UNIVERSITY OF RUHUNA- FACULTY OF TECHNOLOGY
BACHELOR OF ENGINEERING TECHNOLOGY
Level II (Semester I) Examination, October 2018.

Course Unit: ENT2152 Properties of Materials and Their Applications

Time Allowed Two Hours

All symbols have their usual meaning.

Answer ALL (04) Questions.

1) Pure iron (Fe) undergoes three phase transformations upon heating. At temperatures below 912 ^{0}C Iron has BCC crystal structure. Above 912 ^{0}C it transforms to FCC and heating above 1394 ^{0}C it transforms back to BCC before melting. (Refer to the attached Figure 1)
   (I) Sketch crystal structures of Face Centered Cubic (FCC) and Body Centered Cubic (BCC) crystals.
   (II) At room temperature Fe has an atomic number density of 0.084 Å^{-3}. Find the lattice parameter of Fe at room temperature. (Note: $1\,\text{Å} = 10^{-10}\,m$)
   (III) Steel is made by mixing iron(Fe) with carbon(C). What is the maximum solubility of carbon in FCC and BCC crystal structures below 1000 ^{0}C?
   (IV) An iron -carbon alloy at 0.76 wt% of carbon composition is slowly cooled down from a temperature 800 ^{0}C
      a) Sketch the equilibrium microstructure of the austenite phase at temperature 800 ^{0}C.
      b) Sketch the equilibrium microstructure of the pearlite structure below the temperature 727 ^{0}C.
      c) If the system is cooled rapidly(quenched) at the above composition a martensite phase is formed at low temperatures. what is the crystal structure of Fe atoms in the martensite phase? Sketch the shape of a unit cell.

(25 marks)

2) The modulus of elasticity *(E)* of a material is defined by ,

$$\sigma = E\epsilon,$$

where σ is the engineering stress and ϵ is the engineering strain.
   (I) Define the terms engineering stress (σ) and engineering strain (ϵ).
   (II) What is the true Stress (σ_T) ?
   (III) Sketch the variation of engineering stress against the engineering strain for (a) a linear elastic and (b) a nonlinear elastic material.
   (IV) Briefly explain the terms elastic deformation and the plastic deformation.

(V) Carbon nanotube(CNT) is the strongest material on earth. Modulus of elasticity of CNT is $1TPa$ and the tensile strength is $53GPa$.

a) If the diameter of a CNT is $12nm$, what is the maximum force the CNT could support before it breaks?

b) A $1\mu m$ (micro meter) long nanotube breaks after subjecting to a force exceeding the tensile strength. The elongated length of the nanotube at fracture is $1.162\ \mu m$.
Find the ductility of the nanotube in terms of percentage of elongation at fracture.

(25 marks)

3) Electrical conductivity of a semiconducting material can be given by the following equation,

$$\sigma = |e|(n_e\,\mu_e + n_h\mu_h)\ ,$$

where **e** is the charge of an electron, n_e is the electron density, n_h is the hole density, μ_e is the mobility of electrons and μ_h is the mobility of holes.

(I) Briefly explain the process of creating an electron and hole pair in a semiconducting material.

(II) Give two methods that you may use to increase the electron and/or hole density in a semiconductor.

(III) How do the above methods affect the electron and hole mobility in a semiconducting material?

(IV) A sheet of pure silicon is doped with Boron(B) atoms which act as electron acceptors. What type (n or p) of extrinsic semiconductor material is formed in this process?

(V) Show the energy level of the acceptor(Boron) atoms in the band structure diagram.

(VI) How would you approximate the above equation for an intrinsic semiconductor?

(VII) At room temperature an intrinsic Silicon(Si) semiconductor has a carrier concentration (electron of hole) of $1.0 \times 10^{16} m^{-3}$. Electron and hole mobility of Silicon at room temperature is $0.14\ m^2/Vs$ and $0.05\ m^2/Vs$ respectively. Find the electronic conductivity of pure silicon at room temperature. (consider the charge of an electron is 1.6×10^{-19} C)

(VIII) How would you approximate the above equation for extrinsic n-type and p-type semiconductors?

(IX) To make a good electrical contact, a part of the silicon wafer should be highly doped with Boron. To minimize the electrical resistance between the contact metal and the semiconductor the required electrical conductance of the contact region of the semiconductor is $1.00 \times 10^4 (\Omega m)^{-1}$. What it the dopant concentration required to achieve above conductance? (Assume because of doping the room temperature electron and hole mobility reduced to $0.07\ m^2/Vs$ and $0.02\ m^2/Vs$ respectively.)

(25 marks)

4) Crystal nuclei forms in a liquid metal cooled below its melting point. These nuclei grows into crystal grains until they meet the surrounding grains. Finally, the liquid metal solidify as a polycrystalline metal.

(I) How do you reduce the grain size of a polycrystalline metal during the solidification process?

(II) How does the grain size reduction affect the mechanical properties (ex: Yield strength, Tensile strength) of a metal?

(III) What are point defects in a crystalline material?

(IV) What is a solid solution?

(V) How does the solid solution support to strengthen mechanical properties?

(VI) A piece of metal is cold worked to achieve a desired geometry for a special application. Although the desired geometry is achieved the material has become more ductile because of the heavy cold work. However, it is required to have a higher percentage of ductility for the intended special application.
Briefly explain a practical procedure to restore the original ductility of the metal in its' new geometry.

(25 marks)

Figure 1 Equilibrium phase diagram of iron -carbon system.