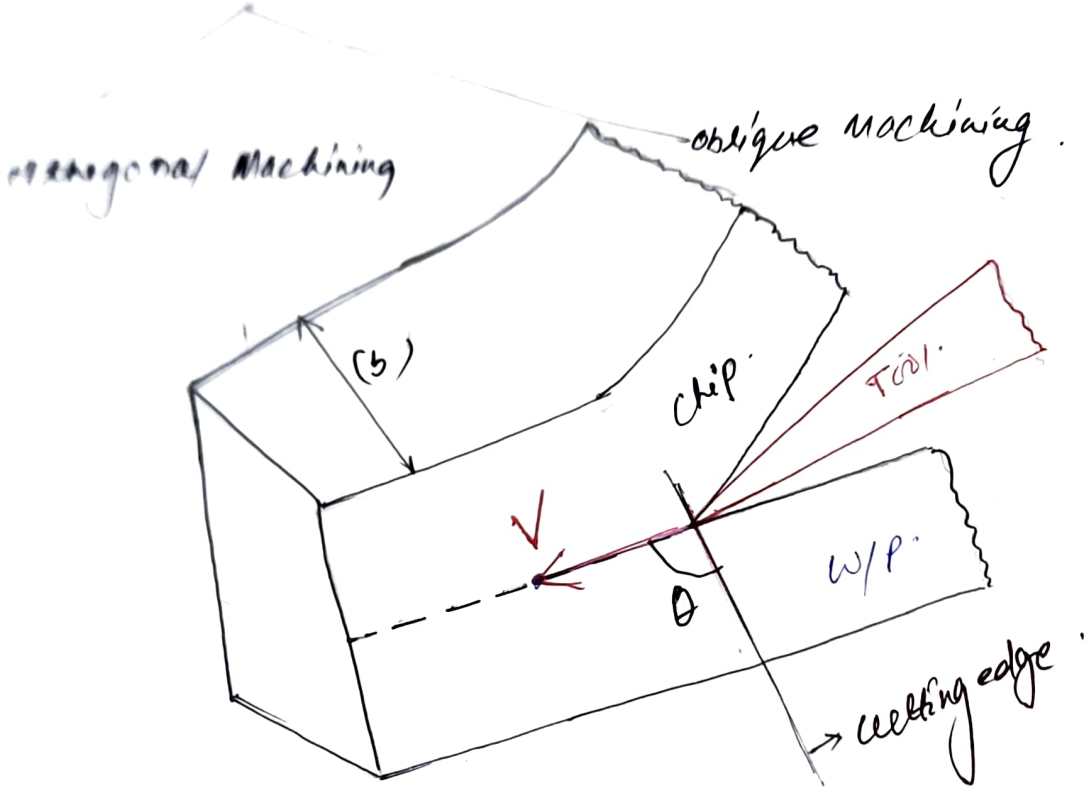
+ve rake



(-) Rake

Rake

Mechanism of machining



$b \rightarrow$  width of cut

$V \rightarrow$  velocity of cutting

# If  $\theta = 90^\circ \Rightarrow$  orthogonal cutting

(Cutting edge and cutting velocity are  $\perp$  to each other)

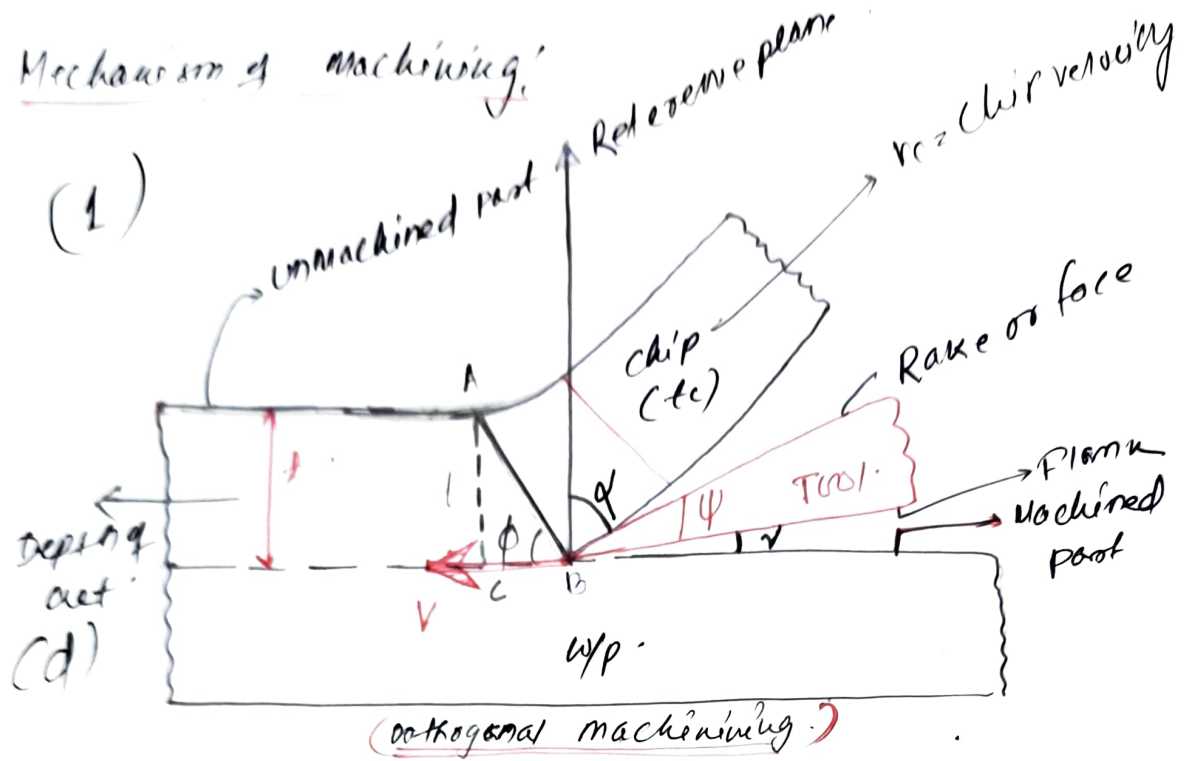
# If  $\theta \neq 90^\circ \Rightarrow$  oblique machining

# Orthogonal machining the forces are only in 2-direction.

# In oblique machining the forces are in 3-direction

# Mechanism of machining:

(1)



(orthogonal machining)

$t$  = Uncut chip thickness

$t_c$  = cut chip thickness or Deformed chip thickness

$d$  = depth of cut

# After cutting it will Release Strain Energy hence Deformed chip thickness  $> t$

$t_c > t \rightarrow$  always

# In orthogonal machining  $t = d$

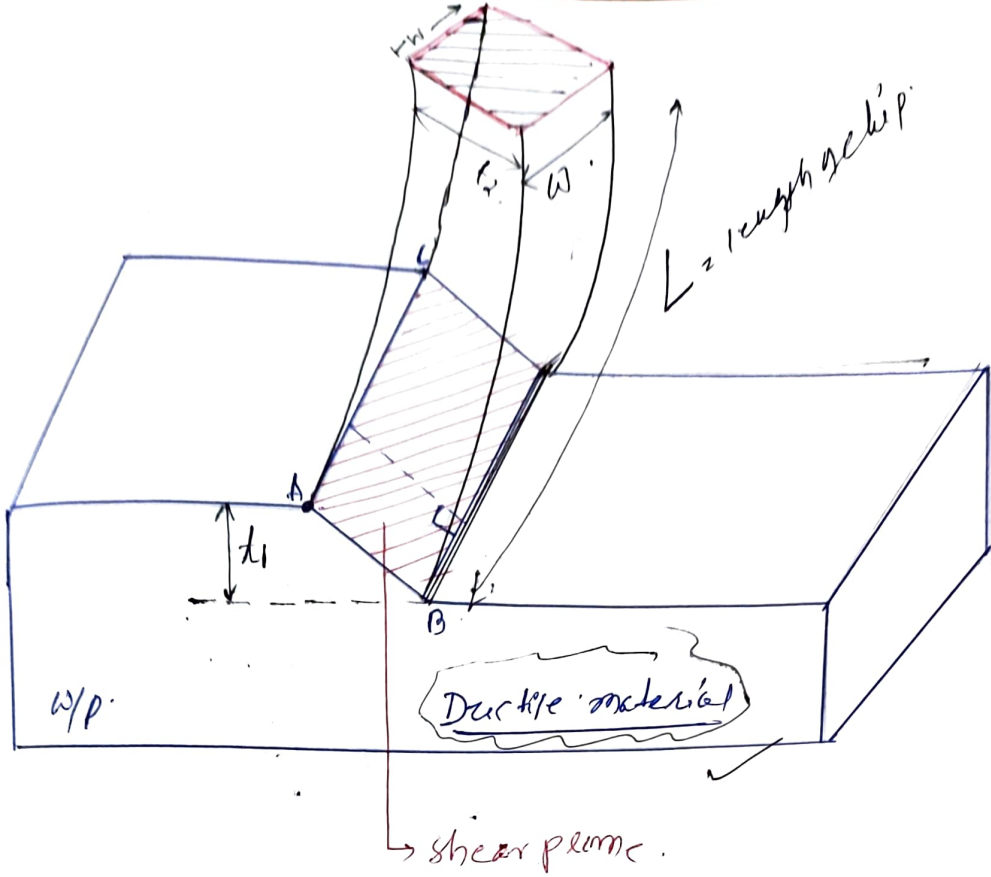
★ Uncut chip thickness = depth of cut for orthogonal cutting

#  $\alpha_0$  = orthogonal rake angle

#  $\nu$  = Relief angle

#  $\psi$  = lip angle / cutting edge angle / wedge angle / Knit edge angle

(1) (c)



$w = \text{width of chip} = \text{width of cut}$

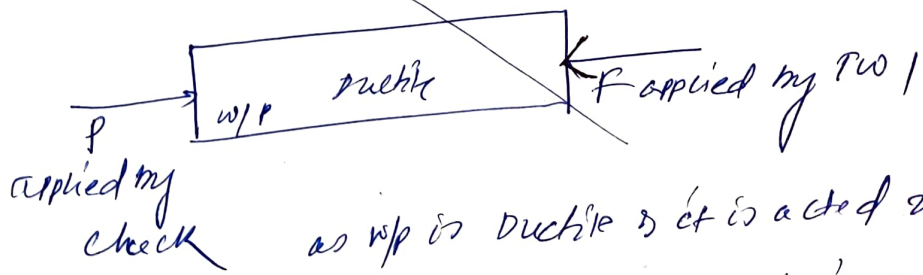
$t_2 = t_c = \text{cut chip thickness}$

$\text{X-S/C Area of chip} = t_2 \times w$

$\text{Volume of chip} = t_2 \times w \times L$

$AB = \text{shear plane}$        $AB > t_2$

Why shear plane Developed?  
MOSP (Max<sup>m</sup> shear stress plane)



as w/p is ductile it is acted upon by compressive force hence a maximum shear stress plane develop along which metal starts sliding or break.

chip compression ratio ( $\lambda$ ) (ratio)

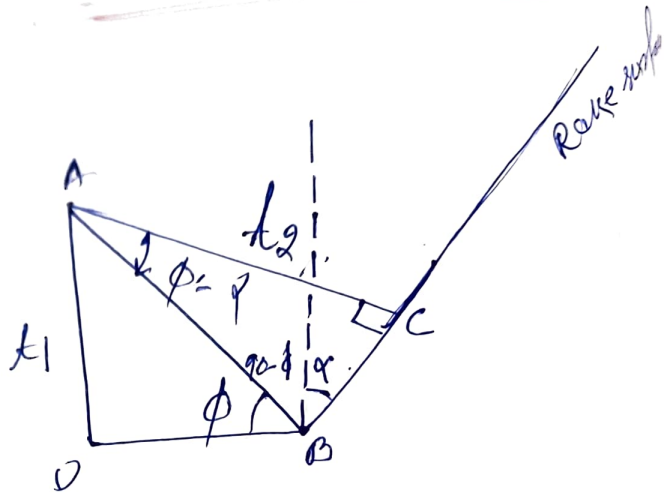
$$\lambda = \frac{t_1}{t_2} = \frac{t_1}{t_1}$$

$[\lambda > 1]$  known as chip compressive Ratio.

chip thickness Ratio.

chip Ratio

chip Ratio



$\Delta ACB$

$$\angle C = 180 - (90 - \phi + 90)$$

$$\boxed{\angle A = \phi - \alpha}$$

in  $\Delta ABD$

$$\sin \phi = \frac{AD}{AB} \Rightarrow$$

$$\boxed{AB = \frac{AD}{\sin \phi} = \frac{t_1}{\sin \phi}} \quad (1)$$

in  $\Delta ACB$

$$\cos(\phi - \alpha) = \frac{AC}{AB}$$

$$AB = \frac{AD}{\sin \phi} \cdot \frac{AC}{\cos(\phi - \alpha)}$$

$$\boxed{AB = \frac{t_2}{\cos(\phi - \alpha)}} \quad (2)$$

(u)

from ① and ②

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

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

$$\sigma = \frac{\sin \phi}{\cos(\phi - \alpha)} \quad \star\star$$

$$\frac{1}{\sigma} = \frac{\cos(\phi - \alpha)}{\sin \phi}$$

$$\frac{1}{\sigma} = \frac{\cos \phi - \cos \alpha + \sin \phi \cdot \sin \alpha}{\sin \phi}$$

$$\frac{1}{\sigma} = \cot \phi - \cos \alpha + \sin \alpha$$

$$\frac{1}{\sigma} - \sin \alpha = \cot \phi - \cos \alpha$$

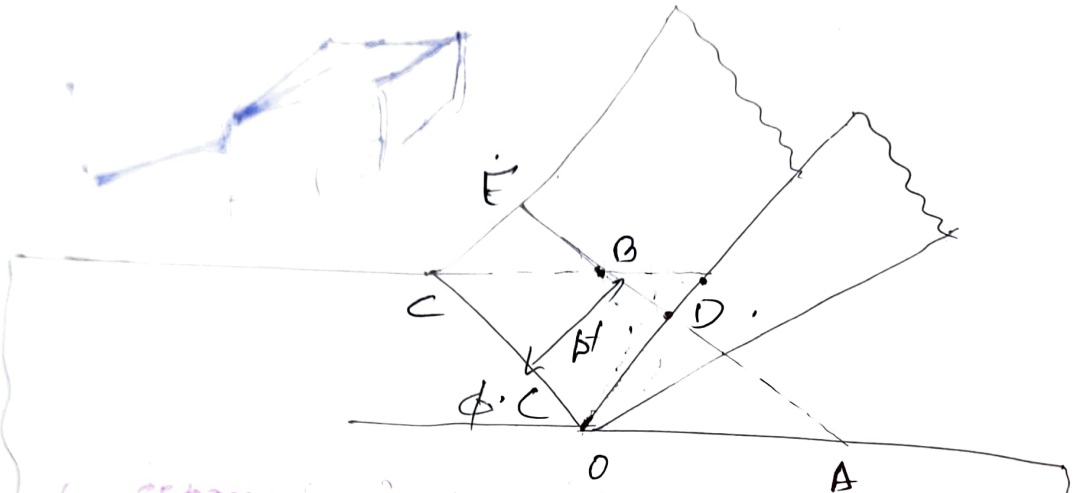
$$\frac{1 - \sigma \sin \alpha}{\sigma \cos \alpha} = \cot \phi$$

$$\tan \phi = \frac{\sigma \cos \alpha}{1 - \sigma \sin \alpha} \quad \star\star\star$$

# Shear strain in metal cutting ( $\epsilon$ )

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

(Derivation)



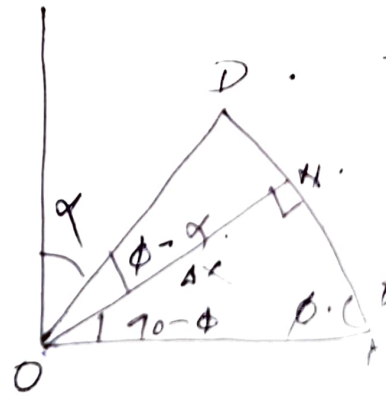
$\epsilon =$  deformation in chip just before fracture  
 Shortest dist<sup>n</sup> b/w two shear planes

Shear strain =  $\epsilon = \frac{AD}{OX}$

Down  $\tan(\phi - \alpha) = \frac{DN}{ON}$

$DN = ON \tan(\phi - \alpha)$

$DN = OX \tan(\phi - \alpha)$



ADW  $\tan \phi = \frac{ON}{NA} \Rightarrow NA = OX \cot \phi$

$\epsilon = \frac{AD}{OX} = \frac{AN + DN}{OX} = \frac{OX \cot \phi + OX \tan(\phi - \alpha)}{OX}$

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

% α = 0,  $\epsilon = \tan \phi + \cot \phi$   
 $= \tan \phi + \frac{1}{\tan \phi}$   
 $\epsilon = 2$

# # Rake angle

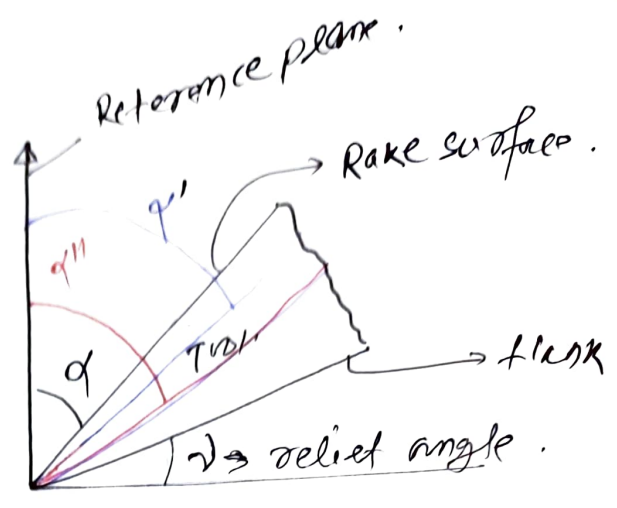
Here RAKE angle is +ve.

$\nearrow \phi \uparrow \Rightarrow$  rake surface more inclined more & more.

$\nearrow \phi \uparrow \Rightarrow$  cutting force  $\downarrow$

$\Downarrow$   
power consumption  $\downarrow \Rightarrow$  tool becomes weaker & weaker

$$\alpha''' > \alpha' > \alpha$$



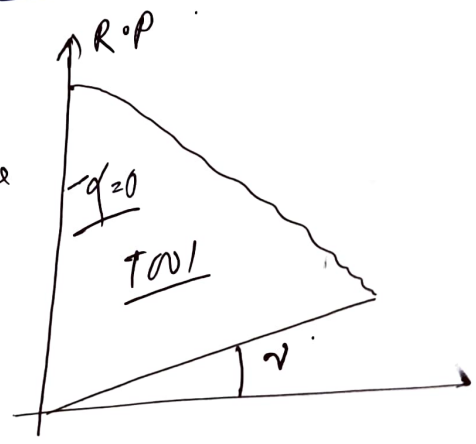
# # +ve rake is used for Ductile material.

## Case-2

# Here rake surface is on the reference plane

# here  $\alpha = 0$

# It becomes a **FORM tool**

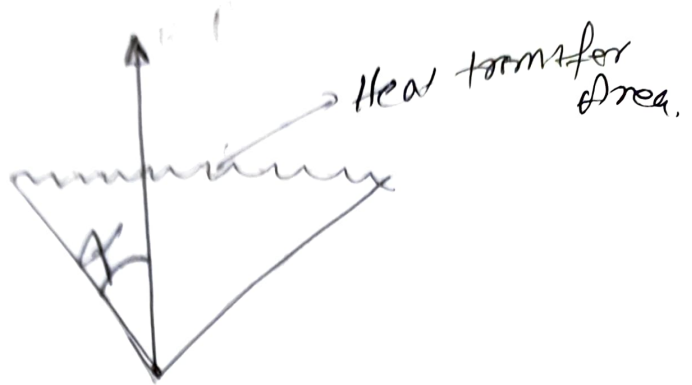


form tool  $\Rightarrow$  replica of object to be cut or required.

#  $\alpha = 0 \Rightarrow$  (or)  $\phi =$  power  $\uparrow \Rightarrow$  tool is strong.

# In form tool  $\alpha_{cut}(0)$  rake angle is provided

# Negative rake angle



# Here ~~the~~ heat dissipation is more.

# Here tool becomes stronger.

# Here no sharp edge  $\Rightarrow$  High power  $\uparrow \Rightarrow$  High velocity Requirement

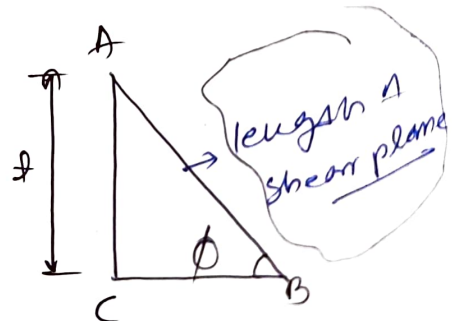
In fig 1

$\phi =$  shear plane angle (Angle b/w  $\vec{V}$  & shear plane)  
 $AB =$  length of shear plane.

In triangle ABC

$$\sin \phi = \frac{t}{AB}$$

$$t = AB \sin \phi$$



★ length of shear plane  $AB = \frac{t}{\sin \phi}$

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

to find shear plane angle

In eqn tan phi = sigma cos phi\_0 / (1 - sigma sin phi\_0)

t\_c = t\_c = for brittle sigma > 1

sigma = chip thickness ratio = Cutting Ratio

sigma = t / t\_c < 1 (always) = uncut / cut

NOTE: Due to shear deformation t\_c > t -> for ductile material, with continuous chip.

1# If phi = 0 => rake angle is zero.

tan phi = sigma => phi = tan^-1(sigma)

2# shear angle phi of t\_c

L-2

t\_c phi => tan phi

- (3) let b = width of cut
bc = width of chip after cut
lc = length of chip
l = length of uncut chip

By volume consistency

b \* l = b/c \* t\_c \* l\_c (if bc = b)

l \* l = t\_c \* l\_c

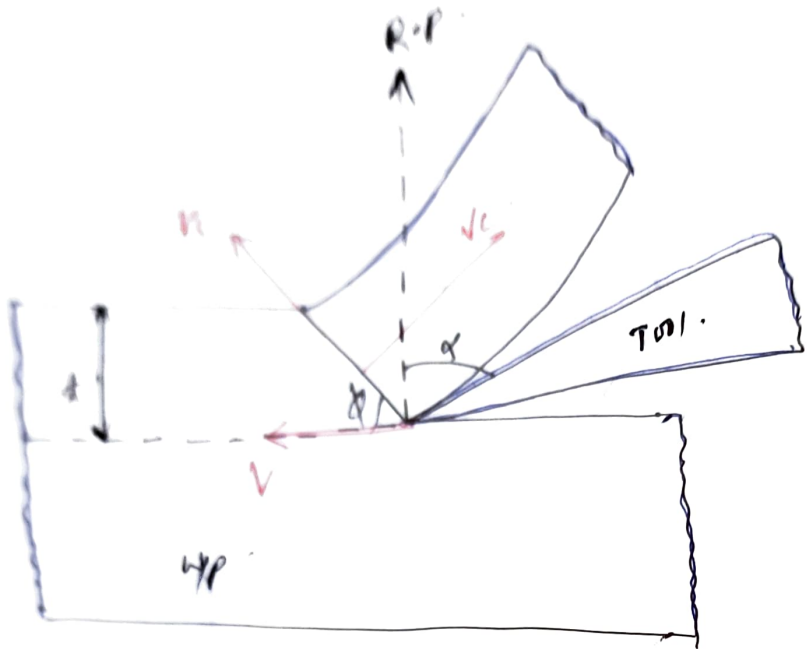
sigma = l / t\_c = t\_c / l = v\_c / v

v\_c = chip velocity
v = cutting velocity



# Velocity in metal cutting

1. Orthogonal

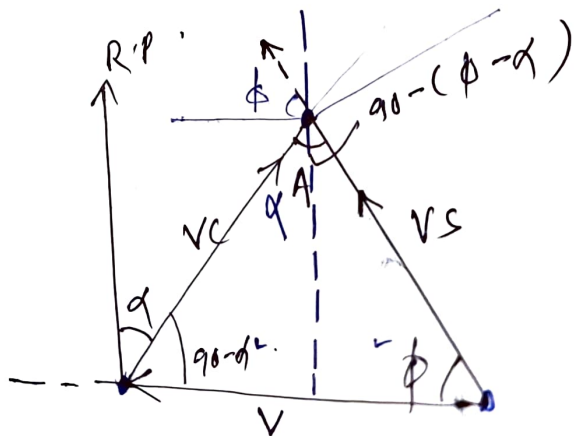


$V \rightarrow$  cutting velocity / velocity of tool w.r.t W/P ✓

$V_s \rightarrow$  shear velocity / velocity of chip w.r.t W/P.

$V_c \rightarrow$  chip velocity / velocity of chip w.r.t tool.

# Velocity Triangle



Here  $A + \phi + 90^\circ - \alpha = 180^\circ$

$$A = 180^\circ - [\phi + 90^\circ - \alpha]$$

$$A = 90^\circ - (\phi - \alpha)$$

Applying sine rule

$$\frac{V}{\sin[90 - (\phi - \alpha)]} = \frac{V_s}{\sin(90 - \alpha)} = \frac{V_c}{\sin \phi}$$

$$\frac{V}{\cos(\phi - \alpha)} = \frac{V_s}{\cos \alpha} = \frac{V_c}{\sin \phi}$$

★ Relation b/w different velocity in metal cutting.

~~$$\frac{V_c}{V} = r = \frac{\cos(\phi - \alpha)}{\sin \phi}$$~~

$$\frac{V_c}{\sin \phi} = \frac{V}{\cos(\phi - \alpha)}$$

$$\frac{V_c}{V} = \frac{\sin \phi}{\cos(\phi - \alpha)}$$

$$\frac{V_c}{V} = r \quad \star \star$$

Shear strain rate ( $\dot{\epsilon}$ ).

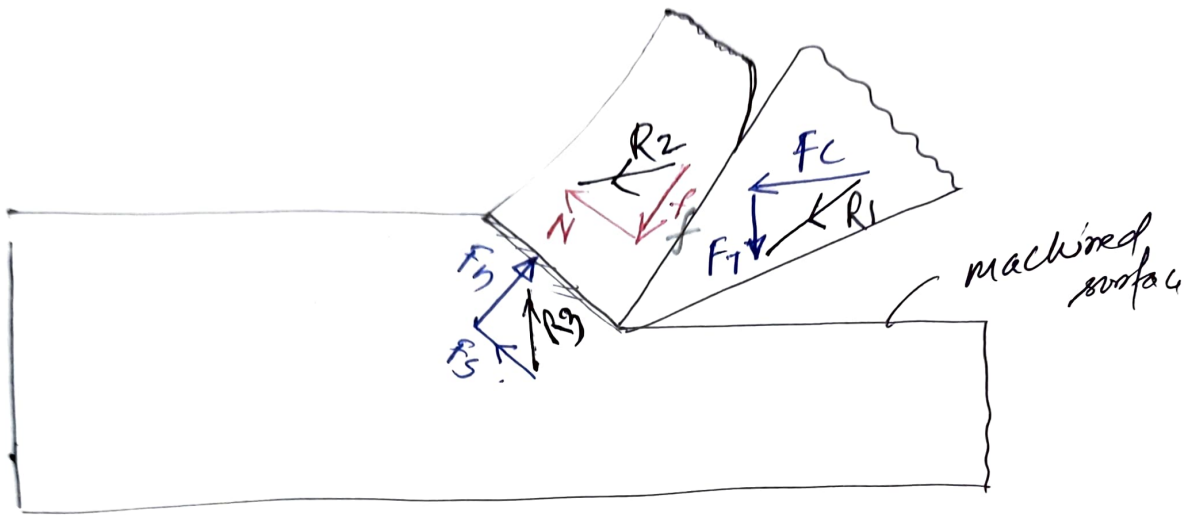
$\dot{\epsilon} = \frac{\text{Shear velocity}}{\text{mean thickness of primary shear zone}}$

$$\dot{\epsilon} = \frac{V_s}{T}$$

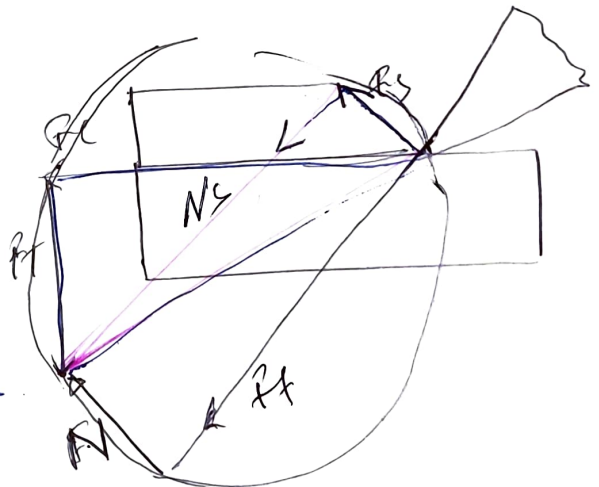
∵  $T$  is not given  
take  $T = 25 \mu m$

# Analysis of Forces in metal cutting.

(Merchant's Force circle diagram).



$F_T$  = Thrust force.  
 $F_C$  = Cutting force.  
 $F_s$  = shear force.



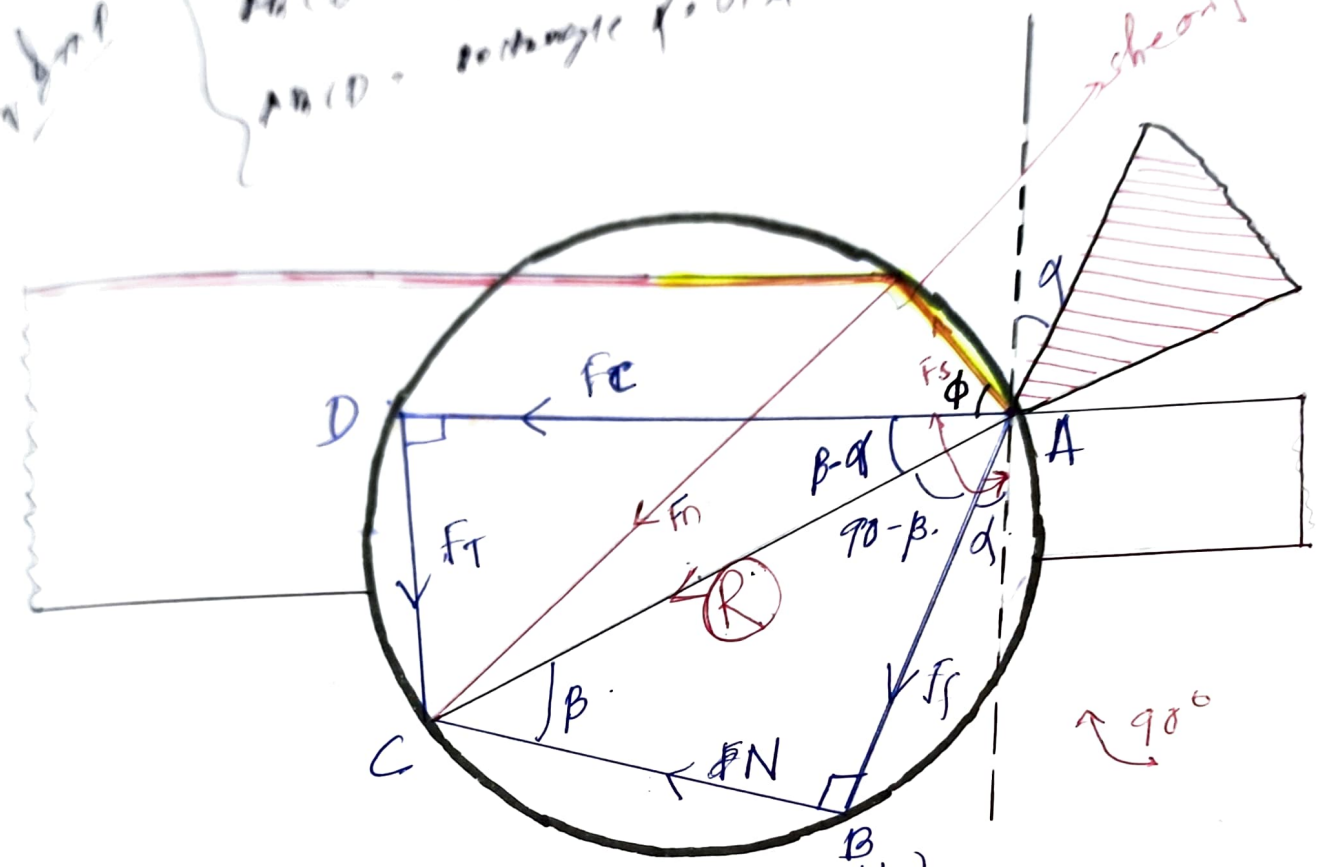
<https://tutorcal.com/gauravbabu>

## Assumption:

- 1) cutting edge is straight and sharp.
- 2) material is homogeneous.
- 3) cutting is orthogonal.
- 4) material is rigid and perfectly plastic.
- 5) Shear zone extends in a very narrow region which can be approximated by a straight line.

1/2

$\Delta ABC$  - Quadrilateral of  $\phi = 0$   
 $\Delta ABD$  - Square of  $\phi = 0, \mu = 1$   
 $\Delta ACD$  - Rectangle of  $\phi = 0, \mu \neq 1$



$\beta =$  friction angle. (b/w  $R \rightarrow N$ ).

Note When two cords are in each other and then we join one line by this cord it becomes Radius.

hence  $R = \text{Resultant} = \text{radius}$ .

$\Delta ABC$   
 $\sin \beta = \frac{F_f}{R} \Rightarrow \boxed{F_f = R \sin \beta} \text{ --- (1)}$

$\cos \beta = \frac{N}{R} \Rightarrow \boxed{N = R \cos \beta} \text{ --- (2)}$

In  $\triangle ACD$ .

$$\sin(\beta - \alpha) = \frac{f_T}{R} \Rightarrow \boxed{f_T = R \sin(\beta - \alpha)} \quad (3)$$

$$\cos(\beta - \alpha) = \frac{f_C}{R} \Rightarrow \boxed{f_C = R \cos(\beta - \alpha)} \quad (4)$$

In  $\triangle AECO$

$$\sin(\beta - \alpha + \phi) = \frac{f_n}{R}$$

$$\boxed{f_n = R \sin(\beta - \alpha + \phi)} \quad (5)$$

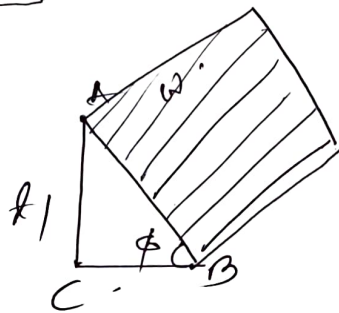
$$\cos(\beta - \alpha + \phi) = \frac{f_s}{R}$$

$$\boxed{f_s = R \cos(\beta - \alpha + \phi)} \quad (6)$$

NOTE

$$\sin \phi = \frac{f_l}{AB}$$

$$AB = \frac{f_l}{\sin \phi}$$



Area of shear plane =  $AB \times w$ .

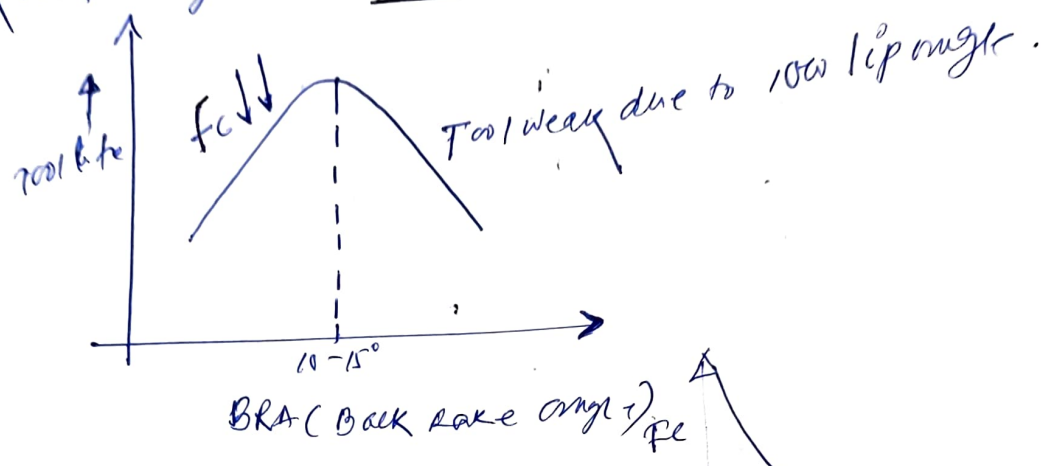
$$\boxed{A_{sp} = \frac{l w}{\sin \phi}} \quad (7)$$

Area of shear plane

High point cutting tool

Lip angle = provide strength to tool

Back rake angle = 10-15°



$f_c \downarrow \Rightarrow$  Tool life  $\uparrow$

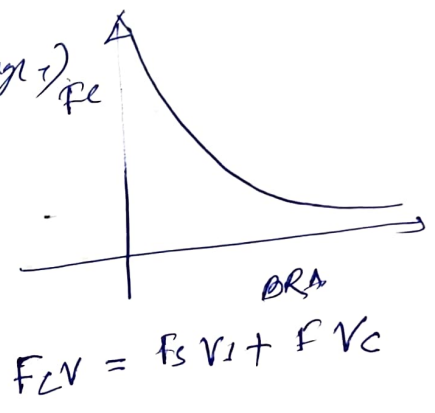
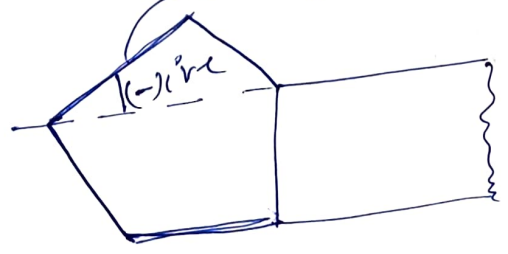
$f_c$  = cutting force.

when work piece  $\rightarrow$  strong  
ex: Brass.

$BRA (\alpha_b) = 0^\circ \Rightarrow$  lip angle  $\uparrow =$  tool life  $\uparrow$

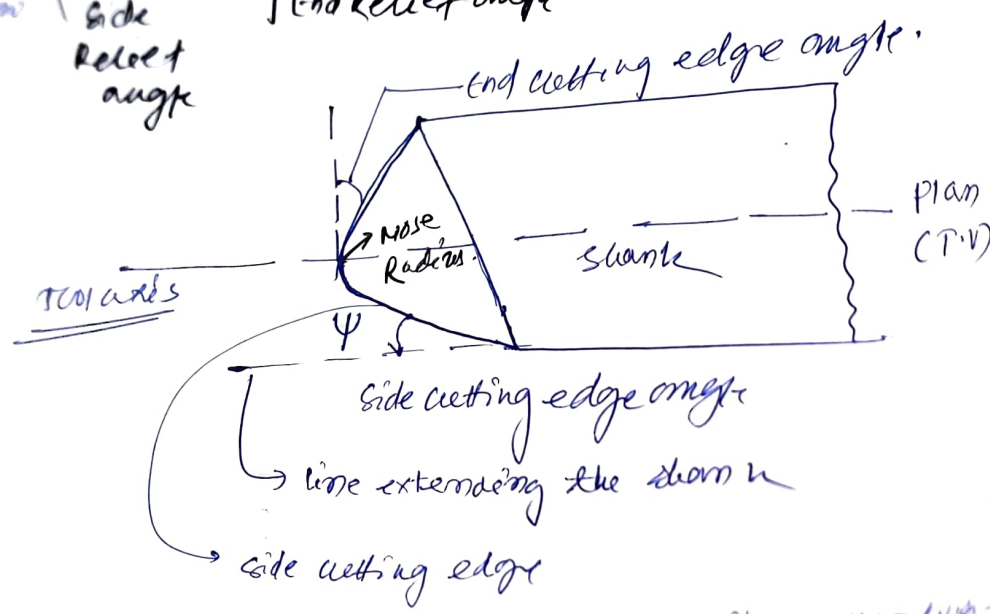
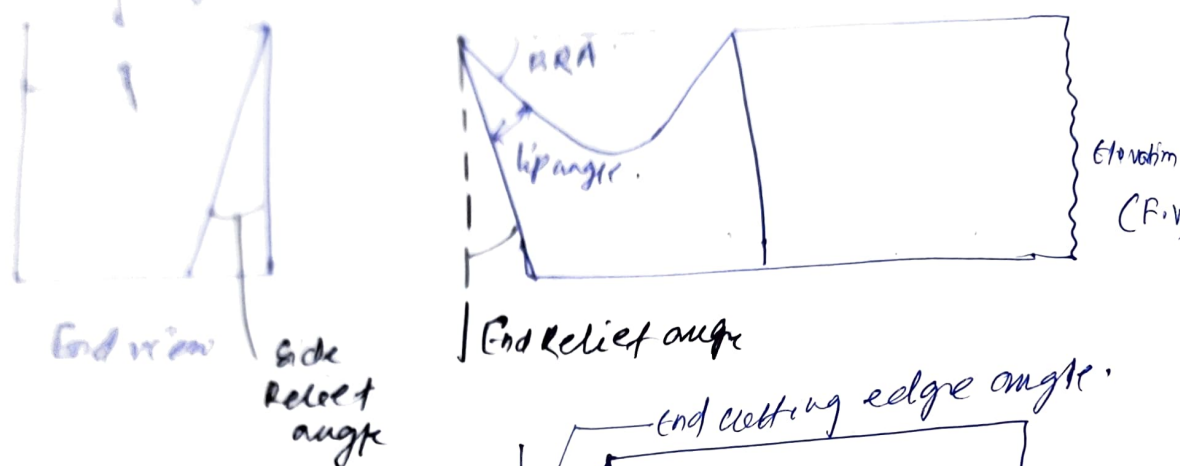
when tool material is brittle }  
ex: Ceramics carbide.

$\alpha_b = (-)$ ive, cutting edge.



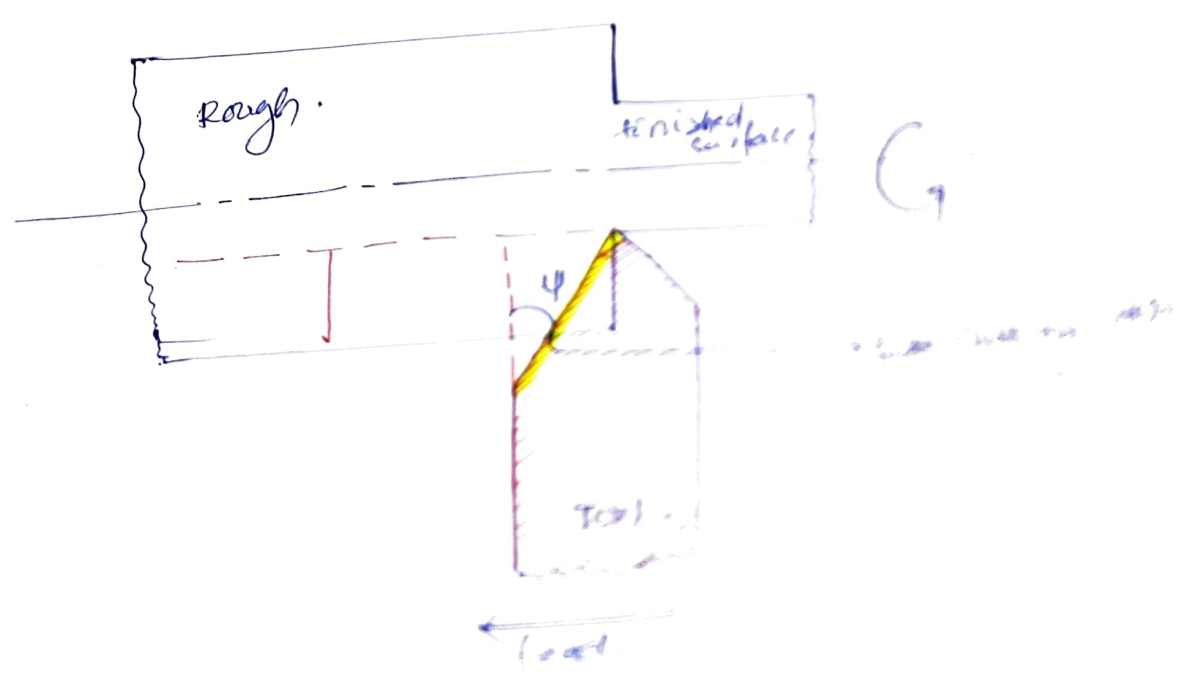
$F_{CV} = F_s V_1 + F V_c$

End Relief angle [from end view]  
 (produces guide the chip)



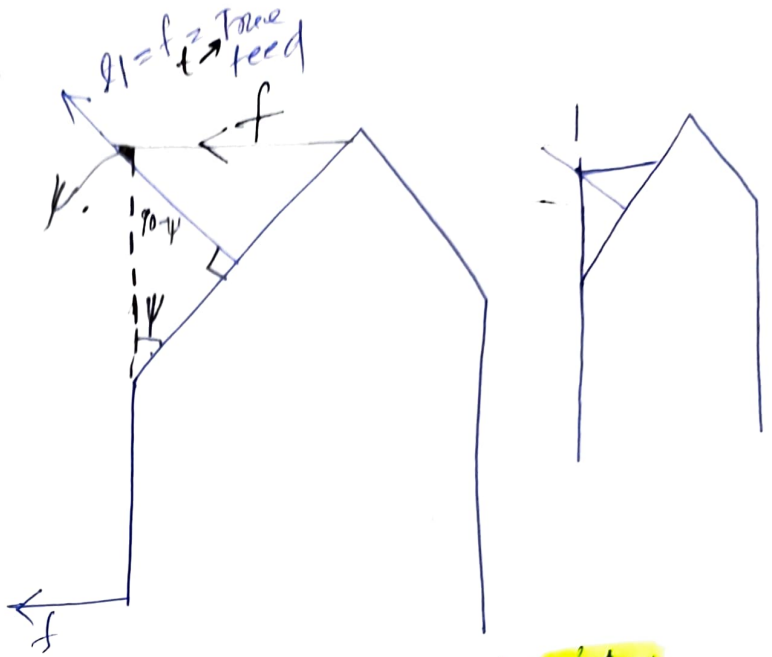
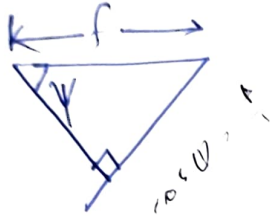
(ψ)  
SCEA

Angle b/w side cutting edge & the line extending from shank in the plane parallel to the base of the shank



inset chip thickness.

$$f_1 = l_1 = f \cos \psi.$$



$\psi \uparrow \Rightarrow$  chips will be thinner and wider.

Relief angle.

# of relief elastic Recovery

+ avoid rubbing b/w finished part and end flank.

chatter  $\rightarrow$  vibrations with high frequency  
 nose radius  $\uparrow \Rightarrow$  chatter  $\uparrow$

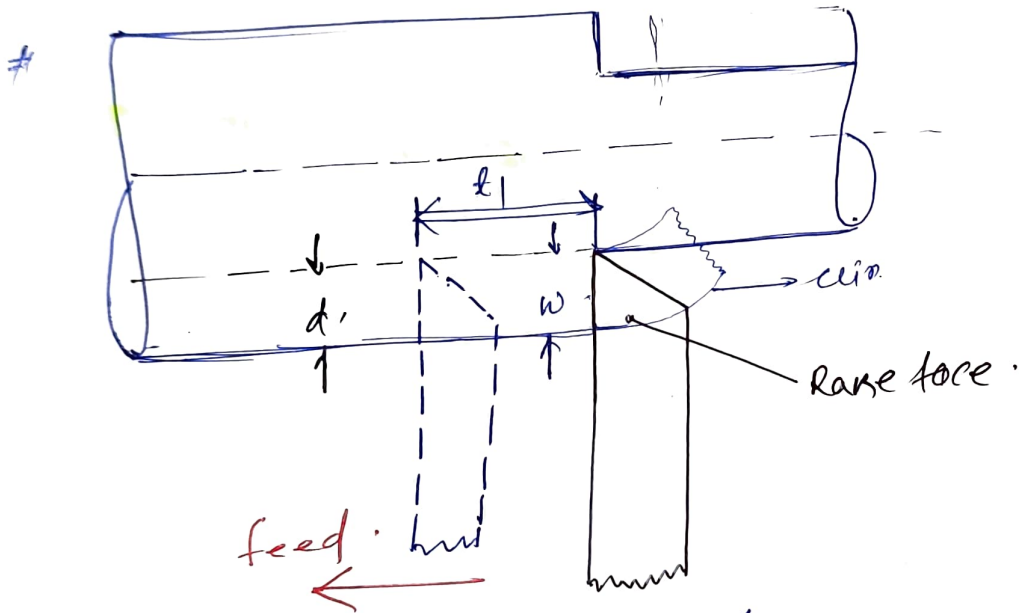
feed =  $\frac{\text{mm}}{\text{rev}}$

# feed represents the uncut chip thickness ( $t_1$ )

# depth of cut  $\rightarrow$  represents the width of chip.

#  $\psi = 0 \rightarrow$   $\begin{cases} t_1 = f \\ w = d \end{cases}$  ~~✗~~

width of chip = depth of cut



$w = \text{width of chip} = \text{depth of cut}$

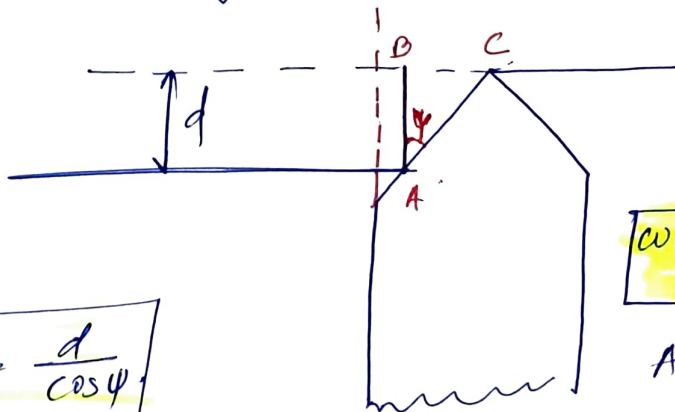
Valid for all tool  $\Rightarrow$   $t_1 \Rightarrow$  feed experienced by the principal cutting edge in the normal dir<sup>n</sup>.

$w \Rightarrow$  length of side cutting edge, covered by chips.

$w = AC$

$\cos \psi = \frac{AB}{AC}$

$AC = \frac{AB}{\cos \psi} = \frac{d}{\cos \psi}$

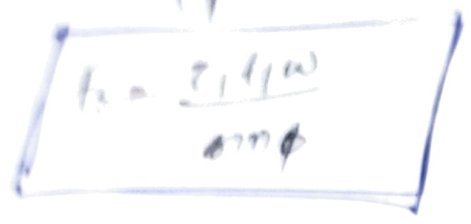


$w = AC = \frac{d}{\cos \psi}$

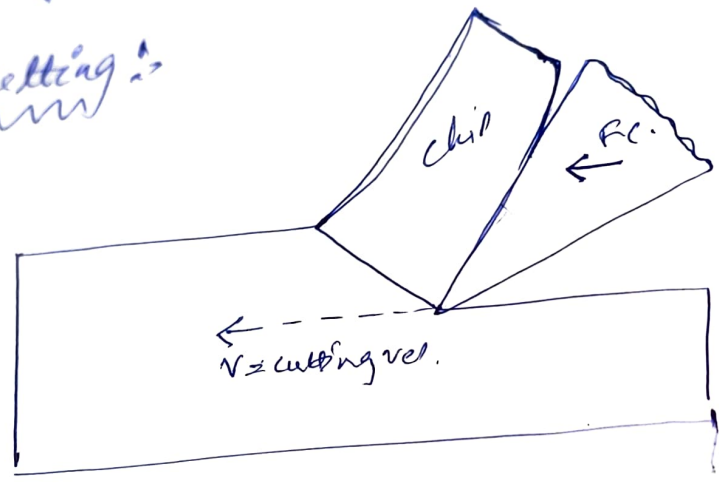
$w = \text{width of chip}$

1. Force strength of work material ( $Z_s$ )

$$Z_s = \frac{F_s}{A_p} \rightarrow R = Z_s \times A_p$$



Force in metal cutting



① Cutting Power = Force  $\times$  velocity  
 $= F_c \times V \cdot \left( \frac{1}{3} \text{ or wall} \right)$

$\neq$  Cutting power is divided into 2 parts.

(1) shear power =  $F_s \cdot V_c$

(2) friction power at tool chip interface

☆☆☆  $F_f \times V_c$

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

Q1 In an orthogonal machining of  $OP^{10}$  chip thickness is 0.8 mm and undeformed thickness is 0.4 mm rake angle of tool is  $10^\circ$ .  $\phi = ?$

Sol<sup>n</sup>

$$\frac{t_1}{t_2} = r = \frac{0.4}{0.8} = 0.5$$

$$\tan \phi = \frac{r \cos \alpha}{1 - r \sin \alpha} = \frac{0.5 \times \cos 10}{1 - 0.5 \sin 10}$$

~~$\phi = \tan^{-1}(\dots)$~~

$\phi = 28.33$  → shear plane angle.

Q2  $r = 0.4$ ,  $\alpha = 0$ ,  $v = 2 \text{ m/s}$ ,  $t_1 = 0.35 \text{ mm}$ ,  $t_2 = ?$

$v_c = ?$ ,  $\phi = ?$

Sol<sup>n</sup>

$$r = \frac{t_1}{t_2} = 0.4 \Rightarrow t_2 = \frac{t_1}{0.4} = \frac{0.35}{0.4}$$

$\Rightarrow t_2 = 0.875$  ————— ①

$$\phi = \tan^{-1} \left( \frac{r \cos \alpha}{1 - r \sin \alpha} \right) = 21.80$$
 ————— ②

$$r = \frac{v_c}{v}$$

$$v_c = r \times v = 0.4 \times 2 = 0.8 \text{ m/s}$$
 ————— ③

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

$$= \cot(21.8) + \tan(21.8 - 0)$$

$E = 2.90$  ————— ④

Determine min<sup>m</sup> value of Shear Strain when  $\alpha = 0$ .

(Sol<sup>n</sup>)  $\epsilon = \cot \phi + \tan(\phi - \alpha)$

$$\frac{d\epsilon}{d\phi} = -\operatorname{cosec}^2 \phi + \sec^2 \phi = 0$$

$$\operatorname{cosec}^2 \phi = \sec^2 \phi$$

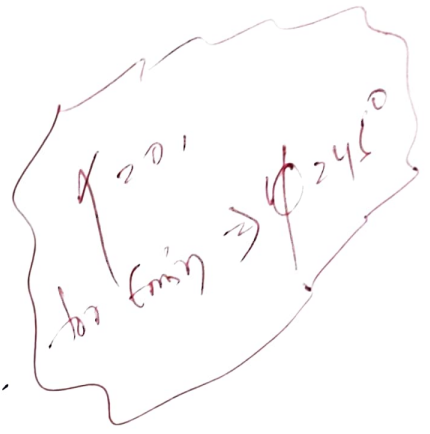
$$\operatorname{cosec} \phi = \sec \phi$$

$$\frac{1}{\sin \phi} = \frac{1}{\cos \phi}$$

$$\tan \phi = 1$$

$$\phi = \tan^{-1}(1)$$

$$\boxed{\phi = 45^\circ}$$



$$\begin{aligned} \epsilon_{\min} &= \cot 45^\circ + \tan 45^\circ \\ &= 1 + 1 \end{aligned}$$

$$\boxed{\epsilon_{\min} = 2} \quad \underline{\underline{\Delta}}$$

Q.  $\epsilon_{\min} = ?$  if  $\alpha = 12^\circ$

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

$$\frac{d\epsilon}{d\phi} = -\operatorname{cosec}^2 \phi + \sec^2(\phi - \alpha)$$

$$\sin \phi = \cos(\phi - 12)$$

$$\cos(90 - \phi) = \cos(\phi - 12)$$

$$90 - \phi = \phi - 12$$

$$2\phi = 102 \Rightarrow \phi = \frac{102}{2} = 51$$

$$\begin{aligned} \epsilon_{\min} &= \cot 51 + \tan(51 - 12) \\ \epsilon_{\min} &= 1.62 \end{aligned} \quad \underline{\underline{\Delta}}$$

mean thickness of primary shear zone, is 25 μm.  
Determine rate of shear strain.

$$\tan \phi = \frac{\tau \cos \alpha}{1 - \tau \sin \alpha} = \frac{0.14 \times \cos 10^\circ}{1 - 0.14 \sin 10^\circ}$$

$$\boxed{\phi = 29.94}$$

$$\frac{V_c}{V} \approx \frac{V_s}{\cos \phi} = \frac{V}{\cos(\phi - \alpha)} = \frac{V_c}{\sin \phi}$$

$$V_s = \frac{V \cos \phi}{\cos(\phi - \alpha)}$$

$$= \frac{2.5 \times \cos 10}{\cos(29.94 - 10)}$$

$$\boxed{V_s = 2.526 \text{ m/s}}$$

Shear strain rate:  $\dot{\epsilon}' = \frac{V_s}{\text{thickness}}$

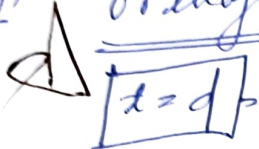
$$= \frac{2.526}{25 \times 10^{-6}}$$

$$\boxed{\dot{\epsilon}' = 1.01 \times 10^7}$$

Wick

fb

Q In an orthogonal turning process chip thickness was obtained as 1mm, depth of cut was 2mm, and feed rate was 0.4 mm/rev. If cutting speed is 180 m/min, then determine chip speed.

sol<sup>n</sup> orthogonal cutting / M/c'ing  

 $t = d$  ~~mm~~  $\Rightarrow$  uncut chip thickness = depth of cut

In orthogonal turning:

Uncut chip thickness = feed.

$t_2 f$

$t_1 = 0.4$

$t_2 = 1 \text{ mm}$

$\therefore \frac{t_1}{t_2} = \frac{0.4}{1} = 0.4$

$V_c = 180 \text{ m/min} =$

$\frac{V_c}{V} = \frac{t_1}{t_2} \Rightarrow \frac{V_c}{180} = 0.4 \Rightarrow V_c = 180 \times 0.4 = 72 \text{ m/min}$

Q1  $\alpha = 15^\circ$

$v = 200 \text{ m/min}$

$W = 5 \text{ mm}$

$t_1 = 0.5 \text{ mm}$

$t_2 = 0.7 \text{ mm}$

$F_c = 120 \text{ N}$

$P_T = 20 \text{ kW}$

determine

(1)  $\phi$  &  $\epsilon$

(2) cutting power.

(3) % of total power consumed in friction

2017)  $\tan \phi = \frac{200 \sin \alpha}{1 - 200 \sin \alpha}$

(11)  $C = \cot \phi + \tan(\phi - \alpha)$

$\phi = 40.23$

$C = 1.65$

$V = 220 \text{ m/min}$

(10) cutting power =  $F_c \times V$   
 $= 1200 \times \frac{200}{60}$   
 $= \frac{24000}{60}$   
 $= 400 \text{ Watt}$

$COP = 4 \text{ kW}$

(11) Friction power =  $\frac{1}{\mu}$  of total power

$\frac{F_f}{V_c}$

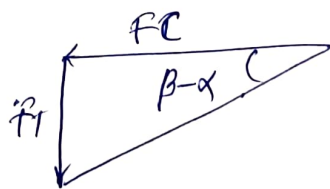
$\propto \frac{V_c}{V} = \gamma$

$V_c = V \times \gamma = 200 \times 0.714$   
 $= 142.8 \text{ m/min}$

$F_f = R \sin \beta$

$R = \sqrt{F_c^2 + F_p^2} = \sqrt{1200^2 + 200^2} = 1216.55$

$\tan(\beta - \alpha) = \frac{F_f}{F_c} = \frac{200}{1200}$



$\beta - \alpha = 9.462$

$\beta = 9.462 + 15 = 24.46$

$F_f = R \sin \beta = 1216.55 \times \sin(24.46) = 503.72 \text{ N}$

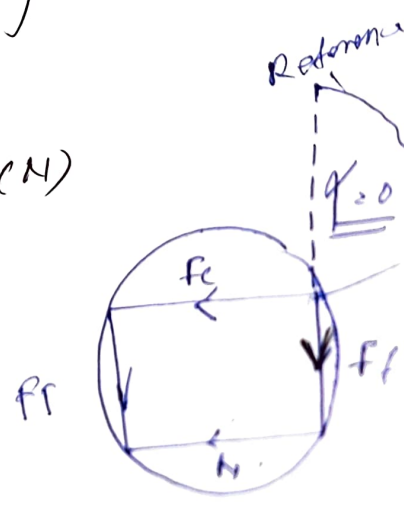
$F \cdot P = F_f \cdot V_c = \frac{503.72 \times 142.8}{60} = 1196.9 \text{ Watt}$

75% ... is 3% ✓

The uncut chip thickness is being carried out at 1800 rpm cutting speed with depth of cut 2mm, width of cut is 5mm and feed is 0.5 mm/rev. It has been observed that cutting force is perpendicular to friction force acting at tool-chip interface. If main cutting force is 1200N then determine (i) rake angle.

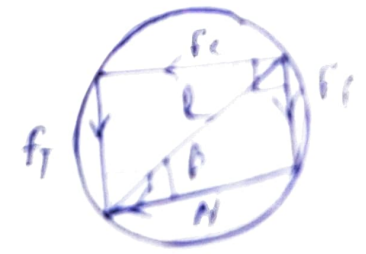
(ii) Normal uncut force (N)

Sol<sup>n</sup>  $F_c = 1200 = N$   $\phi = 0$   
 $F_T = F_f$



$\mu \neq 1$

Sol<sup>n</sup>  $\mu = \tan \beta$   
 $\mu = 1$  when  $\beta = 45^\circ$   
 Here  $\beta \neq 45^\circ \Rightarrow F_f \neq N$



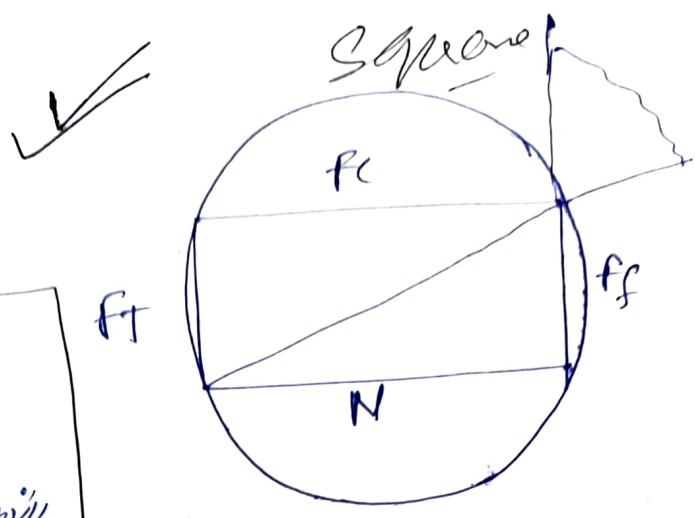
When  $\phi = 0$  and  $\mu \neq 1$

- (i)  $F_c \perp F_f$
- (ii)  $F_T \perp N$

$F_c = F_f$  and  $F_T = F_f$

Case 2  
 $\tan \phi = 0.5$  &  $M = 1$   
 $\Rightarrow \beta = 45^\circ$

Here  $F_c = F_T = F_f = N$   
 $\downarrow$   
 So  $F_c, F_T, F_f$  &  $N$  will form a square.



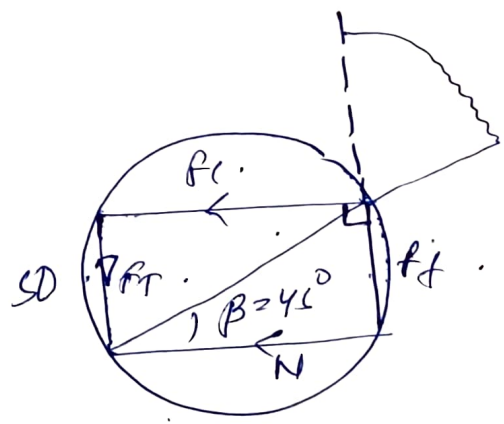
Hence

An orthogonal cutting test is performed on mild steel specimen with cutting speed 2 m/sec.  $t_1 = 0.5$  mm,  $t_2 = 1$  mm,  $w = 4$  mm. It is observed that the friction force is  $1/7$  to cutting velocity vector. If friction force is 500 N.

Then determine (i)  $F_s$   
 (ii) Shear power

Assume  $\frac{F_f}{N} = 1$ .

So as  $\frac{F_f}{N} = 1$   
 $F_f = N$



Here  $F_c = N = F_f = F_T = 500$   
 $\phi = 0$

$$R = \sqrt{500^2 + 500^2}$$

$$R = 707.10 \text{ N}$$

$$\tan \phi = \frac{0.5 \cos(0)}{1 - 0.5 \sin(0)}$$

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

$$F_s = 670.8 \text{ N}$$

$$223.66 \text{ N}$$

$$\phi = 26.56^\circ \Rightarrow \beta = 45^\circ$$

(ii) Shear power (S.P)

$$\frac{V_s}{\cos \phi} = \frac{V}{\cos(\phi - \alpha)}$$

$$V_s = \frac{V \cos \alpha}{\cos(\phi - \alpha)} = \frac{2 \times \cos 0}{\cos(28.58)} = \underline{\underline{2.235 \text{ m/s}}}$$

$$\text{Shear S.P} = F_s \cdot V_s$$

$$= 223.66 \times 2.23$$

$$= 500 \text{ watt}$$

Q

$$F_C = 900 \text{ N}$$

$$F_T = 600 \text{ N}$$

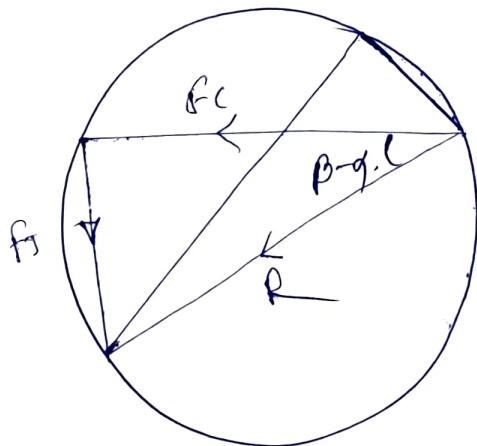
$$\phi = 30^\circ$$

Determine shear force.

si

$$R = \sqrt{900^2 + 600^2}$$

$$R = 1081.6 \text{ N}$$



$$\tan(\beta - \gamma) = \frac{F_T}{F_C} = \frac{600}{900}$$

$$\beta - \gamma = 33.69^\circ$$

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

$$= 1081.6 \cos(33.69 + 30)$$

$$F_s = 479.3 \text{ N}$$

Determine:

- 1) shear angle ( $\phi$ )
- 2) cutting & thrust force.

- 1 - 0.17 mm / rev
- 2 - 0.2
- 3 - 0.2 mm
- 4 - 0.17 mm
- 5 - 400 N/mm<sup>2</sup>
- 6 - 10°

$\frac{1}{2} t_2 = \text{chip}$   
 $r = \frac{t_1}{t_2}$   
 $\tan \phi = \frac{r \cos \alpha}{1 - r \sin \alpha}$

$F_s = \frac{ZstW}{\sin \phi}$

$\tan \beta = 1$   
 $\beta = \tan^{-1} 1 = 26.56^\circ$

$2\phi + \beta - \gamma = 90^\circ$  ~~★ ★ ★ ★ ★~~ → Formula

$2\phi + 26.56 - 10 = 90$   
 $\phi = \frac{90 + 10 - 26.56}{2}$

$\phi = 36.72$

(1)  $F_s = \frac{ZstW}{\sin \phi} = \frac{400 \times 0.2 \times 2}{\sin(36.72)}$

$F_s = 267.6 \text{ N}$

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

$R = \frac{F_s}{\cos(\beta - \gamma + \phi)}$

$R = 447.5 \text{ N}$

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

rdmp

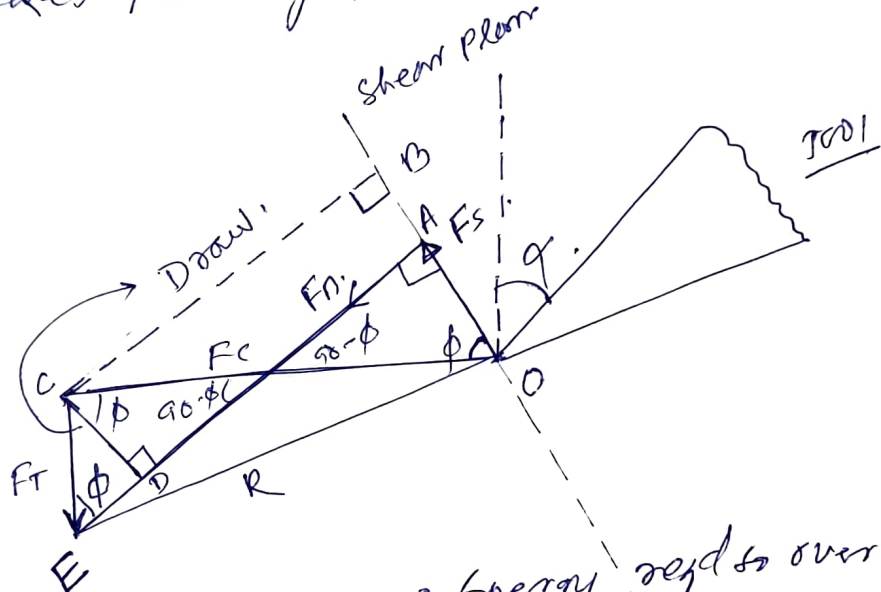
# Metal Cutting

(1)

(03)

## Merchant's circle

- #  $F_c$  always be in the direction of cutting.
- # plane  $I'$  to the cutting edge and normal to base plane.  
(90 deg's plane merchant's circle act).
- # m/c ing takes place by pure shear.



$F_c V = F_{sV} V_s + F_{cH} V_c$  → Energy reqd to overcome friction  
 ↓  
 break crystal structure m/c ing  
 overall cutting energy.

$$F_s = OB - AB \quad (AB = CD)$$

$$F_s = F_c \cos \phi - F_t \sin \phi \quad \text{--- (1)}$$

# Dir<sup>n</sup> of shear plane is always in the dir<sup>n</sup> of minimum power consumption by Merchant's.

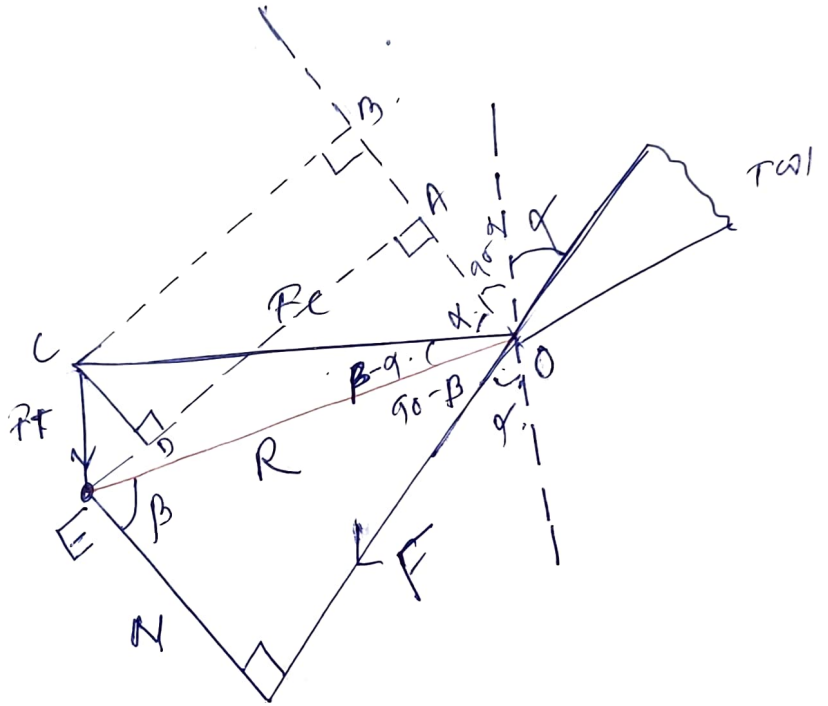
★

$$F_n = AE = AD + DE$$

$$F_n = BC + DE$$

$$(AD = BC)$$

$$F_n = F_c \sin \phi + F_T \cos \phi \quad \text{--- (2)}$$



$$F = AE = AD + DE$$

$$F = BC + DE$$

$$F = F_c \sin \alpha + F_T \cos \alpha \quad \text{--- (3)}$$

$$N = OA = OB - AB$$

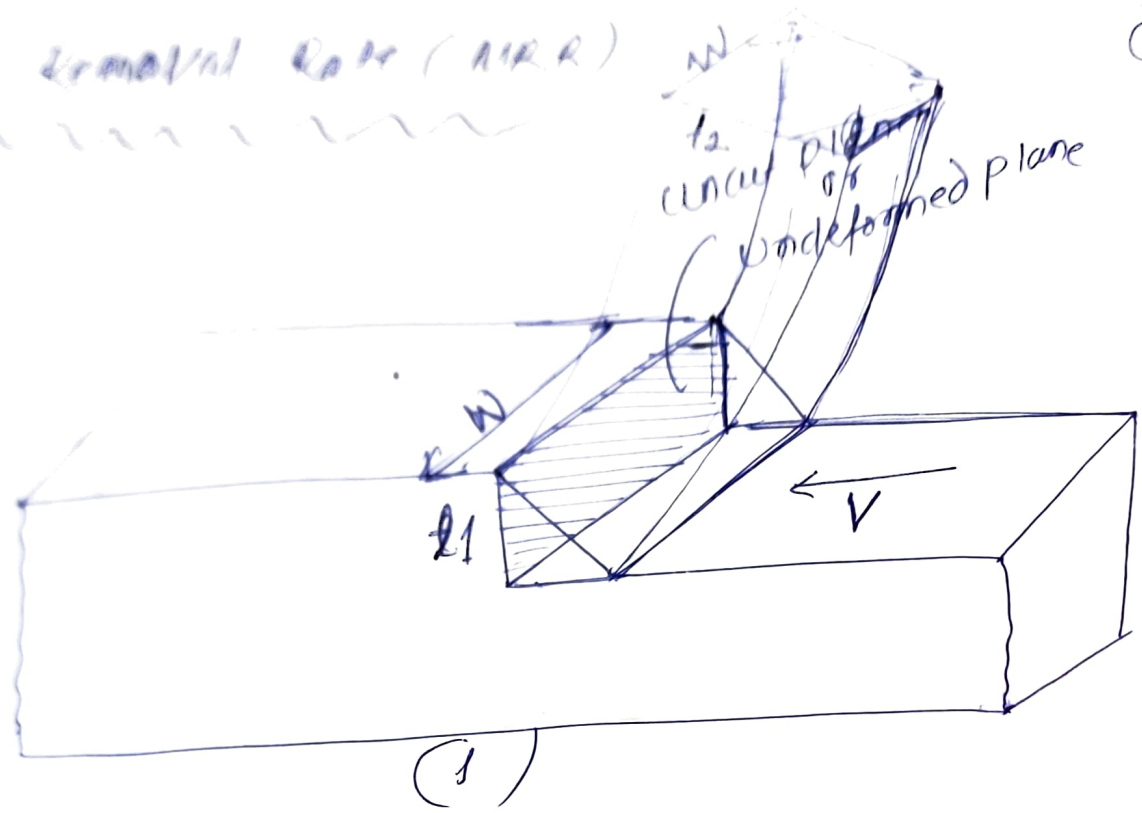
$$N = OB - CD$$

$$N = F_c \cos \alpha - F_T \sin \alpha \quad \text{--- (4)}$$

$$\tan \beta = \mu = \frac{F}{N} = \frac{\frac{F_T}{F_c} + \tan \alpha}{1 - \frac{F_T}{F_c} \tan \alpha}$$

Volume Removal Rate (MRR)

(1)



Discharge  $Q = \dot{V} = \text{volume flow rate}$

$$Q = \frac{A \times L}{t} = \text{Area} \times \text{Velocity}$$

$$Q = \frac{m^3}{s}$$

$V = \text{cutting velocity}$

$$\text{MRR} = \text{cutting speed} \times \text{Area of undeformed plane}$$

$$= V \times t \times W$$

$$\text{MRR} = \frac{\pi}{4} D^2 \times V \times t$$

$$\text{MRR} = t \times W \times V$$

(A)

Handwritten text in a cursive script, possibly a letter or a page from a manuscript. The text is written in dark ink on a light-colored background. The handwriting is fluid and somewhat slanted, characteristic of a cursive style. The text is arranged in several lines, with some words appearing to be written in a larger or bolder hand than others. The overall appearance is that of a personal or official document from a past era.

In case of Turning process:

$\boxed{MRR = f \cdot d}$  → Remember  
feed  $\times$  depth of cut

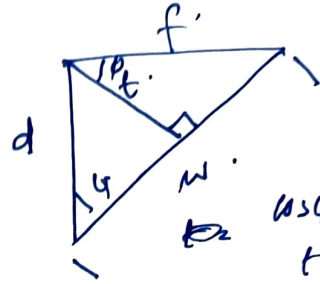
proof it

$\frac{d}{w} = \frac{f}{v}$   
 $f \cdot w = d \cdot v$

So  $MRR = f \cdot w \cdot v$

$\boxed{MRR = f \cdot d \cdot v}$  — (1)

So  $\boxed{t_1 = f}$

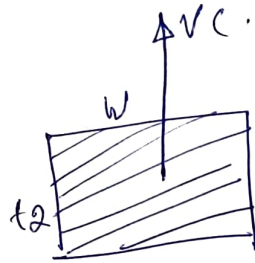


$\cos \phi_s = \frac{f}{d}$   
 $t = f \cdot \cos \phi_s$

$\cos \phi_s = \frac{f}{w}$

In the diagram (1)

(Area) chip =  $t_2 \times w$



$VC =$  chip velocity.

So  $MRR =$  chip velocity  $\times$  Area of chip.

$\boxed{MRR = VC \times t_2 \times w}$  — (2)

If we compare (1) and (2),  
same consistency occurs.

$A = B$

$V \times t_1 \times w = VC \times t_2 \times w$

$\boxed{v = \frac{t_1}{t_2} = \frac{VC}{V}}$

Specific power consumption

power required per unit MRR

1) Specific machining power

$$SMP = \frac{\text{Machining power}}{MRR}$$

$$= \frac{F_c \times V}{MRR} = \frac{F_c \times V}{t \times w \times V}$$

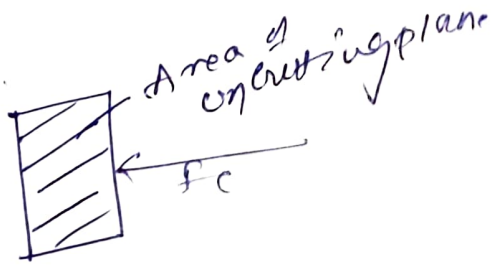
$$\boxed{SMP = \frac{F_c}{t/w}} = \frac{N}{mm^2} = \frac{Nm}{mm^3} = \frac{J}{mm^3}$$

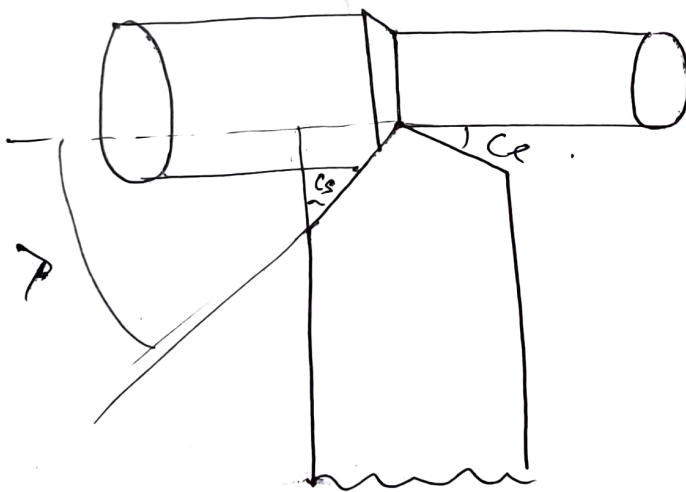
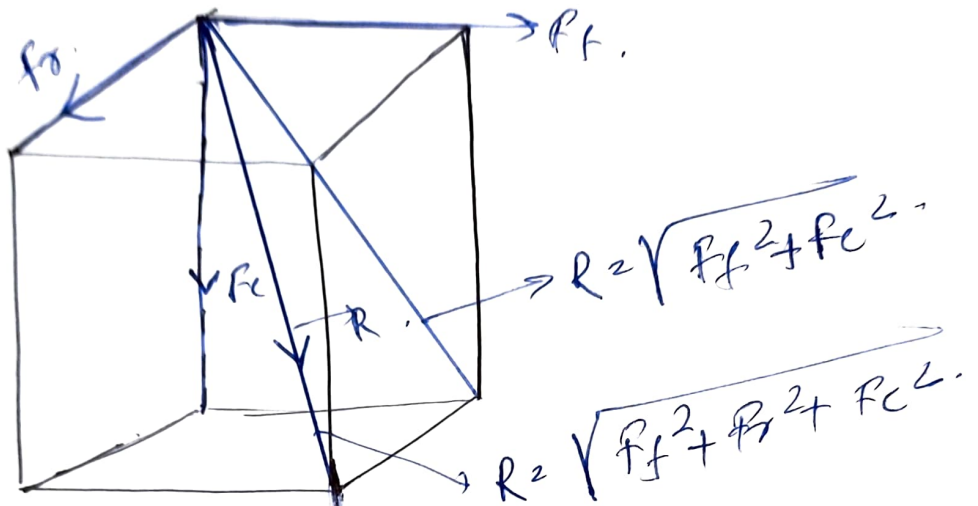
Unit  $SMP = \frac{\text{power}}{MRR} = \frac{J/sec}{m^3/s} = J/m^3 = \frac{\text{Energy}}{\text{Volume. (Unit volume)}}$

Cutting pressure / sp. cutting pressure.

$$\text{pressure} = \frac{F_{\text{one}} (\text{External})}{\text{Area}} \quad (F \perp \text{Area})$$

$$\boxed{SCP = \frac{F_c}{t/w}}$$





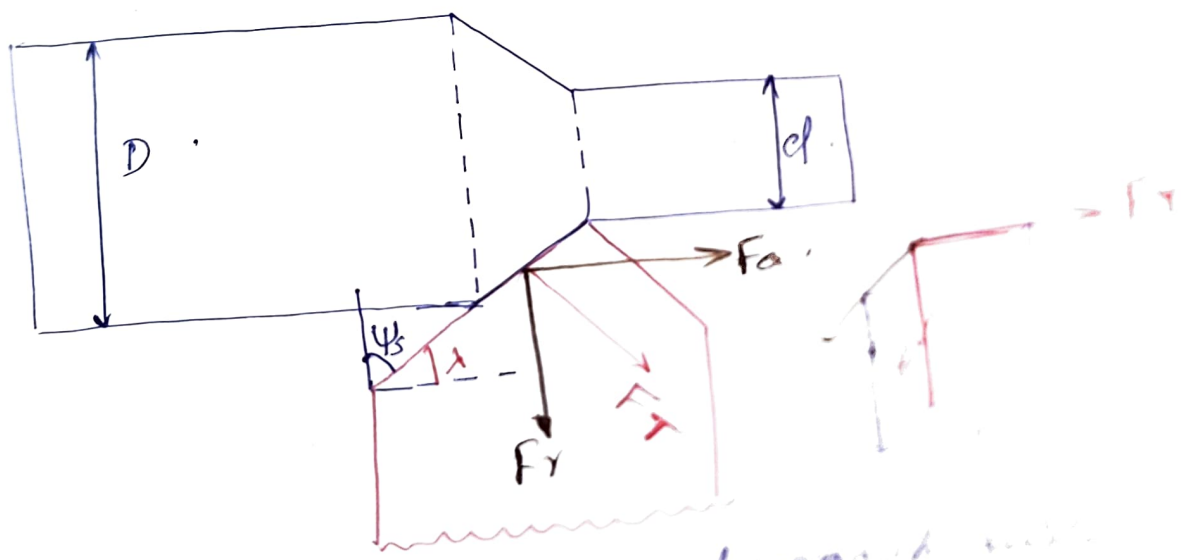
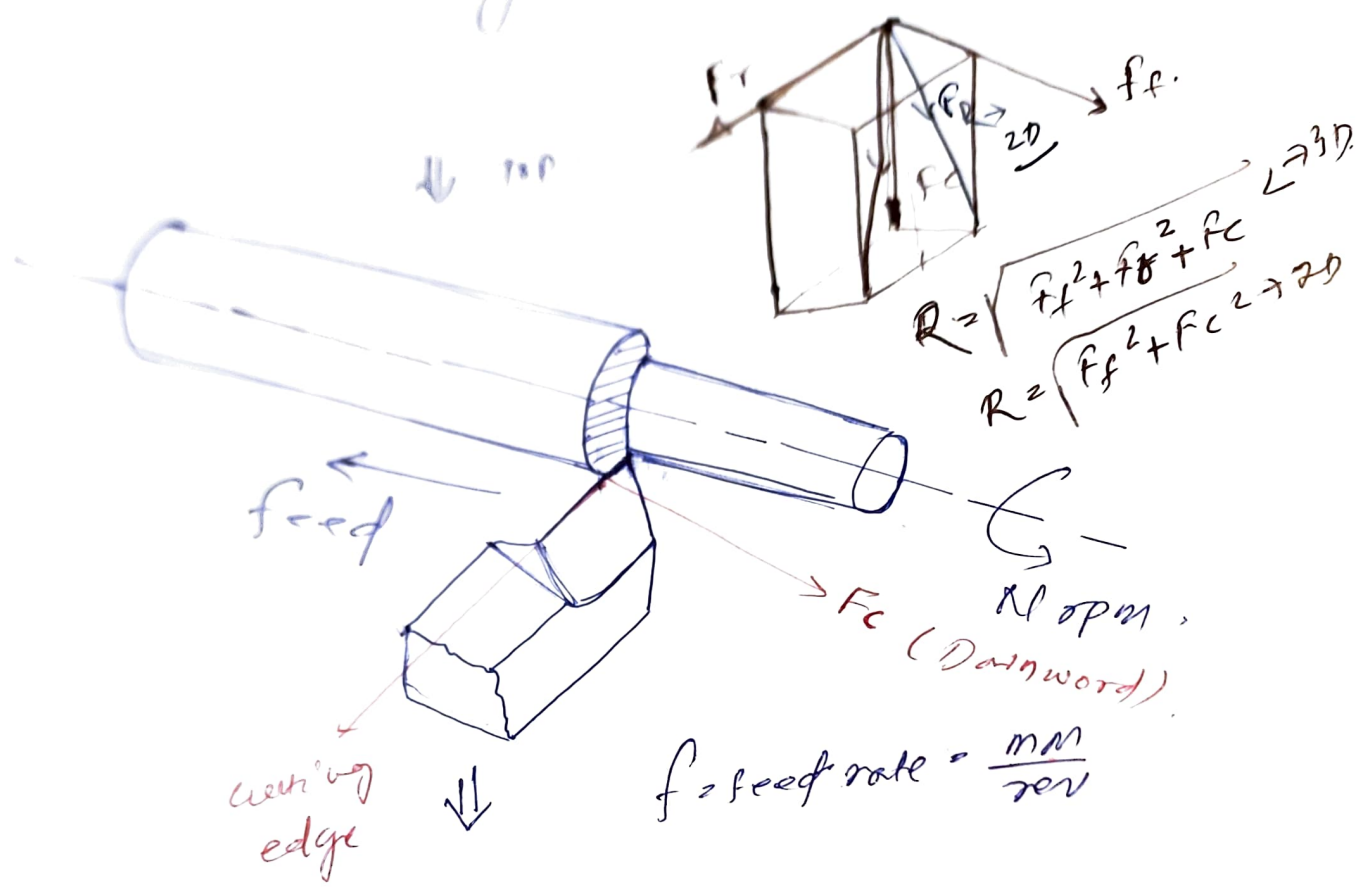
(1)  $\lambda = 0, C_s = 0, C_e = 0$   
 $\lambda = 90^\circ$   
 pure orthogonal condition.  
 of  
 joint kind.

$C_s = 90 - \lambda$   
 $C_e = 90 - \lambda$   
 $\lambda = 90^\circ$

(2) when  $\lambda = 0, 0 < \lambda < 90^\circ$

Flow kind orthogonal.

Turning process  
cutting forces

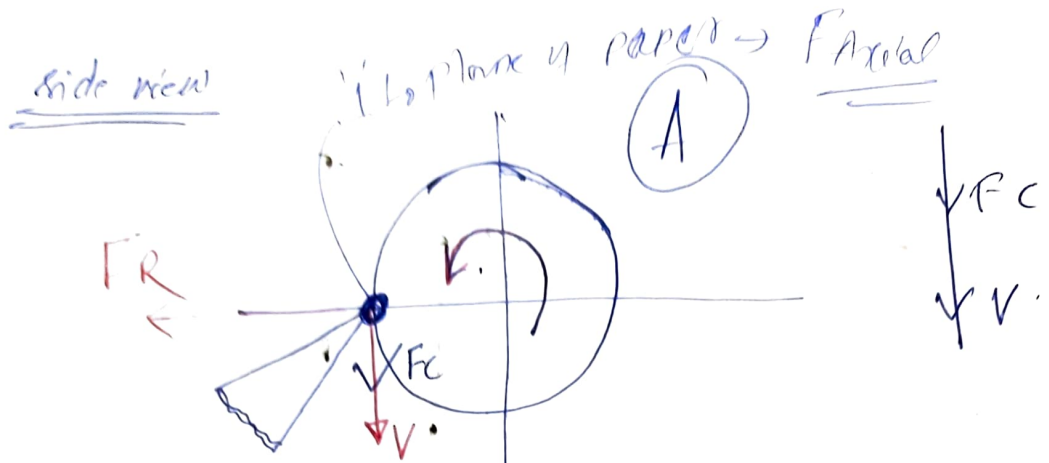


$\psi_s$  = side cutting edge angle / approach angle

$\lambda$  = principal cutting edge angle

let  $\theta = \text{dia of w/p (Initial)}$

$N = \text{rpm}$



(1) In case of turning cutting speed ( $V$ ).

$$V = \frac{\pi D N}{60} \text{ m/s.}$$

(2) feed or axial feed.

(a) Radial feed (feeding)  
or cross feed).

# It is the axial motion of tool w.r.t rotation of w.p.

ex  $f = \frac{2 \text{ mm}}{\text{rev}} \Rightarrow \underline{\underline{1 \text{ rev} \rightarrow 2 \text{ mm metal}}}$

(3) feed velocity / feed speed ( $V_f$ ).

$$V_f = f \cdot N$$

$$= \frac{\text{mm}}{\text{rev}} \times \frac{\text{rev}}{\text{min}}$$

$$V_f = \frac{\text{mm}}{\text{min}}$$

feed speed

# The feed in turning is generally in (mm/rev) i.e. in rev.  
this feed can be converted to a Linear travel rate  
in mm/min (in min)  $f \cdot N = V_f$ .

1) Machining time: w/o overtravel.

(2)

Time =  $\frac{\text{Distance}}{\text{speed}}$

$$T = \frac{L}{f \cdot N}$$

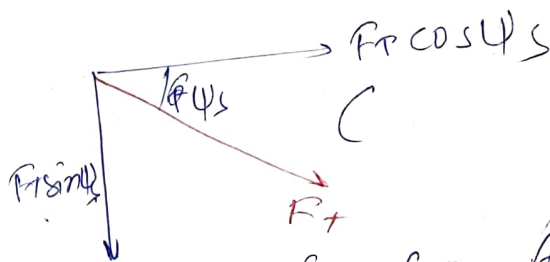
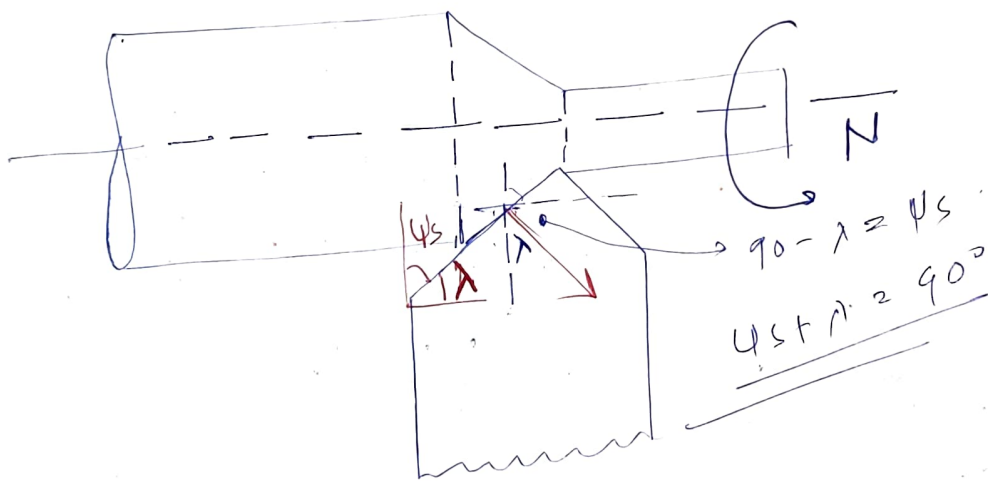
$L = \text{length of job}$

$$T = \frac{L}{f \cdot N}$$

No over travel

5) Forces in Turning.

(i) Cutting force ( $P_c$ ) or Tangential force.



$P_c \cos \psi \rightarrow$  act along Axis of job. hence Axial force.

$P_c \sin \psi =$  act along Radius of job hence Radial force.

So 3 forces  $\rightarrow$  }  
 (1) Tangential force.  
 (2) Axial force ( $P_R$ )  
 (3) Radial force.

Note

$\phi = 15^\circ \text{ to } 30^\circ$  (practical value)

For given values  $F_T \rightarrow F_T \cos \phi > F_T \sin \phi$  hence  
 Axial force  $>$  Radial force.

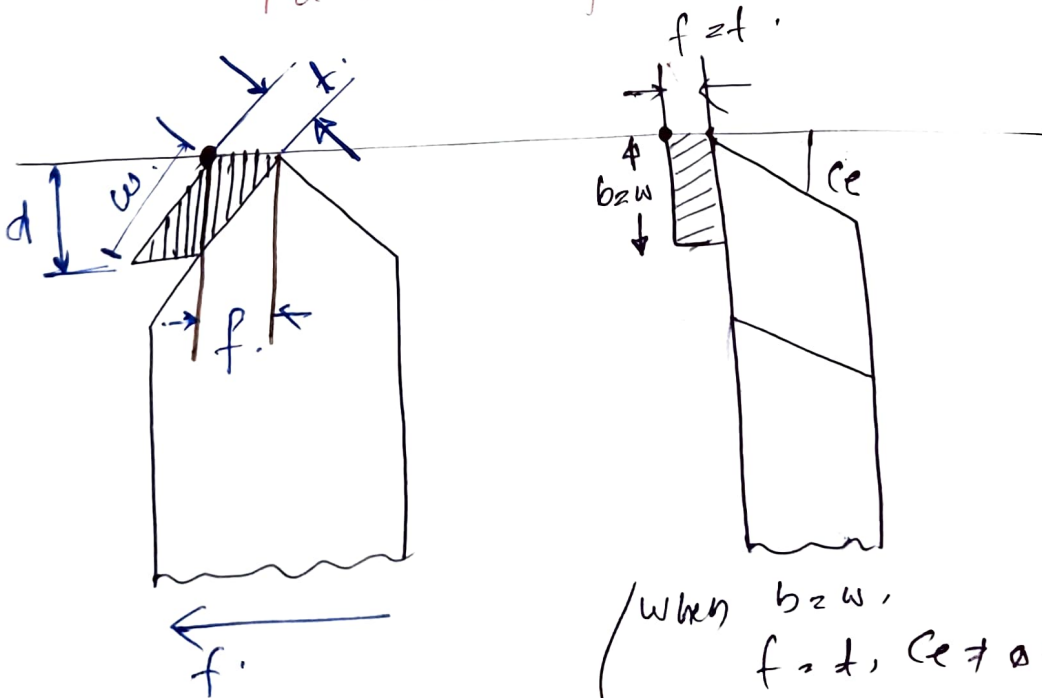
~~$F_{axial} > F_{rad}$~~

★  $F_c > F_{axial} > F_{rad}$

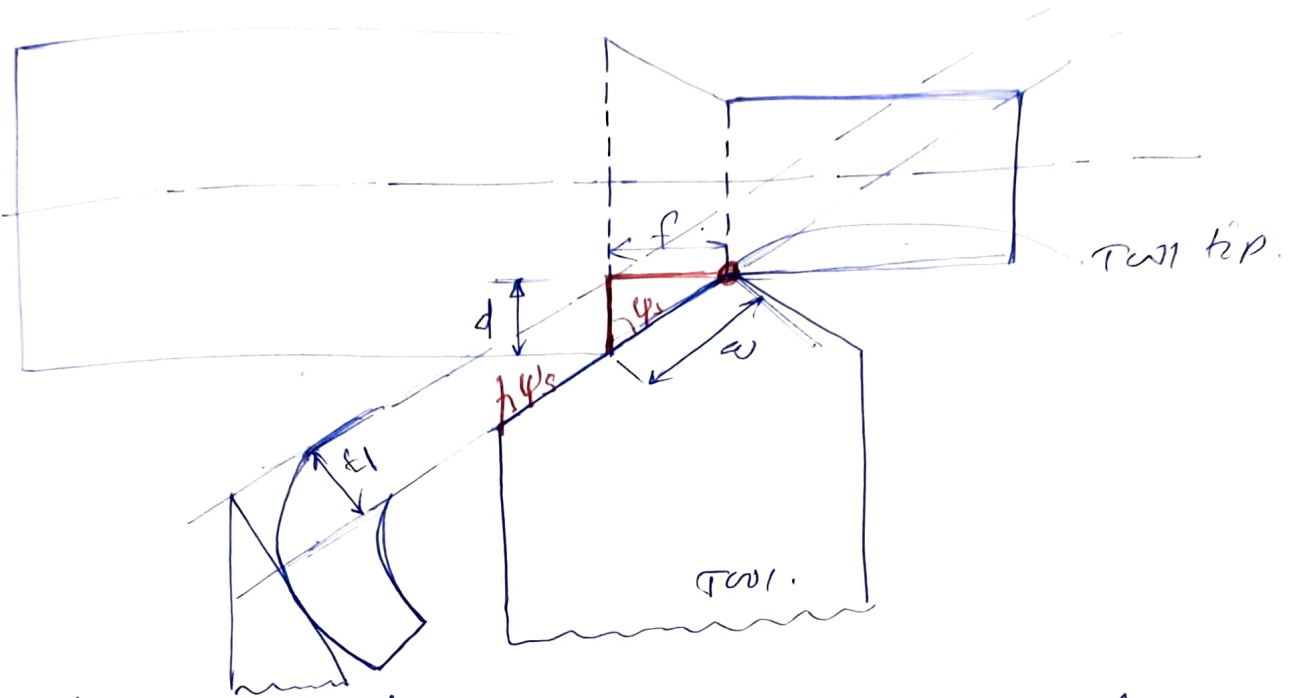
$F_c$  = cutting force.

$F_r$  = Radial force.

$F_a$  = axial force.



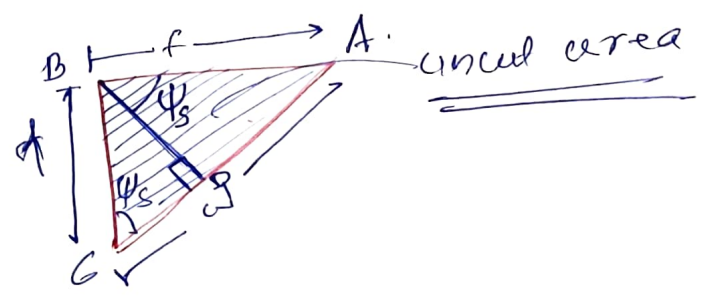
(when  $b < w$ ,  
 $f = t$ ,  $c_e \neq 0$ .  
 : restricted orthogonal)



$d$  = depth of cut.  
 $w$  = width of cut,  $C$  ~~to~~ what position of cutting edge is in contact with w/p.

$f$  = feed

$AD = \ell_1 =$  un-cut chip thickness.



$$\text{In } \triangle ABC \quad \cos \psi_s = \frac{BC}{AC} = \frac{d}{w} \quad \text{--- (1)}$$

$$d = w \cos \psi_s$$

$$\text{In } \triangle ABD \quad \cos \psi_s = \frac{BD}{AB}$$

$$\cos \psi_s = \frac{f}{f} \quad \text{--- (2)}$$

Equating (1) and (2)

$$\frac{d}{w} = \frac{f_1}{f}$$

$$f_1 \times w = f \cdot d$$

from eqn (2)

$$f_1 = f \cos \psi_s$$

for orthogonal cutting  $\psi_s = 0$

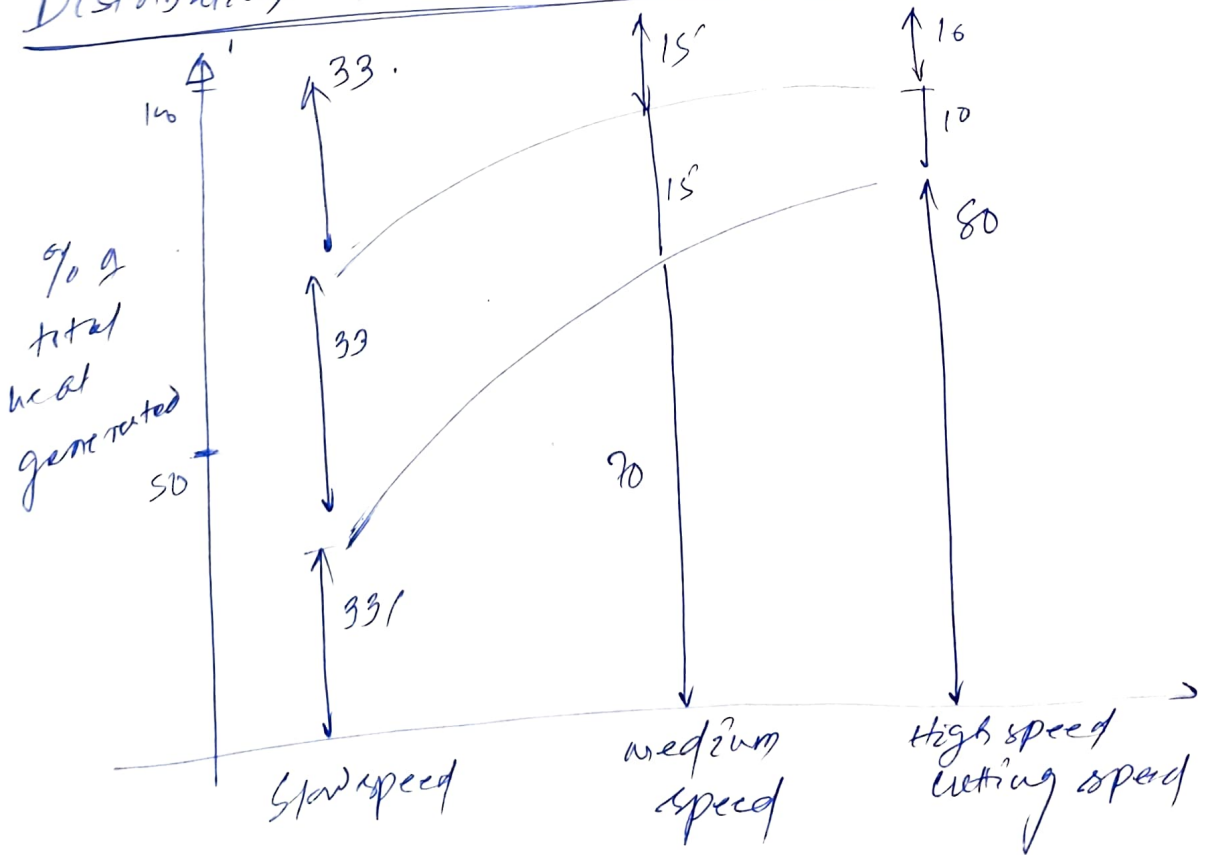
$$f_1 = f$$

$$\text{as } d = w \cos \psi_s$$

$$\psi_s = 0$$

$$d = w$$

### Distribution of heat in Metal cutting.



# Types of chips

1) Continuous chip w/o BUR.

favourable cond<sup>n</sup>

1) work material  $\rightarrow$  Ductile

2) Rake angle  $\rightarrow$  +ve & High.

3) cutting speed  $\rightarrow$  High.

4) feed  $\rightarrow$  Low.

5) Depth of cut  $\rightarrow$  Low.

6) Coolant used or not  $\rightarrow$  Yes.

2) BUR with continuous chips formed due to more heat generation.

# W/P material  $\rightarrow$  ductile.

# Rake angle  $\rightarrow$  (+)ive & high.

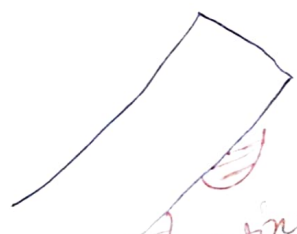
# cutting speed  $\rightarrow$  low

# feed  $\rightarrow$  medium

# depth of cut  $\rightarrow$  medium

# coolant used  $\rightarrow$  No.

here w/p material melts and stick with tool tip called BUR.



continuous chip with BUR.

Q. The cutting speed for turning a 1 inch dia bar has been found to be 575 fpm (175.3 m/min). Calculate the lathe spindle speed (101.6 mm).

Sol

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

$$N = \frac{1000 \times V}{\pi D} = \frac{1000 \times 175.3}{3.1416 \times 101.6} = 549 \text{ rpm}$$

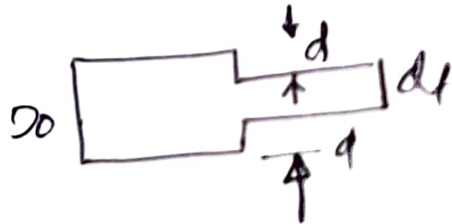
### Depth of Cut in Turning

$$D_f = D_o - 2d$$

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

$D_o$  = original dia.

$D_f$  = final dia



# Cutting Fluid.

①

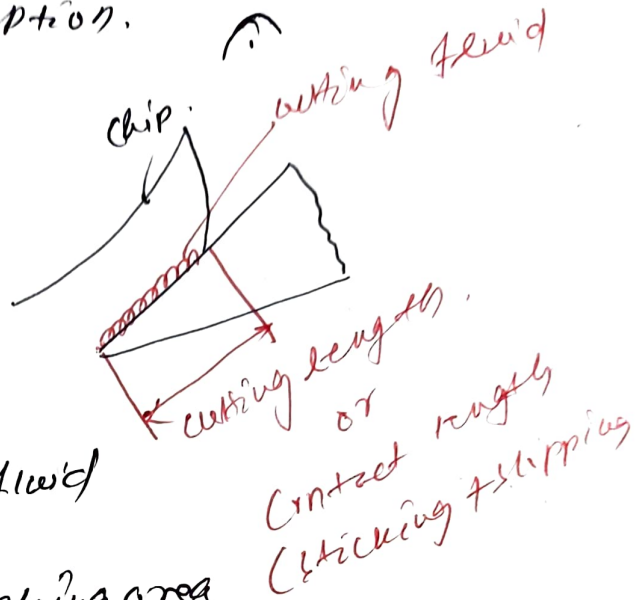
#1) Decreases power consumption.

#2) Decreases friction

$$F_c V_c = F_s V_s + F_e V_c$$

$$\Rightarrow F_c V_c \downarrow \Rightarrow F_c V_c \downarrow$$

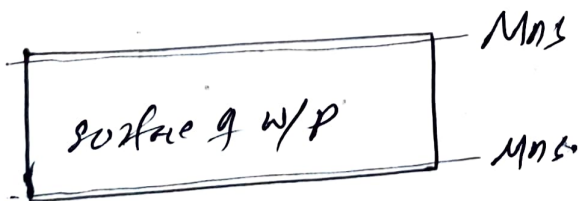
Due to cutting fluid



#3) Taking away heat from machining area.  
(heat at the contact length)

#4) It helps in disposing chip from machining area.

Hot shockness.



surface of w/p contains Manganese as Impurity.

cutting fluid  
 Neat oil  
 oil + EP additive (S, P, Cl).  
 water emulsion.

10. What are the methods to prevent corrosion?

→ when we inject neat oil with EP additive to the surface of w/p the EP additive reacts with the residual manganese present in the surface of w/p and forms MnS (manganese sulphide) which forms a low shear strength zone which decreases  $f_s$  (wear zone).

$$\text{hence } P_c V = P_s V_s + P_o \times V_c$$

( ↓      ↓      ↓ )

Application

(chemical cut" need time)

- 1) Mist → low cutting speed. (through nozzle).
  - 2) Flood → High cutting speed.
- # cutting speed ↑ ⇒ water content in oil ↑ ⇒ viscosity of oil ↓ ⇒ dispoing chip ↑

# Applications

(2)

is selected according to material used

ex) Cast Iron → During milling graphite flakes will come from CI and it mixed with CP and damage the milling area.

So NO CP is used. In sometimes compressed air is used.

ex) Steel → at low speed → Neat oil + EP  
→ at high speed → Water Emulsions.

ex) Aluminium → (Al).

# very soft material.

# at high speed watering is (CF) required

# at low speed → BUR formed ⇒ Neat oil + EP is used

ex) Magnesium Alloy → used in biomedical applications.

# Never use water emulsion

(Due to catching fire)

# Neat oil is used + bio corrosion

ex) Brass & Bronze → (Cu alloys)

# No EP additive

# Benzene is used

10. What are the methods to prevent corrosion?

Ans Tool material like Ceramic & Carbide which is very brittle so during machining C.P is supplied before the start of cutting operation otherwise due to thermal stresses tool will break.

[Improper application of CP drastically decreases the tool life.]

# Economics of Machining. (for 1 component).

1) Minimum cost  $\rightarrow$  At what speed  $g$  should cut the metal so cost will be minimum.

a) Machining cost

$\leq 1 \text{ lakh} \rightarrow 10 \text{ lakh}$ .

life  $\rightarrow 10 \text{ years}$ .

$\Downarrow$

After 10 year Resale value  $\rightarrow 1 \text{ lakh}$ .

10 years  $\rightarrow 9 \text{ lakh}$ . ✓

$$\text{Machine cost } (C_m) = \frac{9,00,000}{10 \times 365 \times 24 \times 3600} = \text{Rs/sec}$$

$$C_1 = C_m T_m$$

$T_m$  = machining time to make one product.

$$T_m = \frac{L}{f \cdot N}$$

$L$  = cutting length.

$f$  = feed

$N$  = rpm

$$V = \frac{\pi N D}{60} \Rightarrow N = \frac{60V}{\pi D}$$

$$T_m = \frac{\pi D L}{60 f V}$$

$$C_1 = C_m \times \frac{\pi D L}{60 f V}$$

①

10. What are the methods to prevent corrosion?

(b) Idle cost

Suppose worker's daily duty = 8 hrs.

Starting 30 min → Tea break  
 1 hr → lunch break  
 30 min → Tea break  
 Total → 2 hrs → Ineffective.

Total Idle time  
 Total no. of products

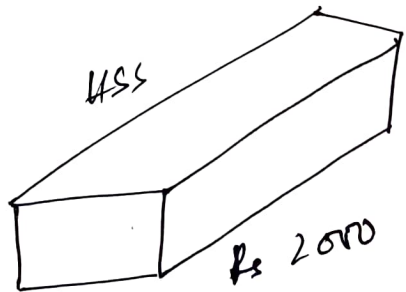
Suppose in 6 hrs → supply of product

$$\text{Idle time/product } T_h = \frac{120}{500} = \frac{12}{50} \text{ min.}$$

$$C_2 = C_m \times T_h = \text{Idle cost} \rightarrow \textcircled{2}$$

(c) Tool cost

$C_e = \text{Total cost/Regrind}$



Suppose 10 Regrind.

$$C_e = \text{Tool cost/Regrind} = \frac{2000}{10} = \text{Rs } 200/\text{Regrind}$$

(Availability in market)  
 ↓  
 Grinding Operator  
 ↓  
 Tool signature

Fixed cost  
 $C_0 = C_e \times \left(\frac{T_m}{T}\right)$   
 $C_0 = \text{cost of tool / period}$

$\frac{T_m}{T} =$  to make 1 product  
 how many times  
 tool changes.

$C_3 = C_e \left(\frac{T_m}{T}\right)$

$C_3 = C_e \left(\frac{KDR}{60+V}\right) \cdot \left(\frac{V}{C}\right)^{\frac{1}{n}}$  → 3

as  $VT^n = C$   
 $T^n = \frac{C}{V}$   
 $T = \left(\frac{C}{V}\right)^{\frac{1}{n}} \Rightarrow \frac{1}{T} = \left(\frac{V}{C}\right)^{\frac{1}{n}}$

(iv) Tool changing cost.

let  $T_c =$  tool changing time (from old one to New one)

here workers is not idle but M/C is not producing  
 any useful work hence, this cost is not included  
 in Idle cost.

$C_A = C_m T_c \left(\frac{T_m}{T}\right)$

total time will be Idle cost  
 NOT producing anything  
 is not idle.

10. What are the methods to prevent corrosion?

$$\# C_A = C_m T_C \left( \frac{\pi D L}{60 f v} \right) \left( \frac{v}{c} \right)^{\frac{1}{n}} \quad \text{--- (9)}$$

Minimum cost:

$$T_C = C_1 + C_2 + C_3 + C_4$$

Here only one variable  $v$  (speed)

$$\text{So } \frac{d(T_C)}{dv} = 0$$

$$v_{\text{optimum}} = \left[ \frac{c}{\left( \frac{C_e}{C_m} + T_C \right) \left( \frac{1}{n} - 1 \right)} \right]^n$$

★  
Remember

$$\% \quad v T_C = c$$

$$v_{\text{optimum}} = \left( \frac{C_e}{C_m} + T_C \right) \left( \frac{1}{n} - 1 \right)$$

★

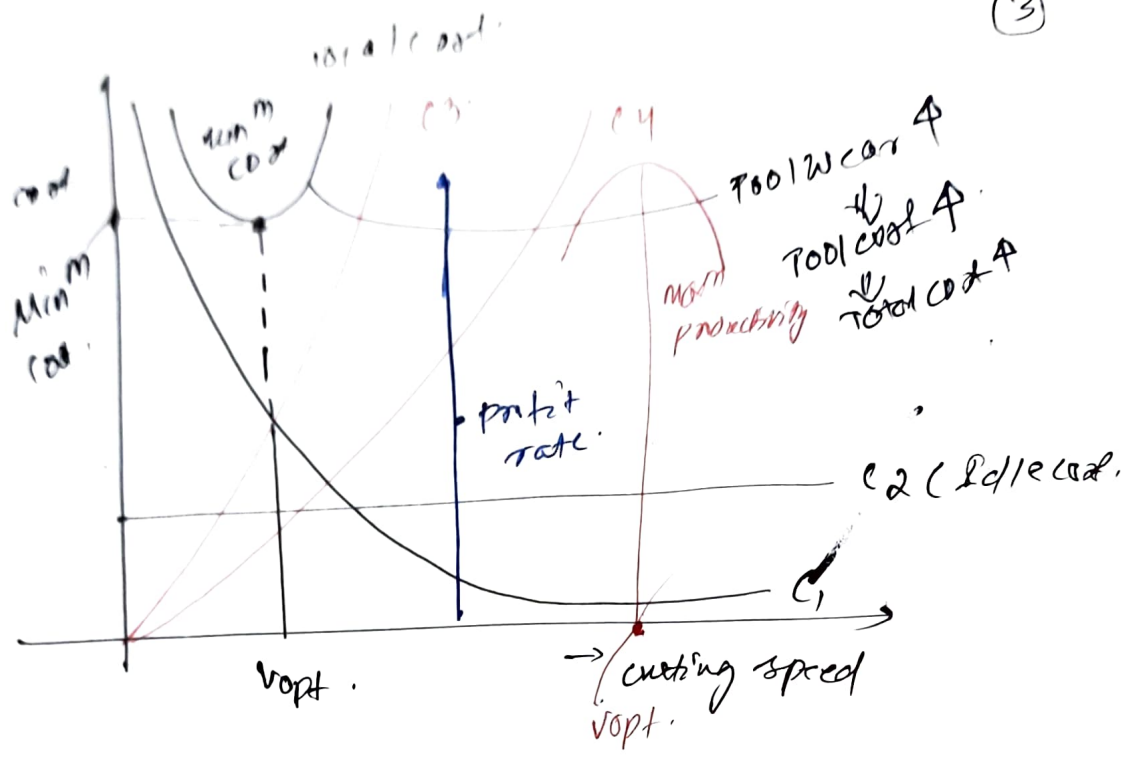
or

$$\frac{d(T_C)}{dv} = \frac{dC_1}{dv} + \frac{dC_2}{dv} + \frac{dC_3}{dv} + \frac{dC_4}{dv}$$

$$= \frac{d}{dv} \left( C_m \times \frac{\pi D L}{f v} \right) + \frac{d}{dv} \left( C_m \times T_C \right)$$

$$+ \frac{d}{dv} \left[ C_e \frac{\pi D L}{f v} \times \left( \frac{v}{c} \right)^{\frac{1}{n}} \right]$$

$$+ \frac{d}{dv} \left[ C_m \frac{\pi D L}{f v} \times \left( \frac{v}{c} \right)^{\frac{1}{n}} \times T_C \right]$$



$C_1 \propto \frac{1}{v}$

Criteria 1  $\Rightarrow$  At what speed the m/cing is carried out so that per unit cost is less.

Criteria 2  $\Rightarrow$  Max productivity.

At what speed m/cing is done for max<sup>n</sup> product

Rate of production =  $\frac{\text{no. of products}}{\text{time}} = \frac{1}{T_{mt} + T_h + \left(\frac{T_m}{v}\right) T_c}$

~~(X)~~

For product

For Rate of production  $\uparrow$  i.e. R  $\uparrow$  denominator to be min<sup>n</sup>.

$\frac{dR}{dv} = 0 \Rightarrow v_{opt} = \left[ \frac{c}{\left(\frac{1}{n} - 1\right) T_c} \right]^n$

# Economics of Leasing.

- 1) min<sup>m</sup> cost criteria.
- 2) Max<sup>m</sup> production rate (not)
- 3) Max<sup>m</sup> profit criteria.

$$\text{Total cost (TC)} = C_1 + C_2 + C_3 + C_4$$

$$= C_m \times T_m + C_m \times T_h + C_e \times \left(\frac{T_m}{T_0}\right) + C_m \left(\frac{T_m}{T}\right) \times TC.$$

$$TC = C_m \times \frac{PDL}{GDFV} + C_m \times T_h + C_m \times \frac{PDL}{GDFV} \times \left(\frac{V}{C}\right)^{\frac{1}{n}} + C_m \times \frac{PDL}{GDFV} \times \left(\frac{V}{C}\right)^{\frac{1}{n}} \times TC.$$

$$\frac{dT_c}{dV} = 0.$$

$$\Rightarrow C_m \times \frac{1}{V} + C_m \times T_h + C_e \times \frac{1}{V} \times \left(\frac{V}{C}\right)^{\frac{1}{n}} + C_m \times \frac{1}{V} \times \left(\frac{V}{C}\right)^{\frac{1}{n}} \times TC$$

$$= -\frac{C_m}{V^2} + \frac{C_e}{C^{1/n}} \left(\frac{1-n}{n}\right) V^{\left(\frac{1-2n}{n}\right)} + \frac{C_m \cdot TC}{C^{1/n}} \times \left(\frac{1-n}{n}\right) V^{\left(\frac{1-2n}{n}\right)}$$

$$= \frac{C_m}{V^2} = \frac{C_e}{C^{1/n}} \left(\frac{1-n}{n}\right) V^{\left(\frac{1-2n}{n}\right)} + \frac{C_m \cdot TC}{C^{1/n}} \times \left(\frac{1-n}{n}\right) V^{\left(\frac{1-2n}{n}\right)}$$

$$\Rightarrow C^{\frac{1}{n}} = \frac{C_e}{C_m} \left(\frac{1-n}{n}\right) \underbrace{V^2 V^{\frac{1-2n}{n}}}_{V^{\frac{2-2n}{n}}} + TC \cdot V^2 \cdot \left(\frac{1-n}{n}\right) \cdot V^{\left(\frac{1-2n}{n}\right)}$$

$$\Rightarrow C^{\frac{1}{n}} = \frac{C_e}{C_m} \times \left(\frac{1-n}{n} \times V\right)^{\frac{1}{n}} + TC \times \left(\frac{1-n}{n}\right) V^{\left(\frac{1}{n}\right)}.$$

$$C^{\frac{1}{n}} = \frac{1-n}{n} \times V^{\frac{1}{n}} \left[ \frac{C_e}{C_m} + TC \right].$$

$$C = \left\{ \frac{1-n}{n} \times \left( \frac{C_e}{C_m} + TC \right) \right\}^n \times V$$

[Multiply n on both sides]

Use Taylor's law  $V^a = e^{a \ln V}$

$$V_{opt} T_{opt}^n = C$$

Standard eq<sup>n</sup>

$$T_{\text{production}} = \left\{ \left( \frac{L}{n} \right) \left( \frac{C}{C_m} + 1 \right) \right\}^n$$

$$V_{\text{production}} = \frac{C}{\left\{ \left( \frac{L}{n} \right) \left( \frac{C}{C_m} + 1 \right) \right\}^n}$$

Min<sup>m</sup> cost  
Criteria<sup>2</sup>

2) Max<sup>m</sup> production Rate Criteria (Rp)

$$R_p = \frac{1}{T} \quad (T = \text{time})$$

$$R_p = \frac{\text{no. of products}}{\text{time}}$$

total time =  $T_m + T_h + \left( \frac{T_m}{T} \right) \cdot T_c$   
 (TT)                       $\downarrow$   $\downarrow$   
 m/c'ing time                      idle time

$$TT = \frac{\pi D L}{60 n V} + T_h + \frac{\pi D L}{60 n V} \times \left( \frac{V}{C} \right)^{\frac{1}{n}} \cdot T_c$$

$$\frac{d(TT)}{dV} = 0 \Rightarrow -\frac{1}{V^2} + \frac{T_c}{C^{1/n}} \times \left( \frac{1-n}{n} \right) V^{\frac{1-n}{n} - 1} = 0$$

$$\frac{1}{V^2} = \frac{T_c}{C^{1/n}} \times \left( \frac{1-n}{n} \right) V^{\frac{1-2n}{n}}$$

$$C^{\frac{1}{n}} = T_c \left( \frac{1-n}{n} \right) \cdot V^2 \cdot V^{\frac{1-2n}{n}}$$

$$C^{\frac{1}{n}} = T_c \left( \frac{1-n}{n} \right) \cdot V^{\frac{1}{n}}$$

$$C = T_c \left( \frac{1-n}{n} \right) \cdot V$$

Compare with  $\sqrt{T} > C$

$$Q_{optimum} = \frac{C}{\{TC (\frac{1-\eta}{\eta})\}^\eta}$$

$$T_{optimum} = TC (\frac{1-\eta}{\eta})^\eta$$

3) Max<sup>m</sup> profit criteria.

profit = S.D - TC Total cost (TC)

(Profit ↑ as TC ↓)

$$Profit Rate = \frac{SP - TC}{T_{mt} T_h + (\frac{T_m}{T}) TC}$$

NOTE  
 $V_{opt} (production rate) > V_{opt} (profit rate) > V_{opt} (min cost)$

★  $\frac{T_{m1}}{T}$  = tool making 1 product, how many time tool change

$$C_e = \text{tool cost / required}$$

Tool changing cost.  
 suppose tool wear takes place <sup>then</sup> new tool is installed.

# Here worker is not idle.

# but M/C is not producing anything useful.

∴  $TC (\frac{T_m}{T}) \rightarrow$  total time M/C is idle and not producing any work but worker is not idle.

# Tool Life (T)

(0)

Actual time between two successive Regrinds.

$T = \text{minute}$

Tool failure  $\rightarrow$  The moment when the tool unable to perform cutting properly.

$\downarrow$   
Then regrind the tool & then use it again.



Here  $T = 100 \text{ min}$  or not?

Suppose a worker performs turning operation and he uses the m/c only for 30 min, even the

Tool life = 30 min. Actual contact of tool & job.

$\downarrow$   
Effective time gap b/w two successive tool change or tool regrinds.

(2)  $T = \text{no. of components produced between two successive regrinds.}$

$T = 100 \text{ components}$

let 1 comp  $\rightarrow$  10 min

$100 \uparrow = 100 \times 10 = 1000 \text{ min}$

(3)  $T$  = volume of material removed b/w two successive regrinds.

let  $T = 1000 \text{ mm}^3$

Analysis of  $VT^n = C$ .

$VT^n = C$  graph

$\ln(VT^n) = \ln C$

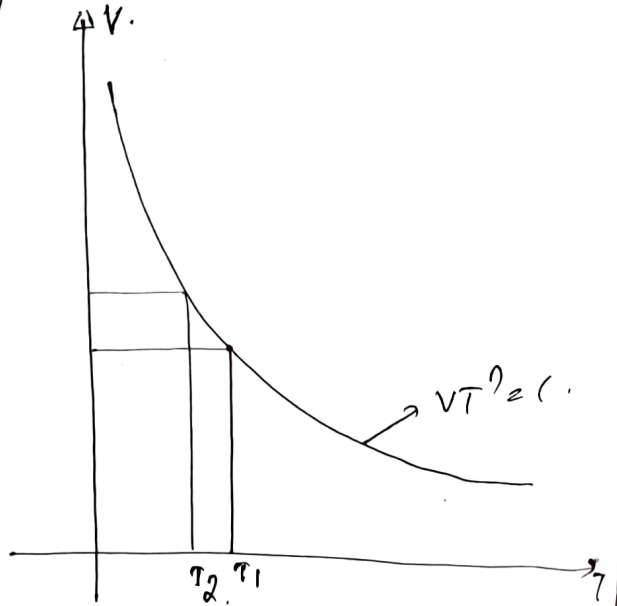
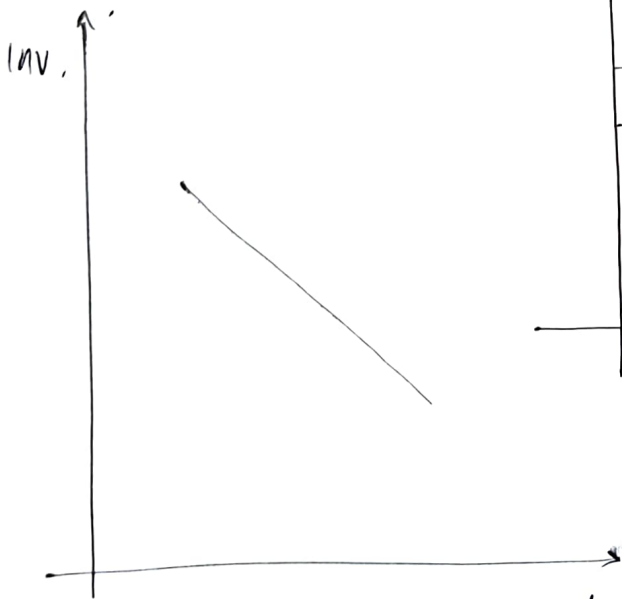
$\ln V + n \ln T = \ln C$  — (1)



compare eq<sup>n</sup> (1) with  $y = mx + c$ .

$y = \ln V = -n \ln T + \ln C$  slope  $m = -n$

$y = \ln V$   
 $\ln T = x$



Note As  $V \uparrow$ , Max<sup>m</sup> temp on rake face  $\uparrow \Rightarrow \uparrow$  diffusion.

Wear: (1) depth of cut  $\uparrow \Rightarrow T \uparrow$ , feed  $\uparrow \Rightarrow T \uparrow$ .

feed,  $d$ ,  $V$  increasing order of Tool life  $\downarrow$ .

# Imp Tool life

(1)

## Taylor's Tool life equation.

$$VT^\eta = C$$
 Empirical relation based on practical.

$$T^\eta = \frac{C}{V}$$
  
$$T = \frac{C^{1/\eta}}{V^{1/\eta}}$$

$V$  = cutting speed (m/min).

$T$  = Tool life (in min).

$\eta$  = exponent (Depend on only tool material).

$C$  = const depends on (tool material, w/p material depends on tool, w/p combination) & many other parameters.

## Modified Taylor's Tool life equation.

$$VT^a f^a d^b = C$$

$d$  = depth of cut.

$f$  = feed.

$$T^a = \frac{C}{V f^a d^b}$$

$$T = \frac{C^{1/a}}{V^{1/a} f^{1/a} d^{b/a}}$$

Which do more dominate on Tool life.

# Generally  $a > b$  → from practical.

let  $\eta = 0.5$  and

$a = 0.3$ , &  $b = 0.1$

$$b = \frac{1}{n} = \frac{1}{2} = 0.5$$

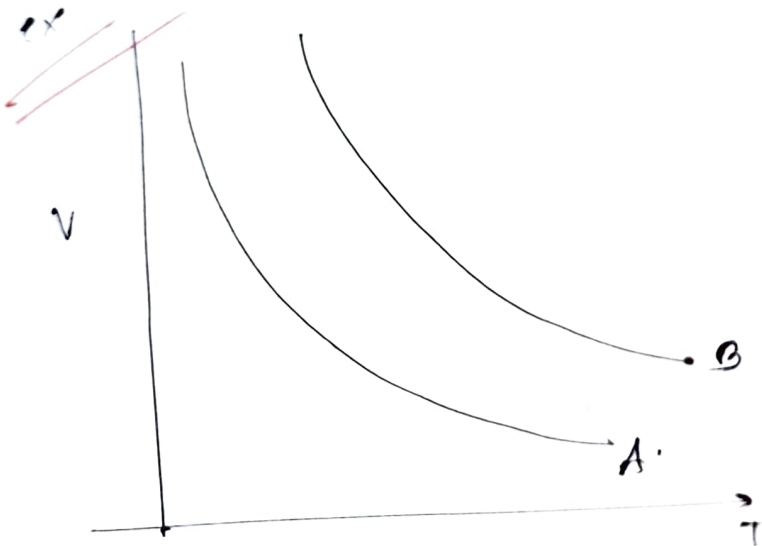
$$f = a \times \frac{1}{n} = 0.3 \times 2 = 0.6$$

$$d = b \times \frac{1}{n} = 0.1 \times 2 = 0.2$$

$$\frac{1}{n} > \frac{a}{n} > \frac{b}{n}$$

$$v > f > d$$

Decreasing order of tool life.



$$\text{As } vT^\eta = C$$

$$\log v + \eta \log T = \log C$$

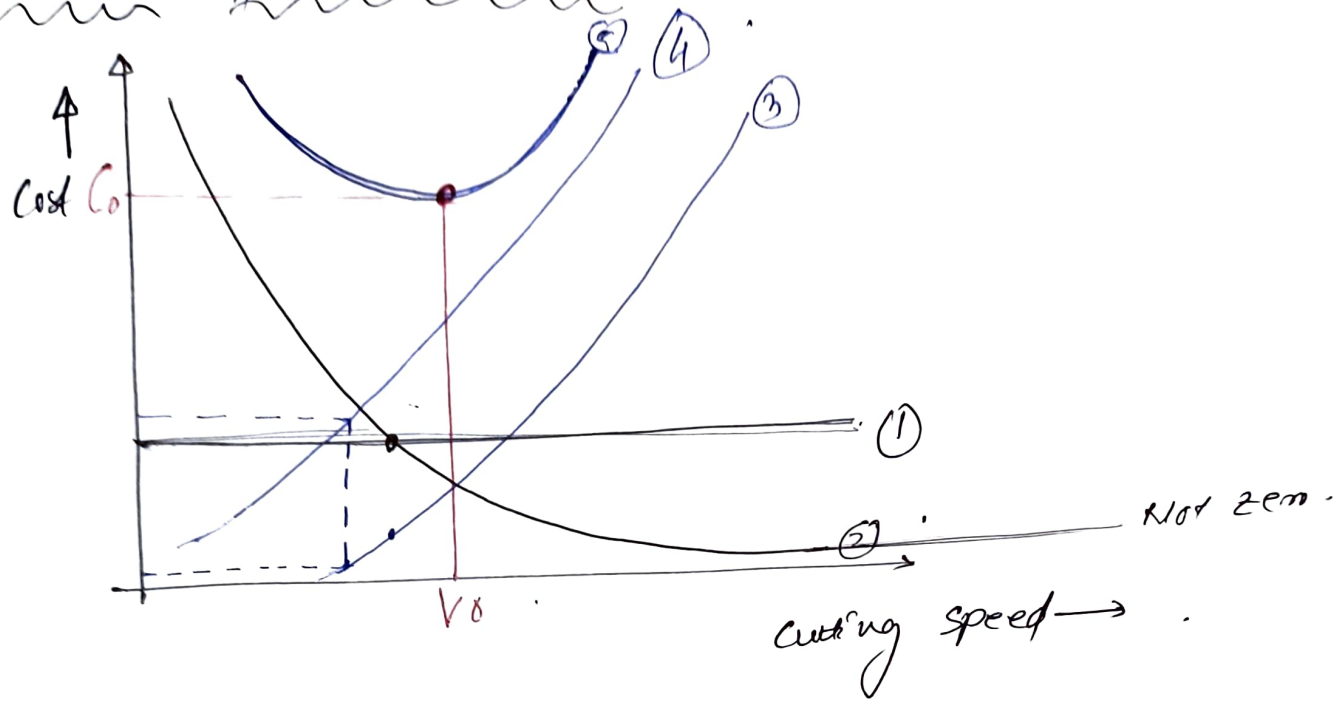
Slope =  $\eta$

Intercept

$$\eta_A = \eta_B$$

For material B,  $C$  is more.

# Economics of Metal Cutting:



- ① → fixed cost or non-productive cost.
- 2 → machining cost.
- 3 → Total Regrinding cost.
- 4 → Total changing cost.
- 5 → Total cost.

$C_0$  → optimum cost.

$V_0$  = optimum speed

Note at max speed curve (3) & (4) is neglected.

$$T_C = T_1 + T_2 + T_3 + \cancel{T_4} + \cancel{T_5}$$

$T_C$  = total cost.

$$T_C = T_1 + T_2 + T_3$$

Let  $T_1 = 500$ ,  $T_2 = 400$ ,  $T_3 = 10$ .

$C = \sqrt{\frac{P}{a \cdot v}}$

ex-2  $T_1 = 500$

$T_2 = 900$

$T_3 = 50$

$T_c = 950$

ex-3 VA

$T_c = 500 + 200 + 100$

$T_c = 800$

ex-4 VA

$T_c = 500 + 150 + 200$

$T_c = 850$

NOTE Find  $V_0$

Determination of optimum cutting speed to find minimum cost.

Method-1 Using Taylor's Tool life eq<sup>n</sup>.

$V T^n = C$

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

$V_0 = \frac{C}{T_0^n}$

( $T_0 =$  optimum tool life)

★ To find  $T_0$  for max<sup>m</sup> production.

minimum cost  
↑  
max<sup>m</sup> profit.

② Optimum tool life for minimum cost.

for max<sup>m</sup> production.

$$T_0 = \left( \frac{1}{n} - 1 \right) T_c$$

$n$  = Taylor's tool life exponent.

$T_c$  = tool changing time in minute.

↓  
after break to change new tool.

$$v_0 = \frac{c}{T_0^n}$$

for minimum cost.

$$T_0 = \left( \frac{1}{n} - 1 \right) \left[ T_c + \frac{C_t}{C_m} \right]$$

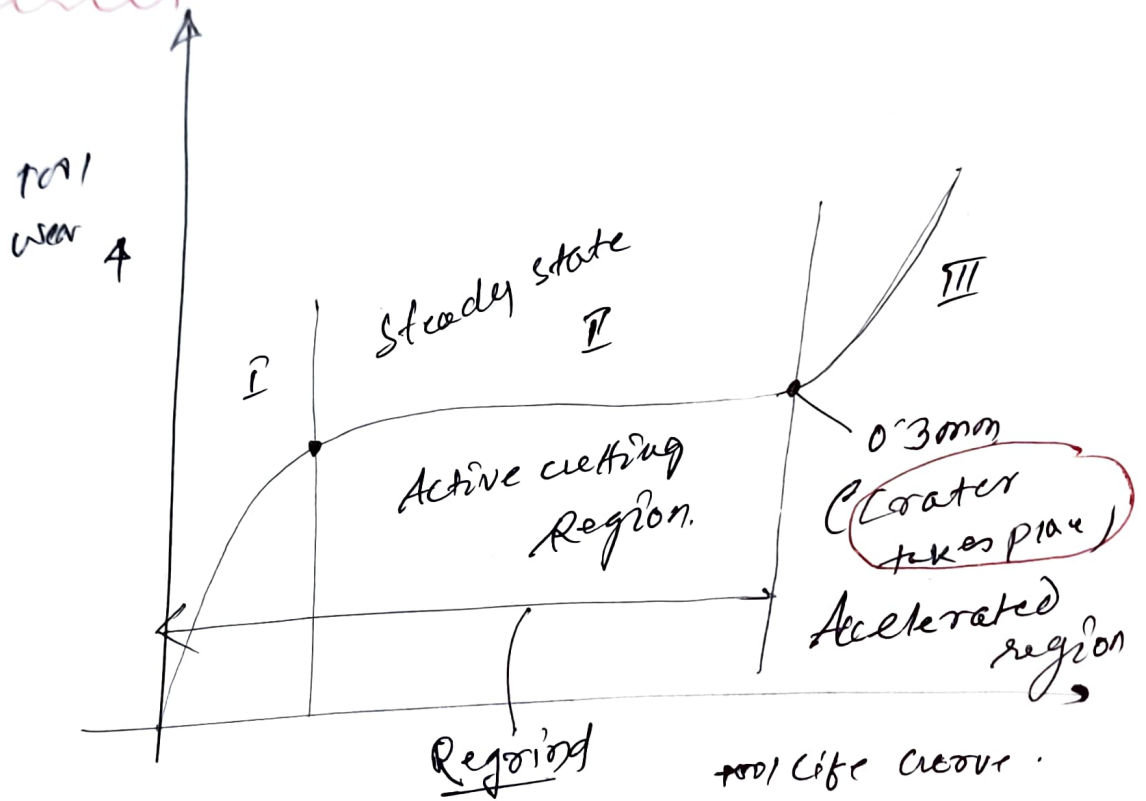
$C_t$  = tooling cost in rupees.

$C_m$  = machining cost in (rupees/min)

then apply  $v_0 = \frac{C}{T_0^n}$

4, 10, 11, 7, 1, 12, 21, 17, 18, 15, 19, 03.

### Tool Wear & Time:



### Region - I

New tools more sharp, when contact with job the sharp points tend to round off. Hence more

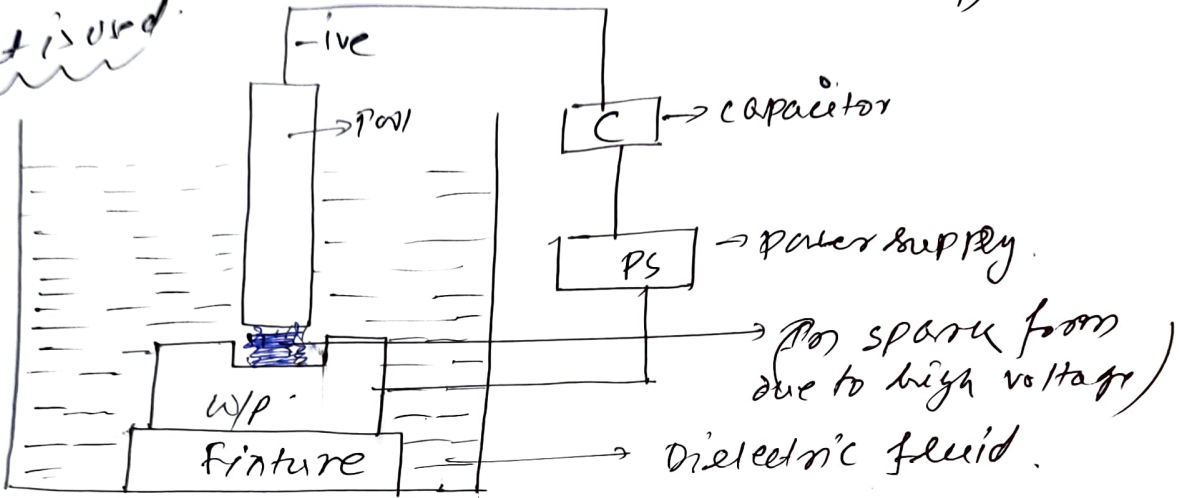
tool wear

Tool life = Time b/w 2 Regime.

# EDM (Unconventional or non-traditional mfg) (NTM)

# High voltage, low current. (DC power supply)

# RC circuit used.



# Tool material → graphite + copper (with very high)

$K =$  conductivity  
 $C =$  sp. heat

Tool →  $K_A, C_A$

WP →  $K_B, C_B$

PS → capacitor charge → Threshold Voltage

## Cycle I

- # ckt closed
- # capacitor charging
- #  $t_1 =$  charging time,

$$t_1 \gg t_2$$

## Cycle-II

- # ckt open
- # capacitor discharging
- #  $t_2 =$  discharging time

Total cycle time = charging time

# Cycle time =  $t_1 + t_2$

$$(t) = t_1 + t_2 \quad (t_2 \approx 0)$$

$$\boxed{V_d = V_0 (1 - e^{-t/RC})} \rightarrow \text{How much voltage discharge by capacitor. \#}$$

$V_d$  = Discharge voltage,

$V_0$  = charging voltage.

$t$  = cycle time

$R$  = Resistance

$C$  = capacitance.

$$V_d = V_0 (1 - e^{-t/RC})$$

$$\Rightarrow e^{-t/RC} = 1 - \frac{V_d}{V_0}$$

$$= \frac{-t}{RC} = \ln\left(\frac{V_0 - V_d}{V_0}\right)$$

$$\Rightarrow \frac{t}{RC} = \ln\left(\frac{V_0}{V_0 - V_d}\right)$$

$$\Rightarrow \boxed{t = RC \ln\left(\frac{V_0}{V_0 - V_d}\right)}$$

$$\# \text{ Frequency } (f) = \frac{1}{t}.$$

$$\boxed{f = \frac{1}{RC \ln\left(\frac{V_0}{V_0 - V_d}\right)}}.$$

$$V = V_0 (1 - e^{-N})$$

$$N = \frac{t}{RC} \rightarrow \text{time variable}$$

and as constant

# Energy

$$E = \frac{1}{2} C V_0^2$$

# power

$$P = \frac{E}{t} = \frac{\frac{1}{2} C V_0^2}{t}$$

$$= \frac{1}{2} \frac{C}{t} V_0^2 (1 - e^{-N})^2$$

$$= \frac{1}{2} \left( \frac{RC}{t} \right) \times \frac{V_0^2}{R} (1 - e^{-N})^2$$

$$P = \frac{V_0^2 (1 - e^{-N})^2}{2RN}$$

For max<sup>m</sup> power.

$$\frac{dP}{dN} = 0$$

$$N = 1.26$$

$$V_0 = 0.22 V_0$$

db

(2)

Dielectric

# temp control

# in b/w fuel & W/P

the gap becomes conductive

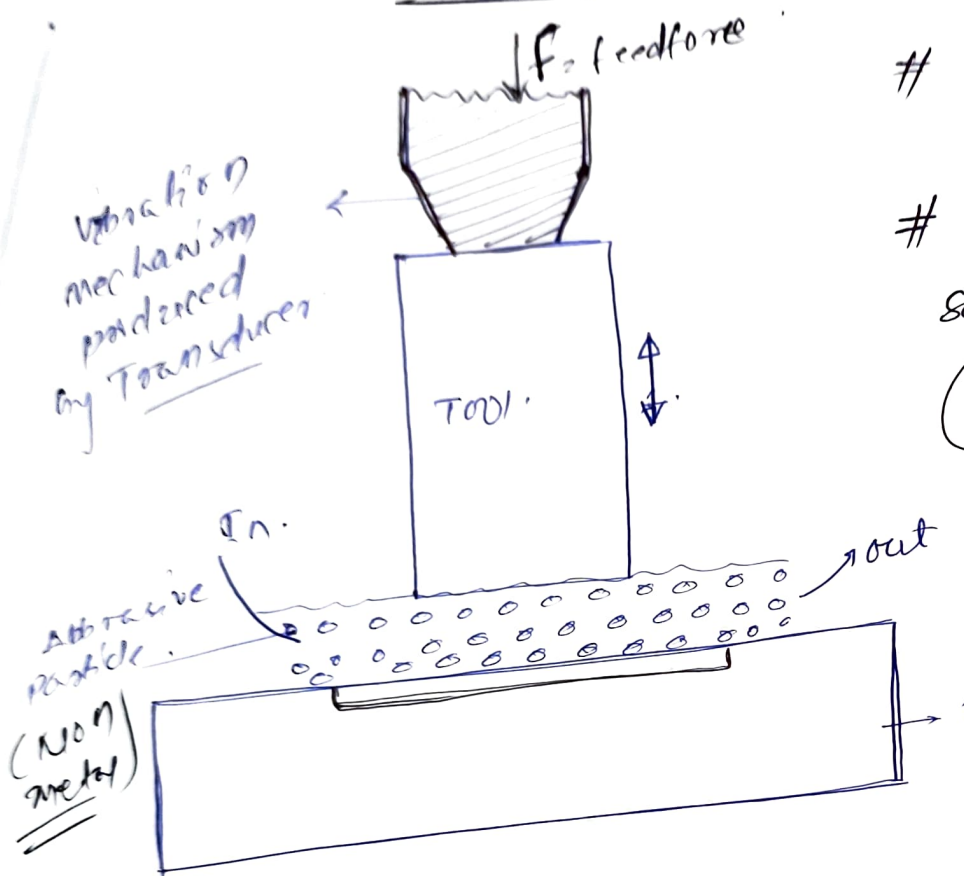
hence burn & acts as

a lubricant.

↓

(hence mett & vapour)

# USM (ultrasonic machining process) 3

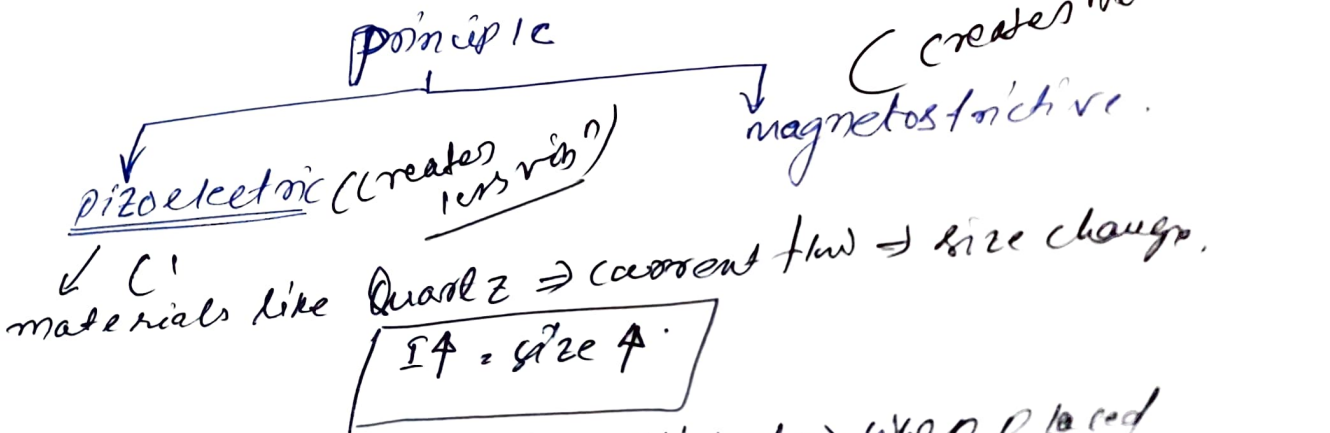


- # Not suitable for Ductile material,
- # Tool material must be soft  $\rightarrow$  Ductile b'coz (high TOUGHNESS. (to reduce wear) tool)

- # tool & W/P gap is filled by Abrasive slurry. Sand in beach
- # TOOL is a **Form** TOOL.

## Components:

1  $\rightarrow$  Transducer  $\rightarrow$  develops vibration.



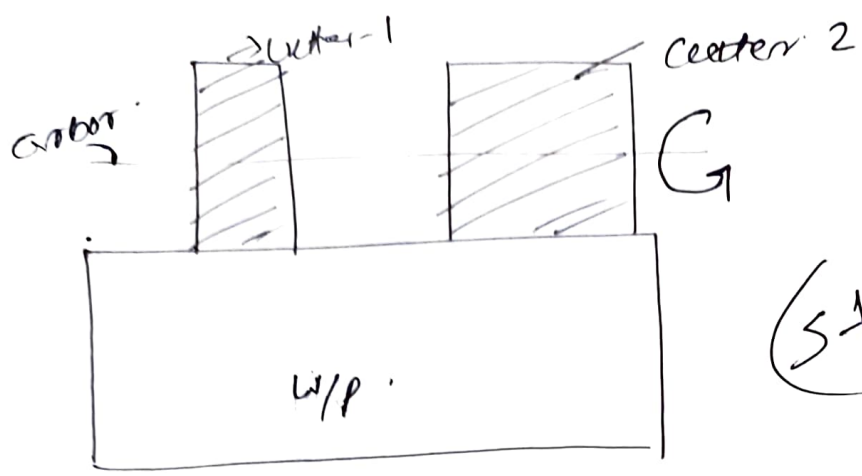
- # magnetostrictive  $\rightarrow$  like Nickel  $\rightarrow$  when placed on strong magnetic field = length  $\uparrow$

(2) Tool holder / Tool Cone (Horn)

It amplifies M<sub>0</sub>E powderes by Transducer.

(3) Abboasive Slurry:

- # to cut metal.
  - # Al<sub>2</sub>O<sub>3</sub>
  - # Boron Carbide (B<sub>4</sub>C)
  - # Silicon carbide SiC
- } → glass or ceramic

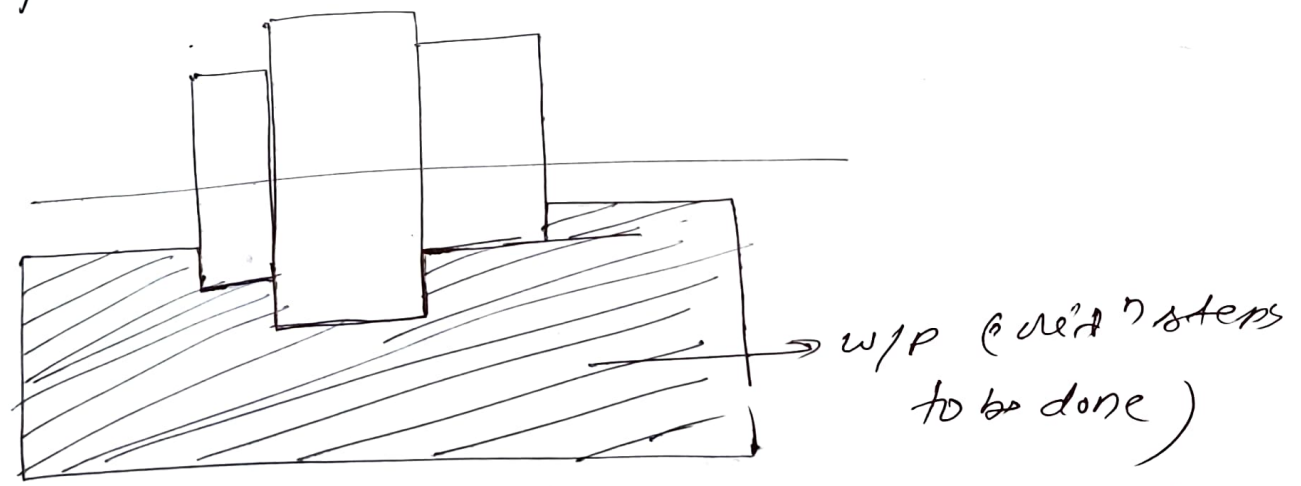


(Straddle milling)  
2 cutter on same arbor

- # Milling is taking place simultaneously by two places.
- # It can also happen by single cutter.  
(T-slot milling) → video U-tube.

5 Gang and Gang.

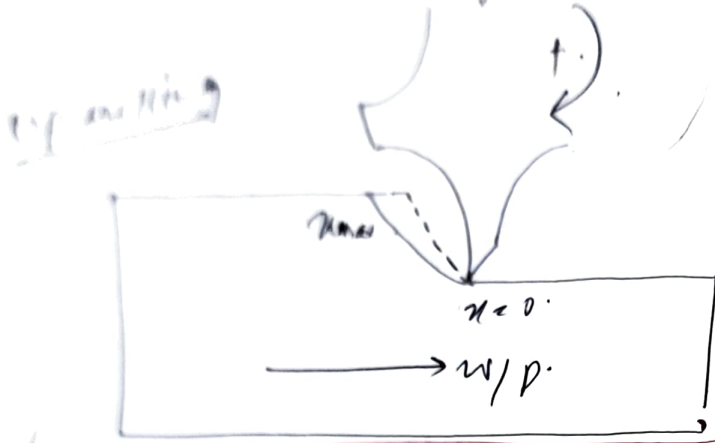
Gang → More than 2-cutter mounted on same arbor.



cutting different steps in work simultaneously.

cut milling

↑ up milling  
↓ down milling



↑ cutter & work → move in opposite dir?

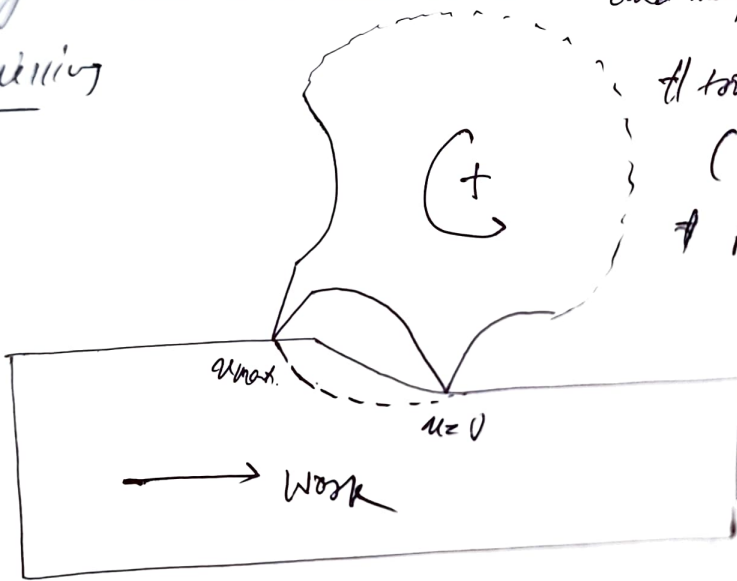
Relative velocity = ↑  
(Due to opposite dir<sup>n</sup>)

↑ chip thickness → min<sup>m</sup> to max<sup>m</sup>

↑ Surface finish ↓  
as tool may hit the w/p and may damage

Accuracy is better on UP Milling.

Down milling



↑ tool life ↓  
(Abrasion wear)

↑  $P = FV$  .  $V ↑ = P ↑$

↑ cutter & work → move in same dir?

↑ relative velocity = ↓

↑ chip thickness → max<sup>m</sup> → min<sup>m</sup>

↑ cutting edge suffers → block at tip.

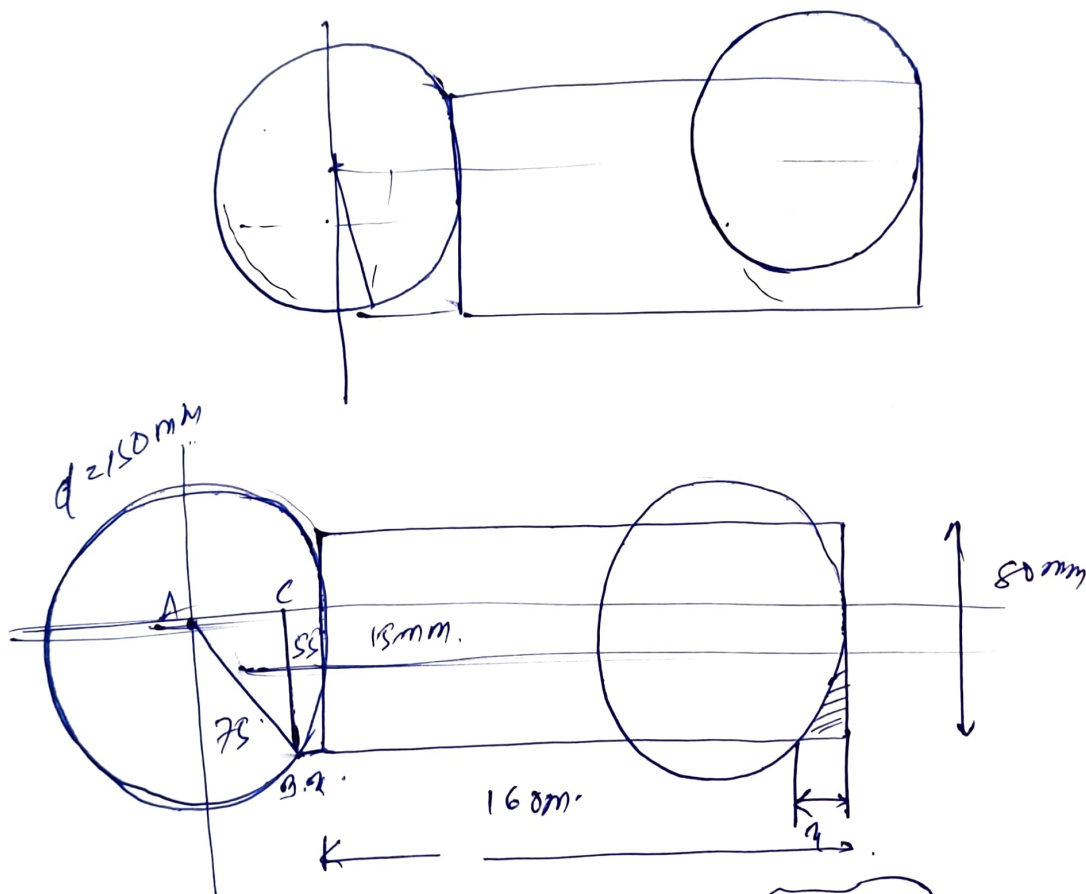
✓ Surface finish is better

↑ Tool life ↑

Note

In up milling the tools which are used to hold w/p are under tension and it doesnot have any effect of backlash, so Accuracy is better.

Q1 Length of cut + upto which feed is activated,



$$AC = \sqrt{75^2 - 55^2} = 51 \text{ mm}$$

$$x = 75 - 51 = \underline{\underline{24 \text{ mm}}}$$

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

$$T_m = 1.73 \text{ min}$$

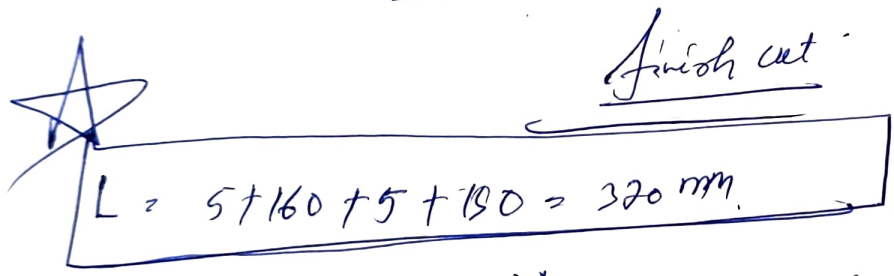
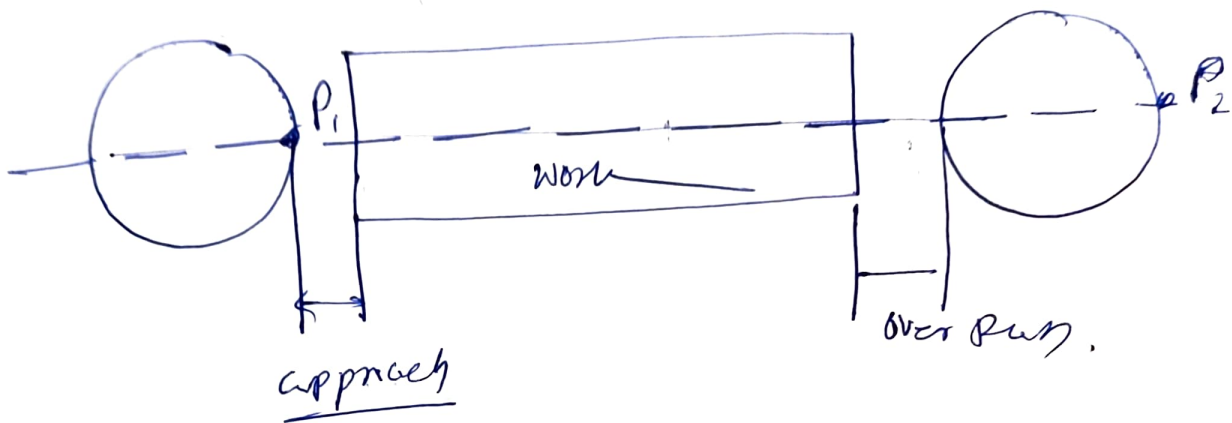
$$\text{Length of cut} = 160 + x = 160 + 24 = 184 \text{ mm}$$

$$f = 2 \text{ mm/rev} = \pi t \times t = 10 \times 0.25 = 2.5 \text{ mm/rev}$$

$$V = \pi DN \Rightarrow 20 \times 10^3 = \pi \times 150 \times N$$

$$N = 42.44 \text{ rpm}$$

28 approach & overrun is given at 83 a  
finish cut



$$T_m = \frac{L}{fN} = \frac{320}{2.5 \times 42.4} = 3.01 \text{ min}$$

P1 to P2 → cutter remove completely from work/c

(2) Symmetry (No offset)

Rough → finish cut  
 (No change in form)

For Rough  $L = 160 + x$

$$Ac = \sqrt{75^2 - 40^2} = 63.44$$

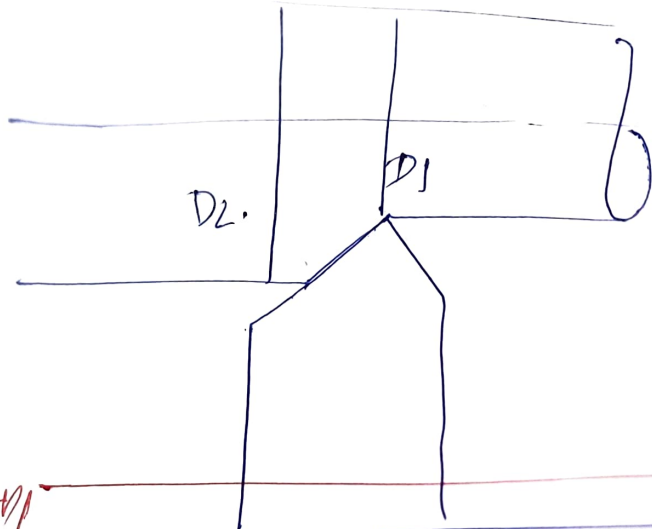
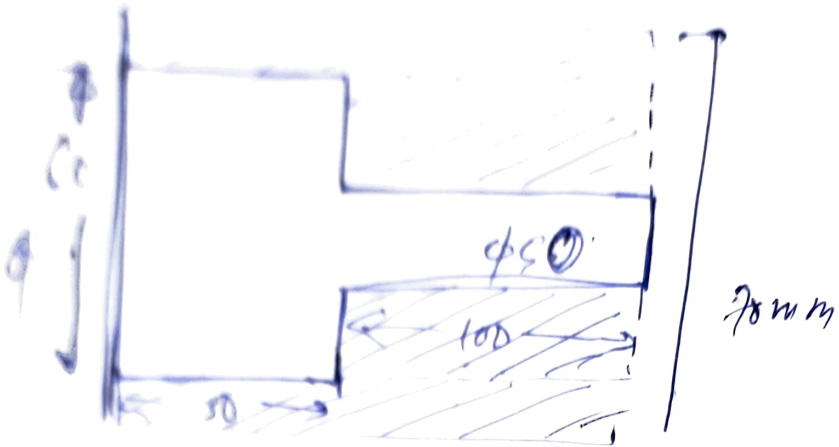
$$x = 75 - Ac = 75 - 63.44 = 11.56$$

$$L = 171.56 \text{ mm}$$

$$T_m = \frac{L}{fN} = \frac{171.56}{2.5 \times 42.4} = 1.61 \text{ min}$$

Ans

Machining Time (Tm)



Given

$$v = \frac{\pi D N}{60} \Rightarrow \phi_{avg} = \frac{D_1 + D_2}{2}$$

$$d = \frac{70 - 60}{2} = 5 \text{ mm}$$

1st cut  $\Rightarrow 70 \rightarrow 60 \text{ mm}$

$$d = 5 \text{ mm}$$

$$f = 1 \text{ mm/rev}$$

$$V = 10 \text{ m/min}$$

Tm = 3.4 min

Time  $\frac{L}{f \cdot V}$   
Length = 70 mm  
V = 10 m/min

1st method

$$60 \text{ mm} \rightarrow 50 \text{ mm}$$

$$d = 5 \text{ mm}$$

$$L = 100 \text{ mm}$$

$$f = 1 \text{ mm/rev}$$

$$V = 10 \text{ m/min}$$

$$D_{avg} = \frac{60 + 50}{2} = 55 \text{ mm}$$

$$T_{m2} = \frac{L}{fN} = \frac{100}{1 \times 57.87} = \underline{\underline{1.72 \text{ min}}}$$

$$T_m (\text{to } 1) = T_{m1} + T_{m2} = 4.78 \text{ min}$$

2nd method

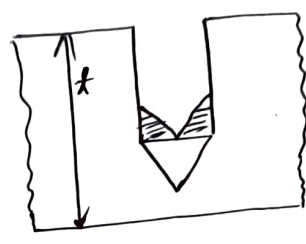
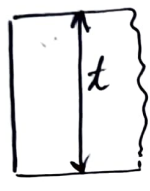
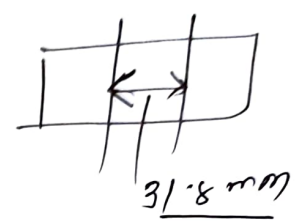
# # Drilling: #

# Drills are always slightly smaller in size b'coz some margin is left for reaming. S<sup>3</sup> B2 HSS

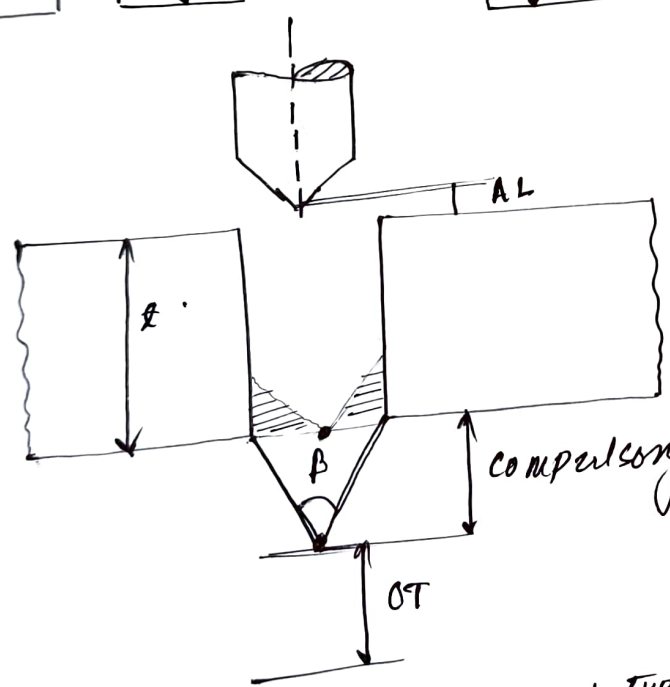
## Drilling

Through hole

Blinded hole.



# Due to backlash some vibration is present hence smaller hole.



# Compulsory Approach is Must for all types of hole.

#  $L$  = length travelled by tool.

$D$  = dia of drill = dia of hole (assume)

$\beta$  = point angle  $\left\{ \begin{array}{l} 115^\circ \rightarrow \text{Double} \\ 135^\circ \rightarrow \text{Single} \end{array} \right.$

$N$  = rpm = rotation of drill

$f$  = feed (mm/rev).

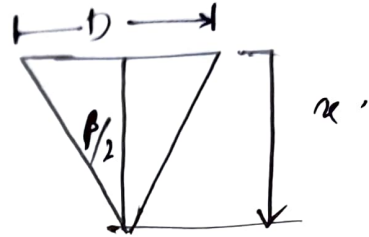
\* Starting from Top Bar)

$$\left[ T_m = \frac{L}{T_v} \right]$$

\*  $L = AL + f + a + OT$

$$\tan(\beta/2) = \frac{D/2}{x}$$

$$x = \frac{D}{2 \tan(\beta/2)}$$



\*  $MRR = A_c \times v$        $\left( \frac{v}{f} = \frac{A_c R}{f} = A_{max} v \right)$

\*  $f \times N = \frac{mm}{rev} \times \frac{rev}{min} = \frac{mm}{min} = \text{Velocity}$

$$\therefore \left[ MRR = \frac{\pi}{4} \times D^2 \times f \times N \right]$$

Q1 Given

$D = 15 \text{ mm}$

$f = 50 \text{ mm}$

$N = 500 \text{ rpm}$

$f = 0.2 \text{ mm/rev}$

$\beta = 118^\circ$

$AL = OT = 2 \text{ mm}$

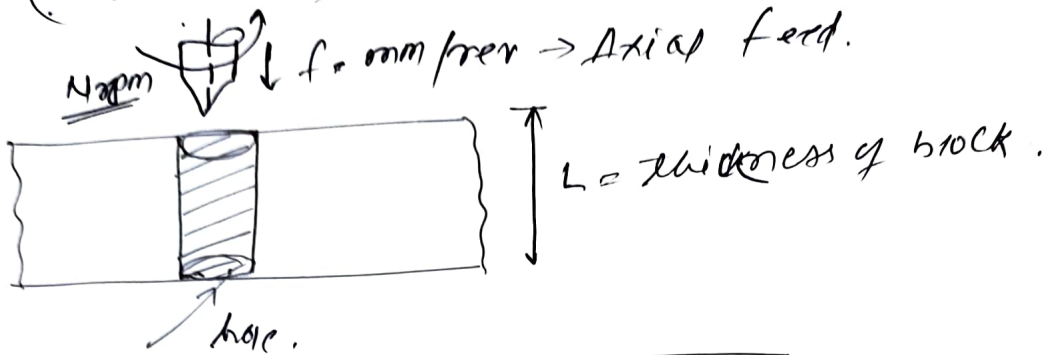
Find  $T_m$  ?

$$\left[ \text{Ans} \rightarrow 35.16 \text{ sec} \right]$$

# # DRILLING #

①

Case-1 (Circular hole)



$$\text{Time for 1 drill } T_m = \frac{L}{fN} \text{ min}$$

# no approach and no overtravel.

Case-2 (Approach & overtravel consider)

$$T_m = \frac{L + AL + OL}{fN}$$

$$T_m = \frac{L + AL + OL + C}{fN}$$

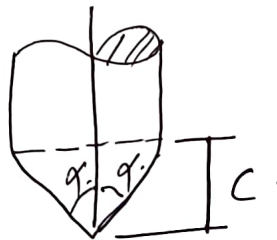
#  $C =$  tool tip distance

$\alpha =$  drill point angle.

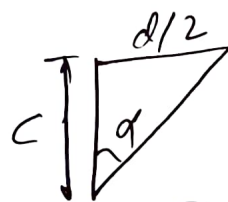
$$\tan \alpha = \frac{d/2}{C}$$

$$C = \frac{d}{2} \times \frac{1}{\tan \alpha}$$

$$C = \frac{d}{2 \tan \alpha}$$



$$\tan \alpha = \frac{d}{2C}$$



NOTE take  $C$  if  $\alpha$  is given

Case 3 (MRR)

$$\boxed{MRR = \frac{\pi d^2 f N}{4}}$$

$\frac{\pi d^2}{4}$  = Area of hole =  $\text{mm}^2$ .

$f$  = Axial feed =  $\text{mm/rev}$ .

$N$  = rpm

$$\boxed{MRR = \text{mm}^2 \times \frac{\text{mm}}{\text{rev}} \times \frac{\text{rev}}{\text{min}} = \frac{\text{mm}^3}{\text{min}}}$$

Case 4 Specific Energy (Same for Drilling, Shaping, milling etc.)

$U$  = Energy reqd to ~~cut~~ <sup>cut</sup> or remove (Unit Volume)

$$= \frac{J}{\text{mm}^3} = \frac{J}{\text{mm}^3} = \frac{\text{kJ}}{\text{mm}^3}$$

$$\# \boxed{U = \frac{\text{power}}{MRR}} = \frac{J/s}{\text{mm}^3/\text{se}} = \frac{J}{\text{mm}^3}$$

$$\# \boxed{\text{Power} = U \cdot MRR}$$

Case 5 (No. of revolutions)

Let total no. of units =  $Q$  to be produced

Carry No. of Requirds!

let total no. of units to be produced = Q.

<sup>ex</sup> let Tm = time for 1 hole = 5 min.

Tool life = 100 min.

$\eta = \text{no. of holes in 1 life} = \frac{100}{5} = 20 \text{ hole} = \eta$

$\eta = \frac{T}{T_m}$  → Tool life  
→ time for 1 hole,

for total 60 holes = ? → Q = 60

No. of Requird = 3.

R.G → 20 R.G 20 R.G 20.  
(After purchase from Market).

No. of Requirds =  $\frac{\text{total production}}{\text{no. of holes in 1 line}} = \frac{Q}{\eta}$ .

Ans =  $\frac{60}{20} = 3$ .

Given

$f = 40 \text{ mm}$

$N_1 = 400 \text{ rpm}$

$f = 0.1 \text{ mm/rev.}$

$AL + OT \text{ together} = 10 \text{ mm}$

$D = 20 \text{ mm}$

$T_m = ?$  (1.25 min) Ans.

	(I)	(II)
	Work	RPM
test (1)	300	150
test (2)	200	300
test (3)	?	200

Ans  $\therefore 4 \text{ holes} = \frac{\text{Total Life}}{4}$

By Taylor's tool life  $VT^n = \text{const.}$

$$150 \times 300^n = 300 \times 200^n \quad \text{(I)}$$

$$200 \times 150^n = 200 \times 150^n \quad \text{(II)}$$

$$200 \times 150^n = 200 \times 150^n \quad \text{(III)}$$

Equating (I) and (II)

$150 \times 300^n = 300 \times 200^n$

$\left(\frac{3}{2}\right)^n = 2$

$n = \frac{\log 2}{\log (3/2)} = 1.21$

Quantity (2) and (1)

$$200 = 200^0 + 200^0 T_3^0$$

$$\left(\frac{20}{200}\right)^0 = 1.5$$

$$T_3 = 253.52 \rightarrow \text{no. of holes}$$

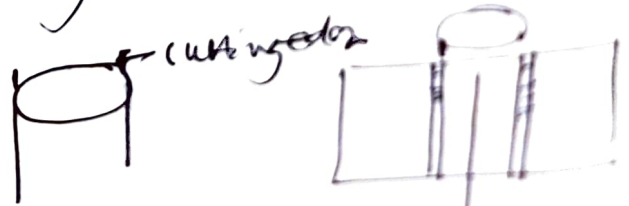
### Note

# Large dia ex  $\phi$  100 drill is not available b'coz it is expensive, more powerful m/c req'd here after drill boring operation is done.

### Trepanning

To produce large hole

ex  $\rightarrow$  for AC fitting hole made on steel



Material removed  
Chip formation

#

## Drill

### Through hole

$$\phi = 10 \text{ mm}$$

$$L = 20 \text{ mm}$$

$$N = 300 \text{ rpm}$$

$$f = 0.2 \text{ mm/rev}$$

$$\alpha = 120^\circ \rightarrow \text{point angle}$$

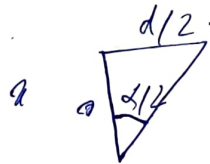
$$OT = 2 \text{ mm}$$

Time for producing a hole = ?

$$T_m = \frac{AL + L + OT + \kappa}{f \cdot N}$$

$$= \frac{0 + 20 + 2 + 2.89}{0.2 \times 300}$$

$$T_m = 24.9 \text{ sec}$$



$$\tan \frac{\alpha}{2} = \frac{\kappa}{d/2}$$

$$\kappa = \frac{d}{2 \tan \frac{\alpha}{2}}$$

$$\kappa = 2.89 \text{ mm}$$

### Q2 Single pass drill operation (through hole)

$$d = 15 \text{ mm}$$

$$L = 50 \text{ mm}$$

$$N = 500 \text{ rpm}$$

$$f = 0.2 \text{ mm/rev}$$

$$\alpha = 118^\circ$$

$$AL + OT = 4 \text{ mm}$$

$$\kappa = \frac{d}{2 \tan(\alpha/2)}$$

$$= \frac{15}{2 \tan 59^\circ}$$

$$= 4.506$$

$$T_m = \frac{L + AL + OT + \kappa}{f \cdot N} = \frac{50 + 4 + 4.506}{0.2 \times 500} \times 60$$

$$T_m = 35.1 \text{ sec}$$

Q3

$d = 20 \text{ mm.}$

$l = 40 \text{ mm.}$

$N = 400 \text{ rpm.}$

$f = 0.1 \text{ mm/rev.}$

$AL + OT = \delta \text{ of drill}$

$AL + OT = 10 \text{ mm.}$

$T_m = \frac{L + AL + OT + K}{f \cdot N} = \frac{40 + 10}{0.1 \times 400} = 1.25 \text{ min}$

Q4 Taylor's Tool Life! (already in copy)  
 $t = 20 \text{ mm.}$

Q5 Through hole.

$l = 15 \text{ mm.}$

$d = 10 \text{ mm}$

$f = 0.25 \text{ mm/rev.}$

$N = 1200 \text{ rpm.}$

MRR = Discharge.

$= \frac{\text{Volume}}{\text{time}} = \frac{A \times L}{t}$   
 $= \text{Area} \times \text{velocity}$   
 $= \frac{\pi}{4} d^2 \times f \cdot N$

$U = \frac{MRR}{\text{Volume}} = \frac{0.7 \text{ mm}}{\text{mm}^3}$

$U = 0.7 \text{ mm/mm}^3$

$\text{Volume} = \frac{\pi}{4} \times d^2 \times L = \frac{\pi}{4} \times 10^2 \times 15$

$MRR = \frac{\pi}{4} d^2 \times f \times N$

$U = \frac{\text{power}}{MRR} = \frac{P/S}{\text{mm}^3/S} = P/\text{mm}^3$

$P = U \cdot MRR$

$= 0.7 \times \frac{\pi}{4} \times 100 \times 0.25 \times 1200$

$= 274.5 \text{ W}$

$\int \text{mm}^3$

$U \times MRR$   
 $\frac{J}{\text{mm}^3} \times \frac{\text{mm}^3}{S}$   
 $= \text{Watt}$

Find  $\tau$

$d = 10 \text{ mm}$ ,  $f = 0.2 \text{ mm/rev}$ ,  $N = 600 \text{ rpm}$ ,  $f = 0.2 \text{ mm/rev}$ .

$\alpha = 10^\circ$

$$\tau = \frac{2901 + 0.19}{f N} = \frac{50 + 0 + 0.88}{0.2 \times 600}$$

$$\tau = \frac{d}{2 \tan \alpha / 2} = \frac{10}{2 \times \tan 60^\circ} = 2.88$$

$T = 0.44 \text{ min}$

here drill wears out after 900 holes.

Given  $VT^{0.3} = C$ .

$V = \text{m/min}$ ,  $T = \text{total life} = \text{min}$ .

(find value of C)

$T = 900 \text{ holes}$

for hole  $T_M = 0.44 \text{ min}$ .

so  $T = 900 \times 0.44 = 396 \text{ min}$ .

$$V = \frac{\pi D N}{1000} = \frac{\pi \times 10 \times 600}{1000} = 18.8 \text{ m/min}$$

$$= \frac{\text{mm} \times \frac{\text{rev}}{\text{min}} \times \frac{1}{1000}}{\text{min}} = \frac{\text{m}}{\text{min}}$$

$\tau = 2.88$

so  $VT^{0.3} = C$ .

$$C = 18.8 \times (396)^{0.3}$$

$C = 72.02$

Q7 ex  $T_m = \text{m/cutting time for 1 hole} = 5 \text{ min.}$

$T = 100 \text{ min (total life)}$

So  $\eta = \text{no. of holes in one life.}$

$$\eta = \frac{T}{T_m} = \frac{100}{5} = 20.$$

¢

$$\text{No. of Regrinds} = \frac{\text{Total production}}{\text{no. of holes in life}} = \frac{Q}{\eta}.$$

NOTE ††

When we purchase a tool from market, it should be 1st Regrind, then use.

Q8  $d = 23 \text{ mm, } L = 100 \text{ mm.}$  (Ph of cylinder and length)

It turned with a ~~cut~~ tool. for which.

$$VT^{0.25} = 55.$$

$V = 22 \text{ m/min, } f = 0.046 \text{ mm/rev.}$  What is the no.

of tool regrinds required to produce 425 cylinders.

Sol<sup>n</sup>  $VT^{0.25} = 55.$

$$T = \left( \frac{55}{22} \right)^{\frac{1}{0.25}} = 39.06 \text{ min.}$$

$$\text{No. of Regrinds} = \frac{Q}{\eta} = \frac{425}{T/T_m} = \frac{425}{39.06 / 5}$$

$$T_m = \frac{L}{fN} = \frac{100}{0.046 \times 280}$$

$$T_m = 7.76 \text{ min}$$

$$\eta = \frac{T}{T_m} = \frac{39.06}{7.76} = 5.03$$

$$\text{No. of Reqs.} = \frac{D}{h} = \frac{425}{5.03} = 84.4 \approx \underline{\underline{85}} \text{ Rev}$$

3

$$V = \frac{\pi DN}{1000}$$

$$22 \text{ m/min} = \frac{\pi \times 25 \text{ mm} \times \frac{\text{rev}}{\text{min}}}{1000}$$

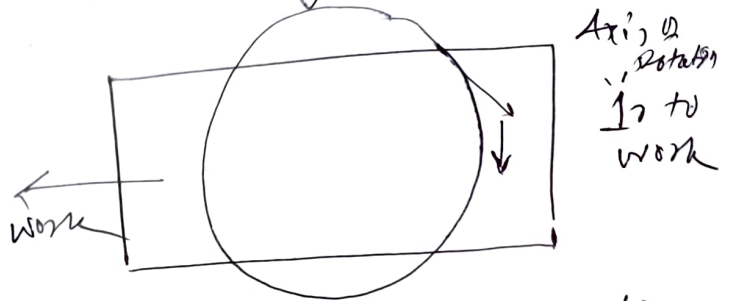
$$N = \frac{22 \times 1000}{\pi \times 25} = 280.1 \text{ rev/min.}$$

1.6. ... milling

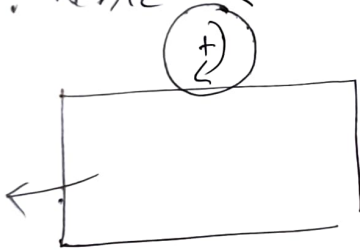
1 = circumferential rake

2 = Radial rake angle

\* During (face) milling chip flows along circumferential



\* During slab milling chip moves from circumference to centre. hence radial rake is effective rake.

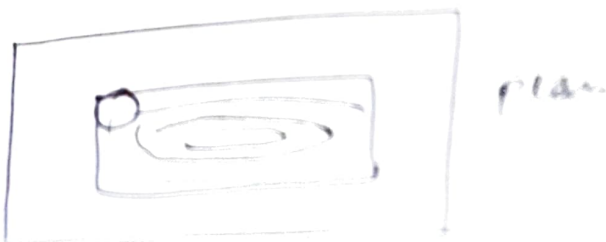
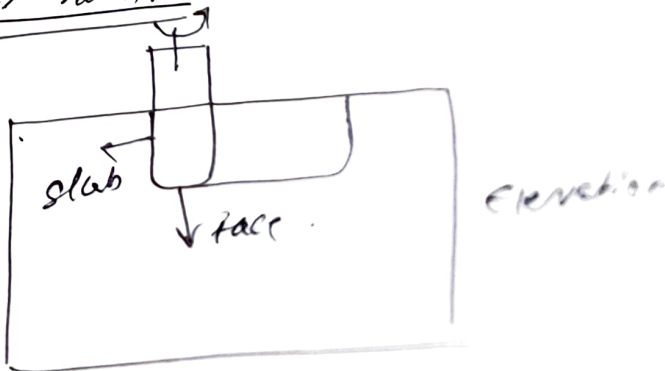


3) End milling operation.

partly material remove like a face & partly by

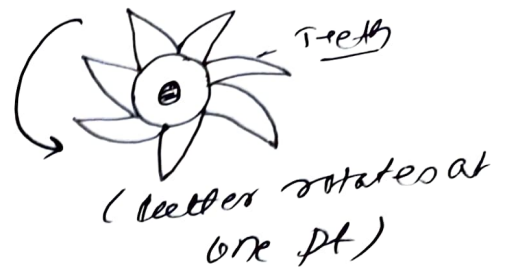
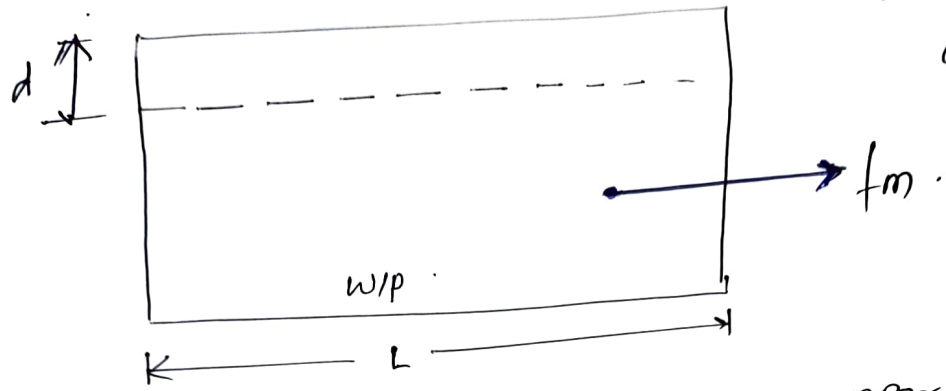
slab.

oil ramp



# Plane Milling: machine.

①



$w$  = width of w/p  $\perp$  to plane of paper.

$L$  = length of w/p

$d$  = depth of cut.

$D$  = dia of cutter.

$Z$  = no. of teeth.

$N$  = speed of cutter (rpm)

1)  $f_m$  = table feed (mm/min.)

2)  $f$  = table feed (mm/rev)

$$\frac{mm}{min} \times \frac{rev}{min}$$

$$f = \frac{f_m}{N}$$

# chip thickness is not uniform (0 to max<sup>m</sup>)

# ~~max~~  $f_t$  = feed/tooth  $\rightarrow$  (mm/tooth)

$$f_t = \frac{f_m}{NZ}$$

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\* Time taken for a single pass in milling

$$T_m = \frac{L}{f_m} \quad \left. \begin{array}{l} \text{min} \\ \text{min/min} \end{array} \right\} \text{for single pass}$$

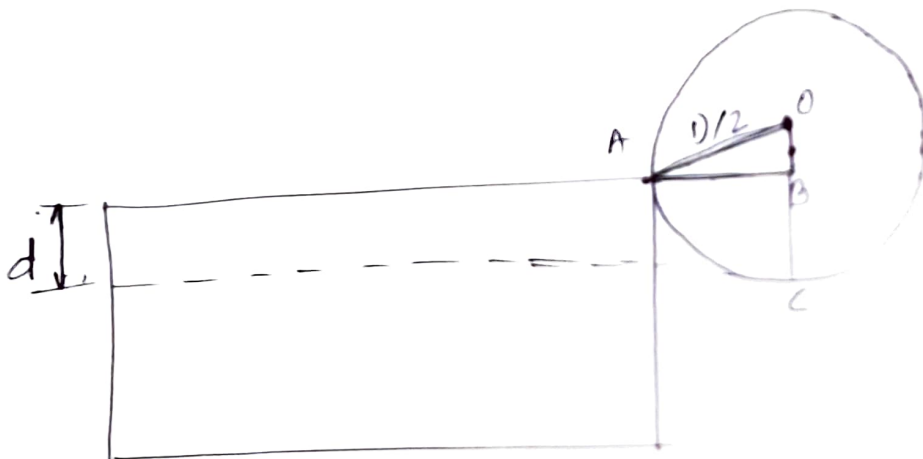
(including approach and overtravel.)

Let  $L$  = length of Approach.

$OL$  = length of Over-travel.

$$T_m = \frac{L + AL + OL}{f_m} \quad \text{in min}$$

Let Approach length.



$AB$  = length of approach.

$$\text{In } \triangle AOB, \quad AB = \sqrt{d^2 - c^2}$$

# Machining time per pass or milling time

$$\boxed{T_m = \frac{L}{f_m}} = \frac{\text{mm}}{\text{mm/min}} = \text{min.} \quad \left. \vphantom{\frac{L}{f_m}} \right\} \text{for single pass}$$

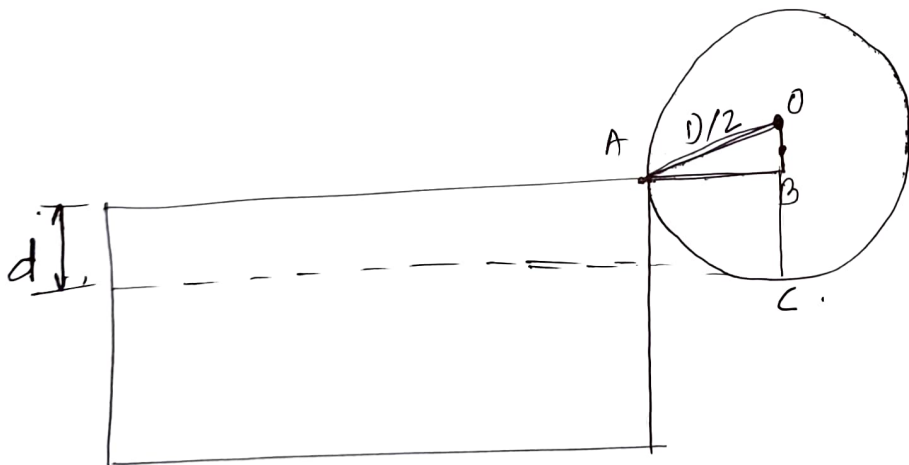
(Here ignoring approach and overtravel.)

Let AL = length of Approach.

OL = length of Over-travel.

$$\boxed{T_m = \frac{L + AL + OL}{f_m}} \rightarrow \text{in } \underline{\text{min}}$$

For Approach length:



AB = length of approach.

$$\begin{aligned} \text{In } \triangle AOB, \quad AB &= \sqrt{AO^2 - OB^2} \\ &= \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d\right)^2} \\ &= \sqrt{\frac{D^4}{4} - \left(\frac{D^2}{4} + d^2 - 2 \cdot \frac{D}{2} \cdot d\right)} \\ &= \sqrt{\frac{D^4}{4} - \frac{D^2}{4} - d^2 + Dd} \end{aligned}$$

$$AB = \sqrt{Dd - d^2}$$

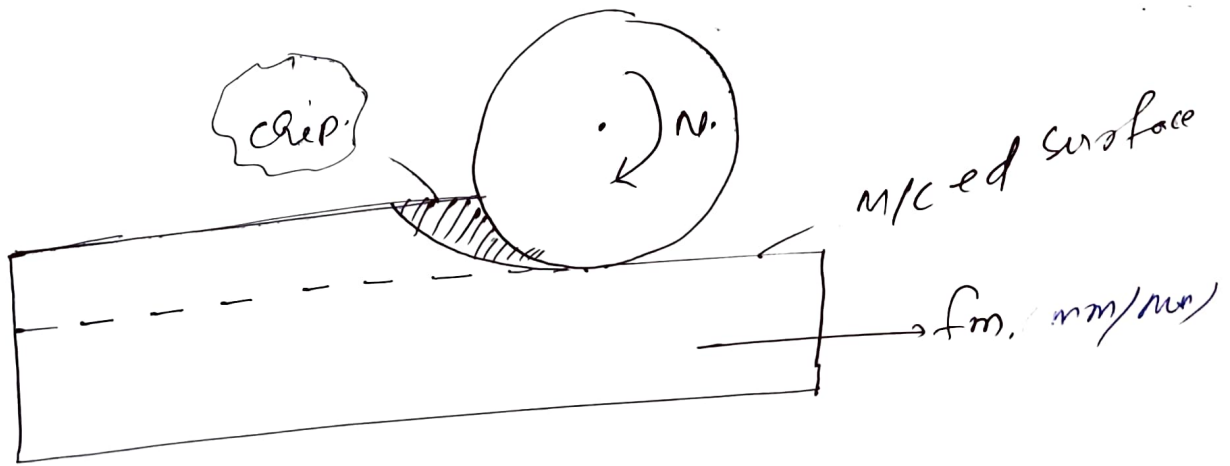
$$AB = \sqrt{d(D-d)} \rightarrow \text{length of approach.}$$

if length of approach & length of overtravel is not given separately then assume  $AL = OL$

So  $T_m = \frac{L + AL + OL}{f_m}$  (let  $AL = OL = A$ )

$$T_m = \frac{L + 2A}{f_m} \text{ min}$$

Case-2



$t_1$  = chip thickness

$D$  = dia of cutter  
 $d$  = depth of cut

$$(t_1)_{min} = 0$$
$$(t_1)_{max} = \frac{2f_m}{V_c} \sqrt{\frac{d}{D}}$$

$$(t_1)_{avg} = \frac{(t_1)_{min} + (t_1)_{max}}{2}$$

$$\boxed{S_0 (\phi_1) \text{ arg} = \frac{f_m}{N Z} \sqrt{\frac{d}{D}}}$$

ans) (MRR).

$$\boxed{MRR = f_m \times d \times W} = \underline{\underline{\text{mm}^3/\text{min}}}$$

$$f_m = \text{mm}/\text{min}$$

$d$  = depth of cut  $\rightarrow$  mm.

$W$  = width of w/p  $\Rightarrow$  mm.

~~1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 14, 15, 17, 18,~~

1, 2, 3, 4, 5, 7, 8, 9, 11, 14, 15, 16, 17, 18, 13

$$\boxed{X_{\text{max}} = 2 f_t \sqrt{\frac{d}{D} \left(1 - \frac{d}{D}\right)}$$

$f_t = \text{feed}/\text{tooth}$   
mm/rev  $\rightarrow$  mm/tooth

$$\boxed{X_{\text{min}} = \frac{0 + 2 X_{\text{max}}}{2} = f_t \sqrt{\frac{d}{D} \left(1 - \frac{d}{D}\right)}$$

$X_{\text{max}}$  = max<sup>m</sup> chip thickness

$X_{\text{min}}$  = min<sup>m</sup> " "

$d < D$   
condition

# Grinding

①

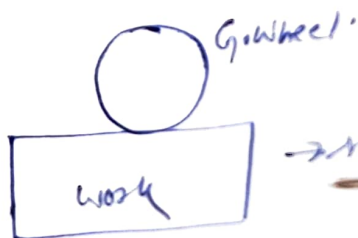
- # There are abrasive that are embedded into some bonding agent
- # It is a multipoint cutting tool b'coz simultaneously many abrasive involved in machining.

# If bonding agent is clay then grinding wheel is made by Castling.



# If bonding agent is metal then it is made by powder metallurgy.

- # Grinding → (1) creep feed grinding.  
(2) high speed grinding.



- # Grinding → 2 feeds → (1) done along the surface  
(2) through and through

## # Creep feed grinding.

(1) Infeed  $\uparrow$  and speed (rpm)  $\downarrow$   
of grinding wheel

# objective  $\rightarrow$  bulk material removal.

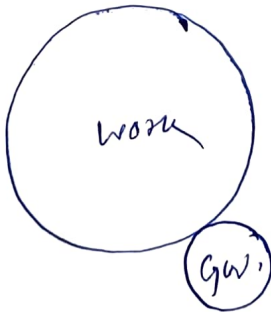
## #1 High speed grinding.

(1) Infeed  $\downarrow$  rpm  $\uparrow$

Infeed  $\rightarrow$  similar to depth of cut of milling

(2) It is used for finishing operation

## # Cylindrical Grinding.



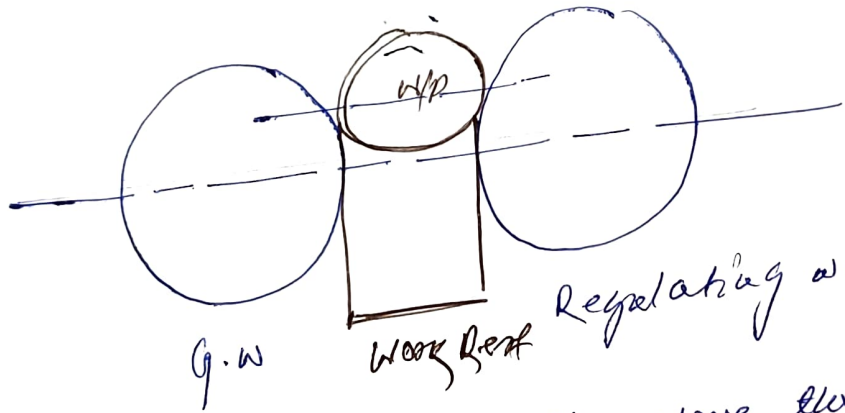
$\Rightarrow$  It remove outer <sup>surface</sup> material is known as External cylindrical grinding.



$\rightarrow$  internal cylindrical grinding

centerless Grinding. v. f. n. p.

- \* During m/ing time workpiece centre is not fixed hence C.G.
- \* Used on large size pipe, small ball, Rods, fragile w/p (of hard & well break)



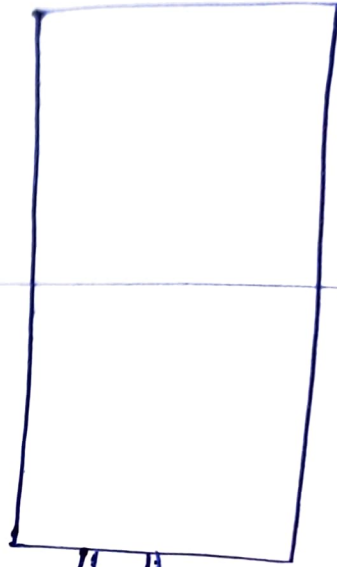
gmp  
 ✓ work centre is slightly above the common axis  
 G.W & R.W,

\* G.W & R.W axes are not || to each other from end  
view.

\* for Automatic through feed regulating wheel's axis are slightly inclined to G.W axis,

\* Hence normal force is developed on R.W axis which further divided into 2 components → one along the G.W and other perpendicular to G.W. which provide through feed & Infeed.

# Mechanism of Grinding



# Gap b/w two abrasive is known as structure.

# open structure → gap is more

# closed " → closed structure  
gap is less

# for mixing ductile material → open structure is used

# for brittle " → closed " "

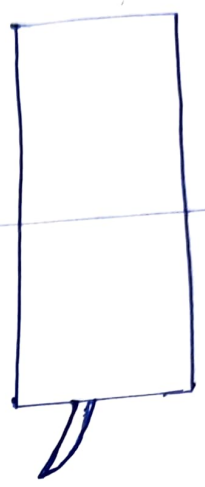
# as ductile material produce continuous chip, hence they may enter into the gap.

# Loading of Grinding wheel → all the abrasive grains welded together and it rub on the work with it ductile material is m/c by closed structure

or

Clogging

- # Initially the abrasive is sharp.
- # After certain stages abrasive blunt & contact Area Increase b/w abrasive & w/p



Self sharpening characteristics of G.W. (S.S.C)

If bonding agent is weak then (S.S.C) is predominate.  
 i.e. in one drag abrasive will automatically leave the grinding wheel & the next abrasive will be in cutting action called S.S.C.

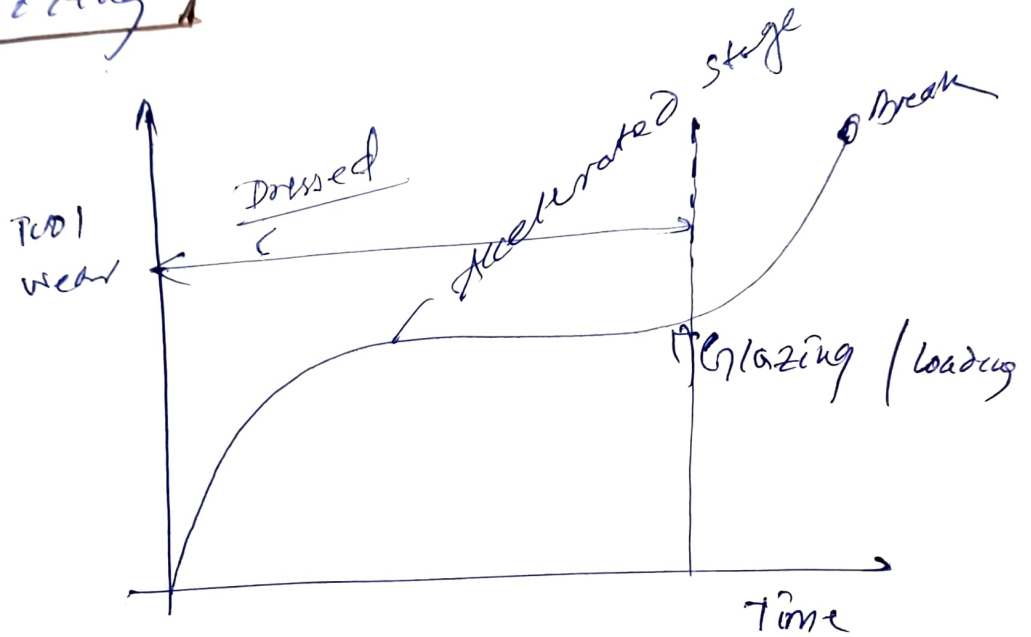
# S.S.C. is predominant is called soft wheel.

# If bonding agent is strong  $\Rightarrow$  hard wheel.

# for machining soft material  $\rightarrow$  hard wheel is used.  
 for " hard "  $\rightarrow$  soft wheel is used.  
 (w/p)

So S.S.C is desirable for hard material.  
 each time we need sharp edges.

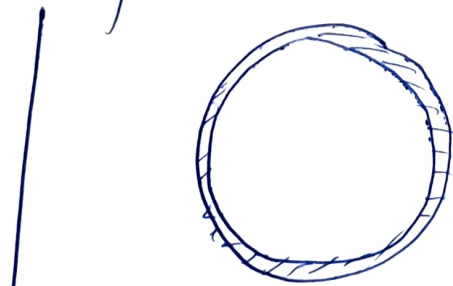
Glazing If hard wheels are used for hard W/P then self sharpening characteristics do not appear. Hence grinding wheel rubs against W/P which is called Glazing.



# Initially sharp cutting edges are surrendering off hence tool wear is more.

# Before the accelerated stage comes wheels are withdrawn from the workshop and DRESSED.

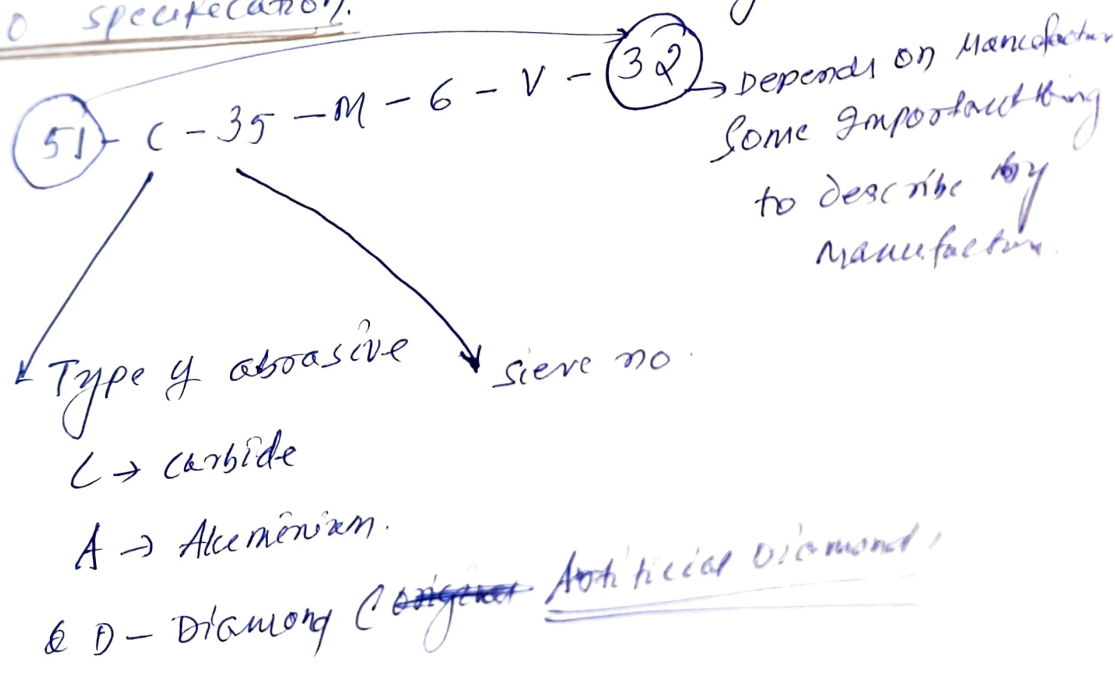
# Dressing is done by diamond tool



→ Remove some material from surface.

A grinding wheel is a metal form surface upon loose  
 the cylindrical hard ~~abrasive~~ abrasive ceramic which  
 is in glass nature  
 to make it again "cylindrical" we do **Wheel Truing**  
 done by USM. (vitrified bond - clay)

ISO specification.



35 sieve no → no of opening / sq inch  
 if sieve no. is more → abrasive hard  
 if is less → coarse abrasive  
 (hardness)

(M - hardened wheel  
 A-H → soft wheel J-P → belt wheel  
 Q → test wheel)

X-axis = mean ...  
 Y-axis = ...

$$\text{So } \frac{1}{(21) \text{ area}} = \text{fm} \cdot \sqrt{\quad}$$

6  $\rightarrow$  structure  $\rightarrow$  varies from 0 - 16

0  $\rightarrow$  close structure

16  $\rightarrow$  open structure.

7  $\rightarrow$  Type of bond.

V  $\rightarrow$  vitreous

~~S  $\rightarrow$  p~~

S  $\rightarrow$  silicate

B  $\rightarrow$  Resonant

M - Metal