**Indian Institute of Technology Kharagpur**
**Department of Metallurgical and Materials Engineering**

Autumn End Sem Examination (2016-2017)
Subject Name: Materials Engineering (MT30001)
No. of Students: 171

Full marks: 100
Time: 3 hours

**Instructions: Answer any five questions. Be specific and to the point in your answer.**

1. **[4+4+4+5+3]**

(a) State the Hall-Petch equation. Explain why fine grain material shows higher strength than the coarse one.

(b) If the true-stress-true-strain curve is given by the relationship: $\sigma = 1400\varepsilon^{0.33}$, where stress is in MPa, what is the ultimate tensile strength of the material?

(c) Derive the expression for engineering strain rate and true strain rate in term of crosshead velocity of a tensile testing machine.

(d) An alurninum-4% copper precipitation strengthened alloy has a yield stress of 600 MPa. Estimate the inter-particle spacing in this alloy. Given G ~ 27.6 GPa; b~0.25 nm.

(e) Finer the grain size of austenite, lesser the hardenability of a material – justify this statement.

2. **[6+3+3+4+4]**

(a) Gallium arsenide (GaAs) and gallium phosphide (GaP) are compound semiconductors that have room-temperature band gap energies of 1.42 and 2.25 eV, respectively, and form solid solutions in all proportions. Furthermore, the band gap of the alloy increases approximately linearly with GaP additions (in mol%). Alloys of these two materials are used for light-emitting diodes wherein light is generated by conduction band-to-valence band electron transitions. Determine the composition of a GaAs–GaP alloy that will emit red light having a wavelength of 0.68 μm. Given, the value of Planck constant ($h$) = $4.13 \times 10^{-15}$ eV- s.

(b) The index of refraction of quartz is anisotropic. Suppose that visible light is passing from one grain to another of different crystallographic orientation and at normal incidence to the grain boundary. Calculate the reflectivity at the boundary if the indices of refraction for the two grains are 1.544 and 1.553 in the direction of light propagation.

(c) How pulse broadening during optical fiber communication could be avoided using graded-index optical fiber?

(d) Explain, with suitable schematic diagram, how conduction electron concentration of both the extrinsic and intrinsic semiconductor changes with temperature.

(e) If the room temperature (25°C) electrical conductivity of intrinsic germanium is 2.2 $(\Omega\text{-m})^{-1}$, estimate its conductivity at 150°C. Given, the value of Boltzmann's constant ($k$) = $8.62 \times 10^{-5}$ eV/K, $E_g$ for germanium is 0.67 eV.

3. **[5+5+4+3+3]**

(a) Derive the condition of instability leading to localized deformation (i.e. necking) during tensile testing.

(b) Draw a typical creep-strain vs. time plot and label on it the primary, secondary and tertiary stages of creep. Also, mention the deformation mechanism associated with each of these stages.

(c) Calculate the rupture time (due to creep failure) of iron specimen at a stress ($\sigma$) level of 140 MPa at 800°C. Given, the Larson - Miller parameter of this iron is $24\times10^3$ K-log hr at 140 MPa stress level.

(d) You want to use an alloy for high temperature application where creep is a major concern. What are the essential features/properties the alloy must possess for this application? You need to justify your answer.

(e) How can you improve the fatigue life of a structural component?

[4+2+3+5+6]

4.

(a) Explain, with suitable schematic plot, how the tensile strength and ductility of a cold-worked material changes during recovery, recrystallization and grain growth stage.

(b) What are the basic differences between gray and white cast iron?

(c) Rank the magnitudes of the diffusion coefficients in the descending order for the following systems and justify your answer: N in Fe at 700°C, Cr in Fe at 700°C.

(d) What is steady state and non-steady state diffusion? State the Fick's second law of diffusion.

(e) For some applications, it is necessary to harden the surface of a steel than its interior by carburizing process in which the steel piece is exposed, at an elevated temperature, to an atmosphere rich in a hydrocarbon gas, such as methane ($CH_4$). Consider that the steel initially has a uniform carbon concentration of 0.25 wt% and is to be treated at 950°C. If the concentration of carbon at the surface is suddenly brought to and maintained at 1.20 wt%, how long will it take to achieve a carbon content of 0.80 wt% at a position 0.5 mm below the surface? The diffusion coefficient for carbon in iron at this temperature is $1.6 \times 10^{-11}$ $m^2/s$; assume that the steel piece is semi-infinite. Given

| Z | erf(Z) |
|---|---|
| 0.35 | 0.3794 |
| Z | 0.4210 |
| 0.40 | 0.4284 |

[5+5+6+4]

5.

(a) State the Griffith theory of fracture for a perfectly brittle material? What is plane strain fracture toughness ($K_{IC}$)?

(b) A material has $K_{IC} = 26$ MPa-$m^{0.5}$. It is observed that failure stress of this material is 112 MPa when the largest flaw size ($a_{max}$) is 9 mm. What will be the failure stress for the same material if the largest flaw size is 4 mm?

(c) The stress intensity factor for a partial-through thickness flaw is given by $K = \sqrt{sec\frac{\pi a}{2t}}\,\sigma\sqrt{\pi a}$ where $a$ is the depth of penetration of the flaw through a wall thickness $t$. If the flaw is 5 mm deep in a wall 12 mm thick, determine whether the wall will support a stress of 140 MPa if it is made from 7075-T6 aluminum alloy with $K_{IC} = 24$ MPa-$m^{0.5}$.

(d) What is thermal fatigue? State the parameters that control the thermal fatigue resistance of a material. Is thermal fatigue a low cycle or high cycle fatigue? Justify your answer.

6. [4+7+5+4]

(a) As a design engineer, you should be more worried about localized corrosion rather than uniform corrosion - justify this statement.

(b) A zinc test specimen of dimensions 3-inch (L) × 2-inch (W) × 0.125-inch (T) with a 0.25 inch diameter circular through-thickness hole is exposed (its all surfaces) for 120 hours in acid solution and it loses 150 milligrams. Calculate the corrosion rate in mpy. Given, density of zinc = 7.14 g/$cm^3$.

(c) What is sensitization and how it happens in a typical 18:8 austenitic stainless steel? How sensitization can be controlled in a typical 18:8 austenitic stainless steel?

(d) What is galvanized steel? Why it is preferred over tin plating from the corrosion point of view?