* Crystal Structure of Ionic materials:
Ionic material must have crystal structures that ensure electrical neutrality, yet ~~present~~ permit ions from the different sizes to be packed efficiently.

① Ionic Radii: the crystal structures of ionically bounded compound, is described by placing the anion of the normal lattice point cell and the cation located at one or more of the intransitial site.

② Electrical neutrality: the over all material have to be electrical neutral.

Allotropy: the ability of the element to exist more the one crystal structure depending on Temp. & pressure.

Polymorphism: Compound have more the one crystal structure.

Chapter 4

* "Crystals are like people it is the defect in them which tend to make them interesting" Colin Humphrey.

* Defect in Solids 0 D (zero), Point defect.
- Vacancies
- Intransitial,
- Impurities.

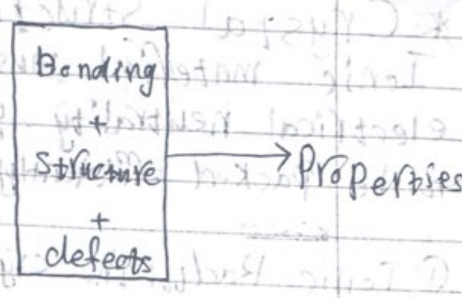
1-D: edge, screw, edge + screw

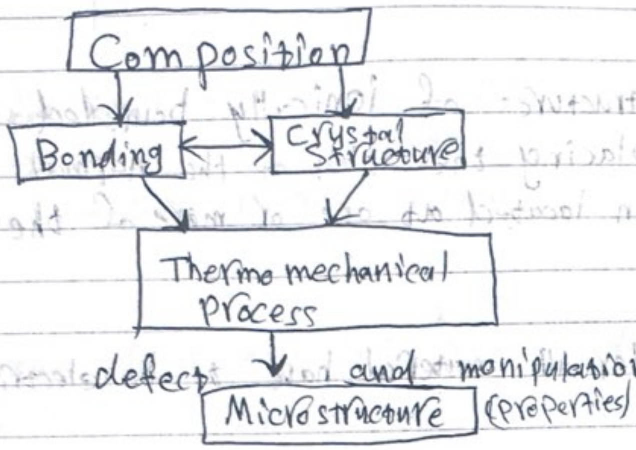
2-D: Surface defect

3-D: Volume defect

Defects:

The process determines the defects

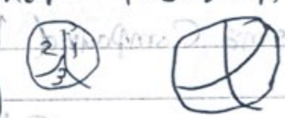




① Point defects: atoms missing or in irregular places

② 1-D: group of atoms in irregular position

③ 2-D: Interfaces between regions of material (grain boundaries)



④ 3-D: racks تشوه

Vacancies: is produced when an atom is missing from a normal site.

* the number of vacancies increas exponentially as increase the Temprature

$$n_v = n \exp\left(\frac{-Q}{RT}\right)$$

n_v: is the number of vacancies per m^3.

n: " " " " Lattice points " m^3.

Q: is the energy required to produces a vacancy in $J \cdot mol^{-1}$

R: is the gas Constant

$R = 1.987 \frac{Cal}{mol.K}$, $R = 8.314 \frac{J}{mol.K}$

T: Tempreture (K).

Ex: Copper

$Q = 83700 \ J.mol^{-1}$

Copper: FCC (Aluminum so too)

Lattice parameter = 0.36161 nm

suggest a heat treatment that will provide 1000 times more Vacancies in copper

$n = \frac{4 \text{ atoms/cell}}{(0.36161 \ nm)^3} = 84.6$ (Fcc) لأنه per m^3

$T = 25 + 273 = 298 \ K$ درجة حرارة الغرفة

$n_v = n \, e^{\left(\frac{-Q}{RT}\right)}$

$n_v = 8.46 \times 10^{28} \, e^{-\left(\frac{83700}{(8.314)(298)}\right)}$

$n_{v_1} = 1.8 \times 10^{13}$

$n_v = 1.774 \times 10^{14}$ Vaca/m^3

New $n_v = 1.774 \times 10^{17} = (\ ) \exp\left(\frac{-83700}{8.314 \, T}\right)$

$\Rightarrow T = 375 \ K = 100 \ C^\circ$

Ex: Calculate the # of Vacancies per cm^3 in copper at 1088c (Just below the melting Point temp). The activation energy for vacancy formation is 20000 Cal/mol.

$a = 3.6151 \times 10^{-8}$ cm

$n = \frac{4}{a^3}$, $n_v = 4.97 \times 10^{19}$ Vac/cm^3

التدرج في تغيير درجة الحرارة بأثر بالتبريد مهم جداً نازل بسرعة ولا بتبرد شوي شوي

Exp: The fraction of lattice points occupied by vacancies in solid AL at 660° is 10^{-3}. What is the activation energy required to create vacancies?

$n_v = n \exp\left(\frac{-Q}{RT}\right)$, $\frac{n_v}{n} = 10^{-3}$.

$Q = 12.800$ Cal/mol

Exp: ρ of a sample of an FCC metal is 11.98 g/cm³ and the lattice parameters is 3.8902 A°. Calculate: Atomic weight = 1.064 g/m
ⓐ the fraction of lattice points that contain vacancies.
ⓑ The total number of vacancies in cm³.

x: number of atoms real

ⓐ $\rho = \frac{(x)(1.064 \text{ g/mol})}{a_0 \text{ (Avogadro)}}$ 4 يكون FCC لو

$x = 3.9905$

$\text{fraction} = \frac{4 - 3.9905}{4} = 0.002375$

$\# \text{ of Vacancies} = \frac{0.0095 \text{ vacancy/uc}}{(a)^3}$

$= 1.61 \times 10^{20} \text{ Vac/cm}^2$

Exp: BCC metal has an $a = 3.5089 \times 10^{-8}$ cm and contains one vacancy per 200 unit cell. Calculate: Aw = 6.94 g/mol
ⓐ # of Vacancies/cm³.
ⓑ ρ.

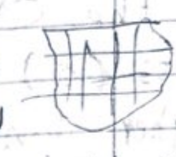
ⓐ $\frac{1 \text{ vac}}{200 (a_0)^3} = 1.157 \times 10^{20} \text{ Vaca/cm}^3$

ⓑ $\rho = \frac{(399/200)(6.94)}{(a_0)^3 \, A_v}$

Ex: anicloium alloy is produced by introducing tungston substational atoms in BCC structure eventually an alloy is produced that has an $a = 0.32554\ nm$ & $\rho = 11.95\ g/cm^3$, Calculate the fraction of the atoms in alloy that are tungeston.

برضو

$$11.95 = \frac{(x)(183.85) + (2-x)(92.91)}{(a_0)^3\ (Avog)}$$



اذا فش عندي انحراف لازم اللوب يتسكر

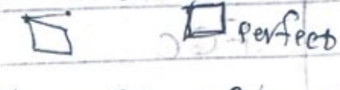
$x = 0.69$ atom/cell

البيرغر فاكتور بكون موجود لما مش مسكرة

مؤشر اديش في انحراف

2 atom per cell in BCC

هو عبارة عن الفراغ



$$frac = \frac{0.69}{2} = 0.345$$

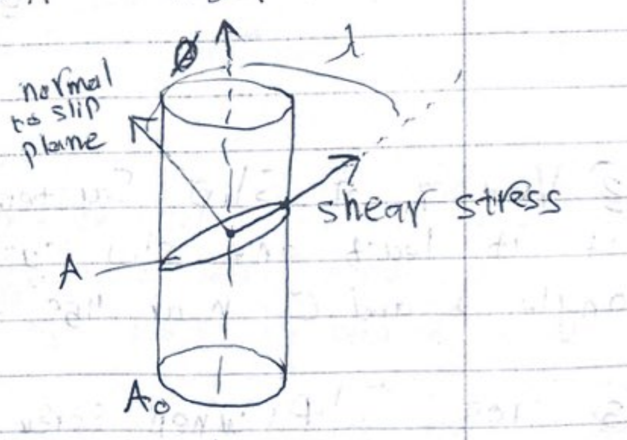
slide 20: الفورس هي ما تحرر ال edge او ال Screw

critical resolve shear stress:

Schmid's Law:

is used to understand the differences in behaviour of metals that have different crystal structures by examining the force required to initiate the slip process. من خلاله بعرف القوة اللي بتعمل slipping اما بتجاوزها

$f_r = f \cos\lambda$



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

$A = A_0 / \cos\phi$

$\tau_r = \sigma \cos\phi \cos\lambda$ (Schimod's Law)

$\tau_r = \frac{f_r}{A}$ = resolved shear stress in the slip direction.

$\sigma = \frac{f}{A_0}$ unidirectional stress

Dr. George Nasr

Influence of Crystal Structure: هون ستكون الدروس

① Critical Resolved Shear Stress (CRSS) يسوي البلشغ

* CRSS: The stress Required to cause dislocation to move and cause slip.

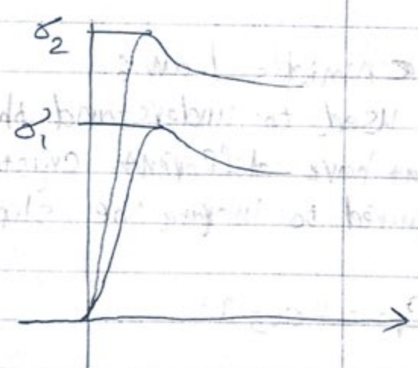
* If the CRSS in a metal is very high the applied stress (σ) must be high in order for τ_r to equal τ_{crss}. A higher τ_{crss} implies a higher stress to plastically deform metals where a higher strength.

اذا بدي اعمل تشكيل بلاستيك اكبر او يساوي

اذا مش ناوي اشكل بلاستيك اقل

BCC	FCC
higher strength	lower strength
ductility low	ductility high

لأنه في ذرات كثير عندي مرونة بقدر اسحب بدون كسر



Strain hardening التقوية بالسحب.

لما سحبناها زدنا القوة بس على حساب ال ductility

وصار عندي هشاشة عالية

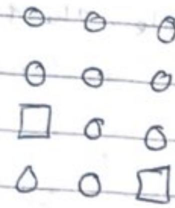
② Number of Slip System:

if at least one slip system is oriented to give the angle λ and ϕ near 45° then $\tau_r = \tau_{crss}$ at low stress

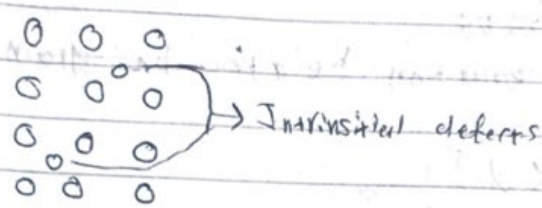
③ Cross Slip: when screw dislocation moving on one slip plane that encounters an obstacles and blocked from further movement

∴ the dislocation can shift to a second intersection slip section this is called cross slip. تذكر تصنيفها لتناسب مع السحب

Vacancy defects:



Intrinsitial defects:

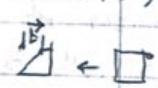


Burger Vector:

slide 27

If we follow a crystallographic plans one revolution around the axis on which the crystal is skewed, starting at point (X) and traveling equal atom spacing in each direction, we finish at point (Y) one atom below our starting point if the screw dislocatio not present the loop would be close.

The vector required to close the loop is called (Burger vector / b - Vector)



Importance of Defects:

1. effect on mechanical properties via control the slip process.

One imprefaction in the crystal raises the internal energy at the location of the improfaction.

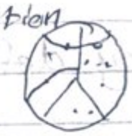
* the local energy increased because near the imprefuction the atoms either are squesed to closely (compresion or forced too far apart (tension).

2. Strain Hardings: هو اللي بخليني احل ← حب defects.
3. Solid solution strengthing. ذرات تنتقل من مكان لآخر لكن في المحاليل

one of the point defect also disrupt the perfecation of crystal structure solid solution is formed when atoms or ions are assiumlated completely into the crostal structure of the host material.

Toughness: the ability to absorb energy
Hardness: resistance of indentation
brittle: material has a little plastic deformation

④ grain size strengthening.



لما يصير

Surface Defects:

Hall-Petch equation Relates the grain size of the Y strength

$$\sigma_y = \sigma_0 + K d^{-\frac{1}{2}}$$

σ_y: Y. strength
d: is the average diameter of the grains.
σ_0, K are constant for material.

Specification of grain size:

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

N: number of grains per in^2 at magnification X100
n: ASTM grain size.

Ex: Copper 2 in alloy has the following prop.

grain diameter	strength	$d^{-1/2}$
0.015	170	8.165
0.025	159	6.325
0.035	151	5.345
0.05	145	4.472

Determine:
① the Constants in the Hall-Patch eq.
② the grain size required to obtain the strength of 200

① $K = 6.77$
$\sigma_0 = 114.7$

بتين بمعادلتين بطلع σ_0, K

② $200 = 114.7 + 6.77/\sqrt{d}$
$\Rightarrow d =$

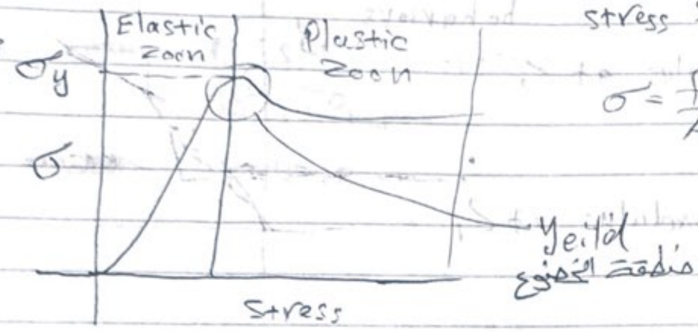
Chapter 6

Ductility: كل المساحة تحت المنحنى

brittle: Elastic بس

stress Strain curve

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



Engineering Stress: $\sigma = \frac{f}{A}$

Strain: $\varepsilon = \Delta L / L_o$ (x 100 %)

σ, ε (+) T

σ, ε (-)

Shear stress: $\tau = \frac{f}{A_o}$

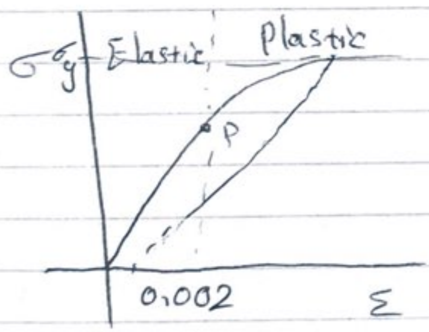
Shear strain: $\gamma = \tan\theta$ (x 100 %)

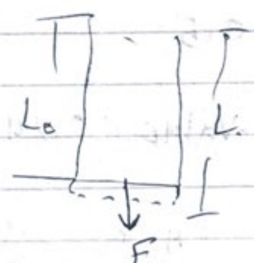
material: Brittle (صلبة، الترابط بين الجزيئات قوي) — Ductile

$\varepsilon_B > \varepsilon_D$

$\sigma_B < \sigma_D$

Stress - Strain behavior

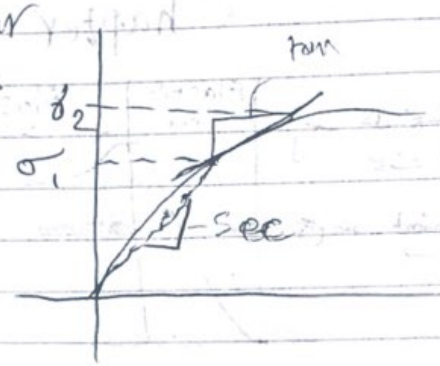




$\sigma = E\varepsilon$

Strain(ε): change in the Length , deflection $= \Delta L = L - L_o$

$\sigma = \frac{F}{A}$, $\frac{\delta}{L} = \epsilon$, $\sigma = E\varepsilon$ (σ: stress, E: specific for material modulus, ε: strain) non-linear behaviors



$\frac{\Delta \sigma}{\Delta \varepsilon}$ = tan modulus at σ_2

$\frac{\Delta \sigma}{\Delta \varepsilon}$ = Second modulus at σ_1

* Anelasticity: الوقت مهم في عملية السحب (المدة)
time dependence of elastic deformation.

* we have assumed that elastic deformation is time independent.
* But in reality deformation takes time (limit rate of deformation processes).
this time dependent elastic behavior is Known as anelasticity

* The effect is normally small for metals but it is significant for polymers

* Poisson's Ratio:

$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} = \frac{-\varepsilon_y}{\varepsilon_z}$$

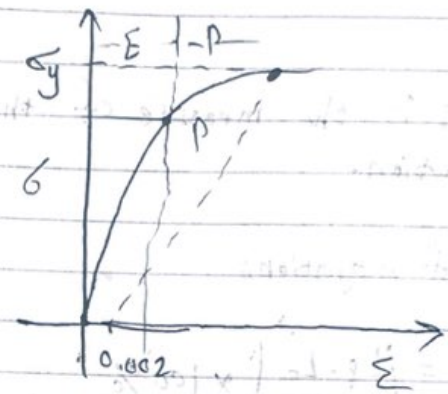
max = 0.5

Typical Value: 0.24 - 0.3

$\sigma_x = 0$ $\sigma_y = 0$ $\varepsilon_z \neq 0$ Plain stress plain strain ??

* Plastic Deformation:

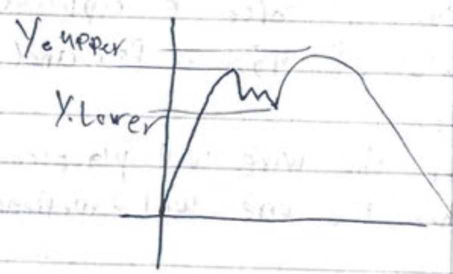
* Stress and strain are not proportional.
* the deformation is not reversible



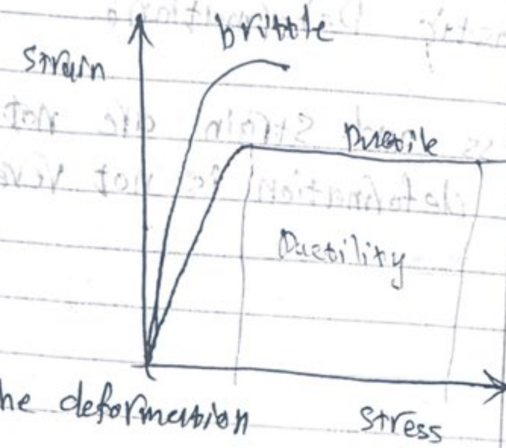
σy = Y. strength (yield): is chosen as that causing a permenant strain of 0.002.

P: Yeild Point: the strain devio from being proportional.

Y.S: is a measure of resistance to plastic deformation.



true stress : ال A اللي تقلصت مش ده



Ductility: is the measure of the deformation as fraction.

Percent of elogations:

$$\%EL = \left(\frac{L_f - L_o}{L_o}\right) \times 100\%$$

Percent reduction in area:

$$\%RA = \left(\frac{A_o - A_f}{A_o}\right) \times 100\%$$

Toughness: The ability to absorb energy up to fraction

Ex: A 850-lb force is applied to 0.15 in diameters nickel wire have Y.S of 45,000 Psi and tensile strength of 55,000 Psi Determine,

① whether the wire will plastically deform?
② whether the wire will experience necking
تعنق

necking framed from ductility

ⓐ $\frac{F}{A} = \sigma = 48,100$ Psi $> 45,000$ Psi
the wire will plastically deform.

ⓑ $48,100 < 55,000$
No necking will occur

Ex: A 3-in diameter rod of copper is to be reduced to a 2-in diameter rod by being pushed through an opening to account for elastic strain, what should be the diameter of the opening.

$E = 17\times10^6$ psi
Y.S = 40,000 psi

$\varepsilon = \sigma/E = 0.00235$ Hook's law

$\varepsilon = \frac{(2-d_0)}{d_0} = 0.00235$

$\Rightarrow d_0 = 1.995$ in

Ex: A steel cable 1.25 in diameter and 50 ft long is to lift 20 ton load what is the length of the cable during lifting
$E = 30\times10^6$ psi

$\sigma = F/A = 32,595$ Psi ← الرقم هادا صعب

$\varepsilon = \sigma/E = 0.0010865$ in

$\varepsilon = (L_f - 50)/50$ ft $\Rightarrow L_f = 50.0543$ ft

Ex: The following data were collected from a standard 0.505 diameter test specimen of copper alloy (initial length $L_0 = 2$ in) after fracture the gage length is 3.014 in and the diameter is 0.374 in. Plot the data.

Toughness: Ability of material to absorb energy

Load (in)	Gage length (in)	Stress (psi)	Strain
0	2	0	0
3,000	2.00167	15,000	0.000825
6,000	2.00333	30,000	0.001666
7,500	2.00417	37,500	0.002085
9,000	2.009	45,000	0.0045
10,500	2.04	52,500	0.02
12,000	2.26	60,000	0.13
12,400	2.5	60,000	0.25
11,400	3.02	57,000	0.51

ⓐ 0.2 % offset Y. strength = 45 000 psi

ⓑ tensile strength = 62 000 psi

ⓒ $E = 18 \times 10^6$ psi

ⓓ % elongation = 50.7 %

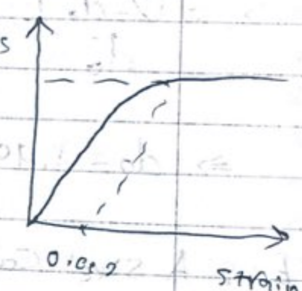
ⓔ % Reduction in area = 45.2 %

ⓕ Eng. stress at fracture = 57000 %

ⓖ true stress at fracture = 103,770 psi

ⓗ modulus of ~~resistance~~ resilience ~~George Nasrallah~~

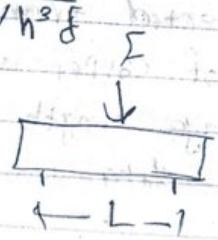
$\frac{1}{2}$ (Y. strength) (strain at Yield) = 39.1 psi



Flexural Strength $= \frac{3FL}{2wh^2}$

~~Flexural~~ slide

Flexural modulus $= \frac{FL^3}{4wh^3 \delta}$



L: من التثبيت للتثبيت

Tensil Test

Bending Test

Hardness Test

الامور الاساسية

*Fracture:

Fracture: Separation of a body into pieces due to stress at temp. below the melting point.

* Steps in fractures
① crack formation. — crack: بداية القطع
② crack propagation. — crack: لحد ما يصير انفصال

خطوتين:

Two fracture modes:

① Ductile fracture - most metals (but not too cold)
* ~~Extreme~~ Extensive plastic deformation a head of crack
* crack "Stable": resists further extention unless applied stress is increased. لازم يصير الـ stress عشان يصير نمو للـ crack

② Brittle fracture, ceramice, cold material
* little plastic deformation.
* crack is "unstable"
propagates rapidly without increase in applied stress.

*Stress Concentration:

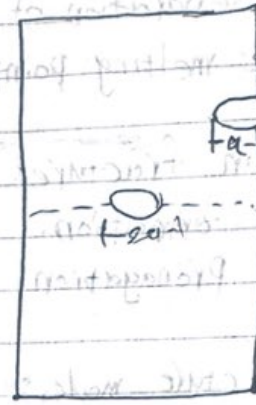
Fracture strength of a brittle solid is related to the cohesive forces between atoms.

The theoretical cohesive strength of a brittle material should be E/10, but experimental fracture strength is normally E/100 - E/10 000

* This much lower fracture strength is explained by the effect of stress concentration of microscopic flaws.

* The applied stress is amlified at the tips of microcracks, voids, notchs, surface, Scra

that are called stress raisers



max stress near the crack tip is

$$\sigma_m = 2\sigma_0 \left(\frac{a}{\rho_t}\right)^{\frac{1}{2}}$$

σ_0: is the applied stress.
a: is the half length of the crack
ρ_t: radius of the curvature of the crack tip

$$K_t = \frac{\sigma_m}{\sigma_0} \simeq 2\left(\frac{a}{\rho_t}\right)^{\frac{1}{2}}$$ Stress concentration factor

Fatigue:
Under fluctuating / cyclic stresses failure can occur at load ~~condition~~ considerable lower than tensile or yield strength of material under static load.

* 90 % of all failures of metalic structures is due to fatigue.
* Fatigue failure is brittle-like stages of fatigue.

Dr George Haddad

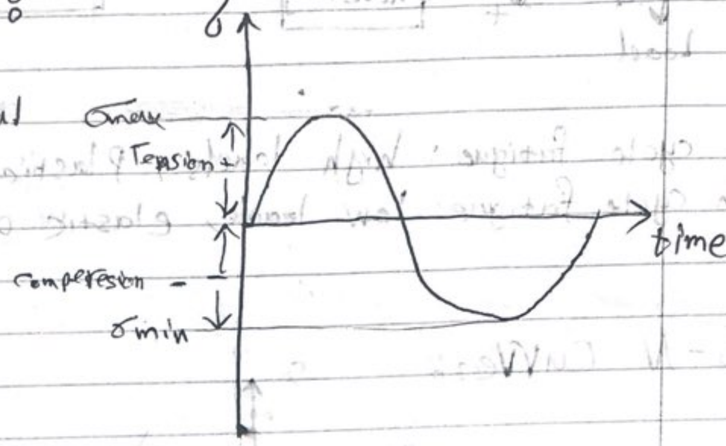
~~③ Crack Initation in the~~ ③ Catastrophic failure

② Incremental Crack Propagation

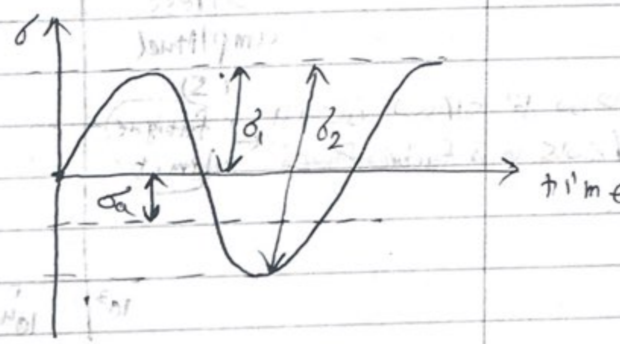
① crack initation in the areas of stress Concentration

Fatigue cycle stresses:

Ⅰ Periodic and symmetrical about zero.



Ⅱ Periodic and a symmetrical about zero.



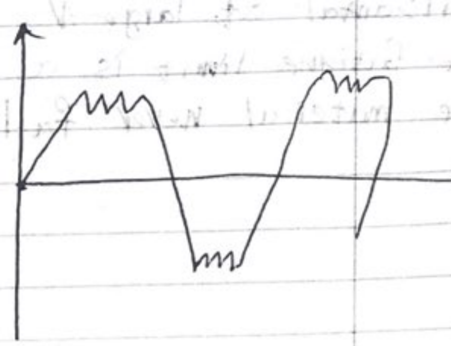
mean stress $= \sigma_m = (\sigma_{max} + \sigma_{min})/2$

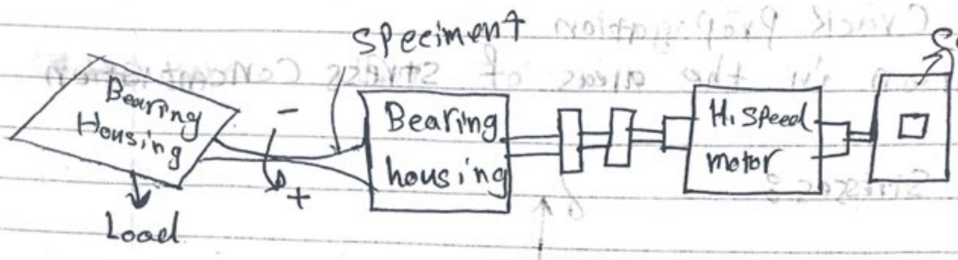
Rang of stress $= \sigma_r = \sigma_{max} - \sigma_{min}$

Stress amplitude $= \sigma_a = \sigma_r/2 = (\sigma_{max} - \sigma_{min})/2$

Stress Ratio $= \sigma_{min}/\sigma_{max}$

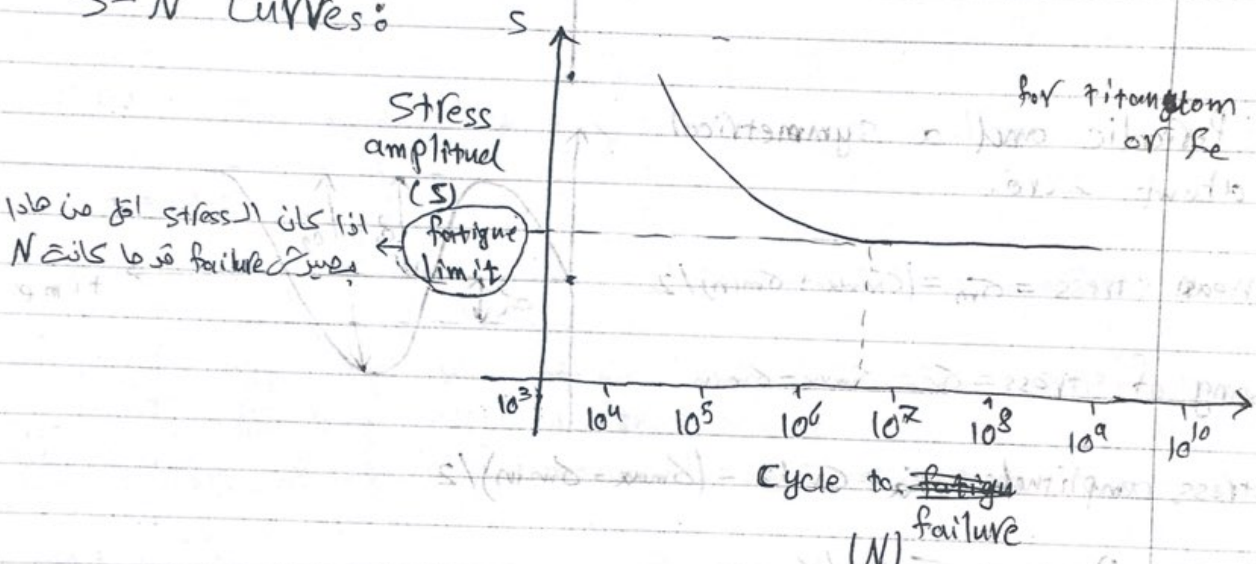
Ⅲ Random Stress



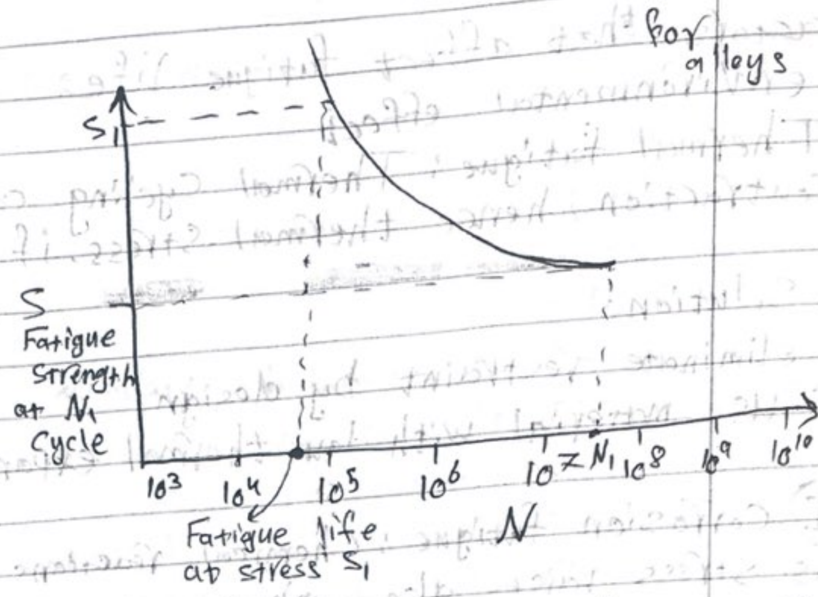


Low cycle fatigue: high loads, Plastic and elastic deformation
High cycle fatigue: low loads, elastic deformation, $N > 10^5$

S-N curves:



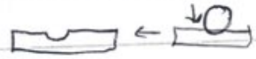
Fatigue Limit (endurance limit): in this case, S-N curve become horizantal at large N.
the fatigue limit is a max stress amplitude below which the material never fails, no matter how large N is.



* Fatigue Strength: Stress at which fractur occur after specified number of cycles (N_1) (10^7) ← عدد ثابت قيمة

* Fatigue life: Number of cycles to fail at ~~stress~~ specified stress level.

Factors that affect fatigue life:
① magnitude of stress
② quality of surface (scratches, edgs, sharp transition ...)

Solution to increase life of fatigue:
① (Removes machining flow) Polishing.
② Shot Peaning الفيديو 
③ Case harding (heat treatment
④ optimizing geometrey: avoid internal corners

* Factors that affect fatigue life:
- environmental effect

* Thermal fatigue: Thermal cycling causes expansion & contraction, hence thermal stress, if component is restrained

Solution:
1. eliminate restraint by design
2. Use material with low thermal expansion coeff.

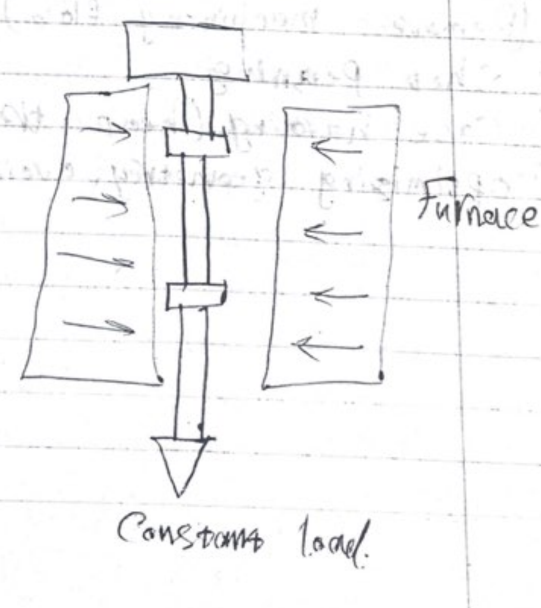
(II) Corrosion fatigue: Chemical reactions induce pits which act as stress raises also enhance crack propagation.

Solution:
1. add protection surface coating.
2. decrease corrosiveness medium.

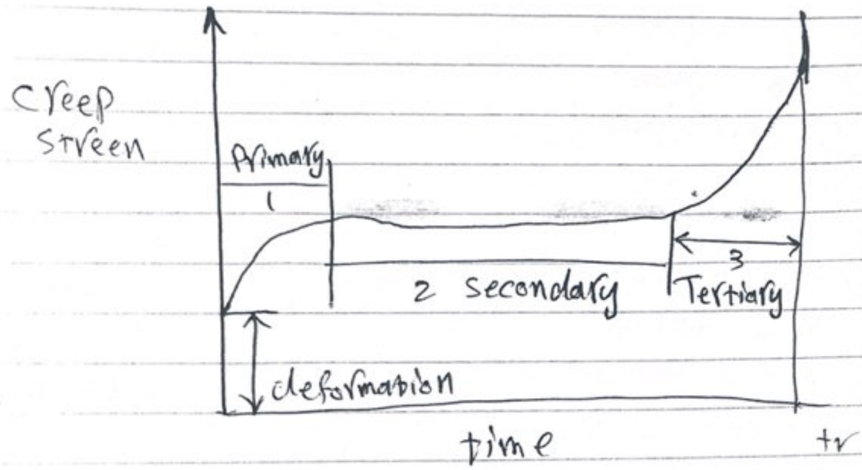
* Creep:

Creep is the time dependent and permenent deformation of materials when subjected to a constant load at a high Tempreture ($> 0.4T_m$)

Examples: turbine blades, steam generators.



مطلوب Hardheness



① Instantaneoues deformation
② Primary / transeat creep
③ secondary / steady-state creep: Rate of straining is
④ Tertiary: Rapidly acceleration strain rate up to failure