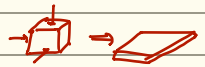
26 Feb 2025

* Introduction :-

→ composite materials (from more than one material) ⟹ a finished or semi-finished products

→ (Metals) are used (and from the oldest materials and most used in Manufacturing

→ the course talks about Metal forming ex: 

↳ other names : metal cutting (material removal) ex: 

metal machining.

↳ casting & welding

→ material forming is about changing the shape (deformation)

→ to have deformation I have to calculate : the power needed for the machine, the force needed for deformation to happen ...

Deformation ⟺ Forces (loading

→ I decide the force based on the material

---

* Mechanical behavior :-

the way in which metallic materials behave (responde) when subjected to mechanical loading.

طريقة استجابة المعادن للـ stimulus من القوة

→ the response is ⇒ the Deformation

→ the stimulus is ⇒ loading

- Mechanical behaviour is : Deformation - loading relationship

---

- Strength (قوة) :- material's resistance to Deformation when subjected to loading.

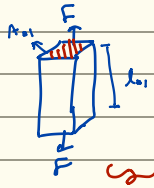
deformation: مقاومة المادة للـ loading عشان ما تتغير

* Chapter two :-

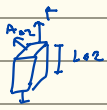
→ tensile strength

→ tensile test → we use this test to decide the materials tensile strength.

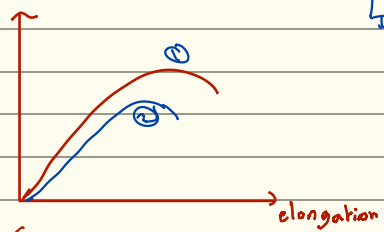
its simply pulling a specimen of the material and record the data.....



P → capital p (force)



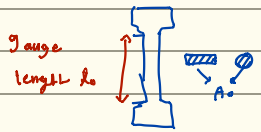
curve #2



this diagram tells me curve #1 is stronger than curve #2 But its the same material but different sizes ⇒ Solution:

Standard specimen

→ I need a way to make the effect of l_o, A_o ⇒ non-existent



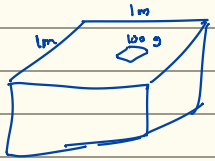
↳ the ways :-

1- Stress $\frac{F}{A}$ $N/m^2 = 1p$ → we use MPa instead of p because p is too small

$1p = 1\ N/m^2$

$1\ MPa = 10^6\ N/m^2$

$1MPa = N/mm^2$



→ engineering or nominal stress :- الإجهاد الهندسي

$$\sigma = \frac{P}{A_o}$$ (F)

A_o → original cross section

→ A_o is the reason to name it engineering because in reality A_o changes

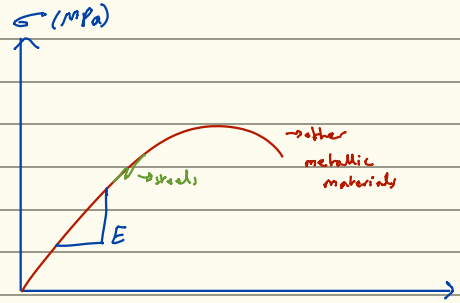
→ nominal : means قيمة اسمية مبدئية حقيقية

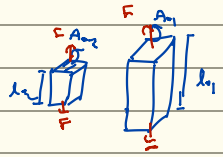
الإجهاد الهندسي يتم بناء على A_o الابتدائية

→ engineering strain :- الانفعال الهندسي (unitless)

$$e = \frac{\Delta L}{l_o} = \frac{l_f - l_o}{l_o}$$ → strain يكون بدون وحدات

A_o, l_o is initial





unified curve material لكل

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

elongation العلاقة بين σ, e يكون

بدون وحدات control يتم

no explosion

---

during the tensile stress :

1) first the l increase and deformation is elastic (temporary)

2) the behaviour continuous (linear + elastic) until the proportional limit → elastic linear range.

3) after that elastic continuous until the yield stress but σ & e relationship is not linear. → elastic non linear range

σ, e → linear relationship

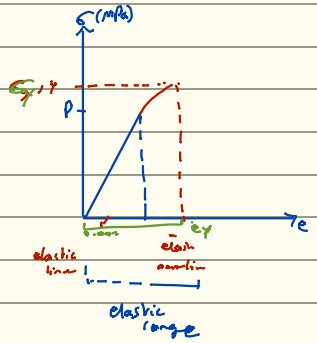
$\sigma = Ee$

E : modulus of elasticity [MPa]

→ elastic range:

deformation is not permanent

↳ elastic recovery: composed will go back to original dimensions



in metals 0.002 → 0.2 % offset method ✓

in non steels there is no obvious point for yield point between elastic & plastic deformation

yield point (σ_y, e_y)

last point in elastic and beggining of plastic.

---

3 March 2025

→ $\sigma = E.e$ (Hook's Law)

→ poisson's ratio (ν) (new): ratio of lateral strains to longitudinal strain (strain in the same direction as the acting force (stress))

longitudinal strain = $e_x = \frac{\Delta x}{x_0}$



$e_y = -\nu . e_x = \frac{\Delta y}{y_0}$

$e_z = -\nu . e_x = \frac{\Delta z}{z_0}$

$\nu \rightarrow 0.2 - 0.75$ according to the material.

---

ex:



$z_0 = 50$ mm

$y_0 = 20$ mm

$x_0 = 100$ mm

if $x_f = 101$ mm, find the volume of the workpiece while still under loading if $\nu = 0.3$

$\Delta x = 101 - 100 = 1$

$e_x = \frac{\Delta x}{x_0} = \frac{1}{100} = 0.01$

$e_y = -\nu . e_x = e_y = 0.003$

$V_f = X_f \cdot Y_f \cdot Z_f$

$-0.003 = \frac{y_f - 20}{20}$ | $0.003 = \frac{z_f - 50}{50}$

$20 - 0.06 = y_f$ | $-0.15 = z_f - 50$

$19.94 = y_f$ mm | $z_f = 50 - 0.15$

$z_f = 49.85$ mm

$V_f = 101 \times 19.94 \times 49.85$

$= 100394.904$ mm^3

$= 100.4$ m^3

write every step in the exam (don't skip on anything)

---

* **Modulos of Resilience (MOR) :**

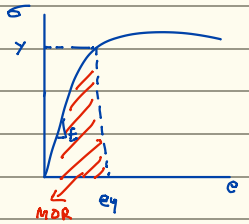
energy per unit volume (specific energy) the material can absorb elastically

كمية الطاقة بكل وحدة حجم يقدر المادة تمتصها بشكل مرن

don't go to plastic range.

elastic range

→ MOR = to area under stress-strain curve in the elastic range.



$MOR = \frac{e_y \cdot y}{2} = \frac{y^2}{2E}$

$e_y = \frac{y}{E}$

unit of $MOR = \frac{P_a^2}{P_a} = P_a$

$= \frac{N}{m^2} \cdot \frac{m}{m} = \frac{N.m}{m^3} = \frac{J}{m^3}$

Joule (energy) / m^3 (volume)

or Pascal

or Pash

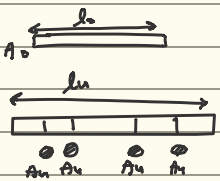
Mon 11 March

→ we are going to the plastic range.

UTS : ultimate tensile stress (the maximum value)

up to this point we have uniform elongation

uniform elongation :

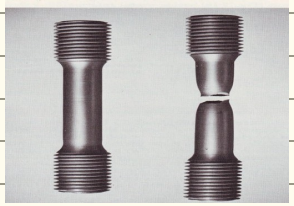


⇒ all uniform

→ here after the uniform elongation we have the necking.

→ it happens in the middle of the specimen

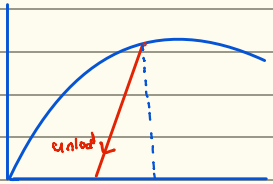
middle في load متغير



→ elastic recovery :-



in the plastic →
if we unload (load = 0)
the strain will not be the same as it is supposed to be at the point we unloaded.



permenant strain = total strain − elastic strain

→ Ductility :

المقدرة على الاستطالة بدون كسر
استطالة البلاستيكي ↓

we can measure it in two ways :

$$El\% = \frac{l_f - l_o}{l_o} \times 100\%$$

يستخدم أكثر ⇐

$$DA\% = \frac{A_o - A_f}{A_o} \times 100\%$$

up to UTS :
we have uniform elongation
$V_f = V_o = A_o \cdot l_o = A_f \cdot l_f$

→ True stress & strain

$$\sigma = \frac{P}{A} \qquad \epsilon = \ln\left[\frac{l_f}{l_o}\right]$$

instantaneous ←

Strain: التغير في الطول بالنسبة

$$d\epsilon = \frac{dl}{l} \leftarrow \text{التغير في الطول}$$

$$\epsilon = \int_{l_o}^{l_f} \frac{dl}{l} = \ln(l)\Big|_{l_o}^{l_f} = \ln(l_f) - \ln(l_o)$$

$$\therefore \ln\left(\frac{l_f}{l_o}\right)$$

During uniform elongation:

$$A_o \cdot l_o = A_f \cdot l_f$$

$$\frac{A_o}{A_f} = \frac{l_f}{l_o}$$

$$\ln\left(\frac{l_f}{l_o}\right) = \ln\left(\frac{A_o}{A_f}\right)$$

$$\epsilon = \ln\left(\frac{A_o}{A_f}\right)$$

if the area is round: $\frac{A_o}{A_f} = \frac{D_o^2}{D_f^2}$

$$\rightarrow \epsilon = \ln\left(\frac{D_o^2}{D_f^2}\right) = 2\ln\left(\frac{D_o}{D_f}\right)$$

← لاحظ نشتق العلاقة بين ال True & eng. strain :

$$e = \frac{l_f - l_o}{l_o} = \frac{l_f}{l_o} - 1 \rightarrow \frac{l_f}{l_o} = e + 1$$

$$\epsilon = \ln\left(\frac{l_f}{l_o}\right) = \ln(e+1)$$

$$\lim_{x \to 0} \ln(x+1) = x$$

(x → 0: very small)

when e is very small ⇒ $\epsilon \approx e$

(e: eng. strain)

→ at very small values of strain, then $\epsilon \approx e$

this is valid in the elastic range where strain (change in dimensions) is very small

e: eng. strain

ϵ: true strain

→ so ϵ is always valid → so it's better to use it

TABLE 2.1 Comparison of engineering and true strains in tension.

e	ϵ
0.01	0.01
0.05	0.049
0.1	0.095
0.2	0.18
0.5	0.4
1	0.69
2	1.1
5	1.8
10	2.4

e: is valid only in elastic range.

ϵ: is valid in elastic and is the true in the plastic range.

eng. is only valid in elastic → so we use the true strain

العلاقة بين true & eng :

$$\sigma_{true} = \frac{P}{A} \qquad \sigma_{eng} = \frac{P}{A_o}$$

$$\frac{\sigma_{true}}{\sigma_{eng}} = \left(\frac{A_o}{A}\right)$$ → this is only valid in the uniform elongation

→ another way always valid.

$$\sigma_{true} = \sigma_{eng} \cdot \left(\frac{A_o}{A}\right)$$

$\exp[\ln(x)] = x$

$$\sigma_{true} = \sigma_{eng} \exp\left[\ln\left(\frac{A_o}{A}\right)\right]$$

$$\sigma_{true} = \sigma_{eng} \cdot \exp^{(\epsilon)}$$

Wed March 12

→ at the UTS we have the necking & the area will decrease in a fast rate, so the load needed is less (so it will decrease), But the area decreases faster

✳ Mechanical Behavior equation / formula

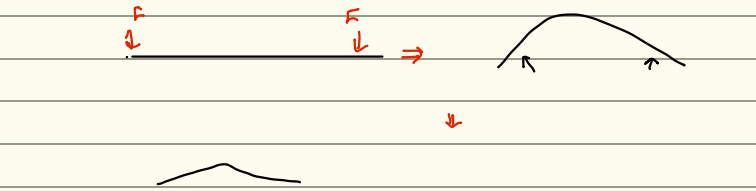
$\sigma = K\epsilon^{n}$ MPa

note: this equation is only for TRUE stress & TRUE strain

→ K : strength coefficient (MPa)

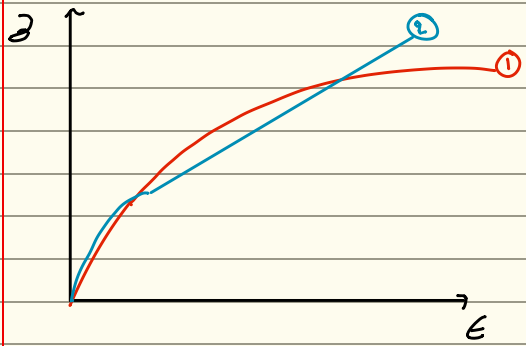
→ n : strain hardening index

→ strain hardening : the increase in material, strength or hardness as a result of plastic strain (plastic deformation)



σ_{true}

$\sigma_{eng} \rightarrow \sigma$



1: high "k" , low "n"

2: low "k" , high "n"

$\sigma_{eng} = \frac{P}{A_o}$, $e = \frac{\Delta l}{l_o}$

↓ σ ↓ log σ

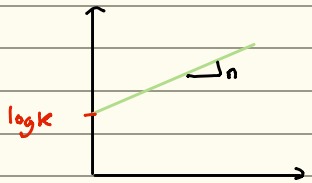
↓ ε ↓ log ε

$\sigma = K\epsilon^n$

$\log \sigma = \log K + n \log \epsilon$

$Y = \log K + n x$

Y axis ← $\log \sigma$ ، slope ← n

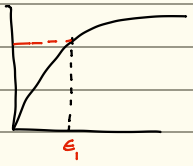


---

* **Flow stress** :-

it's the stress required to continue the plastic deformation at ϵ_1

$\sigma_f = \sigma_1$ ← Flow stress



Avg flow stress :

$$\bar{\sigma}_f = \frac{1}{\epsilon_1} \int_0^{\epsilon_1} K\epsilon^n \, d\epsilon = \frac{K\epsilon^n}{n+1}$$

---

* **Toughness** :-

true stress - true strain الي بالمساحة كاملة تحت ال ←

من 0 ← ϵ_f (fracture strain)

& it's energy

2.2.4 Instability in Tension (Plastic Instability in Tension)

→ it's the necking.

→ at the UTS

← عند هذه النقطة إعادة تشكيل out of control

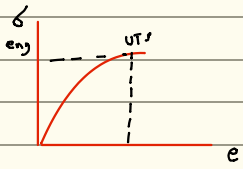
→ the force is decreasing but it's still getting elongating because the area is decreasing faster

$F \downarrow$ ⇐ $A \downarrow$

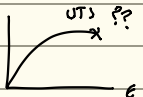
F, A



→ so the last stress I want to get to is UTS, after that I don't want it.



But our problem is where is UTS_{true} ??



↳ UTS here isn't visible.

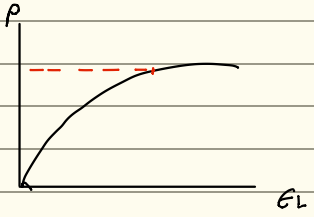
$$P = \sigma_{tr} \cdot A = \sigma_{eng} \cdot A_0$$

$$P = \sigma_{tr} e^{-\epsilon} \cdot A_0$$

$$P = A_0 \cdot \sigma_{tr} \cdot e^{-\epsilon}$$

$$\frac{dP}{d\epsilon} = A_0\left(\frac{d\sigma}{d\epsilon} \cdot e^{-\epsilon} - \sigma \cdot e^{-\epsilon}\right) = 0$$

at UTS ⇓



at UTS

$dP = 0$

at UTS

$$\sigma_{eng} = \sigma_{tr} e^{(-\epsilon)}$$

$$\frac{d\sigma}{d\epsilon} = \sigma$$

At UTS ⟹ $\frac{d\sigma}{d\epsilon} = \sigma = K\epsilon^n$

this is only valid when $\sigma = K\epsilon^n$

$$nK\epsilon^{n-1} = K\epsilon^n \qquad \epsilon = 0.5$$

$$nK\epsilon^n * \epsilon^{-1} = K\epsilon^n$$

$n = \epsilon$ ⇒ at UTS.

because if we are given another relationship I have to [illegible] $d\sigma$

at UTS + $\frac{d\sigma}{d\epsilon} = \sigma$ for the true.

$\epsilon_y = 0.001$ ← [illegible] so not from recovery

$\epsilon_{elastic} = 0.001$

$\epsilon_{plastic}$ [illegible]

$\sigma = 300\,\epsilon^{0.5}$

100

$y = 200$ MPa

$E = 200$ GPa

$\epsilon_p = \epsilon - \epsilon_{elastic}$

$\epsilon_p = f\left(\frac{\sigma}{\sigma_y}\right)$

[illegible] σ [illegible] ϵ

$\epsilon < ?$ [illegible]

$\sigma < y$ ⇓ [illegible] ⇓ $\epsilon_p = -\epsilon_e$

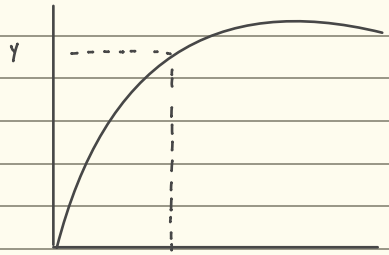
$\sigma > y$ [illegible] elastic [illegible]

plastic [illegible] غير مستوي

So $\sigma = \epsilon_p + \epsilon_e$

UTS ← $\sigma_{eng} = \sigma_{true}\, e^{-\epsilon}$ (I: exponential) ← [illegible] UTS [illegible] stress

22.03.16



Full recovery ← $\epsilon < \epsilon_Y$

Just the ϵ_Y will recover ← $\epsilon > \epsilon_Y$

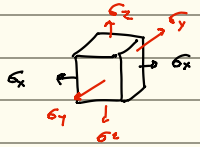
$$\epsilon_x = \frac{Y}{E}$$

---

monday, Mar 24

* 3 dimensional stress system — 2.11.4

elastic range (elastic behavior)



$$\epsilon_x = \frac{\sigma_x}{E} - \frac{\nu\sigma_y}{E} - \frac{\nu\sigma_z}{E} = \frac{1}{E}(\sigma_x - \nu(\sigma_y + \sigma_z))$$

$$\epsilon_y = -\frac{\nu\sigma_x}{E} + \frac{\sigma_y}{E} - \frac{\nu\sigma_z}{E} = \frac{1}{E}(\sigma_y - \nu(\sigma_x + \sigma_z))$$

$$\epsilon_z = -\frac{\nu\sigma_x}{E} - \frac{\nu\sigma_y}{E} + \frac{\sigma_z}{E} = \frac{1}{E}(\sigma_z - \nu(\sigma_x + \sigma_y))$$

- Not every system ikî directions are x, y, z ;-
- $\epsilon_1 = \frac{1}{E}(\sigma_1 - \nu(\sigma_2 + \sigma_3))$
- $\epsilon_2 = \frac{1}{E}(\sigma_2 - \nu(\sigma_1 + \sigma_3))$
- $\epsilon_1 = \frac{1}{E}(\sigma_3 - \nu(\sigma_1 + \sigma_2))$

→ Volum strain: $\Delta = \frac{\Delta V}{V_0}$

$= \ln(V_f/V_0)$

this is only in the elastic range

→ $\Delta = \epsilon_1 + \epsilon_2 + \epsilon_3$

$\Delta = \frac{1-2\nu}{E}(\sigma_1 + \sigma_2 + \sigma_3)$

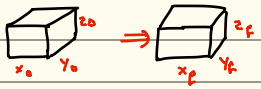
→ Volume strain in the plastic range is equal to zero.

→ plastic deformation doesn't cause change in the volume.

→ Yield criteria :-

→ common geometries :

1- Solid cube :



$V = x.y.z$

$\epsilon_1 = \epsilon_x = \ln(x_f/x_0)$ $\epsilon_2 = \epsilon_y = \ln(y_f/y_0)$ $\epsilon_3 = \epsilon_z = \ln(z_f/z_0)$

2- Solid cylinder :



$V = \frac{\pi}{4}.D.D.L$

$\epsilon_1 = \epsilon_2 = \epsilon_D = \ln(D_f/D_0)$

$\epsilon_3 = \epsilon_l = \ln(l_f/l_0)$

3- Solid sphere :

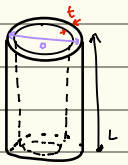


$V = \frac{\pi}{6}.D.D.D$ → we use this formula

$= \frac{4}{3}\pi.r^3$

$\epsilon_1 = \epsilon_2 = \epsilon_3 = \epsilon_D = \ln(D_f/D_0)$

4- thin Cylindrical shell :



$D \& L \gg t \rightarrow$ thin

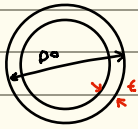
we want ϵ for the metal part not the void

$\epsilon_1 = \epsilon_D = \ln(D_f/D_0)$

$\epsilon_2 = \epsilon_L = \ln(L_f/L_0)$

$\epsilon_3 = \epsilon_t = \ln(t_f/t_0)$

5- thin spherical shell :



$V = \frac{\pi}{2}.D.D.t$

$\epsilon_1 = \epsilon_2 = \epsilon_D = \ln(D_f/D_0)$

$\epsilon_3 = \epsilon_t = \ln(t_f/t_0)$

→ shells usually have internal pressure that tries to increase the circumference and decreasing thickness.

---

ex: in a cylindrical shell:

→ circumference "C"

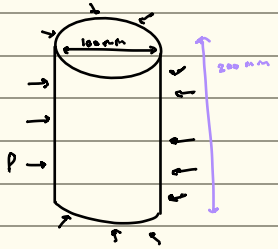
$C = \pi . D$

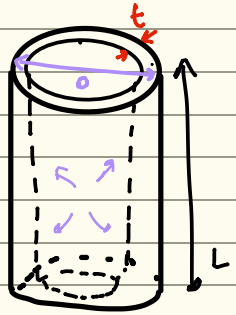
* $\epsilon_C = \ln(C_f/C_o) = \ln(\pi D_f/\pi . D_o) = \ln(D_f/D_o)$

$= \epsilon_D$

Both the ratio is the same so the strain

Questions-



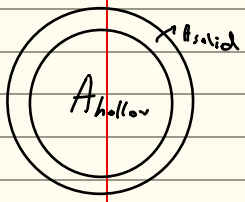


$L \gg t$

$D \gg t$

P avg

any shell has pressure inside it.





$\sigma_L = \frac{F}{A_{\perp L}}$

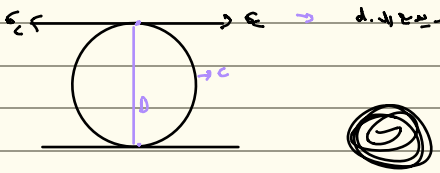
(1) → $\sigma_L = \frac{F_{\perp L}}{A_{\perp L}} = \frac{F}{A_s} = \frac{P . A_h}{A_s} = \frac{P . \pi . D^2/4}{\pi . D . t} = \frac{PD}{4t} = \frac{P.r}{2t}$ (MPa)

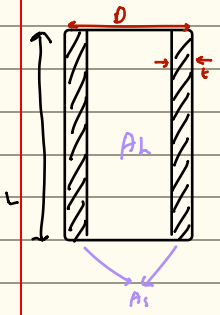
$C . t = A_s$

this is σ_L stress on the length.

we have also the σ_θ , σ_t

2) $\sigma_D = \frac{F_{\parallel D}}{A_{\perp D}}$



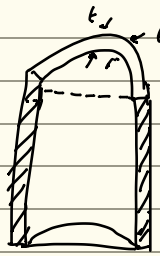


$$\sigma_c = \frac{F_{\parallel c}}{A_{\perp c}} = \frac{P \cdot A_h}{A_s} = \frac{P \cdot D \cdot 1}{2 \cdot t \cdot 1} = \frac{PD}{2t} = \frac{Pr}{t}$$

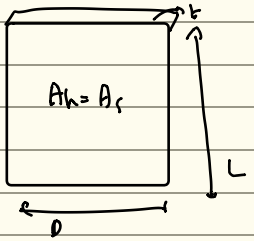
$\sigma_c = 2\sigma_L$ → so usually when a pipe breaks up it's usually the diameter

so → that means if there is going to be a failure it's gonna break up like this not this

---



→ any cross section ⊥ and is ⊥ on t



$$\sigma_t = \frac{-P \cdot A_h}{A_s} = -P$$ ← that's why

But we assume that $\sigma_t = \phi$ (zero)

because $\sigma_t \ll\ll \sigma_D + \sigma_L$

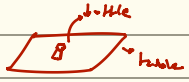
we assume

* Pressure Vs Stress :-

Pressure = contact stress

so in the pressure the fluid (gas or liquid) should be in contact with all of the surface

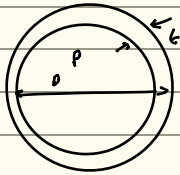
Ball in steel



this bubble makes stress with all of the surface

→ also there is no pressure negative (absolute) not relative.

Thin spherical shell :-

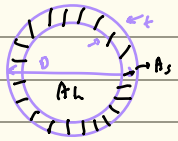


assume only elastic deformation

$D_o = 250$ mm $\quad P = 5$ MPa $\quad$ Find the final dimensions

$t_o = 2$ mm $\quad$ Steel $\quad$ (D_f, t_f) after pressurizing

$\sigma_D = \frac{F \parallel D}{A \perp D}$



$= \frac{P \cdot A_h}{A_s} =$

$\epsilon_1 = \epsilon_2 = \epsilon_D = \ln(D_f/D_o)$

$\epsilon_3 = \epsilon_t = \ln(t_f/t_o)$

$\sigma_D = \frac{P \pi r^2}{2\pi r \cdot t}$ ← قيمة A هي مساحة الدائرة هي مساحة الدائرة πr^2

$\sigma_D = \frac{P \cdot r}{2t}$

inplastic range

$\epsilon_1 + \epsilon_2 + \epsilon_3 = D$

$\sigma_1 = \sigma_2 = \frac{P \cdot r}{2t}$

$\sigma_3 = -P$

$\epsilon_t = \frac{1}{E}(\sigma_t - \nu(\sigma_D + \sigma_D))$

$\epsilon_1 = \epsilon_2 = \epsilon_D = \frac{1}{E}(\sigma_D - \nu(\sigma_D + \sigma_t))$

$\epsilon_D = \ln(D_f/D_o)$

$= \ln(D_f/250)$

$t_f < t_o \Leftarrow \epsilon_t$ negative

$$\epsilon_1 = \frac{1}{E}(\sigma_1 - \nu(\sigma_2 + \sigma_3)) \rightarrow \text{in elastic}$$

in the plastic deformation what is it?.

the plastic deformation → begins at the yield stress

when is this??

we have yield criteria

materials

max shear stress criterion

---

plane stress & plane strain

$(\sigma_1, \sigma_2, 0)$	$(\epsilon_1, \epsilon_2, 0)$
$(\sigma_1, 0, \sigma_3)$	$(\epsilon_1, 0, \epsilon_3)$
$(0, \sigma_1, \sigma_2)$	$(0, \epsilon_2, \epsilon_3)$

plain stress عشان يكون عندنا plain strain

Yield criteria in Plane stresses & plane strain

→ tresca

$\sigma_2 = 0$, $\sigma_3(+)$, $\sigma_1(-)$

if $\sigma_1 = 0$

$\sigma_3 - 0 = y \rightarrow y = \sigma_3$

if $\sigma_1 = -y$

$\sigma_3 - -y = y$

in this quarter σ_1 can only be 0 OR $-y$

$\sigma_2 = \sigma_3 > \sigma_1(-)$, $\sigma_2(-)$

σ_2 is max

less negative $\sigma_1 > \sigma_3$

$\sigma_2 - \sigma_3 = y$

$\sigma_3 = y$

$\sigma_3 > \sigma_1$

$\sigma_2 - \sigma_1 = y$

$\sigma_1 = -y$

$\sigma_1(+)$, $\sigma_2 = 0$, $\sigma_3(+)$

if $\sigma_1 > \sigma_3$

$\sigma_1 - \sigma_2 = y$

$\sigma_1 = y$

if $\sigma_3 > \sigma_1$

$\sigma_3 - 0 = y \Rightarrow \sigma_3 = y$

in this quarter σ_3 can only be

$\sigma_3 = 0$ OR $\sigma_3 = -y$

$\sigma_1 - 0 = y$

$\sigma_1 = y$

$\sigma_1 - (-y) = y$

$\sigma_1 = -y$

$\sigma_3 = -y$ this is yielding plane

any point on the plane or outside we will have yielding

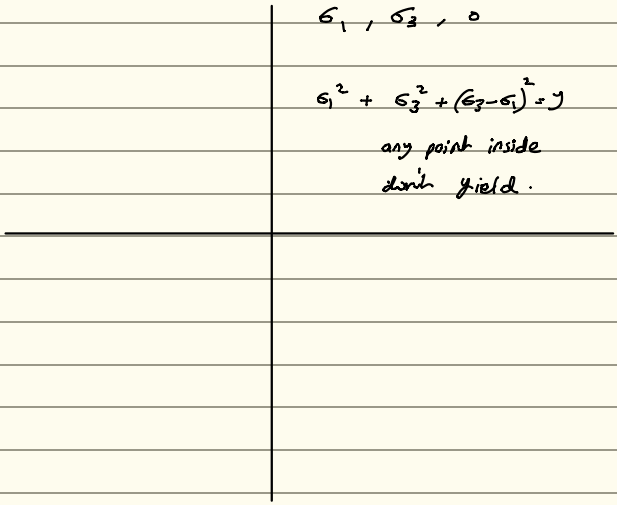
but any point inside we won't have yielding.

ex $\sigma_1 = y/2$, $\sigma_3 = y/4$ } first quad

$\sigma_{max} - \sigma_{min} = y$

$y/2 - 0 = y/2 \rightarrow$ no yielding

Yielding Crave (Von mises)



14/4/2025

2.12:-

$$W_T = W_I + W_F + W_R$$

→ W_T : total work of Deformation

→ W_I : ideal " " " (Plastic work) → calculated

→ W_F : frictional " " " } estimated : 15 - 30 % W_T

→ W_R : frictional " " "

* $W_I = U_I \cdot V$ وذا بدنا نحسب ما بتكل الطاقة ←

→ $U_I = \int_0^{\bar{\varepsilon}} \bar{\sigma} \cdot d\bar{\varepsilon}$ من لحد ما fracture

* Temp rehve rise due to Plastic deformation

temp. rise (ΔT) ← حرارة بتتولد ← work بالشغل ←

$$\Delta T = \frac{U_T}{\rho \cdot c}$$

→ $U_T = U_I + U_F + U_R = W_T / V$ (volume.) (Kg/m^3)

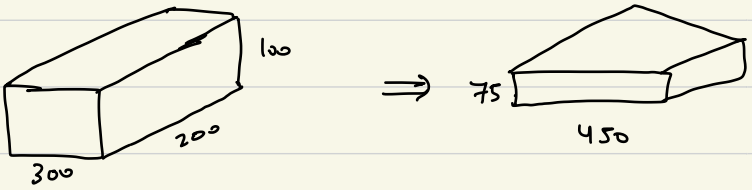
→ ρ : w/p material density (Kg/m^3)

→ c : " " specific heat $Kg/Kg.k^\circ$

→ plastic deformation ⇒ $\Delta V = 0$

$\epsilon_1 + \epsilon_2 + \epsilon_3 = 0$

ex:



$\sigma = 300\,\epsilon^{0.5}$ MPa

$\rho = 8$ g/cm^3

$C = 0.5$ kJ/kg·K°

material follow : Von-mises (OF

$W_F + W_R = 30\%\ W_T$

Find the rise in Temp. in the W.p (work peice)

$$\Delta T = \frac{U_T}{\rho C}$$

(ρ, C ↳ given)

$$U_T = U_I + U_W + U_F$$

$$U_I = \int_0^{\bar{\epsilon}} \bar{\sigma}\, d\bar{\epsilon} \Rightarrow \bar{\epsilon} = \frac{\sqrt{2}}{3}\left[(\epsilon_1-\epsilon_2)^2 + (\epsilon_2-\epsilon_3)^2 + (\epsilon_3-\epsilon_1)^2\right]^{1/2}$$

$\epsilon_1 = \ln(12/10) = 0.405$

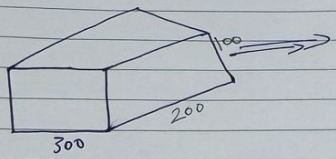
$\epsilon_2 = \ln(h_f/h_0) = -0.288 \Rightarrow \epsilon_3 + \epsilon_1 + \epsilon_2 = 0$

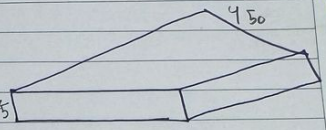
$\epsilon_3 = -0.117$

$\bar{\epsilon} = 0.417 \rightarrow U_I = 0.7\,U_T$

"Lec 10"

Ex:





$\bar{\sigma} = 300\,\bar{\epsilon}^{0.5}$ MPa $\rho = 8\ g/cm^3$

$C = 0.5\ kJ/kg\,K^\circ$ material follows: Von Mises (DE) or Hencky

$w_F + w_R = 30\%\, w_T$

find the rise in temperature in the W.P

$\Delta T = \frac{u_T}{C}$ (given)

$u_T = u_I + u_R + u_F$

$u_I = \int_0^{\bar{\epsilon}} \bar{\sigma}\, d\bar{\epsilon}$

$$\bar{\epsilon} = \frac{\sqrt{2}}{3}\left[(\epsilon_1-\epsilon_2)^2 + (\epsilon_2-\epsilon_3)^2 + (\epsilon_3-\epsilon_1)^2\right]^{1/2}$$

$\epsilon_1 = \ln(L_f/L_0) = \ln(450/300) = 0.405$

$\epsilon_2 = \ln(h_f/h_0) = \ln(75/100) = -0.288$

in plastic def Σ of ϵ = zero $\Rightarrow$ volume constant

$\epsilon_1 + \epsilon_2 + \epsilon_3 = 0$

$\epsilon_3 = -0.117$

$$\bar{\epsilon} = \frac{\sqrt{2}}{3}\left[(0.405+0.288)^2 + (-0.288+0.117)^2 + (-0.117-0.405)^2\right]^{1/2} = 0.417$$

$$u_I = \int_0^{0.417} 300\,\bar{\epsilon}^{0.5}\, d\bar{\epsilon} = \frac{300}{3/2}\,\bar{\epsilon}^{3/2}\Big]_0^{0.417} = 53.86 \times 10^6\ J/m^3$$

$\hookrightarrow 53.86 \times 10^3\ kJ/m^3$

$u_I = 0.7\, u_T \Rightarrow u_T = \frac{u_I}{0.7}$

$u_T = 76.94 \times 10^3\ kJ/m^3$

$W_T = u_T \cdot V = 76.9 \times 10^3 \times (6 \times 10^{-3}) = 461.4$

lec 12

Wed Apr 16

Ch6 :- Bulk deformation processes :-

→ classification of metal forming processes :-

1) according to sequence in operations:

a- primary processing : initial processing in preparation for further processing.

b- secondary processing : intermediate or final processing

2) according to processing temp:

note ⇒ Homologous temp (T_H or H_T) fraction of the melting temp

$$T_H = \frac{\text{processing temp } (K^\circ)}{\text{melting temp } (K^\circ)}$$

of material property

a- if $T_H < 0.5$: Cold forming (Cold working):

- requires high level of force & energy — I would put the money because it's final processing
- reduces high mechanical properties because of (strain hardening (high)) at lower temp
- limited formability (lower ductility at lower temp)
- produces good surface finish & dimensional accuracy
- mostly final processing.

Cold forming: final processing

b- if $T_H > 0.5$: hot forming (hot working)

- requires low level of force & energy (lower strength at high temp)

- reduces low mechanical properties
because of no (strain hardening)

- High formability (high ductility at high temp)

- produces poor surface finish & dimensional accuracy (oxidation)

- usually primary processing.
← final processing ← hot working

ex: forging, rolling → surface finish
or there is coating after the working.

c- $T_H \approx 0.5$: warm forming (warm working)

3) according to starting workpiece geometry :-

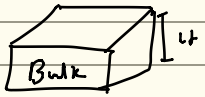
ch6 ← a- bulk deformation processes : metal forming processes involving wips with relatively low surface-area to thickness ratio.

ch7 ← b- sheet metal forming processes involving wips with relatively high surface-area to thickness ratio.

Sheet metal thickness (t) ≤ 6mm

if t > 6mm → plate
even if the ratio is high

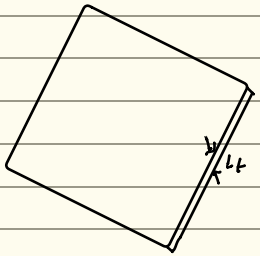
(أشكال مختلفة) rods, cylindrical :



→ bulk of material

material كمية كبيرة من

$\frac{\text{surface}}{\text{thickness}}$ low



Sheet metal

$\frac{\text{surface}}{\text{thickness}}$ → high

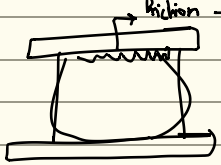
Open-die forging

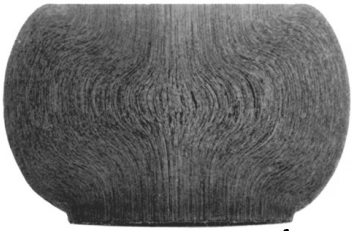
- primary processing & hot working
- W/P volume < die-cavities volume.
- used for simple shapes
- lowest force & energy levels among forging operations

---

actual open die forging (barrelling)

friction → lubrication (solution)



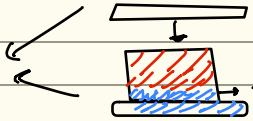


hot forming → plate cold < W/P

because of the cold die

↳ solution: heating the plate a little bit W/P

heating



this part is now cold because of the die plate

the grain → so strength↑, ductility↓ في اتجاه forging

Impression-die forging:-

- wip volume larger than die-cavity volume
- used for relatively complex shapes with fine details
- mostly hot (but maybe cold) forming + final processing
- requires highest levels of force and energy levels among forging operations

---

→ the flash (excess material) has two jobs:-

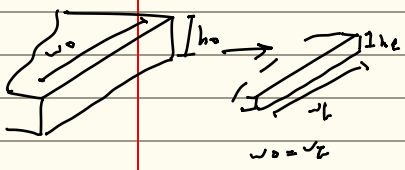
1) makes the metal to flow in the fine details ↑ being
2) prevent contact between the two dies because of high force they might break

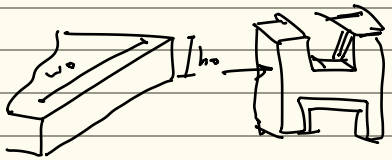
* in the end we trim the flash

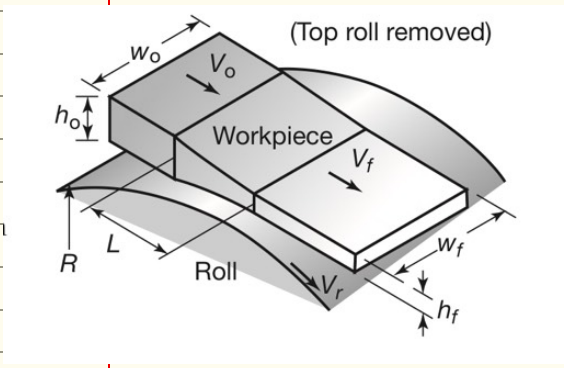
Mon Apr 21th

Rolling

- Flat rolling
  - the goal is to only reduce the thickness
- Shape rolling
  - the goal: is to change the cross section







h_o: initial height of wp in mm

h_f: final " " " " "

R: roll radius in mm

α: entry angle:
angle between the point of the first touch (entry point) with the normal

in rad
in deg } as sin, cos
↳ rad or degree doesn't matter

$w_o = w_f$ → constant = width of the strip / plate (w/p) : mm

L: length of contact (mm)

V_o: entry or initial velocity : m/s

V_f: final velocity : m/s

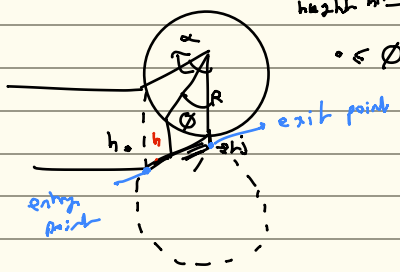
V_r: roll's surface velocity : m/s

$V_r > V_o$ → fixed

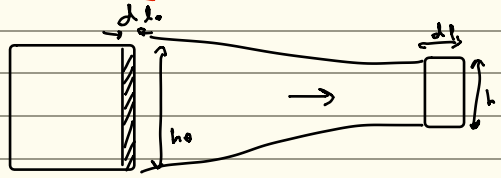
$\emptyset$: any angle on the arc of contact that corresponds to height "h"

any height of the w/p such that $h_o \geq h \geq h_f$

$0 \leq \emptyset \leq \alpha$



⇒ initially the w/p approches the rollers at a constant initial velocity (V_o), while the rollers rotate at a constant surface velocity (V_R), and where $V_R > V_o$. As such, this difference in speed (roller & plate) causes the material to squeeze in between the two rollers with a corresponding reduction in height and increase in velocity. Width is constant



volume

$$\frac{dl}{dt} \cdot h_o \cdot w = \frac{dl}{dt} \cdot h \cdot w$$

velocity: $V_o \cdot h_o = V \cdot h$

$h_o > h$

$$\frac{V}{V_o} = \frac{h_o}{h} \Rightarrow V > V_o$$

at any point on the arc

⇒ the material's velocity is larger than its initial velocity (V_o) but still smaller than (V_R). however, this continuous increase in velocity causes the material's velocity to reach the roller surface v (V_R) at a certain point on the arc of contact known as the neutral point. ($V = V_R$)

⇒ After the neutral point the material's velocity exceeds V_R ($V > V_R$) where frictional forces are reversed in direction leading to a phenomen known as forward slip

$$\text{Forward slip} = \frac{V_f - V_R}{V_R}$$

Forward slip :- Sliding or slipping of the material over the surface of the rollers due to the larger velocity of the material within the exit zone (doesn't happen in entry zone or arc of contact)

the zone between the entry point & the nuetral point is known as the entry zone and zone between exist & neutral point ⇒ exist zone

---

Wed Apr 23th

ex:

$h_o = 100\ mm$

$h_f = 90\ mm$

$R = 250\ mm$

$\sigma = 500\,\bar{\epsilon}^{0.5}\ MPa$

material follows MSS → $\bar{\epsilon} = \frac{2}{3}(\epsilon_1 - \epsilon_3)$ criteria

find roll P at the nutral point ↳ عشان كمان

$\mu = 0.5$ ↳ friction coeff. between material & roll

بين entry & exit zones

اي حاجة بتنتج حا بزوم لاقيا موجودة بالتنتين

at exit :

$$P = \sigma_f' \frac{h}{h_f} e^{\mu H}$$, at nutral point $h = h_n$, $H = H_n$, $\alpha = \alpha_n$

$$P_n = \sigma_f' \frac{h_n}{h_f} e^{\mu H_n}$$

$$\sigma_f' = \frac{2}{\sqrt{3}}\sigma_f = \frac{2}{\sqrt{3}}(500\,\bar{\epsilon}^{0.5})$$

$$= \frac{2}{\sqrt{3}}(500 \times (0.3)^{0.5})$$

$$= 314.92\ MPa$$

$\epsilon_w = 0$

$\epsilon_h = \ln(h_f/h_o) = \ln(\frac{90}{100}) = -0.223$

$\epsilon_L = 0.223$ in plastic range $\epsilon_1 + \epsilon_2 + \epsilon_3 = 0$

$\bar{\epsilon} = \frac{2}{3}(\epsilon_L - \epsilon_h) = 0.3$

$$\rightarrow h_n = h_f + 2R(1 - \cos\phi_n)$$

$$\phi_n = \sqrt{\frac{h_f}{R}} \cdot \tan\left(\frac{H_n}{2}\sqrt{\frac{h_f}{R}}\right)$$

$$H_n = \frac{1}{2}\left(H_o - \frac{1}{\mu}\cdot\ln\left(\frac{h_o}{h_f}\right)\right)$$

$$H_o = 2\sqrt{\frac{R}{h_f}} \cdot \tan^{-1}\left(\sqrt{\frac{R}{h_f}} \cdot \alpha\right)$$ → $\alpha = \phi$ at entry (o)

$h_o = h_f + 2R(1 - \cos\alpha) \Rightarrow \alpha = 0.28$ rad

$H_o = 1.625$

$\rightarrow H_n = 0.59$

$\rightarrow \phi_n = 0.095$ rad

$\rightarrow h_n = 82.3$ mm

$\Rightarrow$ exit

$$p = \sigma_f' \frac{h}{h_f} e^{\mu H}$$

$$p_n = \sigma_f' \frac{h_n}{h_f} e^{\mu H_0} = 314 \cdot \frac{82.3}{80} e^{0.5(0.59)}$$

$$p_n = 435 \text{ MPa}$$

$\Rightarrow$ entry $\quad p_n = \sigma_f' \frac{h_n}{h_f} e^{\mu (H_0 - H_n)}$

$$= 314 \frac{82.3}{80} e^{0.5(1.625 - 6.59)}$$

$$p_n = 433 \text{ MPa}$$

← طبع في ورقة بسيطة بس عادية.

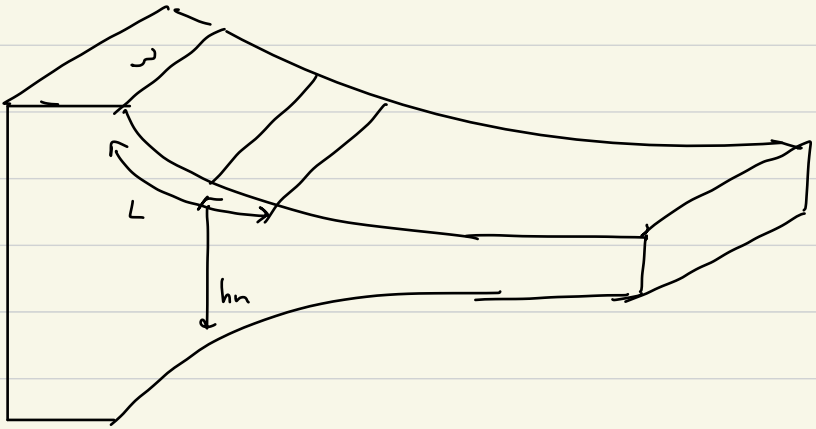
← ممكن يعطيني عند نقطة معينة بده إل p ⇐ لازم اعرف اذا النقطة بال exit OR entry

1) بطلع h عند النقطة ، 2) بطلع h_n

same thing if the question gave us ϕ at the point

entry eqn ⇐ $h > h_n \Rightarrow$ entry

exit eqn ⇐ $h < h_n \rightarrow$ exit



$$F = P \cdot A \hookrightarrow dF = P \cdot dA \; ; \; dA = w \cdot dL \; ; \; dL = R \cdot d\phi$$

h فلازم نعرف ... بالعلاقة $\leftarrow$ { at the entry & at the exit & h حسب تغير

as $h = f(\phi)$ a function of ϕ

$$dF = P \cdot w \cdot R \, d\phi \qquad , \; w, R \rightarrow \text{constants}$$

$$F = \int_{0}^{\phi_n} P w R \, d\phi + \int_{\phi_n}^{\alpha} P w R \, d\phi$$

P_{entry} $\qquad$ P_{exist}

$$0 < \phi < \alpha \Rightarrow 0 < \phi < \phi_n + \phi_n < \phi < \alpha$$

$$F = L \, w \, P_{avg.}$$

$$L = \sqrt{RDh}$$

question :-

assume : $w = 500$ mm $\quad h_0 = 160$ mm $\quad h_f = 80$ mm

$\sigma = 500\,\epsilon^{0.5}$ $\quad \bar{\sigma}_f = 314$ MPa

$\mu = 0.5$ $\quad R = 25\%$

$\Delta h = 0.02$ m

$\rightarrow \bar{\sigma}_f = \frac{\bar{\sigma}_f}{1+n} = \frac{314}{1.5} = 209$

low friction

$F = L \cdot w \cdot \bar{\sigma}_f$

$L = \sqrt{R \cdot \Delta h}$ in m

$= \sqrt{0.25 \times 0.02} = 0.07$

$F = 0.07 \times 0.5 \times 209 \frac{N}{m} \times 10^6$

$= 7315$ KN

high friction

$F = L w \bar{\sigma}_f \left(1 + \frac{\mu L}{2 h_{avg}}\right)$

$h_{avg} = \frac{h_0 + h_f}{2} = \frac{160 + 80}{2} = 120$

$= 7315 \left(1 + \frac{0.5 \times 0.07}{2 \times 0.09}\right)$ in m

$= 8737$ KN

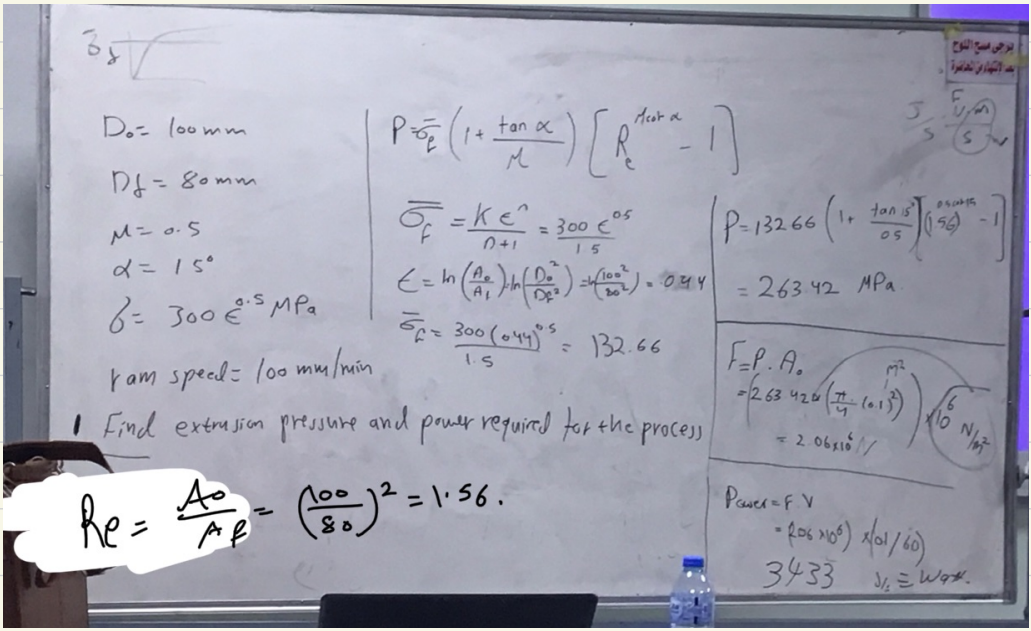
$\mu = 0$ ← no friction ← أقل شيء يكون

length of contact (L) و coeff. of friction (μ) تبعت لـ

$L \uparrow \Rightarrow F \uparrow$

Monday May-19

Question :-



$$\text{power} = \frac{\text{energy}}{\text{time}}$$

for per

$$\text{energy} = \text{power} \cdot \text{time}$$

$$\text{work (energy)} = F \cdot L_o$$

L_o ← → L_c

L_o : container

ex: L_o = 500 mm

L_c = 600 mm

L_o = 500 mm

L_c = 600 mm

container → γ = 200 MPa

E = 200 GPa

find the container's external dimension so that it absorb the whole process without plastic deformation