

Manu (1)

Sana Househ

Manufacturing processes : [the mechanical behaviour in metal forming.]

→ processes : casting (welding) ⇒ heat. -- ①

cutting ⇒ material removal process -- ②

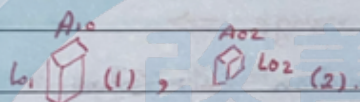
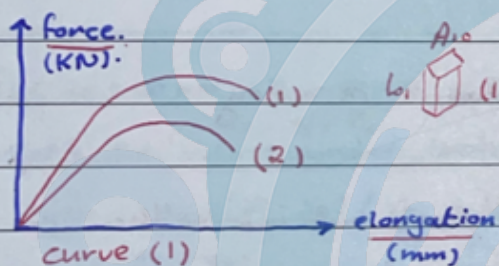
metal forming ⇒ compressive and/or Tensile force --- ③

*] The mechanical behaviour is to help the understanding of
[Loading - Deformation Relationships].

*] Strength : material resistance to deformation when subjected to mechanical load.

*] Test for strength : (1) Tensile strength: pulling a standard specimen and recording data such as load applied and elongation experienced.

*] Mechanical behaviour : materials behave under mechanical loading
"Quantitative loading-deformation relationship".



Note: all metal Except steel can be present in the curve.

$A_{02} < A_{01} \Rightarrow$ Since the strength is the resistance of deformation ⇒ when dimensions are less the amount of resistance will be less. *

(2): less elongation $\Rightarrow L_{02} < L_{01}$.

the solution for the test ⇒ standard specimen ⇒ makes all the results the same.

(no effect of dimensions).

* لازم (كل من تأثير الطول الابتدائي والمساحة الابتدائية)

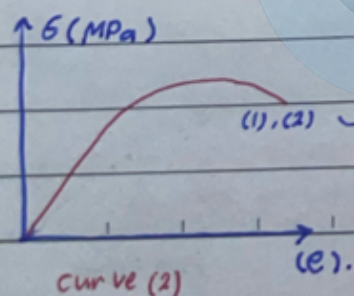
stress : amount of applied load per unit area. $\Rightarrow (1 Pa = 1 N/m^2), (MPa = 1 N/mm^2)$.

① $[\sigma = P/A_0]$, A_0 : Original cross section area $\Rightarrow$ engineering (nominal) stress. *

initial. constant dim. in design قيمة نسبية ليست حقيقية

② Engineering strain : relative elongation per unit length

$[\epsilon = \Delta L / L_0 = (L_f - L_0) / L_0]$ (unitless). التغيير النسبي في الابعاد



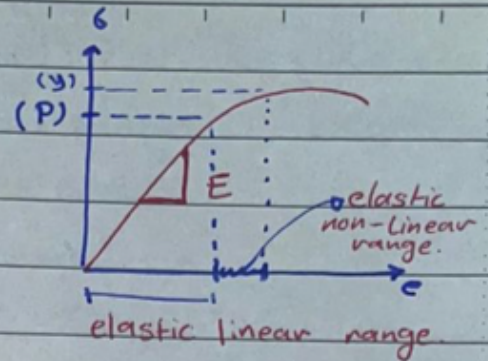
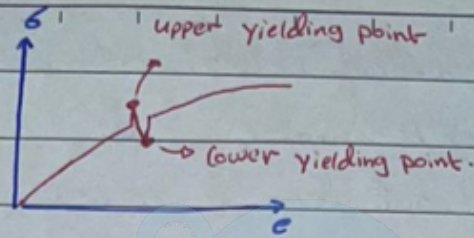
from curve (1) to curve (2) $\Rightarrow$ divide by the largest area.

no effect from initial dim.

for all metal Except steel.

لكل قطعة and the length for each spec.

for steels:



through (loading):

① Upon loading: the specimen elongate when load (stress) increasing
 is elastic and temporary. $\rightarrow$ (linear)

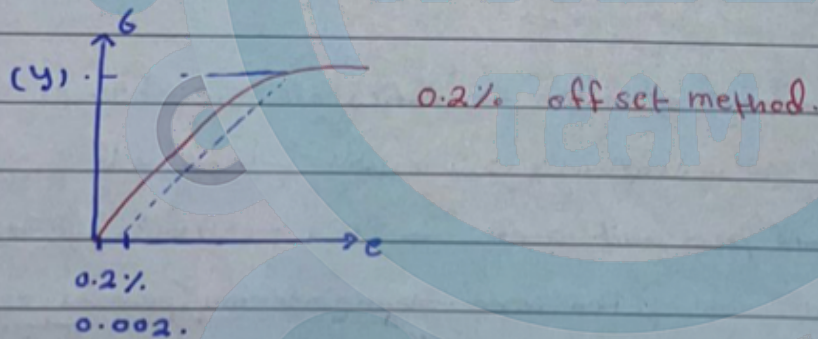
$\rightarrow [\sigma = E \epsilon]$, E : modulus of elasticity (MPa)

$\rightarrow$ will continue to be (elastic and linear) till the (proportional limit).
 (P)

② After proportional limit: will be elastic till the "yield point" (y), σ_y .
 elastic but the relationship no longer linear.

$\rightarrow$ Both from the elastic range $\rightarrow$
 non-permanent deformation. $\rightarrow$ Elastic recovery.

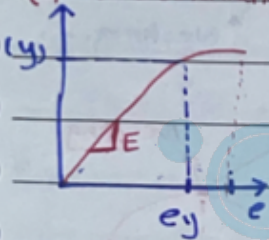
* the yielding point only can be determined in the steels but not in the
 other metal $\rightarrow$ will use the 0.2% offset method.



Note $MPa = \frac{N}{mm^2} \rightarrow \frac{N}{m^2} \times \frac{m}{m} = \frac{J}{m^3}$

characteristics for elastic range = modulus of resilience (MOR) ①

→ (MOR) = energy per unit volume the material can absorb elastically
(plastic deformation) طاقة تتخزن في المادة في المدى المرن (elastic range)



MOR = area under curve = $(\epsilon_y \cdot \sigma_y) / 2$, $\sigma = E \cdot \epsilon \Rightarrow [\epsilon_y = \sigma_y / E]$.
in (Hook's law)

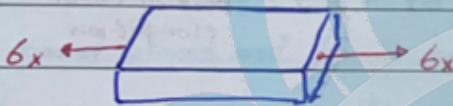
MOR = $\sigma_y^2 / 2E \Rightarrow \text{J/m}^3 \Rightarrow \text{energy per unit volume}$.

the part supposed to stay in the elastic range الجزء المفترض أن يبقى في المدى المرن
the energy stored الطاقة المخزنة

② Poisson's ratio: (ν) ratio of lateral strains to longitudinal strain

$$(\epsilon_x = \sigma_x / E)$$

(in the elastic range)



$$\epsilon_y = -\nu \epsilon_x = -\nu (\sigma_x / E)$$

$$\epsilon_z = -\nu \epsilon_x = -\nu (\sigma_x / E)$$

⇒ the same because it's relative change in dim. (not actual change).

Ex: $X_0 = 100 \text{ mm}$, $Y_0 = 20 \text{ mm}$, $Z_0 = 50 \text{ mm}$, $X_f = 101 \text{ mm}$, $\nu = 0.3$.

what's the volume under loading? if the volume released: $V_{\text{initial}} = 100000 \text{ mm}^3$.

Solu: $\epsilon_x = (X_f - X_0) / X_0 = (101 - 100) / 100 = 0.01$, $\epsilon_z = \epsilon_y = -\nu \epsilon_x = 0.3 \times 0.01 = -0.003$

$$\left[\frac{Y_f - Y_0}{Y_0} \right] = -0.003 \quad Y_f = (-0.003 \times 20) + 20 = 19.94, \quad \frac{Z_f - Z_0}{Z_0} = -0.003 \Rightarrow Z_f = 49.85 \text{ mm}$$

$$\text{Volume} = X_f \cdot Z_f \cdot Y_f = 101 \times 19.94 \times 49.85 = 100394.909 \text{ mm}^3 = \text{final volume.}$$

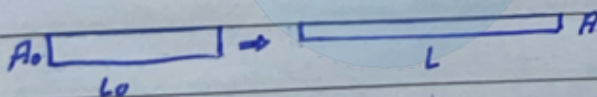
After the yield point [plastic (permanent) deformation] ⇒ stress will increase until reaching a maximum value (The Ultimate Tensile stress) (UTS).

UTS ⇒ max. stress, $UTS = P_{\text{max}} / A_0$, P_{max} = max. load applied.

until reaching the (UTS) point there will be a (uniform elongation").

⇒ increase in length & reduction in (A) are uniform throughout the whole length.

same area throughout the whole specimen.



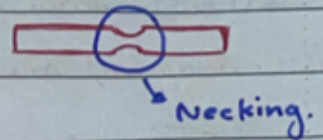
(UTS) point is reached.

→ up to UTS ⇒ uniform elongation (↑ L, ↓ A)
at UTS ⇒ Necking

what happen at UTS : "Necking phenomenon" → concentrated reduction in the cross sectional area.

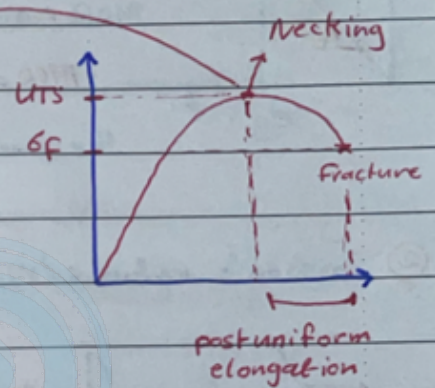
⇒ Lead to reduction in stress level

↳ fracture at the necked region.



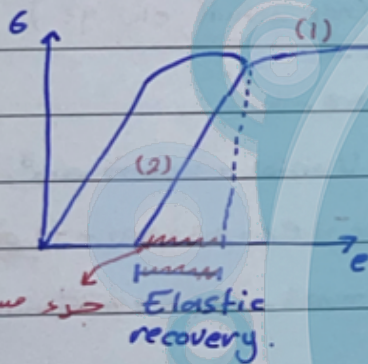
$\sigma = P/A_0$, since A_0 is constant and the reduction of area is fast the stress will increase.

Load will decrease because it will be less amount from material to resist.



⇒ Load ↓ at the Necking

uniform means the Load is increasing.



in this case the specimen started the plastic range unload after the yielding point.

كم مقدار تعدي
Plastic deformation
قبل ما تنكسر

characteristic of plastic range :

Ductility : The material ability to deform plastically before fracture.

two type of test : Elongation = $\left(\frac{l_f - l_0}{l_0} \right) * 100\%$ ①

Reduction of area = $\left(\frac{A_0 - A_f}{A_0} \right) * 100\%$ ②

Quiz (1): $L_0 = 500 \text{ mm}$, $E = 200 \text{ GPa}$, $y = 200 \text{ MPa}$

$L_f = 502$ when the load still applied.

Find the length after the load has been released:

(1): to check if it's elastic or plastic ... [Max. elastic strain (yielding) = e_y].

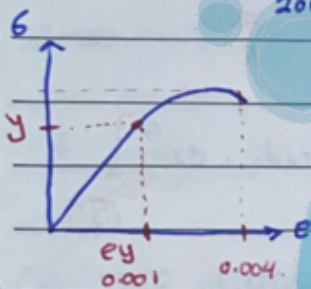
$$e_y = \frac{y}{E} = \frac{200 \times 10^6}{200 \times 10^9} = 0.001 \quad , \quad (2) \quad e_{\text{Total}} = \frac{L_f - L_0}{L_0} = \frac{502 - 500}{500} = 0.004$$

$e_{\text{Total}} > e_y \rightarrow$ over the elastic range.

$$e_{\text{Total}} = e_{\text{elastic}} + e_{\text{plastic}} \Rightarrow 0.004 = 0.001 + e_p \Rightarrow e_p = 0.003$$

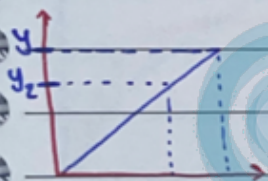
$$0.003 = \frac{L_f - L_0}{L_0} \Rightarrow (0.003 \times 500) + 500$$

$$L_f = 501.5 \text{ mm.}$$



nominal stress and strain only valid in design.

$\rightarrow$ designs usually in elastic range. (with safety factor).



in the engineering stress and strain

the Yielding point. $\Rightarrow$ because we assume we have constant dim. (invalid for metal forming).

(2.2.2) True stress and True strain:

• stress $\sigma = P/A$, A : actual (Instantaneous) area.

• strain (since the strain is the relative change in dim.) $\Rightarrow e = \Delta L/L = (L_f - L_0)/L_0$

$$\hookrightarrow \text{True strain } \epsilon = \int_{L_0}^{L_f} \frac{dL}{L} \text{ the instantaneous change in length.}$$

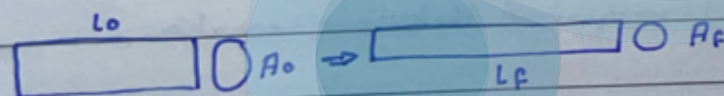
$$= \ln(L_f) - \ln(L_0) = \ln(L_f/L_0)$$

$$\text{equ. (2.10)} \quad \epsilon = \ln\left(\frac{L}{L_0}\right) = \ln\left(\frac{A_0}{A}\right) \text{ valid within the uniform elongation range}$$

& plastic range before necking.

$$[A_0 L_0 = A_f L_f] \text{ up to } (\underline{UTS})$$

no necking



in necking $\rightarrow A_0 L_0 \neq A_f L_f$

equ (2.10) volume constancy equation.

$$\frac{A_0}{A_f} = \frac{L_f}{L_0} \Rightarrow E = \ln(L_f/L_0) = \ln(A_0/A_f)$$

*] The relationship between the engineering and true values.

$$(1) \text{ Strain: } e = \frac{L_f - L_0}{L_0} \Rightarrow \frac{L_f}{L_0} - \frac{L_0}{L_0} = \left(\frac{L_f}{L_0} - 1\right) \Rightarrow \frac{L_f}{L_0} = e + 1 \Rightarrow [E = \ln(e + 1)] \quad \textcircled{1}$$

$$(2) \text{ Stress: } \sigma_{true} = P/A, \sigma_{eng} = P/A_0 \Rightarrow \frac{\sigma_{true}}{\sigma_{eng}} = \frac{P/A}{P/A_0} = \frac{A_0}{A}$$

$$\sigma_{true} = \sigma_{eng} \left(\frac{A_0}{A}\right) = \sigma_{eng} \cdot \left(\exp^{\ln(A_0/A)}\right) \Rightarrow [\sigma_{true} = \sigma_{eng} \cdot \exp^E] \quad \textcircled{2}$$

Note: $\ln(x+1) = x$ when x approach to zero (very small).

$$\ln(e+1) = e \quad " \quad e \quad " \quad " \quad " \quad " \quad " \quad "$$

So we can use the engineering strain in the elastic range only but always use the true strain.

best solution for Example:

$L_0 = 500$, $L_f = 502$ while load, $\gamma = 200 \text{ MPa}$, $E = 200 \text{ GPa}$

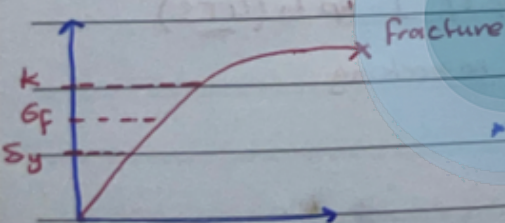
$$\text{soln: } E_e = \gamma/E = 200/200 \times 10^3 = 0.001, E_{tot} = \ln\left(\frac{L_f}{L_0}\right) = \ln\left(\frac{502}{500}\right) = 0.0039$$

$$E_p = E_{tot} - E_e = (0.0039 - 0.001) = 0.0029 = \ln\left(\frac{L_{f \text{ unload}}}{L_0}\right)$$

$$\ln\left(\frac{L_f}{500}\right) = 0.0029 \Rightarrow L_f = 501.19 \text{ mm}$$

(2.2.3) True stress strain curve

$$[\sigma = K \epsilon^n] \text{ mechanical behaviour equation.}$$

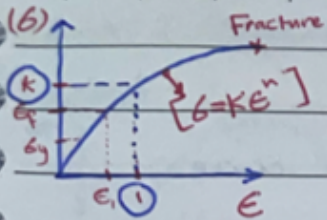


* always increase because we divide by the true area which always decreasing.

(في تزايد بعد (UTS))

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

(2.2.3) True stress-strain curve:



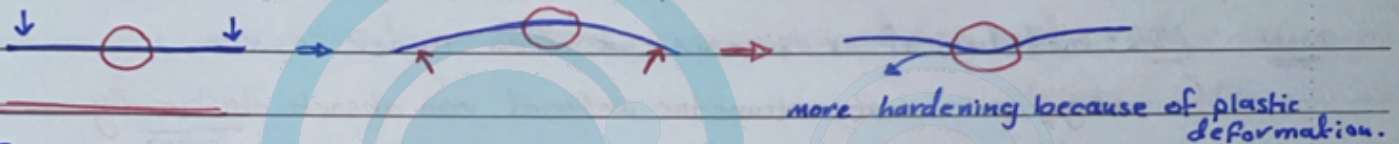
True stress-strain curve use the true dimensions

• engineering stress & strain is used only in elastic.
 used in elastic & plastic
 change in dim. is relatively close.

$[\sigma = K\epsilon^n]$: mechanical behaviour equation

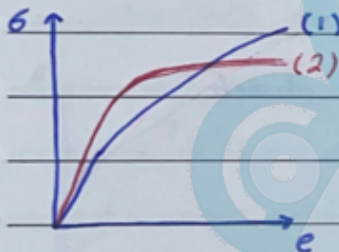
K : strength coefficient (MPa), n : strain hardening index.

strain hardening: The increase in strength and/or hardness of the material as a result of plastic deformation or plastic strain.



more hardening because of plastic deformation.

(*) The Relationship between (K) and (n):



curve (1) : low (K), high (n).

small (K): material started with low strength, after the plastic deformation the strength increased quickly.

curve (2) : High (K), small (n)

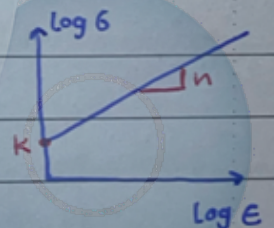
the material had a high strength, and after plastic deformation no obvious change in strength.

* (K) & (n) values from table 2.2

How to find the values of (K) & (n): make a $[\log \sigma - \log \epsilon]$ curve.

its slope = n , always use the table.

$$\log \sigma = \log K + n \log \epsilon \rightarrow [K = \sigma] \text{ when } \epsilon = 1$$



(*) Flow stress: [the true stress required to continue

plastic deformation], at particular true strain.

the true stress at the true strain $\rightarrow \sigma = K\epsilon^n$

(*) Average flow stress: $[\bar{\sigma}_f]$,

$$[\bar{\sigma}_f = \frac{1}{\epsilon_1} \int_0^{\epsilon_1} \sigma d\epsilon] = \frac{1}{\epsilon_1} \int_0^{\epsilon_1} K\epsilon^n d\epsilon = \left[\frac{K\epsilon^{n+1}}{n+1} \right]$$

General case. *

→ 1 Toughness : the area under the true stress-strain curve.

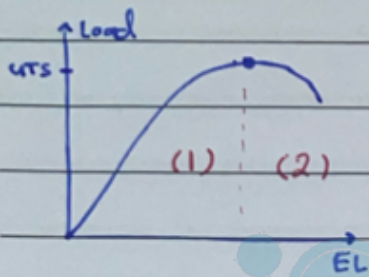
$$\text{Toughness} = \int_0^{\epsilon_F} \sigma d\epsilon$$

note MOR : modulus of resilience $\Rightarrow$ area under curve
 $\hookrightarrow$ energy per unit volume the material can absorb elastically.

$$\text{MOR} = \sigma^2 / 2E$$

but the Total energy per unit volume the material can absorb before fracture. = Toughness.

(2.2.4) Instability in tension: (Necking at the UTS).



(1) elastic (before UTS).

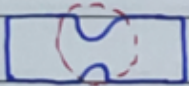
$$\hookrightarrow S.H \uparrow, \Delta A \downarrow$$

(2) plastic (after UTS).

$$S.H \uparrow, \Delta A \downarrow$$

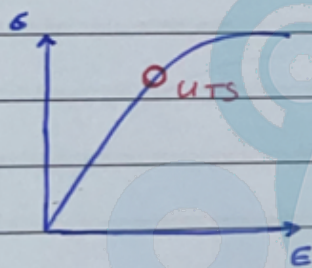
Load increase
because of the
strain hardening

because of
uniform elong.

Note:

(1) from zero to UTS the Rate of increase in load from the strain hardening exceeds the Rate of decrease in load from reduction from cross sectional area.

(2) after the UTS the Rate of increase in load because of strain hardening. Less than the Rate of decrease because of the reduction in the cross sectional area.



UTS: when the curve changes the slope.

$$UTS = \frac{P_{max}}{A_0}, \quad P_{max} \text{ when the curve at UTS.}$$

$dP = \text{Zero}$ at UTS. (where the necking begins)

$$P = A_0 \cdot S_{eng} = A_0 \cdot \frac{S_{true}}{e^E} = A_0 \cdot S_{true} \cdot e^{-E}$$

$$dP = A_0 d(S_{true} \cdot e^{-E}) = 0, \quad \left(\frac{dS}{dE} \right) \cdot e^{-E} + (-S \cdot e^{-E}) = 0 \Rightarrow S = \frac{dS}{dE} \text{ at UTS}$$

$$\frac{d\sigma}{d\epsilon} = \sigma, \quad \sigma = K\epsilon^n \rightarrow [nK\epsilon^{n-1} = K\epsilon^n], \quad [E=n].$$

منحنى (الاستيك)

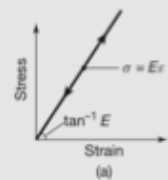
Ex: $\sigma = 300\epsilon^{0.3}$ MPa, find the true & engineering values at UTS.

$$\rightarrow K\epsilon^n = nK\epsilon^{n-1} \rightarrow n = E = 0.3 \text{ only true when } \sigma = K\epsilon^n.$$

$$UTS = 300 \cdot 0.3^{0.3} = 209.04 \text{ MPa.}$$

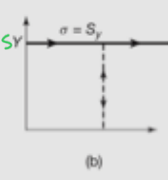
$$UTS_{eng.} = UTS_{true} \cdot e^{-E} = 209 \cdot e^{-0.3} = 154.8 \text{ MPa.}$$

Lec (6)



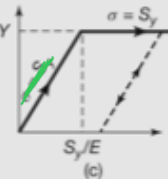
perfectly elastic : from the first loading till the fracture $\Rightarrow$ No plastic deformation.

$\sigma = E \epsilon$, E : modulus of elasticity.
جس اللفظ او اللفظ

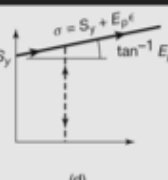


Rigid, perfectly plastic : rigid (no elastic range)
 $\Rightarrow$ the stress starts from the yield (no strain till the yield).

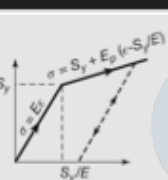
$\sigma = \sigma_y$, used in materials that have a high ductility, temp $\uparrow \rightarrow$ closed to perfectly plastic.



Elastic, perfectly plastic : Elastic ($\sigma = E \epsilon$)
 $\hookrightarrow$ till ($\epsilon \leq \frac{\sigma_y}{E}$) max. elastic strain --- ① elastic.
then ($\sigma = \sigma_y$), $\epsilon \geq \frac{\sigma_y}{E}$ --- ② plastic



Rigid, linearly strain hardening : no elastic range
 $\hookrightarrow$ it starts from plastic [$\sigma = \sigma_y + E_p \epsilon$]
 E_p : modulus of plasticity.

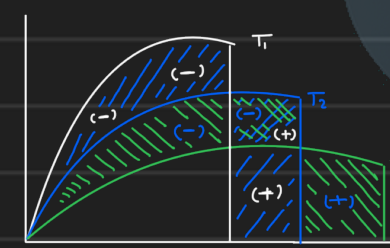


Elastic linearly strain hardening.
① Elastic $\sigma = E \epsilon \rightarrow [0 \leq \epsilon \leq \frac{\sigma_y}{E}]$
② Plastic $\sigma = \sigma_y + E_p (\epsilon - \frac{\sigma_y}{E}) \rightarrow [\epsilon \geq \frac{\sigma_y}{E}]$
لنشا ما يلبسنا منه الصفر

(2.2.6) Effects of temperature:

1] when you increase the temp
[UTS, Yielding point, E , hardness] will decrease $\Rightarrow$ strength
but Ductility increases.
 $\hookrightarrow$ (the ability of plastically deformation).

$\Rightarrow$ The relationship between Toughness and temp.



$T_1 < T_2 < T_3$

area under the curve.
 $\Rightarrow$ The decrease in toughness from decreasing the strength is less than the increase in toughness because of the increase of ductility

(2.2.7) Effect of Strain Rate (Change in strain in unit of time)

increasing strain Rate :
 $\hookrightarrow$ increase the strength, decrease the ductility.

① Engineering strain rate.

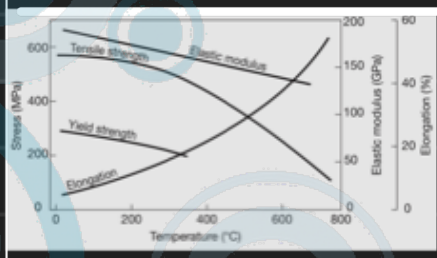
$$\dot{\epsilon} = \frac{d\epsilon}{dt} = \frac{d(\frac{l-l_0}{l_0})}{dt} = \frac{dl}{l_0 dt} = \frac{v}{l_0} = \dot{\epsilon}$$

v : velocity $\Rightarrow$ constant : make a constant velocity since I have already constant length.
(l_0)

② True strain rate

$$\dot{\epsilon} = \frac{d\epsilon}{dt} = \frac{d(\ln(\frac{l}{l_0}))}{dt} = \frac{dl}{l dt} = \frac{v}{l} = \dot{\epsilon}$$

$\hookrightarrow$ to make it constant change the velocity with the same rate as (l) (constant ratio between (l) & (v)).



everything decrease with temp. unless the Elongation because it's related to ductility.

TABLE 2.3 Typical ranges of strain, deformation speed, and strain rates in metalworking processes.

Process	True strain ϵ	Deformation speed m/s	Strain rate $\dot{\epsilon}$ (s^{-1})
Cold Working --- ①			
Forging, rolling	0.1-0.5 max	0.1-100	$1-10^3$ min
Wire and tube drawing	0.05-0.3	0.1-100	$1-10^4$
Explosive forming	0.05-0.2 min	10-100	$10-10^5$ max
Hot working and warm working ②			
Forging, rolling	0.1-0.5 min	0.1-30	$1-10^3$ max
Extrusion	2-5 max	0.1-1	$10^{-1}-10^2$ min
Machining	1-10	0.1-100	10^3-10^6
Sheet metal forming	0.1-0.5	0.05-2	$1-10^2$
Superplastic forming	0.2-3	$10^{-4}-10^{-2}$	$10^{-4}-10^{-2}$

two types of processes [Cold Working, Hot working].

① High strain at a high temp.

$\hookrightarrow$ because the ductility increase at a higher temp.

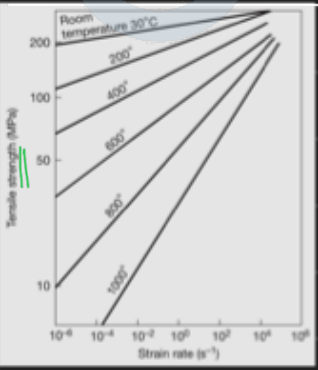
② High strain Rate at lower temp.

$\hookrightarrow$ because of the mechanical behavior equation. (sensitivity of strain rate).

$$\sigma = C \dot{\epsilon}^m$$

the mechanical behavior in the strain Rate:

m = strain rate sensitivity index, $m \uparrow \rightarrow$ strength $\downarrow$



The Relationship between the strain rate sensitivity (m) & temp.

Note that as the temp. increases, the slope increases. The tensile strength become more sensitive to strain rate as temp. increases.

temp $\uparrow \rightarrow$ strength $\downarrow$, Ductility $\uparrow \Rightarrow$ higher increase in slope $\Rightarrow m$ (larger at temp $\uparrow$)
 $\hookrightarrow$ more sensitive to strain rate.
strain rate $\uparrow \rightarrow$ strength $\uparrow$, Ductility $\downarrow$

TABLE 2.3 Typical ranges of strain, deformation speed, and strain rates in metalworking processes.

Process	True strain ϵ	Deformation speed m/s	Strain rate s^{-1}
Cold Working			
Forging, rolling	0.1-0.5	0.1-100	$1-10^3$
Wire and tube drawing	0.05-0.5	0.1-100	$1-10^3$
Explosive forming	0.05-0.2	10-100	$10-10^5$
Hot working and warm working			
Forging, rolling	0.1-0.5	0.1-30	$1-10^3$
Extrusion	2-5	0.1-1	$10^{-1}-10^2$
Machining	1-10	0.1-100	10^3-10^6
Sheet metal forming	0.1-0.5	0.05-2	$1-10^2$
Superplastic forming	0.2-3	$10^{-4}-10^{-2}$	$10^{-4}-10^{-2}$

At a lower temp. the material is less sensitive to strain rate
more strain rate $\rightarrow$ strength $\uparrow$ (very small)
بشكل القطعة بسرعة عالية مع ازدياد بسيط في strength

At Hot working $\rightarrow$ less strain rate because the material is highly sensitive to strain rate with high ductility.
منخفض المعدل مع حساسية عالية للمادة معشاة نقل مقاديرها ونسجتها. معشاة هبنة مستخدم (low strain rate)

more strain because of high ductility.
الربط تشكيل المادة بشكل كبير وسرعة قليلة مطروقة انتقادية
Cold (high strain rate) hot (high ductility).

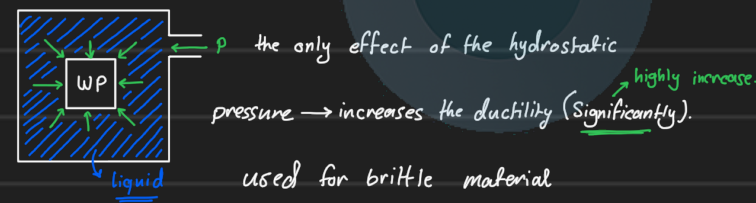
TABLE 2.4 Approximate range of values for C and m in Eq. (2.18) for various annealed metals at true strains ranging from 0.2 to 1.0, and at a strain rate of $2 \times 10^{-4} s^{-1}$.

Material	Temperature $^{\circ}C$	C MPa	m
Aluminum	200-500	82-14	0.07-0.23
Aluminum alloys	200-500	310-35	0-0.20
Copper	300-900	240-20	0.06-0.17
Copper alloys (brasses)	200-800	415-14	0.02-0.3
Lead	100-300	11-2	0.1-0.2
Magnesium	200-400	140-14	0.07-0.43
Steel			
Low carbon	900-1200	165-48	0.08-0.22
Medium carbon	900-1200	160-48	0.07-0.24
Stainless	600-1200	415-35	0.02-0.4
Titanium	200-1000	930-14	0.04-0.3
Titanium alloys	200-1000	900-35	0.02-0.3
Ti-6Al-4V	800-950	65-11	0.50-0.80
Zirconium	200-1000	830-27	0.04-0.4

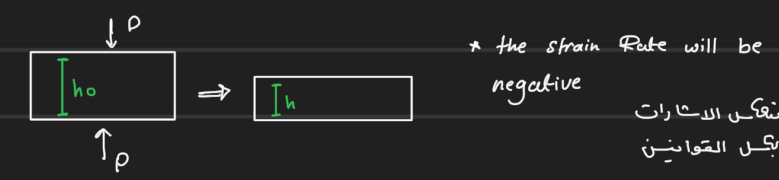
Note: As temperature increases, C decreases and m increases. As strain increases, C increases and m may increase or decrease, or it may become negative within certain ranges of temperature and strain. Source: After T. Altan and F.W. Boulger.

At a high temp $\rightarrow$ (C) decrease (C is related to material strength).
 $\rightarrow$ (m) increase.

(2.2.8): Effects of Hydrostatic pressure:



(2.3) Compression :



$$\epsilon_{eng} = \frac{-P}{A_0} , \epsilon_{true} = \frac{-P}{A}$$
$$e = \frac{h_f - h_0}{h_0} = (-) , \epsilon = \ln\left(\frac{h_f}{h_0}\right) = (-)$$

 $\ln(x > 1) \rightarrow +$
 $\ln(x < 1) \rightarrow -$

(2.11) Yield Criteria :

3D - stress system: [In Elastic Range]

Triaxial stress sys. :

$$\epsilon_x = \frac{\sigma_x}{E} - \nu \frac{\sigma_y}{E} - \nu \frac{\sigma_z}{E}$$
$$\epsilon_y = \frac{\sigma_y}{E} - \nu \frac{\sigma_x}{E} - \nu \frac{\sigma_z}{E}$$
$$\epsilon_z = \frac{\sigma_z}{E} - \nu \frac{\sigma_x}{E} - \nu \frac{\sigma_y}{E}$$
$$\epsilon_1 = \frac{1}{E} (\sigma_1 - \nu (\sigma_2 + \sigma_3))$$
$$\epsilon_2 = \frac{1}{E} (\sigma_2 - \nu (\sigma_1 + \sigma_3))$$
$$\epsilon_3 = \frac{1}{E} (\sigma_3 - \nu (\sigma_1 + \sigma_2))$$

ν = poisson's ratio.

Solid Cuboid :

$$\epsilon_1 \text{ could be } \epsilon_x = \ln\left(\frac{x}{x_0}\right)$$
$$\epsilon_2 \text{ could be } \epsilon_y = \ln\left(\frac{y}{y_0}\right)$$
$$\epsilon_3 \text{ " " } \epsilon_z = \ln\left(\frac{z}{z_0}\right)$$

* volume = $z \cdot y \cdot x$

Solid Cylinder :

$$V = \frac{\pi}{4} \cdot D \cdot D \cdot L \rightarrow \epsilon_1 = \epsilon_2 = \epsilon_D = \ln\left(\frac{D}{D_0}\right)$$
$$= \frac{\pi}{4} D^2 \cdot L \rightarrow \epsilon_3 = \epsilon_L = \ln\left(\frac{L}{L_0}\right)$$

Solid sphere

$$V = \frac{\pi}{6} D^3$$
$$\rightarrow \epsilon_1 = \epsilon_2 = \epsilon_3 = \epsilon_D = \ln\left(\frac{D}{D_0}\right)$$

Lec (8)

In the elastic range, the strains in the elements are represented by the generalized Hooke's law equations:

$$\epsilon_1 = \frac{1}{E} [\sigma_1 - \nu (\sigma_2 + \sigma_3)], \quad (2.34a)$$

$$\epsilon_2 = \frac{1}{E} [\sigma_2 - \nu (\sigma_1 + \sigma_3)], \quad (2.34b)$$

$$\epsilon_3 = \frac{1}{E} [\sigma_3 - \nu (\sigma_1 + \sigma_2)]. \quad (2.34c)$$

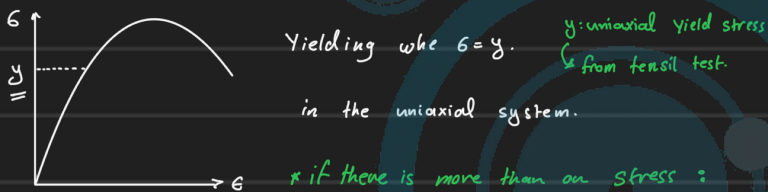
Thus, for simple tension where $\sigma_2 = \sigma_3 = 0$,

$$\epsilon_1 = \frac{\sigma_1}{E},$$

and

$$\epsilon_2 = \epsilon_3 = -\nu \frac{\sigma_1}{E}. \quad (2.35)$$

2.11 Yield Criteria



*] The yield criteria is used in manufacturing operations where plastic deformation is involved
and the material is generally biaxial or triaxial.

Based on the types of materials $\Rightarrow$ there will be 2 types
 $\Rightarrow$ (from material behavior & when the yield occurs)

(2.11.1) Maximum-shear-stress-Criterion. $\Rightarrow$ (Tresca Criterion).

$(\tau_{max} \geq k) \Rightarrow$ Yielding, k : constant $= \frac{S_y}{2}$, S_y : uniaxial yield strength.

$[\sigma_{max} - \sigma_{min} = S_y]$ Mohr's circle.
 $[\sigma_1 - \sigma_3 = S_y]$

(2.11.2) Distortion-Energy Criterion: (von Mises Criterion)

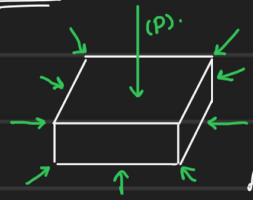
the intermediate principle stress is included

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2 S_y^2$$

Lec (9) :

The internal & external pressure.

Example in the Elastic range :



$$z_0 = x_0 = y_0 = 100 \text{ mm.}$$

$$\text{if } E = 200 \text{ GPa, } \nu = 0.25, P = 20 \text{ MPa.}$$

find the final dim after pressurizing

$$\text{Soln : } \epsilon_1 = \epsilon_x = \frac{1}{E} (\sigma_x - \nu (\sigma_y + \sigma_z)) = \ln \left(\frac{x}{x_0} \right).$$

$$\text{External (P)} \Rightarrow \sigma_x = \sigma_y = \sigma_z = (-)P \rightarrow \text{compression}$$

$$\frac{1}{200 \times 10^9} (-20 \times 10^6 - 0.25 (-40 \times 10^6)) = \ln \left(\frac{x}{x_0} \right).$$

$$\ln \left(\frac{x}{100} \right) = -5 \times 10^{-5} \text{ (no unit for } \epsilon).$$

$$\text{the final length (x)} = 99.995 \text{ mm.}$$

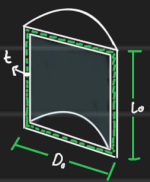
What is the difference between Pressure and stress ?

Pressure is kind of stress (contact stress) $\Rightarrow$ from fluid.

the source of pressure is in contact with the all surface.

Internal pressure :

Hollow Cylinder [Thin Cylindrical shell] :



$$\textcircled{1} \delta_L \quad \begin{matrix} A_{ex} \\ P \\ A_{in} \end{matrix} \quad \text{(ياخذ المادي على ابي يدنا كسيلة)}$$

$$\delta_L = \frac{F}{A_{in}} = \frac{P \cdot A_{in}}{A_{ex}} = \frac{P \cdot \frac{\pi D_i^2}{4}}{\pi D_o \cdot t} \Rightarrow \frac{PD}{4t} = \frac{Pr}{2t} = \delta_L$$

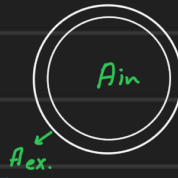
$$\textcircled{2} \delta_D \quad \begin{matrix} A_{in} \\ P \\ A_{ex} \end{matrix} \quad \delta_D = \frac{P \cdot A_{in}}{A_{ex}} = \frac{P \cdot D \cdot L}{2tL} \Rightarrow \frac{PD}{2t} = \frac{Pr}{t} = \delta_D$$

$$\textcircled{3} \delta_t \quad \begin{matrix} \rightarrow \\ \rightarrow \\ \rightarrow \\ \rightarrow \end{matrix} \quad \begin{matrix} \text{Same as the External pressure} \\ \delta_t = -P \end{matrix}$$

*] Since $\delta_t \ll \delta_D, \delta_L$ we assume

$$\text{that } \delta_t = 0$$

*] Thin Spherical shell : [with internal pressure]



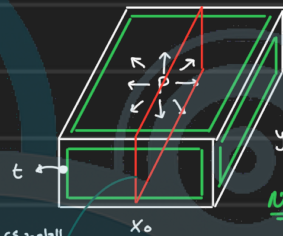
and we also assume δ_t here to be zero

$$\delta_D = \frac{P \cdot A_{in}}{A_{ex}} = \frac{P \cdot \pi D^2}{4 \pi D t}$$

$$\delta_D = \frac{P \cdot D}{4t} = \frac{Pr}{2t}, \quad \delta_t = 0$$

Quiz (3) : if $x_0 = z_0 = y_0 = 100 \text{ mm}$

$$P = 10 \text{ MPa, } E = 200 \text{ GPa, } \nu = 0.2$$



Solution : Since $x_0 = y_0 = z_0$ $[\delta_x = \delta_y = \delta_z]$.

$$\delta_x = \frac{P \cdot A_{in}}{A_{ex}} = \frac{P \cdot (yz)}{2t(z+y)} = \frac{10 \frac{\text{N}}{\text{mm}^2} \cdot 10000}{2 \cdot 2(200) \text{ mm}^2} \Rightarrow \delta_x = 125 \text{ MPa.} \quad \textcircled{1}$$

Note : MPa $\rightarrow$ N/mm²

for the horizontal & vertical ϵ , $\epsilon_x =$

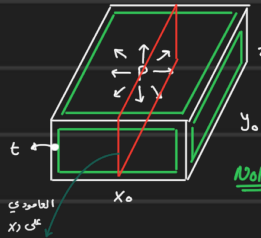


Always when there is a internal pressure

$$\text{the equation starts with } \delta = \frac{P \cdot A_{in}}{A_{ex}}$$

Quiz (3): if $x_0 = z_0 = y_0 = 100 \text{ mm}$

$P = 10 \text{ MPa}$, $E = 200 \text{ GPa}$, $\nu = 0.2$

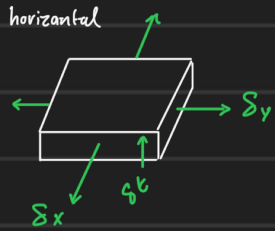


Solution: Since $x_0 = y_0 = z_0$, $[\sigma_x = \sigma_y = \sigma_z]$.

$$\sigma_x = \frac{P \cdot A_{in}}{A_{ex}} = \frac{P \cdot (yz)}{2t(z+y)} = \frac{10 \frac{\text{N}}{\text{mm}^2} \cdot 10000}{2 \cdot 2(200) \text{ mm}^2} = 125 \text{ MPa} \quad \textcircled{1}$$

Note: MPa $\rightarrow$ N/mm²

for the horizontal & vertical ϵ , $\epsilon_x =$



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

$$\textcircled{2} \epsilon_{xv} = \frac{1}{E} (\sigma_x - \nu(\sigma_2 + \sigma_3))$$

Only in this case

$$\sigma_x = \sigma_y = \sigma_z$$

$$\epsilon_{xv} = \epsilon_{xh}$$

if $x_0 = 150$, $y_0 = 200$, $z_0 = 100$ find the final length

$P = 10 \text{ MPa}$, $E = 200 \text{ GPa}$, $\nu = 0.2$, $t_0 = 10 \text{ mm}$

$\sigma_x \neq \sigma_y \neq \sigma_z$, $x_0 \neq y_0 \neq z_0$

$$\sigma_x = \frac{P \cdot A_{in}}{A_{ex}} = \frac{10 \frac{\text{N}}{\text{mm}^2} \cdot (200 \cdot 100)}{2 \cdot 10 \cdot (150 + 100)} = 33.33 \text{ MPa}$$

$$\sigma_y = \frac{10 \frac{\text{N}}{\text{mm}^2} \cdot (150 \cdot 100)}{2 \cdot 10 \cdot (150 + 100)} = 30 \text{ MPa}, \quad \sigma_z = \frac{10 \frac{\text{N}}{\text{mm}^2} \cdot (150 \cdot 200)}{2 \cdot 10 \cdot (150 + 200)} = 42.9 \text{ MPa}$$

$$\epsilon_{xv} = \frac{1}{E} (\sigma_x - \nu(\sigma_z)) = \frac{1}{200 \cdot 10^9} (33.3 \cdot 10^6 - 0.2 \cdot 42.9 \cdot 10^6) = 1.236 \cdot 10^{-4}$$

$$\epsilon_{xh} = \frac{1}{E} (\sigma_x - \nu(\sigma_y)) = \frac{1}{200 \cdot 10^9} (33.3 \cdot 10^6 - 0.2 \cdot 30 \cdot 10^6) = 1.365 \cdot 10^{-4}$$

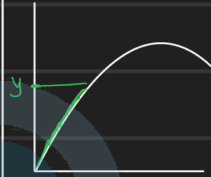
$$\epsilon_{xv} = \ln\left(\frac{x}{x_0}\right) \quad \text{or}$$

$$\epsilon_{xh} = \ln\left(\frac{y}{y_0}\right)$$

2.1.1.1 Maximum-Shear-Stress Criterion

The maximum-shear-stress criterion, also known as the Tresca criterion, states that yielding occurs when the maximum shear stress within an element is equal to or exceeds a critical value. As shown in Section 3.3, this

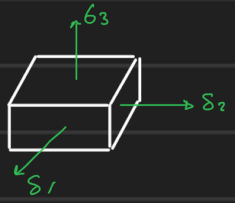
$$\sigma_{\max} - \sigma_{\min} = S_y$$



(LSS)

$$\sigma_{\max} - \sigma_{\min} \geq Y$$

$$\text{if } \sigma_1 > \sigma_2 > \sigma_3 \Rightarrow \sigma_1 - \sigma_3 \geq Y$$



Will the material yield? $Y = 500 \text{ MPa}$

$$\sigma_{\max} - \sigma_{\min} \geq Y$$

$$300 - (-250) \geq 500$$

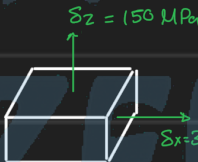
$$550 \geq 500 \rightarrow \text{yield}$$

2.1.1.2 Distortion-Energy Criterion

The distortion-energy criterion, also called the von Mises criterion, states that yielding occurs when the relationship between the principal stresses and uniaxial yield strength, S_y , of the material is

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2S_y^2 \quad (2.39)$$

Example: find (σ_y) so that the material yields if $Y = 500 \text{ MPa}$.



$$(300 - \sigma_2)^2 + (\sigma_2 - 150)^2 + (150 - 250)^2 = 2(500)^2$$

$$(90000 - 600\sigma_2 + \sigma_2^2) + (\sigma_2^2 - 300\sigma_2 + 22500) + 22500 = 500000$$

$$2\sigma_2^2 - 900\sigma_2 - 36500 = 0$$

$$\sigma_2^2 - 450\sigma_2 - 182500 = 0$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2} \Rightarrow \frac{450 \pm \sqrt{450^2 + 4(182500)}}{2}$$

2.11.3 Plane Stress and Plane Strain

Plane stress [2 Dim. $\Rightarrow (\epsilon_1, \epsilon_2, 0), (\epsilon_1, 0, \epsilon_3), (0, \epsilon_2, \epsilon_3)$].
 Plane strain [2 Dim. $\Rightarrow (\epsilon_1, \epsilon_2, 0), (\epsilon_1, 0, \epsilon_3), (0, \epsilon_2, \epsilon_3)$].

ليس شرط انه الدشي الى اعطاني (plane stress) يعطيني (plane strain) والعكس.

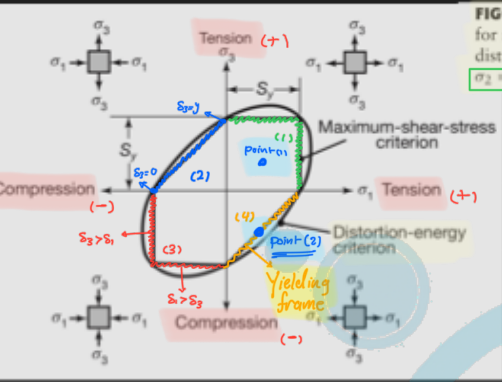


FIGURE 2.32 Plane-stress diagrams for maximum-shear-stress and distortion-energy criteria. Note that $\sigma_2 = 0$.

the yield criterion in the plane stress.

when will be yielding in the Maximum-shear-stress?

① First quarter: $\sigma_1^+, \sigma_2^+, \sigma_3 = 0, \sigma_2 = \min$,
 if $\sigma_1 > \sigma_3 \Rightarrow \sigma_1 - \sigma_2 \geq y, \underline{\sigma_1 = y}$.
 if $\sigma_3 > \sigma_1 \Rightarrow \sigma_3 - \sigma_2 \geq y, \underline{\sigma_3 = y}$.

② 3rd quarter: $\sigma_1^-, \sigma_3^-, \sigma_2 = 0 \Rightarrow \sigma_2 = \max$.
 if $\sigma_1 > \sigma_3 \Rightarrow -\sigma_3 = y, \underline{\sigma_3 = -y}$ // $\sigma_3 > \sigma_1 \Rightarrow -\sigma_1 = y, \underline{\sigma_1 = -y}$.

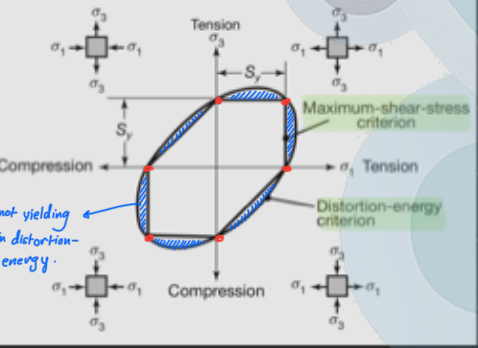
③ 2nd quarter: $\sigma_1^-, \sigma_2^+, \sigma_3 = 0, \max - \min = y$.
 $\sigma_3 - \sigma_1 = y, (0, y), (-y, 0) \Rightarrow$

any point in or out the yielding frame $\Rightarrow$ there will be yielding.

for example $\Rightarrow$ point (1)

point (1) $\Rightarrow (\frac{y}{2}, \frac{y}{2}) \rightarrow \frac{y}{2} - 0 = y, \frac{y}{2} \neq y$ no yielding.

point (2) $\Rightarrow (\frac{y}{2}, -\frac{y}{2}) \rightarrow \frac{y}{2} - (-\frac{y}{2}) = y, y = y$ Yielding.



part (2)
 Yielding criterion (Distortion-energy).

*] Maximum-shear-stress meets Distortion-energy when there at least one of the value = (y).

Materials that follows the distortion-energy needs more stress for yielding.

$$\sigma_1 - \sigma_3 = \frac{2}{\sqrt{3}} S_y = 1.15 S_y = S'_y.$$

equation for flow stress under flow strain. (chapter (6)).

2.11.5 Volume Strain

$$V_{elastic} = (1 + 2\nu) \epsilon_1 + \epsilon_2 + \epsilon_3 = \frac{1 + 2\nu}{E} (\sigma_1 + \sigma_2 + \sigma_3), \quad (2.47)$$

$$\Delta = \frac{\text{Volume change}}{\text{Original volume}} = \frac{1 + 2\nu}{E} (\sigma_1 + \sigma_2 + \sigma_3) = \frac{\Delta V}{V_0} \rightarrow \text{eng} \quad (2.48)$$

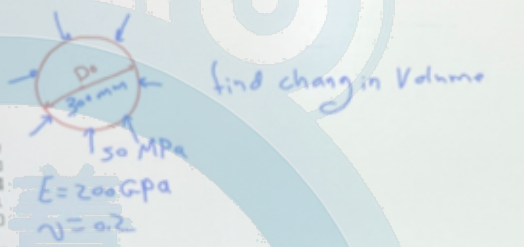
only in elastic range.
 we can use $(\frac{U_f}{V_0})$.

Note that in the plastic range, where $\nu = 0.5$, the volume change is zero. Thus, in plastic working of metals,

$$\epsilon_1 + \epsilon_2 + \epsilon_3 = 0, \quad (2.49)$$

Volume is constant in the plastic range.

Quiz (4)



$$V = \frac{\pi}{6} D^3 = \frac{\pi}{6} (0.03)^3 = 1.41 \times 10^{-9} \text{ m}^3, \quad \epsilon_1 = \epsilon_2 = \epsilon_3 = -150$$

$$\Delta = \frac{1 + 2(0.2)}{200 \times 10^9} (-450 \times 10^6) = -1.3 \times 10^{-3}, \quad \Delta = \frac{\Delta V}{V_0} \Rightarrow -1.3 \times 10^{-3} \times 1.41 \times 10^9 = -1.85 \times 10^6 \text{ m}^3.$$

2.1.1.6 Effective Stress and Effective Strain

Representative / equivalent.

one stress or one strain that include all stresses or all strains

Effective stress ($\bar{\sigma}$), Effective strain ($\bar{\epsilon}$)

① For the Maximum-shear-stress criterion :

$$[\bar{\sigma} = \sigma_{\max} - \sigma_{\min}], \text{ assuming that } \sigma_1 > \sigma_2 > \sigma_3 \Rightarrow \bar{\sigma} = \sigma_1 - \sigma_3.$$

② For the distortion-energy criterion :

$$[\bar{\sigma} = \frac{1}{\sqrt{2}} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{\frac{1}{2}}]$$

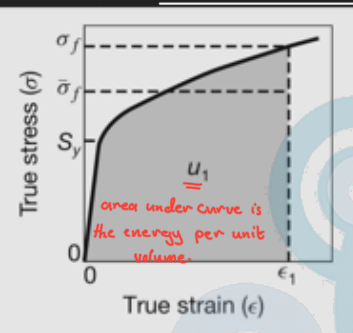
① For the Maximum-shear-stress criterion :

① if σ_1, σ_3 are known, ϵ_1, ϵ_3 same dir. as σ_1, σ_3

$$[\bar{\epsilon} = \frac{2}{3} (\epsilon_1 - \epsilon_3)] \Rightarrow \text{② if } \sigma_1, \sigma_3 \text{ are unknown, assume } \epsilon_{\max} = \epsilon_1, \epsilon_{\min} = \epsilon_3$$

② For the distortion-energy criterion :

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



Effective stress & Effective strain are

useful in the Tensile stress-strain curve

to find the relationship between ($\bar{\sigma}, \bar{\epsilon}$)

note that : The tensile stress is uniaxial

stress system.

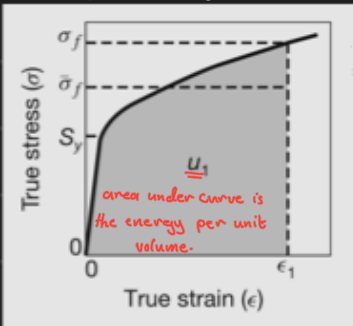
(*) It's found that relationship between uniaxial stress strain is totally

Applied on the triaxial stress strain ($\bar{\sigma}, \bar{\epsilon}$).for yielding : $\sigma_1 - \sigma_3 = y. \Rightarrow$ then yieldingwhen $\bar{\sigma} = y$

same as dealing with single stress.

in distortion-energy $\Rightarrow 2\bar{\sigma}^2 = 2y^2 \Rightarrow \bar{\sigma} = y$

2.12 Work of deformation. :



there are two types for energy

per unit volume :

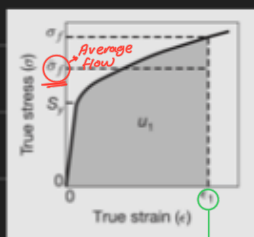
① Elastic range (modulus of resilience)

② plastic range (Toughness)

 $U_1 : J/m^3 \Rightarrow$ Energy : $U_1 * \text{Volume}$

Lec (13) :

Flow stress : the stress needed to continue the plastic deformation of the material at specific strain



*1 Average flow stress : $(\bar{\sigma}_f)$

*3 Since the forming the material starts from the plastic range (from yield) $\rightarrow$ we use the average flow stress.

① if $\sigma_f = K \epsilon^n \Rightarrow$ then $\bar{\sigma}_f = \frac{K \epsilon^n}{n+1}$... ①

② Work deformation : $W_T = W_I + W_F + W_R$
 total work deformation = Ideal work of def. + Frictional work of def. + Redundant work of def.
 calculated. External friction internal friction.
 Estimated (15-35% W_T).
 plastic work of deformation only depends on : (Mechanical behavior of materials).

③ $W_I = U_I \cdot V$ $\rightarrow$ volume of the W/P
 $\rightarrow$ energy per unit volume required for plastic def.

$$W_I = U_I \left(\frac{V}{m^3} \right) \cdot V (m^3) = J$$

As described in Section 2.2.3, true stress-true strain curves generally can be represented by the simple expression

$$\sigma = K \epsilon^n$$

Thus Eq. (2.56) can be written as

$$u = K \int_0^{\epsilon_1} \epsilon^n d\epsilon$$

$$U_I = \int_0^{\epsilon_1} \sigma d\epsilon$$

but if $\sigma = K \epsilon^n$ (uniaxial) then $\bar{\sigma} = K(\bar{\epsilon})^n$ (effective stress & strain)

$$④ U_I = \int_0^{\bar{\epsilon}} \bar{\sigma} d\bar{\epsilon}$$

The total specific energy required :

$$u_{total} = u_{ideal} + u_{friction} + u_{redundant}$$

$$= \frac{W_T}{V}$$

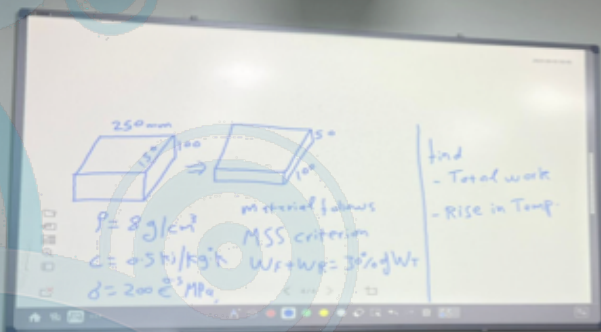
The efficiency, η of the process

$$\eta = \frac{u_{ideal}}{u_{total}} = \frac{W_I}{W_T}$$

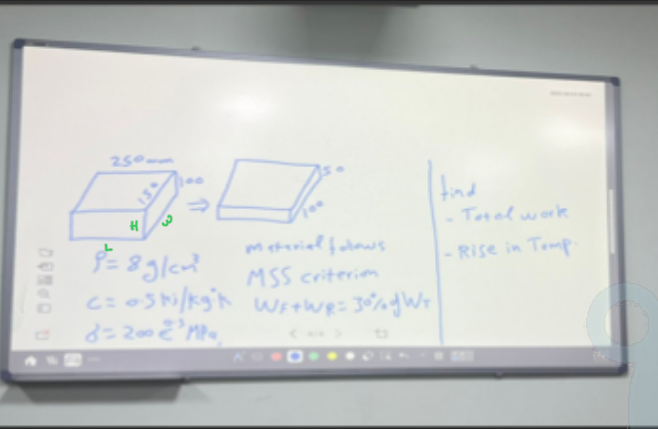
Eventually most of the energy will turn to change in temperature $\Rightarrow$ (temperature rise ΔT).

$$\textcircled{5} \dots \Delta T = \frac{u_{total}}{\rho c_p}, \quad \Delta T = \frac{\left(\frac{KJ}{m^3} \right)}{\left(\frac{Kg}{m^3} \right) \cdot \left(\frac{KJ}{Kg \cdot K^\circ} \right)} = K^\circ$$

Quiz :



Solution in Lec (14) :



$$W_F + W_R = 30\% \text{ of } W_T \Rightarrow W_I = 70\% \text{ of } W_T$$

$$W_I = U_I \cdot V \rightarrow U_I = \int_0^{\bar{E}} \bar{S} d\bar{E} \rightarrow \bar{E} = \frac{2}{3} (\epsilon_1 - \epsilon_3)$$

we should find the $(\bar{\epsilon})$ using the true strain (plastic range)

$$\epsilon_w = \ln\left(\frac{\omega_f}{\omega_o}\right) = \ln\left(\frac{100}{150}\right) = -0.4 \rightarrow \epsilon_2.$$

$$\epsilon_H = \ln\left(\frac{H_f}{H_0}\right) = \ln\left(\frac{50}{100}\right) = -0.7 \rightarrow \epsilon_3$$

$$\Rightarrow \sum E = \text{zero} \Rightarrow E_L + E_w + E_H = 0 \Rightarrow E_L - 0.4 - 0.7 = 0$$

$$E_L = 1.1 \Rightarrow E_L$$

according to Max. shear stress $\Rightarrow \bar{\epsilon} = \frac{2}{3}(\epsilon_1 - \epsilon_3)$.

$$\bar{E} = \frac{2}{3}(1.1 - (-0.7)) = 1.2.$$

$$S = 200 \text{ €}^{0.5} \rightarrow \bar{S} = 200 (\bar{\text{€}})^{0.5}$$

$$U_1 = \int_0^{\bar{\epsilon}} \bar{\delta} d\bar{\epsilon} \Rightarrow \int_0^{1.2} 200 (\bar{\epsilon})^{0.5} = \left. \frac{200}{1.5} (\bar{\epsilon})^{1.5} \right|_0^{1.2} = 175.25 \text{ MPa}$$

$$U_{\text{I}} = 175.25 \times 10^6 \frac{\text{J}}{\text{m}^3}$$

$$\mu_{Pa} = 10^6 \frac{J}{m^3}$$

$$\omega_I = \mathcal{U}_I * V,$$

$$V \text{ in } m^3 = 0.25 \times 0.15 \times 0.1 = 3.75 \times 10^{-3} m^3$$

$$W_I = 175.25 \cdot 10^3 \frac{\text{kJ}}{\text{m}^3} \cdot 3.75 \cdot 10^{-3} \text{ m}^3 = W_I = 657.26 \text{ kJ}$$

$$\omega_I = 0.7 \omega_T \Rightarrow \omega_T = \frac{\omega_I}{0.7}$$

$$W_T = \frac{657 \cdot 26}{0.7} = W_T = 938.95 \text{ kJ}$$

② To find the rise in temp.

$$\Delta T = \frac{U_T}{P \cdot C} \Rightarrow$$

$$U_T = \frac{U_I}{0.7} = \frac{175.25 \times 10^3}{0.7} \left(\frac{\text{Kj}}{\text{m}^3} \right) \Rightarrow U_T = 250.4 \times 10^3 \frac{\text{Kj}}{\text{m}^3}$$

$$\rho \left(\frac{\text{kg}}{\text{m}^3} \right) = \frac{8 \text{ g}}{\text{cm}^3} * \frac{1 \text{ kg}}{1000 \text{ g}} * \frac{(10^2)^3 \text{ cm}^3}{1 \text{ m}^3} \Rightarrow \rho = \frac{8000 \text{ kg}}{\text{m}^3}$$

$$\Delta T = \frac{Q_r}{\rho \cdot c} = \frac{250.4 \cdot 10^3 \left(\frac{\text{KJ}}{\text{m}^3} \right)}{8000 \left(\frac{\text{kg}}{\text{m}^3} \right) \cdot 0.5 \left(\frac{\text{KJ}}{\text{kg} \cdot \text{K}} \right)} =$$

end of chapter (2) ~~XX~~

Classification of metal forming processes :

① According to sequence in operations (processing).

- **Primary processing** : initial processing in preparation for further

processing steps. معالجة أولية

- **Secondary processing** : intermediate and/or final processing. معالجة نهائية

② According to processing temperature.

⊕ **Homologous temp.** (T_H , T_H)

$$\left(T_H = \frac{\text{Processing temp. (K)}}{\text{Melting temp. (K)}} \right) \Rightarrow \text{fraction of melting temp (unitless).}$$

- if ($T_H < 0.5$) : **cold forming [cold working]**.

✓ ⊕ Good surface finish & dimensional accuracy.

✓ ⊕ Good mechanical properties (due to the strain hardening).

⊕ May require a several steps (due to the limited ductility).

⊕ Requires relatively high force & energy levels

(due to higher strength at lower temp.)

⊕ Mainly final processing آخر مراحل التصنيع

- if ($T_H > 0.5$) : **Hot forming [Hot working]**.

⊕ **poor** surface finish & dimensional accuracy.

⊕ **low** mechanical properties (there is no strain hardening).

⊕ normally performed in **one step** (due to the **high** ductility)

⊕ Requires relatively **low** force & energy levels

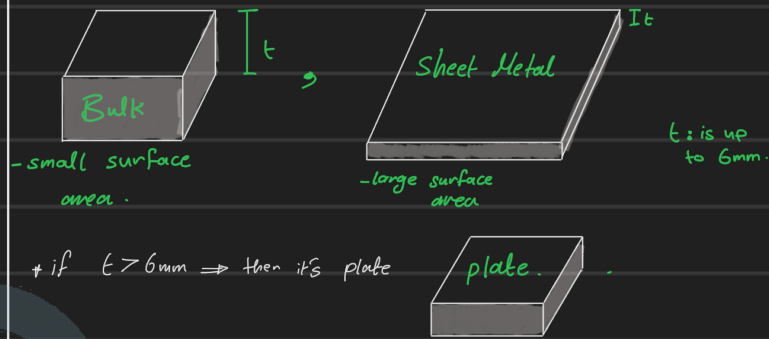
(due to **lower** strength at **higher** temp.)

⊕ Could be primary or secondary processing.

③ According to starting work piece geometry.

- **Bulk deformation process** : Metal forming processes involving work pieces with relatively small surface-area-to-thickness ratio.

- **Sheet metal forming** : Metal forming processes involving work pieces with relatively large surface-area-to-thickness ratio.



6.2 Forging

التشكيل بالضغط

Forging denotes a family of processes used to make discrete parts, in which plastic deformation is caused by compressive stresses applied through various dies and tooling. Forging is one of the oldest metalworking operations, dating back to 5000 B.C. (See Table 1.1). Historically, forgings could be produced with a heavy hammer and an anvil, using techniques practiced

① Open-Die Forging

تشكيل بقالب مفتوح.



properties :

⊕ Die-cavity volume larger than w/p volume

⊕ Mainly hot primary processing

⊕ Simple shapes and geometries

⊕ Requires the lowest force and energy levels among forging operations.

primary processing to reduce the height.

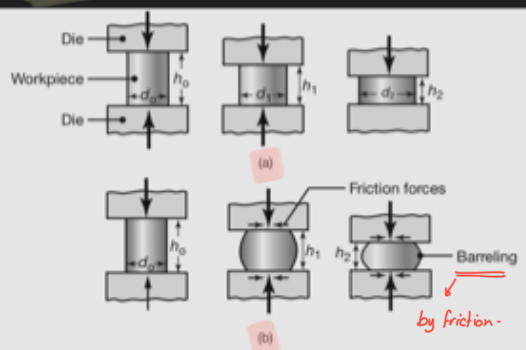
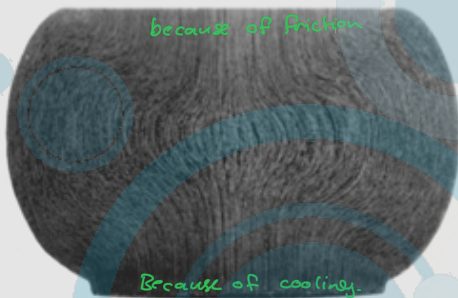


FIGURE 6.3 Grain flow lines in upsetting a solid, cylindrical steel specimen at elevated temperatures between two flat cool dies. Note the highly inhomogeneous deformation and barreling, and the difference in shape of the bottom and top sections of the specimen. The latter results from the hot specimen resting on the lower die before deformation proceeds. The lower portion of the specimen began to cool, thus exhibiting higher strength and hence deforming less than the top surface.



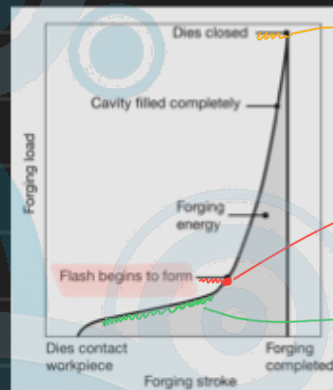
a) Ideal deformation of solid cylindrical specimen compressed.

b) Def. in upsetting with friction at the die-w/p interface.

① The function of Flash: (Two main functions).

- To help filling all the details of die cavity by forcing the metal to flow into these locations under the high forces.

- To prevent the direct contact between the two die halves and avoiding die distortion, breakage or fracture.



only when there is trimming to the Flash.

when the flash begins to form, the friction will highly increase & the load.

no effect from the friction (ideal force)

⇒ Barreling: because of:

① The upper & lower faces are in contact with the plates

↳ will be a friction ⇒ will stop the metal from flowing to the sides.

② The cooling, (Open-Die forging).

(6.2-3) Types of Forging:

② Impression-die forging: قالب مختلف ورج استكل القطعة بشكل القوالب

- Work piece volume is larger than the die-cavity volume
- Usually hot (could be cold) forming but either intermediate or final processing
- Requires the highest levels of force and energy among forging operations
- Usually for complex shapes with fine details

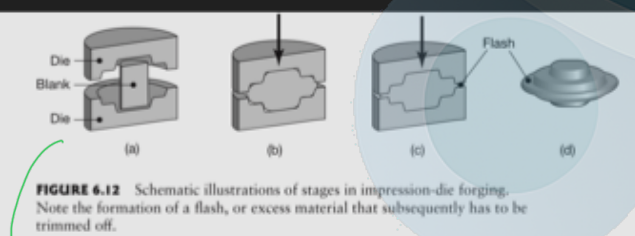


FIGURE 6.12 Schematic illustrations of stages in impression-die forging. Note the formation of a flash, or excess material that subsequently has to be trimmed off.

* Require high friction.

Extremely good surface & dimensional accuracy.

③ Precision forging:

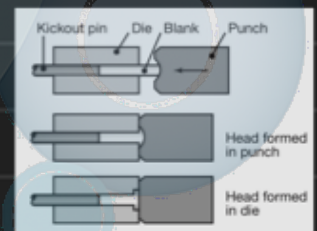
- The w/p has exactly the same volume as the die-cavity. used in simple shapes or materials with high ductility.

④ Closed-die forging:

- No flash & the w/p is completely surrounded by the dies.
- material volume is essential to produce a desired shape.

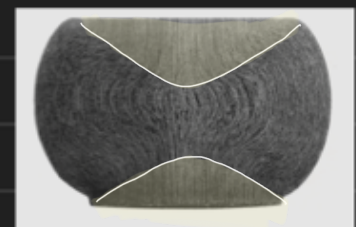
Ex: ① Coining (minting of coins).

② Heading ⇒



no metal flow

H.W: Why there is no def. in the highlighted

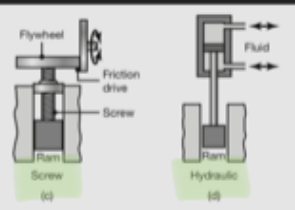


Explain the triangular shape of the undeformed metal zone.

ليس استكل قتل.

6.2.8 Equipment

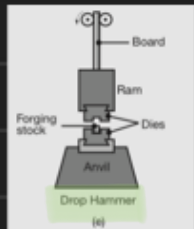
Forging equipment of various designs,



presses: Gradual

Hydraulic: depends in the direction of the hydraulic fluid.

Screw: rotation using Flywheel



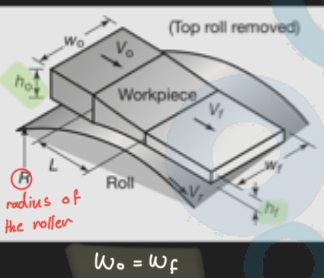
Hammer: Sudden

- Free fall
- power with the gravity.
 - Hydraulic
 - mechanical

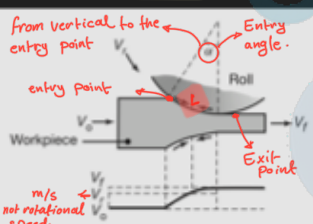
6.3 Rolling:

process of reducing the thickness or changing the cross section of a long workpiece by compressive forces.

Rolling accounts for about 90% of all metals produced by metalworking Operations.



then the material goes into the Rolling with constant initial velocity (V_0). then out with constant final velocity (V_f)



but inside the roller the velocity is changing (no constant velocity).

V_r : surface velocity of the roller $V_r \gg V_0$

L : arc of contact (length of contact) قوس التماس

* Volume rate of metal flow is constant

Roll deflections and roll flattening:

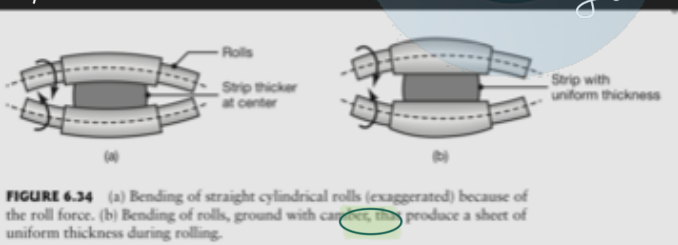


FIGURE 6.34 (a) Bending of straight cylindrical rolls (exaggerated) because of the roll force. (b) Bending of rolls, ground with cambers, that produce a sheet of uniform thickness during rolling.

One method for avoiding this problem is to grind the roll in such way that its diameter at the center is slightly larger than at the edges [this curvature is known as **Camber**]

* Spreading:

assuming constant width in the flat-rolling, so when the width increase $\Rightarrow$ Spreading

6.3.2 $\Rightarrow$ Defect in Rolled product **Selfreading**

2 types of Rolling:

1 Flat-Rolling: Only decrease the thickness. بدون تغيير الشكل

2 Shape-Rolling: Change the shape

6.3.5 Miscellaneous Rolling Operations:

1 Shape rolling: straight structural shapes of (hot) various cross sections.

2 Ring rolling: used to produce rings. (hot)

3 Thread rolling

Mechanics of Flat Rolling:

The basic flat-rolling process $\rightarrow$ Strip of thickness (h_0) enters the roll gap and reduced to a thickness of (h_f) by the powered rotating rolls at a surface speed V_r , while the volume flow rate of metal flow is constant.

& the velocity of the strip must increase as it moves through the roll gap, At the exit of the roll gap $\Rightarrow$ the velocity is V_f

Roll deflection part (2):

① When roller length $\gg$ diameter بصير المنطق من الدوائر
so we use the camber, $\Rightarrow$ Slight convex so the surface be flat

② Not a stiff roll material (rigid)

في حال (camber) بجني rad أكبر فلما يصير deflection بال roller
بصير radius أصغر وبصير flat.

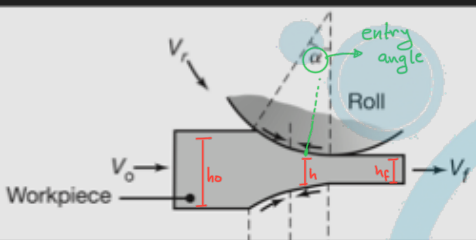
6.3 Rolling

average flow stress $\bar{\sigma} = \frac{k \bar{\epsilon}^n}{n+1}$, $\bar{\epsilon} \dots \dots$ ①

average flow stress in plane-strain conditions:

$$\bar{\sigma}_p = \sqrt{\frac{2}{3}} \bar{\sigma}_f = 1.15 \bar{\sigma}_f \dots \dots$$
 ②

μ : coefficient of friction between roll material & the work piece.



$$\alpha \Rightarrow 0 \leq \phi \leq \alpha$$

ϕ : angle to specific (h)

$$h_0 \Rightarrow \alpha$$

$$h_f \Rightarrow 0$$

Equations

$$h = h_f + R\phi^2 \xrightarrow{\text{rad}}$$

$$h = h_f + 2R(1 - \cos \phi) \xrightarrow{\text{normal}}$$

R: radius

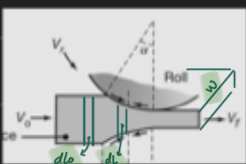
... ①

$$H = 2 \sqrt{\frac{R}{h_f}} \tan^{-1} \left(\sqrt{\frac{R}{h_f}} \phi \right) \dots \dots$$
 ②

H: variable value not thickness not (h).

phase (1): initially at the start of rolling process the material approaches to the rollers at constant initial velocity (V_0) while the rollers are rotating with constant surface velocity (V_r), & $V_r \gg V_0$

And as a result of this difference in velocity together with frictional force between rollers & W/P the material is pulled in between the 2 rollers. as consequence the material will experience a reduction in height (thickness) with a corresponding increase with velocity.



since constant volume $V_0 = V$ (volume)

$$h_0 d l_0 v_0 = h d l v \Rightarrow h_0 \frac{d l_0}{d t} = h \frac{d l}{d t}$$

$$[h_0 V_0 = h V] \Rightarrow V = \frac{h_0 V_0}{h}, \quad \frac{h_0}{h} > 1$$

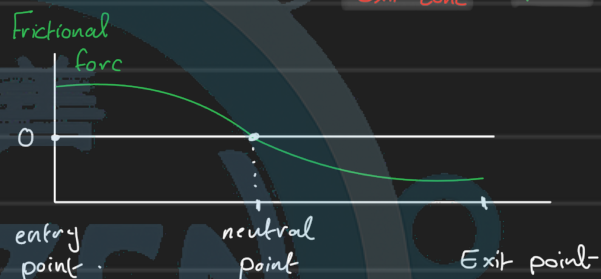
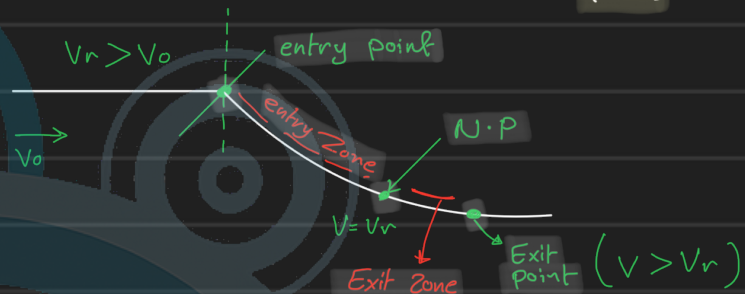
$$\Rightarrow V > V_0$$

Length of contact (arc).

phase (2): the velocity of the material continue to increase as it passes over the arc of contact, reaching or passing through a point where ($V = V_r$) $\Rightarrow$ this point known as "the neutral point" where frictional forces disappear.

phase (3):

After the neutral point the material velocity exceeds the roller surface velocity causing a phenomenon known as "forward Slip" & "Reversal of frictional forces"



*] The zone between the entry point & (N.P.) $\Rightarrow$ Entry Zone

*] The zone between (N.P.) & Exit point $\Rightarrow$ Exit Zone

كل ما قلت ال (thickness) بتزيد ال velocity

At the entry, $\phi = \alpha$; hence, $H = H_0$ with ϕ replaced by α . At the exit, $\phi = 0$, so that $H = H_f = 0$. Also, at entry and exit, $p = \sigma_f'$. Thus, in the entry zone,

$$C = \frac{R}{b_f} e^{\mu H_0}$$

and

$$p = \sigma_f' \frac{b}{b_0} e^{\mu(H_0 - H)}$$

In the exit zone,

$$C = \frac{R}{b_f}$$

and, hence,

$$p = \sigma_f' \frac{b}{b_f} e^{\mu H}$$

*] plane strain:

2 strains (length, height) & width constant

or

$$H_0 = \frac{1}{2} \left(H_0 - \frac{1}{\mu} \ln \frac{b_0}{b_f} \right) \quad \text{N.P.} \quad (6.32)$$

Substituting Eq. (6.32) into Eq. (6.29),

$$\phi_0 = \sqrt{\frac{b_f}{R}} \tan \left(\frac{H_0}{2} \sqrt{\frac{b_f}{R}} \right) \quad (6.33)$$

Lec (19)

Question :

$$h_o = 100, h_f = 85, R = 250, \mu = 0.5$$

$$S = 400 \text{ E}^{0.5}, \text{ find roll pressure at neutral point}$$

using MSSC : & P_{exit}

$$\Rightarrow \textcircled{1} P_{en} = G_f' * \frac{h}{h_o} * e^{\mu(H_o - H)}$$

$$\text{at (N.P.) : } h = h_n, H = H_n$$

$$\textcircled{2} G_f' = 1.15 G_f, \bar{G}_f = K \bar{E}^n, \bar{E} = \frac{2}{3}(E_1 - E_3)$$

$$E_n = \ln\left(\frac{85}{100}\right) = -0.16, E_w = \ln(1) = 0$$

$$\Sigma E = 0 \Rightarrow E_L = 0.16, \bar{E} = \frac{2}{3}(0.16 - 0.16) = 0.21$$

$$G_f' = 1.15 (400 * 0.21^{0.5}) = 210.8 \text{ MPa}$$

$$\textcircled{3} h_n = h_f + R \phi_n^2 \Rightarrow \phi = \sqrt{\left(\frac{h_f}{R}\right)} \tan\left(\frac{H_n}{2} \sqrt{\frac{h_f}{R}}\right)$$

$$\left[H_n = \frac{1}{2} \left(H_o - \frac{1}{\mu} \ln\left(\frac{h_o}{h_f}\right) \right) \right] \Leftarrow \left[H_o = 2 \sqrt{\frac{R}{h_f}} \tan\left(\sqrt{\frac{R}{h_f}} * \alpha\right) \right]$$

$$\left[h_o = h_f + R \alpha^2 \right] \Rightarrow \left[\alpha = \sqrt{\frac{h_o - h_f}{R}} \right] \Rightarrow \alpha = \sqrt{\frac{100 - 85}{250}} = 0.245 \text{ rad}$$

$$\textcircled{2} H_o = 2 \sqrt{\frac{250}{85}} \tan\left(\sqrt{\frac{250}{85}} * (0.245)\right) = 1.36$$

$$\textcircled{3} H_n = \frac{1}{2} \left(1.36 - \frac{1}{0.5} \ln\left(\frac{100}{85}\right) \right) = 0.517$$

$$\textcircled{4} \phi_n = \sqrt{\left(\frac{85}{250}\right)} \tan\left(\frac{0.517}{2} \sqrt{\frac{85}{250}}\right) = 0.08 \text{ rad}$$

$$\textcircled{5} h_n = 85 + (250 * (0.08)^2) = 86.6$$

$$\Rightarrow \textcircled{1} P_{en} = G_f' * \frac{h}{h_o} * e^{\mu(H_o - H)}$$

$$P_{en} = 210.8 * \frac{86.6}{100} * e^{0.5(1.36 - 0.517)} =$$

$$P_{en} = 278.25 \text{ MPa}$$

$$\Rightarrow \textcircled{2} P_{exit} = G_f' \left(\frac{h}{h_f}\right) e^{\mu(H)}$$

$$210.8 \left(\frac{86.6}{85}\right) e^{0.5 * (0.517)}$$

$$P_{ex} = 227.06 \text{ MPa}$$

Notes :

to check in the entry point

$$P_{en} = P_{exit} \quad \dots \textcircled{1}$$

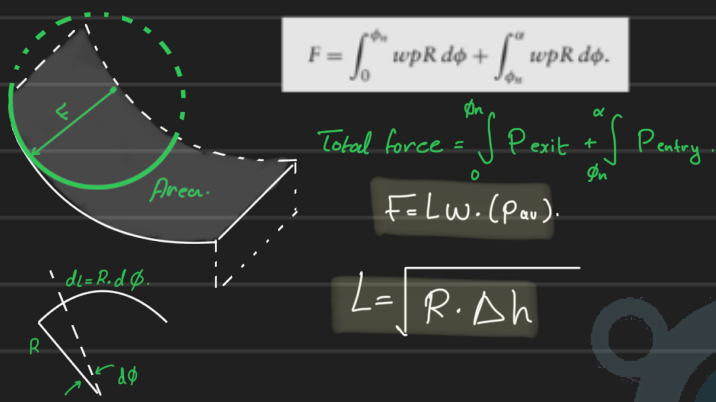
$$h_o \leq h \leq h_f \quad \dots \textcircled{2}$$

Self Reading section :

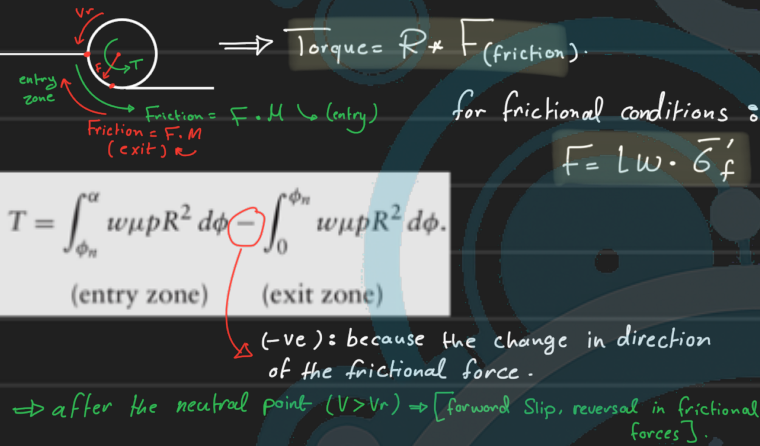
6.3.2 Defects in Rolled Products

There may be surface defects on rolled plates and sheets, or structural defects within the material. Surface defects may result from inclusions and impurities in the material, scale, rust, dirt, roll marks, and other causes related to the prior treatment and working of the material. In hot rolling of blooms, billets, and slabs, the surface is usually preconditioned by various means, such as by scarfing (using a torch).

Structural defects can affect the integrity of the rolled product. Some typical defects are shown in Fig. 6.36. Wavy edges are caused by bending of the rolls, whereby the edges of the strip become thinner than at the center. Because the edges then elongate more than the center and are restrained by the bulk of the material from expanding freely, they buckle. The cracks shown in Fig. 6.36b and c are usually caused by low material ductility and barreling of the edges. Alligatoring is a complex phenomenon that results from inhomogeneous deformation of the material during rolling or from defects in the original cast ingot, such as pipe (see Section 6.4.4).



* Torque



For higher frictional conditions:

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

$\bar{\sigma}'_f = \frac{k \epsilon^n}{n+1}$, $\bar{\sigma}'_f = 1.15 \bar{\sigma}_f$

the torque per roll is then

$$T = \frac{FL}{2}$$

The power required per roll is

$$\text{Power} = T\omega = \frac{FL\omega}{2} = \frac{\pi FLN}{60}$$

minutes إلى seconds revolution إلى radian

EXAMPLE 6.4 Power Required in Rolling

Given: A 225-mm-wide 6061-T6 aluminum strip is rolled from a thickness of 25 mm to 20 mm. The roll radius is 300 mm and the roll speed is $N = 100$ rpm.

Find: Estimate the total power required for this operation.

Solution: The length of the arc of contact, L , is obtained from Eq. (6.34) as

$$L = \sqrt{R\Delta h} = \sqrt{(300)(25 - 20)} = 38.73 \text{ mm}$$

For 6061-T6 aluminum, $K = 201$ MPa and $n = 0.2$ (from Table 2.2). The true strain in this operation is

$$\epsilon_1 = \ln \left(\frac{25}{20} \right) = 0.223$$

Thus, from Eq. (6.10),

$$\bar{\sigma}_f = \frac{K\epsilon^n}{n+1} = \frac{(201)(0.223)^{0.2}}{1.2} = 126 \text{ MPa}$$

and, from Eq. (2.46),

$$\bar{\sigma}'_f = (1.15)(126) = 145 \text{ MPa}$$

Therefore, noting that the width is $w = 225$ mm, Eq. (6.39) yields

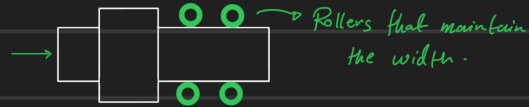
$$F = Lw\bar{\sigma}'_f = (0.03873)(0.225)(145 \times 10^6) = 1.26 \text{ MN}$$

so that the power per roll is

$$\text{Power} = \frac{(\pi)(1.26 \times 10^6)(0.03873)(100)}{60} = 255 \text{ kW}$$

Therefore, the power needed for both rolls is 510 kW.

for Spreading to keep constant width :



(6.4) Extrusion

part (1).

Extrusion part (2) :

Extrusion ratio $R_e = \frac{A_0}{A_f}$, $R_e > 1$ بجانب

*] Metal flow in Extrusion :

(6.4) Extrusion

6.4 Extrusion

work piece

or container

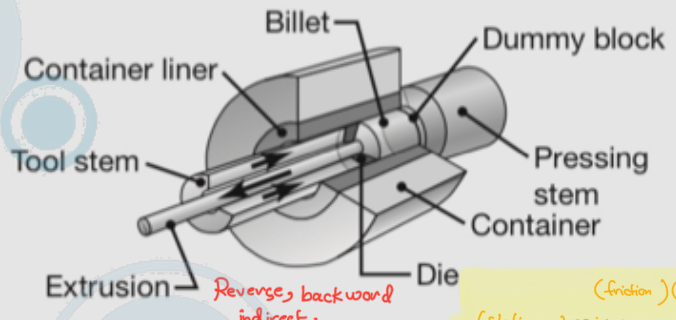
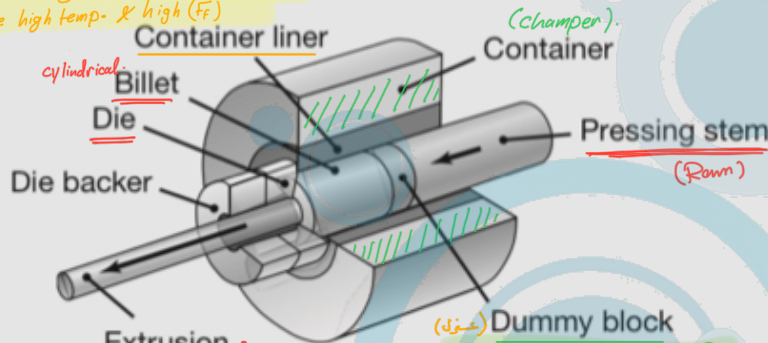
die opening: منقطة حسب شكل القطعة التي نرسلها اليها

In the extrusion process (Fig. 6.45), developed in the late 1700s for producing lead pipe, a billet is placed in a chamber and forced through a die opening by a ram. The die may be round or of various shapes. Typical parts made are railings for sliding doors, window frames, aluminum

* Mostly Extrusion is a (hot) process. (high temp.).

Sliding happens at higher temp.

Extremely hard material to resist the high temp. & high (F)



product اسم المنتج process اسم العملية

(a) Direct Extrusion: friction (الفرك) بين المعدن والمواد التي نرسلها اليها (billet) و بين المعدن والمواد التي نرسلها اليها (ram) و بين المعدن والمواد التي نرسلها اليها (die) و بين المعدن والمواد التي نرسلها اليها (container) و بين المعدن والمواد التي نرسلها اليها (pressing stem) و بين المعدن والمواد التي نرسلها اليها (die backer) و بين المعدن والمواد التي نرسلها اليها (extrusion).

Dummy block (غرفة) ما الذي دور بالقضية لكنه دورها الاساسي فصل ال (stem) عند ال (hot billet)

non continuous lengths: كل ما نرسله (billet) نرسله استعمل ال (ram) و نرسله (billet) جديدة

(Stationary) (billet) عند (bellit) و container. no relative motion between bellit & container. لما ادفع (stem) المعدن بيننا وفي مشوية (friction) المعدن هو طالع.

(friction) *

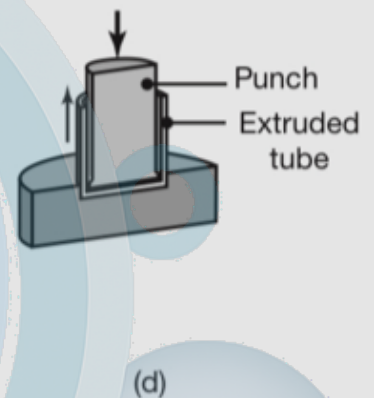
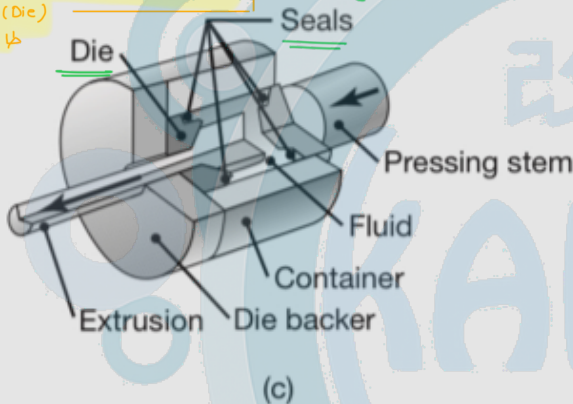
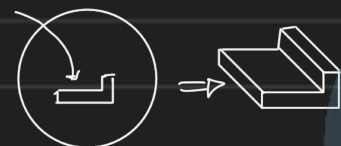


FIGURE 6.45 Types of extrusion: (a) direct; (b) indirect; (c) hydrostatic; (d) impact.

Forward reverse (Backward)

Die shape (opening)



steps: Billet into container → push it using Ram (stem), will have the shape of the die opening

① Forward Extrusion: (direct).

- Metal flow same dir. as ram movement.
- High Frictional process.
- produce larger lengths. (continuous).

③ hydrostatic: increase the ductility.

- the Force not directly from the ram, but the stem دفع the fluid → the the fluid صحت بالقوة فبفعلها (Extrusion of brittle & hard materials).

④ Impact:

indirect ← يشبه

- used for extremely ductility materials

② Back word:

- Metal flow opposite dir. of ram.
- no relative motion (less friction).
- produce limited, noncontinuous lengths

Extrusion Ratio:

$$R_e = \frac{A_0}{A_f}, R_e \gg 1.$$

6.4.1 Metal Flow in Extrusion

The *metal flow pattern* in extrusion is important in the overall process, as it is in all metalworking processes. Figure 6.47 shows three patterns typical of direct extrusion with *square dies*, where the die angle is 90° . From this figure, common flow patterns can be identified:

1. The most homogeneous (uniform) flow pattern (Fig. 6.47a) occurs when there is **no friction** at the interfaces. This type of flow also occurs in indirect extrusion, where there is no friction at the billet-container interfaces because there is no movement.
2. When friction along all interfaces is high, a **dead-metal zone** develops (Fig. 6.47b). Note the high-shear area as the material flows into the die exit (similar to liquid flowing into a funnel). This configuration may cause the billet surfaces (with their oxide layer and entrained lubricant) to enter this high-shear zone and be extruded, resulting in product defects (see Section 6.4.4).
3. In the third configuration, note that the **high-shear zone** extends farther back into the billet (Fig. 6.47c). This situation can be due to

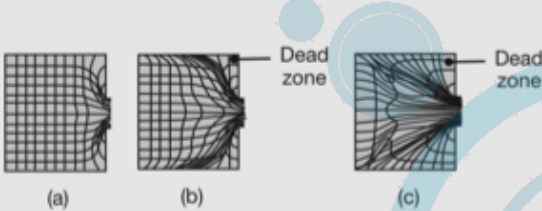


FIGURE 6.47 Schematic illustration of three different types of metal flow in direct extrusion. The die angle in these illustrations is 90° .

highly lubricated process (effective)

mild friction

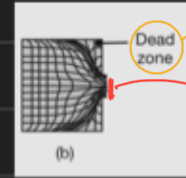
high friction

a.) no friction



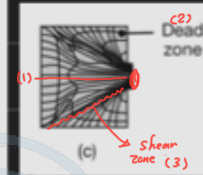
friction عند التماس
لا يكون استوي + flow يكون موازي لـ اتجاه القوة (direct flow)
* open-die forging, friction happens on the tangency.

b.) mild friction



no flow. كل ما بعد عن center المادة منظرية تغير اتجاهها الزاوية تقترب منه (90)
لا المادة غيرت اتجاهها مادح يوحذ
تغيره ان Force كامله بي اتي بالوسط
بمعدننا ($F \propto \cos \theta$)

3.) high friction



بيدي احاول التي زاوية اتل عننا ن احيين ($\cos$) قيمته أعلى
zone (1) = easily flow zone
zone (2) = Dead zone (no flow)
zone (3) = Shear zone
Extremely hard flowing zone. (Shear)

* كل ما زاد ال (friction) بتزيد عننا ال (Dead zone & shear zone)

改善
KAIZEN
TEAM

Mechanical of Extrusion :

1.] Ideal force, no friction. (plastic or ideal work)

$$E_1 = \ln\left(\frac{A_0}{A_f}\right) = \ln\left(\frac{Lf}{L_0}\right) = \ln(P_e)$$

(perfectly plastic material with yield strength S_y).

* Energy in plastic deformation per unit volume $[u = S_y \epsilon_p]$

↪ then the work $[\text{Work} = A_0 \int_0^u u = \text{Volume} \times u.]$

↪ $W_{\text{work}} = \underline{F} \underline{L_0} = P(A_0 L_0) = A_0 L_0 * u$

Extrusion force
by the ram.

$$\underline{S_o} \quad p = u = S_y \ln \left(\frac{A_o}{A_f} \right) = S_y \ln Re. \quad \neq = S_y \epsilon_1$$

(ideal force ($F = PA_0$)) ...

Note : for strain-hardening materials $\Rightarrow \bar{S}_y$ will be average flow stress $\bar{\sigma}_F$

Ideal $\rightarrow$ perfectly plastic sy.

strain-hardening $S_y \Rightarrow \bar{\sigma} = \frac{k\epsilon^n}{n+1}$

2.] Ideal force, with friction

the material is not perfectly plastic $\Rightarrow$ strain-hardening materials

if $\delta = K\epsilon^n$, then $\bar{\delta} = \frac{K\epsilon^n}{n+1}$, $\delta_y \Rightarrow \bar{\delta}$

① for perfectly plastic ε

$$P = S_y \left(1 + \frac{\tan \alpha}{\mu} \right) [R_e^{\mu \cot \alpha} - 1]$$

die angle

coefficient friction between the bellit & die or container

② Strain-hardening : $\bar{\sigma} = \frac{K\epsilon^n}{n+1}$ instead of S_y

Special case $\alpha = 45^\circ$: $P = S_y \left(1.7 \ln P_c + \frac{2L_0}{D_0} \right)$ bellit-length

(6.5) Rod, Wire, and Tube Drawing:

Drawing : The cross-sectional area of tube is reduced or changed in shape

by pulling it through a converging

→ final cross-section
بُعد نهایی

All bulk deformation processes are compressive forces.

Mechanics of Rod & Wire drawing:

① Ideal deformation: perfectly plastic material, No friction.

$$\sigma_d = S_y \ln\left(\frac{A_0}{A_f}\right), \quad \sigma_d: \text{drawing stress.}$$

* Same approach as that used for extrusion.

Strain-hardening material $F = \bar{\sigma}_f A_f \ln\left(\frac{A_0}{A_f}\right)$ F : drawing force

② Ideal deformation and friction :

Perfectly plastic: $G_d = S_y \left(1 + \frac{\tan \alpha}{\mu} \right) \left[1 - \left(\frac{A_f}{A_0} \right)^{\mu \cot \alpha} \right]$

strain hardening $\sigma_y \Rightarrow \bar{\sigma}$

③ Redundant work depends on the internal friction & [Ductility]

$$G_d = \bar{G}_f \left[\left(1 + \frac{\tan \alpha}{\mu} \right) \left[1 - \left(\frac{A_f}{A_o} \right)^{\mu \cot \alpha} \right] + \frac{4}{3\sqrt{3}} \alpha^2 \left(\frac{1-r}{r} \right) \right]$$

r : fractional reduction of area and α is the die angle.

$$\rightarrow \left(\frac{v_o - v_f}{v_o} \right)$$

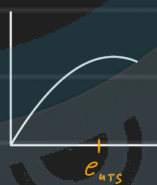
in case small die angles: محس درجات او اقل

$$G_d = G_f \left[\left(1 + \frac{\mu}{\alpha}\right) \ln\left(\frac{A_o}{A_f}\right) + \frac{2}{3} \alpha \right] \dots$$

Note :

$UTS \equiv$ plastic instability in tension.

$$\frac{ds}{d\epsilon} = \delta \Rightarrow \underset{\text{UTS}}{C} = \ln(1 + \underset{e_{\text{UTS}}}{e}) \quad , \quad \max C = C_{\text{UTS}}$$



$$, 6 = K E^n \Rightarrow E = n \text{ ab WTS.}$$

EXAMPLE 6.7 Power Required and Die Pressure in Rod Drawing

Given: A round rod of annealed 302 stainless steel is being drawn from a diameter of 10 mm to 8 mm at a speed of 0.5 m/s. Assume that the frictional and redundant work together constitute 40% of the ideal work of deformation.

Find: Calculate the power required in this operation, and the die pressure at the die exit.

Solution: The true strain that the material undergoes in this operation is

① Stage (1) till $(0.3) = \ln\left(\frac{D_o}{D_f}\right)$

$0.3 = \ln\left(\frac{10^2}{D_f^2}\right) \Rightarrow D_f = 8.6 \text{ mm}$

② Stage (2)

$0.146 = \ln\left(\frac{8.6^2}{D_f^2}\right) = 8 \text{ mm}$

$\epsilon_1 = \ln\left(\frac{10^2}{8^2}\right) = 0.446$

* # of stages
= $\frac{\text{Total strain}}{\text{strain at instability}}$

$n < 1$ is (1) stage
 $1 < n < 2$ round up
 $2 < n < 3$

From Table 2.2, for this material and condition, $K = 1300 \text{ MPa}$ and $n = 0.30$. Hence,

$\bar{\sigma}_f = \frac{K\epsilon_1^n}{n+1} = \frac{(1300)(0.446)^{0.30}}{1.30} = 785 \text{ MPa}$

② $\frac{0.446}{0.3} > 1 \Rightarrow$ بمرحلة واحدة

From Eq. (6.63), the drawing force is

$F = \bar{\sigma}_f A_f \ln\left(\frac{A_o}{A_f}\right)$

where

$A_f = \frac{(\pi)(0.008)^2}{4} = 5 \times 10^{-5} \text{ m}^2$

Therefore,

$F = (785)(5 \times 10^{-5})(0.446) = 0.0175 \text{ MN}$

and

$\text{Power} = (F)(V_f) = 8.75 \text{ kW}$

As given in the problem statement, the actual power will be 40% higher, or

$\text{Actual power} = (1.4)(8.75) = 12.25 \text{ kW}$

The die pressure can be obtained by noting from Eq. (6.69) that

$p = \sigma_f - \sigma$

where, at the exit of the die, σ_f represents the flow stress of the material and σ refers to the drawing stress. Thus,

$\sigma_f = K\epsilon_1^n = (1300)(0.446)^{0.30} = 1020 \text{ MPa}$

Hence, using the force obtained above,

$\sigma_d = \frac{F}{A_f} = \frac{(1.4)(0.0175)}{0.00005} = 490 \text{ MPa}$

Therefore, the die pressure at the exit is

$p = 1020 - 490 = 530 \text{ MPa}$

مجموع (ε) بكل المراحل لازم
يساوي (total strain)

$\bar{\sigma}_f \rightarrow 0.3$ for stage (1)
 $\rightarrow 0.146$ " " (2)

$\frac{\text{N} \cdot \text{m}}{\text{s}} \rightarrow \frac{\text{J}}{\text{s}} \rightarrow \text{Watt}$

End of chapter
(6) //