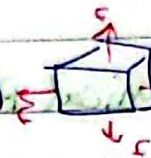


2.1

* Metals are the most used Materials in manufacturing.

⇒ Categories in manufacturing metals:

① Metal forming : putting the metal under load (force)



② Metal Cutting

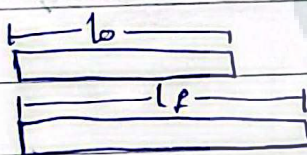
③ Casting and welding.

* plastic deformation: Shaping materials by applying forces on the work-piece by various means. (deformation processing)

↳ bulk deformation processes

↳ Sheet forming processes.

* Strain: the amount of deformation to which the material is subjected. (the relative elongation per unit length)



⊗ A_0

⊗ A_f

$$\epsilon = \frac{\Delta L}{L_0} = \frac{L_f - L_0}{L_0}$$

ϵ : engineering or nominal strain.

* Stress: The amount of applied load per unit area.

unit: pascal ($1 \text{ Pa} = 1 \text{ N/m}^2$) or ($1 \text{ MPa} = 1 \text{ N/mm}^2$)

$$\sigma = \frac{P}{A_0}$$

σ : nominal or engineering stress

P: applied force

A_0 : original c.s area.

* Strength: Definition Material's resistance to deformation when subjected to loading.

* Mechanical Behavior: The way in which metallic materials behave (respond) when subjected to mechanical loading causes in (deformation-loading) relationships.

response stimulus
↓ ↓
Strain stress

2.2

* Tensile test: Consists of pulling a standard specimen of the material in interest and recording data such as the load applied and the elongation experienced.

⇒ it's most common for determining the (strength-deformation) characteristics of metals.

How does the tensile test work?

① when the load is first applied, the specimen elongates proportionately to the load up to the proportional limits.

(linear elastic behavior)

② the material will continue to deform elastically until it reaches the yield point. relationship between stress and strain is no longer linear. (elastic non-linear range).

Note: if the load is removed before the yield point is reached, the specimen will return to its original length.

* Modulus of elasticity / Young's modulus:

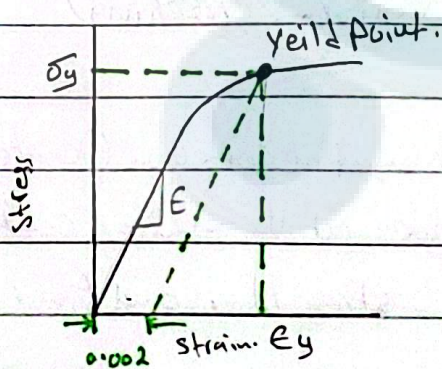
$$E = \frac{\sigma}{\epsilon} \quad * \text{Hook's Law.}$$

However ① + ② are in "elastic range"

↳ not permanent deformation.

↳ elastic recovery if load is released.

* The yield point can be determined by the 0.2% offset method.



* The area under the stress-strain curve up to the yield point is known as Modulus of resilience.

unit: J/m^3

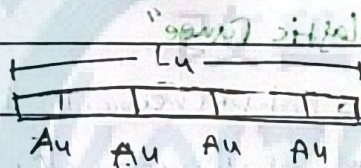
$$MOR = \frac{\sigma_y^2}{2E}$$

③ After the yield point, plastic (permanent) deformation takes place with stress value still increasing until reaching a max value known as "The Ultimate Tensile Stress" (UTS)

$$UTS = \frac{P_{max}}{A_0}$$

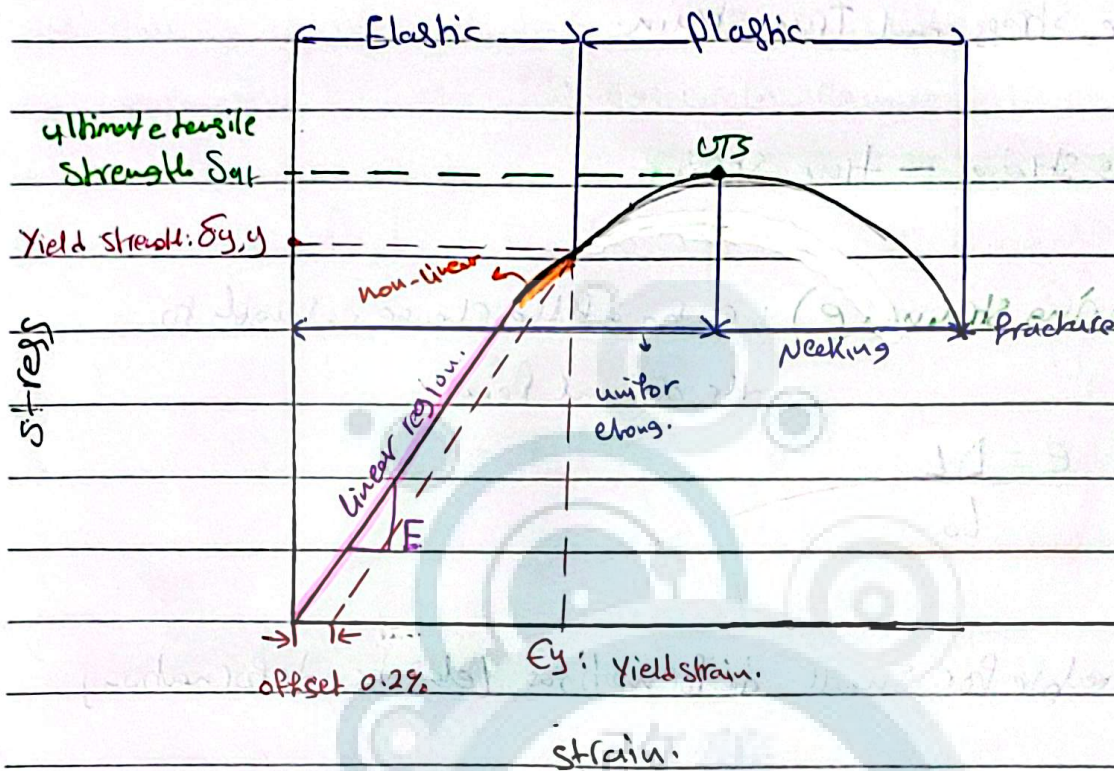
Up to this point the specimen exhibits "uniform elongation"

* uniform elongation: the increase in length and the reduction in C.S area are uniform throughout the whole length of the specimen.



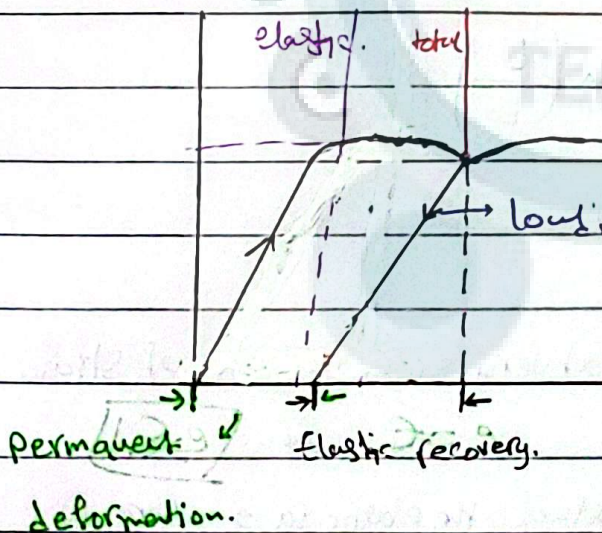
④ when the test specimen is loaded beyond S_{UTS} , it begins to neck and the elongation is no longer uniform. (necking)

⇒ At this stress level the necking phenomenon (concentrates reduction in C.S area) takes place at the middle (center) of the specimen leading to reduction in stress level and final fracture at the "necking region"



* loading and unloading of tensile test specimen.

Book P.9.54.



المادة يتخرج الجزء من تلك الامثلة وهو عائد عن النقطة الى شكلها الاول منها مطروقة منها . elastic.

$$\text{Permanent deformation} = \text{total} - \text{elastic}$$

2.2.2 True Stress and True Strain.

(*) Engineering Strain — True Strain.

⇒ Engineering strain (e): ratio of the change in length to the original length.

$$e = \frac{\Delta L}{L_0}$$

Use case: Suitable for small deformations (elastic deformation).

⇒ True Strain (E): instantaneous changes in length.

is obtained by integrating the small changes in strain over deformation process.

$$E = \int_{L_0}^L \frac{dL}{L} = \ln\left(\frac{L}{L_0}\right)$$

or, in terms of eng. strain:

$$E = \ln(1+e)$$

at very small values of strain.

$$e = E \quad \text{when } e \text{ is very small}$$

⇒ This is valid in the elastic range where the change in dimensions (strain) is very small.

Use case: Used for plastic deformation, metal forming, and high strain applications.

* During uniform elongation and only if the area has one parameter (one dimension) e.g.: circle, square :

$$A_0 L_0 = A_f L_f$$

Square: $\frac{L_f}{L_0} = \frac{A_0}{A_f}$, found $\frac{A_0}{A_f} = \frac{D_0^2}{D_f^2}$

$$\therefore E = \ln\left(\frac{L_f}{L_0}\right) = \ln\left(\frac{A_0}{A_f}\right) = \ln\left(\frac{D_0^2}{D_f^2}\right) = 2 \ln\left(\frac{D_0}{D_f}\right)$$

* Engineering Stress - true Stress.

⇒ Engineering Stress : (σ_e) applied force divided by the original c.s area.

$$\sigma_e = \frac{P}{A_0}$$

use case: in basic material testing and for small deformations, (elastic)

⇒ True Stress (σ_t): applied force divided by the actual (instantaneous) c.s area

$$\sigma_t = \frac{P}{A}$$

used in plastic deformation.

when all cases.

$$\sigma_t = \sigma_e \exp(E)$$

when elongation only

$$\frac{\sigma_t}{\sigma_e} = \frac{A_0}{A}$$

2.2.1 Ductility:

Def: the capability of the material to deform plastically (permanently) before fracture.

④ Elongation:

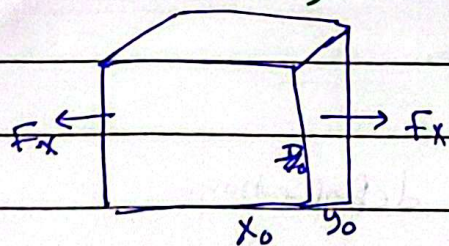
$$\text{Elongation} = \frac{L_f - L_0}{L_0} \times 100\%$$

④ Reduction of Area:

$$\text{Reduction of Area} = \frac{A_0 - A_f}{A_0} \times 100\%$$

④ Poisson's ratio (ν): ratio of lateral strain to longitudinal strain (strain in the same direction as the acting force (stress))

$$\text{longitudinal stress} = e_x = \frac{\Delta x}{x_0} \quad \text{for } \nu = 0.2 - 0.35$$



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

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

Quiz

ex: if $Z_0 = 50\text{mm}$, $Y_0 = 20\text{mm}$, $X_0 = 100\text{mm}$, $X_f = 101\text{mm}$.Find the volume of the work piece while still under loading given that

$$v = 0.3$$

Sol:

$$V_f = X_f \times Y_f \times Z_f$$

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

$$= \frac{101 - 100}{100} = 0.01$$

$$e_y = -v \cdot e_x = -0.3 \times 0.01$$

$$= -0.003$$

$$\Rightarrow e_y = \frac{\Delta y}{y_0} = \frac{y_f - y_0}{y_0}$$

$$-0.003 = \frac{y_f - 20}{20} \Rightarrow \boxed{y_f = 19.94\text{mm}}$$

$$e_z = -v \cdot e_x = -0.3 \times 0.01$$

$$= -0.003$$

$$\Rightarrow e_z = \frac{\Delta z}{z_0} = \frac{z_f - 50}{50} = -0.003 \Rightarrow \boxed{z_f = 49.85\text{mm}}$$

$$V_f = 101 \times 19.94 \times 49.85$$

$$= 100394.9 \text{ mm}^3$$

2.2.3 True stress - True strain Curve.

⊛ Mechanical Behavior equation: only for true stress-true strain curves.

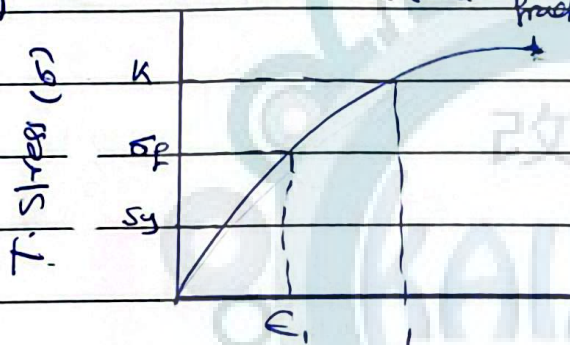
$$\sigma = K \epsilon^n$$

K : Strength coefficient. (MPa)

n : strain-hardening index/exponent

is used to construct true stress-true strain curves.

a) $\sigma_t - \epsilon$ curve in tension



* it has no UTS point because they're divided by the true area.

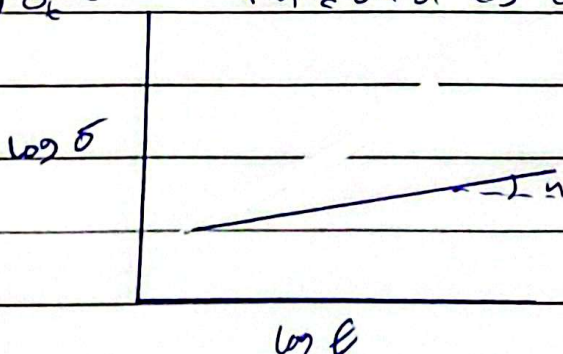
T. Strain (ϵ)

⊛ True stress - True strain curve in tension.

⊛ The slope is always positive (Slope ↓ when strain ↑)

⊛ on this curve σ_y is Yield strength, σ_p : Flow stress

b) $\sigma - \epsilon$ curve Plotted on a log-log scale



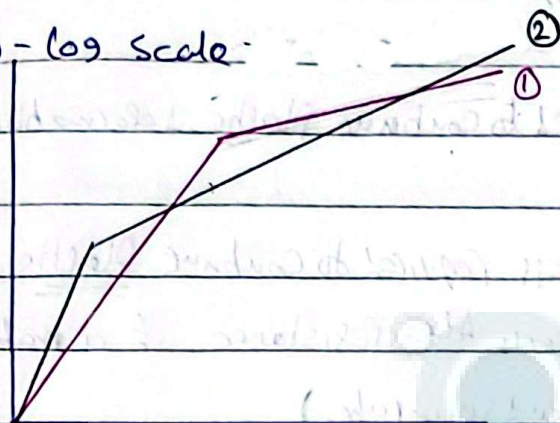
$$Y = \log K + nX$$

where: $Y = \log \sigma$

$X = \log \epsilon$

$n \rightarrow$ slope

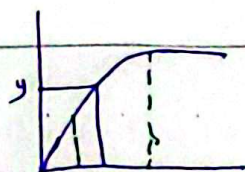
c) log-log scale

1: High(k), Low(n)2: High(n), Low(k)⊕ Flow stress: σ_f Same σ on the curve but it should be in the plastic range.Def: true stress required to continue plastic deformation at a particular true strain ϵ .⇒ For strain-hardening materials, the Flow Stress increases with increasing strain.

* Strain hardening: the increase in material's strength or hardness as a result for plastic strain (plastic deformation)

* Note: Hook's law: $\sigma = E \epsilon$ if ϵ is total strain then ① $\epsilon \leq \epsilon_y$ elastic deformation. ϵ_y : Yield strain.② $\epsilon > \epsilon_y$ elastic + plastic

in case ① when load is removed full recovery occurs

in case ② when load is released/removed $\epsilon_{net} = \epsilon_{tot} - \epsilon'_{elastic}$ recovery $\leftarrow \epsilon < \epsilon_y$ $\epsilon \rightarrow \epsilon_{net}$ plastic + elastic (no recovery)

الكلام على خواص المواد

④ Flow stress: (σ_f)

Def: the true stress required to continue plastic deformation at a particular true strain (ϵ_1).

(is the instantaneous value of stress required to continue plastic deformation in a material. It represents the resistance of a material to deformation at a given strain and strain rate.)

Flow stress $\uparrow$ when strain $\uparrow$

- Average flow stress ($\bar{\sigma}_f$)

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

$$\bar{\sigma}_f = \frac{K\epsilon^n}{n+1}$$

ϵ : total strain

ϵ_1 : true strain.

* **Toughness**: The area under the true stress - true strain curve (energy per unit volume that the material can handle before fracture)

$$\text{Toughness} = \int_0^{\epsilon_f} \sigma d\epsilon, \quad \epsilon_f: \text{strain fracture}$$

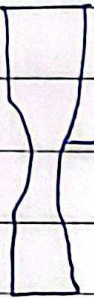
Note:

Toughness $\rightarrow$ الطاقة تمتصها المادة
plastic + elastic

MOR $\rightarrow$ الطاقة تمتصها المادة قبل كسر
elastic.

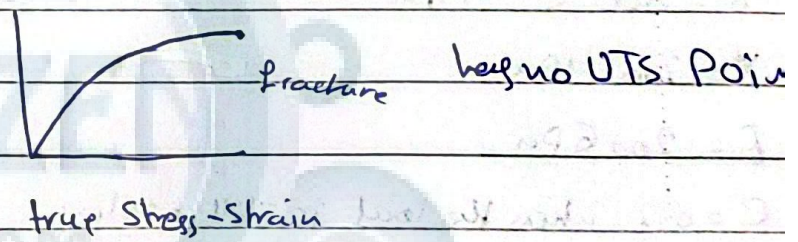
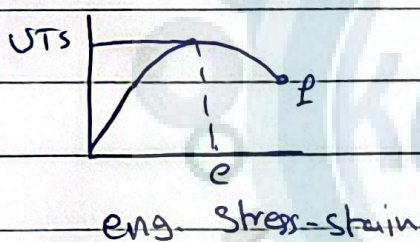
2.2.4 Instability in Tension

⇒ Plastic instability in tension (necking phenomenon)



at UTS point $F \downarrow A \downarrow$, F : force, A : area.

huge decrease in Area because non-uniform thickness
 * when area decreases less force needed therefore the force applied on the specimen decrease until fracture.



at UTS $\rightarrow P_{max}$

$dP = 0 \rightarrow P_{max}$ عند الحد الأقصى

(لا يتغير بعد الحد الأقصى)

$$P = \sigma_{tr} A = \sigma_{eng} A_0 \Rightarrow \frac{d\sigma}{d\epsilon} = \sigma$$

شرط الاشتقاق هو جد في الرتبة

whenever

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

then

$$\epsilon = n$$

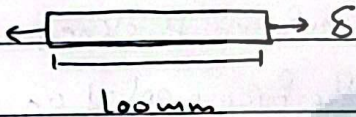
فيما سأل عن كيفية إيجاد علاقة مختلفة لـ σ

فيما سأل عن الحالة بوجود مشتقة القانون اعطى وبسلاوي

بار σ

$$\sigma = \text{القيمة}$$

eg: Quiz:



Given that:

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

$$Y = 200 \text{ MPa}$$

$$E = 200 \text{ GPa}$$

$\epsilon = 0.2$ when the load is still applied.

Find:

a- UTS true and UTS eng of the material.

b- Find the length of the specimen after releasing the load.

$$a- \text{UTS}_{\text{true}} = 300 \epsilon^{0.5} = 300 (0.2)^{0.5} = 134.16 \text{ MPa}$$

$$\text{UTS}_{\text{eng}} = \text{UTS}_{\text{true}} \bar{\epsilon}^{\epsilon} = 134.16 \cdot \bar{\epsilon}^{-0.5} = 81.37 \text{ MPa}$$

$$b- \epsilon = \ln\left(\frac{L}{L_0}\right) \rightarrow 0.2 = \ln\left(\frac{L}{100}\right)$$

$$L = 122.14 \text{ mm}$$

Finding UTS Very Imp:

$$UTS_{true} = K \epsilon^n$$

$$UTS_{eng} = UTS_{true} e^{-\epsilon}$$

$$\rightarrow \epsilon = n$$

$$\sigma_y \equiv S_y \equiv \sigma_y$$

yield stress

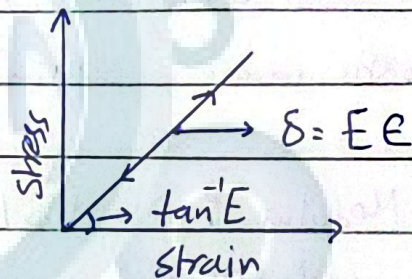
yield

2.2.5: Types of stress-strain curves.

a) A perfectly elastic material:

brittle materials (rubber)

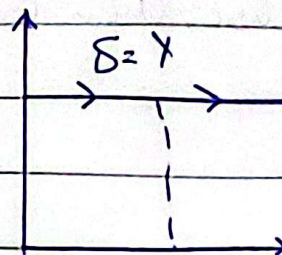
- no plastic range from zero stress until fracture no permanent deformation. (linear relation).



b) A rigid, perfectly plastic

soft materials and doesn't harden with strain (clay).

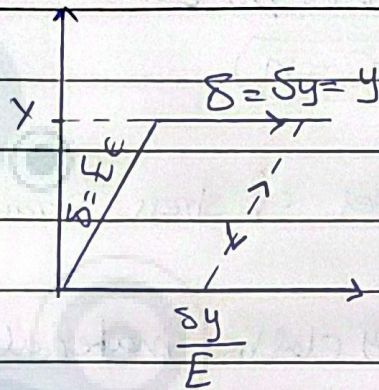
- Starts from Yield point (Y), no elastic range, no strain hardening.



c) elastic, perfectly plastic

ductile materials (lead and Tin).

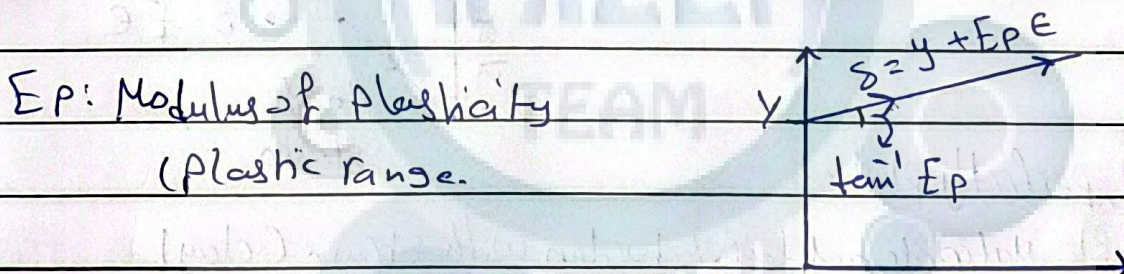
- Has elastic range but when reach to plastic it has no strain hardening.



d) rigid, linearly strain-hardening

low carbon steel, Aluminum alloys, cold worked copper.

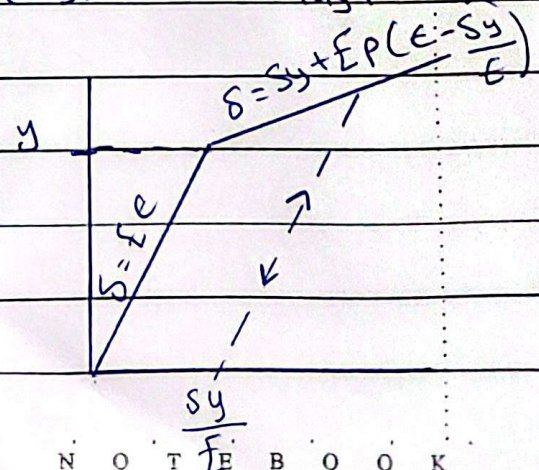
- no elastic range, strain hardening increase linearly.



e) elastic, linearly strain-hardening.

Mild steel, Aluminum alloys, Titanium alloys...

- Has elastic range, when reaching plastic strain-hardening increase linearly:



Imp. notes:

$$\epsilon_y = \frac{\delta_y}{E}$$

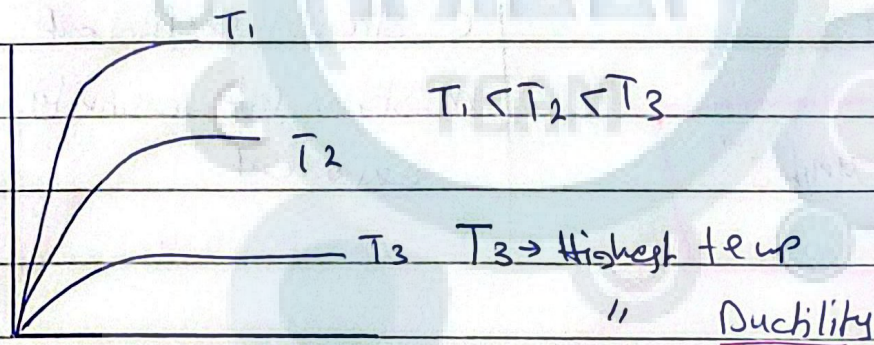
$$\delta_y = \delta_y = y$$

$$\delta = E \cdot \epsilon ; \epsilon \leq \epsilon_y$$

$$\delta = y ; \epsilon > \epsilon_y$$

2.2.6: Effects on temperature.

when temperature $\uparrow$ $\left\{ \begin{array}{l} \text{Strength} \downarrow \\ \text{Hardness} \downarrow \\ \text{Ductility} \uparrow \end{array} \right.$



استطاعة الممتص بالعرض

Toughness increase with the increase of the area under the curve

بمعنى النظر في زيادة المنطقة تحت منحنى القوة والامتداد.

2.2.7 Effects of strain Rates

= strain rate: strain per unit time.

→ Increase in strain rate increase:

- Strength (σ , UTS, ...)
- Hardness
- E

* engineering strain rate

$$\dot{\epsilon} = \frac{V}{L_0} \quad \text{unit } s^{-1}$$

* true strain rate:

$$\dot{\epsilon} = \frac{V}{L} \quad \text{unit } s^{-1}$$

* effect of strain rate on the strength:

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

C: strength coefficient

m: strain rate sensitivity exponent.

to make 2-

- constant eng. rate → const. deformation velocity
- constant true rate → const. ratio between velocity and length

Figure 2.9 Page 63

* effect of temp. on strain rate:

① Cold working: (low temp. deformation). → usually at room temperature.

low temperature → high strain rate → stronger and harder

→ increase in strain hardening.

→ reduce ductility

⇒ strain rate ↑ strength ↑ temp ↓ ductility ↓ strain ↓

② Hot forming: (high temp. deformation). →

high temperature → low strain rate → reduce strength

→ reduce strain hardening

→ increase ductility

⇒ temp ↑ strain rate ↓ strength ↓ ductility ↑ strain ↑

Q: explain why: Cold forming has a high strain rate but low strain. and hot forming has low strain rate and high strain?

answer:

Strength and strain have an inverse relationship, where the strength is the material's resistance for deformation (strain). Therefore in Cold forming the material has high strength (high resistance for strain) so it has low strain, and in hot forming the material has low strength (low resistance for strain) so it has high strain.

* important notes:

- مع زياده strain rate $\leftarrow$ UTS بتزيد
- شداقت (Tensile Strength) بتزيد مع زياده strain rate
- شداق درجه حراري عاليه $\leftarrow$ الشداق قليله
- لكن مع زياده strain rate $\leftarrow$ شداق بتزيد
- كلما انخفضت درجه الحرارة $\leftarrow$ بتزيد الشداق
- لكن مع زياده strain rate $\leftarrow$ شداق بتزيد
- اعمد $\leftarrow$ بتزيد باره $\leftarrow$ slope

2.2.8 Hydrostatic pressure.

- Ductility increase under hydrostatic pressure.
- used for forming Brittle materials to increase Ductility.
- Zinc has higher ductility than alloys (Copper, aluminum)

2.3 Compression.

$$\epsilon_{eng} = \frac{-\Delta L}{L_0}, \quad \epsilon_{true} = \frac{-\Delta V}{V_0}$$

$$e = \frac{\Delta h}{h_0} \rightarrow -ve, \quad E = \ln\left(\frac{h}{h_0}\right) = \ln(\text{value}) \rightarrow -ve$$

$$\dot{\epsilon} = \frac{-\dot{V}}{V_0} \rightarrow \dot{\epsilon} = \frac{-\dot{V}}{V} \rightarrow \dot{\epsilon} = \frac{-\dot{V}}{V}$$

2.11: yield criteria

- Materials are subjected to biaxial or triaxial stresses:

1- Biaxial:

- Stress is applied in 2 perpendicular directions
- Typical in Thin plates or surfaces (Metal sheets under pressure)

Stress components:

- 2 non zero Principal stresses (σ_1, σ_2)

- 3rd principal stress (σ_3) is neglected or zero.

eg: A flat plate subjected to tension in both the x and y directions.

2- Triaxial:

- Stress is applied in 3 mutually perpendicular directions.

- Typical in deep drawing in sheet metals and in drawing of a rod or wire through a conical die.

* Strain eqn: in elastic range, generalized Hooke's law.

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

* $\nu \rightarrow$ Poisson ratio.

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

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

* For simple tension where $\sigma_2 = \sigma_3 = 0$

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

$$\epsilon_2 = \epsilon_3 = -\nu \frac{\sigma_1}{E} \rightarrow \text{the negative sign indicates a contraction of the element in the lateral dimensions.}$$

* in a simple tension or compression test when the applied stress reaches the uniaxial yield strength σ_y , the material will deform plastically.

2.11.1: Maximum-shear-stress criterion.

Tresca criterion

Def: is a yield criterion used in material mechanics to predict when a ductile material will begin to yield plastically deform under complex loading.

- yielding begins when the maximum shear stress in a material reaches the maximum shear stress in a simple tension test

$$\left[\frac{\sigma_1 - \sigma_3}{2} \right]_{\max} = \frac{\sigma_y}{2}$$

⇒ Maximum shear stress $\Rightarrow \tau_{\max}$

$$\left[\frac{\sigma_1 - \sigma_3}{2} \right]_{\max} = \frac{\sigma_y}{2}$$

* According to the Tresca criterion, yielding occurs when

$$\tau_{\max} \geq \tau_{\text{yield}} = \frac{\sigma_y}{2}$$

$$\tau_{\max} \geq k$$

$\tau_{\text{yield}}, k \Rightarrow$ shear yield strength.

$\sigma_y \Rightarrow$ yield strength of the material in uniaxial tension.

* The principal stresses and their directions can be determined from Mohr's circles for stresses.

$\Rightarrow$ the max-shear-stress criterion can be written as:

$$\sigma_{\max} - \sigma_{\min} \geq \sigma_y \rightarrow \text{at this point yield occurs.}$$

2.11.2 :: Distortion-Energy Criterion.

Von Mises criterion:

Def: is a widely used method for predicting the onset of yielding in ductile materials under complex loading conditions.

- Yielding occurs when the relationship between the principal stresses and uniaxial yield strength σ_y of the material is:

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

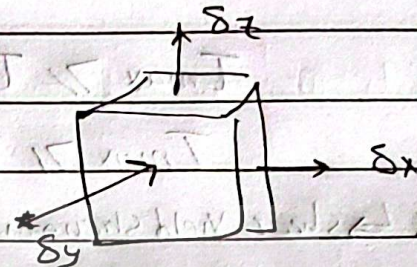
ex: Does yield occur in this situation if the Material follows Maximum-shear-stress?

if $\gamma = 300 \text{ MPa}$

$\sigma_z = 200 \text{ MPa}$

$\sigma_x = 300 \text{ MPa}$

$\sigma_y = -250 \text{ MPa}$



Yield occurs in Tresca when $\sigma_{max} - \sigma_{min} \geq \gamma$.

$$\sigma_{max} = \sigma_x = 300 \text{ MPa}$$

$$\sigma_{min} = \sigma_y = -250 \text{ MPa}$$

$$300 - (-250) = 550 \geq 300$$

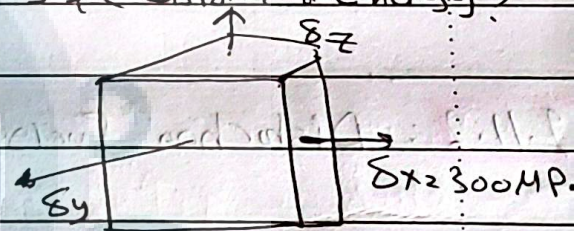
Yield occurs.

Quiz: Find σ_y for yielding to take place using the distortion Energy?

if: $\gamma = 500 \text{ MPa}$.

$\sigma_x = 300 \text{ MPa}$

$\sigma_z = 200 \text{ MPa}$.



$$\sigma_1 = \sigma_x, \sigma_2 = \sigma_y, \sigma_3 = \sigma_z$$

$$(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 = 2\sigma_y^2$$

$$(300 - \sigma_y)^2 + (\sigma_y - 200)^2 + (200 - 300)^2 = 2(500)^2$$

$$90000 - 600\sigma_y + \sigma_y^2 + \sigma_y^2 - 400\sigma_y + 40000 + 10000 = 50000$$

$$2\sigma_y^2 - 1000\sigma_y + 360000 = 0 \Rightarrow \sigma_y^2 - 500\sigma_y - 180000 = 0$$

$$\sigma_y = 742.44 \text{ MPa}$$

$$\sigma_y = \frac{-(-500) \pm \sqrt{500^2 - 4(1)(-180000)}}{2(1)} \Rightarrow \sigma_y = -242.44 \text{ MPa}$$

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

$$300 - (-242.44) = 542.44 \geq 500$$

Yield occurs

2.11.3. plane stress and plane strain.

- Plane stress is only in 2-dimension (Biaxial) and the third stress is zero, and same for plane strain.

plane stress

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

plane strain

 $(\epsilon_1, \epsilon_2, 0)$ $(\epsilon_1, 0, \epsilon_2)$ $(0, \epsilon_2, \epsilon_3)$

Plane stress و Plane strain کے لیے

Uniaxial stress کے لیے

Plane strain و stress کے لیے

Chapter 6: Bulk deformation processes

Subject

Date

No.

Intro:

Classifications of metal forming processes:-

① According to sequence in operations.

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

eg:- Forming for large cast ingots.

b- secondary processes: intermediate or final processes.

② According to processing Temp.

* Homologous Temp. (T_H or H_T)

$$T_H = \frac{\text{Processing Temp (}^\circ\text{K)}}{\text{Melting Temp (}^\circ\text{K)}}$$

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

- Requires high levels of force and energy (high strength at lower temp).

- produces high mechanical properties (strain hardening)

- limited formability (lower ductility at lower temps.)

- produces good surface finish and dimensional accuracy.

- Mostly final processing.

b- if $T_H > 0.5$: Hot Forming (Hot working)

- Requires low levels of force and energy (Lower strength at higher temp).
- Produce low mechanical properties. (No strain hardening)
- High formability (Higher ductility at higher temps.)
- Produces poor surface finish and dimensional accuracy (oxidation)
- Mostly primary processing.

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

- its properties are in between the cold and hot forming.

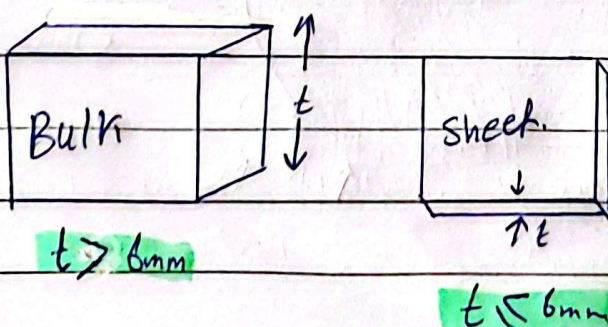
③ According to Strain work piece geometry.

a- Bulk forming processes : Metal forming processes

involving work pieces with relatively low surface-area-to-thickness ratios.

b- Sheet Metal forming processes : Metal forming processes

involving work pieces with relatively high surface-area-to-thickness ratios.



if the surface area divided by the thickness :

↳ Bulk : Very small ratio

↳ sheet : very high ratio

$t \propto$ thickness

6.2: Forging

* 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.

6.2.1: open-Die Forging

↳ (open) : because the die is open for the material to expand.

* open-Die forging typically involves hot working and large deformations. using simple tools as - Flat dies - Rounded sections - punches/saddles

④ Upsetting in open-Die Forging:

Def: upsetting is the process of reducing the height (or length) of a cylindrical workpiece while increasing its diameter by applying compressive force axially.

① Uniform Upsetting (Homogeneous deformation) :

- The work piece deforms evenly along its length, and the diameter increases uniformly across the entire face. (ideal case).
- Because the volume of the cylinder remains constant in plastic deformation, any reduction in its height causes an increase in diameter.
- conditions for uniform upsetting:
 - Low friction between the workpiece and the die (well-lubricated)
 - Short height-to-diameter (H/D) ratio.
 - Homogeneous material properties.
 - Proper alignment of dies and work piece.

②

b- if $T_H > 0.5$: Hot Forming (Hot working)

- Requires low levels of force and energy (lower strength at higher temp).
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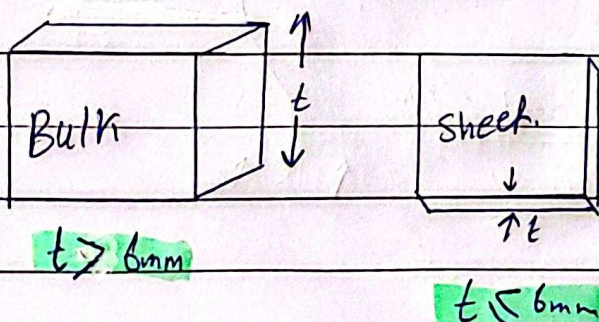
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- Homogeneous material properties.

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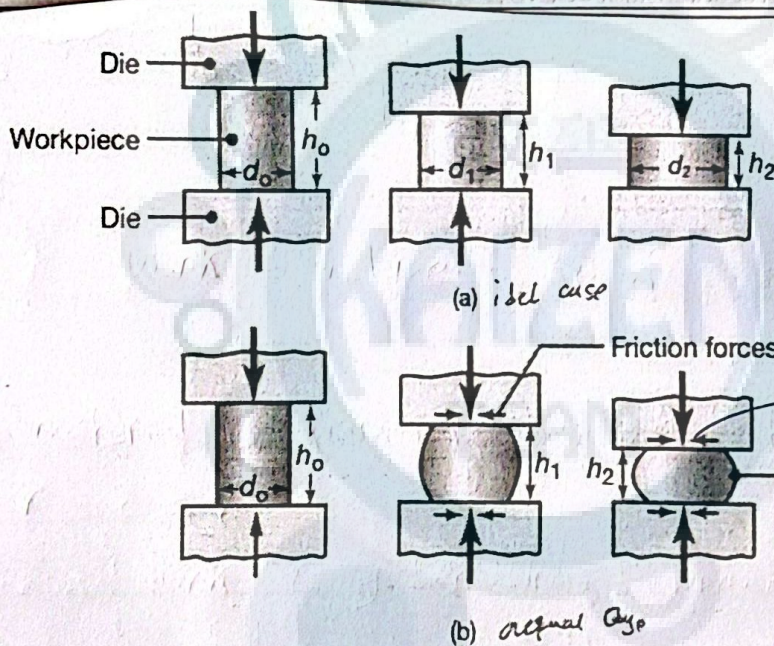
② Non-uniform upsetting: (actual case).

- Deformation is uneven, material doesn't flow uniformly leading to distortions like barreling or buckling.

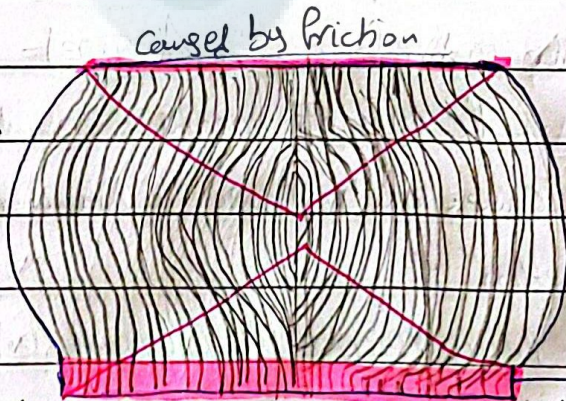
Types of non uniform upsetting

⇒ Barreling: - The middle bulges outwards more than the ends

- Caused by high friction between die and the work piece, which restricts flow at the ends.



Grain Flow lines in
upsetting, cylindrical
steel 8-



لا تقا القطة من تحت يتصلص او plate لغزة بجاذبي لا بها جبرود ياتس لا multi length / strength ومانع من شكلها
بشر انجذابا به بائي اسخت او plates بين صفة لنفس در به مارد القطة

⊕ Reduction in height

$$\text{Reduction in height} = \frac{h_0 - h_1}{h_0} \times 100\%$$

⊕ engineering strain

$$e_1 = \frac{h_0 - h_1}{h_0}$$

⊕ true strain

$$e_1 = \ln \left(\frac{h_0}{h_1} \right)$$

⊕ Strain rate

$$\dot{e}_1 = - \frac{\dot{V}}{h_0}$$

$$\dot{e}_1 = - \frac{\dot{V}}{h_1}$$

⊕ Forces and work of deformation under ideal conditions

- Friction at the work piece - die interfaces is zero
- material is perfectly plastic
- compressive stress on the specimen is uniform.

$$F = S_y A_1 \quad A_1: \text{cross sectional area}$$

Volume constancy

$$A_1 = \frac{A_0 l_0}{l_1}$$

$$\text{work} = \text{volume} \int_0^{\epsilon_1} \sigma d\epsilon$$

⊗ the material is strain hardening with a true stress - true strain curve
or $\sigma = K \epsilon^n$

Force and work at any stage during deformation

$$F = \sigma_f A_1 \quad \sigma_f: \text{flow stress}$$

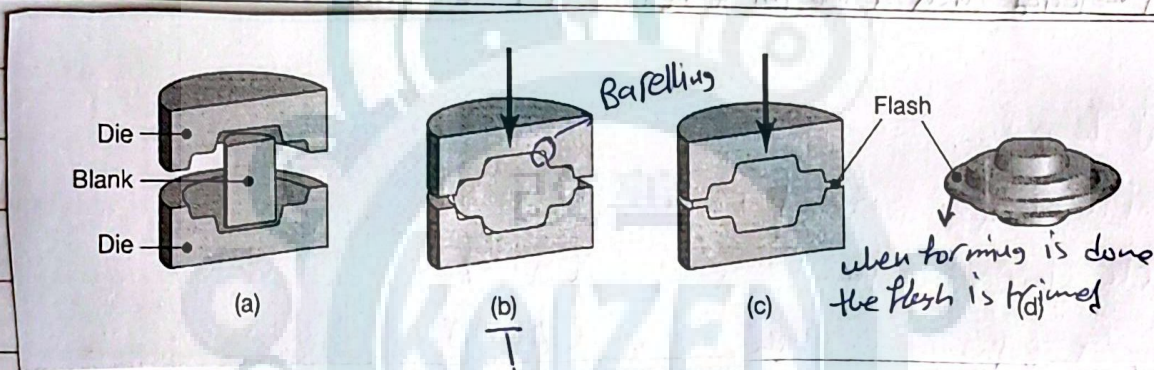
$$\text{work} = \text{volume} (\bar{\sigma}_f) (\epsilon_1) \quad \bar{\sigma}_f: \text{avg. flow stress}$$

$$\bar{\sigma}_f = \frac{K \epsilon_1^n}{n+1}$$

6.2.3 & Types of Forging

① Impression - die Forging

- work piece Volume larger than die-cavity volume.
- Used for relatively complex shapes with fine details.
- Mostly hot (but mainly cold) and final processing.
- requires highest levels of force and energy levels among forging operations.



when forming is done the flash is trimmed

metal of low will not be smooth in the details

- purpose of the Flash

- ① to force the metal to flow in fine details
- ② to prevent direct contact between Die- plates so it doesn't brake or deform

* when flash begins to form. High increase in load and very low increase in forging force.

graph page 316

* when dies are closed forging is complete the flash is trimmed.

* Forging force

$$F = K_p S_p A$$

K_p Pressure-Multiplying Factors

F Forging force

S_p Flow stress

A Projected area of the forging (including the flash)

$\Rightarrow$ K_p values:

$\rightarrow$ Simple shapes, without flash (3-5)

$\rightarrow$ Simple shapes, with flash (5-8)

$\rightarrow$ Complex shapes, with flash (8-12)

② precision forging

③ closed-die forging

Die cavity volume = workpiece volume.

④ isothermal forging

⑤ incremental forging

6.2.4: Miscellaneous forging operations:

1- Coining

2- Heading → Page 318

3- Piercing

4- Hubbing

5- Cogging

6- Fullering and edging

7- Roll forging → Page 320

8- Skew rolling

6.2.8: Equipment

① presses

a) Mechanical presses

b) screw presses

c) Hydraulic presses

d) servo presses

② hammers

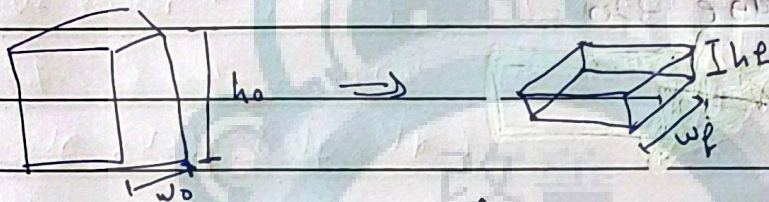
- Count blow hammers.

③ High-energy-rate forging machines.

6.3 : Rolling

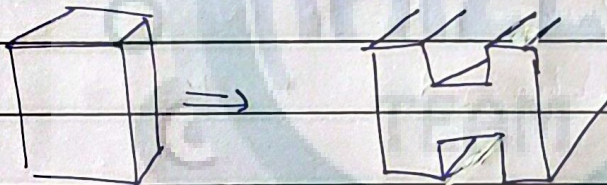
Def: Rolling is the process of reducing the thickness or changing the cross section of a long workpiece by compressive forces applied through a set of rolls.

① Flat Rolling is reduce thickness only



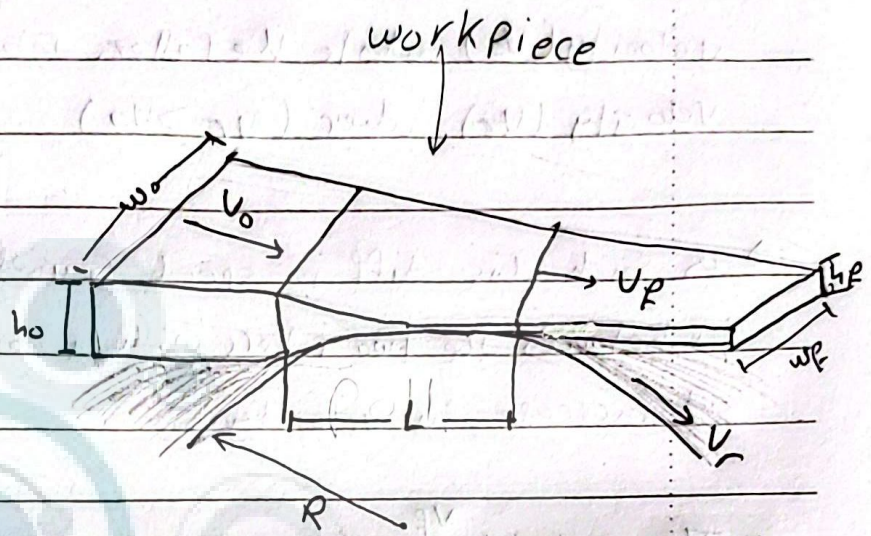
$$w_0 = w_f$$

② Shape Rolling is produce structural sections (I Beams, channels, ...)



① Flat rolling process

Figure 6.28



h_0 : initial height of w/p in mm

h_f : final " " " " " "

R : Roll radius in mm

α : Entry angle in Rad

v_0 : initial or entry velocity in m/s

v_f : final or exit " " " "

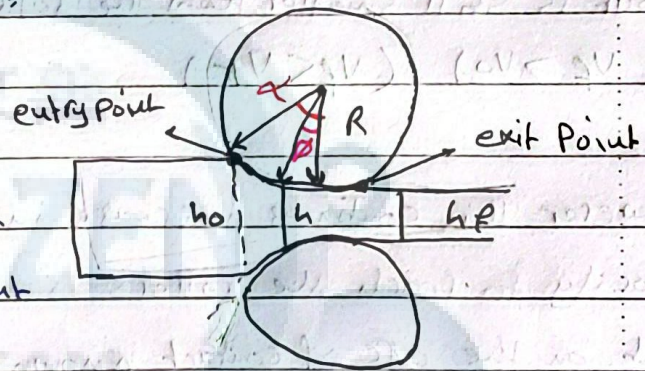
v_r : Roll's surface velocity (m/s)

L : length of contact

ϕ : any angle on the contact

arc that corresponds to height

" h "



notes:

→ $v_r > v_0$

→ $0 \leq \phi \leq \alpha$

→ h is the height at any point in the contact area.

→ α is the angle of entry and exit of the workpiece.

⇒ initially the w/p approaches the rollers at a constant initial velocity (V_0) while the rollers rotate at a constant surface velocity (V_r) where ($V_r > V_0$)

⇒ as such this diff in speed causes the material to squeeze in between the two rollers with a corresponding reduction in height and increase in velocity.

⇒ The material velocity is larger than its initial velocity but is still smaller than the rollers' surface velocity ($V_p > V_0$), ($V_p < V_r$)

⇒ However, this continuous increase in velocity causes the material's velocity to reach the rollers' surface velocity (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 where friction forces are reversed in direction leading to a phenomenon known as forward slip.

⇒ The zone between the entry point and the neutral point is known as the neutral zone and the zone between the entry point and exit point is known as the exit zone

⊛ Neutral point: Some point on the material where $V = V_r$

$$(*) \text{ Volume} \Rightarrow \frac{dL_0}{dt} \cdot h_0 = \frac{dL}{dt} \cdot h$$

$$V_0 \cdot h_0 = V \cdot h$$

$$\frac{V}{V_0} = \frac{h_0}{h} \Rightarrow V > V_0$$

$$h_0 > h$$

(*) 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. happens only in the exit zone.

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

Equations:

$$(*) h = h_f + 2R(1 - \cos \phi) \rightarrow \text{Both give the same answer}$$

$$h = h_f + R \phi^2 \rightarrow \phi \text{ must be in rad}$$

h decrease, σ_p increase $\rightarrow h_f$: final thickness of the strip.
due to cold working.

$$(*) H = 2 \sqrt{\frac{R}{h_f}} \tan^{-1} \left(\sqrt{\frac{R}{h_f}} \phi \right) \rightarrow H: \text{theoretical variable} \quad \text{تجربی اعتبار ندارد}$$

$$\rightarrow \phi: \text{must be in rad.}$$

neutral point is

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

⊗ Rolling pressure

L, entry zone

$$P = \sigma'_p \frac{h}{h_0} e^{\mu(H_0 - H)}$$

→ μ : Coef. of friction

→ exit zone

$$P = \sigma'_p \frac{h}{h_f} e^{\mu H}$$

between the material and the roll

$$\textcircled{*} H_n = \frac{1}{2} \left(H_0 - \frac{1}{\mu} \ln \left(\frac{h_0}{h_f} \right) \right) \rightarrow n: \text{neutral point.}$$

$$\textcircled{*} \phi_n = \sqrt{\frac{h_f}{R}} \tan \left(\frac{H_n}{2} \sqrt{\frac{h_f}{R}} \right) \rightarrow n: \text{neutral point.}$$

important notes:

→ at entry, $\phi = \alpha$, $H = H_0$, $P = \sigma'_p$ → at exit, $\phi = 0$, $H = H_f = 0$, $P = \sigma'_p$ → σ'_p = flow stress in plane strain conditions.⇒ Plane strain conditions 2 3 $\in$ one of them is equal to zero.

$$\rightarrow \sigma'_p = \frac{2}{\sqrt{3}} \sigma_p = 1.15 \sigma_p; \text{ if } \sigma = K \epsilon^n \text{ then } \sigma_p = K \bar{\epsilon}^n$$

ex: if $h_0 = 100 \text{ mm}$, $h_f = 80 \text{ mm}$, $R = 250 \text{ mm}$, $S = 500 \text{ E}^{0.5} \text{ MPa}$
 $\mu = 0.5$

if the Material follow Mss criteria find roll pressure at neutral Point

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

$$E_1 = E_n \text{ : height}$$

$$S = 500 \text{ E}^{0.5} \Rightarrow S_f = 500 \text{ E}^{0.5}$$

$$E_2 = E_w \text{ : width}$$

$$\bar{E} = \frac{2}{3} (E_3 - E_1)$$

$$E_3 = E_L \text{ : length.}$$

$$E_n = \ln\left(\frac{h_f}{h_0}\right) = \ln\left(\frac{80}{100}\right) = -0.223$$

$$E_L \Rightarrow E_n + E_w + E_L = 0$$

$$E_L = 0.223$$

$$\Rightarrow \bar{E} = 0.297$$

$$S_f = 500 (0.3)^{-0.5}$$

$$S_f = 273.8 \Rightarrow S_f = 1.15 S_f = 314.87$$

$$H_n = \frac{1}{2} \left(H_0 - \frac{1}{\mu} \ln\left(\frac{h_0}{h_f}\right) \right)$$

$$H_0 = 2 \sqrt{\frac{R}{h_f}} \tan^{-1} \left(\sqrt{\frac{R}{h_f}} \phi \right) \quad \phi = \alpha \text{ at entry.}$$

$$h_0 = h_f + 2R(1 - \cos \alpha)$$

$$100 = 80 + 2(250)(1 - \cos \alpha)$$

$$\alpha = \phi = 0.28 \text{ rad}$$

$$H_0 = 2 \sqrt{\frac{250}{80}} \cdot \tan^{-1} \left(\sqrt{\frac{250}{80}} \cdot 0.28 \right)$$

$$= 1.625$$

$$H_n = \frac{1}{2} \left(1.625 - \frac{1}{0.5} \cdot \ln \left(\frac{100}{80} \right) \right)$$

$$= 0.589$$

$$h_n = h_f + R \phi_n^2$$

$$\phi_n = \sqrt{\frac{h_f}{R}} \cdot \tan \left(\frac{H_n}{2} \sqrt{\frac{4R}{h_f}} \right)$$

$$\Rightarrow \phi_n = 0.095 \text{ rad}$$

$$= \sqrt{\frac{80}{250}} \cdot \tan \left(\frac{0.59}{2} \sqrt{\frac{80}{250}} \right)$$

$$h_n = 80 + 250 (0.095)^2$$

$$h_n = 82.125 \text{ mm}$$

$\Rightarrow$ at entry zone

$$P_n = \frac{\sigma_f h_n}{h_f} e^{0.5(H_0 - H_n)}$$

$$= \frac{314.87 \cdot 82.25}{80} \cdot e^{0.5(1.625 - 0.59)}$$

$$P_n = 540 \text{ MPa}$$

$\Rightarrow$ at exit zone

$$P_n = \frac{\sigma_f h_n}{h_f} e^{0.5 H_n}$$

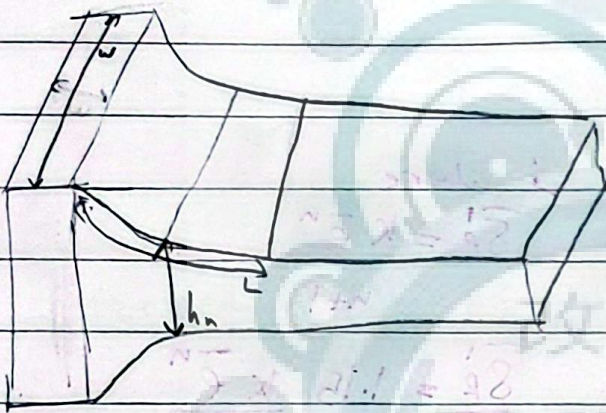
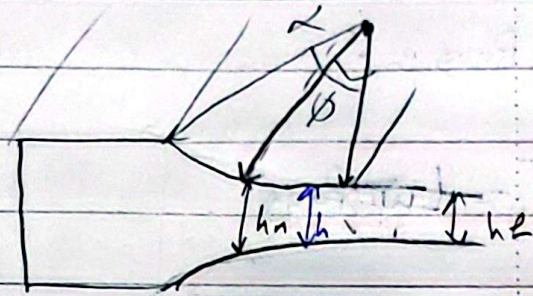
$$P_n = \frac{314.87 \cdot 82.25}{80} \cdot e^{0.5(0.59)}$$

$$P_n = 434.8 \text{ MPa}$$

Must be close from each other.

Notes:

- $h < h_n \rightarrow$ use exit eqn
- $h > h_n \rightarrow$ use entry eqn
- $\phi < \phi_n \rightarrow$ exit eqn
- $\phi > \phi_n \rightarrow$ entry eqn.



* Roller causes pressure on the material in the contacted area

* P varies from point to point (not constant) → P varies from point to point (not constant)

$$F = P \cdot A$$

$$dF = P \cdot dA \quad ; \quad dA = w \cdot dL$$

$$; \quad dL = R \cdot d\phi$$

$$\Rightarrow dF = P \cdot \underbrace{w \cdot R}_{\text{constant}} \cdot d\phi$$

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

P_{entry}

P_{exit}

→ $h = f(\phi)$

$$h = f(\phi)$$

Function of ϕ

$$0 < \phi < \alpha$$

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

Subject

for P_{avg} :

$$F = L w P_{avg}$$

$$\Rightarrow L = \sqrt{R D_h} \quad \text{for length}$$

⊕ low Praction conditions

$$F = L w \bar{\sigma}_p'$$

⊕ high Praction conditions

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

where

$$\bar{\sigma}_p = k \bar{\epsilon}^n$$

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

avg flow stress in plane strain conditions.

Ex: Continue of previous example assume $w=400\text{ mm}$, $\bar{\sigma}_p = 314\text{ MPa}$

Find F at low Praction and high Praction

$$\bar{\sigma}_p' = \frac{314}{1+1.5} = 209\text{ MPa}$$

$$L = \sqrt{R D_h} = 0.07\text{ m}$$

$$\begin{aligned} F_{low} &= L w \bar{\sigma}_p' \\ &= 0.07 \times 400 \times 209 \\ &= 5852\text{ kN} \end{aligned}$$

$$h_{avg} = \frac{100 + 60}{2} = 90\text{ mm} = 0.09\text{ m}$$

$$\begin{aligned} F_{high} &= L w \bar{\sigma}_p' \left(1 + \frac{\mu L}{2 h_{avg}} \right) \\ &= 0.07 \times 400 \times 209 \left(1 + \frac{0.5 (0.07)}{2 \times 0.09} \right) \\ &= 8127.7\text{ kN} \end{aligned}$$

⊛ Roll torque and power.

$$T = \int_{\phi_n}^{\infty} w \mu p R^2 d\phi \ominus \int_0^{\phi_n} w \mu p R^2 d\phi$$

Because of friction forces.

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

Torque Per roll

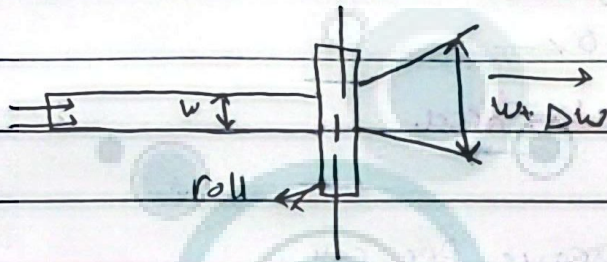
$$\text{Power} = Tw = \frac{fLw}{2} = \frac{\pi fLw}{60'} \quad \text{Power required per roll}$$

$w \rightarrow \omega \rightarrow \text{السرعة الزاوية} \rightarrow \text{Angular velocity} \rightarrow \boxed{\text{rad/sec}}$

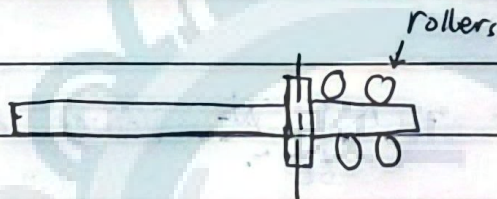
$N \rightarrow \text{the roll speed in } \boxed{\text{Revolutions/min}}$

⑧ Types of defects in rolling

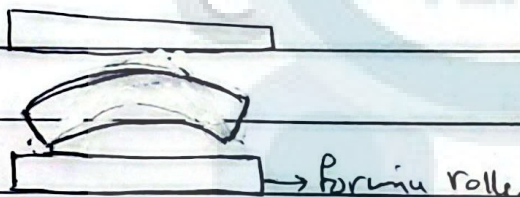
① Spreading & increase in width in flat rolling



Sol & use side rollers



② Camber: a measure to correct the lack of flatness from the rolls



Sol &

- 1- Roll alignment
- 2 Roll bending
- 3- Tension leveling.

6.3.2 : Defects in Rolled products. → داخل الامتحان بين السطور مباشرة

① Surface defects.

- Caused by impurities, rust, dirt, scale, or prior treatments.
- also arise from roll marks or poor surface conditions of the material.
- Before rolling large metal pieces (blooms, billets, slabs), surfaces are usually cleaned or treated (scarfing with a torch) to reduce defects.

② structural defects

- Affect the material's internal quality and shape.

Common types :- Fig 6.36, Page. 340

a) wavy edges : Caused by uneven elongation where edges thin out more than the center, often from bending during rolling.

c) edge cracks : from poor material properties at the edges.

b) zipper cracks : Appear in the center due to low ductility or brittleness.

d) Alligatoring : A split that resembles an alligator's mouth, caused by uneven deformation or cooling defects.

⊛ Residual Stresses

- Form due to non-uniform deformation during rolling.
- Caused by small roll diameters or small reductions in thickness.

Fig 6.37 . Page 341

- a) Small rolls / thin reduction $\rightarrow$ compressive stress on surface, tensile in the center.
 - b) Large rolls / heavy reduction $\rightarrow$ tensile stress on surface, compressive inside.
- These stresses can reduce product performance and must be managed in design and process.

6.3.5: Miscellaneous Rolling operations.

Ring Rolling

- Stage 1: Blooming rolls
- Stage 2: Edging rolls
- Stage 3: Roughing horizontal and vertical rolls.
- Stage 4: Intermediate horizontal and vertical rolls.
- Stage 5: Edging rolls.
- Stage 6: Finishing horizontal and vertical rolls.

6.4: Extrusion.

Procedure: 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.

⇒ Final shape after extrusion must have a fixed C.S along the product

Types of extrusion:

a) Direct or Forward:

- Continuous process
- Metal flow direction the same as the ram / pressing stem direction.
- Main friction is due to the relative motion between the container and Billet.

Diameter of Billet < Diameter of container.

So it's close to the open die forging. therefore very high friction occurs.

b) Indirect or Reverse:

- not continuous.
- Metal flow is in the opposite direction of the ram
- Billet is stationary there fore no relative motion between the Billet and container.

c) Hydrostatic:

- used for very brittle materials.
- hydrostatic pressure increase the ductility.
- no direct contact between the ram and the w/p, they have fluid in between.
that gives a very high pressure.

d) Impact:

- for extremely soft and ductile materials
- nearly close to the hammering process.

⑧ Extrusion Ratio:

$$R_e = \frac{A_0}{A_f} = \left(\frac{D_0}{D_f} \right)^2$$

$$A = \frac{\pi D^2}{4}$$

$$A = \pi r^2$$

6.4.1: Metal flow in extrusion.

- Metal flow depends on the amount of friction.
- extrusion $\rightarrow$ uniaxial stress system.
- we don't calculate $\bar{\epsilon}$, $\bar{\sigma}$.
- it's a uniform elongation therefore a uniform cross section.

⑧ Conditions of extrusion:

1- Ideal force, no friction (perfectly plastic, no friction)

⑧ true strain.

$$\epsilon_1 = \ln \left(\frac{A_0}{A_f} \right) = \ln \left(\frac{L_f}{L_0} \right) = \ln(R_e)$$

* Energy dissipated in plastic deformation per unit volume.

$$u = S_y \epsilon_1$$

note:

$S_y, S_y = y \Rightarrow$ yield strength.

* work

$$\text{work} = A_0 L_0 u$$

$$\text{work} = F L_0 = P A_0 L_0$$

L_0 : Billet length.

P : extrusion pressure.

* $P = u$ only in perfectly plastic, no friction.

$$P = u = S_y \ln\left(\frac{A_0}{A_f}\right) = \ln(R_e)$$

$\Rightarrow$ equal to the area under true stress-strain curve.

* Ideal force

$$F = P \cdot A_0$$

Note:

in strain hardening (not perfectly plastic) S_y must be replaced by $\bar{S}_p$

2. Ideal force with friction

$$\cot(\alpha) = \frac{\cos(\alpha)}{\sin(\alpha)}$$

⑧ Extrusion Pressure (when perfectly plastic)

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

α : die angle
 μ : friction coef.

Special Case 2: The Material flow along a 45° "die angle"
then the extrusion pressure

$$P = S_y \left(1.7 \ln R_e + 2 \frac{L}{D_o} \right)$$

⑧ Extrusion Pressure when strain hardening

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

units:

Power = $N \cdot m/s$ = energy/time = watt (= $F \cdot \overset{\text{velocity}}{v}$)

energy = $N \cdot m$ = Power · time = watt · time (= $F \cdot L_o$)

energy, MoR · volume.

work = $F \cdot L_o = P \cdot A_o L_o$ = Joule.

$U = J/m^3$

Pressure = Pascal / MPa.

ex: $D_o = 100 \text{ mm}$, $D_p = 80 \text{ mm}$, $\mu = 0.5$, $\alpha = 15^\circ$, $\delta = 300 \text{ MPa}$ n
5.5

ram speed = 100 mm/min . $\bar{\sigma}_p$ ✓

Find extrusion pressure and power required for the process.

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

$$\bar{\sigma}_p = \frac{K \bar{\epsilon}^n}{n+1} = \frac{300 \text{ MPa}}{n+1} = \frac{300 (0.44)^{0.5}}{1+0.5} = 132.66$$

$$\bar{\epsilon} = 2 \ln \left(\frac{D_o}{D_p} \right) = 2 \ln \left(\frac{100}{80} \right) = 0.44$$

$$R_e = \frac{A_o}{A_p} = \left(\frac{D_o}{D_p} \right)^2 = \left(\frac{100}{80} \right)^2 = 1.56$$

$$P = 132.66 \left(1 + \frac{\tan 15}{0.5} \right) \left[1.56^{0.5 \cot 15} - 1 \right]$$

$$\cot 15 = \frac{\cos 15}{\sin 15} = 3.73$$

$$P = 263.2 \text{ MPa}$$

$$\text{Power} = F \cdot V = P \cdot A_o \cdot V$$

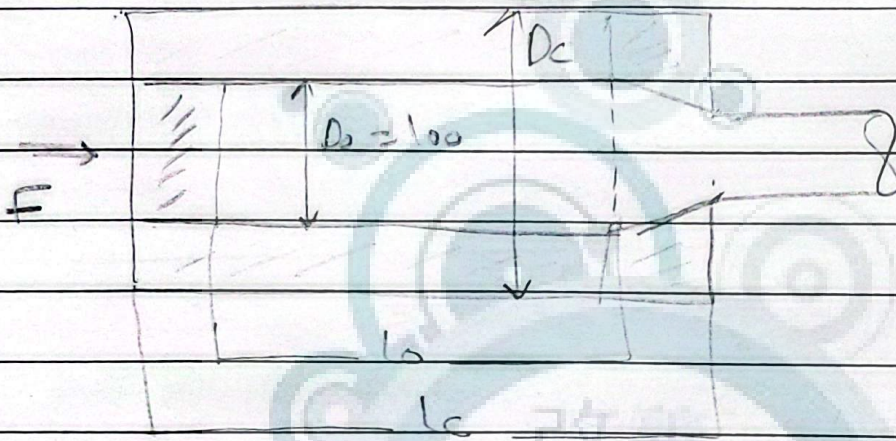
$$= 263.2 \times 10^6 \times \frac{\pi}{4} (0.1)^2 \times \frac{0.1}{60}$$

$$= 3445 \text{ watt}$$

Ex: $D_o = 100 \text{ mm}$, $L_o = 500 \text{ mm}$, $L_c = 600 \text{ mm}$.

For container material; $\gamma = 400 \text{ MPa}$, $E = 200 \text{ GPa}$.

Find the container's diameter so that it can absorb the whole process without experiencing any plastic deformation.



$$MOR = \frac{\gamma^2}{2E} = \frac{(400 \times 10^6)^2}{2(200 \times 10^9)} = 4 \times 10^5 \text{ J/m}^3$$

$$\text{energy} = MOR \cdot \text{Volume.}$$

6.5: Rod, wire, and Tube Drawing.

⇒ uniaxial system. don't calculate $\bar{\epsilon}$

6.5.1: Mechanics of Rod and wire drawing

- wire drawing is the only that has tensile stresses

The variables in determining the drawing stress are

- 1- Reduction in cross area.
- 2- die angle.
- 3- friction.

1- ideal deformation (frictionless)

⊕ drawing stress

Perfectly
plastic

$$\sigma_d = S_y \ln \left(\frac{A_0}{A_f} \right)$$

$$S_y = S_y$$

Perfectly plastic

$$\bar{\sigma}_p = S_y$$

Strain-
hardening

$$\sigma_d = \bar{\sigma}_p \ln \left(\frac{A_0}{A_f} \right)$$

⊕ drawing force

Strain
hardening

$$F = \bar{\sigma}_p A_f \ln \left(\frac{A_0}{A_f} \right)$$

Strain-hardening

Perfectly
plastic

$$F = S_y A_f \ln \left(\frac{A_0}{A_f} \right)$$

2- ideal deformation and friction.

$$\delta_d = \frac{S_y}{\tau} \left(1 + \frac{\tan \alpha}{n} \right) \left[1 - \left(\frac{A_f}{A_o} \right)^{n \cot \alpha} \right]$$

S_y for strain hardening.

Example 6.7

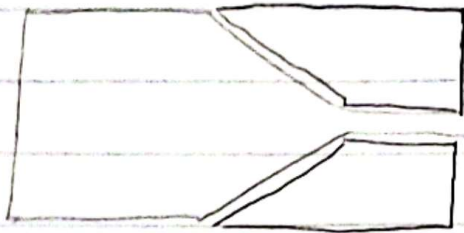
3- Maximum reduction per pass.

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

maximum value because it doesn't depend on ϵ

$$\frac{A_o}{A_f} = e$$

$$\text{Max reduction per pass} = \frac{A_o - A_f}{A_o} = 1 - \frac{1}{e} = 63\%$$


 D_f


$\sigma_d \leq \sigma_p$

no friction in this area.

- $\sigma_d \leq \sigma_p$ So no stretching will occur therefore actual $D_f < D_f$ after drawing.

• at the exit

$\sigma_d \leq \sigma_{p \text{ exit}}$

$$\sigma_d = \sigma_p \cdot \ln\left(\frac{A_0}{A_f}\right)$$

$$\frac{k \epsilon_1^n}{n+1} \cdot \epsilon_1 = \frac{k \epsilon_1^n}{n+1}$$

$$\frac{1}{n+1} \cdot \epsilon_1 = 1$$

$$\frac{\ln(A_0/A_f)}{n+1} = 1 \Rightarrow \frac{A_f}{A_0} = e^{-(n+1)}$$

Chapter 7: Sheet Metal Processes.

Subject

Date

No.

(*) important parameters that affect the sheet metal forming process:

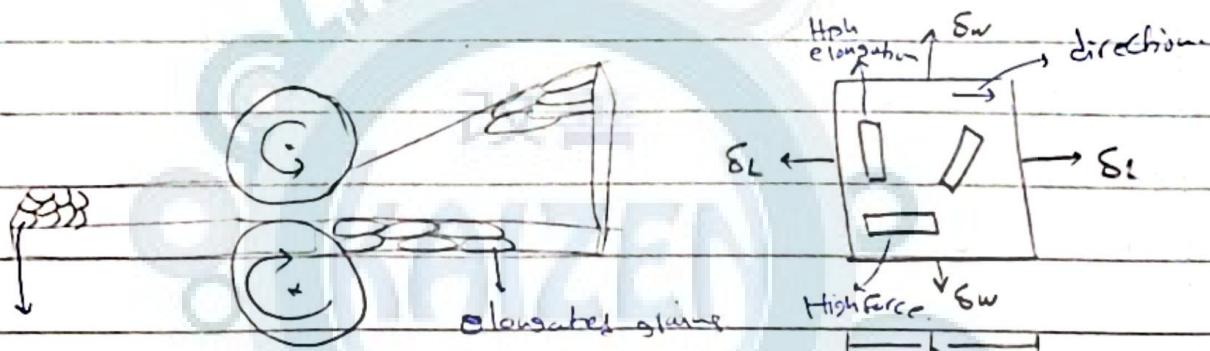
1- Yield point elongation: most commonly used low-carbon steels.

in sheet metals yield occurs in areas near to the force.

Figure 7.2 Page 395

2- Anisotropy, differences in property due to differences in directions

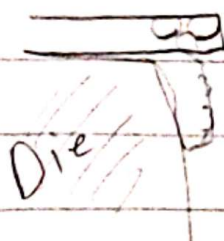
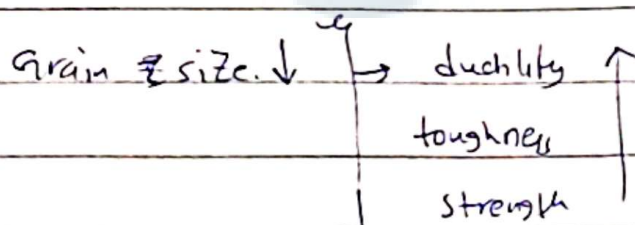
- Sheet metals are made by flat rolling



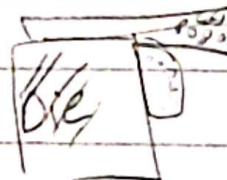
Grains are spherical

(equiaxed grain structure)

3- Grain size: larger grain size $\rightarrow$ more defects, known as (orange peel).



large grain size
rough surface.



small grain size
smooth surface.

4- Residual stresses: Inner stresses due to nonuniform deformation.

5- Spring back & elastic recovery in sheet metal.

Ratio of elastic strain to total strain in sheet metal is higher than it in Bulk

6- wrinkling: due to unsupported compressive stresses.

(Lack of support for sheet metal under compressive load)

7 Coated sheet: Most sheet metals are precoated with coatings, films, laminates.

its characteristics: flexibility, durability, hardness, resistance to abrasion and chemicals, color, texture, gloss