ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2012 SESSION

Open-book examination

Calculators : only authorized models

Duration : 3 hours

04-MB-11

Materials

1- <u>Deformation of materials</u>

Sodium chloride is often cited as the prototype of a brittle material. Explain this statement. Describe the mechanism of deformation of this type of material. **(5 points)**

2- <u>Tensile test</u>

A cylindrical rod of 3 cm in diameter and 10 cm high is subject to a rupture test. Several materials are available. The mechanical properties are provided in table 1:

material	Modulus of elasticity	Limit of elasticity	Limit breaking	ductility	tenacity
A	72 GPa	250 MPa	350 MPa	15%	20 MPa√m
B	84	200	400	20	35

<u>Table 1</u> : mechanical properties

(Elasticity's modulus is often named «Young's modulus»).
The units are shown in each column.

It is assumed that the consolidation is linear.

2-1 What is maximum reversible elongation of the test piece made of material A? **(5 points)**

2-2 Calculate the energy spent to break this rod **(3 points)**

3- <u>Mechanical properties</u>

Table 2 below gives the mechanical properties of materials

material	Modulus of elasticity	Yield strength	Tensile strength	Elongation at rupture	Coefficient of thermal expansion	critical stress intensity factor, Kic
C	70 GPa	275 MPa	400 MPa	20 %	$18\ 10^{-6}\ {}^{0}C^{-1}$	20 MPa√m
D	210	200	400	ND	$12\ 10^{-6}\ {}^{0}C^{-1}$	35
E	380	200	200	ND	$4\ 10^{-6}\ {}^{0}C^{-1}$	10
F	0,3	10	ND	80	ND	15

ND: not determined

Table 2: some materials mechanical properties

3-1 What is the class of the material F (metal, ceramic, polymer) ? Why? **(5 points)**

3-2 Mechanical properties comparison:

3-3-1 which is the most ductile material? **(3 points)**

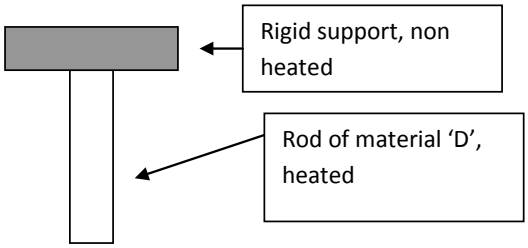
3-3-2 which is the most brittle material? **(3 points)**

3-3-3 which material has the largest reversible deformation? **(2 points)**

Justify your answers.

4- Thermal expansion

A cylinder of the material **'D'** (table 2) is heated. The size of this cylinder is the following: length of 20 cm, 3 cm in diameter.



4-1 This rod is heated from 20 ^{0}C to 100 ^{0}C. Calculate its length increase. **(3 points)**

4-2 What is the stress in the material at this temperature? **(2 points)**

5- Fatigue

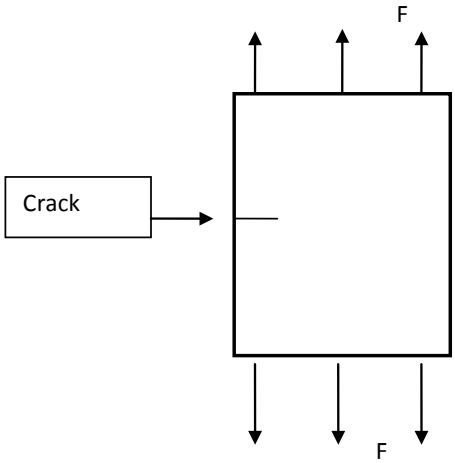
The specimen is made of material 'D' of the table 2.

5-1 What is the difference between the stress intensity factor at threshold of a fatigue crack ΔK_s (Paris' relation) and the endurance limit σ_D (S-N curves) **(5 points)**

5-2 The crack propagation rate is described by the classical following relationship:

$$\mathbf{da / dn = 8 * 10^{-9}\ \Delta K^3,}$$

with da / dn, stand for the crack propagation, expressed in mm/cycle and ΔK, variation of stress intensity factor, in MPa√m.
The crack is located in a specimen with large dimensions (see following figure).



High : 15 cm; width : 10 cm; thickness : 1 cm; initial crack length : 1 mm.

The applied load varies from 0 to 50 kN.

The load is uniformly applied on the two faces of the specimen.

5-2-1 What is the number of cycles required for the crack to spread from 3 to 5 mm? **(3 points)**

5-2-2 what is the maximum length of the crack to avoid rupture? **(3 points)**

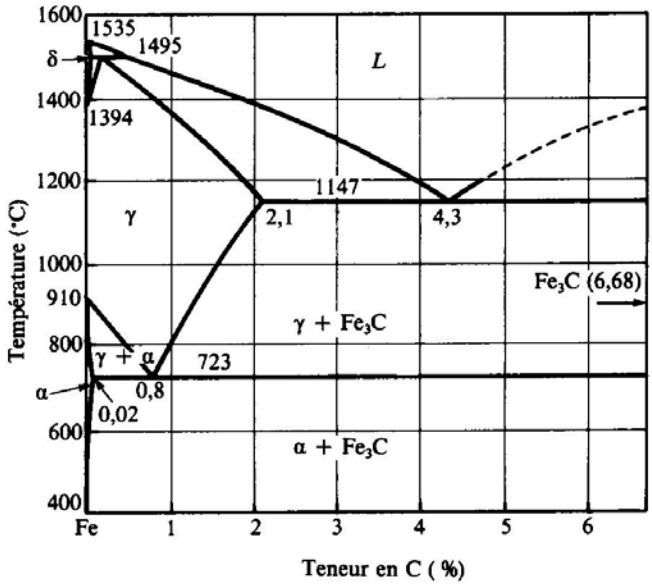
6- <u>Heat treatment : precipitation hardening and quench</u>

6-1 Define «precipitation hardening». Which materials are precipitation hardening sensitive ? Explain? **(5 points)**

6-2 What are the materials that harden after quenching? Explain your answer. **(3 points)**

7- <u>Heat treatment of steel</u>

The following figure schematizes the iron-carbon phases diagram.



7-1 For an alloy containing 0,4 % C, which heat treatment produces the greatest hardness? **(5 points)**

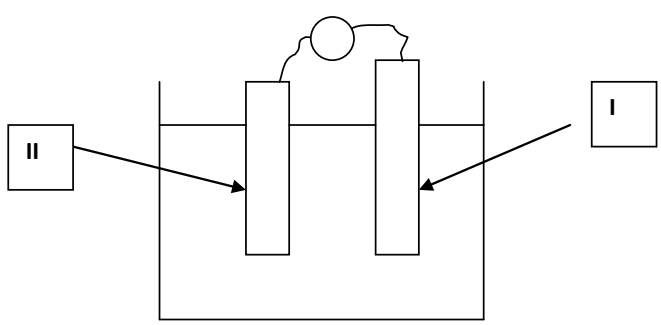
7-2 Calculate the percentage of phases for this alloy at the temperature of 200°C **(5 points)**

8- <u>Modification of properties by heat treatment</u>

Compare the Young modulus (modulus of elasticity) of quenched steel with the one of a steel quenched and tempered. Explain your answer.**(3 points)**

9- <u>Corrosion</u>

Two metal plates are dived in an electrolyte, low oxygen, see figure below.



Mis en forme : Anglais (Canada)

The circle represents an ampermeter.

The material I is aluminum and the material II is iron. The immersion is 10 cm deep, the width of the material I is 2 cm, the one of material II is 1 cm. The thickness of the two samples is 3 mm.

9-1 What is the material that corrodes? Why? **(5 points)**

9-2 Knowing that the measured current is of 12 µA, calculate the life time of the assembly, i.e. the time of disappearance of the anode? **(5 points)**

	A (g/mol)	**n (Valencia)**	**density (g/cm3)**
Iron	**56**	**2**	**7,8**
Al	**27**	**3**	**2,7**

Table 3: Electrochemical properties

Tableau 8.1 Potentiels standard d'équilibre d'oxydo-réduction, à 25 °C

Réaction	**Potentiel standard d'équilibre E_H (V)**
$Au \rightleftarrows Au^{3+} + 3e$	+1,50
$2\ H_2O \rightleftarrows O_2 + 4\ H^+ + 4e$	+1,23
$Pt \rightleftarrows Pt^{2+} + 2e$	+1,19
$Ag \rightleftarrows Ag^+ + e$	+0,80
$4\ OH^- \rightleftarrows O_2 + 2\ H_2O + 4e$	+0,40
$Cu \rightleftarrows Cu^{2+} + 2e$	+0,34
$H_2 \rightleftarrows 2H^+ + 2e$	0
$Pb \rightleftarrows Pb^{2+} + 2e$	−0,13
$Sn \rightleftarrows Sn^{2+} + 2e$	−0,14
$Ni \rightleftarrows Ni^{2+} + 2e$	−0,25
$Cd \rightleftarrows Cd^{2+} + 2e$	−0,40
$Fe \rightleftarrows Fe^{2+} + 2e$	−0,44
$Cr \rightleftarrows Cr^{3+} + 3e$	−0,74
$Zn \rightleftarrows Zn^{2+} + 2e$	−0,76
$Al \rightleftarrows Al^{3+} + 3e$	−1,67
$Mg \rightleftarrows Mg^{2+} + 2e$	−2,37
$Na \rightleftarrows Na^+ + e$	−2,71

10- <u>Heat treatment</u>

The diagram below describes Au–Pb alloys.

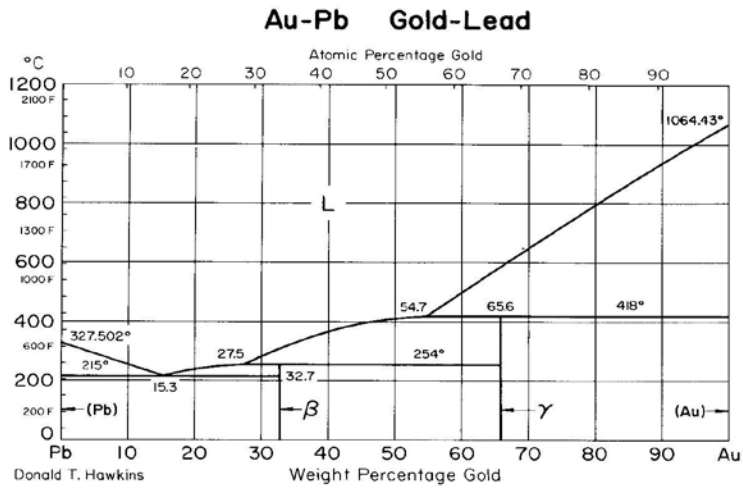


Figure 4 : phase diagram Au-Pb
(figure p268 de ASM vol. 8 8ed)

For an alloy which contain 20% Au :

10-1 how it is possible to increase the mechanical properties? **(2 points)**

10-2 what is (are) the composition of eutectic(s)? **(2 points)**

10-3 draw the cooling curve from 400^0C down to room temperature (**3 points)**

11- <u>Polymers</u>

11-1 What are polymers that are sensitive to the cross-linking? Compare the properties of a polymer cross-linked to amorphous polymer. **(5 points)**

11-2 How to increase the melt temperature of a thermo-plastic polymer? **(5 points)**

12- <u>Ceramics</u>

12-1 What are the properties of ceramics? **(5 points)**

12-2 Ceramics are sensitive to the effect of notch. Why? **(5 points)**