University of Anbar
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فيزياء المواد

Physics of Materials

المرحلة الثالثة
الكورس الاول

اعداد
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9. Composite materials المواد المتراكبة

A **composite material** is composed تتكون of at least two materials, which combine تتراكب to give properties superior متفوقة to those of the individual components. Materials that have specific محددة and unusual غير عادية properties are needed اللازمة for a host لمجموعة of high-technology applications such as those found in the aerospace الفضاء, underwater تحت الماء, bioengineering الهندسة الحيوية, and transportation industries صناعات النقل.

A composite المتراكب is considered يعتبر to be any multiphase متعدد الطور material that exhibits يعرض a significant ذو اهمية proportion نسبة of the properties of both constituent المكونة phases الاطوار such that a better combination مزيج افضل of properties is realized يتم تحقيقة.

Many composite materials are composed of just two phases; one is termed the matrix المادة الاساس, which is continuous and surrounds تحيط the other phase, often called the dispersed مشتت phase. The properties of composites are a function دالة of the properties of the constituent phases, their relative amounts الكميات النسبية, and the geometry الشكل الهندسي of the dispersed phase. Dispersed phase geometry in this context means السياق يعني the shape of the particles الحبيبات and the particle size حجم الحبيبات, distribution التوزيع, and orientation الاتجاه.

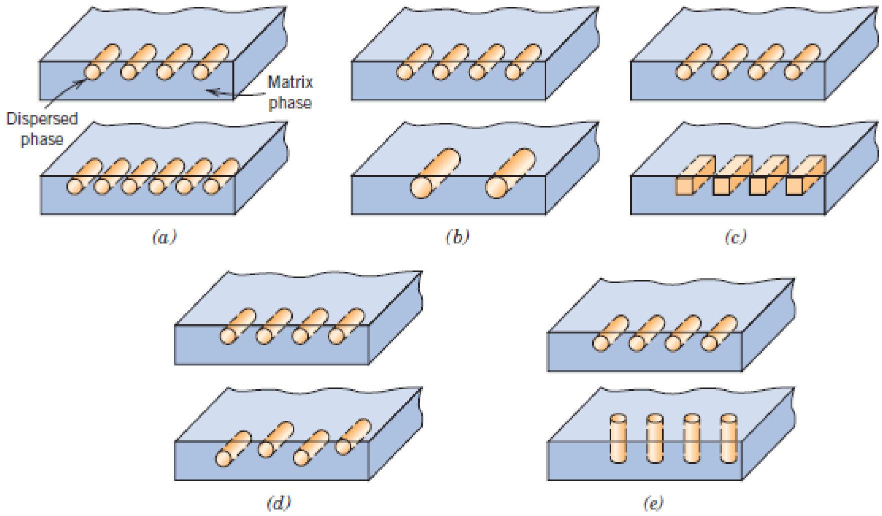

Figure 9.1 Schematic representations of the various geometrical and spatial characteristics of particles of the dispersed phase that may influence the properties of composites: (a) concentration, (b) size, (c) shape, (d) distribution, and (e) orientation.

9.1 Particle-Reinforced Composites المتراكبات المدعمة بالجسيمات

For dispersion-strengthened composites للمركبات المقواة بالتشتت , particles are normally much smaller, with diameters اقطار between 0.01 and 0.1 μ m (10 and 100 nm). Particle–matrix interactions تفاعلات الجسيمات والاساس that lead to strengthening occur on the atomic or molecular level.

Two mathematical expressions تعبيرين رياضية have been formulated for the dependence اعتماد of the **elastic modulus معامل المرونة** on the volume fraction الكسر الحجمي of the constituent phases الاطوار المكونة for a two-phase طورين composite.

$$E_c(u) = E_m V_m + E_p V_p$$

$$E_c(l) = \frac{E_m E_p}{V_m E_p + V_p E_m}$$

In these expressions التعابير, E and V denote تشير الى the elastic modulus and volume fraction, and the subscripts c, m, and p represent تمثل composite, matrix, and particulate phases, respectively.

9.2 Fiber-Reinforced Composites المتراكبات المدعمة بالالياف

Fiber-reinforced composites with exceptionally high specific strengths مع نقاط قوة محددة عالية بشكل استثنائي and moduli have been produced that use low-density fiber فايبر قليل الكثافة and matrix materials. Fiber-reinforced composites are subclassified مصنف فرعي by fiber length طول الفايبر. For short fiber, the fibers are too short to produce a significant improvement in strength. The mechanical characteristics of a fiber-reinforced composite depend تعتكد not only ليس فقط on the properties of the fiber, but also on the degree درجة to which an applied load الحمل المسلط is transmitted to the fibers ينتقل إلى الألياف by the matrix phase. Influence of fiber length, orientation and concentration. **The main fibres used as reinforcements are**: Glass fibres, Carbon fibres, Boron fibres, Ceramic fibres, Metal fibres, Aramid fibres, Natural fibres: sisal, hemp, flax, etc.

Elastic Behavior—longitudinal Loading السلوك المرن لتوزيع الطولي

An expression for the modulus of elasticity of a continuous and aligned fibrous composite in the direction of alignment (or longitudinal direction), E_{cl}, as

$$E_{cl} = E_m V_m + E_f V_f$$

It can also be shown, for longitudinal loading, that the ratio of the load carried by the fibers to that carried by the matrix is

$$\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m}$$

The total load sustained by the composite Fc is equal to the sum of the loads carried by the matrix phase Fm and the fiber phase Ff,

$$F_c = F_m + F_f$$

From the definition of stress, Equation 6.1, F = σA

The expressions for Fc, Fm, and Ff in terms of their respective stresses (sc, sm, and sf) and cross-sectional areas (Ac, Am, and Af)

$$\sigma_c A_c = \sigma_m A_m + \sigma_f A_f$$

$$\sigma_c = \sigma_m \frac{A_m}{A_c} + \sigma_f \frac{A_f}{A_c}$$

where *Am*/*Ac* and *Af*/*Ac* are the area fractions of the matrix and fiber phases

If the composite, matrix, and fiber phase lengths are all equal, *Am*/*Ac* is equivalent to the volume fraction of the matrix, *Vm*, and likewise for the fibers, *Vf* = *Af* /*Ac*.

$$\sigma_c = \sigma_m V_m + \sigma_f V_f$$

If the strains are equalled

$$\epsilon_c = \epsilon_m = \epsilon_f$$

And when each term in Equation is divided by its respective strain,

$$\frac{\sigma_c}{\epsilon_c} = \frac{\sigma_m}{\epsilon_m} V_m + \frac{\sigma_f}{\epsilon_f} V_f$$

Elastic Behavior—Transverse Loading السلوك المرن لتوزيع العرضي

A continuous and oriented fiber composite may be loaded in the transverse direction; that is, the load is applied at a 90° angle to the direction of fiber alignment. For this situation the stress σ to which the composite and both phases are exposed is the same,

$$\sigma_c = \sigma_m = \sigma_f = \sigma$$

This is termed an isostress متساوي الاجهاد state. The strain or deformation of the entire composite ϵ_c is

$$\epsilon_c = \epsilon_m V_m + \epsilon_f V_f$$

but, because $\epsilon = \sigma / E$,

$$\frac{\sigma}{E_{ct}} = \frac{\sigma}{E_m} V_m + \frac{\sigma}{E_f} V_f$$

where E_{ct} is the modulus of elasticity in the transverse direction. Now, dividing through by σ

$$\boxed{\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}}$$

which reduces to

$$E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m} = \frac{E_m E_f}{(1 - V_f)E_f + V_f E_m}$$

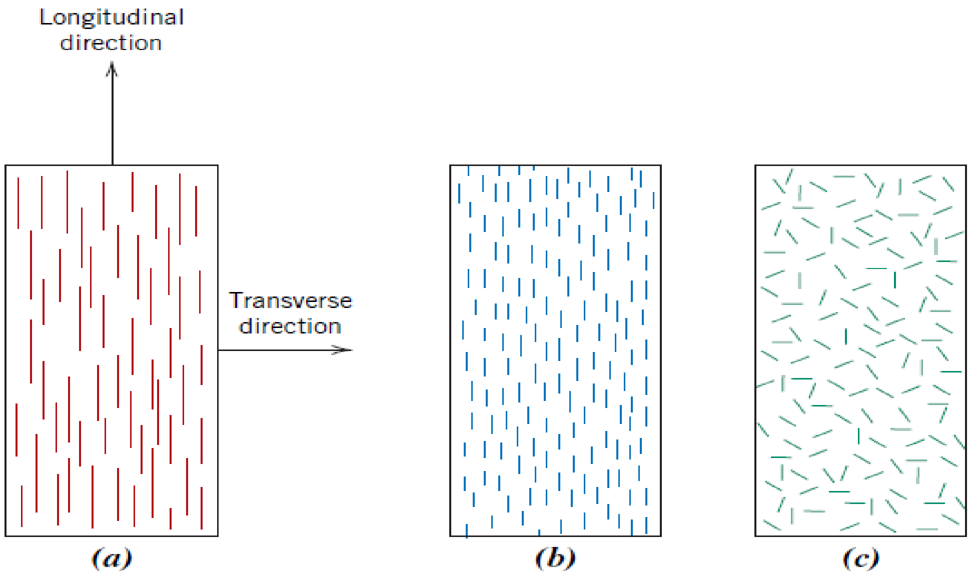

Figure 9.2 Schematic representations of (*a*) continuous and aligned, (*b*) discontinuous and aligned, and (*c*) discontinuous and randomly oriented fiber–reinforced composites.

Example 9.1 home work

A continuous and aligned glass fiber–reinforced composite consists of 40 vol% glass fibers having a modulus of elasticity of 69 GPa and 60 vol% polyester resin that, when hardened, displays a modulus of 3.4 GPa.

(a) Compute the modulus of elasticity of this composite in the **longitudinal** direction.

(b) If the cross-sectional area is 250 mm^2 and a stress of 50 MPa is applied in this **longitudinal** direction, compute the magnitude of the load carried by each of the fiber and matrix phases.

(c) Determine the strain that is sustained by each phase when the stress in part (b) is applied.

Solution

(a) The modulus of elasticity of the composite is calculated using Equation.

$$E_{cl} = E_m V_m + E_f V_f$$

$$E_{cl} = (3.4\text{ GPa})(0.6) + (69\text{ GPa})(0.4)$$
$$= 30\text{ GPa}$$

(b) To solve this portion of the problem, first find the ratio of fiber load to matrix load, using Equation

$$\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m}$$

$$\frac{F_f}{F_m} = \frac{(69GPa)(0.4)}{(3.4GPa)(0.6)} = 13.5$$

$$F_f = 13.5\, F_m.$$

In addition, the total force sustained by the composite F_c may be computed from the applied stress s and total composite cross-sectional area A_c according to

$$F_c = A_c\, \sigma = (250\text{ mm}^2)(50\text{ MPa}) = 12{,}500\text{ N}$$

this total load is just the sum of the loads carried by fiber and matrix phases; that is,

$$Fc = F_f + F_m = 12{,}500\text{ N}$$

Substitution for F_f from the preceding equation yields

$$13.5\, F_m + F_m = 12{,}500\text{ N}$$

or

$$F_m = 860\text{ N}$$

whereas

$$F_f = F_c - F_m = 12{,}500\text{ N} - 860\text{ N} = 11{,}640\text{ N}$$

(c) The stress for both fiber and matrix phases must first be calculated. Then, by using the elastic modulus for each [from part (a)], the strain values may be determined. For stress calculations, phase cross-sectional areas are necessary:

$$A_m = V_m A_c = (0.6)(250\text{ mm}^2) = 150\text{ mm}^2$$

And

$$A_f = V_f A_c = (0.4)(250\ \text{mm}^2) = 100\ \text{mm}^2$$

Thus

$$\sigma_m = \frac{F_m}{A_m} = \frac{860\ \text{N}}{150\ \text{mm}^2} = 5.73\ \text{MPa}$$

$$\sigma_f = \frac{F_f}{A_f} = \frac{11{,}640\ \text{N}}{100\ \text{mm}^2} = 116.4\ \text{MPa}$$

Finally, strains are computed as

$$\epsilon_m = \frac{\sigma_m}{E_m} = \frac{5.73\ \text{MPa}}{3.4 \times 10^3\ \text{MPa}} = 1.69 \times 10^{-3}$$

$$\epsilon_f = \frac{\sigma_f}{E_f} = \frac{116.4\ \text{MPa}}{69 \times 10^3\ \text{MPa}} = 1.69 \times 10^{-3}$$

Therefore, strains for both matrix and fiber phases are identical.

9.3 Polymer-Matrix Composites

Polymer–matrix composites (PMCs) consist of a polymer resin as the matrix and fibers as the reinforcement medium الوسط المدعم.

9.3.1 Glass Fiber–Reinforced Polymer (GFRP) Composites:

Fiberglass is simply a composite consisting of glass fibers, either continuous or discontinuous, contained within a polymer matrix;

9.3.2 Carbon Fiber–Reinforced Polymer (CFRP) Composites:

Carbon is a high-performance fiber material that is the most commonly used reinforcement in advanced polymer-matrix composites.

9.3.3 Aramid Fiber–Reinforced Polymer Composites

Aramid fibers are high-strength, high-modulus materials. They are especially desirable for their outstanding strength-to-weight ratios. The aramid fibers are most often used in composites having polymer matrices.

Table 1 comparation between Glass, Carbon, and Aramid fibers.

Property	Glass (E-Glass)	Carbon (High Strength)	Aramid (Kevlar 49)
Specific gravity	2.1	1.6	1.4
Tensile modulus			
Longitudinal [GPa (10^6 psi)]	45 (6.5)	145 (21)	76 (11)
Transverse [GPa (10^6 psi)]	12 (1.8)	10 (1.5)	5.5 (0.8)
Tensile strength			
Longitudinal [MPa (ksi)]	1020 (150)	1240 (180)	1380 (200)
Transverse [MPa (ksi)]	40 (5.8)	41 (6)	30 (4.3)
Ultimate tensile strain			
Longitudinal	2.3	0.9	1.8
Transverse	0.4	0.4	0.5

9.4 Hybrid Composites المركبات الهجينة

A relatively new fiber-reinforced composite is the hybrid هجينة, which is obtained by using two or more different kinds of fibers نوعين من الفايبر in a single matrix; hybrids have a better all-around combination of properties than composites containing only a single fiber type. The most common system, both carbon and glass fibers are incorporated into a polymeric resin.

9.5 Structural Composites المتراكبات الهيكلية

A structural composite is a multi-layered متعدد الطبقات and normally low-density composite used in applications requiring structural integrity, ordinarily high tensile, compressive, and torsional strengths and stiffnesses. The properties of these composites depend not only on the properties of the constituent materials, but also on the geometrical design التصميم الهندسي of the structural elements. Laminar composites المركبات الصفائحية and sandwich panels الواح السندوج are two of the most common structural composites.

9.5.1 Laminar Composites المركبات الصفائحية

A laminar composite is composed of two-dimensional sheets الواح ثائية الابعاد bonded تربط to one another. Each ply كل طبقة has a preferred high-strength direction, such as is found in continuous and aligned fiber–reinforced polymers. A multi-layered structure تركيب متعدد الطبقات such as

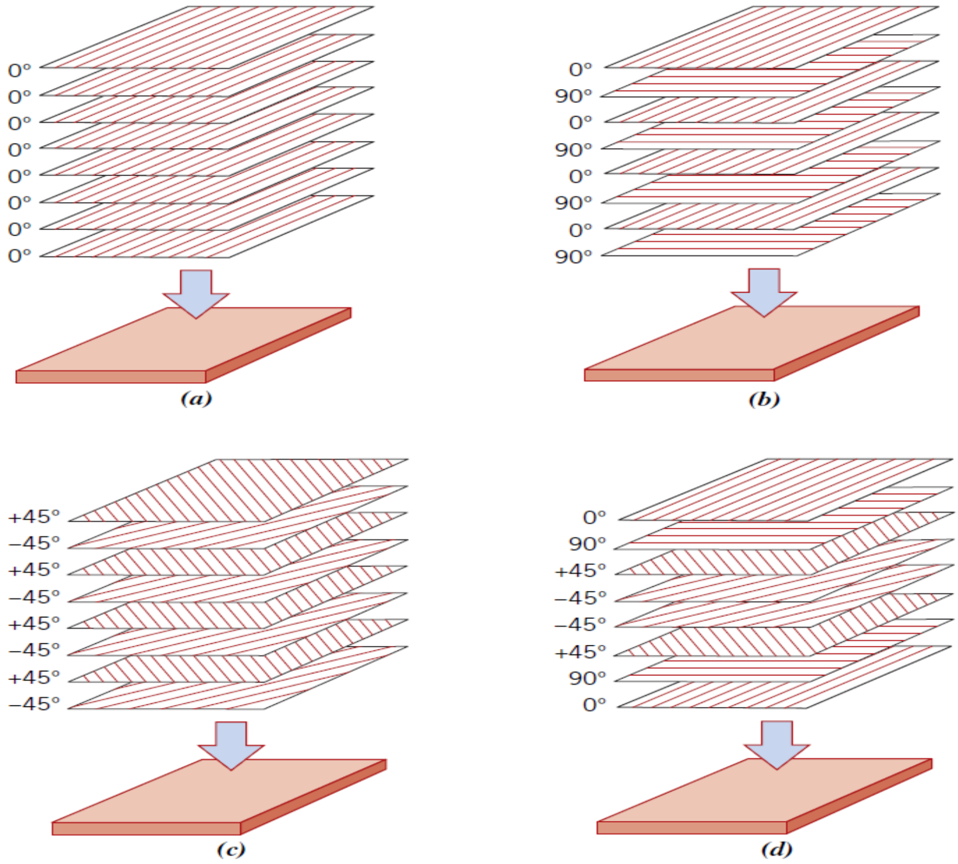

Figure 9. 3 schematics for laminar composites. (a) Undirectional; (b) cross-ply; (c) angle-ply; and (d) multidirectional.

9.5.2 Sandwich Panels الواح السندوج

Sandwich panels, a class of structural composites, are designed تصمم to be panels having relatively high stiffnesses and strengths. A sandwich panel consists of two outer sheets, faces that are separated by and adhesively bonded ترتبط بلاصق to a thicker core قلب سميك.

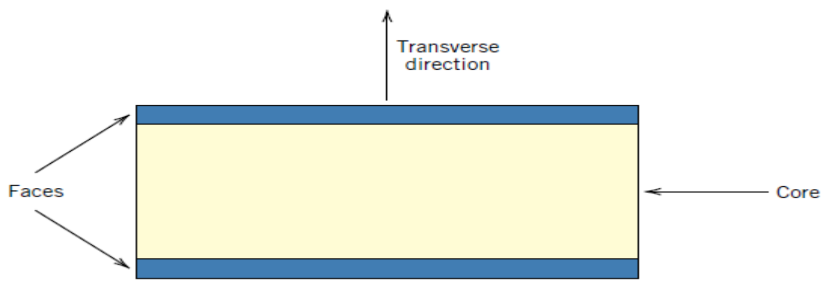

Figure 9.4 Schematic diagram showing the cross section of a sandwich panel.

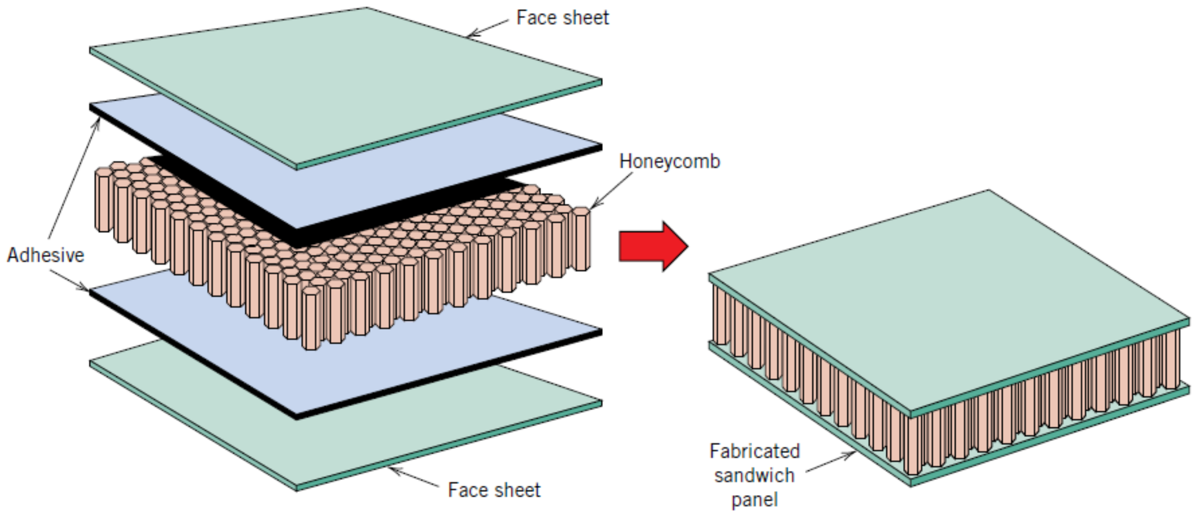

Figure 9.5 Schematic diagram showing the construction of a honeycomb خلية نحل core sandwich panel.

9.6 Nanocomposites

The material's world عالم المواد is experiencing a revolution يشهد ثورة with the development بتطوير of a new class نوع جديد composite materials—the nanocomposites. Nanocomposites are composed تتكون of nanosized حجم نانوي particles جسيمات (or nanoparticles جسيمات نانوية) that are embedded تغمر in a matrix material في المادة الاساس. They can be designed يمكن ان تصمم to have mechanical, electrical, magnetic, optical, thermal, biological, and transport properties that are superior to conventional filler materials التي تتفوق على مواد الحشو التقليدية; furthermore, these properties can be tailored تصمم for use in specific applications. For these reasons لهذه الاسباب, nanocomposites are becoming important مهمة in a number of modern technologies.

Reference

1- Materials _Science_ and _Engineering_9th .pdf · version 1