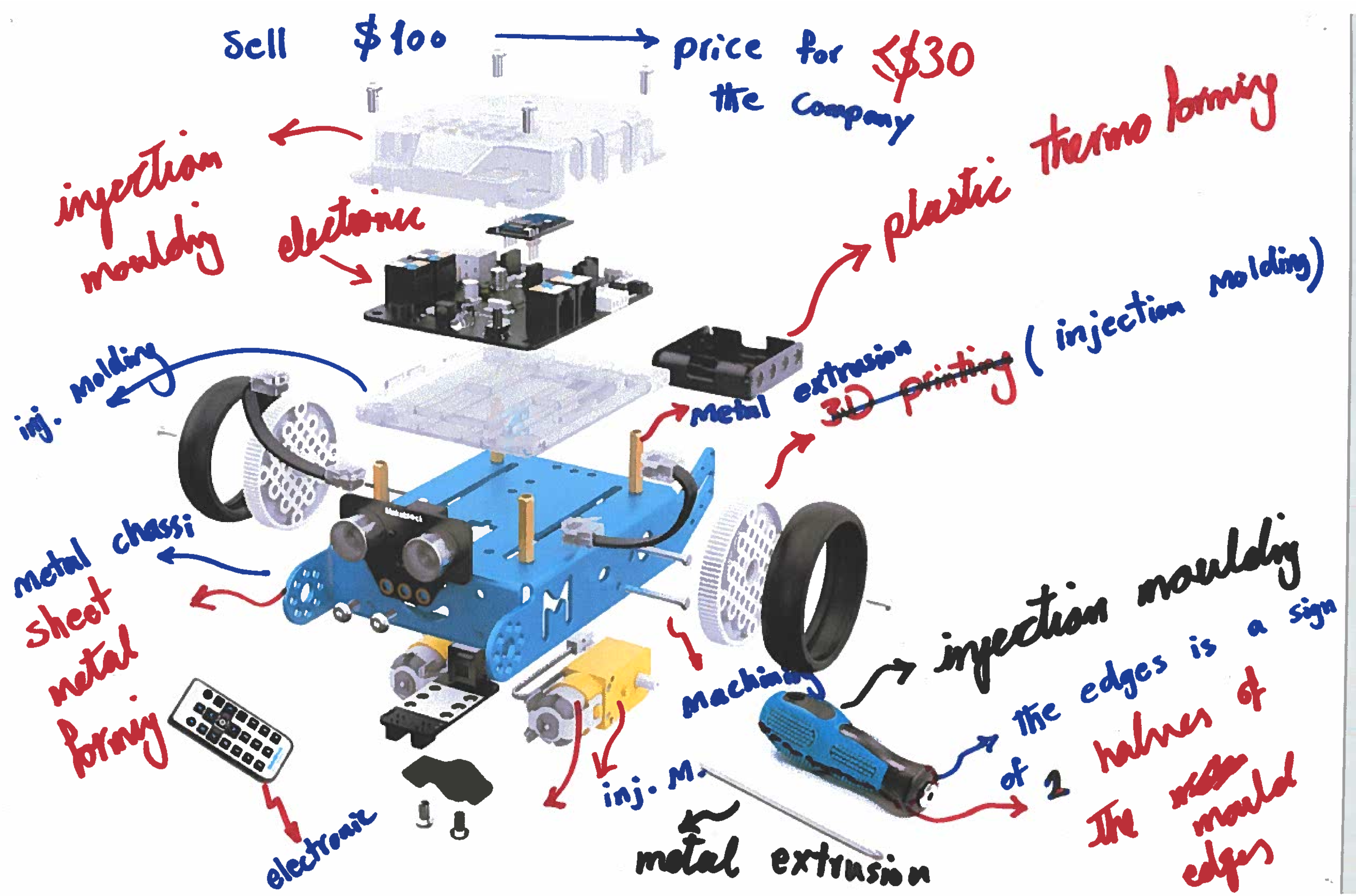


Sell $100 → price for the company <$30
injection moulding
electronic
plastic thermo forming
inj. molding
metal extrusion
~~3D printing~~ (injection molding)
metal chassi
sheet metal forming
machining
injection moulding
the edges is a sign of 2 halves of
The mould edges
inj. M.
metal extrusion
electronic

Process Selection:

How much? How fast?

The 4 Main Attributes of each manufacturing process: <u>Cost</u>, <u>Rate</u>, <u>Quality</u>, and <u>Flexibility</u>

Process \ Attribute	Cost	Rate	Quality	Flexibility
Machining	high		high	mid
Sheet Metal Forming				
Thermoforming				
Injection molding		high		low
Casting			surface low	
3D Printing		low		high

$$\boxed{C = V + I}$$

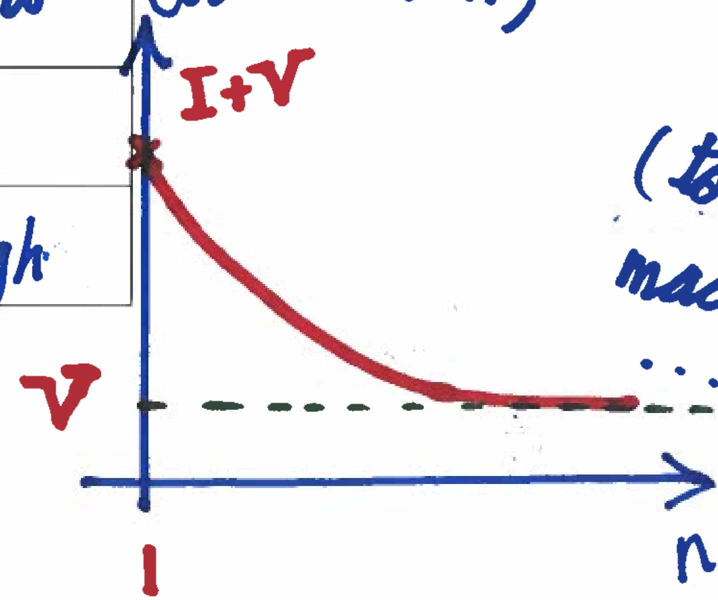
need to change the shape?

The variable cost (material, labour, ...)

The investment cost (tools, machine, shop, ...)

if we make n parts ⇒

$$C = V + \frac{I}{n}$$



Course Modules:

metal
1. Machining ← Turning, Milling
2. Sheet Metal Forming → cutting, bending

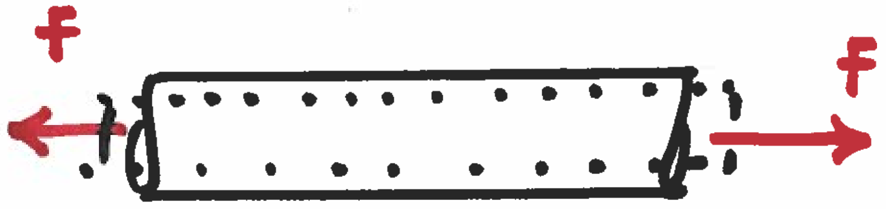
plastic
3. Injection Molding
4. Thermoforming
5. Casting → sand, die, investment
6. Additive Manufacturing (3D printing)
7. Quality and Monitoring ✓

~~8. Forging~~

~~9. Automation~~

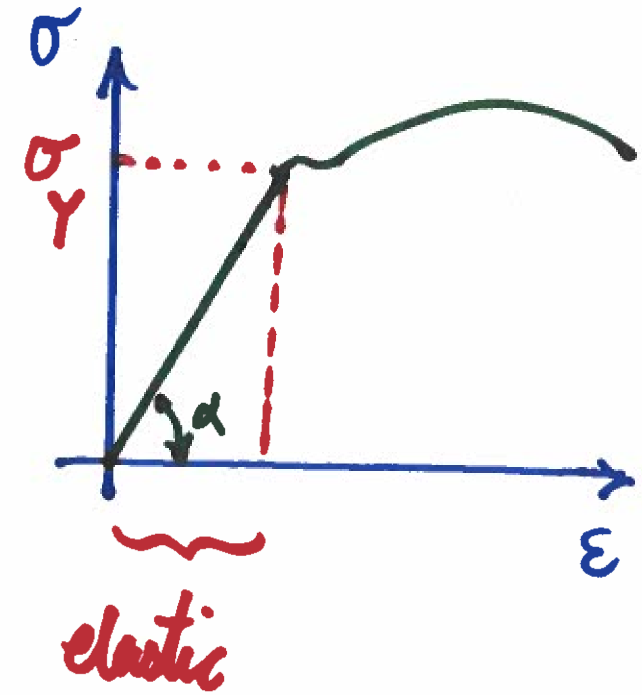
~~10.~~

A Brief Review



$$\sigma = \frac{F}{A}$$

$$\varepsilon = \frac{\delta}{L}$$



Lateral strain $= -\nu\varepsilon$

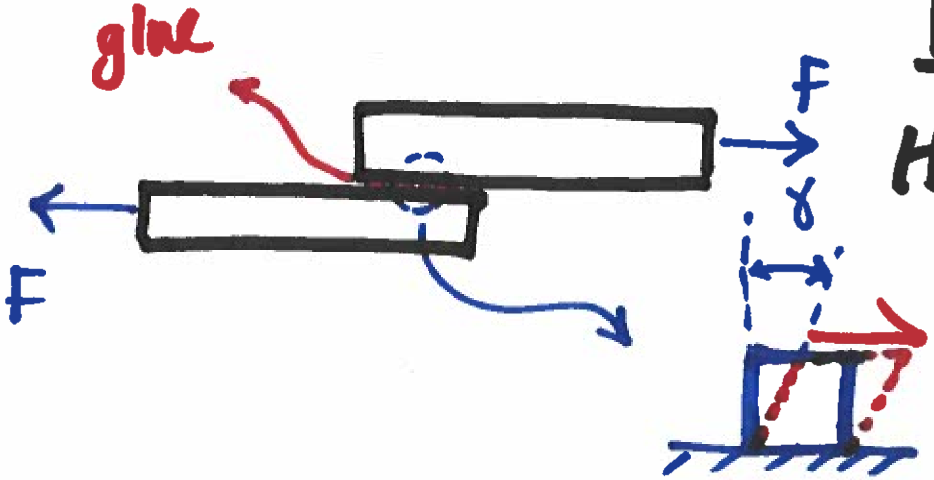
Poisson ratio

$\tan\alpha = E$

module of elasticity

$$\boxed{\frac{\sigma}{\varepsilon} = E}$$

Hooke's law

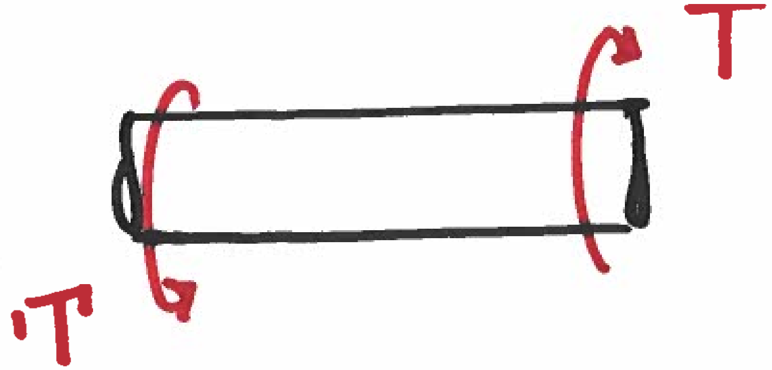


$$\tau = \frac{F}{A}$$

$$\boxed{G = \frac{E}{2(1+\nu)}}$$

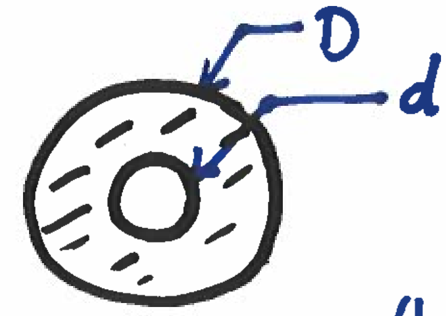
shear angle $\gamma = G\tau$

shear Module of elasticity



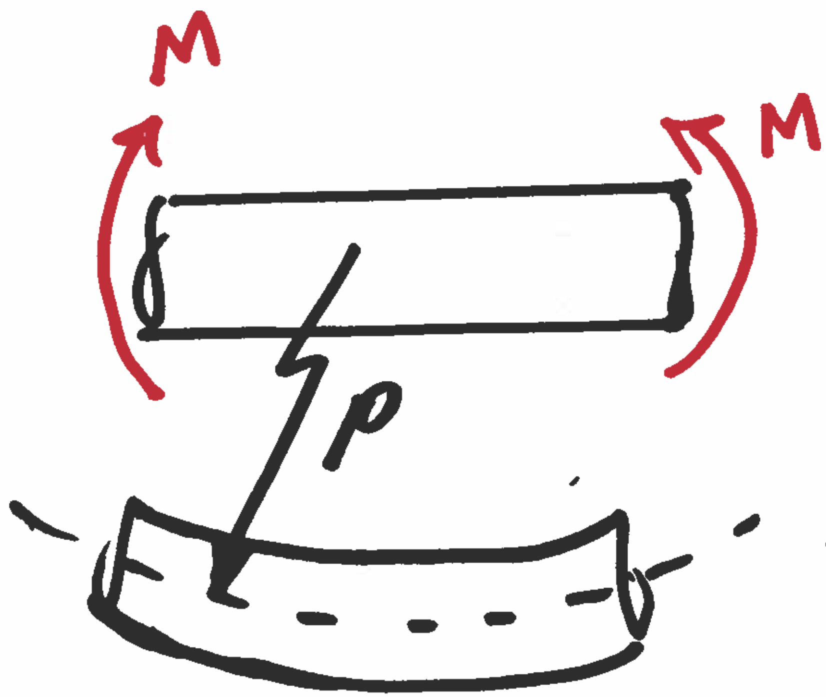
$$\tau = \frac{Tc}{J}$$

radius

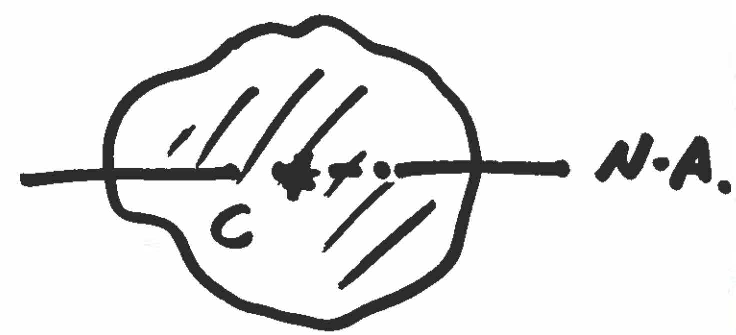


$$J = \frac{\pi}{32}\left(D^4 - d^4\right)$$

$$\phi = \frac{TL}{GJ}$$



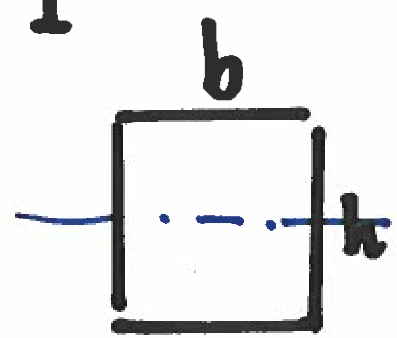
$$\sigma = \frac{Mc}{I}$$



cross-section

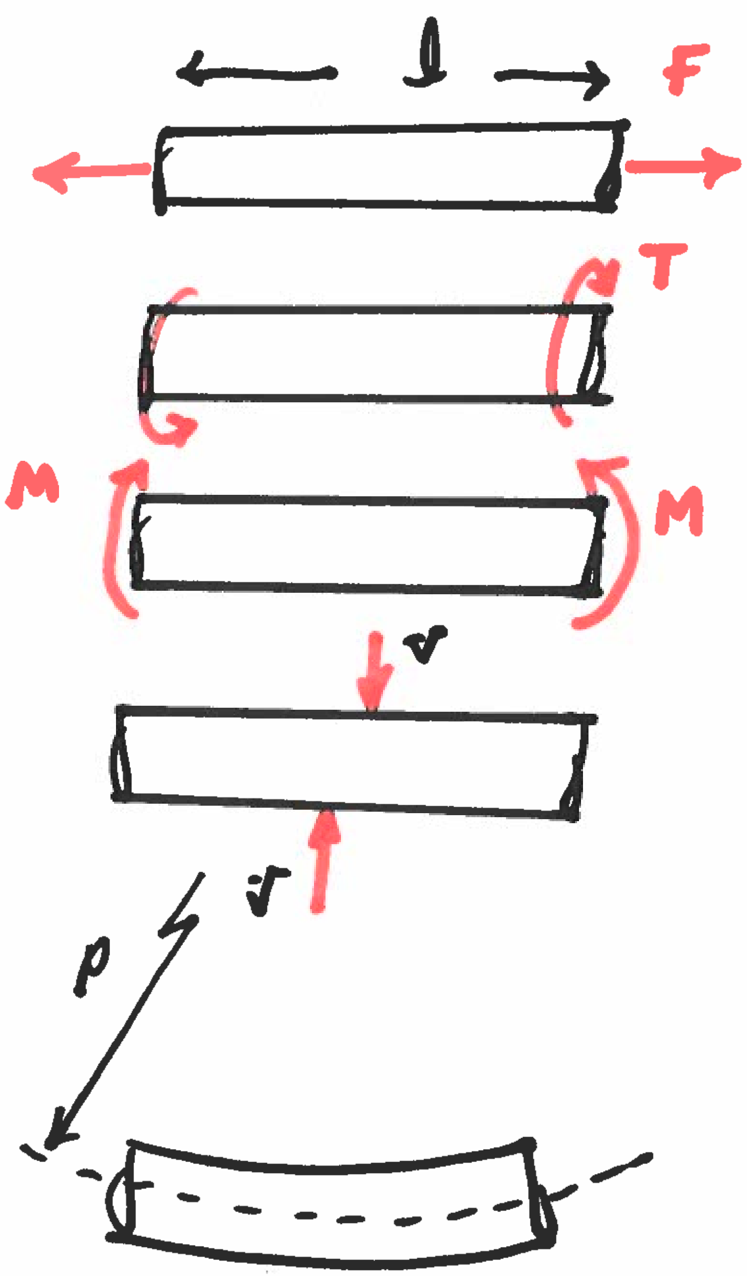
I about N.A.

$$\frac{1}{\rho} = \frac{M}{EI}$$



$$I = \frac{1}{12} b h^3$$

A Brief Review



Stress

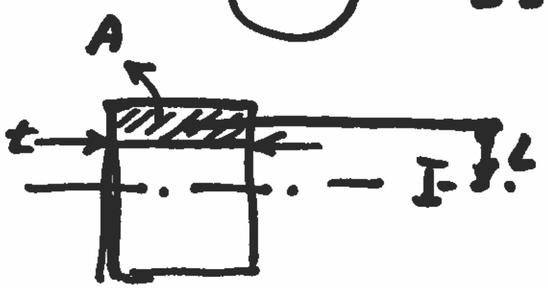
$\sigma = \pm F/A$

$\tau = \dfrac{TC}{J}$

$\sigma = \dfrac{MC}{I}$

$\tau = \dfrac{VQ}{It}$

$Q = A \cdot L$



page (5.5)

$D/2$

$\epsilon = \dfrac{\delta}{L}$

$J = \dfrac{\pi}{32}(D^4 - d^4)$

$\frac{1}{12} b h^3$

N.A.

$I = \frac{\pi}{64} D^4$

$\tan\alpha = E$

$\boxed{\sigma = \epsilon E}$

Deformation

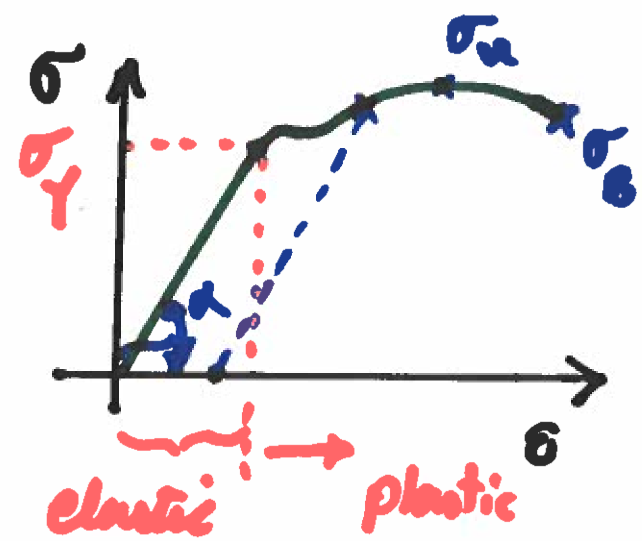
$\delta = \dfrac{FL}{AE}$

D

d

$\phi = \dfrac{TL}{GJ}$

$\dfrac{1}{\rho} = \dfrac{M}{EI}$



Module 1. Machining

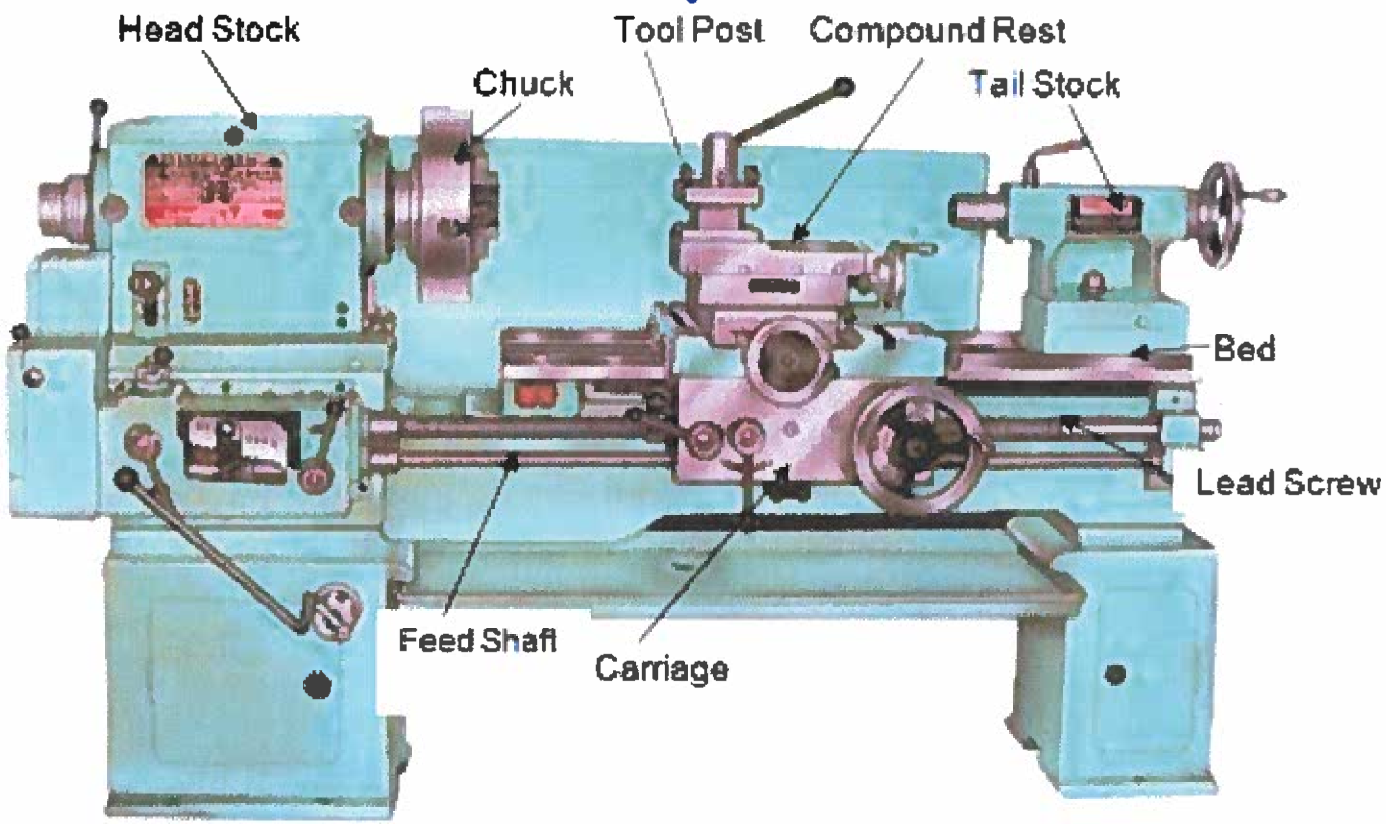
metals ✓
wood

workpiece is fixed
tool rotates

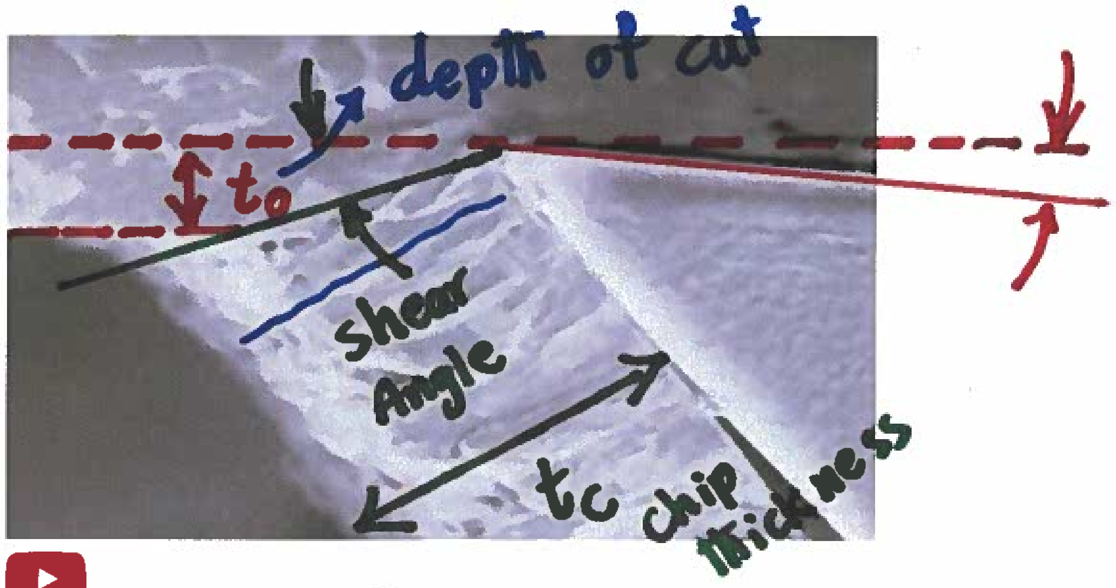
milling, drilling, boring, turning, facing, tapping, threading, and cut-off.

tool is fixed
workpiece rotates

Turning:



The mechanism of material removal:



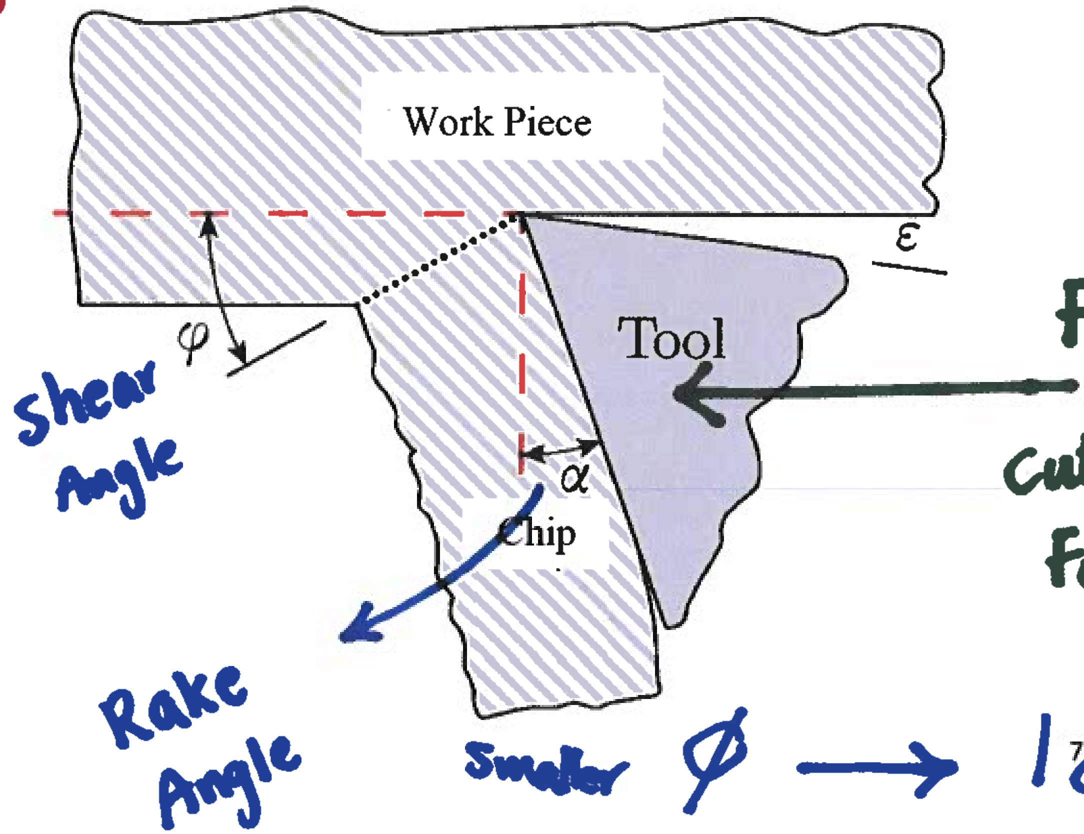
Relief Angle

$\rightarrow r = \frac{t_o}{t_c}$

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

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

β → $\tan^{-1}(\mu)$ → friction coef.



F_c: Cutting Force

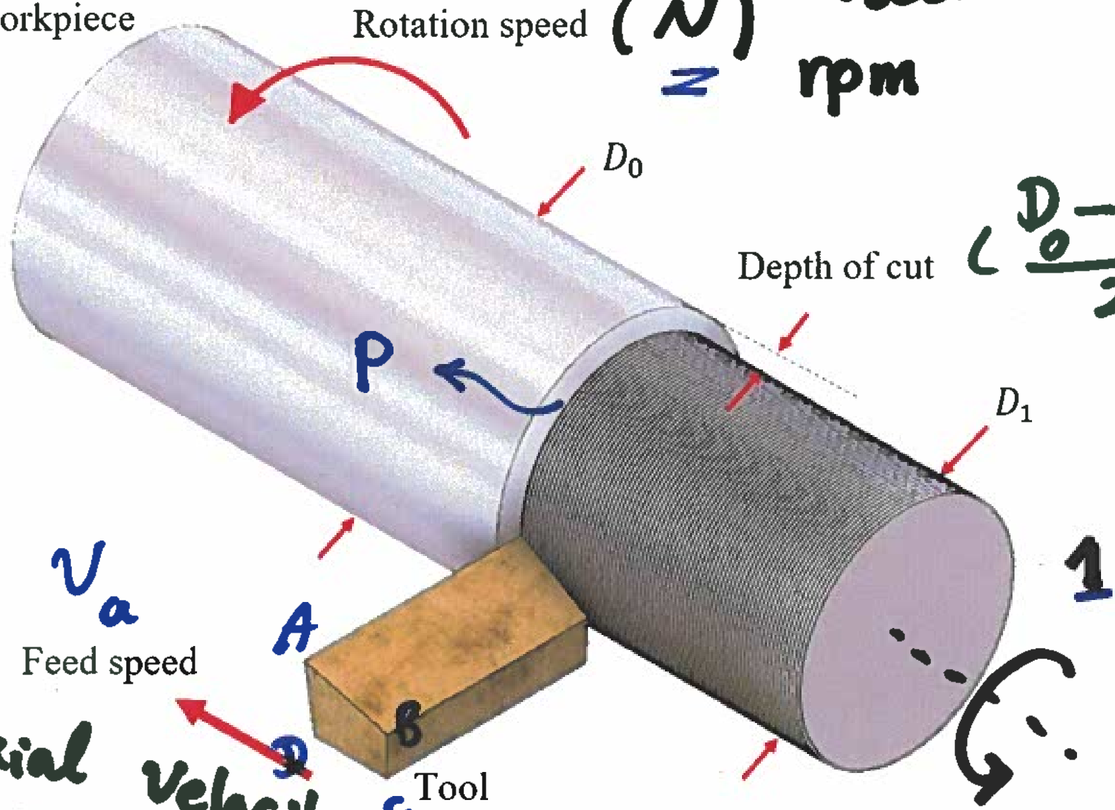
$$\tau = G\gamma$$

γ → shear strain

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

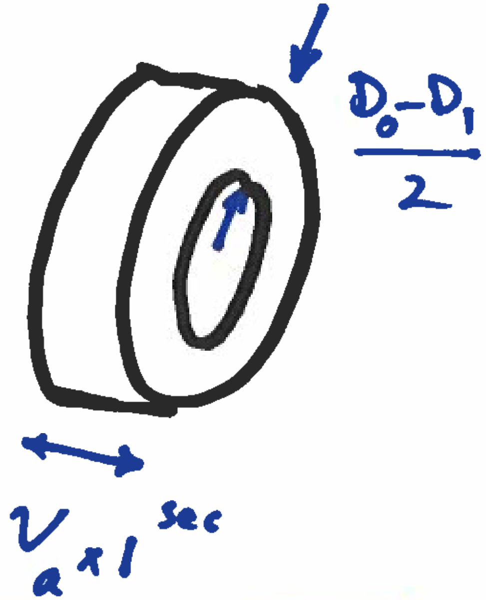
Smaller ϕ → larger stress

Material Removal Rate (MRR):

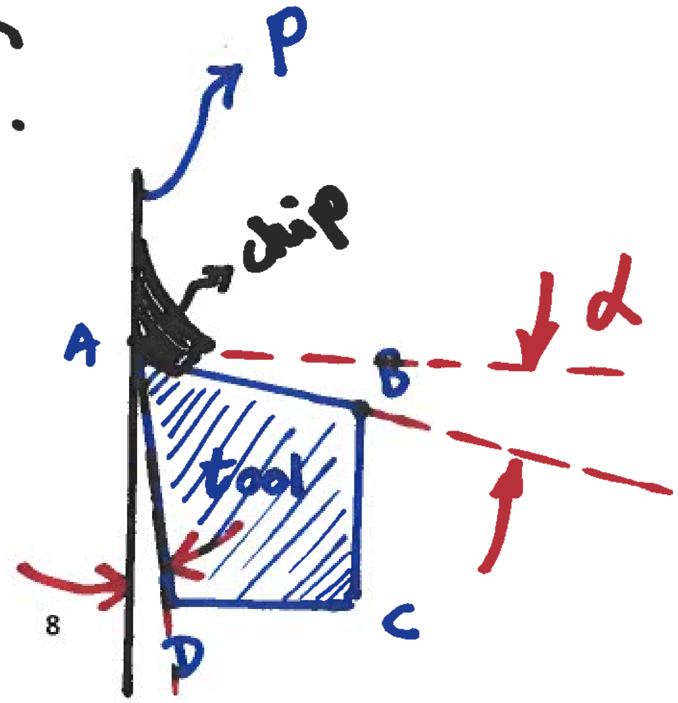


axial velocity of the tool

mm/sec , mm/rev. × N



rev/sec $\boxed{MRR = N \pi D_0 \times V_a \times \frac{D_0 - D_1}{2}}$



How much power we need to cut?

Example 1) On a lathe the operator is machining an Aluminum rod. The initial diameter of the rod is 2.0cm, and he set up the tool for a depth of cut 0.2cm. If the rotation speed is N= 500 RPM, and the tool axial velocity is 0.4 mm/~~min~~ rev., what is the material removal rate?

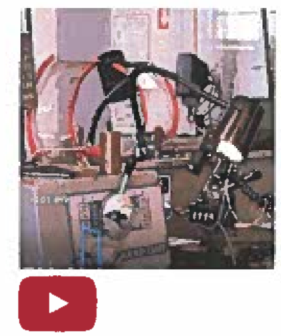
$$\text{Feed} = 0.4 \ \text{mm/rev}$$

$$MRR = \pi D_o N (\text{Feed})(\text{depth of cut})$$

$$= \pi \times 20 \times \frac{500}{60} \times 0.4 \times 2 = 418 \ \text{mm}^3/\text{sec}$$

Experimental Test:

Measuring the cutting forces during cutting:



cutting Force

1- Feed increase → increase ↑

2- Smaller Rake angle → increase ↑

3- Spindle rpm increase → no change —

4- Depth of cut increase → increase ↑

5- Smaller diameter of stock → no change

Conclusion: Feed speed affects the cutting force, but rotation speed does not. the cutting force depends on Rake angle and the depth of cut.

Merchant's Relation:

Shearing Stress during machining and the chip formation:

$\tau = G(\cot(\emptyset) + \tan(\emptyset - \alpha))$ if $\emptyset \downarrow \Rightarrow \tau \uparrow$ → more required Power.

G: Shear Module of Elasticity if $\phi \downarrow$ — $\left(\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}\right) \Rightarrow$ smaller r (bigger t_c)

$\emptyset$ is called shear angle and can be calculated by Merchant's formula:

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

β friction angle

in general the bigger the $r = \frac{t_o}{t_c}$ means better Machining.

Merchant proved that smaller shear angle results in: $\phi \downarrow \leftarrow$ (smaller α larger μ)

1. Chip thickness increase t_c
2. Energy dissipation via shear increase $\leftarrow J \uparrow$
3. Heat generation and temperature increase

* Heat & vibrations are the enemy of tools & machining

Cutting Tools: steel 32 RW

- HSS (High Speed Steel) 64 RW
- Carbide 77 RW

increase feed speed $\Longrightarrow$ failure of the tool.

(watch video; emailed link)

Observation from the demo (above video): with Carbide he could cut at higher feed speed, but eventually he had to stop because of not enough power.

Tools with different layers of coating: TiN, TiCN, Al_2O_3

TiN → less friction

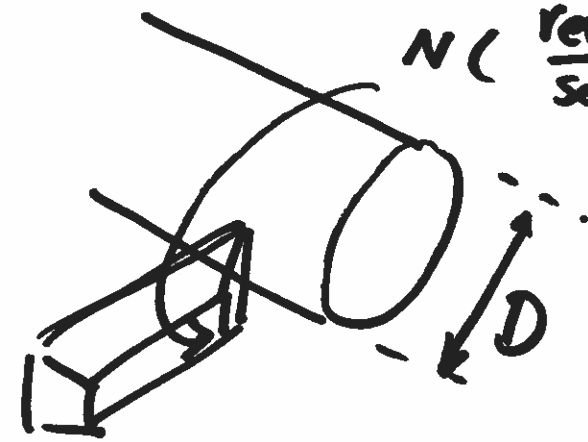
TiCN → wear resistance

Al_2O_3 → TBC → thermal barrier coating → better temperature stability

Power Requirement:

$V = 2\pi \frac{D}{2} \times N$ mm/sec

Specific cutting energy (SCE) is the amount of energy required to cut a given volume of work material ($W.Sec/mm^3$):



Material	SCE (W.s/mm³)
Brass	0.7 ✓
Aluminium alloy	0.8
Stainless steels	1.4
Steel 1330	2.5
Titanium	3 ✓

cutting force

$\pi D N$

Required Power $\boxed{P = MRR * SCE}$

$P = (F_c)($cutting speed$)$

→ estimate F_c

Example 2) Calculate the required power in Example 1? Aluminum specific cutting energy:

$SCE = 0.82\, W.s/mm^3$ $\rightarrow \frac{J}{s} \cdot s / mm^3 = \frac{J}{mm^3} = \boxed{\frac{N \cdot m}{mm^3}}$ *

$MRR = 418\ mm^3/sec$

$P = (MRR)(SCE) = (418)(0.82) = \ldots\ W$

Required time for removing volume material V:

$MRR = \frac{Volume}{time} \rightarrow time =$ ✓

Example 3) What is the minimum time it would take to machine 250 mm^3 of aluminum if your machine could provide 0.4 kW of power?

$P = (MRR)(SCE) \rightarrow 400 = (MRR)(0.82) \rightarrow MRR = \ldots$

$time = 250 / MRR = \ldots$

Example 4) Consider differences in machining two metals, an alloy of Steel (with module of elasticity 200GPa, and thermal conductivity of 50 W/m.K) and an alloy of Copper(with module of elasticity 115GPa, and thermal conductivity of 400 W/m.K). Compare machining of these two materials?

Steel { Higher strength → larger stress → more power

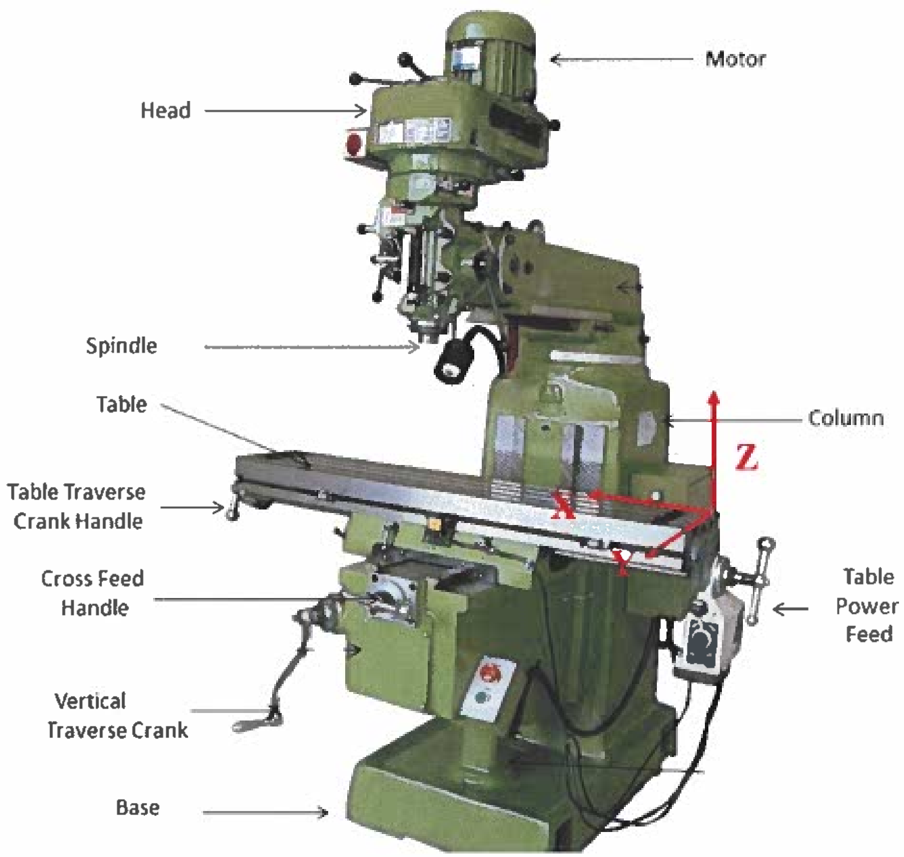
larger stress → greater heat generation → higher Temp.

Lower thermal conductivity → higher temperature in the tool

⟹ need more cooling

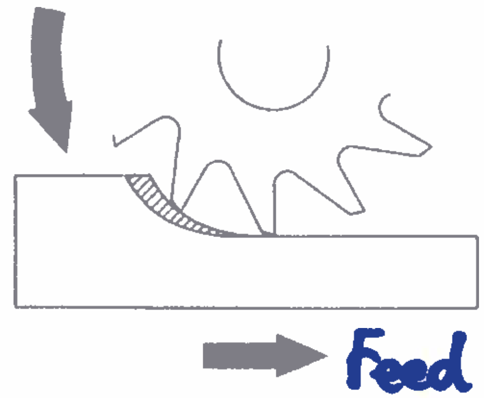
Copper {

Milling:



Two modes of milling:

* rotation

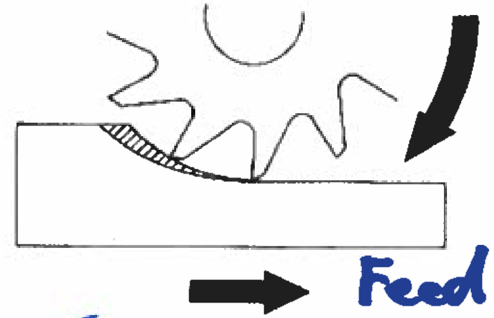


Feed

✓ **Climb cutting**
(Direction of cutter rotation same as feed direction)

- Safer

✓



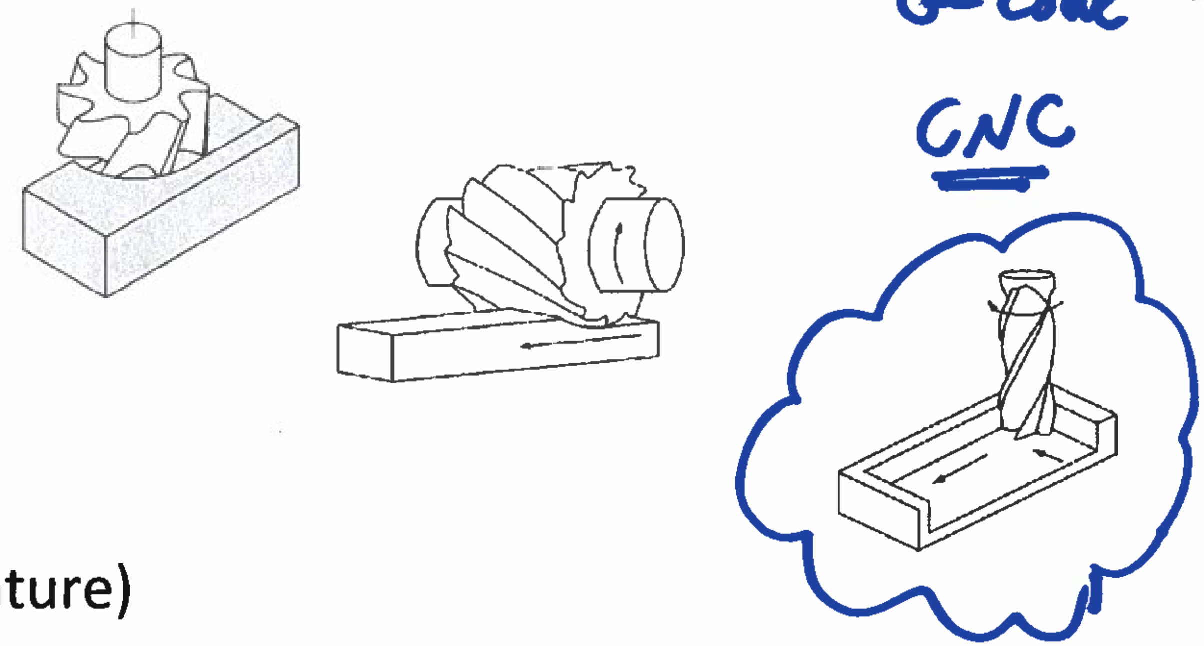
Feed

✓ **Counter cutting**
(Direction of cutter rotation) oppose to feed direction

- higher force to clamp

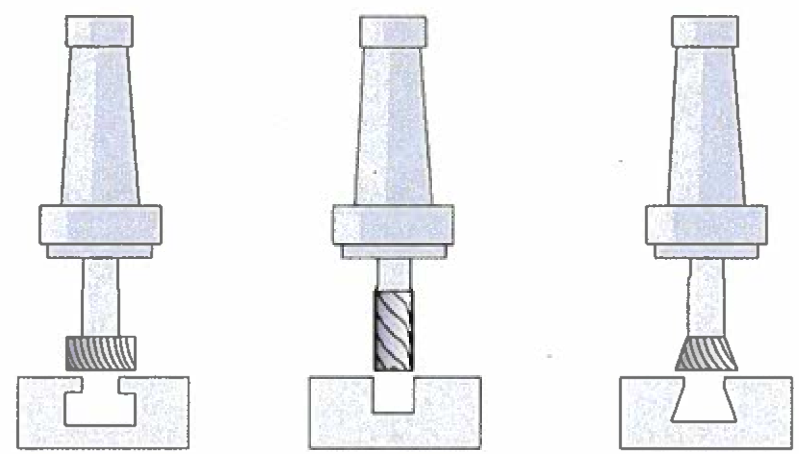
Types of milling operations:

- Face milling
- Shoulder/side (end milling)
- Contour milling (complex surface curvature)
- Cutting slots and grooves
- Holes and taps



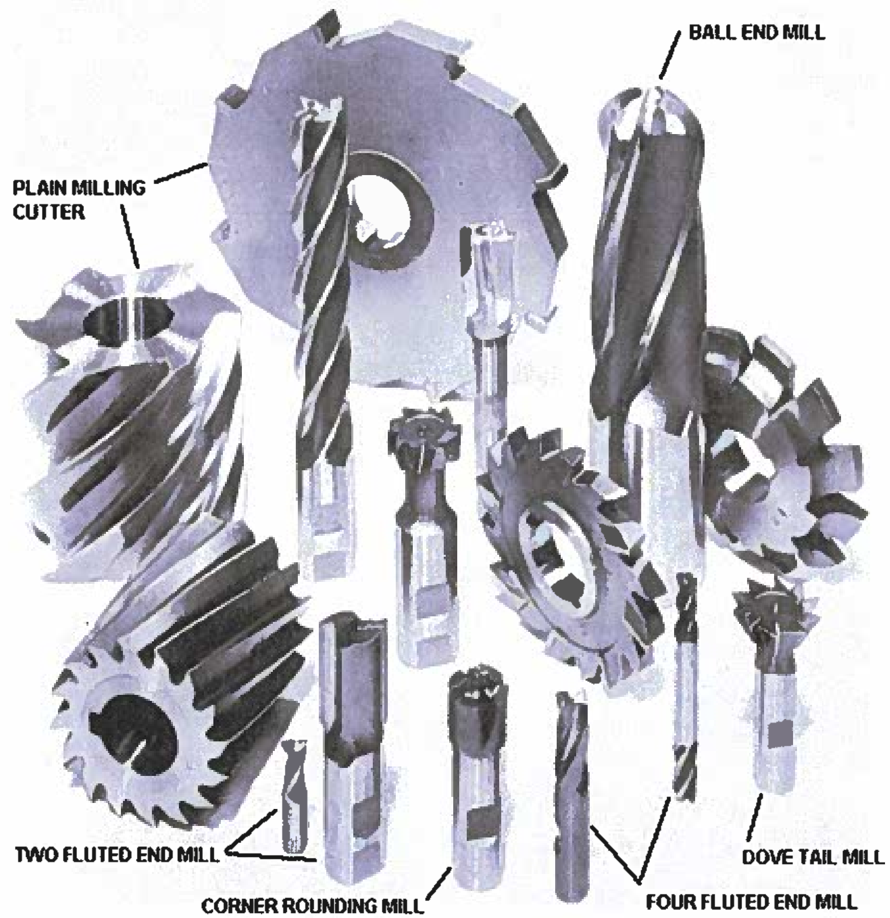
G-code

CNC



Types of tools:

- Face mill
- End mill
- Peripheral/Side mill
- T-slot, Slot, Dovetail-slot mill

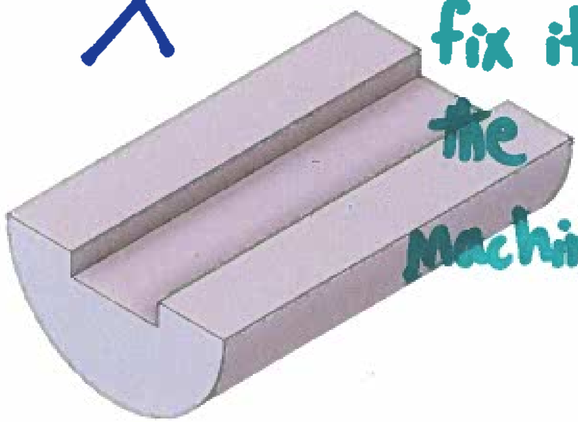


Example 5) In milling, what is the feed per tooth (in millimeters), f, if the tool velocity, v = 25 mm/s, the rotational speed, N = 1000 RPM, and the number of teeth, n = 4?

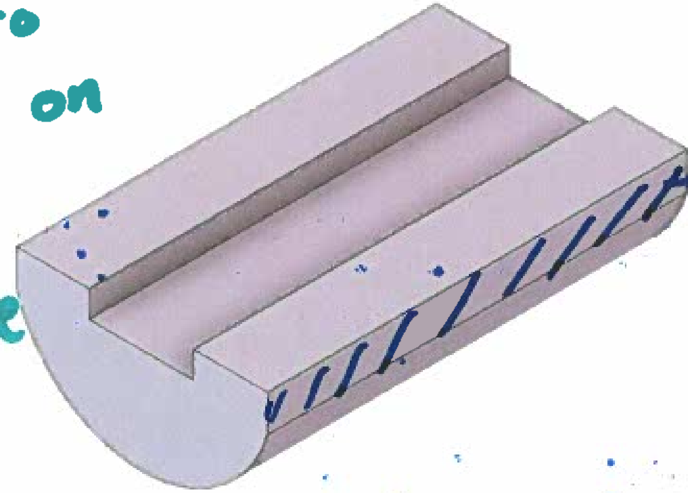
$$\text{Feed} = \frac{V}{N} = \frac{25}{\left(\frac{1000}{60}\right)} = 1.5 \ {}^{mm}/_{rev.}$$

$$\text{Feed per teeth} = \frac{\text{Feed}}{n} = \frac{1.5}{4} = 0.375 \ {}^{mm}/_{rev.}$$

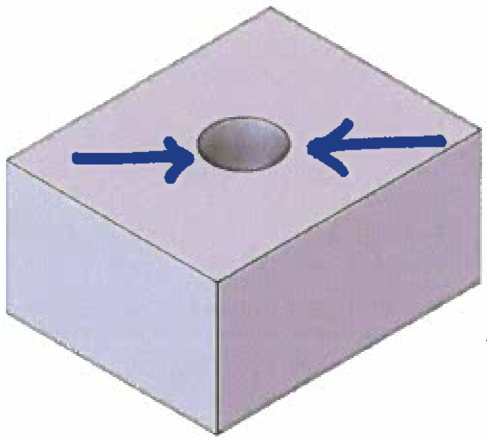
Design for Machining:



X difficult to fix it on the machine



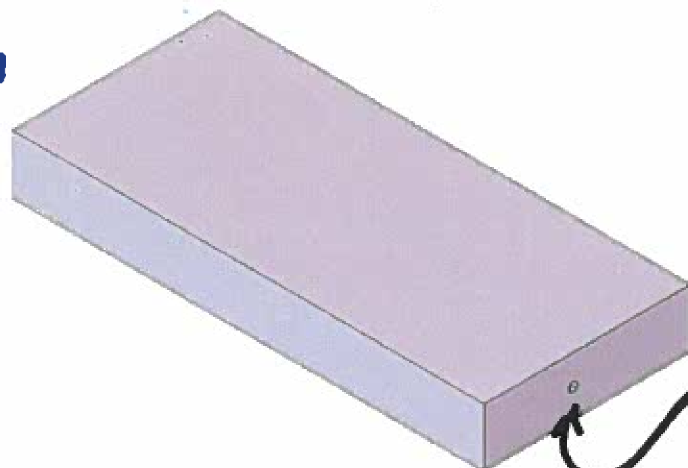
flat surface (for clamping & fixing it on the machine)



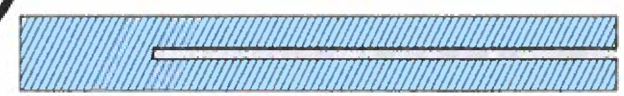
~~10.627~~ mm

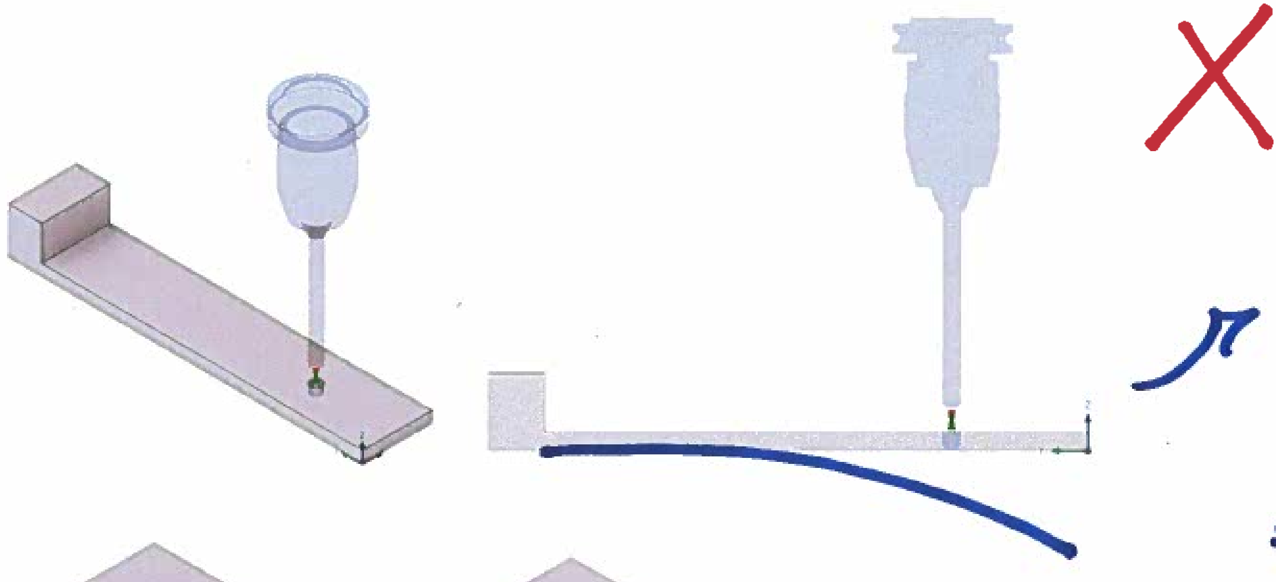
10.625

standard size



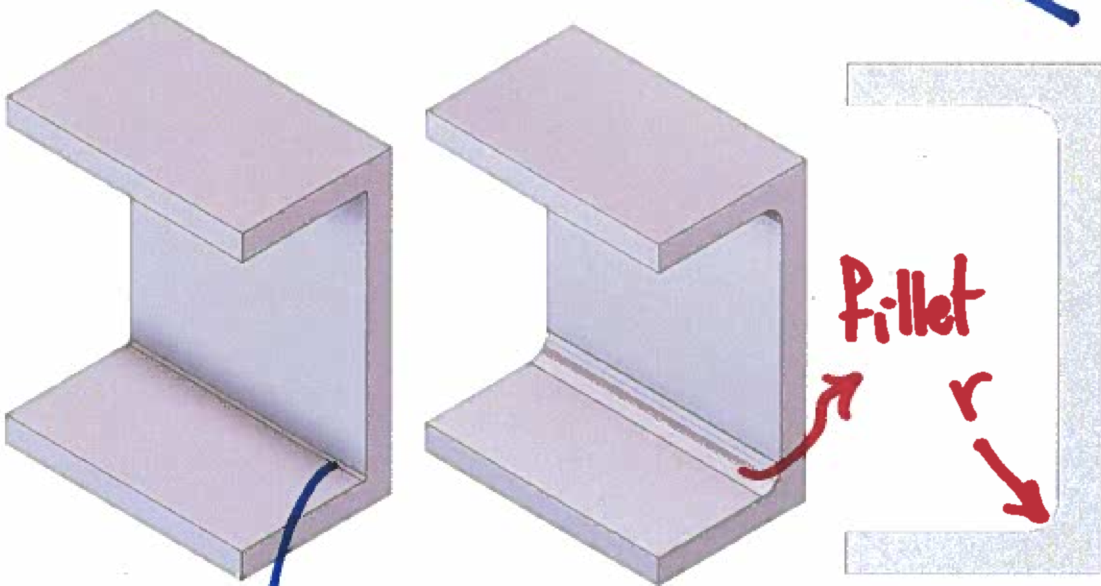
avoid long, thin hole





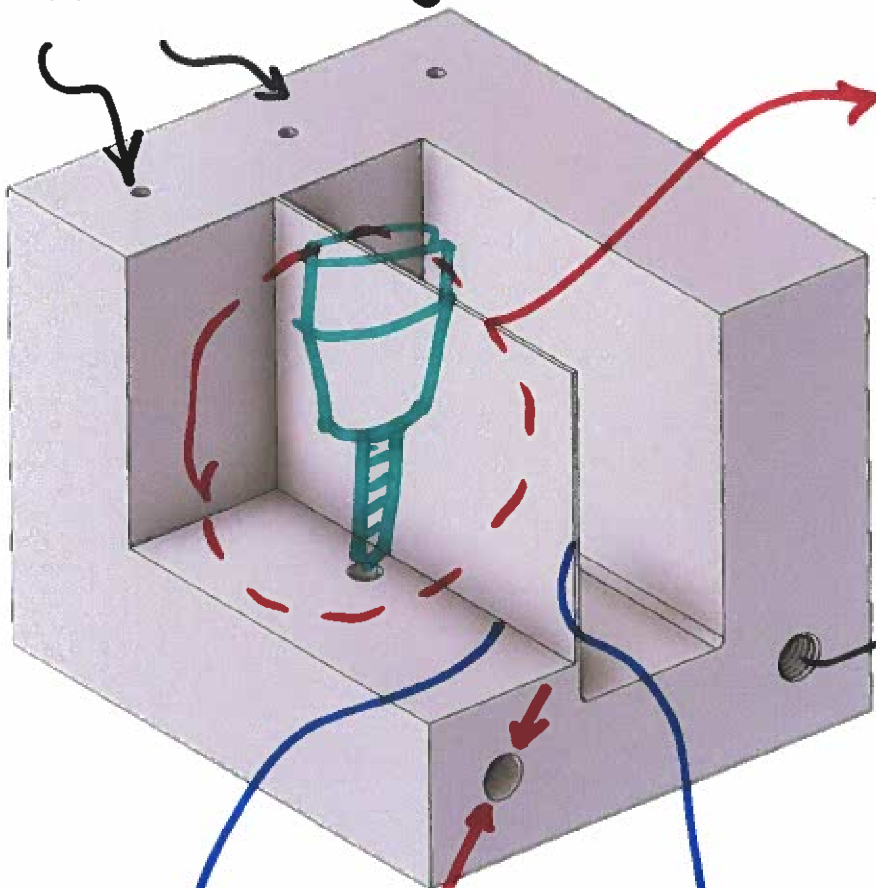
over hanged long workpiece

⇒ results in large deflection

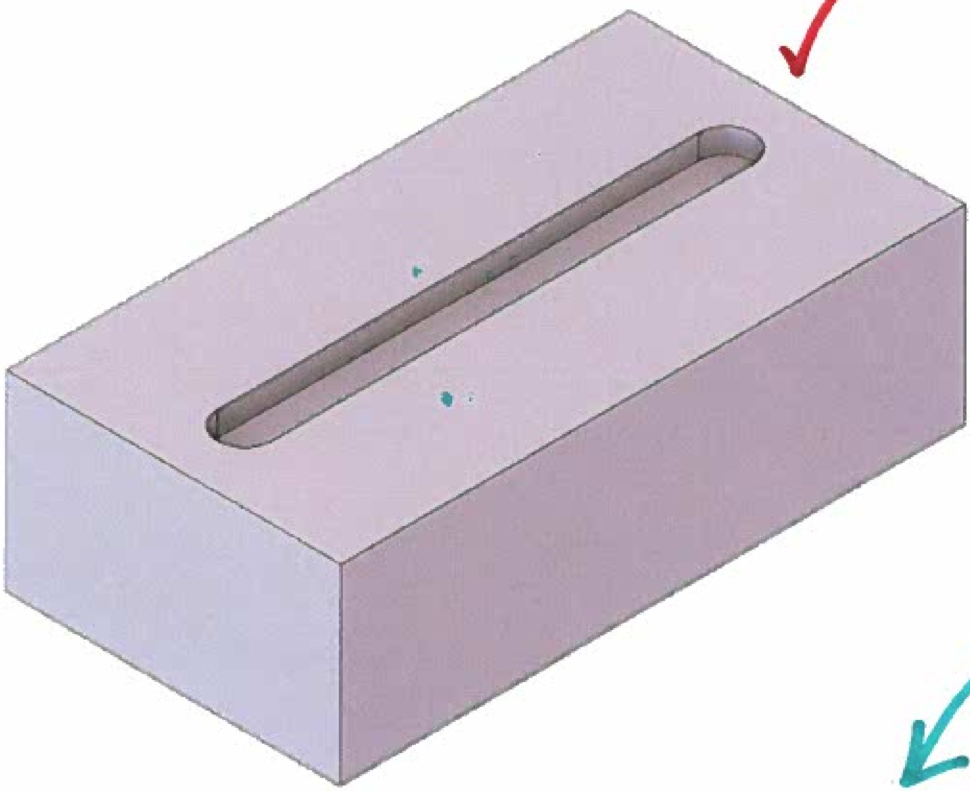


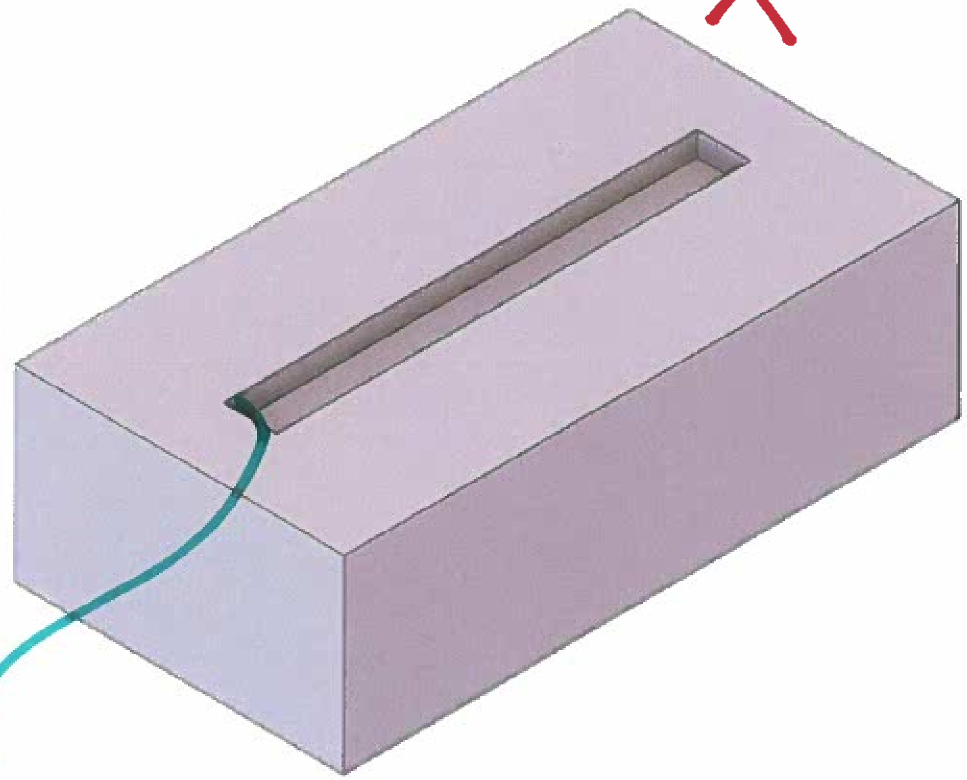
avoid sharp corner

Example 6) What is wrong with machining this part?



Example 7) You want to mill a pocket that is wide and narrow. Which of the following shapes should you pick from a Design for Machining perspective?





difficult (impossible) to machine.

Example 8) We need to make a thermoform mold that needs 0.05 inch-diameter holes to draw vacuum. Which of the following designs is optimized for manufacturability?