
MCG2361 – Engineering Materials II

Mid-term Exam 2
Thursday, March 19th, 2015
Duration: 60 minutes
SOLUTIONS

Answer ALL Questions
Total marks: 40

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1. Define what is a composite material and list some of the advantages (in terms of properties) of polymer composites over metals such as steel and aluminum. *(5 mark)*

   Answer:

   A composite material is made up of at least 2 different materials, which are identifiable at the macroscopic level. The composite has improved properties compared to the individual materials (matrix and reinforcement)

   Compared to metals such as steels and aluminum, polymer composites have these properties: higher specific strength, higher specific stiffness, light-weight, dimensional stability, corrosion resistance

2. Describe what are laminar composites and how would high strength be achieved in these composites? (*4 mark*)

   Answer:

   Laminar composites are composites made by stacking a series of sheets or layers.

   Higher strength in laminar composites can be achieved by stacking the layers in such a way that the high strength direction varies from layer to layer. In this case a relatively high strength in virtually all directions within the laminate is obtained.

3. For a fiber reinforced polymer matrix composite

   a) List two important functions for each of the two constituent phases (matrix and reinforcement). *(4 marks)*

   b) Explain why it is important to have a strong interfacial bonding between the matrix and reinforcement in a composite material. *(4 marks)*

Answer:

Matrix functions: (i) transfer load to reinforcement, (ii) protects the reinforcement from damage due to the environment.

Reinforcement functions: (i) carries the load from the matrix, (ii) provides strength and stiffness to the composite

A strong interfacial bonding provides (i) strengthening to the composite by allowing effective transfer of load from matrix to reinforcement, (ii) allows for fiber pull-out (in this case the strength of bonding is not high so that higher toughness is desirable) or (ii) reduces pull-out if failure is to be avoided (in this case the bonding is strong). *What is desirable is not a strong bonding but an optimum bonding so that higher strength and toughness are obtained.*

4. The development of polymer composite materials has led to significant improvements in properties such as strength, stiffness and toughness. Explain how a fiber reinforced polymer (e.g. CFRP or GFRP) results in higher strength and stiffness compared to the polymer matrix and higher fracture toughness compared to both the polymer matrix and fiber reinforcement phases. *(9 marks)*

Answer:

A fiber-reinforced polymer has higher strength and stiffness compared to the polymer matrix because of the presence of the reinforcement, which is usually made of strong and stiff fibers.

A fiber-reinforced polymer has higher fracture toughness compared to the polymer matrix and fiber reinforcement, because it combines the properties of both matrix and fibers. The matrix, being more ductile, provides more resistance to crack propagation because if its ability to deform plastically, and as a result increases the fracture toughness of the composite. The fracture toughness of Fibers alone is not good but when combined with the matrix, the overall toughness increases.

5. For effective strengthening and stiffening of polymer composites, the use of critical fiber length, fiber orientation relative to the applied stress, and volume fraction of fibers are very important. Give your comments. (*6 mark*)

Answer:

For effective strengthening of the composite the fiber length is a critical factor. For each composite there is a critical length that the fiber should have if effective transfer of load from matrix to reinforcement were to take place.

i) If the fiber length is smaller than the critical fiber length, there will be no transfer of load and no strengthening of the composite.

ii) If the fiber length is equal to the critical fiber length, there will be transfer of load but not enough to provide higher strength to the composite.

iii) If the fiber length is bigger than the critical length, there will effective transfer of load and hence maximum strength is achieved in the composite.

You can drawings to justify your answer.

6. A unidirectional fiber reinforced polymer composite is made from materials having the following properties: E_f= 100 GPa, σ_f = 300 MPa, E_m = 5 GPa, σ_m = 30 MPa.

   a) If the elastic modulus of the composite normal to the fiber axis is 7 GPa, determine the volume fraction of the fibers in the composite *(4 marks)*

   b) If the composite is designed to elastically carry the stress, σ_c = 70 MPa along the fiber axis at failure, what should the fiber volume fraction be? *(4 marks)*

Modulus of composite in the longitudinal direction (along the fiber axis) is:

$$E_c = E_m V_m + E_f V_f$$

Modulus of composite in the transverse direction (normal to the fiber axis) is:

$$E_c = \frac{E_m E_f}{E_f V_m + E_m V_f}$$

Answer:

a) The modulus in the transverse direction is:

$$E_c = \frac{E_m E_f}{E_f V_m + E_m V_f} = \frac{(5GPa)(100GPa)}{(100GPa)(1-V_f)+(5GPa)(V_f)}$$

V_f = 0.3 = 30%

b) In the longitudinal direction, (isostrain), $\varepsilon_c = \varepsilon_m = \varepsilon_f$. The composite fails at an elastic strain equal to the strain at which the fiber deforms plastically.

$$\epsilon_f = \frac{\sigma_f}{E_f} = \frac{300MPa}{100MPa} = 3\times10^{-3} = \epsilon_c$$

$$E_f = \frac{\sigma_c}{\epsilon_c} = \frac{70MPa}{3\times10^{-3}} = 23.3\ GPa$$

$$E_c = E_m(1 - V_f) + E_f V_f$$

$$23.3GPa = 5GPa(1 - V_f) + (100GPa)(V_f)$$

$V_f = 0.193 = 19.3\%$