25/6/2016

chapter 1 or Unit 1

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Production Engineering
(S.K. Mondal)

Theory of Metal Cutting

Manufacturing is a process of converting raw material into finished product.

Classification of manufacturing process.

- Shaping or forming. (Zero Process) → no mass change
- joining process. (positive process) → mass added
- Removal process. (Negative process).
- Regenerative manufacturing.

Q.) What is Rapid Prototyping? &

Q.) What is Regenerative Manufacturing?

Interview only

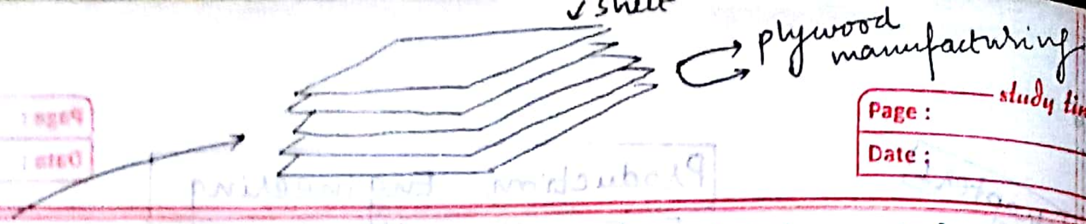
REG. MAN.

Production of solid products in layer by layer from raw materials in different forms.

→ Liquid – e.g., Stereo Lithography

→ powder – e.g., selective sintering → powder metallurgy term

power heat से पिघला होता है photocopy m/c

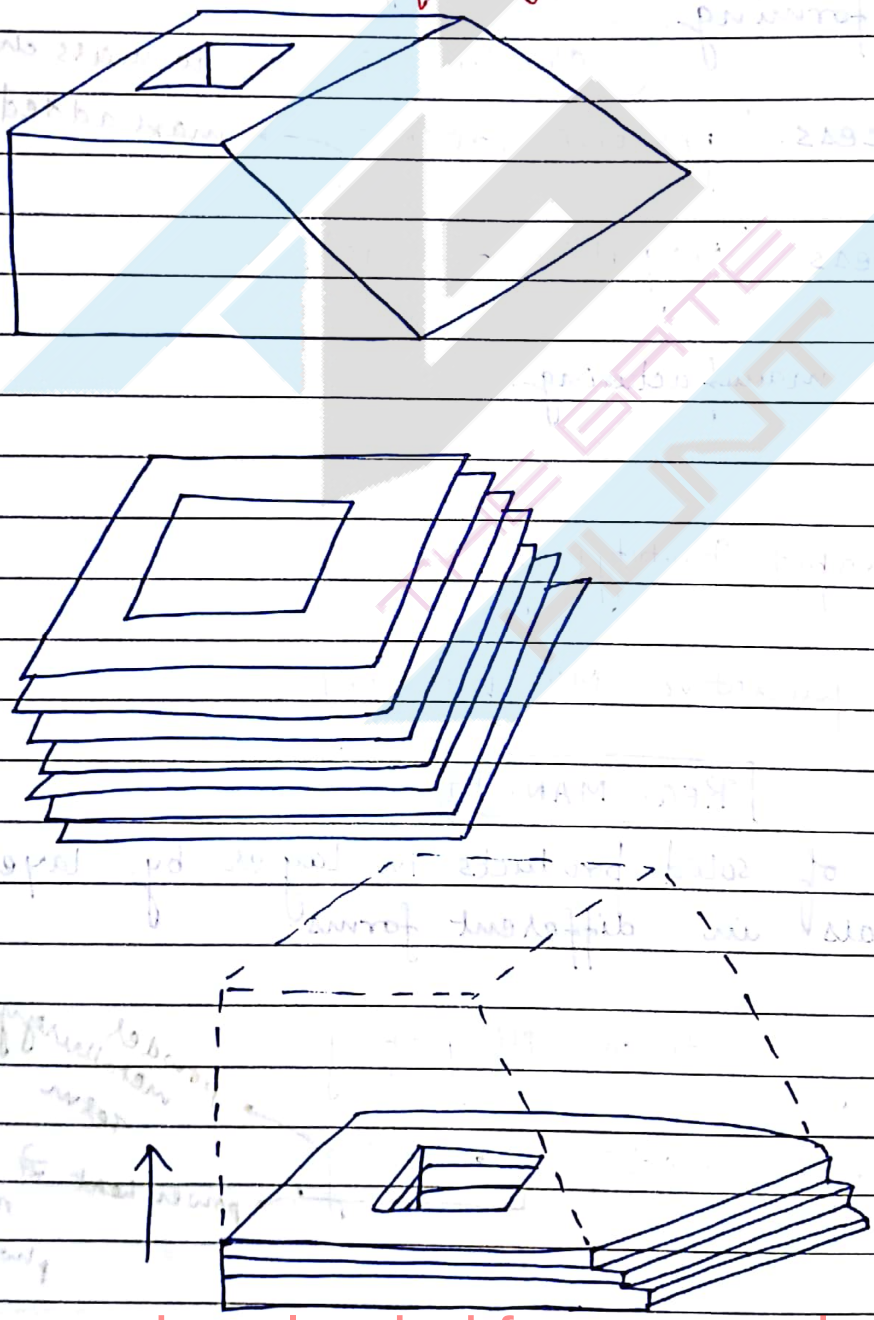


→ Sheet - e.g., LOM (laminated object manufacturing)

→ wire - e.g., FDM. (Fused Deposition Modeling)

✓✓ very rapid, accurate and used for Rapid prototyping and tooling

✓ Basic Principle of Regenerative Manufacturing



video Faisa

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Advantages :-

1.> Process in independent of Part feature.

single m/c

workpiece

2.> No Blanks are Requires.

usi ka preformed shape

circular dia → Take circular

Bar. → Take Bar

3.> Toolless Process.

4.> Easily Automation ~~Process~~ Possible.

Machining.

Preformed Blank → Desired dimensions + surface finish

cutting tool

formation of chips.

Machining aim to :-

a.> fulfill its requirement (functional).

b.> Improve its performance. ← honning

abrasive stick

cylinder.

c.> Prolong its service Life (Regrind)

Drawback in Machining :-

a.> Loss of material in the form of chips.

b.> Low Productivity (slow Process).

machine Tool

cutter + power operated

study time

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✓ Why even a Battery operated pencil sharpener cannot be accepted as a machine tool?

Ans. Inspite of having all other major features of machine tools, the sharpener is of low value.

low Value

OPQ → low value

lathe m/c → high value

milling m/c → high value

✓ IAS 2009 main

✓✓ Name four independent variables and three dependent variables in metal cutting. —— (5 marks)

$$\overset{\text{depend}}{y} = f(\overset{\text{indep.}}{x})$$

But Reverse → Possible

↓

Since Mathematical Relation.

Ⓡ → But Practically y can't be change. after Modelling Mathematical.

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Independent Variables

- Starting Materials
  (tool/work)
  Aluminium → force
  if iron → force ↑

  But force ↑ ↛ Aluminium

- Tool Geometry

- Cutting Velocity

- Lubrication

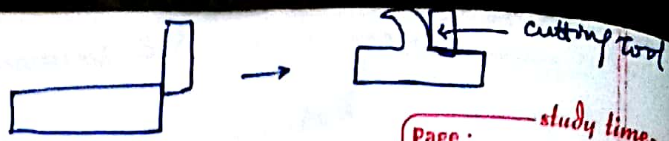
- Feed and Depth of cut

Dependent Variables

- Force/power requirements

- maximum ~~geometry~~ tempr. is .

25/8/2016



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ORTHOGONAL MACHINING

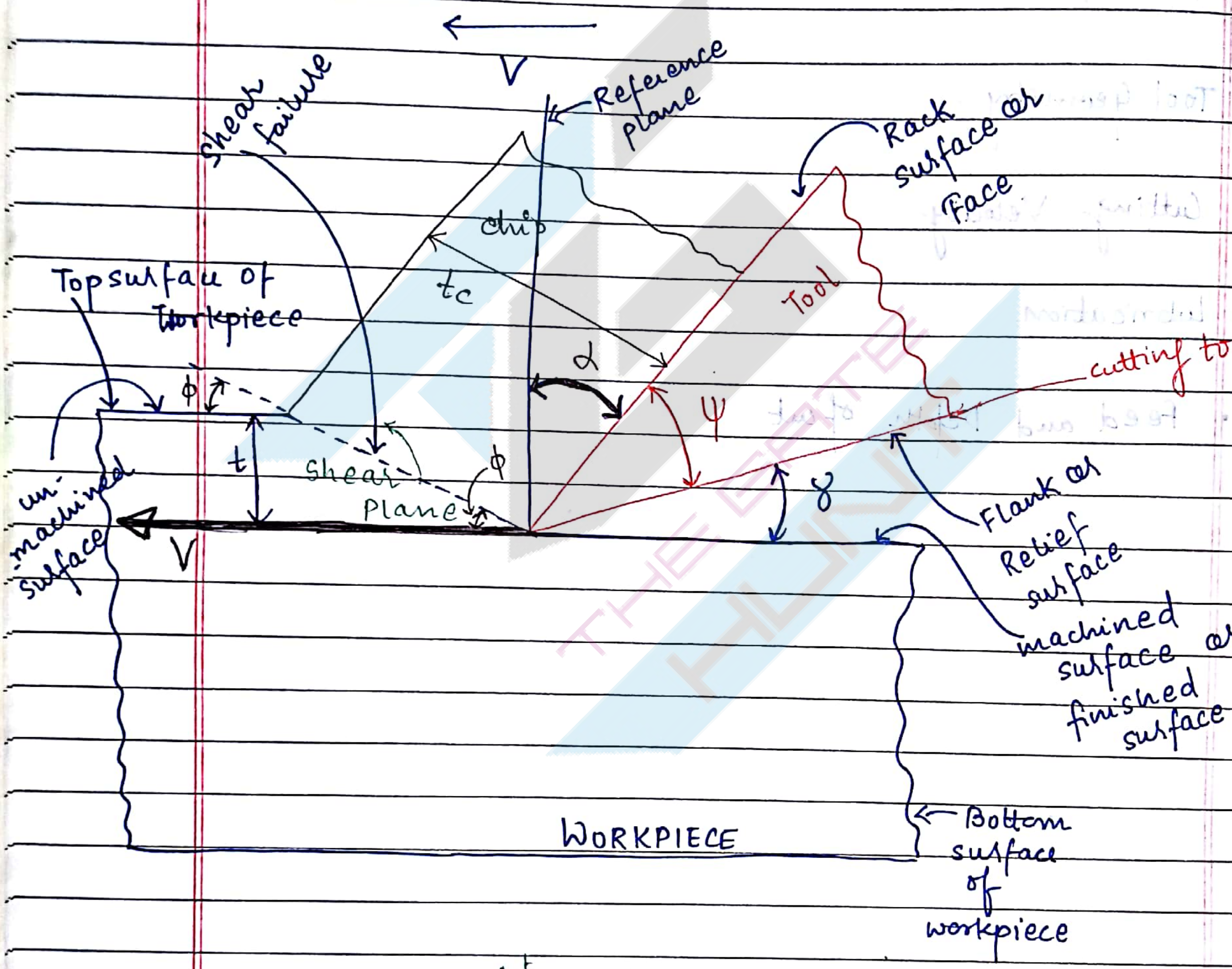
✓ Cutting edge and cutting velocity 90°.

vector

✓ others than OM, then Oblique → 89°

→ 170

→ 70°



after shear failure → chip formation

Reference plane ⊥ machined surface.

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$\alpha \rightarrow$ Rack angle (in some books $\rightarrow \alpha$)

$\gamma \rightarrow$ clearance angle (in american language system → Relief angle).

$\phi \rightarrow$ shear angle → orthogonal metal cutting का ∠.

$\psi \rightarrow$ lip angle or wedge angle or Knife angle or cutting angle.

Tool ka angle

After the cut, the $t_c \rightarrow$ chip thickness.
$t \rightarrow$ uncut chip thickness.
or undeformed chip thickness.

$\boxed{t_c > t} \rightarrow$ due to plastic deformation (shear failure)

major reason

t_c will be 2 to 3 times of t

✓ Due to temperature increase of the chip t_c will increase marginally (few microns)

thermal expansion

chinese answer

A A A A A

$\Rightarrow$ $\boxed{t = d}$ (Depth of cut)

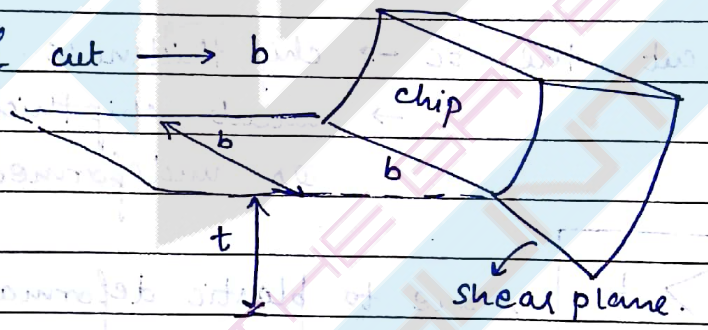
orthogonal machining

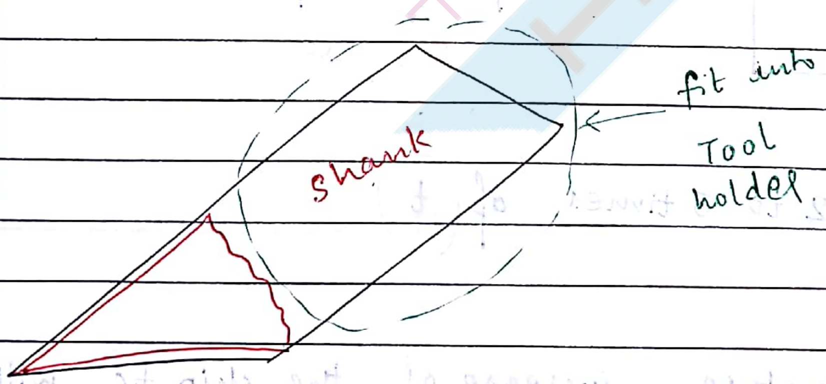
But, this $\boxed{t = f\sin\lambda}$ (Turning)

feed

Principal cutting edge angle

✓ width of cut → b





* RAKE SURFACE OR FACE

The surface along which the chip moves upward is called rake surface of Tool.

* Flank / Relief surface

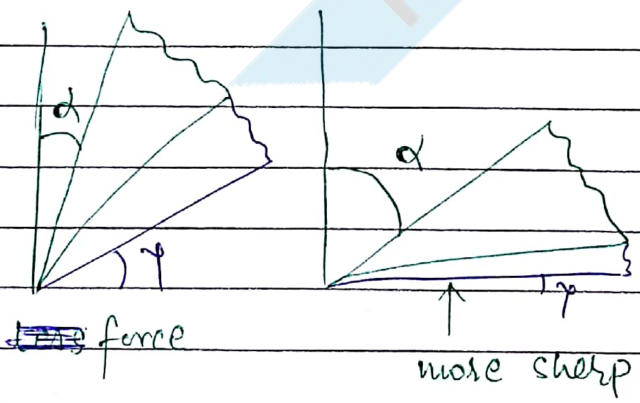
The other surface which is relief to avoid rubbing with the machined surface, is called 'Flank' or 'Flank surface'.

* Rake angle ∠

✓ ∠ of inclination of Rake surface from reference plane i.e. normal to horizontal machined surface.

✓ It allows chip flow direction / control chip flow direction.

✓ It reduces the cutting force required to shear the metal and reduce the power consumption.



α ↑ less force
γ → same

Sharpness

✓ It provides keenness to the cutting edge.

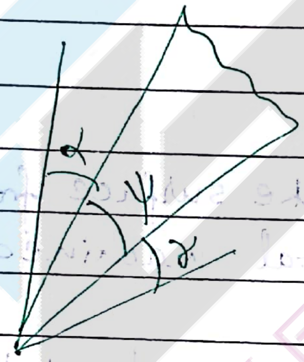
✓ It improves surface finish.

* Clearance ∠ and/OR Relief angle γ

↳ angle of inclination of clearance / flank surface from the finished surface.

↳ It reduces friction and Tool wear.

↳ It improve tool life.



↳ excessive clearance ∠ weakens the tool.

↳ must be positive (3° to 15°).

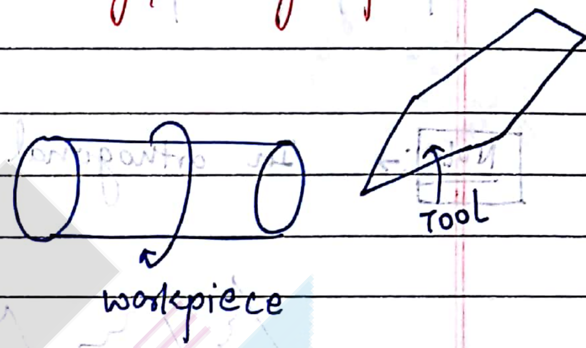
TURNING

✓ Preliminary concepts → OBLIQUE CUTTING

* SPEED, FEED and DEPTH OF CUT

✓ Tangential Velocity / cutting Velocity / cutting Speed.

$$\boxed{V = r \cdot \omega}$$



$$V = \frac{D}{2} \cdot \frac{2\pi N}{60}$$

where $\boxed{r = D/2}$

$\boxed{\omega = 2\pi N/60}$

$\Rightarrow$ $\boxed{V = \frac{\pi D N}{60} \; (m/s)}$ — D in m; unit of V

and

$\Rightarrow$ $\boxed{V = \pi D N \; (m/min)}$ — D in m

not MKS
not CGS
not SI

Jugaad unit

and

$\Rightarrow$ $\boxed{V = \frac{\pi D N}{1000} \; (m/min)}$ — D in mm

Lathe m/c

speed change gearbox

feed change gear box

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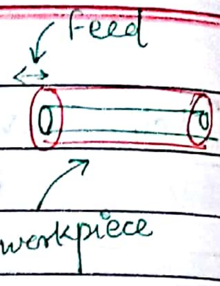
study time

Feed

direction

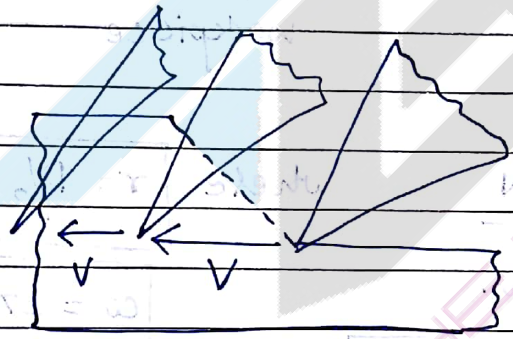
Tool + Tool post



feed → f mm/rev

for proper positioning of the tool.

Note: → In orthogonal cutting → position change of tool due to velocity hence no need of feed.



2mm/rev.

feed

workpiece

rev = r.

N rpm.

V_f $f\,\dfrac{N\,mm}{min}$

$$\boxed{V_f = f N \text{ mm/min}}$$

✓ 0.2 mm/rev ⟶ f

✓ 0.4 m/min — fN (mm) ← axial speed — $f \cdot N$

✓ 0.4 × 1000 mm/min = $N \cdot f$

feed direction & axial velocity

✓ Depth of Cut

$$D_1 = D_2 + 2d$$

$$\boxed{d = \frac{D_1 - D_2}{2}}$$

Turning

IES 2013

Sol.>

$d = 30\ mm$

$N = 1000\ \frac{rev}{min}$

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

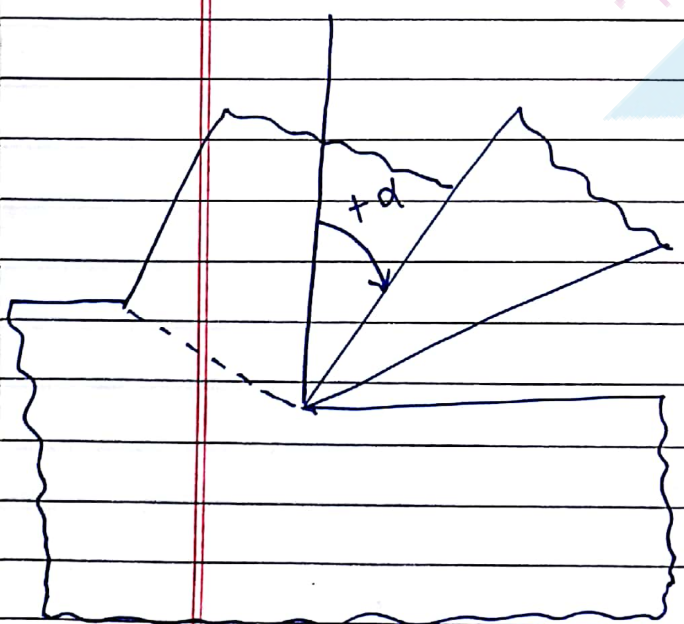
$V = \frac{\left(30/1000\right) m \cdot 1000\ rpm}{}$

$\boxed{V = 94.2\ m/min}$

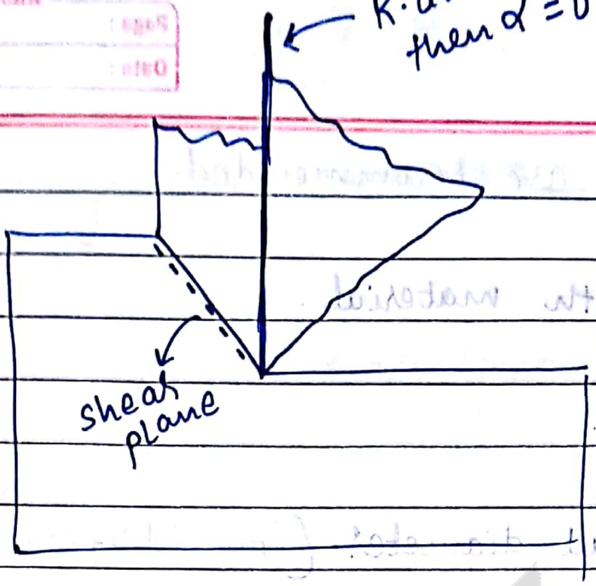
(c) ✓

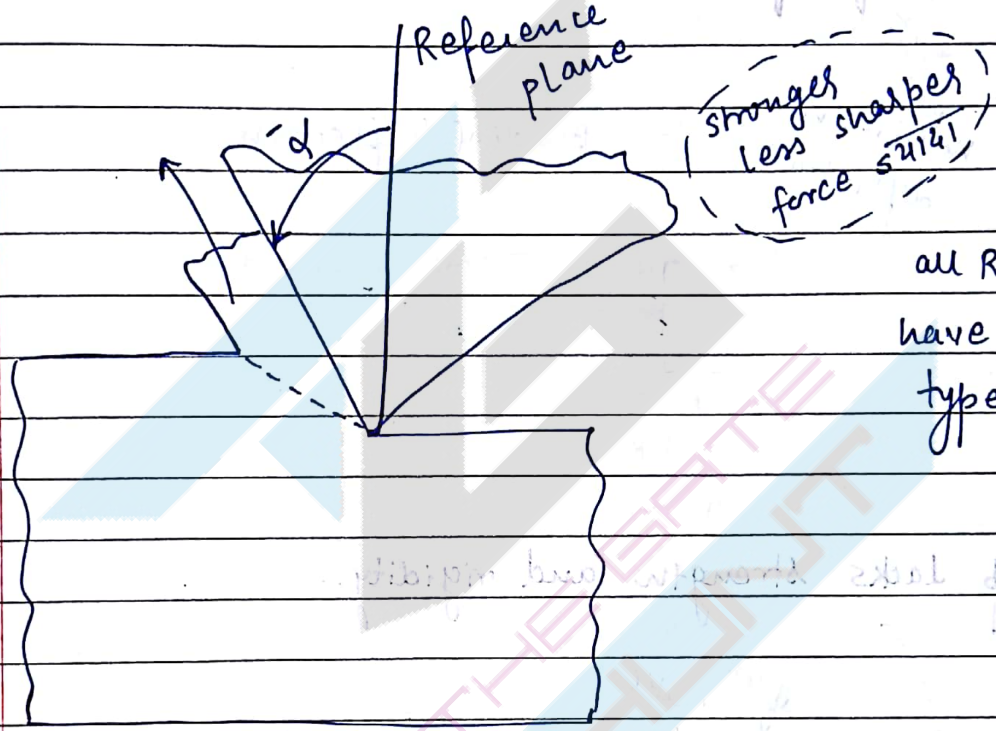
✱ Discussion on Rake angle

Rake ∠ can be +ve, −ve, 0.



sharper
weaker
force कम





all Rake ∠'s have particular type of use.

✓ Positive Rake Angle (5 - 30°)

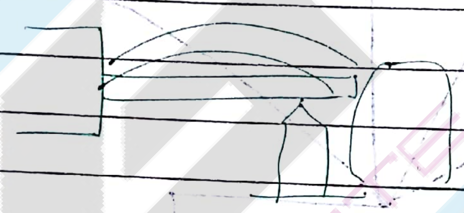
✓ Reduce cutting force

✓ Reduce —"— power (F × V = Power)

✓ Positive rake angles are recommended.

- Machining low strength material.
- Low power machine.
- Long shaft of small diameter. (low stiffness)

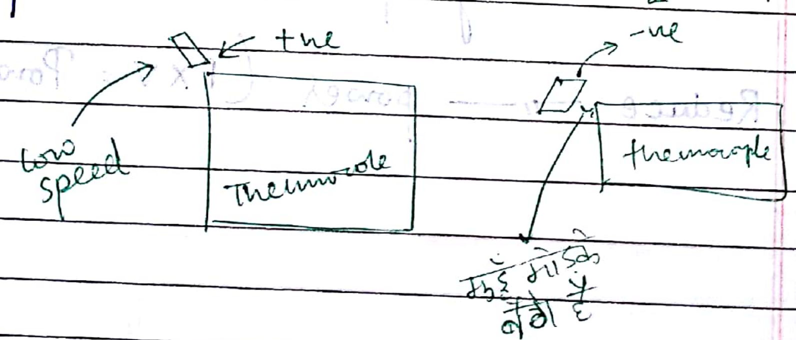
minimum deflection → Bending /Deflection



- Set-up lacks strength and rigidity.

machine खराबी → if use -ve Rake ∠ → machine उखड़ आएगी

- Low cutting speed. → if high speed & -ve rank



Steel
alloy
C + Fe → 2% C → Iron oxide

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- **Cutting tool materials : HSS** → +ve Rake angle

high speed steel → but runs on low speed.

(hema-malini relate)

Previously, High Carbon steel.

Room tempr. of HCS of speed → 7.5m/min ← ductile

due to tempr. ← low speed

Development after HCS → $\boxed{\text{HSS}}$ ← Ductile

30m/min

18 - 4 - 1
18% W
4% Cr
1% V
Rest Fe

High speed steel

now use

Rate of production → 4 times due to HSS.

Now,

Carbide → 150 m/min

then Ceramic → 600 m/min

Brittle

use now a days

don't use

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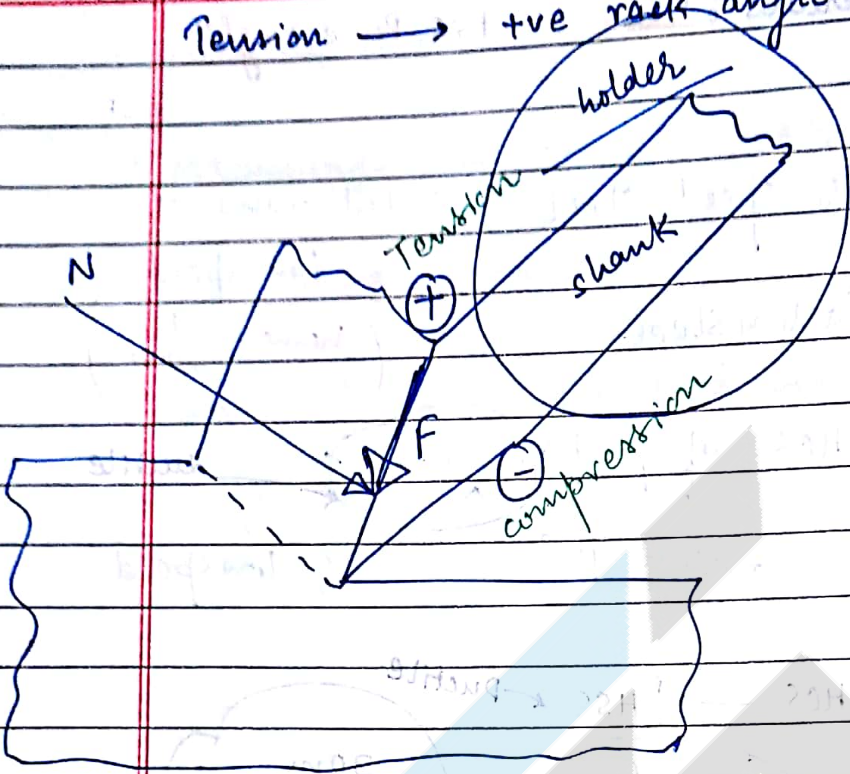
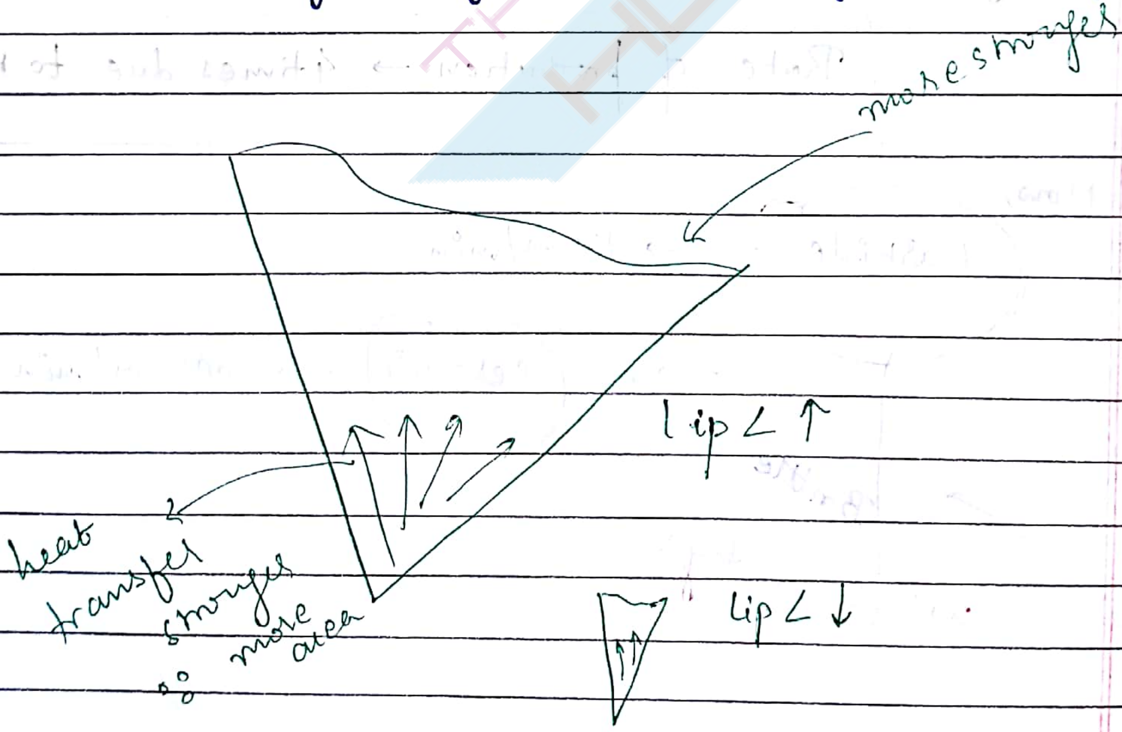
Tension ⟶ +ve rack angle से aata hai.



$F = \mu N$

* Negative Rake

• Increased edge length (Mechanically / Thermally)



Carbide, Ceramic → compression → high strength
↳ Tension → low strength
↓
fail

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- Increases life of the tool.
- Increases the cutting force.
- Requires high cutting speed.
- Requires ample power (VERY VERY High POWER)

$F \times V = P$

$\because F\uparrow$ and $V\uparrow$ and $P\uparrow$

- Heavy impact loads.

✓ Negative Rack ∠'s are Recommended (operator ko kaise pata hoga).

- Machining high strength alloy
- High speed Cutting (+ve se cut payenge but झेल नहीं पाएगा)

like Carbide (+ve mein) → Tempr. doesn't Resist

- With Rigid Set-up. → झटका (impact)
- Cutting tool material : Ceramic, Carbide.

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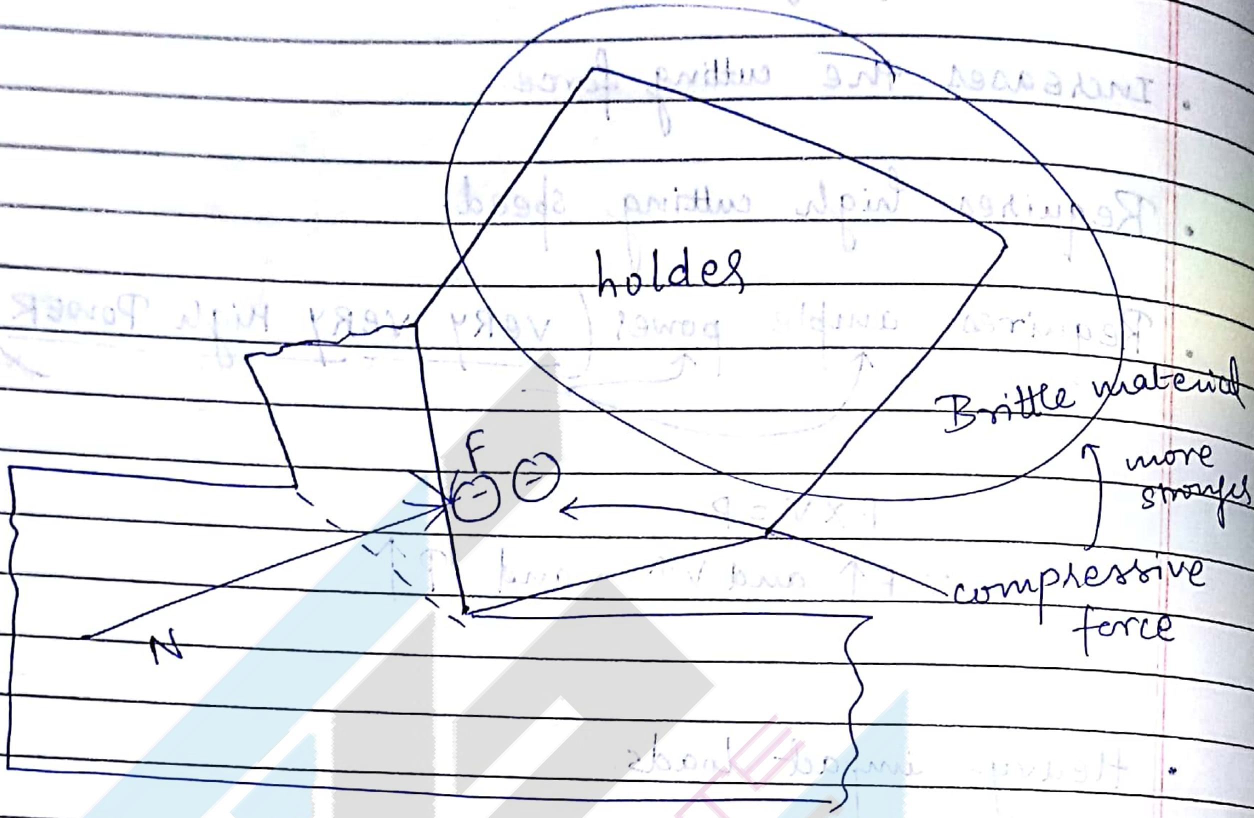
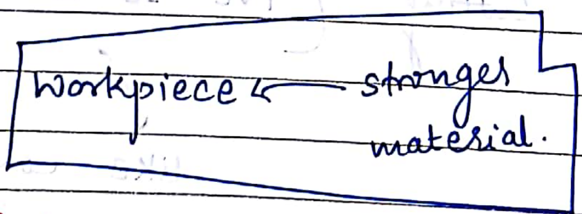
Carbide



Tension $\xrightarrow[\text{weak}]{}$ Brittle material

Compression $\xrightarrow[\text{stronger}]{}$ Brittle material

imp



But

Toughness Problem

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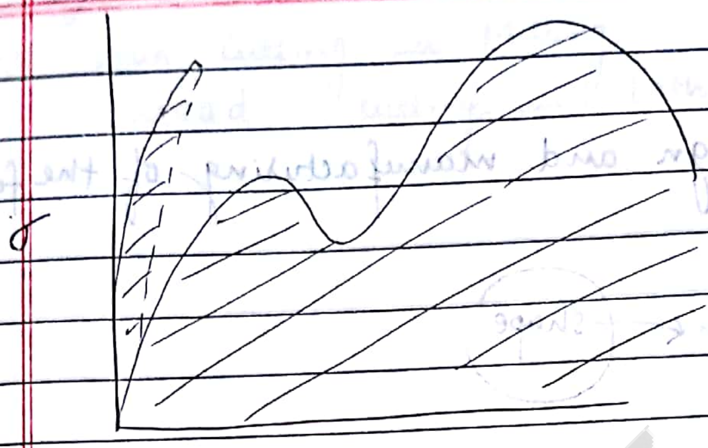
Brittle material



ϵ ↓

hence

Carbide Insert

low Toughness

show absorbing capacity of any material

IES-2005

(b) Carbide → Brittle material ke karan.

IES-2005

hard → harder

(b)

MOHIT CHOUKSEY

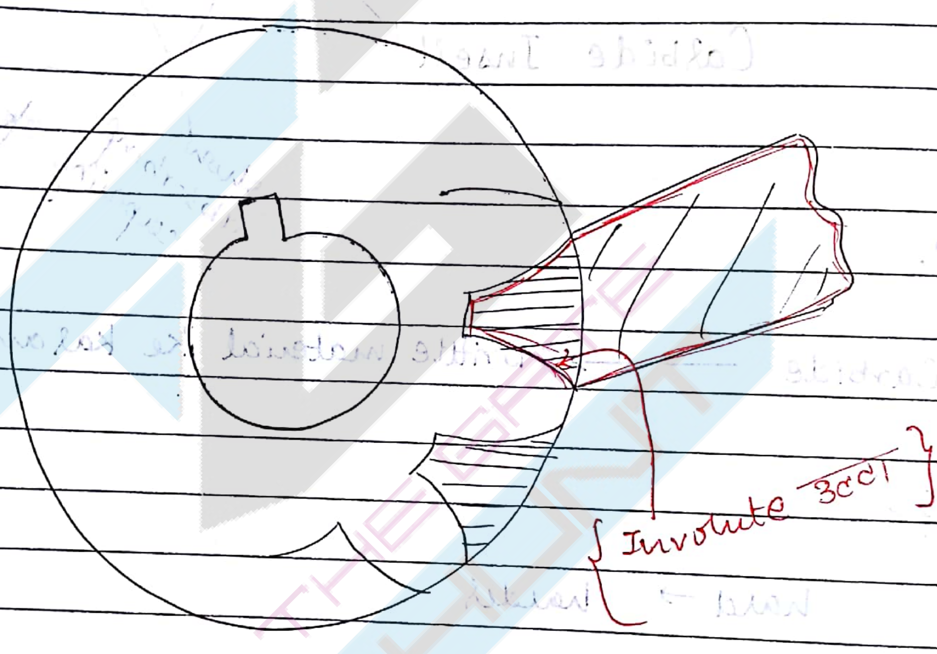
* ZERO RACK

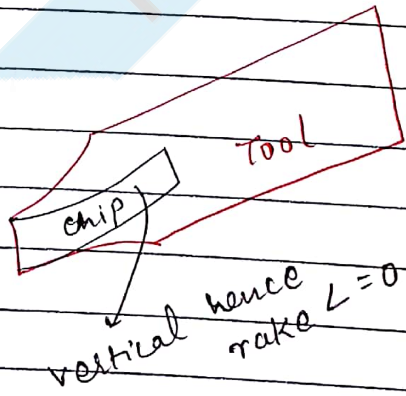
- To simplify design and manufacturing of the form tools.

form ← shape

↓

shape of the Tools → Shape of the product





MOHIT CHOUKSEY

not in hobbing m/c

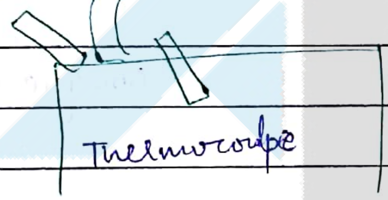
Ex:- Gear Cutting in Milling machine.
Thread cutting in lathe machine.] → FORM TOOL

SHAPE

• Increases the tool strength.

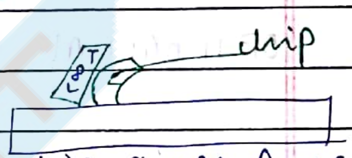
• Avoids digging of the tool in the workpiece.

+ve Rake ∠



0 Rake ∠

but



chip gives force to tool

• Brass is turned with zero rake angle.

soft material

(CONTROLLING OF CHIP IS DIFFICULT)

strong metal

• CI uses zero Rake ∠.

work material is Brittle cannot withstand impact load, poor surface finish.

MOHIT CHOUKSEY

IES 2001 → zero ∠.

IES 1995 → zero ∠.

IES 1993

IES 2011 (b) → clearance∠ depend.

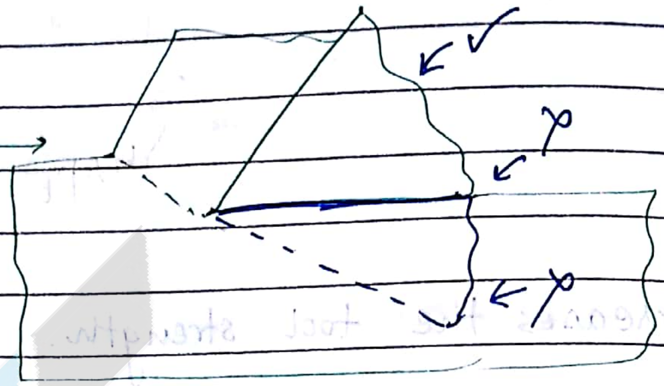
Clearance ∠ →

↓

always +ve

↓

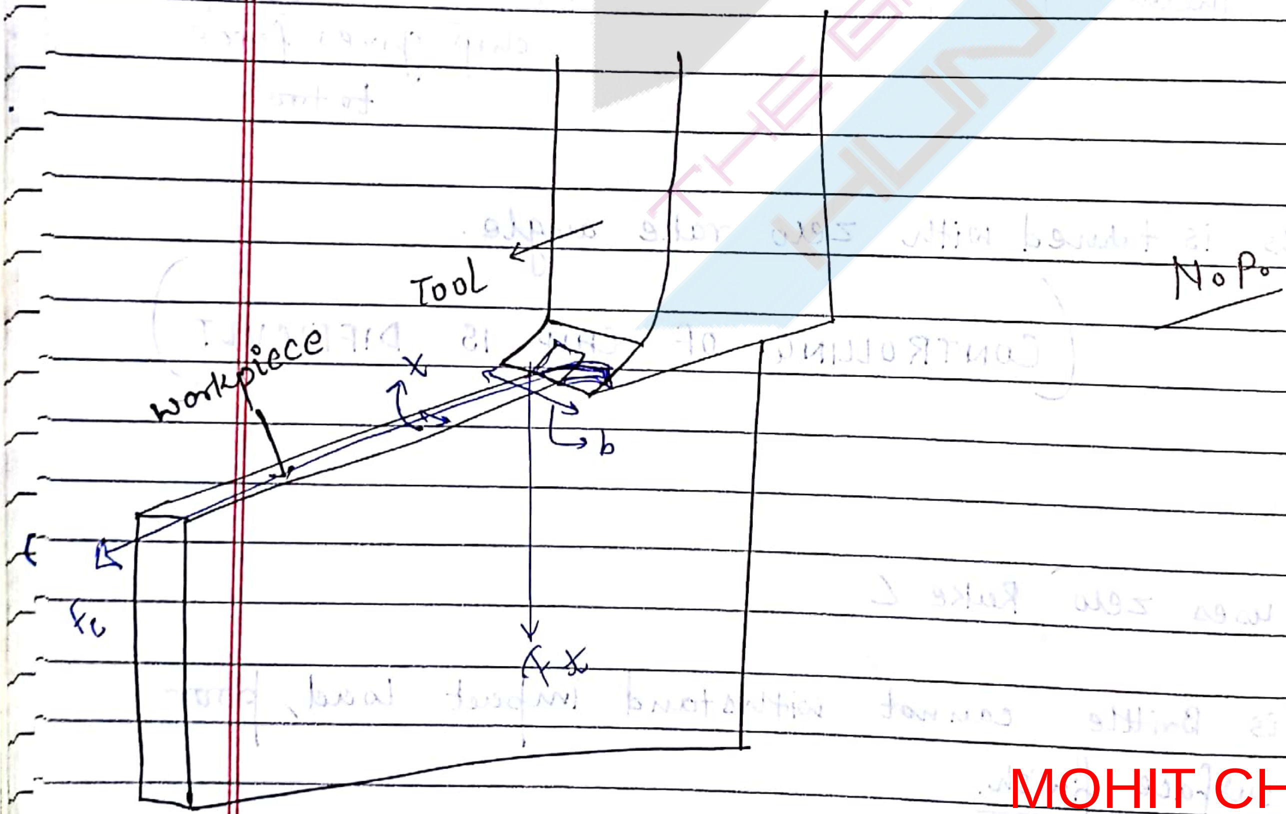
3 to 5°

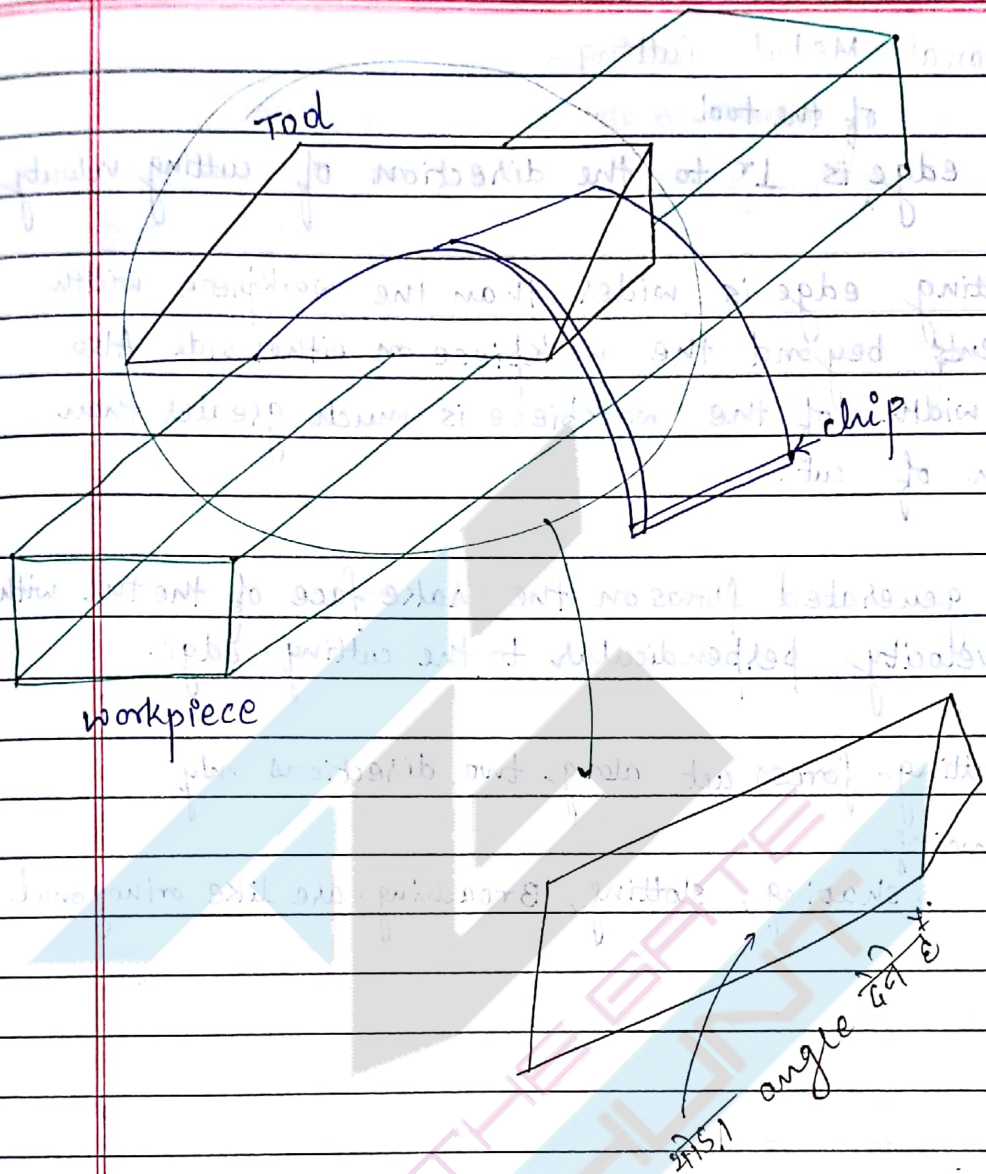


* TYPES OF MACHINING

ORTHOGONAL Cutting

Oblique cutting




Tool
chip
workpiece
angle

* ORTHOGONAL Metal Cutting.

1.) Cutting edge of the tool is $\perp^r$ to the direction of cutting velocity.

2.) The cutting edge is wider than the workpiece width and extends beyond the workpiece on either side. Also the ~~wor~~ width of the workpiece is much greater than the depth of cut.

3.) The chip generated flows on the rake face of the tool with chip velocity perpendicular to the cutting edge.

4.) The cutting forces act along two directions only.

Ex:- ✓ Planning, shaping, slotting, Broaching are like orthogonal cutting.

MOHIT CHOUKSEY

26/06/2016

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METAL CUTTING continues....

✓ Geometry of Single Point ~~cutting~~ Turning Tool.

But

Note → During metal cutting an increase in cutting speed causes cutting forces to remain unaffected or slightly reduced.

↓

tempr. ↑ → metal strength ↓ of workpiece

(But power, heat, temperature will increase.)

Now,

oblique → lathe

Geometry of a single Point Turning Tool.

✓ Classification of tool according to the no. of major cutting edges [points] involve :-

only this we have to study

• Single point : Turning, shaping, planning, slotting tools, parting tools etc.

ek baar mein ek hi chip niklegi

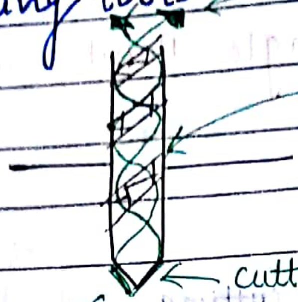
cross dirn. में feed करना होगा

Table move hoga workpiece long

slot gear

vertical axis shaper (cutter)

✓ Double point : drilling tools. ← 2 path for removal of chip



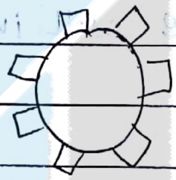
for chip flow

cutting edge 2

2 chips simultaneously removed

- Multipoint : Milling, broaching, hobbing tools, saw, grinding wheel etc.

Milling →



cutting edge

50 micron

cutting edge

in a single pass

slot $\frac{\phi 16}{IG 41}$

gears manufacturing

hobb is rotating and job is rotating.

✓ Internal gears manufacturing → Shaper with pinion

Q → IES 2006

Parting tool → single point cutting tool.

✓ System of Description of Tool Geometry

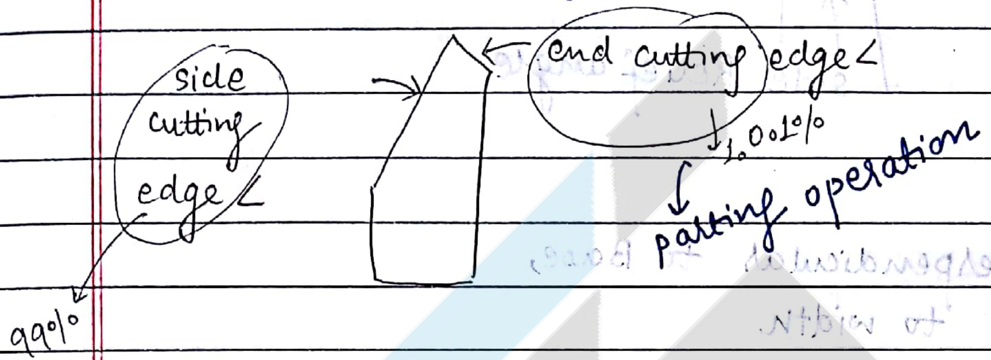
Description आसान → Calculation कठिन

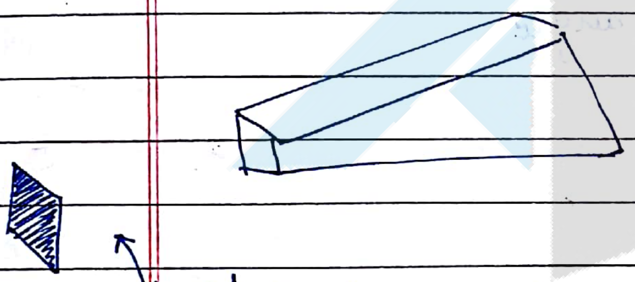
(I) Machine reference system : ASA or ANSI

(II) Tool reference system : ORS and NRS

orthogonal → ISO old; Normal → ISO New

(III) Work reference system : WRS





✓ ⊥r to Base, || to width → side rake ∠, side Relief ∠.

✓ || to Base plane, ⊥r to width → end cutting edge ∠

side — " — " — .

✓ along || to the length, ⊥r to Base, Back Rake ∠ ← end se.

end Relief ∠.

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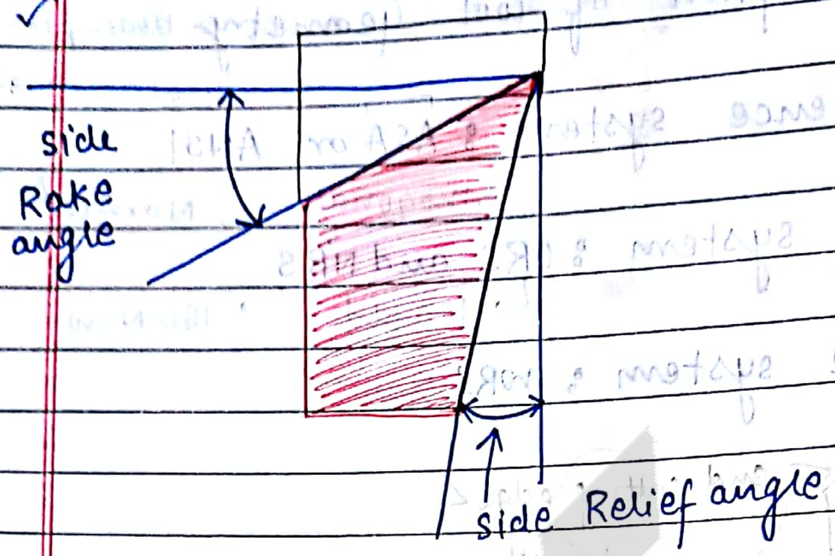
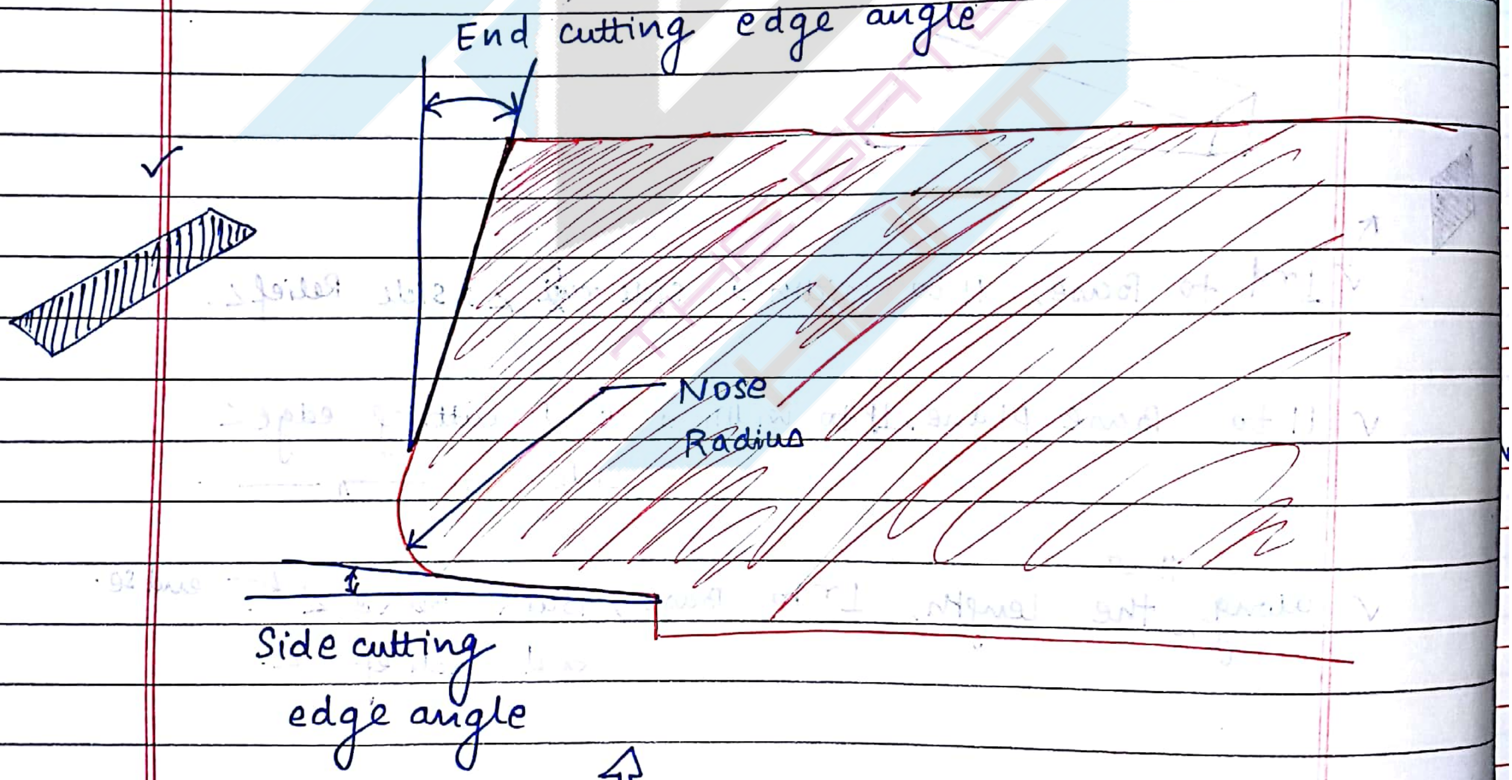
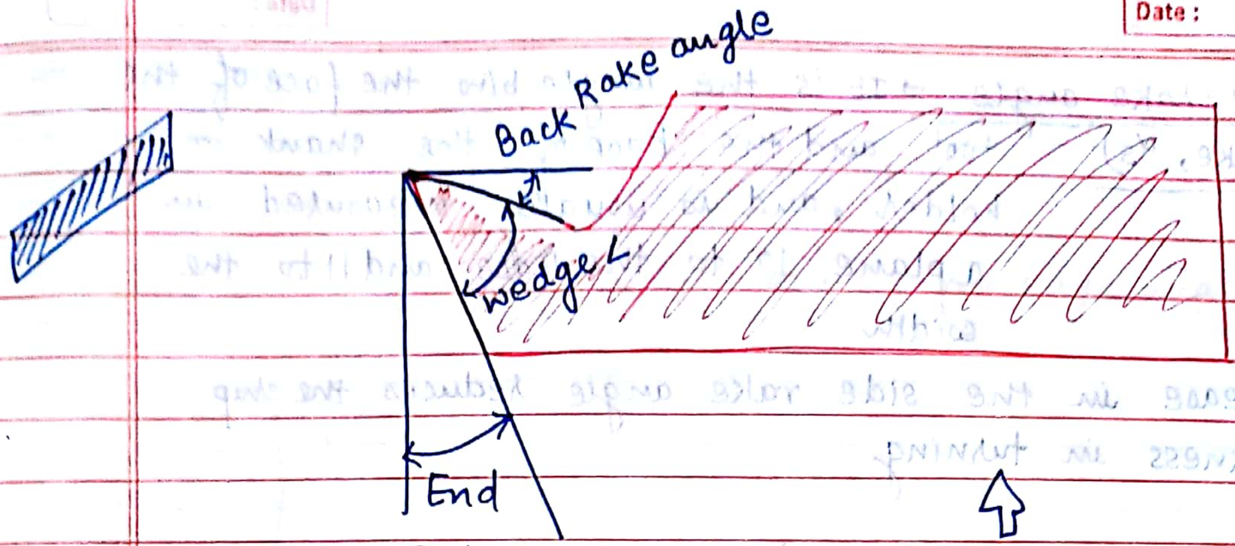


Section Perpendicular to Base, parallel to width



Parallel to Base
⊥r to width



⊥r to Base
|| to length

✓ American system → cut through 3 ⊥r planes.

* Back Rake angle (α_b) ⇒ It is the angle between the face of the tool and the base of the shank or holder, and is usually measured in a plane perpendicular to the Base and parallel to the length of the tool.

It affects the ability of the tool to shear the work material and form the chip.

In turning, positive Back rake angle takes the chips away from the machined surface, whereas negative Back rake angle directs the chip on to the machined surface.

horizontal wrt Base since isometric change.

safe

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* **Side-rake angle (axial rake, α_s)** → It is the angle b/w the face of the tool and the base of the shank or holder, and is usually measured in a plane ⊥r to the Base and ∥ to the width

- increase in the side rake angle reduces the chip thickness in turning.

* **End-Relief angle (γ_e)** → it is the angle b/w the portion of the end flank immediately below the end cutting edge, and a line drawn through this cutting edge perpendicular to the Base. It is usually measured in a plane ⊥r to the end flank.

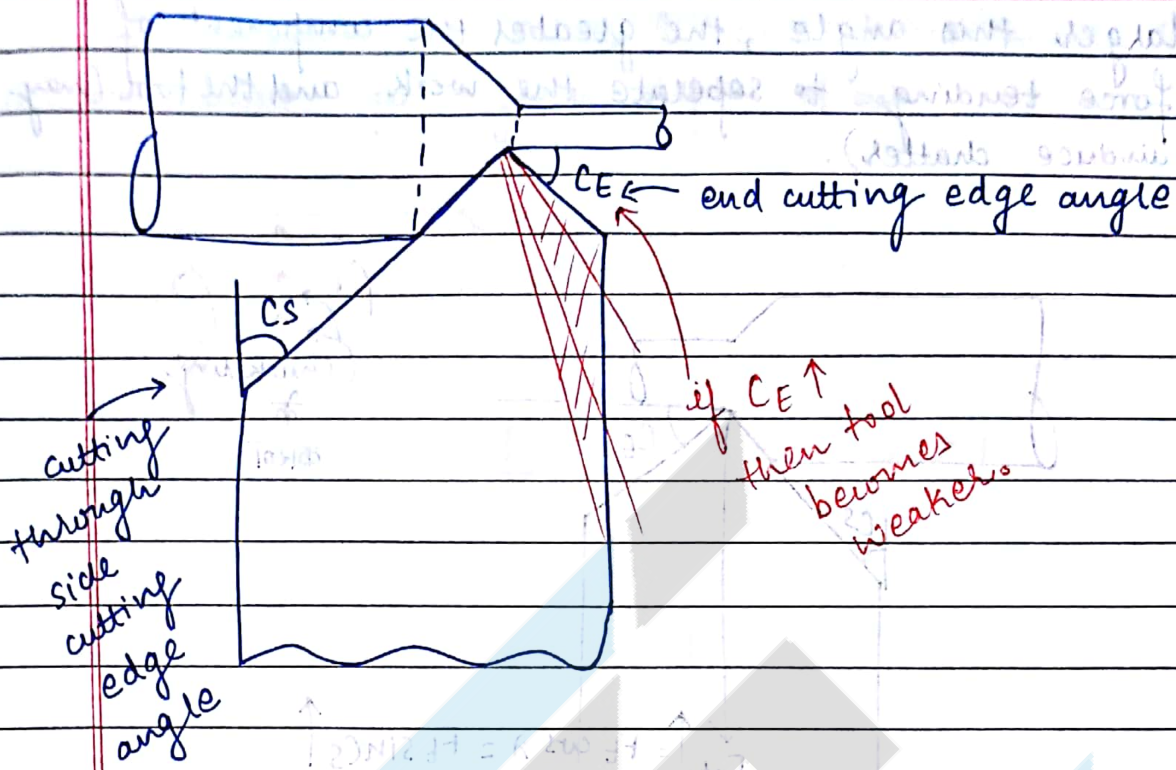
- The end Relief angle prevents friction on the flank of the Tool.

* **Side-Relief angle (γ_s)** → It is the angle between the portion of the side flank immediately below the side-cutting edge, and a line drawn through this cutting edge ⊥r to the Base.

- It is measured in a plane perpendicular to the side flank.

* **End cutting edge angle, ECEA (C_e)**

The end cutting edge angle is the amount that the end-cutting edge slopes away from the nose of the tool, so that it will clear the finished surface on the workpiece, when cutting with the side-cutting edge.



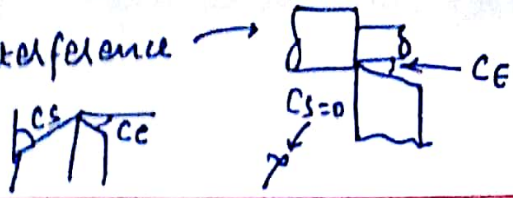
- It prevents the trailing end of the cutting edge of tool from rubbing against the workpiece.
- A larger end cutting edge angle weakens the tool
- It is usually kept b/w 8° to 15°.

***** Side Cutting edge angle, SCEA (C_S)

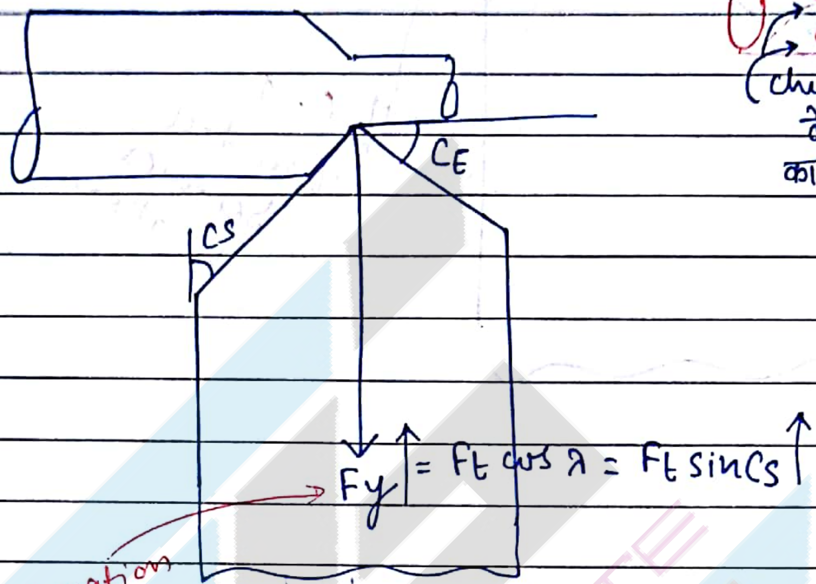
It is the angle which prevents the interference as the tool enters the work materials. (Normally 15° to 30°).

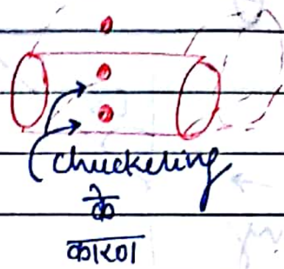
N.P.

Takkar   interference



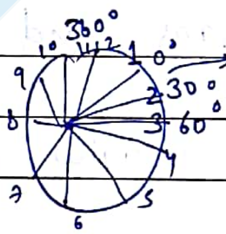
- larger this angle, the greater the component of force tending to seperate the work and the tool. (may induce chatter).





Q. $d = 100\,mm$
$N = 500\ rpm$

30°



$V = \frac{\pi d N}{60}$ $v = fN$

$12 \times 30^\circ = 360^\circ$

1 rotation → 12 chattering   12 chuckering → 1 rpm

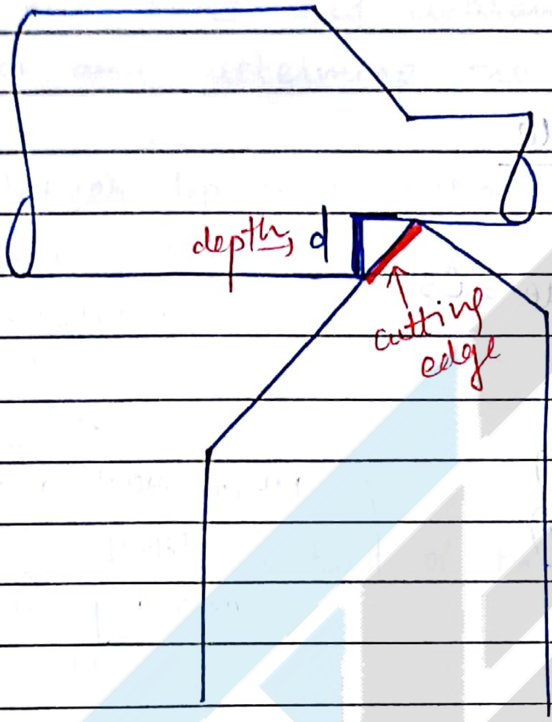
~~12 rotation = 12×500 chattering.~~

rpm → 500 rotation = 12×500 chattering

rps → $\frac{500}{60}$ = $\frac{12}{60} \times 500$ 100 chattering

100

- at its increased value, it will have more of its length in action for a given depth of cut.



- at its increased value it produce thinner and wider chip that will distribute the cutting heat (increase Tool life).

- zero SCEA is desirable when machining casting and forging with hard and scaly skins, because of the least amount of tool edge should be exposed to the destructive action of the ~~scale~~ skin.

रक्खाहे

- SCEA has no influence on cutting force (F_2 F_z) or cutting power.

- F_y : Thrust force or Radial force will decrease

$$F_y\uparrow = F_t\cos\lambda = F_t\sin C_s\uparrow$$

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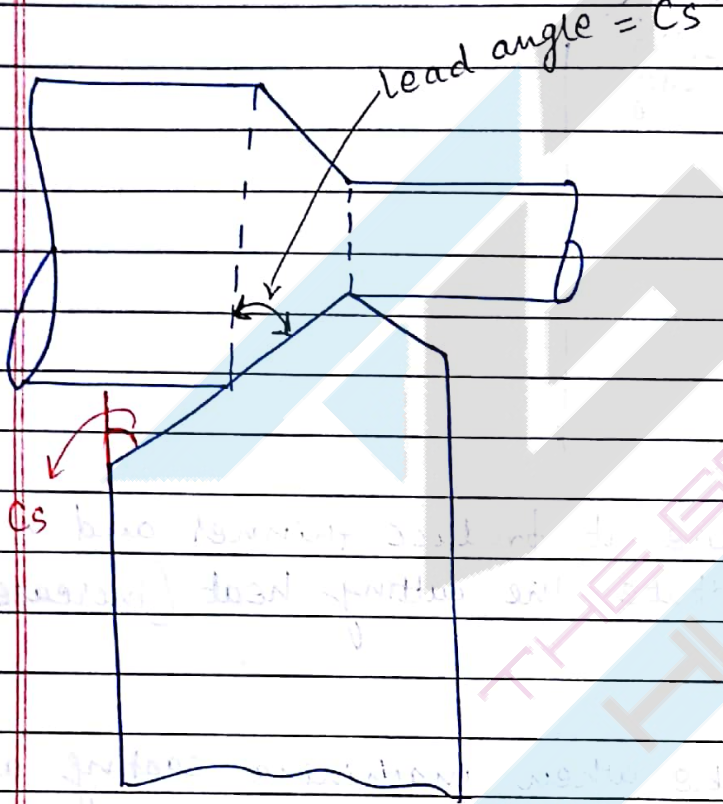
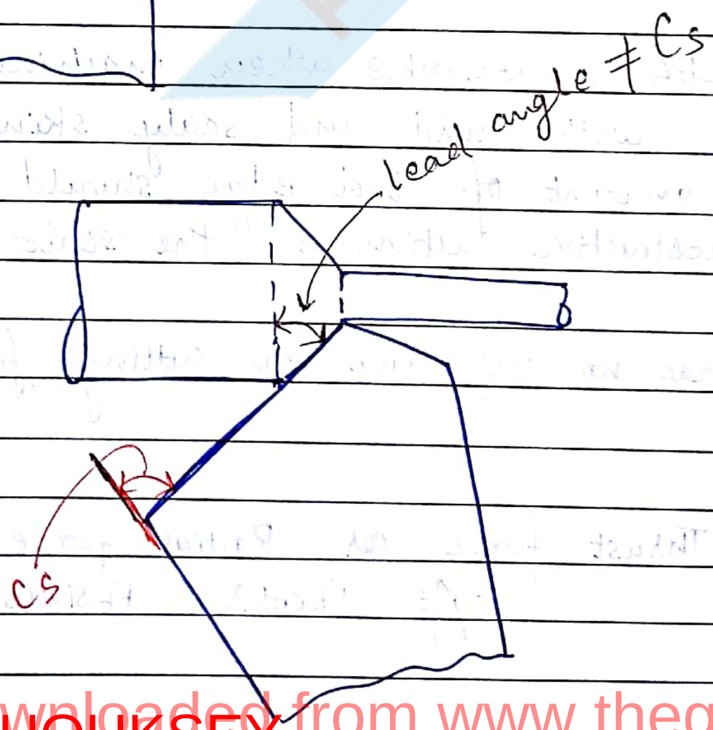
(i) Fx : axial or feed force will decrease

$$F_x \downarrow = F_t \sin\lambda = F_t \cos C_s \uparrow$$

* SCEA and Lead Angle



actual machining
हमेशा
lead angle में
होगा



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* Lip angle / wedge angle / Knife angle / cutting ∠

- Lip angle / —,, ——,, ——,, ——,, —— depends on the rake and clearance angle provided on the tool and determine the strength of the cutting edge

- A larger lip angle permits the machining of harder metals, allow heavier depth of cut, better heat dissipation, increase tool life.

* Nose Radius

- It is the curvature of the tool tip.

- It strengthen the tool nose by reducing stress concentration.

- It provide better surface finish.

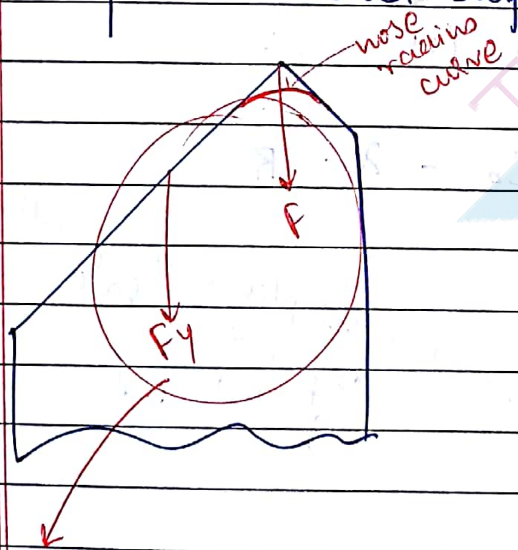
$$h = \frac{f^2}{8R}$$

avg. height of Roughness

Nose Radius

~~Surface Roughness~~ ↑

~~अच्छा~~



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- But too large nose radius will induce chatter.

- If nose radius increased, cutting force and cutting power will also increased.

- It increases tool life.

dont use in calculations.

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* Tool Designation or Tool Signature (ANSI) or ASA *

american system

side rake, end relief, end cutting

$\alpha_b - \alpha_s - \gamma_e - \gamma_s - C_e - C_s - R$

Back, side relief, cutting side

To remember easily, follow the rule

- rake, relief, cutting edge
- side will come last
- finish with nose radius (inch)

$10^\circ - 12^\circ - 5^\circ - 7^\circ - 15^\circ - 30^\circ - 1(mm).$

* ORthogonal Rake System (ORS)

$i - \alpha - \gamma - \gamma_1 - C_e - \lambda - R$

76°

- inclination angle (i)
- orthogonal rake angle (α) → ek hi plane orthogonal sey rake surface katengey.
- side relief angle (γ)
- End relief angle (γ_1)
- C_e → end cutting edge.

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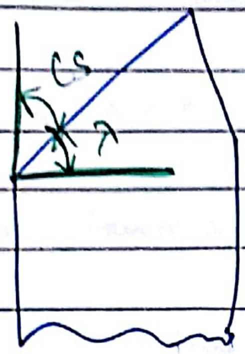
$$C_s + \lambda = 90^\circ$$



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

- Principal cutting edge angle or Approach angle $(90 - C_s = \lambda)$

- Nose radius (R)(mm).

- For orthogonal cutting, $i = 0$
- For oblique cutting, $i \neq 0$.

6th No. $C_e \rightarrow$ finding whether American or ORS system.

α, $C_e \longrightarrow$ used for Calculation purpose.

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$5 + 0 = 5$
$5 - 0 = 5$
$5 \times 0 = 0$
$5/0 = \infty$

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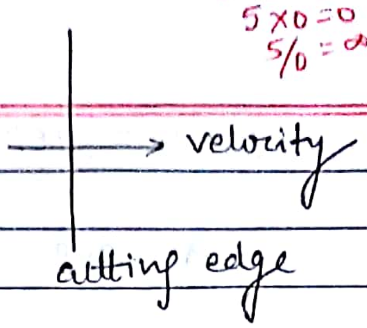
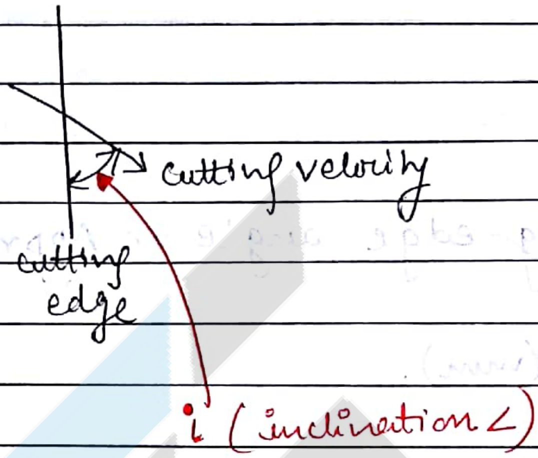
Orthogonal



oblique



* Interconversion between ASA and ORS

$\tan\alpha = \tan\alpha_s \sin\lambda + \tan\alpha_b \cos\lambda$

$\tan\alpha_b = \cos\lambda \tan\alpha + \sin\lambda \tan i$

$\tan\alpha_s = \sin\lambda \tan\alpha - \cos\lambda \tan i$

$\tan i = -\tan\alpha_s \cos\lambda + \tan\alpha_b \sin\lambda$

for UPSC

$\tan\alpha_b = \cos\lambda \tan\alpha$

$\tan\alpha_s = \sin\lambda \tan\alpha$

$0 = -\tan\alpha_s \cos\lambda + \tan\alpha_b \sin\lambda.$

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* Critical Correlations

✓ $\boxed{\text{when } \lambda = 90^\circ \quad \alpha_s = \alpha}$

like $\tan\alpha = \tan\alpha_s \xcancel{\sin 90}^{\,1} + \xcancel{\tan\alpha_b \cos 90}^{\,0}$

$\tan\alpha = \tan\alpha_s$

$$\boxed{\alpha = \alpha_s}$$

✓ when $i = 0$ $\quad \alpha_n = \alpha$

✓ when $i = 0$ and $\lambda = 90^\circ$ $\quad \alpha_s = \alpha_n = \alpha$

(Pure orthogonal cutting)

λ is principle cutting edge angle
i is inclination $\angle$.
α_s is side rake angle (ASA) → ISO old
α is orthogonal rake angle (ORS)
α_n is normal rake angle (NRS). → new ISO.

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orthogonal

Shear angle (ϕ)

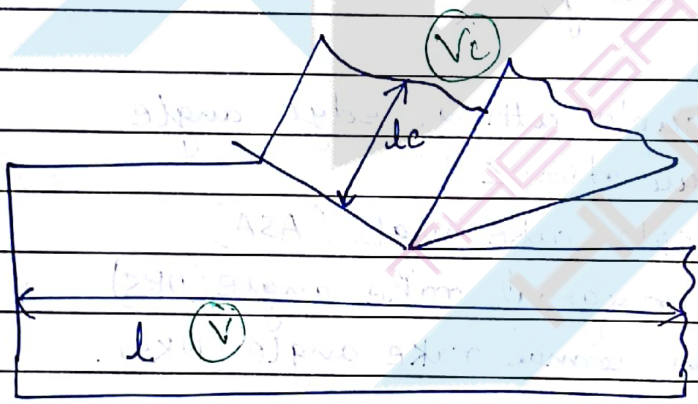
$$r = \frac{t}{t_c} = \frac{l_c}{l} = \frac{V_c}{V} = \frac{\sin\phi}{\cos(\phi - \alpha)} = 1/h$$

and $$\boxed{\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}}$$ Ganesh ji

where

r = chip thickness ratio or cutting ratio; $r < 1$.

$h = 1/r$ = Inverse of chip ratio or chip reduction factor or chip compression ratio; $h > 1$



Q → Gate 2011

$\alpha = 12^\circ$

$t = d = 0.81$ mm

$\frac{0.81}{1.8}$

(b) ✓ 26°

Q IES 2014 conventional

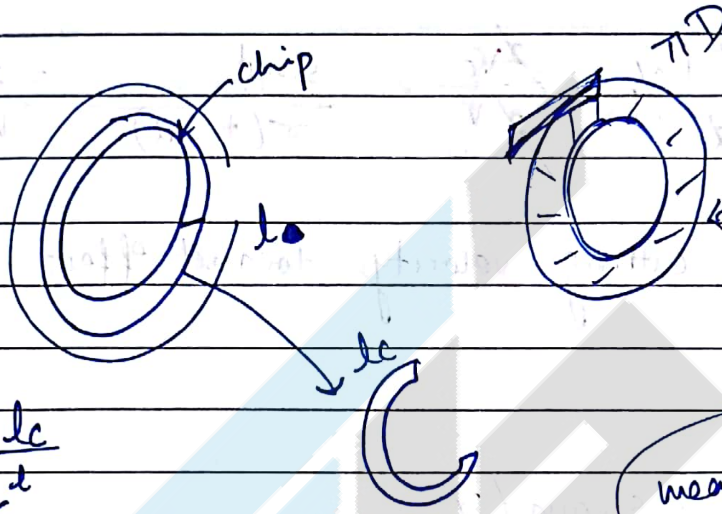
68.9 mm

dia = 70mm
$\downarrow$
68mm

2mm

$\alpha = 10^\circ$

0.32



circular hi orthogonal cutting ho sakti hai

$$r = \frac{l_c}{l}$$

$l \rightarrow \pi D$

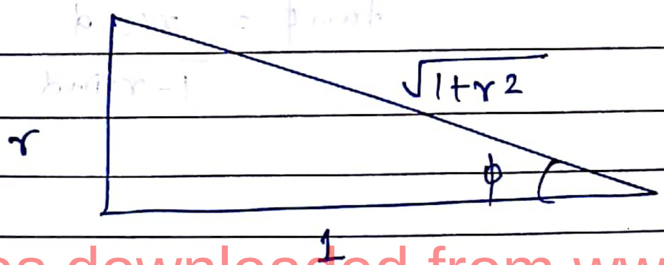
mean length → outside length of the chip

$$r = \frac{68.9}{\pi \times 69} = 0.318$$

$$\phi = \boxed{18.58^\circ}$$

- $\boxed{\text{if } \alpha = 0}$

$$\tan\phi = \frac{r\cos 0}{1 - r\sin 0} = r$$



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$$\sin\phi = \frac{r}{\sqrt{1+r^2}}$$

$$\cos\phi = \frac{1}{\sqrt{1+r^2}}$$

IES Qn.

$$r = \frac{\cancel{b}\,t}{\cancel{b}\,t_c} = \frac{\cancel{b}\,l_c}{\cancel{b}\,l} = \frac{\cancel{b}V_c}{\cancel{b}V} = \frac{\sin\phi}{\cos(\phi-\alpha)} = \frac{1}{h}$$

cutting velocity does not effect.

* Cutting Shear strain (γ)

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

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

(रटना नहीं है)

in most questions ϕ can be found by Ganeshji formulae

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

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• If $\alpha = 0$

$$\gamma = \cot\phi + \tan\phi \geq 2$$

$x + \frac{1}{x}$ form

$\boxed{AM \geq GM}$

$$\boxed{\frac{x + 1/x}{2} \geq \sqrt{x \cdot 1/x}}$$

or $\boxed{x + 1/x \geq 2}$

$\gamma_{minimum}$ value ≥ 2 when $\alpha = 0$

also, $$\frac{d\gamma}{d\phi} = -\mathrm{cosec}^2\phi + \sec^2\phi = 0$$

$$\sec^2\phi = \frac{1}{\mathrm{cosec}^2\phi}$$

$$\cos\phi = \sin\phi$$

$$\tan\phi = 1 = r$$

Not possible practically $t/t_c = 1/r$.

but theoretically

$$\gamma_{min} = 1 + 1 \neq = 2$$

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

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Q. if $\gamma = \cot\phi + \tan(\phi - 12)$

$\frac{d\gamma}{d\phi} = 0$

$\Rightarrow -\operatorname{cosec}^2\phi + \sec^2(\phi - 12) = 0$

$\Rightarrow \sec^2(\phi - 12) = \operatorname{cosec}^2\phi$

$\Rightarrow \frac{1}{\cos(\phi - 12)} = \frac{1}{\sin\phi}$

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

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

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

$\Rightarrow 2\phi = 102$

$\Rightarrow \boxed{\phi = 51^\circ}$

$\gamma_{min.} = \cot 51^\circ + \tan(51^\circ - 12^\circ)$

$\gamma_{min} = 1.61$

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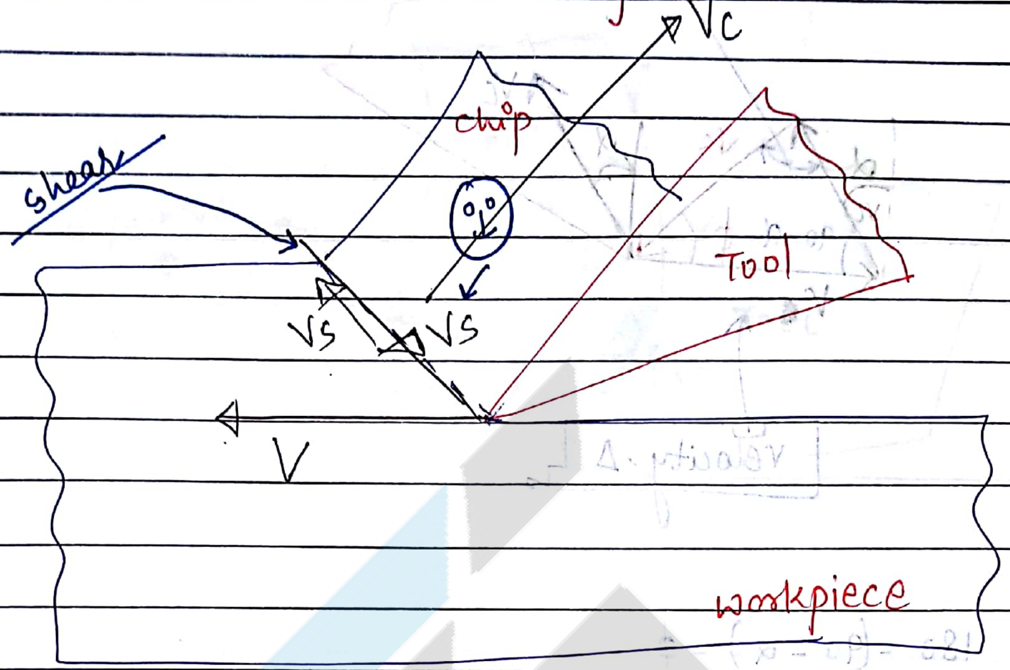
orthogonal

* Velocities in Metal Cutting



(i) The velocity of the tool relative to the work piece (V) is called the cutting speed.

(ii) The velocity of the chip relative to the workpiece, (Vs) is called shear velocity.

(iii) The velocity of the chip relative to the tool, (Vc) is called chip velocity

Q.> Describe the expression for Velocities in Metal Cutting.

ESE -2004 (Conv.)

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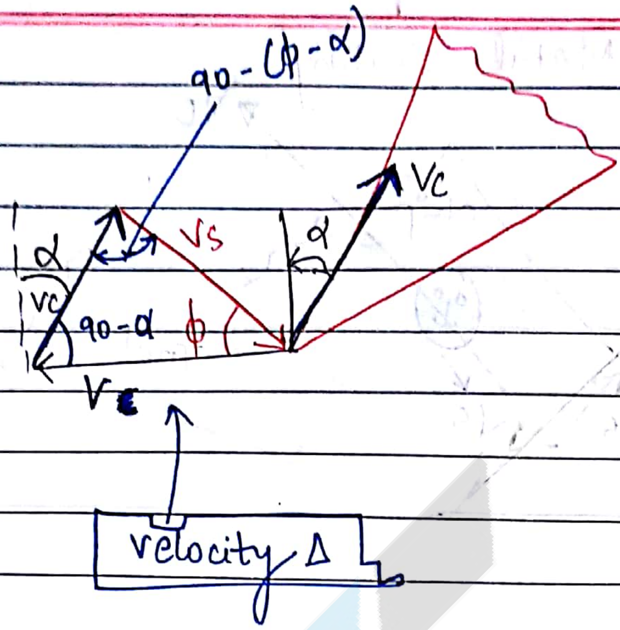

$= 180 - (90 - \alpha) - \phi$

$= 90 - \phi + \alpha$

$= 90 - (\phi - \alpha)$

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

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

if $$\boxed{\frac{V_c}{V} = \frac{\sin\phi}{\cos(\phi-\alpha)} = r}, \; V_c < V$$

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

Caunchy $\rightarrow \tan\phi = \dfrac{r\cos\alpha}{1 - r\sin\alpha}$

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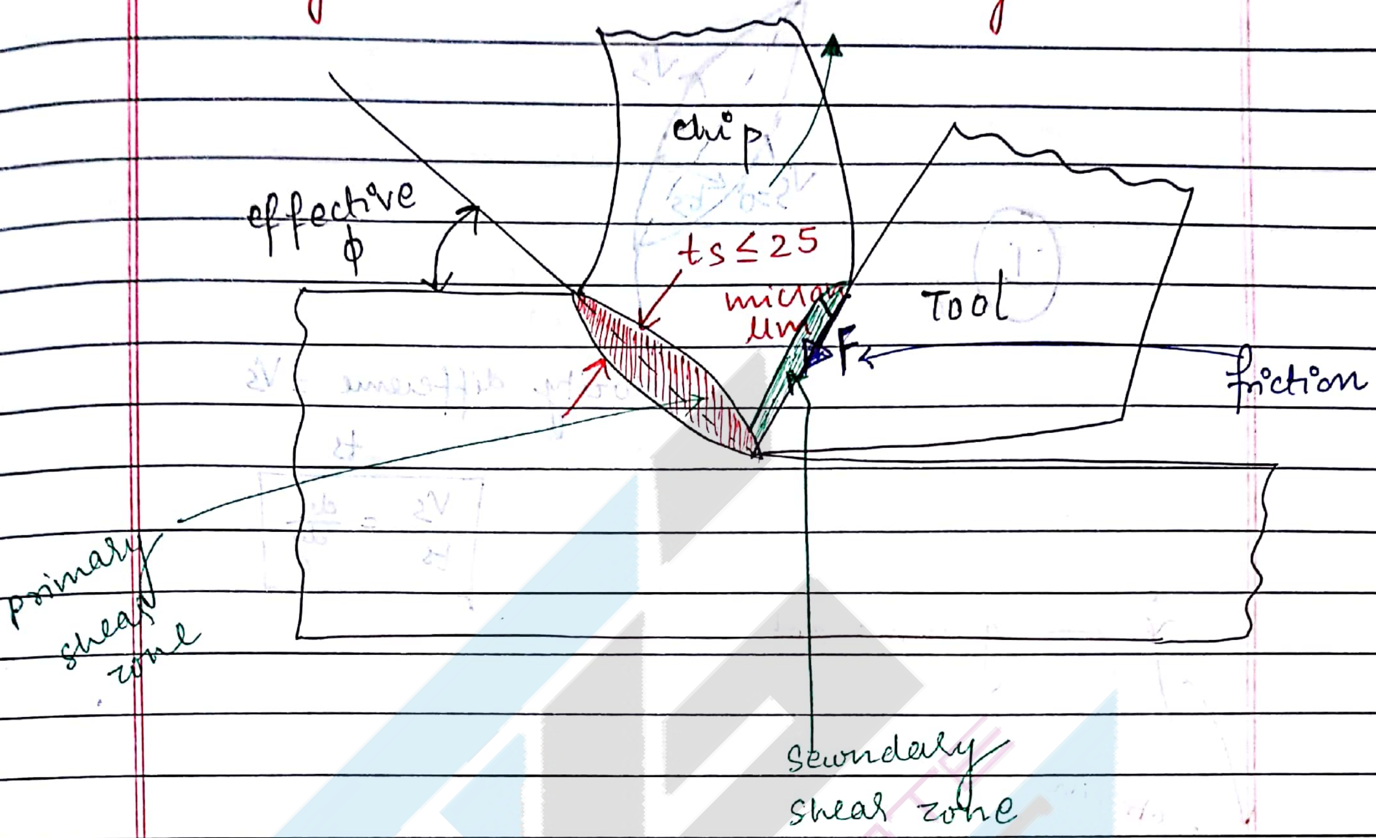
* Primary shear Zone and Secondary shear Zone.

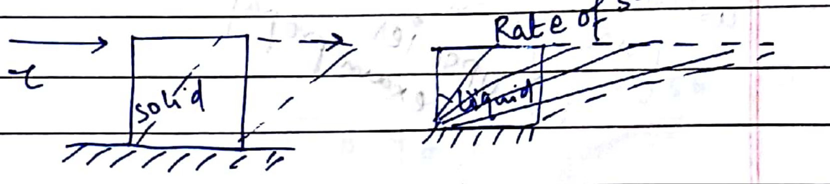


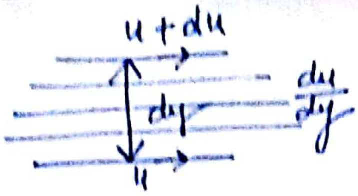
✓✓✓ $\boxed{t_s \leq 25\ \mu m}$

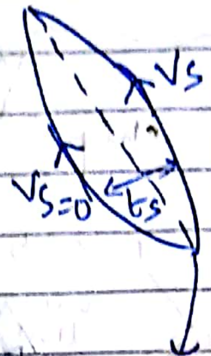
* Shear strain Rate / Rate of shear

(Note :- It is not shear strain it is rate of shear strain i.e. flow)

$$\dot{\gamma} = \frac{d\gamma}{dt} = \frac{V_s}{\text{Thickness of shear zone } (t_s)}$$







velocity difference $= \frac{V_s}{t_s}$

$$\boxed{\frac{V_s}{t_s} = \frac{du}{dy}}$$

$\dot{\gamma}$ ← gamma dot

shear strain rate
or
rate of shear strain
that is flow

✓ Thickness of shear zone can be taken as 1/10 (10%) of shear plane length and its maximum value is 25 micron.

assume it if not given in UPSC ies exam prepapes

Unit of $\dot{\gamma} \rightarrow \frac{m/s}{m}$

Q.) Sol.)

$r = 0.4$

$t = 0.6\ mm$

$\alpha = +10^0$

$V_s = 2.5 m/s$

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$t_s = 25$

$\dot{\gamma} = \frac{V_s}{t_s}$

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

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

0.100 micron

$\phi = 23^0$

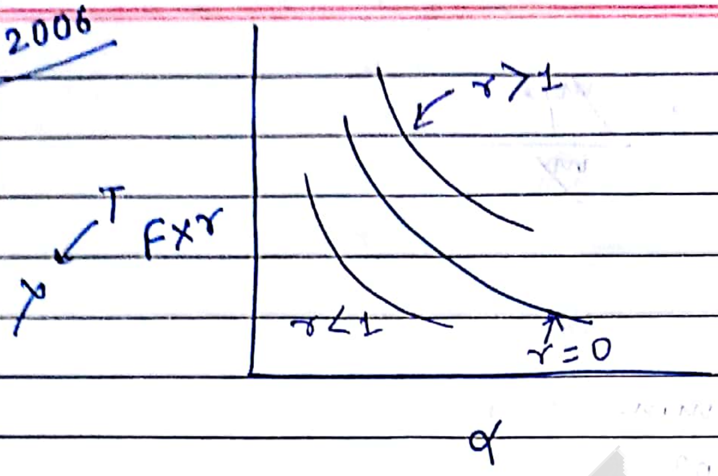
0.100×10^6

$\frac{2.5}{\sin 90 - (23 - 10)}$

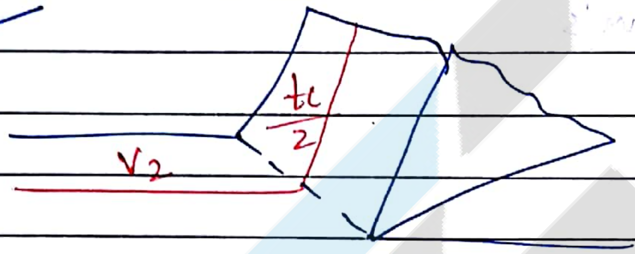
$V_s = 2.52$

$\frac{2.5}{0.97} \rightarrow 2.56$

IES 2006



IES 1995



Feed Rate → doubled

↓

Kausey ?

Chip thickness ratio unchanged → hence halved.

*

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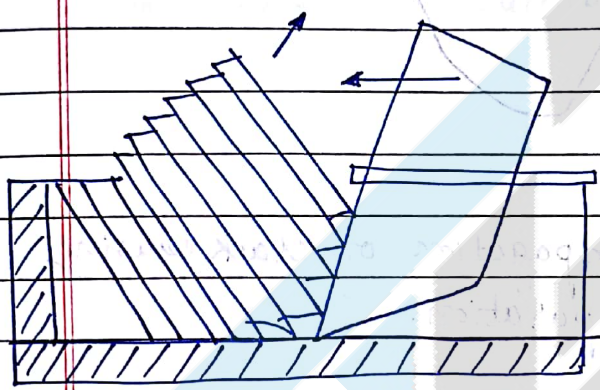
27/06/2016

* Causes of chip Formation

Shear yielding - in ductile material.
Brittle fracture - in Brittle material.

* Mechanism of chip formation in ductile material



Piispanen Card Model

(a) shifting of the postcards by partial sliding against each other.

(b) chip formation by shear in lamella.

* Mechanism of chip formation in Brittle material

Crack Initiation and propagation

N. P.

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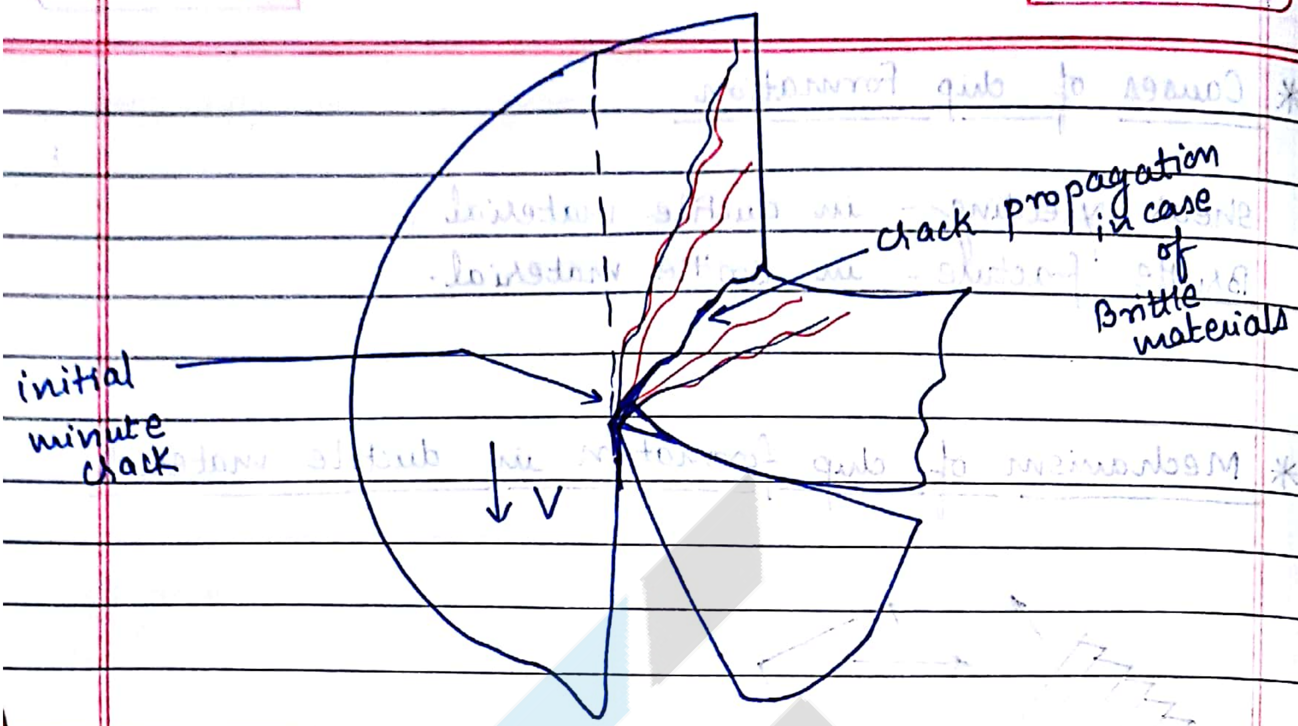

Development and Propagation of crack causing chip separation.

* Types of Chip :-

(a) Continuous chip.

(b) Discontinuous chip. → भरभरा की तरह

(c) Continuous chip with Built up Edge

(d) Serrated Chip.

* Conditions for forming discontinuous chip of irregular size and shape.

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www.glaceum.com/vdebuk → videos

Discontinuous → spiral नहीं बनता
and Transportation
आसान होता है

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✓ of irregular size and shape

grey C.I. ⟶ turning.

work material Brittle (such as grey cast iron)

✓ of regular size and shape

work material - ductile but hard and work hardenable.

chip due to strain hardening ⟶ more harden

- feed - large
- Depth of cut - large
- tool rake - negative
- cutting fluid - absent / inadequate

$t = f \sin \lambda$

$t \uparrow f \uparrow$

then $t_c \uparrow$

ये smooth pass देगा तो chip आसानी से chip तोड़ेगा नहीं

chip thickness → more stress diff b/w दोनों Top & Bottom → ~~crack~~ ~~fracture~~ rapidly

- with multipoint cutter like milling, Broaching.

Gate 1995
discontinuous chip ⟶ mild steel + Regular
since ductile

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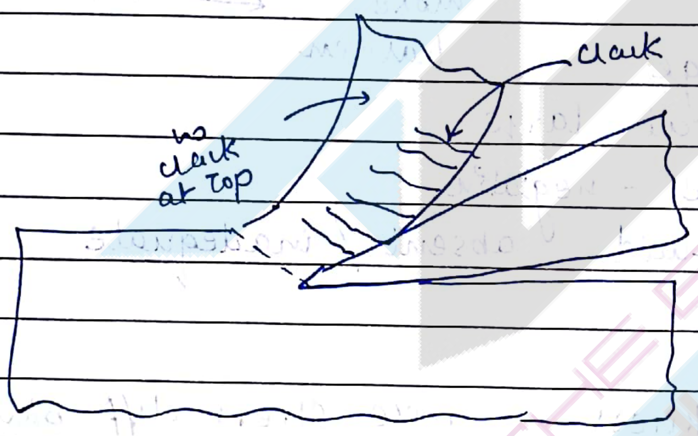
* Conditions for forming continuous chip without Built up edge.

- work material - ductile.
- cutting velocity - high.
- Feed - low
- Rake angle - positive and high.



- Cutting fluid - Both cooling and lubricating.

* Conditions for forming continuous with BUE

- work material - ductile
- cutting velocity - medium
- feed - medium
- Cutting fluid - absent / inadequate.

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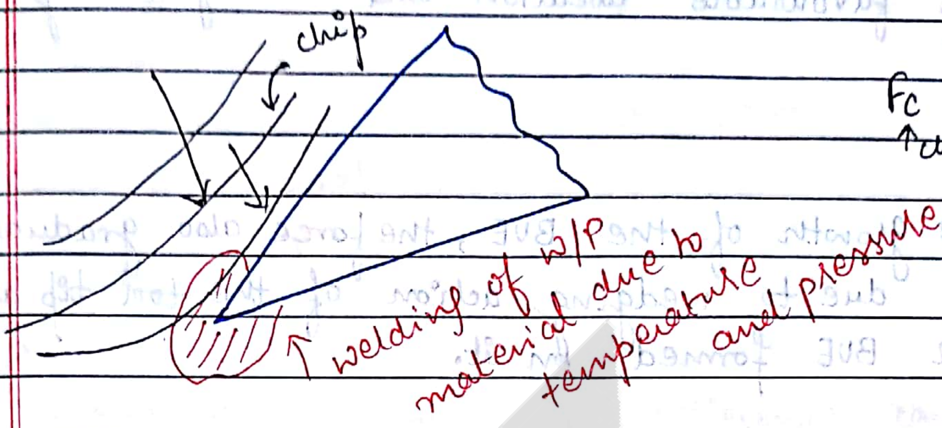
* Built - up - Edge (BUE) formation



F_c > Bonding force
↑chip

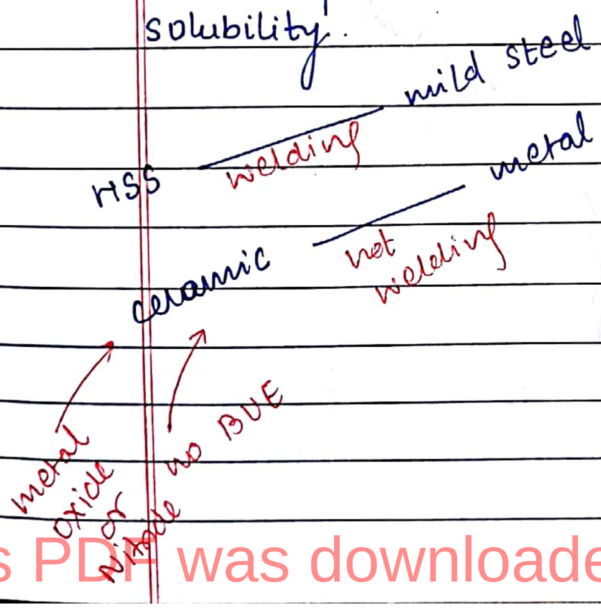
↓

chip
उखाड़
देगा
BUE.

- In machining ductile material with long chip tool contact length, lot of stress and temperature develops in the secondary deformation zone at the chip tool interface.

- Under such high stress and temperature in between 2 clean surfaces of metals, strong bonding ~~make~~ may locally take place due to adhesion similar to welding.

- Such bonding will be encouraged and accelerated if the chip tool materials have mutual affinity or solubility.



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- The weld material starts forming as an embryo at the most favourable location and thus gradually grows.

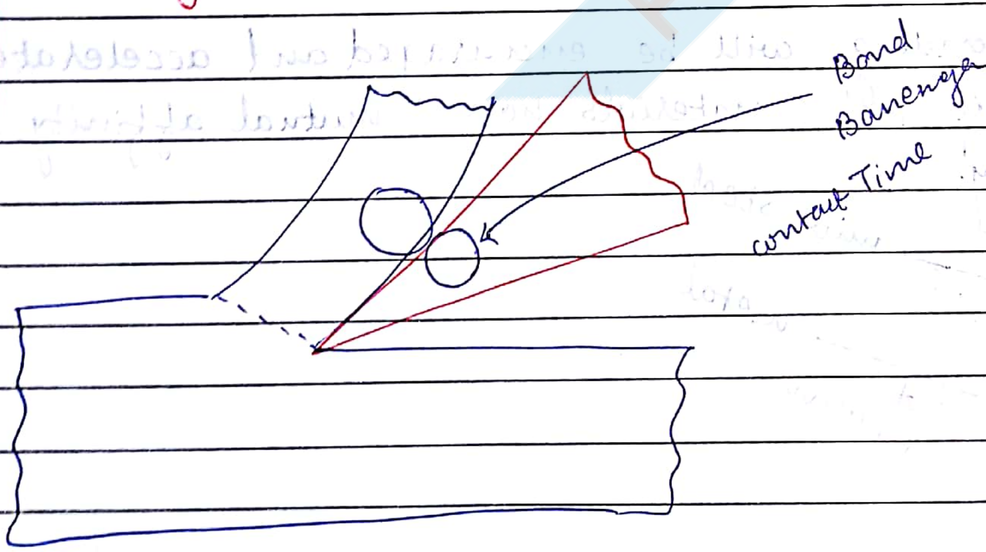
- With the growth of the BUE, the force also gradually increased due to wedging action of the tool tip along with the BUE formed on it.

- Whenever the force exceeds, the Bonding force of BUE, the BUE is broken or sheared off and taken away by the flowing chip. Then again starts forming and grow.

Temp ↓ → no BUE √ Time ↔ Reason
P ↓

- low cutting speed also contributes to the formation of BUE.
(Ex :- Milling and Broaching)

→ But high speed → Temp ↑ → welding → BUE
P ↑



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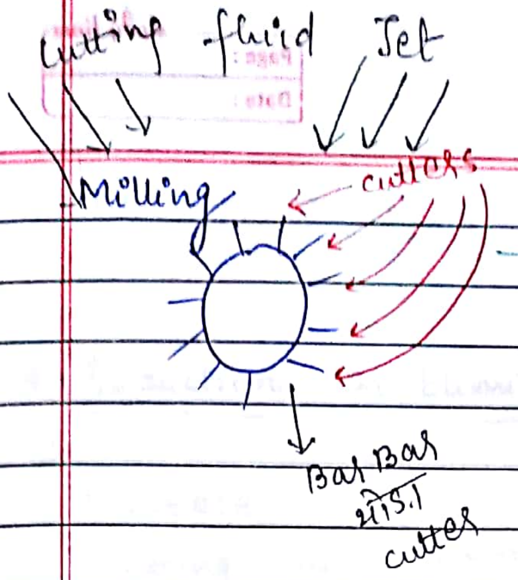
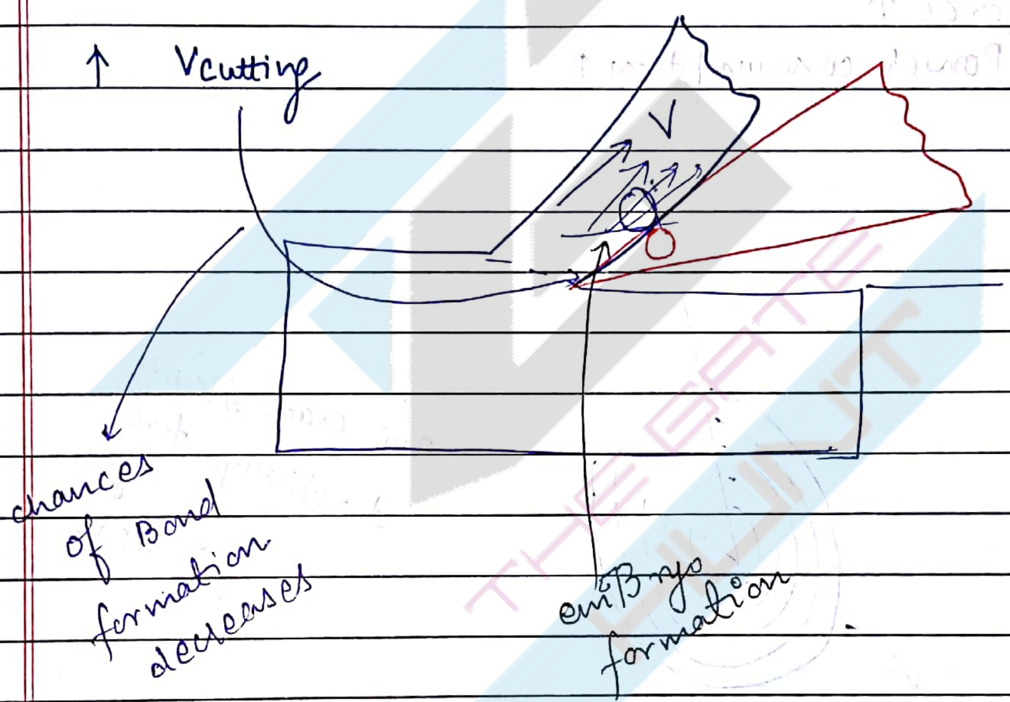


Gate 2009

Friction at the tool- chip interference can be reduced by



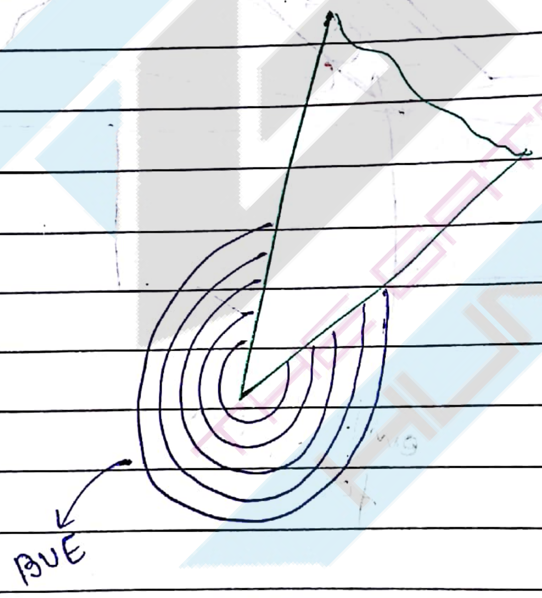
* Effects of BUE formation

- Harmful effect

✓ Poor surface finish

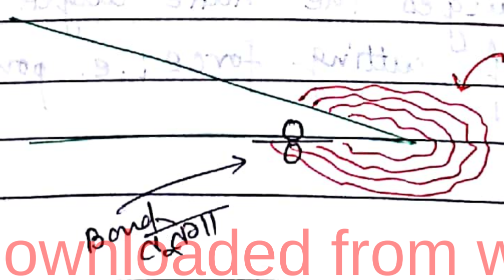
✓ It unfavourably changes the rake angle at the tool tip causing increase of cutting force i.e. power consumption.

✓ Induced vibration.



• Good Effect

✓ BUE protects the cutting edge of the tool i.e.



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increases tool life (marginally).

* Reduction or Elimination of BUE

✓ Increase

↑ cutting speed → F↓. P↓ Heat↓ Temp↓

Temp↑

↑ Rake angle

not simultaneously

✓ Decrease

↓ Feed → less amount of metal cut → less force

Temp↓

↓ Depth of cut

✓ use

- Cutting fluid → speed → no Tempr. → no bond
- Change cutting tool material (as ceramics). cermets in metal matrix

Brittle → no Bond formation.

Pg 136 → रटना है cutting tool materials

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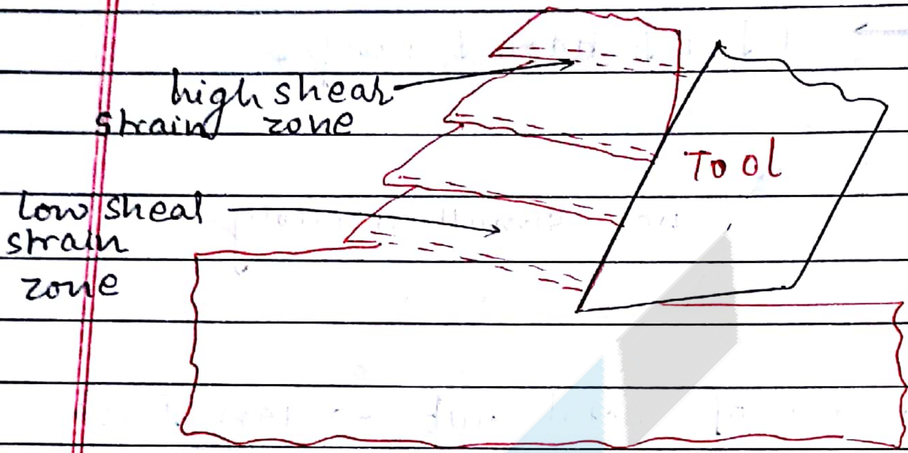
Serrated Chips

- Serrated chips also called segmented or non-homogeneous chips are semi-continuous chips with zones of low and high shear strain



- Metals with low thermal conductivity and strength that decreases sharply with tempr, such as titanium exhibit this behaviour, the chips have sawtooth like appearance

Titanium oxide → Carbide

↓ ✗ → nahin mil raha hai.

Titanium. ~~Carbide~~

Strength of Titatinium = strength of iron

But $\boxed{w_T = \frac{w_i}{2}}$

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aircraft → 20 Tonn

AC Train coach → 78 Tonn

sleeper → 56 tonn

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Alloy of Titanium → aircraft

But machining locha

Hence water Jet machining → So Tempr. ↓

* When is forced chip breaking necessary and why?

When chips continuously form and come out very hot, sharp and at quite high speed

why this chip formed?

✓ Under the condition
- soft ductile work material.
- flat rake surface with +ve or zero rake angle.

✓ For
- Safety and convenience of the operator.
- easy collection and disposal of chips.

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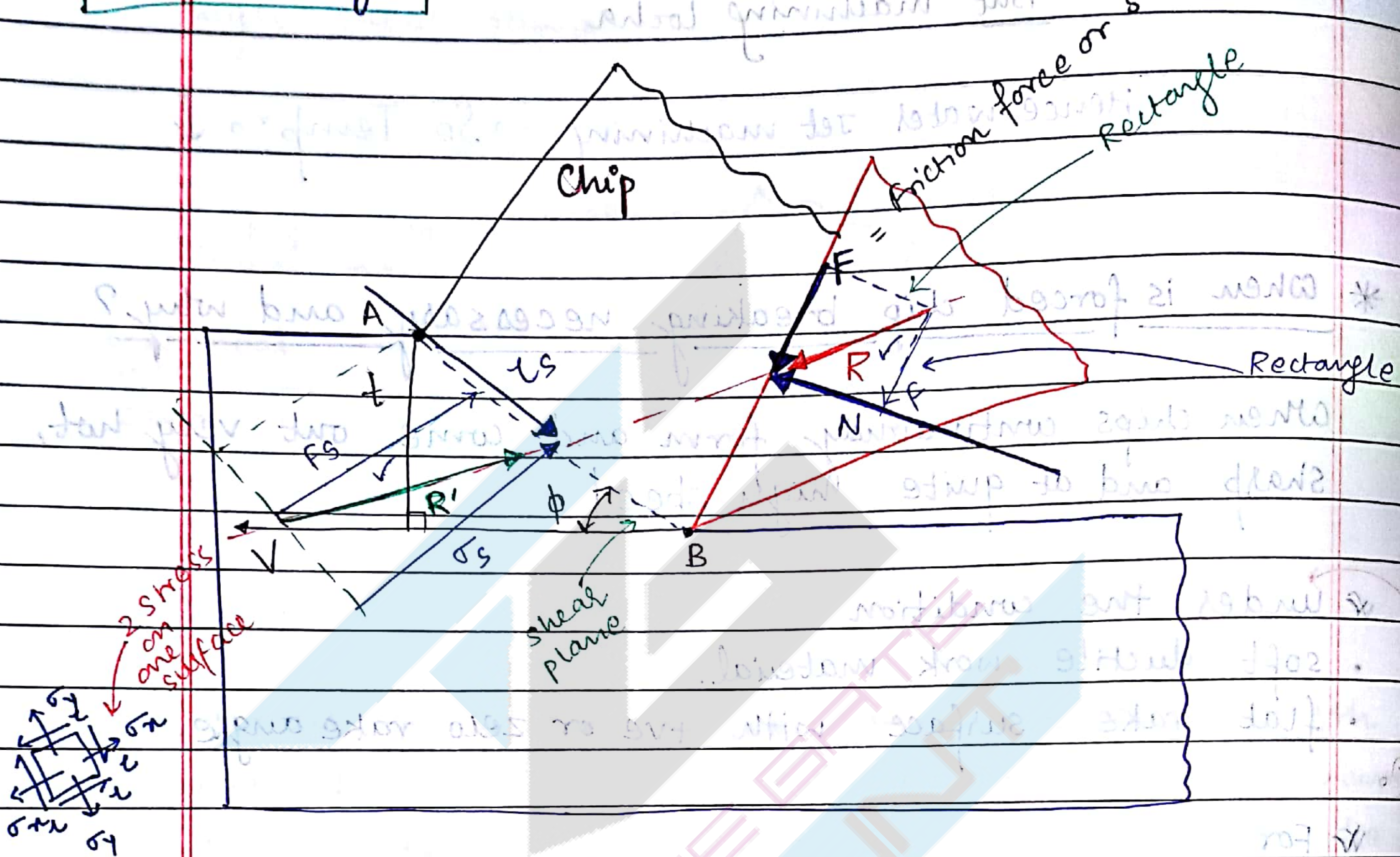
Chapter 2

ORthoGonal Metal cutting – Analysis of Metal cutting



✓ $\boxed{F = \mu N}$ → Normal Reaction

R → Resultant
F → force friction.
N → Normal Rxn.

✓ $AB = \dfrac{t}{\sin\phi}$ = Length of shear plane.

✓ area of shear plane $= \dfrac{t}{\sin\phi} \times b$ = As

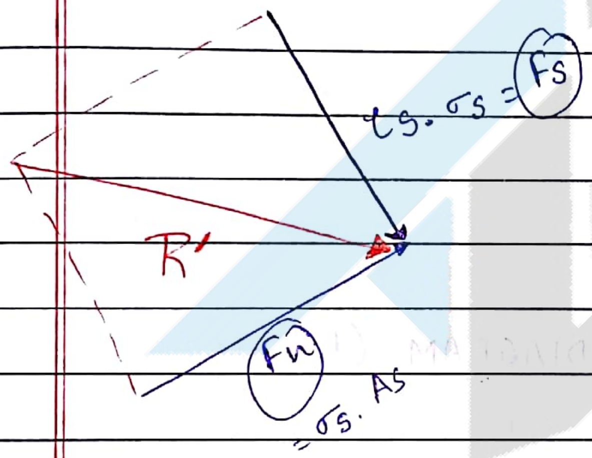
चौड़ाई

✓ Shear force on shear plane

$$F_s = \tau_s \cdot A_s = \tau_s \cdot \frac{bt}{\sin\phi}$$

✓ Normal force on shear plane

$$F_n = \sigma_s \cdot A_s = \sigma_s \cdot \frac{bt}{\sin\phi}$$



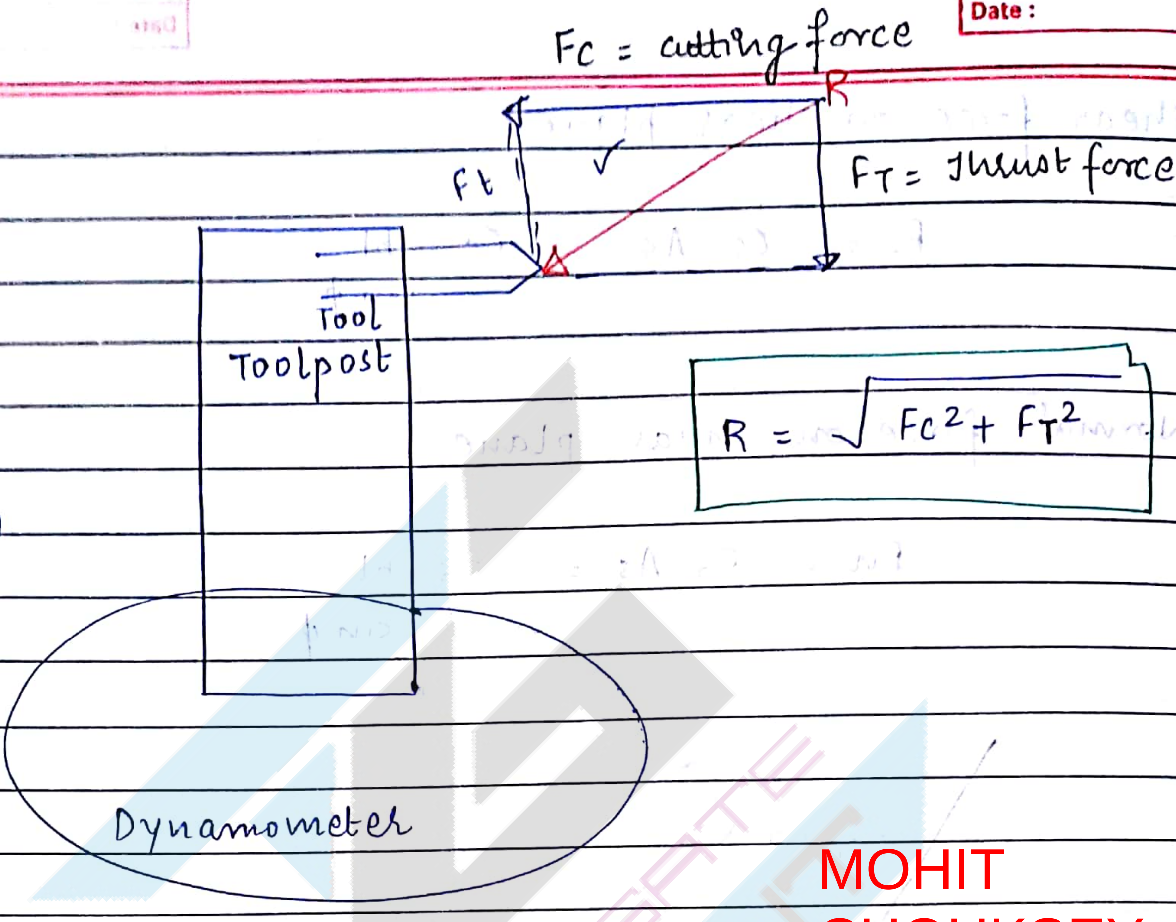
✓ as chip is moving with constant velocity V_c, net resultant force on the chip must be zero.

∴ R and R' must be equal and opposite.

4 Forces → F
N
Fs
Fn

no experimental evidence

(all 6 forces → 2D → on one plane)



$$R = \sqrt{F_C^2 + F_T^2}$$

$6C_2 = 15$

formulae

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* MERCHANT FORCE CIRCLE DIAGRAM (MCD)

3 Δ

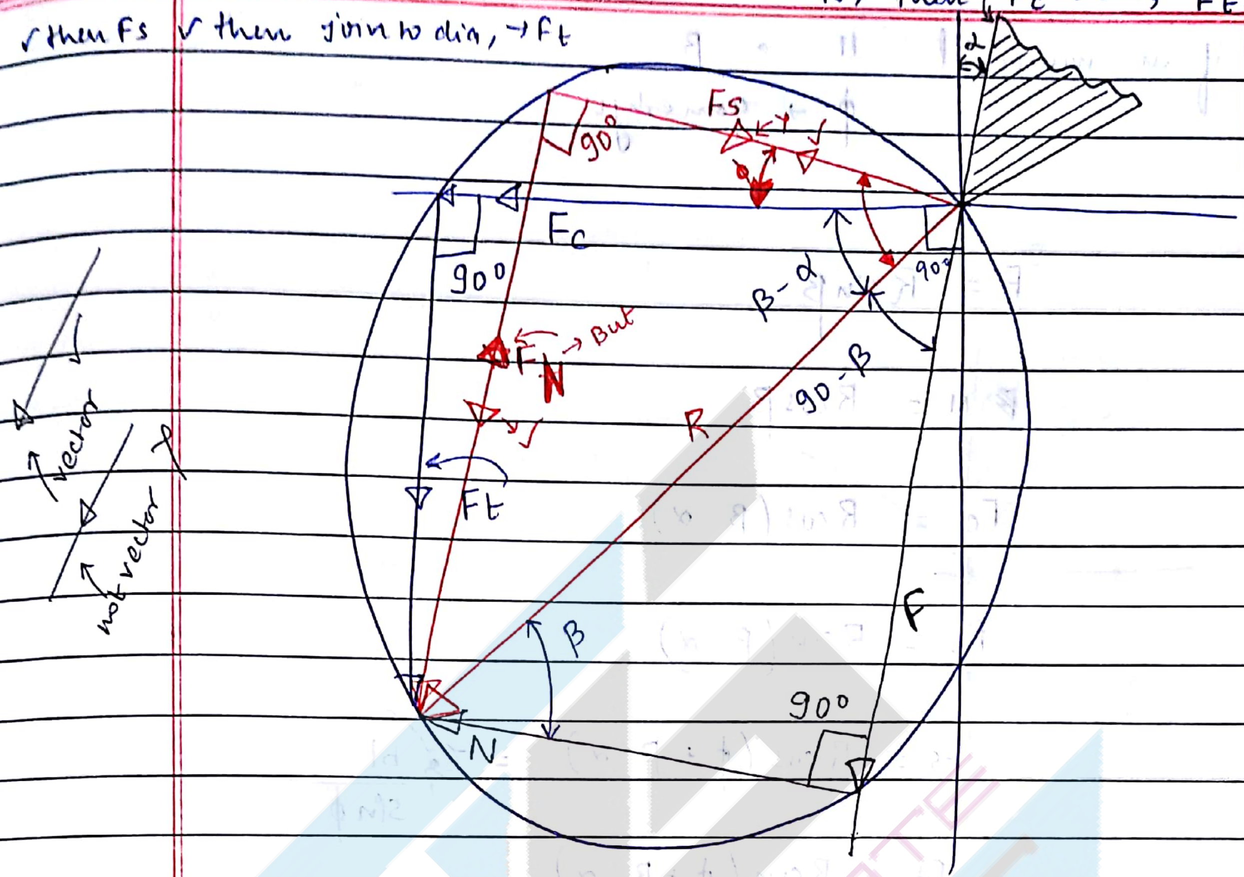
$\because R = \sqrt{F_C^2 + F_T^2}$

assume $R = 100\ kN$

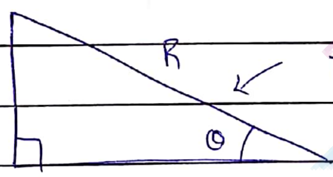
Scale : $1\ kN = 1\ mm$

$\Rightarrow 100\ kN = 100\ mm$

✓ first O → dia 100 mm
✓ then R ←
✓ then R → ← | vertical, —— horizontal line draw
✓ then angle α, ✓ then F, then N, then Fc → ——, Ft →
✓ then Fs ✓ then join to dia, → Ft



Schematic Diagram



Trigonometry

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

$$\boxed{\beta = \tan^{-1}(\mu)}$$

friction angle.

if in numerical $\mu \rightarrow \beta$
$\phi \rightarrow$ ganeshji.

$$F = R\sin\beta$$

$$N = R\cos\beta$$

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

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

$$F_s = R\cos(\phi+\beta-\alpha) = \tau_s \frac{bt}{\sin\phi}$$

$$F_n = R\sin(\phi+\beta-\alpha)$$

ESE 2000 conventional

$\alpha = 10^\circ$
$r = 0.35$
$t = 0.51\,mm$
$b = 3\,mm$
(shear strength) $\sigma_s = 285\,N/mm^2$
$\mu = 0.65$

step ① $\alpha = 10^\circ$

② $\beta = \tan^{-1}(\mu) = 33.02^\circ$

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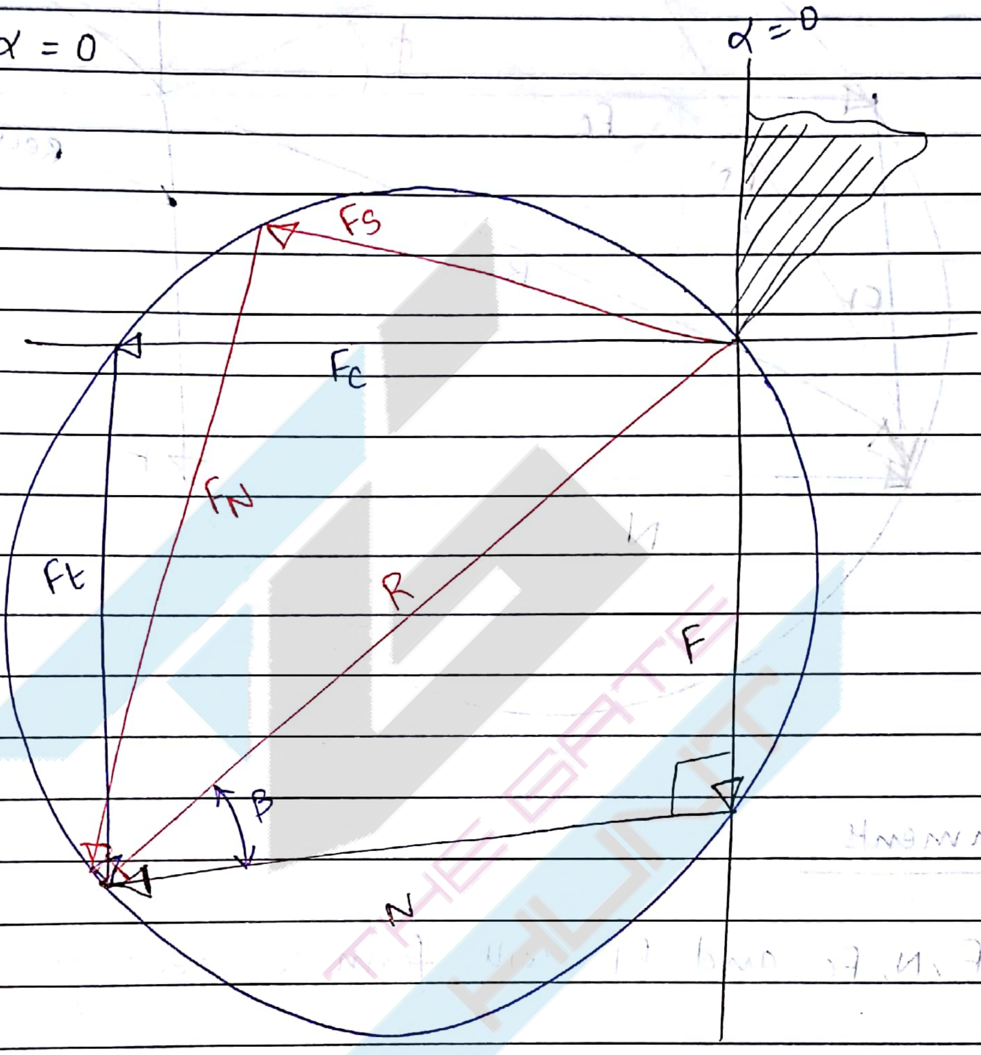
* If $\boxed{\alpha = 0}$

if $\alpha = 0$



(N.P.)

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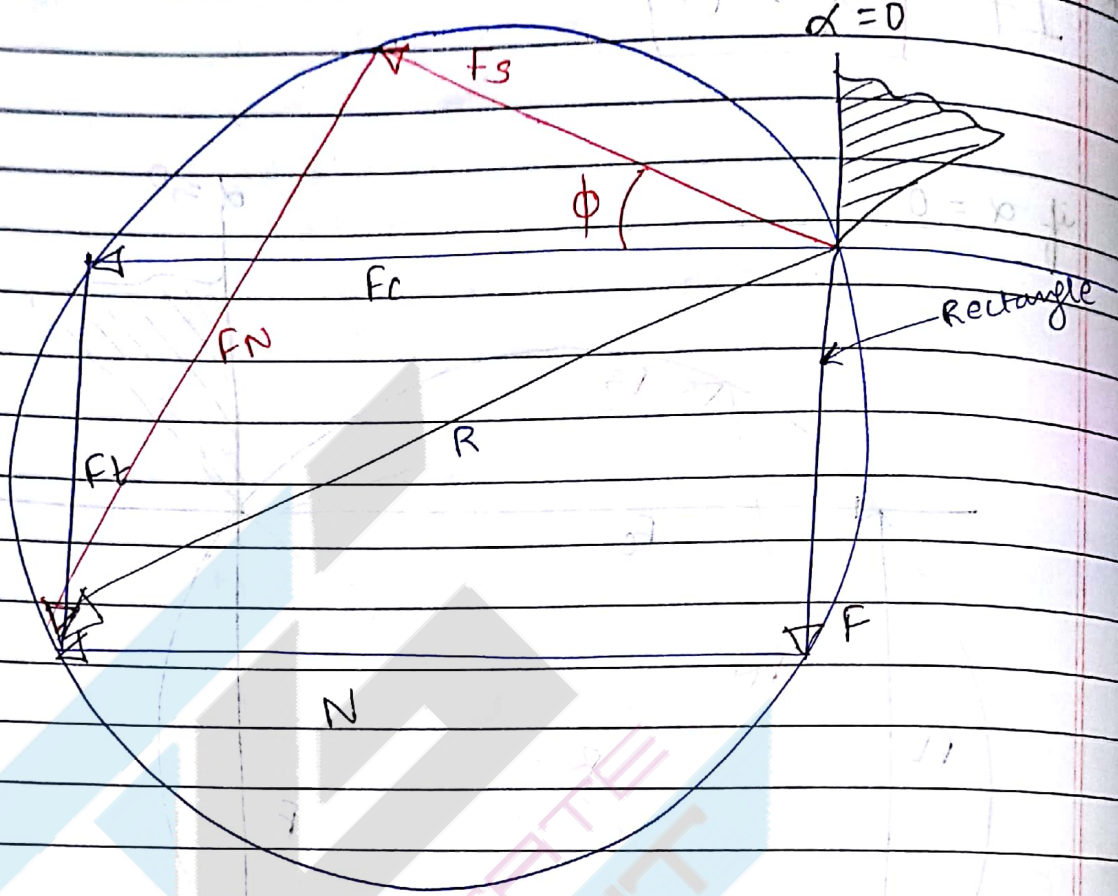

Comments

① F, N, Fc and Ft will form a rectangle.

① $\boxed{F = F_t}$ and $\boxed{N = F_c}$

② ☆☆☆☆☆

$F \perp F_c$ or $F \perp V$ means $\alpha = 0$

FIRST TOP comment

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Friction Force $\perp$ar Cutting Force $\Rightarrow$ $\alpha = 0$

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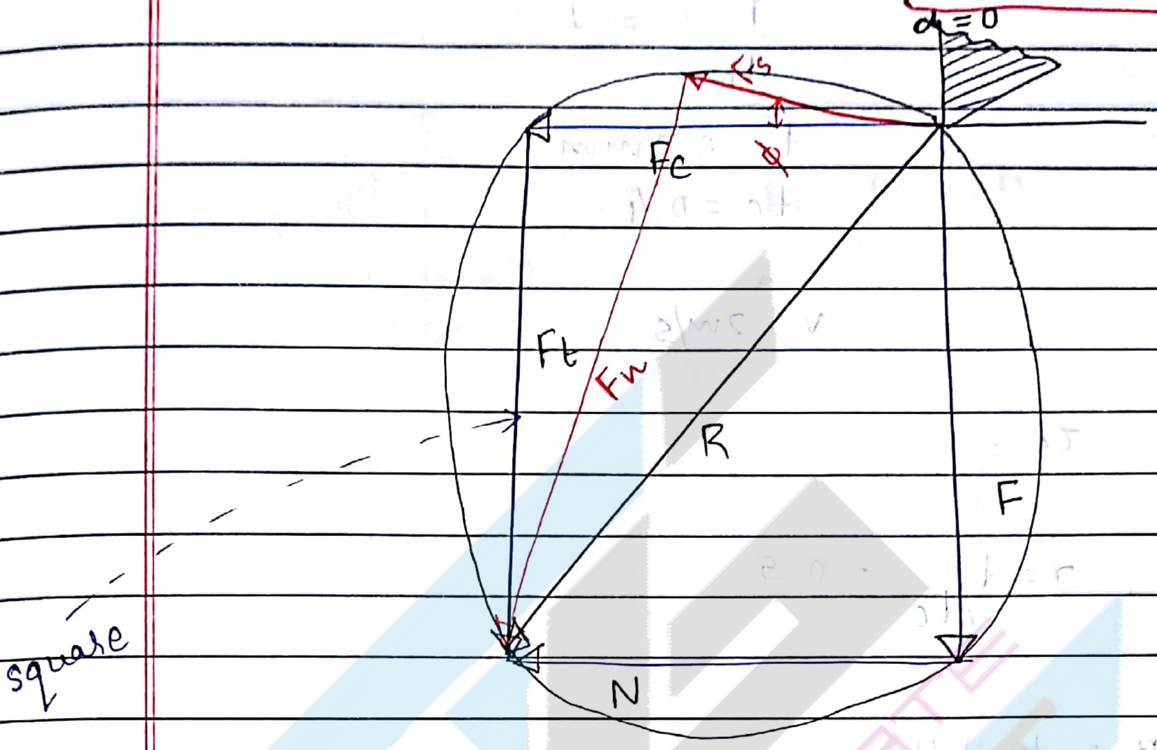
* If $\boxed{\alpha = 0}$ and $\boxed{\mu = 1}$



comments

① F = N = Fc = Ft will form a Square.

② ☆☆☆☆☆☆

$F \perp F_c$ or $F \perp V$ means $\alpha = 0$.

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~~IES?~~ GATE 2010 PI Linked S-1

Q.) $F = 402.5N$

$\alpha = 0$

$$\frac{F}{F_N} = 1$$

$t = 0.2mm$

$t_c = 0.4$

$V = 2m/s$

$\tau_s =$

$r = t/t_c = 0.5$

$\beta = \tan^{-1}\mu$

Normal R×n. → along the chip tool interface. →.

$\phi = ?$

$F = \mu N$

$402.5N = \mu$

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha \to 0}$$

$\tan\phi = r$

$$\boxed{\phi = \tan^{-1} r}$$

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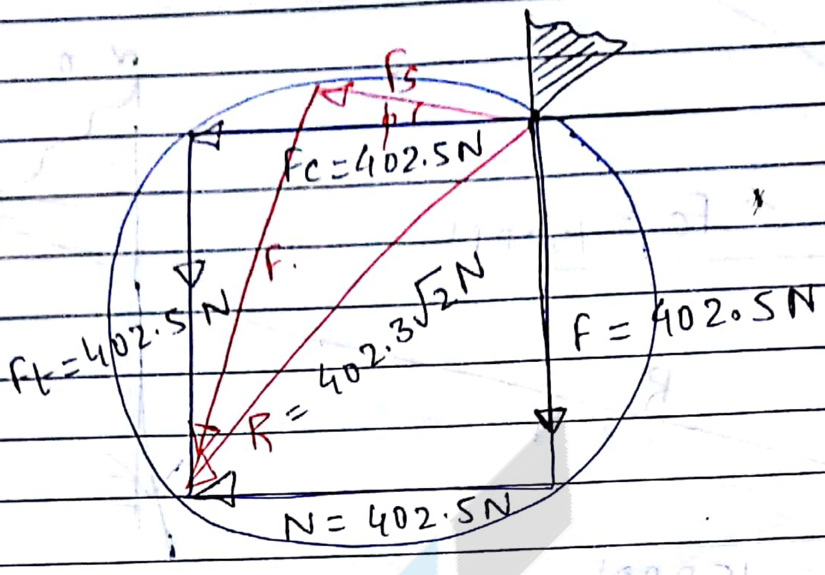
$\alpha = 0, \ \mu = 1$

SIR →



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

$$= 402.5\sqrt{2}\cos(26.56 + 45 - 0)$$

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} \qquad \phi \to 26.56^\circ$$

Q) Gate 2013 S-1

main cutting force ⊥ friction force → $\alpha = 0$

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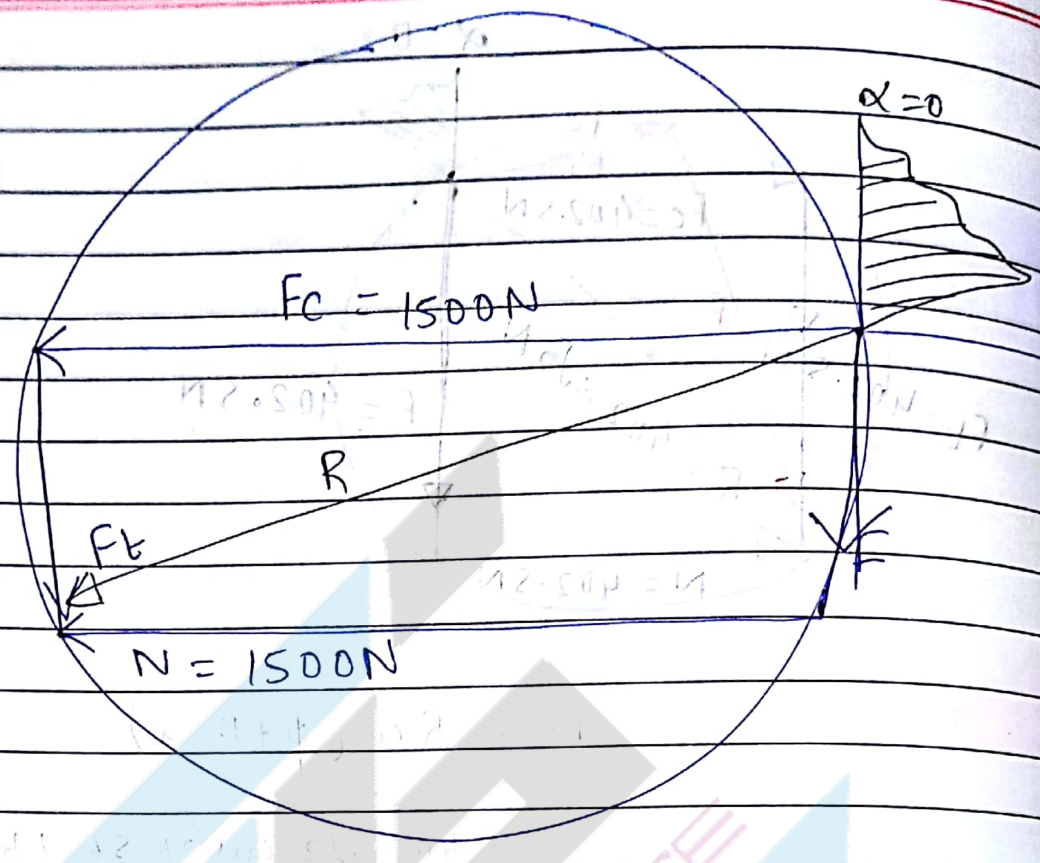
Q) Gate 2013 S-2

$d = 100\text{ mm}$ $\qquad V_c = 90\text{ m/min.}$

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

$t = \text{depth of cut} = 4\text{ mm}$



not take $\mu = 1$ if not given

Gate 2015

$\alpha = 0$

$\mu = 0.7$

$F_T = 490$

$R = \sqrt{F_c^2 + F_{T}^2}$

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

$\boxed{F_c = R \times 0.81}$

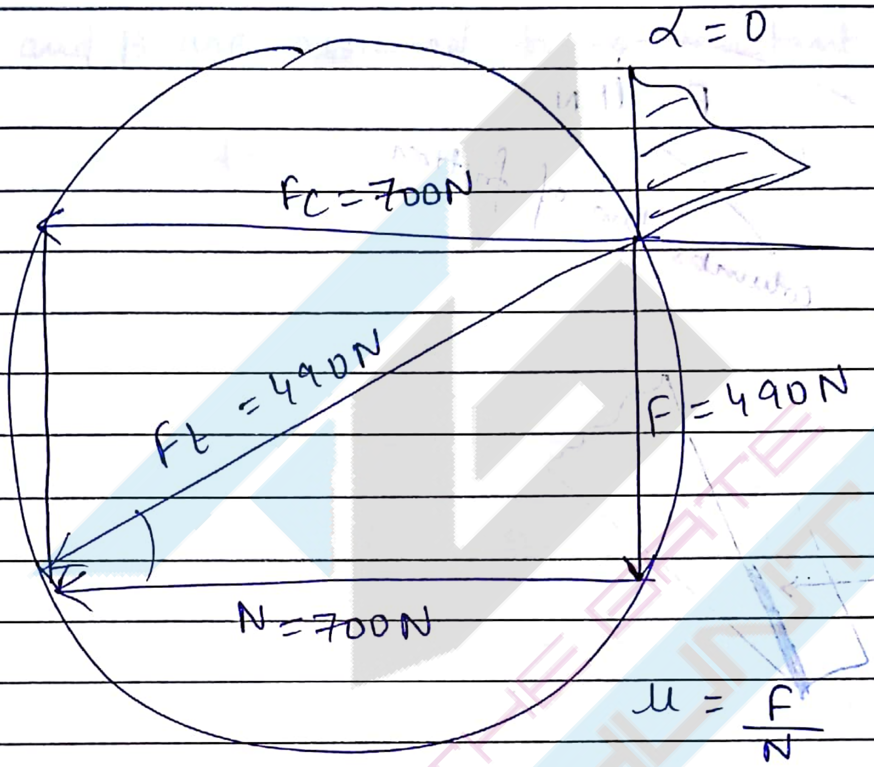
$\beta = \tan^{-1} 0.7$

$\beta = 34.99$

$$R^2 = 0.67 R^2 + 240100$$

$$0.33 R^2 = 240100$$

$$R = 852 \text{ mm}$$



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

$$0.7 = \frac{490}{N}$$

my $\longrightarrow$ Power $= F_c \cdot V$

$$= 698.0 N \times \frac{180}{60} \left(m/s\right)$$

$$= \underline{2.09 \text{ KW}}$$

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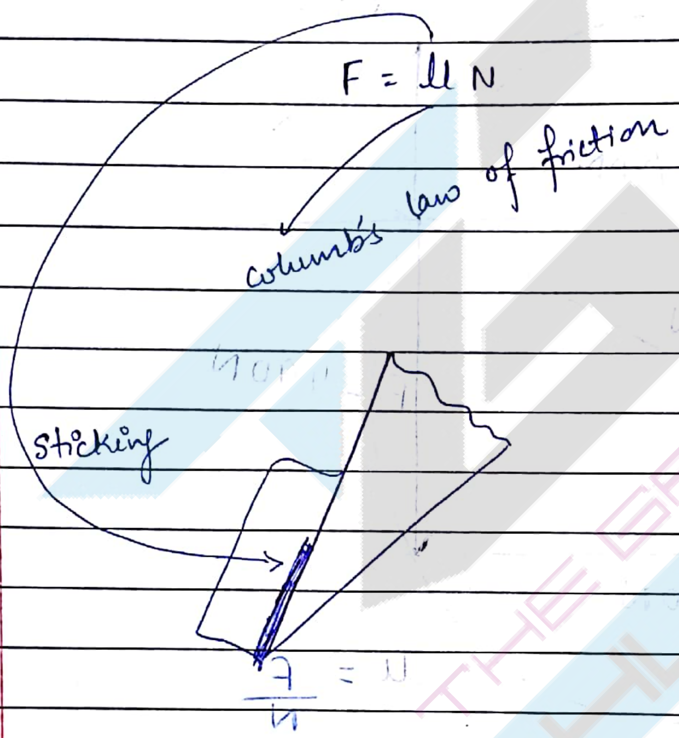
merchant circle diagram

* LIMITATIONS OF USE OF MCD

① MCD is valid only for orthogonal cutting.

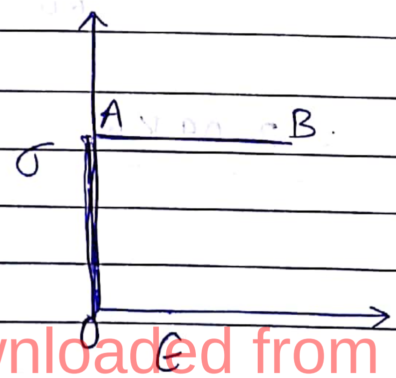
② By the ratio F/N, the MCD gives apparent (not actual) coefficient of friction.



* MERCHANT THEORY OR MERCHANT ANALYSIS

✓ Assumption

- The work material behaves like an ideal plastics. (behaviour of material)



OA – Rigid
AB – plastic.

In engineering
[plastic → polymer]

- The theory involves minimum energy principal.

उसमें ऊर्जा कम होती

no need to differentiation.

- τ_s and β are assumed to be constant, independent of ϕ.

$$\frac{d\tau_s}{d\beta} = 0$$

- It is based on single shear plane theory.

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

rad rad rad rad

याद formulae

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

for calculation

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

degree degree degree degree

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ESE 2005 Conventional.

$\alpha = 10^\circ$

$\beta = 10 \quad \tan^{-1}(0.5) = 26.56^\circ$

~~$\tan\phi = \frac{r \ldots}{\ldots}$~~

~~$r = t/t_c \rightarrow ?$~~

applying MT.

$\phi = 45^\circ + \alpha/2 - \beta/2$

then

R के लिए $\frac{\tau_s b t}{\sin\phi}$

Gate 1997 बाद में

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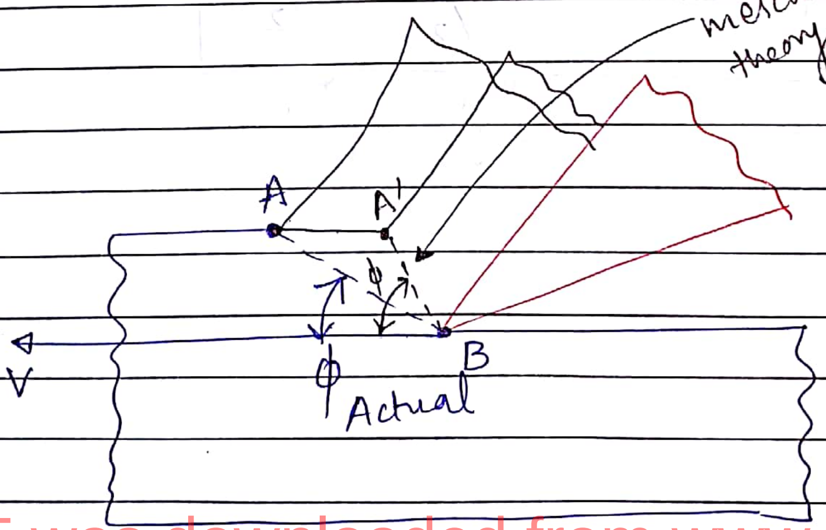
- Merchant Theory gives higher shear plane ∠ means smaller shear plane which means lower shear force.

- Result : lower cutting forces, power, temperature, all of which mean easier machining.



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$F_s = \tau_s A_s$

R ↓ → सब कुछ छोटा hojayega

Gate 2014

β ↓

φ ↑.

↓ Force

Cow - River example

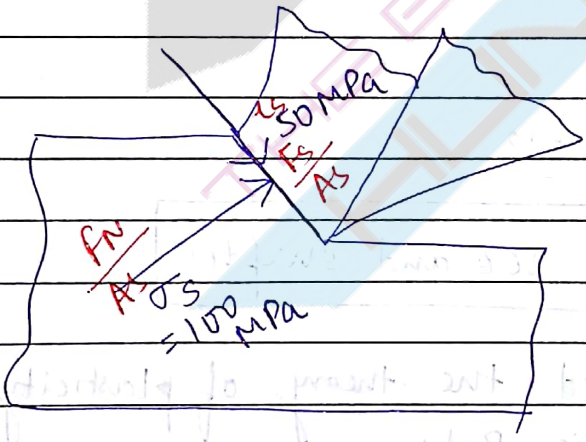
Gate 2014

(a) area of shear plane

(b) thinness → sharpness → less force.

* MODIFIED MERCHANT THEORY

Mohr circle वाला



$F_s = A_s \tau_s$

$= 50\, A_s$

80

$F_s = (A_s \tau_s + K \sigma_s)$

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$$\tau_s = \tau_{s0} + K\sigma_s$$

$$= \frac{F_s}{A_s} + K\frac{F_n}{A_s}$$

where, σ_s is the normal stress on shear plane

$$\left[\sigma_s = \frac{F_n}{A_s}\right]$$

and then $2\phi + \beta - \alpha = \cot^{-1}(K) = C$.

merchant machinability constant

dont use this formulae in numerical solving

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Pg no. 10 + 2 = 12

✓ Theory of lee and shaffer

- They applied the theory of plasticity for an ideal-rigid - plastic Body
- They also assumed that deformation occured on a thin - shear zone

and derive $\boxed{\phi = \frac{\pi}{4} + \alpha - \beta}$

dont use this theory in numerical

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

* VIMP $\longrightarrow$ orthogonal $\longrightarrow$ dynamometer

The force relations

$$F = F_c \sin\alpha + F_t \cos\alpha$$
$$N = F_c \cos\alpha - F_t \sin\alpha$$
$$F_n = F_c \sin\phi + F_t \cos\phi$$
$$F_s = F_c \cos\phi - F_t \sin\phi$$

$\rightarrow$ easy calculation

and $\mu = F/N = \tan\beta$

Q Find $\mu = \frac{F}{N} = \tan\beta$ and $\tau_s = \frac{F_s}{A_s}$

$$\tau_s = \frac{F_s}{\frac{bt}{\sin\phi}}$$

$$\tau_s = \frac{F_s \sin\phi}{bt}$$

if Q^{n} $\rightarrow$ F_c & F_t given $\rightarrow$ then use above formulae

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Q) $F_c = 900N$

$F_T = 600N$

$\phi = 30^0$

(c) ✓

$$F_s = F_c \cos\phi - F_t \sin\phi$$

$$= \underline{900 \cos 30 - 600 \sin 30}$$

$x = 479.$

Q.7

IES 2000

$F_c = 1000N$

$F_t = 500N$

$$\mu = \frac{F}{N} = \frac{F_t}{F_c} = \frac{500}{1000}$$ ✓

Gate 2016

$\frac{F_t}{F_c}$

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****** Note → Sometimes we have to use merchant theory to find β but it will be third option.

(1) option 1 → $\beta = \tan^{-1}(\mu)$, this μ will be given in question.

(2) option 2 → we can calculate $\mu = \frac{F}{N}$ from given F_c and F_t and find β.

(3) option 3 → from merchant theory, if above 2 options fail.

$$\phi = 45^\circ + \alpha/2 - \beta/2$$

$$2\phi = 90^\circ + \alpha - \beta$$

$$\beta = 90^\circ + \alpha - 2\phi$$

$\cancel{\alpha = 0}$

Gate 2006

$$r = t/t_c = \frac{0.5}{0.7} \qquad \tan\phi = \text{—}$$

(d) ✓

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TURNING OPERATION

Page : study time
Date :

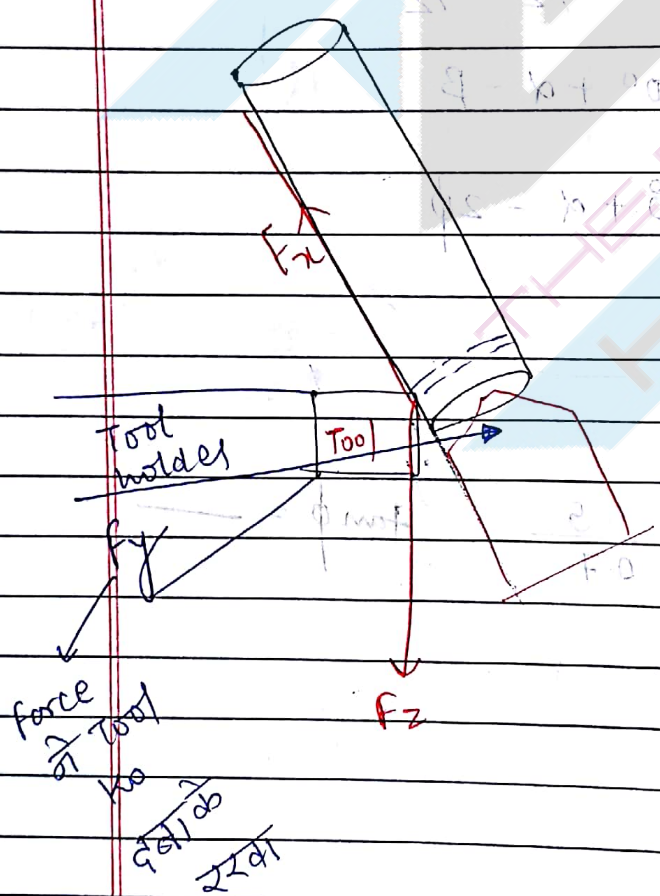
Pg. no. 14
slide 2 ✓

Feed Power $= F_x \cdot V_f$

$$V_f = fN \text{ mm/min}$$

$$= \frac{fN}{60000} \text{ m/sec}$$

$\therefore$ Feed power is $< 1\%$ of Total power



Fy → Thrust force
जो कोई power use नहीं करता
also is a Radial force.

thrust force in turning.

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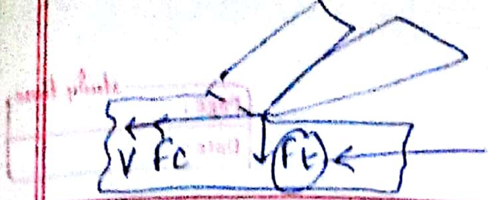

no use of power.

CONVERSION FORMULAE

we have to convert turning (3D) to orthogonal cutting (2D)

$$F_c = F_z$$

$$F_t = F_{xy} = \frac{F_x}{\sin\lambda} = \frac{F_y}{\cos\lambda} = \sqrt{F_x^2 + F_y^2}$$

EQUIVALENT ORTHOGONAL

Pg no. 15 → slide 2

orthogonal plane → Merchant's Circle
use Kalengey.

ESE 2013 Conventional → Turning data

$D = 160$ mm

$\alpha = 0$
$\lambda = 75$ } ORS

$d = 4.0$ mm

$N = 400$ rpm

$f = 0.32$ mm/rev

$F_z = 1200$ N, $F_x = 800$ N, d_2

$t_c = 0.8$ mm

$F_c = F_z = 1200\,N$

$$F_t = \frac{F_x}{\sin\lambda} = \frac{800\,N}{\sin 75} = 828\,N$$

$t = f\sin\lambda = 0.32 \sin 75 = 0.3091\,mm$

$$b = \frac{d}{\sin\lambda} = \frac{4}{\sin 75} = 4.14\,mm$$

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

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

$F_s = F_c \cos\phi - F_t \sin\phi$

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha} \quad r = t/t_c$$

$$= \frac{0.3091}{0.8}$$

$\phi = 21.125$

$$P = F_c \cdot V = F_c \cdot \frac{\pi D N}{60} = \frac{1200 \times \pi \times 0.160 \times 400}{60}$$

W

$\frac{}{1000}$ kW

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28/06/2016

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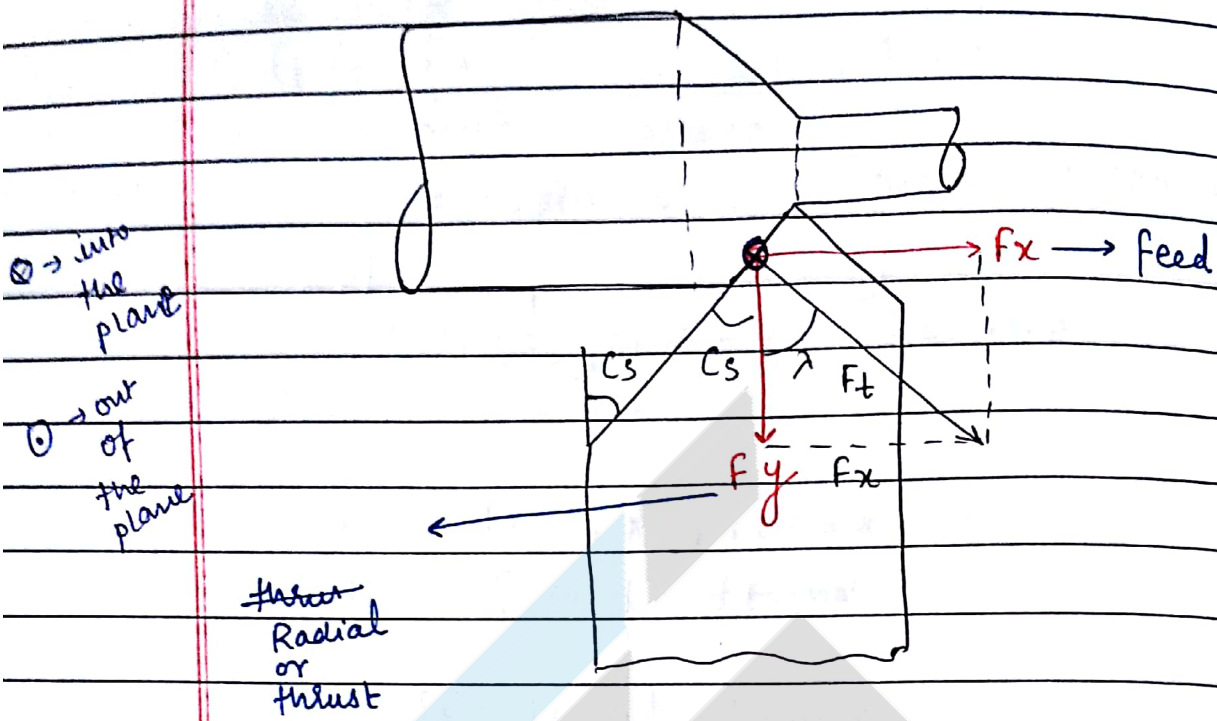

✓ Tangential force (F_z) → ⊥r to Board.

✓ $\frac{F_x}{F_t} = \sin\lambda$

✓ $F_t = \frac{F_x}{\sin\lambda}$

✓ $\frac{F_y}{F_t} = \cos\lambda$

✓ $F_t = \frac{F_y}{\cos\lambda}$

✓ $F_t = \sqrt{F_x^2 + F_y^2}$

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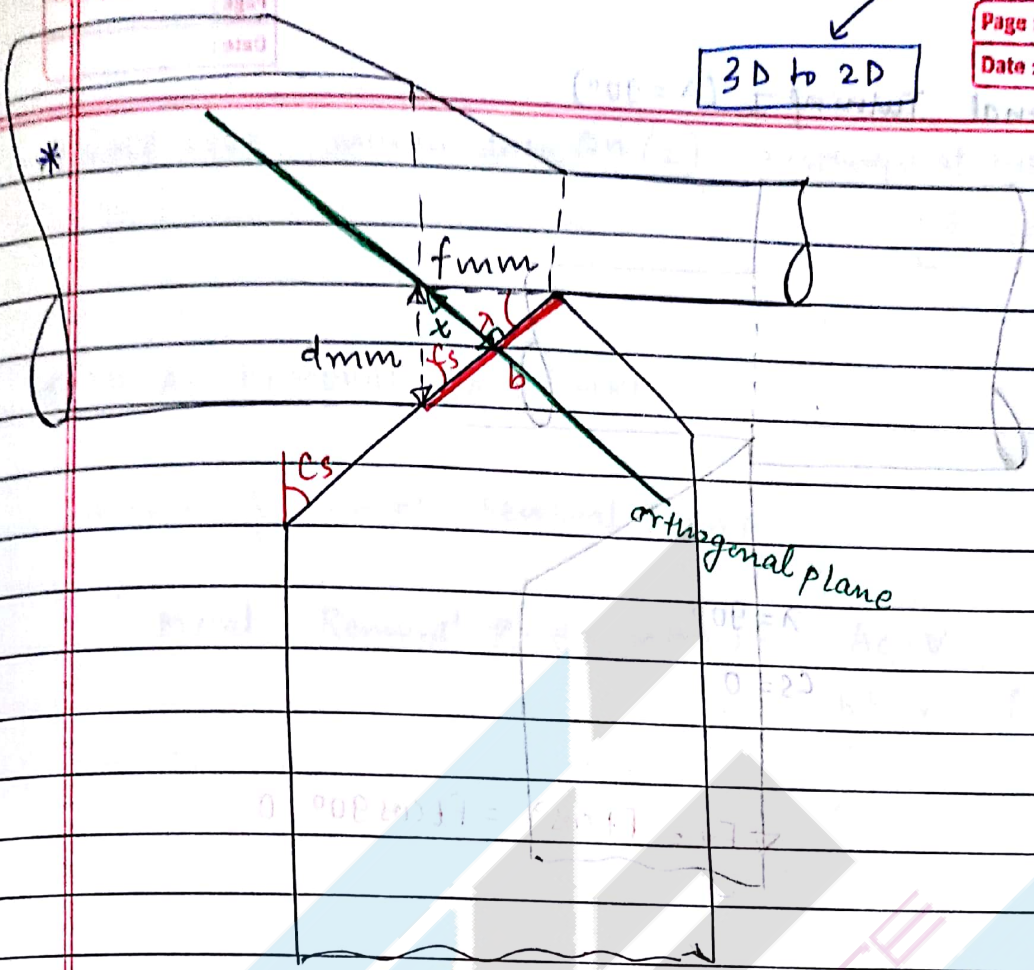
Turning → oblique → converting into orthogonal cutting

↙

3D to 2D

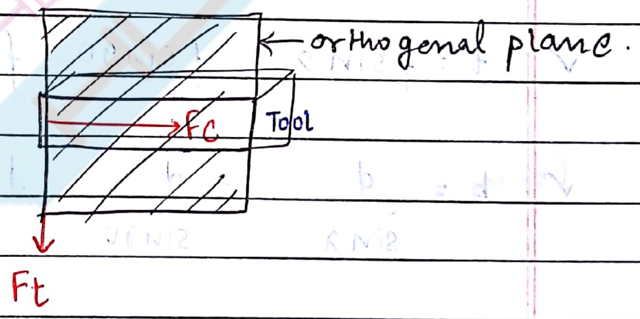


✓ f mm → transient surface.

✓ jitna cutting edge contact mein aaya → width of cut 'b'

✓ $\frac{d}{b} = \sin\lambda$

$$\boxed{b = \frac{d}{\sin\lambda}}$$



✓ $\frac{t}{f} = \sin\lambda$

$$\boxed{t = f\sin\lambda}$$

✓ $\boxed{\tan\lambda = d/f}$

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Orthogonal Turning → $\boxed{\lambda = 90^\circ}$

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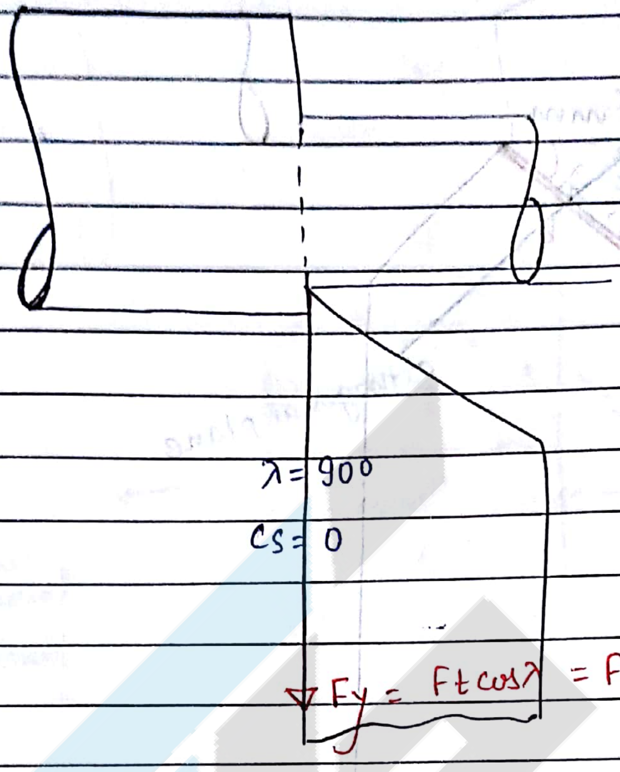
✓ Orthogonal Turning :- ($\lambda = 90^\circ$)



$F_y = F_t \cos\lambda = F_t \cos 90^\circ = 0.$

✓ $F_z = F_c$

✓ $F_t = \dfrac{F_x}{\sin\lambda} = \dfrac{F_x}{\sin 90} = F_x$

✓ $t = f \sin\lambda = f \sin 90 = f$

✓ $b = \dfrac{d}{\sin\lambda} = \dfrac{d}{\sin 90} = d.$

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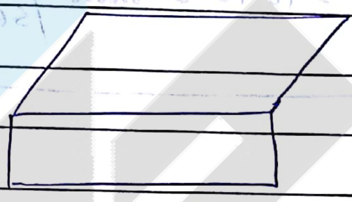
Q Gate 2003 common data Qn (1) → orthogonal Turning $\boxed{\lambda = 90^\circ}$

* METAL REMOVAL RATE (MRR).

amount of metal removal / time

$$\text{Metal Removal Rate (MRR)} = A_c \cdot V$$
$$= \underbrace{bt}_{} \cdot V = fdV.$$



$$t = f \sin\lambda$$
$$b = \frac{d}{\sin\lambda}$$
$$tb = fd$$

where A_c = c/s area of ~~unit~~ uncut chip (mm2).

IES 2004

$MRR = f \times d \times V$

$$50\,m/min \times 0.8\,mm/rev \times 1.5\,mm$$

$$\frac{50{,}000\,mm}{60\,sec} \times \frac{0.8\,mm \times 1.5\,mm}{rev}$$

$$= 60000\,\frac{mm^3}{\cancel{min}}$$

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Q> Gate 2013

200 m

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

$V = 1675.5$ mm/sec

$$MRR = 0.25 \left(\frac{mm}{rev}\right) \times 4\,mm \times 1675.5\,\frac{mm}{sec}$$

⇒ (d) ✓ $\boxed{MRR = 1675.5\ mm^3/sec}$

IES 2016

10 mm

9 mm

$d = 0.5$ mm

125 mm long

$V = \pi D N$

$= 169.6$ m/sec

$f \cdot N = 175$ mm/min

$$f = \frac{175}{360}\ mm/min$$

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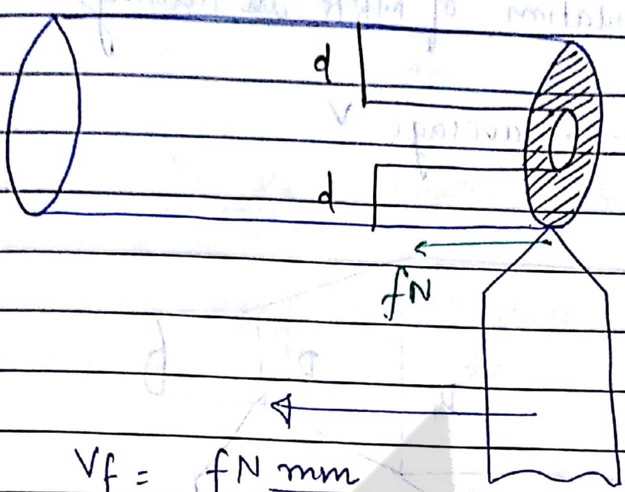
Sir →



$A_c = \frac{\pi}{4}D_1^2 - \frac{\pi}{4}D_2^2$

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

$f \times N = 175$

another method ↓ Jugaad

✓ $f = 0.48$ mm/min

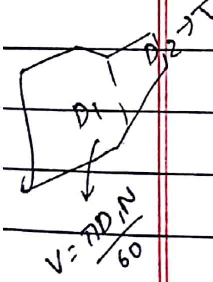
✓ MRR = 1253.49 ~~X~~

$= \frac{\pi}{4}(D_1^2 - D_2^2) fN$

fD ↑ average velocity

if calculator not given

$\frac{\pi}{4}(10^2 - 9^2) \times 175$



$\frac{\overset{11}{\cancel{22}}/\cancel{7}}{\underset{2}{\cancel{4}}}(10^2 - 9^2) \times \overset{25}{\cancel{175}}$

$\frac{11 \times 19 \times 25}{2}$

$11 \times 9.5 \times 25$

275

2612.5

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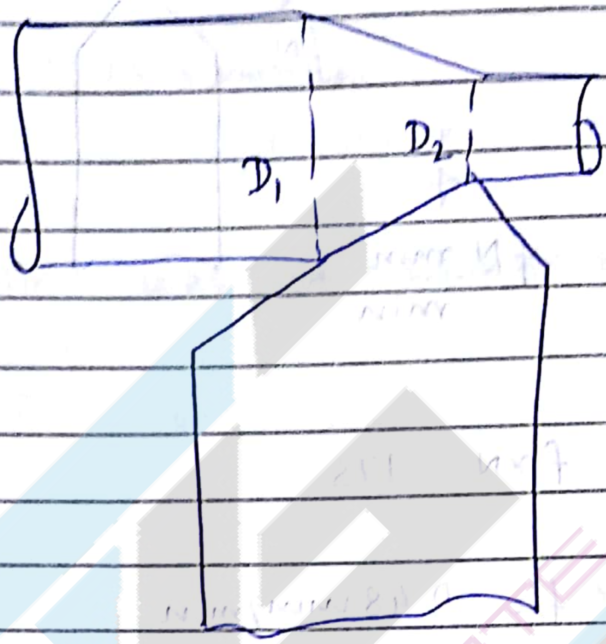
for correct calculation of MRR in turning

MRR = $f \cdot d \cdot V$, average V



Since, $MRR = \left(\frac{\pi}{4}\right)(D_1^2 - D_2^2) \times f N$

$= \pi \times \left(\frac{D_1 + D_2}{2}\right) \times \left(\frac{D_1 - D_2}{2}\right) \times f \cdot N.$

$\downarrow$ $D_{avg.}$ $\downarrow$ depth of cut d

$= \pi D_{avg} d f N$

$= f d V_{avg}.$

MOHIT CHOUKSEY

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Gate 2013

$D_1 = 200 mm$

$D_2 = 192 mm$

$\frac{D_1 + D_2}{2} = D_{avg.} = 196$

$V_{avg.} = \frac{\pi D_{avg.} N}{60} = \frac{\pi \times 196 \times 160}{60} mm/s$

$= 1642$

errored answer

is not $\neq 1675.5$

* POWER CONSUMED DURING METAL CUTTING

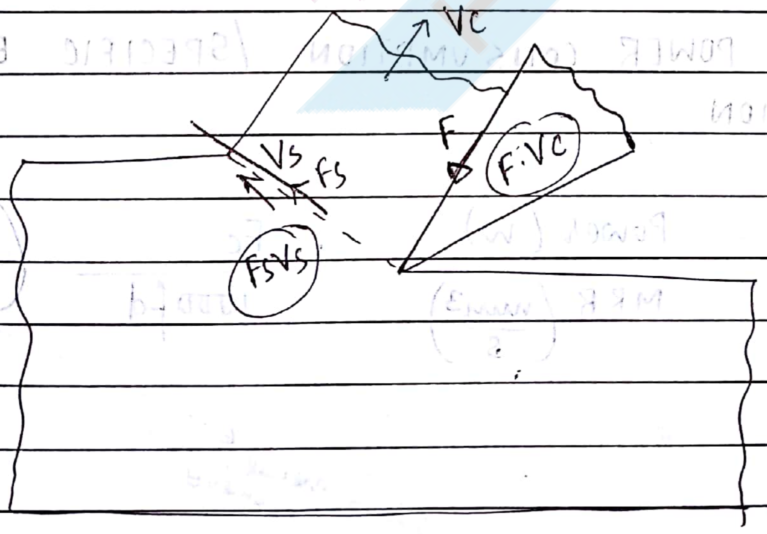
Pg.no. 17
slide 138

$F_c \times V$ (W)

N m/s

where F_c = cutting force (in N)

V = cutting speed $= \frac{\pi D N}{60}$, m/s



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$$\text{Total power} = \text{shearing power} + \text{Frictional power}$$

$$F_c \cdot V = F_s V_s + F \cdot V_c$$

65 - 70% 30 - 35%
shear sh friction

% of shearing power or heat

$$= \frac{F_s \cdot V_s}{F_c \cdot V} \times 100\%$$

% of frictional heat or power

$$= \frac{F \cdot V_c}{F_c \cdot V} \times 100\%$$

* SPECIFIC POWER CONSUMPTION / SPECIFIC ENERGY CONSUMPTION

$$e = \frac{\text{Power (W)}}{\text{MRR}\left(\frac{mm^3}{s}\right)} = \frac{F_c}{1000\,fd} \qquad J/mm^3$$

1 Joule.

1mm metal remove

MOHIT CHOUKSEY

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Sometimes it is also known as specific power consumption.

$$= \frac{F_c \cdot V}{f\, d\, V}$$

F_c → N, V → m/s; f → mm, d → mm, V → mm/s

Gate 2007

2.0 J/mm3

$V_c = 120\ m/min$

$f = 0.2\ mm/rev$

$d = 2mm$

$$= \frac{F_c \cdot V}{f d \cdot V}$$

$$\Rightarrow \quad e = \frac{F_c}{1000 f d}$$

$$\Rightarrow \quad \boxed{F_c = 800\ N}$$

P1 2016

$V_c = 120\ m/min$

$f = 0.25\ mm/rev$

$d = 4\ mm$

$$\Rightarrow \quad e = \frac{F_c}{1000 f d}$$

$$\Rightarrow \quad \frac{1 \times \cancel{3}\ J}{10^{9}6} = \frac{F_c}{1000 f d}$$

$$1 \times 10^3 \ \frac{J}{(1000)^3}$$

MOHIT CHOUKSEY

SIR → $\cancel{e = \frac{F_c \cdot V}{f \cdot d \cdot V}}$

$\cancel{1\times10^3\ J/m^3 =}$

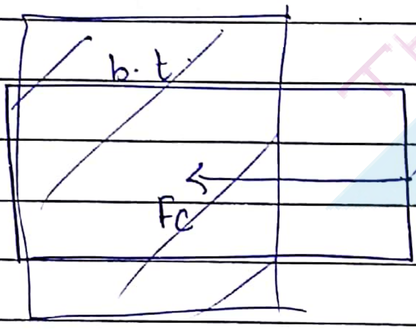
SIR → $e = \frac{F_c V}{f d V}$

$$1\times10^3\ J/m^3 = \frac{F_c}{0.25}$$

* SPECIFIC CUTTING PRESSURE

Pg. no. 18
Slide 145

The - - - - - -



Gate 2014
Q

400 N

$d = 2\,mm$

$f = 0.1\,mm$

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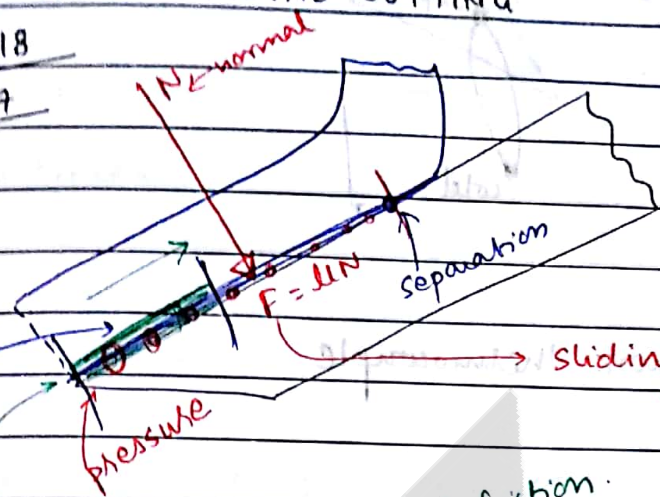
* FRICTION IN METAL CUTTING

Pg no. 18
S 147



→ sliding friction → F force
shear force
stress

each & every point shear failure in welding region

temp more so welding B/w chip and tool → hence sticking friction.

$$\boxed{\begin{aligned} \frac{F}{A} &= \mu\, N/A \\ \tau &= \mu p \end{aligned}}$$

Gate 1993 ✓

IES 2000

IES 2014

MOHIT CHOUKSEY

* HEAT DISTRIBUTION

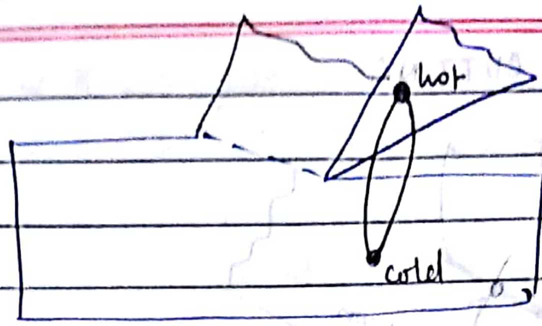
Pg 18
slide 149

* Determination of cutting heat and tempr. experimentally

Pg no. 19
slide 157

$F_c \cdot V \times$ time

unit time mein heat



Tool- work thermocouple

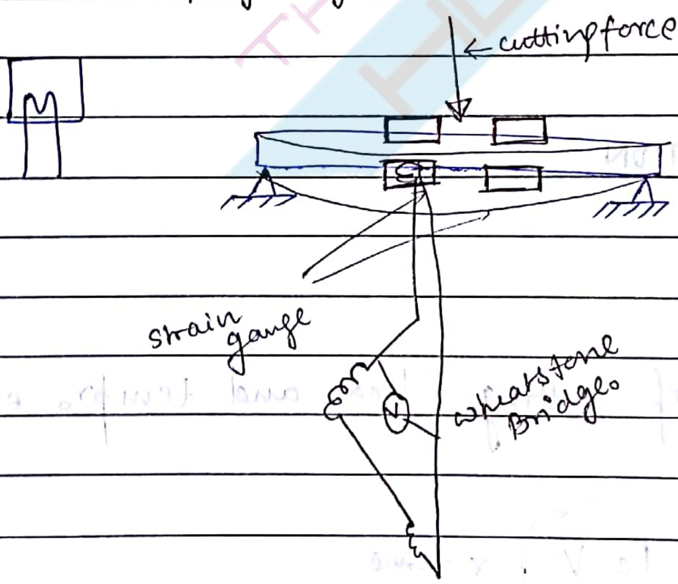
* DYNAMOMETER

Pg 19 — A
S 59 — T

* TYPES OF DYNAMOMETERS.

Pg 20
S 163

S 164 → strain gauge dynamometer.



8

MOHIT CHOUKSEY

study time
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NEW CHAPTER-3

* TOOL WEAR, TOOL LIFE, ECONOMICS & Machenability

Pg.no. 20
S. 171

Tool Failure

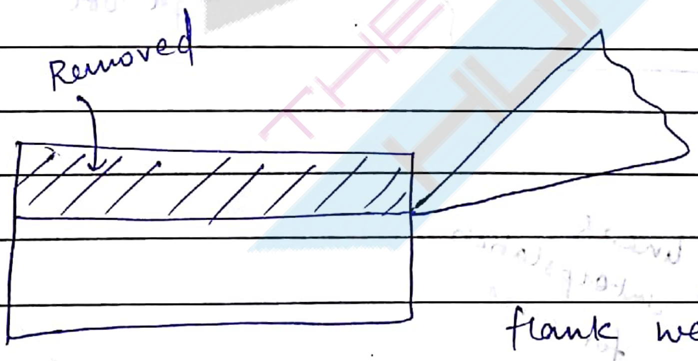
Two types:-

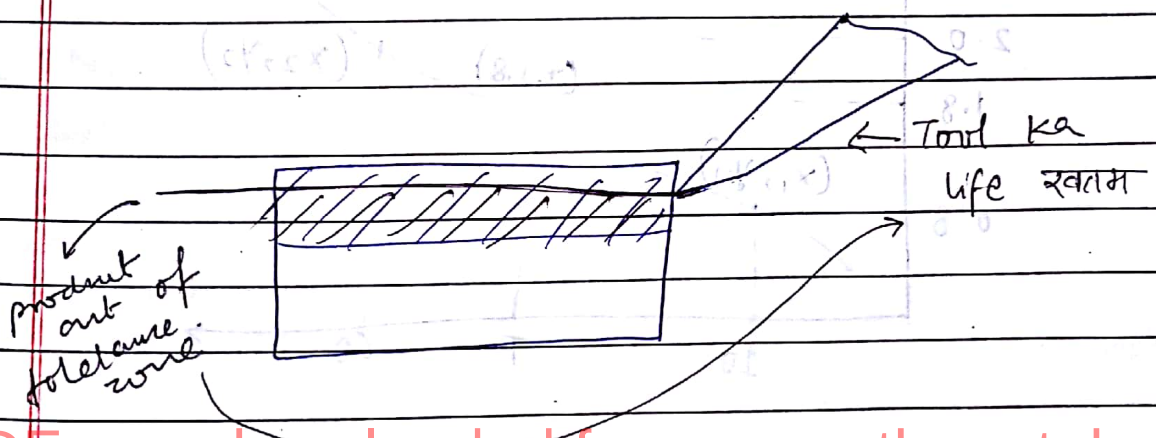
1. Slow - death
2. Sudden - death

1. Slow - death → Pg 20 (slide 169)

Pg 21
S 175

Crater wear   flank wear
↓
ज्यादा दुरवी
↓
Product dimension affected.





* FLANK WEAR : (wear land)

ppt → Reason 177 ppt

ppt 179

ppt 180

✓ Flank wear : (wear land)

Effect

✓ F →

stages

Primary → very rapidly

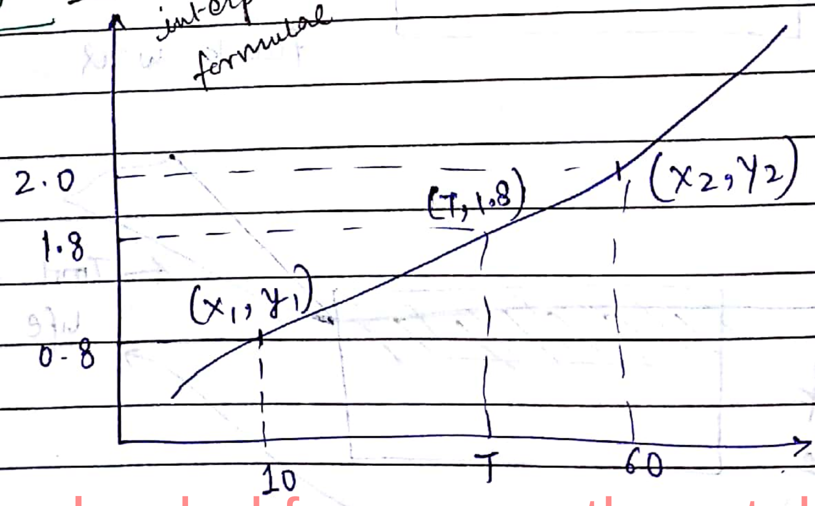
Secon. → slowly

Tertia. → rapidly

due to heat aur ghisaai hoga Tool

IES 2004

Gate 2008 (P1) → linear interpolation formulae



$$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}$$

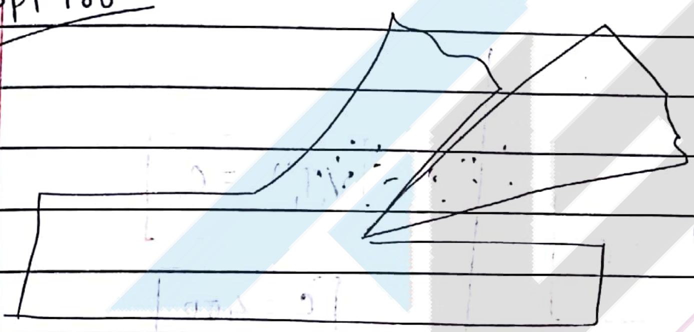
$$\frac{\overset{\nearrow 10.8}{y} - 0.8}{20 - 0.8} = \frac{\overset{\nearrow T}{x} - 10}{60 - 10}$$

✓ Tool life criteria ISO

ppt 187

✓ Crater wear

ppt 188



Tempr. of Tool ↑ of atom

Tempr. of chip ↑ of atom

molecule exchange → diffusion.

IAS 2007

IES 1995

✓ Wear Mechanism.

✓ slide 199.

MOHIT CHOUKSEY

✓ Notch Wear

slide 201

slide 203

slide 206

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✓ TOOL LIFE

Slide 207

✓ Taylor's Tool Life Eqn.

Q) $V = 100\ m/min$, $T = 16\ min$ | $V = 200\ m/min$, $T = 4\ min$

$n\ \&\ C = ?$

$VT^n = C$

$$\boxed{V_1 T_1^n = V_2 T_2^n = C}$$

$$\frac{100}{200} \cdot 16^n = 4^n$$

$$\frac{1}{2} = \left(\frac{1}{4}\right)^n$$

$$2^1 = 4^n$$

$$2^1 = 2^{2n}$$

$$2n = 1$$

$$\boxed{n = 1/2}$$

$$\boxed{V_1 T_1^n = C}$$

$$\boxed{C = 400}$$

ans → $\boxed{0.5\ \&\ 400}$

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Gate 2009 (P1)

$$VT^n = C$$

$$100\,(10)^n = 75\,(30)^n$$

$$1.333 = (3)^n$$

$$\frac{100}{75} = \left(\frac{30}{10}\right)^n$$

But $3^n = 4/3$

$$n \ln 3 = \ln(4/3)$$

$$n = \frac{\ln(4/3)}{\ln(3)}$$

$$\boxed{n = 0.26}$$

Calculator

But in case of virtual calculation

SOLVE f^n.

$$x^2 - 4 = 0$$

alpha + solve =

shift + solve

$$x^2 - 4 = 0$$

now, $100 \times 10^{\wedge}(x) = 75 \times 30^{\wedge}(x)$

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✓ Calculator steps → ALPHA + X ⇒ X
ALPHA + solve → =
and shift + solve → ans → 2bar में ans aayga

$$\boxed{100 \times 10^n = 75 \times 30^n}$$ ← इस eqn. ko calc. se solve karo

Gate 2016

$n = 0.25$

$V_1 = 50\%$

$V_2 = \frac{V_1}{50}$

$V_1, \quad V_2 = V_1/2$

$$V_1 T_1^n = V_2 T_2^n$$

$$\cancel{V_1} T_1^n = \frac{\cancel{V_1}}{2} T_2^n$$

$$\left(\frac{T_1}{T_2}\right)^n = \frac{1}{2}$$

$$\frac{T_1}{T_2} = 0.0625$$

~~$T_2 - T_1$~~
~~ΔT~~

$$\boxed{T_2 = 16 T_1}$$ Ans.

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$$\Delta T = T_2 - T_1$$
$$= 16 T_1 - T_1$$
$$\boxed{\Delta T = 15 T_1}$$

Ans

$$\frac{T_2 - T_1}{T_1} \times 100\%$$

$$\frac{15 \cancel{T_1}}{\cancel{T_1}} \times 100\%$$

15 %

Gate 2010

$A \rightarrow V T^{0.45} = 90$

$B \rightarrow V T^{0.3} = 60$

$x T_A^{0.45} = 90$

$x T_B^{0.3} = 60$

$$\Rightarrow T_A = \left(90/x\right)^{1/0.45}$$

MOHIT CHOUKSEY

$$T_A > T_B$$

$$\left(\frac{90}{x}\right)^{1/0.45} > \left(\frac{60}{x}\right)^{1/0.3}$$

$\Downarrow$

$(90 \div x) \wedge (1 \div 0.45) = (60 \div x) \wedge (1 \div 0.3)$

$$\left(\frac{90}{x}\right)^{1/0.45} = \left(\frac{60}{x}\right)^{1/0.3}$$

$$\left(\frac{90}{x}\right)^{0.3} = \left(\frac{60}{x}\right)^{0.45}$$

$$\frac{x^{0.45}}{x^{0.3}} = \frac{(60)^{0.45}}{(90)^{0.3}}$$

Gate 2013

$$VT^{1.6} = 3000 \longrightarrow xT^{1.6} = 3000$$

$$VT^{0.6} = 200 \longrightarrow xT^{0.6} = 200$$

$$VT^{1.6} = 3000 \checkmark$$

$$\cancel{T_c^{1.6} \quad T_{HSS}^{0.6}}$$

$$\not{0}$$

$$\boxed{T_c > T_{HSS}}$$

Tool life only

$$\left(\frac{3000}{x}\right)^{1/1.6} > \left(\frac{200}{x}\right)^{1/\cancel{200}0.6}$$

$$\boxed{\left(\frac{3000}{x}\right)^{1/1.6} = \left(\frac{200}{x}\right)^{1/0.6}}$$

$$\boxed{x = 39.38 = V}$$

20/06/2016

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Example

	V_1	V_2	V_3	V_4	V_5
Cutting speed, m/min	49.74	49.23	48.67	45.76	42.58
Tool life, min	2.94	3.90	4.77	9.87	28.27
	T_1	T_2	T_3	T_4	T_5

$V_1 T_1^n = C$ — (i)

$V_2 T_2^n = C$ — (ii)

$V_3 T_3^n = C$ — (iii)

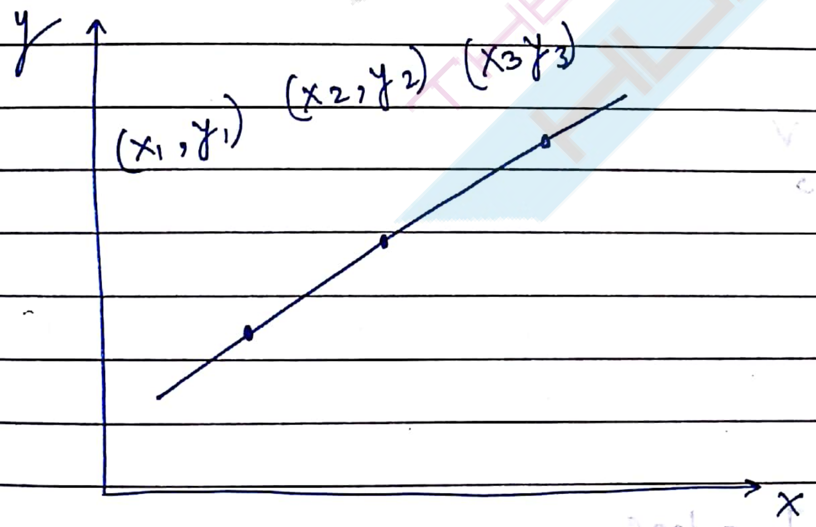
$V_4 T_4^n = C$ — (iv)

$V_5 T_5^n = C$ — (v)

5 eqn.'s → 5 eqn. + 2 unknown

use all 5 eqn's

⇒ **Linear Regression analysis**



$y = A + Bx$

$y_1 = A + Bx_1$

$y_2 = A + Bx_2$

$y_3 = A + Bx_3$

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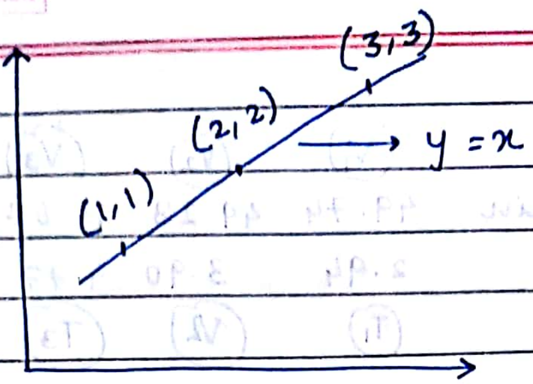
Ex →



$y = 0 + 1 \cdot x$

$\boxed{\text{Note}}$ → · calculator

shift + Mode + 3 + = → all clr since statistical data.

1, 1 $\boxed{DT}$ $n = 1$

2, 2 $\boxed{DT}$ $n = 2$

3, 3 $\boxed{DT}$ $n = 3$

MF

→ then AC then shift 2 → A B C
1 2 3

A B V
1 2 3

1 $\boxed{=}$

A = 0

✓ $\log V + n \log T = \log C$

$(\log V) = (\log C) - (n)(\log T)$

$y = A + Bx$

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$\boxed{\log V = y}$ $\boxed{\log C = A}$ $\boxed{n \to B}$ $\boxed{\log T = x}$

$\underbrace{x_1}, \underbrace{y_1}, \quad \log T_1, \log V_1 \quad \underbrace{\log 2.94}, \underbrace{\log 49.74}$

$n = 1$

$x_2, y_2, \quad \log T_2, \log V_2, \quad \log 3.90, \quad \log 49.23$

$x_3, y_3 \quad \log 4.77, \quad \log 48.67$

$x_4, y_4 \quad \log 9.87, \quad \log 45.76$

$x_5, y_5 \quad \log 28.27, \quad \log 42.58$

$A = 1.733 = \log C \Rightarrow \boxed{C = 10^{1.733} = 54}$

$B = -0.07 = -n$

$n = 0.07$

$$\boxed{VT^{0.07} = 54}$$

* $\boxed{\text{VIRtual}}$ $\rightarrow \quad y = A + Bx$

Σ

$\Rightarrow \quad \Sigma y = An + B\Sigma x$ ------- (1)

$\Rightarrow$ Now, $xy = Ax + Bx^2$

$\Rightarrow \quad \Sigma x y = A\Sigma x + B\Sigma x^2$ ------- (2)

x	y	xy	x^2
1	1	1×1	1^2
2	2	2×2	2^2
3	3	3×3	3^2
$\Sigma x = 6$	$\Sigma y = 6$	$\Sigma xy = 14$	$\Sigma x^2 = 14$

Now $6 = A\cdot3 + B\cdot6$ —— (1)

$14 = A\cdot6 + B\cdot14$ —— (2)

Gate 2003 → 500   50 rpm   f 0.25 mm/rev, t/d 01 mm

122   80 rpm   f 0.25 mm/rev, t 1 mm

?   60 rpm

Soln → Now, $VT^n = C$

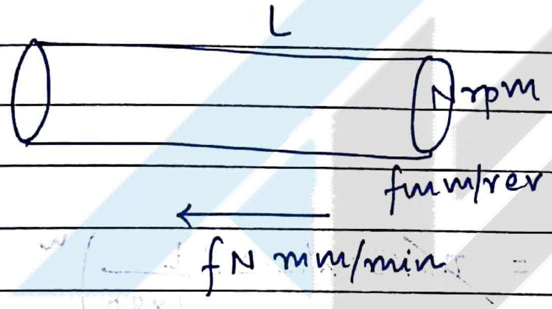
V → $\left(\frac{m}{min}\right)$, T → (min)

500 comp.

$V_1 = \pi D \times 50$ m/min

$T_1 = 50 \times T_1$ min ↓ Time req. to produce one component.

*** $\boxed{\text{NOTE}}$ → in any question if no. of part produce is given
** tool life req. to no. of part produce × time req. to produce one component.



$$\boxed{t = \frac{L}{fN} \text{ min.}}$$

time req. to produce one component

$$t_1 = \frac{L}{f \times 50} \text{ min}$$

$$t_2 = \frac{L}{f \times 80} \text{ min}$$

$$t_3 = \frac{L}{f \times 60} \text{ min.}$$

hence

$$T_1 = 50 \times t_1$$

$$T_1 = \cancel{50} \times \frac{L}{f \times \cancel{50}} = L/f \text{ min}$$

$$V_2 = \pi D \times 80 \text{ m/min}$$

$$T_2 = 12.2 \times \frac{L}{f \times 80} \text{ min.}$$

$$V_1 T_1^n = V_2 T_2^n$$

$$\Rightarrow \cancel{\pi D} \times 50 \times \left(\frac{L}{f}\right)^n = \cancel{\pi D} \times 80 \times \left(12.2 \times \frac{L}{f \times 80}\right)^n$$

$$0.62 \cancel{\left(\frac{L}{f}\right)^n} = (0.15)^n \cancel{\left(\frac{L}{f}\right)^n}$$

$$0.62 = (0.15)^n$$

$$\log 0.62 = n \log 0.15$$

$$\boxed{n = 0.25}$$

Now,

$$V_3 = \pi D \times 60 \text{ m/min}$$

$$T_3 = x \cdot \frac{L}{f \times 60} \text{ min.}$$

$$V_1 T_1^n = V_2 T_2^n = V_3 T_3^n = V_4 T_4^n$$

$$V_1 T_1^n = V_3 T_3^n$$

$$\cancel{\pi D} \times 50 \left(\cancel{L/f}\right)^{0.25} = \cancel{\pi D} \times 60 \times x \left(\frac{\cancel{L}}{f \times 60}\right)^{0.25}$$

$$0.83 = 0.35\, x^{0.25}$$

$$\log 2.37 = \log x^{0.25}$$

$$0.375 = 0.25 \log x$$

$$\boxed{x = 29}$$

Gate 1999

0 rake angle.

$$\text{Tool life} \propto \frac{1}{\text{Tool wear}}$$

$$T \propto \tan \alpha$$

$$\boxed{T = K \tan \alpha}$$

$$\% \text{ change} = \frac{T_2 - T_1}{T_1} \times 100\%$$

$$= \left(\frac{T_2}{T_1} - 1\right) \times 100\% = \left(\frac{\cancel{K} \tan \alpha_2}{\cancel{K} \tan \alpha_1} - 1\right) \times 100\%$$

$$= \left(\frac{\tan 7}{\tan 10} - 1\right) \times 100\% = 30\%$$

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* Extended or Modified Taylor's eqn.

$$\boxed{VT^n f^a d^b = C}$$

4 constant

$$T^n = \frac{C}{Vf^a d^b}$$

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

$$1/n > a/n > b/n$$

Ex:- $n = 0.2$
$a = 0.6$
$b = 0.4$

$$T = \frac{C^5}{V^5 f^3 d^2}$$

Velocity affects more.

IES 1994, 2007 → $MRR = fdV$

Economical → productivity doubles
means MRR doubles
hence $d\uparrow$ → economical
$V\uparrow$ → uneconomical

ESG 1999, IAS 2010

$$VT^{0.13} f^{0.6} d^{0.3} = C$$

$$\Rightarrow 40 \times 60^{0.13} \times 0.25^{0.6} \times 2.0^{0.3} = C$$

$$\boxed{C = 36.49}$$

$$\boxed{VT^{0.13} f^{0.6} d^{0.3} = 36.49}$$

Together increased by 25%.

$$50\, T_1^{0.13} (0.3125)^{0.6} (2.5)^{0.3} = 36.49$$

$40 \times 1.25 \rightarrow 50$

$0.25 \times 1.25 \rightarrow 0.3125$

$2.0 \times 1.25 \rightarrow 2.5$

$$\boxed{T_1 = 2.3 \text{ min.}}$$

Now, individually

$$50\, T_2^{0.13}\, 0.25^{0.6} \times 2.0^{0.3} = 36.49$$

$$\boxed{T_2 = 10.8 \text{ min.}}$$

$$40\, T_3^{0.13} \times 0.3125^{0.6} \times 2.0^{0.3} = 36.49$$

$$\boxed{T_3 = 21 \text{ min}}$$

$$40 \times T_4^{0.13} \times 0.25^{0.6} \times 2.5^{0.3} = 36.49$$

$$\boxed{T_4 = 3.5 \text{ min}}$$

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Gate 2016

$$VT^{0.14} f^{0.7} d^{0.4} = C$$

$$45\ 30^{0.14}\ 0.35^{0.7}\ 2.0^{0.4} = C \to cv$$
$$= 45.84$$

togerner

$$50\ 30^{0.14}\ 1.38 \times 1.44 = C$$

$$T^{0.14} = \frac{45.84}{99.36}$$

$$\boxed{T = 3.22}$$

*** TOOL LIFE CURVE

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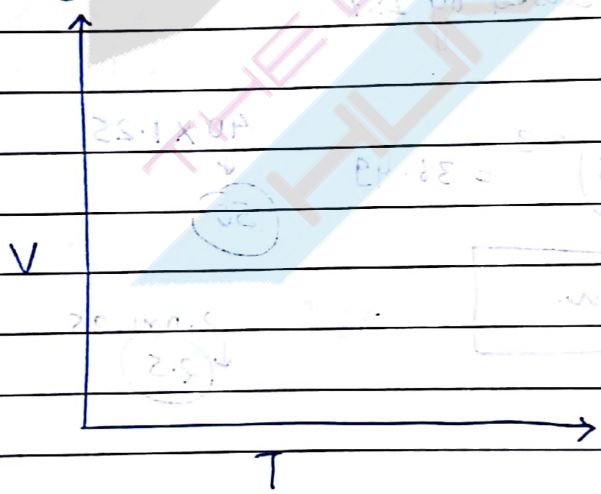
Pg 29

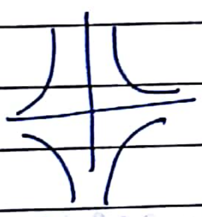
Taylors

$$VT^n = C$$
$$y\, x^n = C$$

$$\boxed{y = \frac{C}{x^n}}$$

hyperbola





4 chord

$n = 0.08$ to 0.2
0.2 to 0.4
0.5 to 0.7

✓ Analogy $PV^{\gamma} = C$

$$y\, x^{y} = C$$

$$\boxed{y = \frac{C}{x^y}}$$

if y
stiffness

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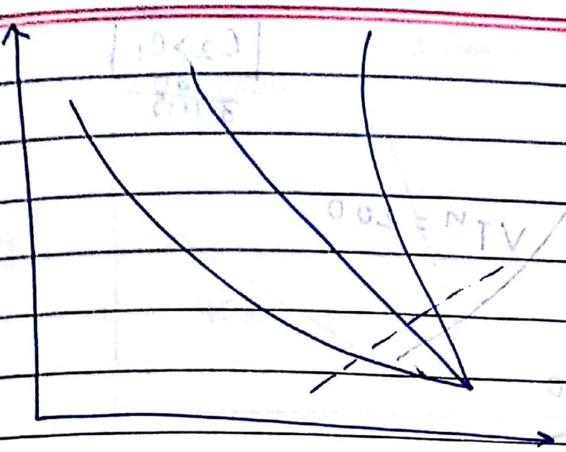

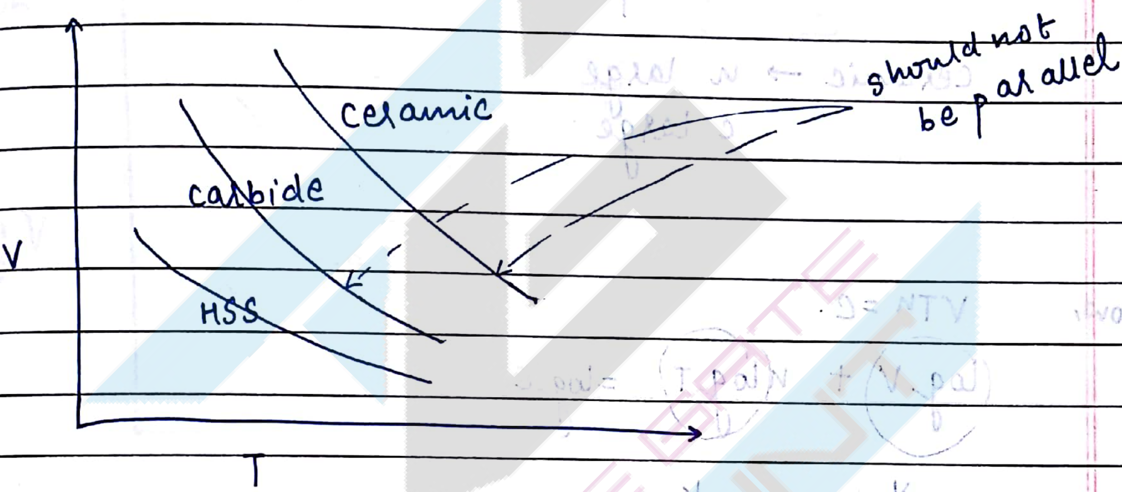

✓ Mathematically.

slope , $\dfrac{dy}{dx} = \dfrac{-nc}{x^{n+1}} < 0$ negative

Rate of change of slope,

$$\frac{d^2y}{dx^2} = \frac{n(n+1)c}{x^{n+2}} > 0 \quad \text{positive}$$

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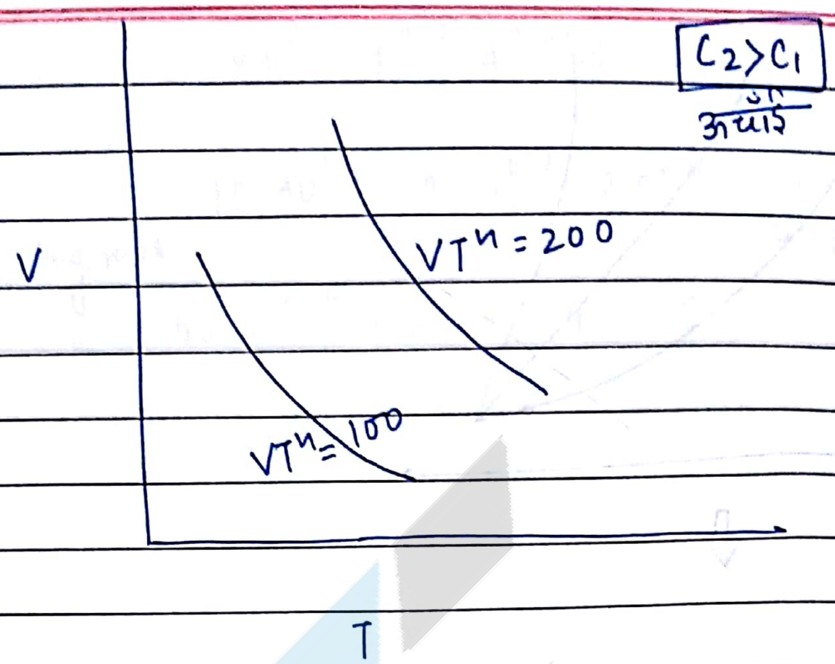


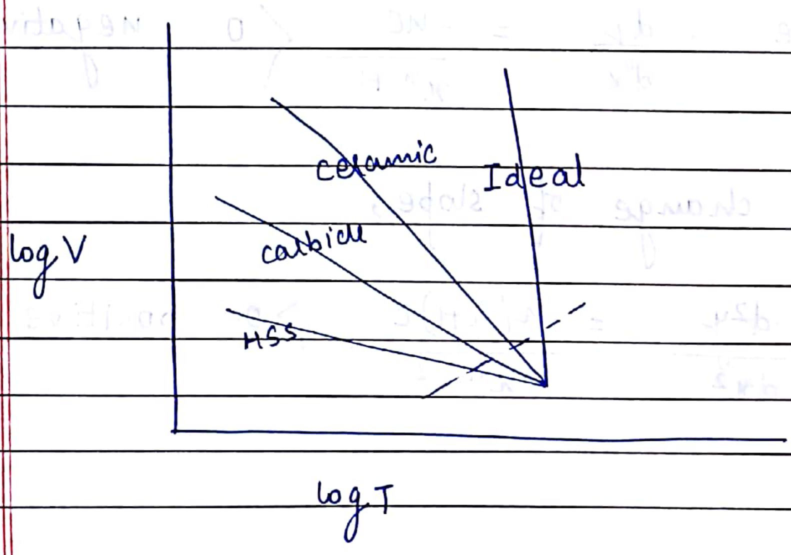
ceramic → n large.
c large.

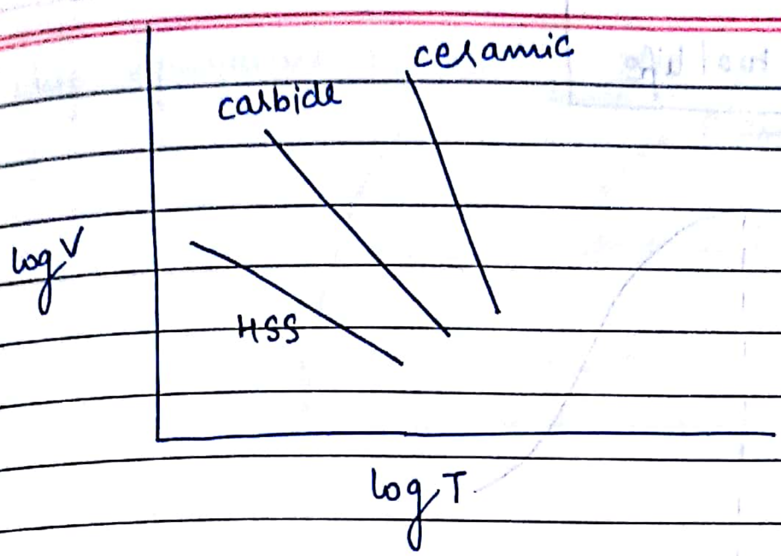
Now, $VT^n = C$

$\log V + n \log T = \log C$

$y + nx = K$

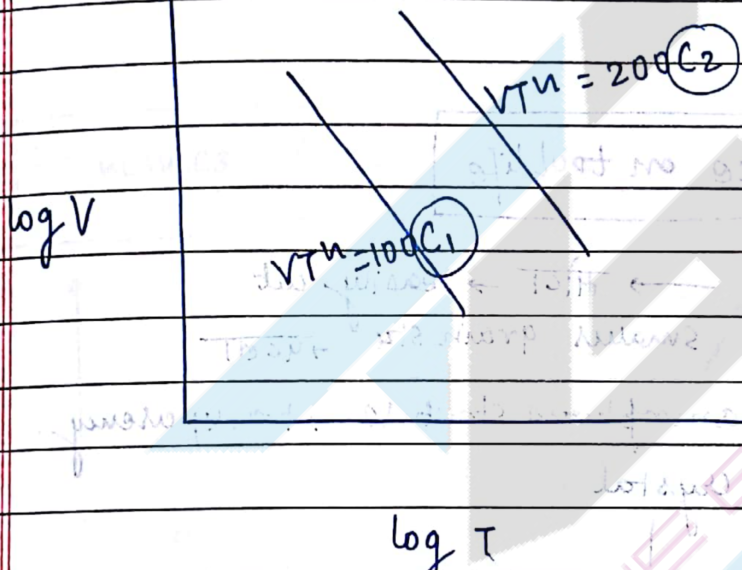
$$\boxed{y = -nx + K}$$



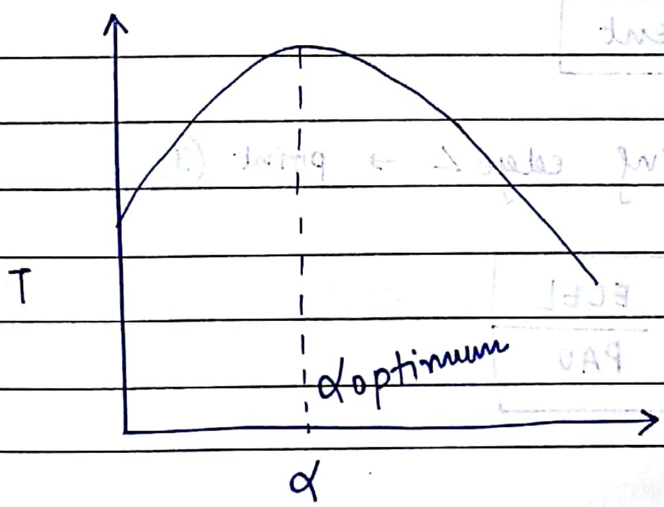


Now,

$\boxed{C_2 > C_1}$

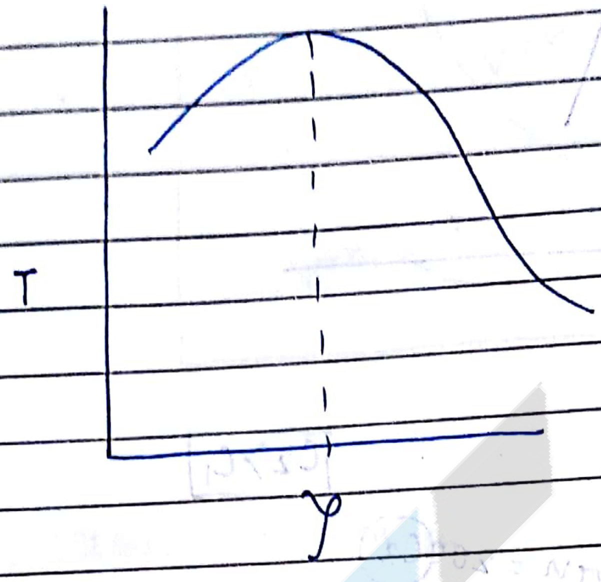


* **Effect of Rake ∠ on tool life**



effect

* clearance ∠ on tool life



* Effect of workpiece on tool life

larger grain size ⟶ मोटा → easily cut

smaller grain size →पतला

workpiece

glass →. amorphous structure → transparency.

iron → crystal

can be seen by

crystallography

* Chip Equivalent

side cutting edge ∠ → point ③

$$\boxed{q = \frac{ECEL}{PAO}}$$

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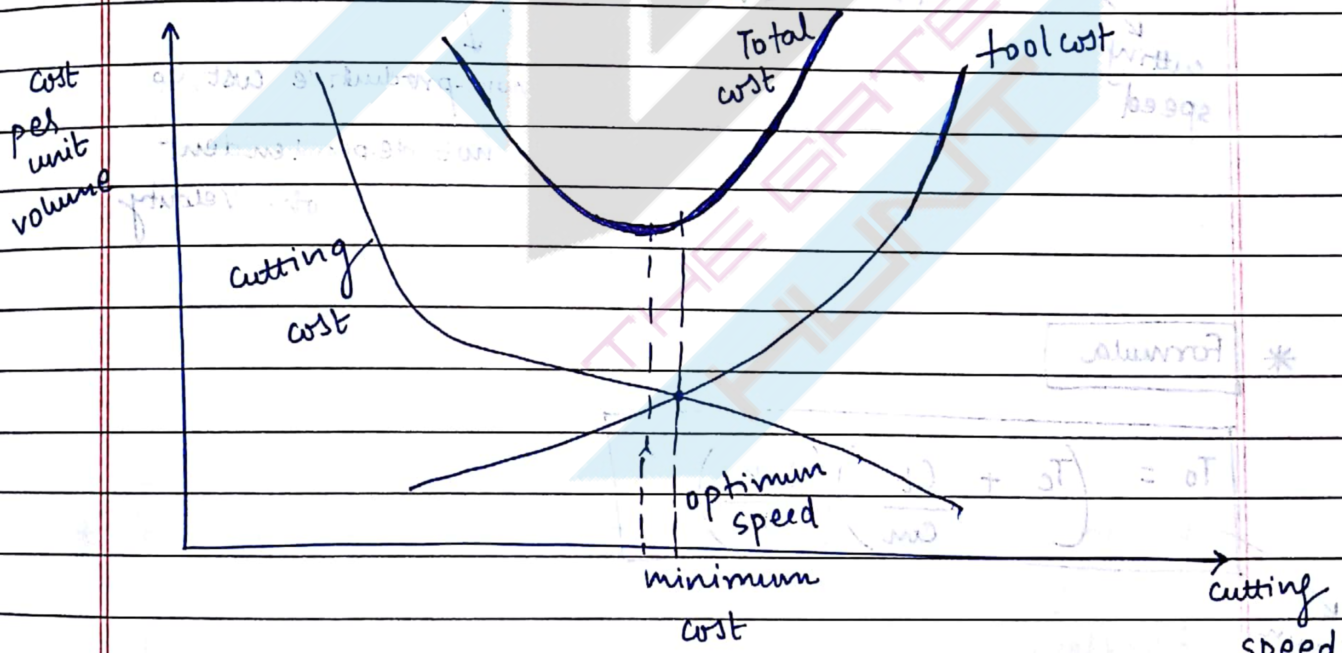
chip equivalent (q) = $\frac{\text{Engaged cutting edge length}}{\text{Plan area of cut}}$

can't be ↑

if nose radius ↑
or side cutting edge ∠↑.

IES 1996 → (b) ✓

* Economics of Metal Cutting



Maximize the Profit → here minimizing the cost

optimality due to minimize the cost
—"— —"— —"— maxm —"— profit
—"— —"— —"— productivity.

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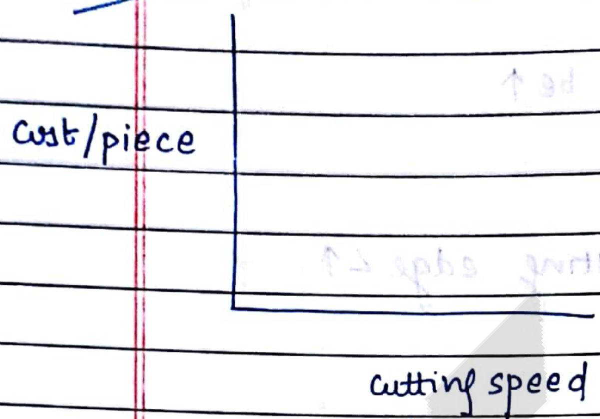


$$C_u = C_m + C_t + C_c + C_n$$

Total cost

$$\frac{dC_u}{dV} = \frac{dC_m}{dV} + \frac{dC_t}{dV} + \frac{dC_c}{dV} + \cancel{\frac{dC_n}{dV}}^{\,0} = 0$$

cutting speed

non-productive cost is not dependendent on velocity.

* Formula

$$\boxed{T_o = \left(T_c + \frac{C_t}{C_m}\right)\left(\frac{1-n}{n}\right)}$$

optimum Tool life for minm. cost.

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

for maxm productivity i.e the minimum production time

Gate 2014 maxm. production rate:

$\Rightarrow \quad T_o = T_c\left(\frac{1-n}{n}\right)$

$\Rightarrow \quad T_o = 1.5\left(\frac{1-0.2}{0.2}\right)$

$\Rightarrow \quad \boxed{T_o = 6\,min.}$

ESE 2001

$\left(\frac{45}{}\right)^n 50 = 100 \times (10)^n$

$n = 0.46$

$VT^n = C$

$T_o = T_c\left(\frac{1-n}{n}\right) = 2.34\ min$

$V_o T_o^n = C$

$\boxed{V_o = 195\ m/min}$ Ans

* $\boxed{\text{for Minimum Cost}}$ → C_m → m/c cost → overhead cost.

↓

Tooling cost → (C_t)

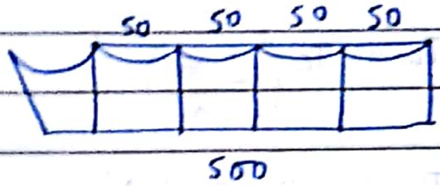
500 → Blank

↓

400

100 → depreciation due to grinding of Blank

✓✓ If grinding not required, tool directly from market



$$C_t = \frac{Rs\ 500 + 50 \times 4}{5} / \text{use} = \frac{700}{5}$$

✓ n times grinding
✓ (n+1) bar use

IES 2009

$T_c = 3\text{ min}$

$t_g = 3\text{ min}$

$C_m = 0.50 / \text{min}$

$d = Rs.\ 5.0$

$c = 60$

$n = 0.2$

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

$$C_t = t_g \times C_m + d$$

$$\boxed{C_t = 6.5\ Rs/\text{Regrind}}$$

$$\boxed{T_0 = 64\text{ min}}$$

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

$$\boxed{V_0 = 26.11\ m/sec}$$

Gate 2016

$$C_t = 270C/TV$$

$$C_m = 180C/V$$

$$VT^{0.25} = 150$$

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

$$T_o = \left(T_c + 1.5\right)(3)$$

Sir

$$C_u = C_m + C_t$$

$$C_u = \frac{18C}{V} + \frac{270C}{TV}$$

and $VT^{0.25} = 150$

$$\boxed{T = \left(\frac{150}{V}\right)^4}$$

$$\frac{dC_u}{dV} = \frac{18C}{V} + \frac{270C}{\left(\frac{150}{V}\right)^4 \cdot \cancel{V}} = 0$$

$$\Rightarrow \frac{18C}{V} + \frac{270C \times V^3}{150^4} = 0$$

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Example

minm. production cost.

Answer (contd.....)

$$t = \frac{L}{fN} = \frac{\pi D L}{1000 f N}$$

51.58 min $\longrightarrow$ 2 min

5.669 $\longrightarrow$ $\frac{2 \times 5.669}{51.58}$

Total $\times C_m + C_t \times \frac{T_m}{T_o}$ = cost of operation

$= 10.89 \times 0.8667 + \frac{10.875 \times 5.669}{51.58}$

* $\boxed{\text{Minimum Cost VS Production Rate}}$

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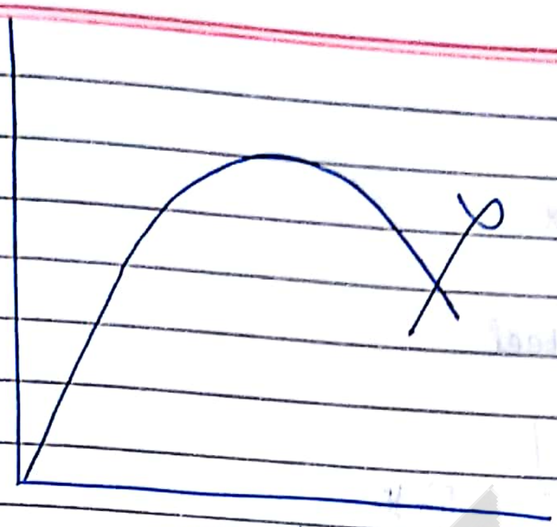
To maxm. the profit.

V_o minm. cost = 10 m/min.

V_o maxm. cost = 15 m/min.

IES 2010

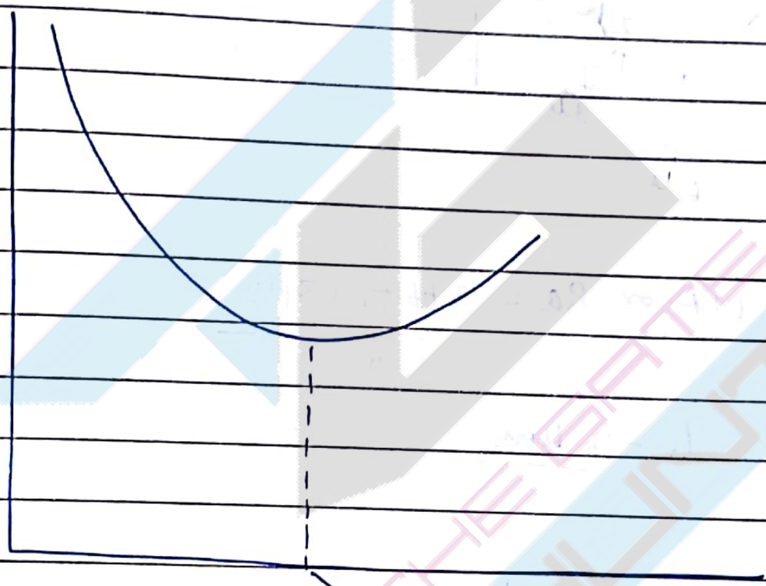
Prodn. Time



velocity

S.I.R

prod. Time



V

V_0 min production time

= maxm. productivity

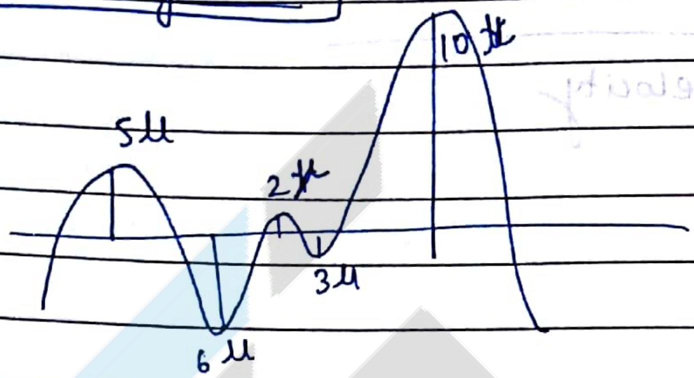
* Machinability

✓ Machinability Index

✓ Machinability of steel

ppt's

* Surface Roughness



$$CLA \text{ or } R_a = \frac{5+6+2+3+10}{5}$$

$$h = 16 \ \mu m$$

✓ final m/c → less d, f

Practical

✓ depth of cut $\xrightarrow[\text{effect}]{\text{no}}$ surface Roughness.

Gate 2005 r = nose radius = 0

* Cutting Fluid

Metal Cutting Completes