University of Babylon / College of Material's Engineering
Dept. of Engineering Metallurgy
Third Year (2012-2013)
Subject: Mechanical Metallurgy
Total Units = 5, Th. =2, Pract. = 1, Disc. = 1
Total Hrs. = 4

Dr.Haydar Al-Ethari

The Programmed course:

First: Introduction:-

The course will be consisted of theoretical and practical parts. The theoretical part will cover all the facts, theories, and analytical methods related to how metals respond to applied mechanical loads in both a macroscopic and microscopic sense at the level of bachelor engineering. Laboratory (practical part) provides the opportunity to explore the concepts through hand-on experiments including planed tests.

Second: Syllabus

<table>
<tr><th>Week No.</th><th>Subject</th></tr>
<tr><td>1</td><td rowspan="7"><u>Stress and Strain Relationships for Elastic Behavior</u>
- Review to: Plane Stress and plane strain, Factor of safety, Stress concentration
- Stresses in Three Dimensions and Stress Tensor
- Invariants of Stresses
- Mohr's stress Circle – Three Dimensions
- Description of strain at a point and Strains in Three Dimensions
- Invariants of Strains
- Elastic Stress – Strain Relations
- Octahedral Shear Stress and Shear Strain
- Stress-strain curves; Plastic deformation; criteria for necking
- Strain Energy
- Yielding Criteria for Ductile Metals
- Experimental stress analyses/strain gauge</td></tr>
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<tr><td>3</td></tr>
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<tr><td>5</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td><td rowspan="2"><u>Plastic Deformation of Single Crystals</u>
- Theoretical strength of solids
- Lattice Defects
- Deformation by Slip</td></tr>
<tr><td>9</td></tr>
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10 **11** **12**	- Slip in a Perfect Lattice - Slip by Dislocation Movement - Critical Resolved Shear Stress for Slip - Deformation of Single Crystals - Deformation by Twining - Stacking Faults - Deformation Bands and Kink Bands
13 **14** **15** **16**	**<u>Introduction to Dislocation Theory</u>** - Observation of Dislocations - Burgers Vector and the Dislocation Loop - Energies of dislocations - Intersection of Dislocations - Jogs - Dislocation Sources
17 **18** **19** **20** **21**	**<u>Strengthening Mechanisms</u>** - Strengthening from Grain Boundaries - Strain Aging - Solid – Solution Hardening - Strengthening from Fine Particles - Fiber Strengthening - Strengthening due to Point Defects - Martensite strengthening - Strain Hardening
22 **23**	**<u>Introduction to fracture mechanics</u>** - Stress intensity factor - Fracture toughness - Brittle and ductile fracture
24 **25** **26**	**<u>Fatigue of metals</u>** - Stress cycles - The S-N curve - Effect of mean stress on fatigue - Low cycle fatigue - Fatigue crack propagation - Effect of stress concentration - Cumulative fatigue damage - Effect of metallurgical variables

<table>
<tr><td>27</td><td rowspan="4"><u>Creep</u>
- The high-temperature materials problems
- The creep curve
- Structural changes during creep
- Mechanism of creep deformation
- Superplasticity
- High-temperature alloys</td></tr>
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<tr><td>30</td></tr>
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<u>Practical part:</u>

The mechanical metallurgy laboratory will include experiments concerning with:

1- Strain hardening.
2- Fatigue of metals
3- Creep.
4- Impact test.

<u>Third: Distribution of the marks:</u>

The marks will be distributed as following:

1- Two season examinations/each of 15%.
2- Quizzes (two at least per semester)/5% for each season.
3- Laboratory/ 5% for each season.
4- Final examination carries 50% of the total mark.

<u>Forth: Textbook/references:</u>

Required Text:

Dieter G. E, 1986, *Mechanical Metallurgy*, 3rd ed., McGraw Hill,.

Reference texts:

1- Meyers M.A & Chawla K.K., 1999 *Mechanical Behavior of Materials*, Prentice Hall.
2- Hosford W.F, (2005), Mechanical Behavior of Materials, Cambridge
3- Hearn E.j., 1977, Mechanics of Materials, Vol.1&2., Pergamon Press, London.

Lecture #1

-Stress and strain in 2D/Review

- Allowable working stress.

-factor of safety.

- Stress concentrations.

References:

1- Dieter G.E., (1986), Mechanical Metallurgy, McGraw-Hill

2-Timoshenko S, Goodier J.N.,(1984), Theory of elasticity,McGraw-Hill Company, Inc.

3- Robert J. A., Vlado A. L., (2006), Mechanics of solids and materials, Cambridge university press.

4- Hearn E.j., 1977, Mechanics of Materials, Vol.1&2., Pergamum Press, London.

- Stress and strain in 2D/Review:

Ex.1

ε_x= -400*10^{-6}, ε_y = 200*10^{-6}, γ_{xy} = 800*10^{-6} rad, E=200GPa, υ = 0.3

a) Principal strains:

$$\varepsilon_{1,2} = \frac{1}{2}(\varepsilon_x + \varepsilon_y) \pm \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2}$$

$$\varepsilon_{1,2} = \frac{-4+2}{2} \pm \sqrt{\left(\frac{-4-2}{2}\right)^2 + \left(\frac{8}{2}\right)^2}$$

So:

ε_1 = 400*10^{-6} and ε_2= - 600*10^{-6}

b) Max. shear strain:

$$\frac{\gamma_{max}}{2} = \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2} \Rightarrow \gamma_{max} = 5 * 10^{-6} \text{ rad.}$$

c) Location of the Principal strains:

$$\tan 2\theta_p = \frac{\gamma_{xy}}{\varepsilon_x - \varepsilon_y} = \frac{8}{-4-2} \Rightarrow \theta_p = -26.5^0$$

To determine which value of θ_p is associated with each principal strain sub. θ_p = - 26.5 in:

$$\varepsilon_\theta = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{1}{2}(\varepsilon_x - \varepsilon_y)\cos 2\theta + \frac{1}{2}\gamma_{xy} \sin 2\theta$$

$\Rightarrow \varepsilon_\theta = -600 * 10^{-6}$ which represents the min. principal strain.

So: $\theta_{p_{\min}} = -26.5^0$ and $\theta_{p_{\max}} = -116.5^0$

d) Principal Stresses:

$$\sigma_1 = \frac{E(\varepsilon_1 + \upsilon\varepsilon_2)}{1-\upsilon^2} = 48.3MPa \quad \text{and} \quad \sigma_2 = \frac{E(\varepsilon_2 + \upsilon\varepsilon_1)}{1-\upsilon^2} = -105.5MPa$$

$$\tau_{\max} = \frac{1}{2}(\sigma_1 - \sigma_2) = 76.9MPa$$

e) Stresses at +40^0 from x-axis:

$$\sigma_x = \frac{E(\varepsilon_x + \upsilon\varepsilon_y)}{1-\upsilon^2} = -74.8MPa \quad \text{and} \quad \sigma_y = \frac{E(\varepsilon_y + \upsilon\varepsilon_x)}{1-\upsilon^2} = 17.6MPa$$

$$\tau_{\max} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2} \Rightarrow \tau_{xy} = 61.5MPa$$

$$\tau_{\theta=40} = \frac{1}{2}(\sigma_x - \sigma_y)\sin 2\theta + \tau_{xy}\cos 2\theta = -34.8MPa$$

$$\sigma_{\theta=40} = \frac{\sigma_x + \sigma_y}{2} + \frac{1}{2}(\sigma_x - \sigma_y)\cos 2\theta - \tau_{xy}\sin 2\theta = -97.2MPa$$

f) Strains at +40^0 from x-axis:

$$\varepsilon_{\theta=40} = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{1}{2}(\varepsilon_x - \varepsilon_y)\cos 2\theta + \frac{1}{2}\gamma_{xy}\sin 2\theta = 241 * 10^{-6}$$

<u>Ex.2 (To be worked by you at the class):</u>

If $\varepsilon_x = -800*10^{-6}$, $\varepsilon_y = 200*10^{-6}$, $\gamma_{xy} = -200*10^{-6}$ rad, E=200GPa, $\upsilon = 0.3$, determine the principal strains, the principal stresses, the max. shearing stress, the max. shearing strain, the stresses and strains at plane 20^0 apart from the x-axis.

<u>Allowable working stress-factor of safety</u>

The most suitable strength or stiffness criterion for any structural element or component is normally some maximum stress or deformation which must not be exceeded. In the case of stresses the value is generally known as the ***maximum allowable working stress.*** Design procedures, production methods, etc., designers generally introduce a ***factor of safety*** into their designs, defined as follows:

Factor of safety = (**maximum stress)/(allowable working stress)**

= **(σ_{yp} or UTS) / (allowable working stress)**

In this case a factor of safety of 3 implies that the design is capable of carrying three times the maximum stress to which it is expected the structure will be subjected in any normal loading condition. There is seldom any realistic basis for the selection of a particular safety factor and values vary significantly from one branch of engineering to another. Values are normally selected on the basis of a consideration of the social, human safety and economic consequences of failure. Typical values range from ***2.5*** (for relatively low consequence, static load cases) to ***10*** (for shock load and high safety risk applications)**.**

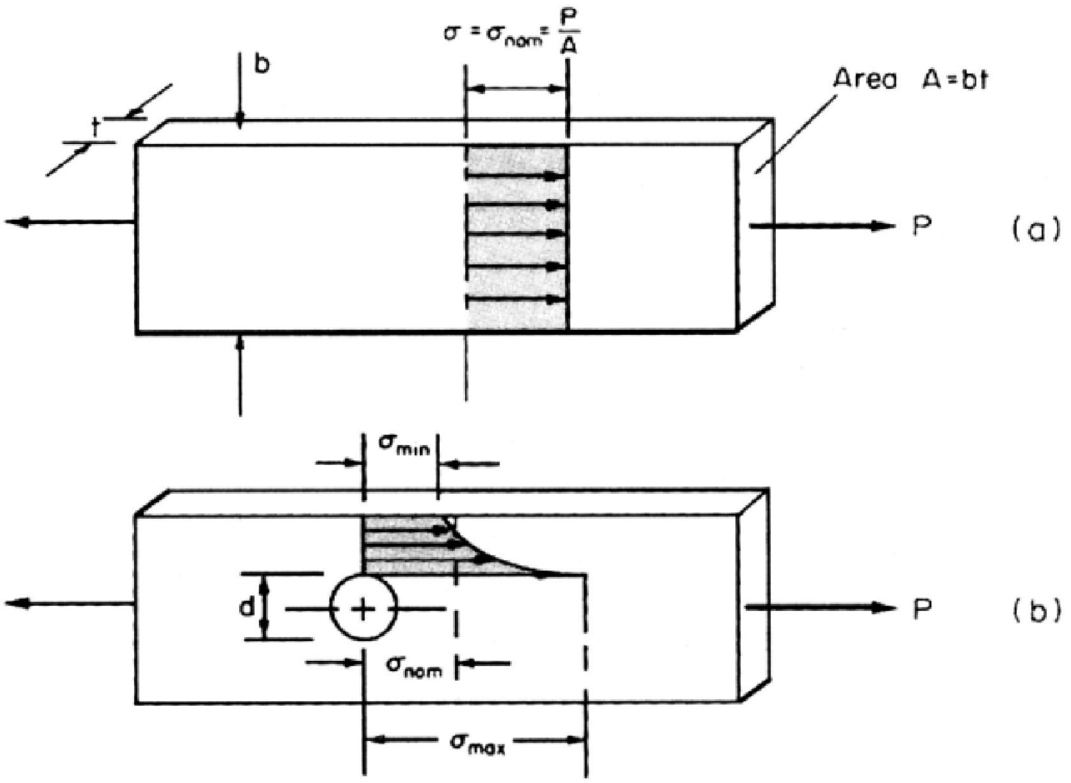
Stress concentrations

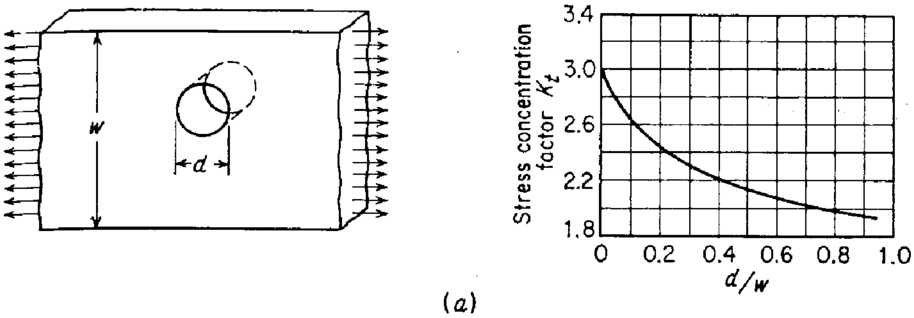
All the loading conditions and components have been analyzed with stresses assumed to be uniform or smoothly varying. In practice, however, this rarely happens owing to the presence of grooves, fillets, threads, holes, keyways, points of concentrated loading, material flaws, etc. In each of these cases, and many others too numerous to mention, the stress at the "discontinuity" is likely to be significantly greater than the assumed or nominally calculated figure and such discontinuities are therefore termed ***stress raisers or stress concentrations.*** Most failures of structural members or engineering components occur at stress concentrations. In fatigue loading conditions, for example, virtually all failures occur at stress concentrations

and it is therefore necessary to be able to develop a procedure which will take them into account during design strength calculations.
Geometric discontinuities such as holes, sharp fillet radii, keyways, etc. are probably the most prevalent causes of failure.

$$\textbf{Stress concentration factor } K_t = \frac{\textbf{maximum stress}}{\textbf{nominal stress}} = \frac{\sigma_{max}}{\sigma_{nom}}$$

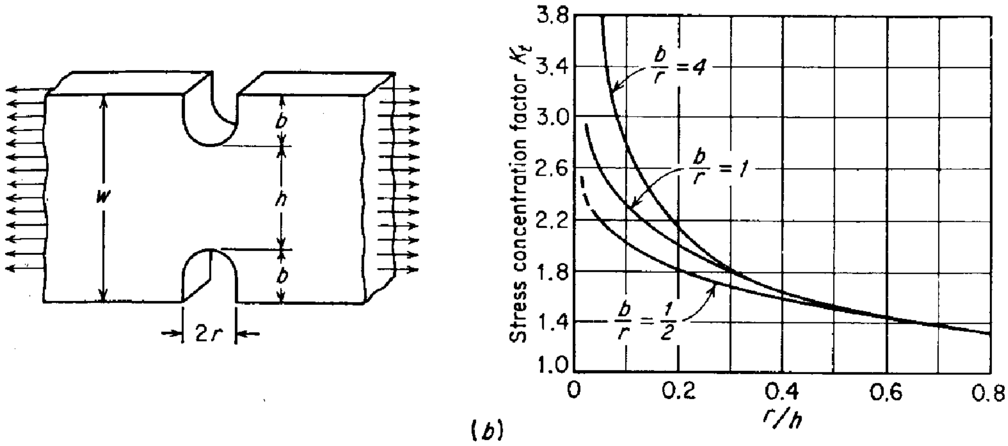
For a small hole $K_t \simeq 3$.





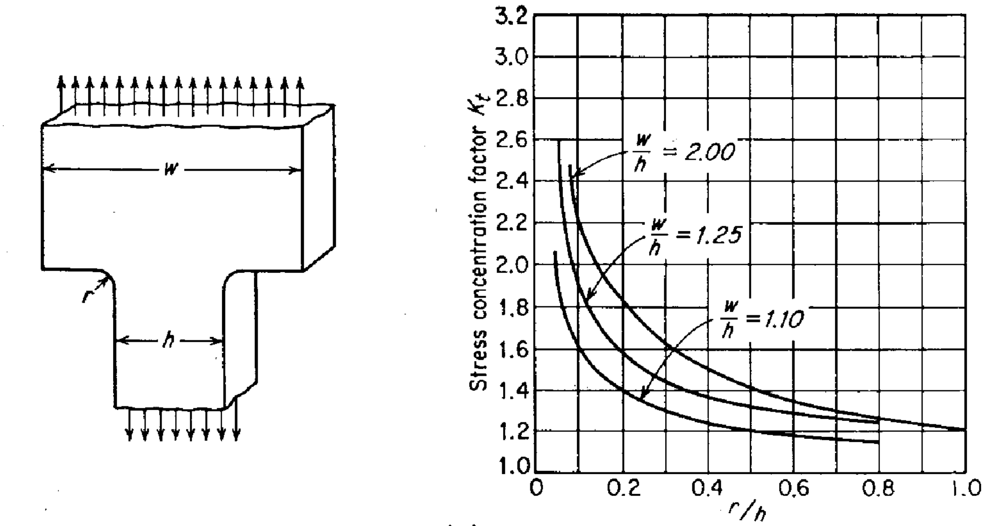
w
d
Stress concentration factor K_t
3.4
3.0
2.6
2.2
1.8
0
0.2
0.4
0.6
0.8
1.0
d/w

(a)



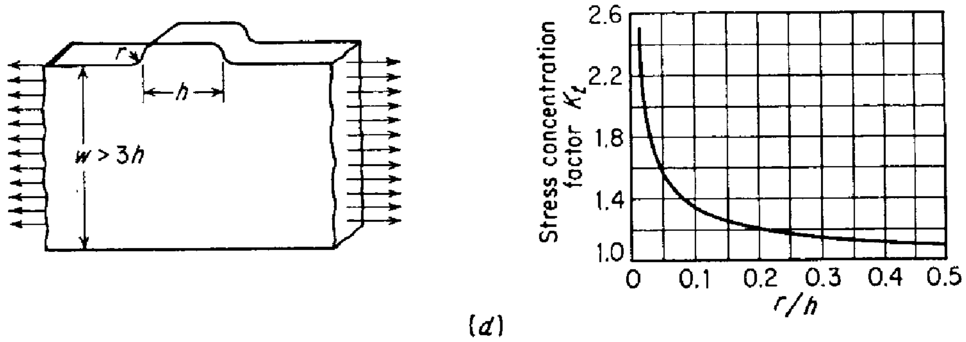
w
b
h
b
2r
Stress concentration factor K_t
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
$\frac{b}{r} = 4$
$\frac{b}{r} = 1$
$\frac{b}{r} = \frac{1}{2}$
0
0.2
0.4
0.6
0.8
r/h

(b)

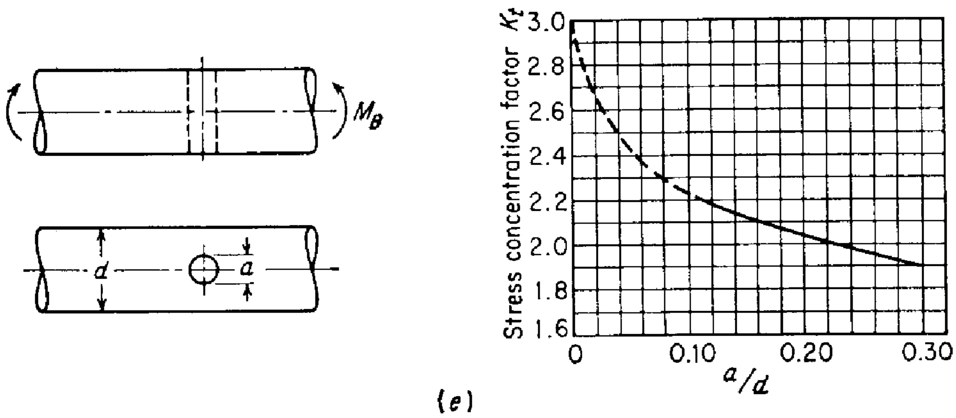


w
r
h
Stress concentration factor K_t
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
$\frac{w}{h} = 2.00$
$\frac{w}{h} = 1.25$
$\frac{w}{h} = 1.10$
0
0.2
0.4
0.6
0.8
1.0
r/h

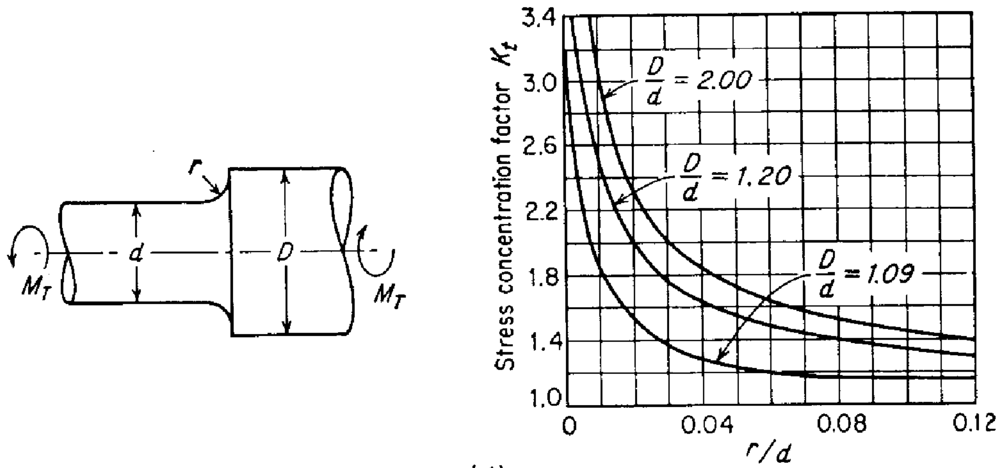
(c)



(d)



(e)



(f)

Theoretical stress-concentration factors for different geometrical shapes.