Biomaterials

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Composite Biomaterials

Biomaterials are solids which contain two or more distinct constituent materials or phases, on a scale larger than the atomic. The tem "composite" is usually reserved for those materials in which the distinct phases are separated on a scale larger than the atomic, and in which properties such as the elastic modulus are significantly altered in comparison with those of a homogeneous material. Accordingly, reinforced plastics such as fiberglass as well as natural materials, such as bone are viewed as composite materials. Natural composites often exhibit hierarchical structures in which particulate, porous, and fibrous structural features are seen in different micro-scales.

Composite materials offer a variety of advantages in comparison with homogeneous materials. Those include the ability for the scientist or engineer to exercise considerable control over material properties. This is the potential for stiff, strong, light-weight materials as well as for highly resilient and compliant materials. Some applications of composites in biomaterial applications are:

(1) Dental filling composites;

(2) Reinforced methyl methacrylate bone cement and ultra-high molecular weight polyethylene;

(3) Orthopedic implants with porous surfaces.

Structure

The properties of composite materials depend very much upon structure. Composites differ from homogeneous materials in that considerable control can be exerted over the larger scale structure, and hence over the desired properties.

In particular, the properties of a composite material depend upon the shape of the heterogeneities, upon the volume fraction occupied by them, and upon the interface among the constituents. The shape of the heterogeneities in a composite material is classified as follows:

a- The particle, with no long dimension;

b- The fiber, with one long dimension;

c- The platelet or lamina, with two long dimensions.

Bonds on Properties

Mechanical properties in many composite materials depend on structure in a complex way, however for some structures; the prediction of properties is relatively simple. The simplest composite structures are the idealized Voigt and Reuss models, shown in Fig.2. The dark and light areas in these diagrams represent the two constituent materials in the composite. In contrast to most composite structures, it is easy to calculate the stiffness of materials with the Voigt and Reuss structures, since in the Voigt structure the strain is the same in both constituents, in the Reuss structure the stress is the same. The Young's modulus, E, of the Voigt composite is given by:

$$E = E_i V_i + E_m [1 - V_i]$$

Where E_i is the Voigt modulus of the inclusions,

V_i is the volume fraction of the inclusions,

E_m is the Young's modulus of the matrix.

The Reuss stiffness R, is less than that of the Voigt model

$$E = \frac{V_i}{E_i} + \frac{1 - V_i^{-1}}{E_m}$$

The Voigt and Reuss models provide upper and lower bounds respectively upon the stiffness of a composite of arbitrary phase geometry. For composite materials which are isotropic, the more complex relations of Hashin and Shtrikman provide

tighter bounds upon the moduli both the Young's and shear moduli must be known for each constituent to calculate these bounds.

An isotopic material has the same material properties in any direction.

Anisotropic composites offer superior strength and stiffness in comparison with isotropic ones.

Particulate Composites

It is often convenient to stiffen or harden a material, commonly a polymer, by the incorporation of particulate inclusions. The shape of the particles is important. In isotropic systems, stiff composite, followed by fibers and the last effective geometry for stiff inclusions is the spherical particles.

Particle reinforcement has been used to improve the properties of bone cement. For example, inclusion of bone particles in PMMA cement somewhat improves the stiffness and improves the fatigue life considerably. Moreover, the bone particles at the interface with the patient's bone are ultimately resorbed and are replaced by ingrown new bone tissue.

Rubber, used in catheters, rubber gloves, etc is usually reinforced with very fine particles of silica (SiO_2) to make the rubber stronger and tougher.

Teeth with decayed regions have traditionally been restored with metals such as silver amalgam. Metallic restoration is not considered desirable for interior teeth for cosmetic reasons. Acrylic resins and silicate cements had been used for anterior teeth, but their poor material properties led to short service life and clinical failures. Dental composite resins have virtually replaced these materials and are

very commonly used to restore posterior teeth as well as anterior teeth.

The dental composite resins consist of a polymer matrix and stiff inorganic inclusions. The inorganic inclusions confer a relatively high stiffness and high wear resistance on the material. Available dental composite resins use quartz, barium glass and colloidal silica as fillers. Fillers have particle size from 0.04 to 13mm, and concentrations from 33 to 78% by weight.

In restoring a cavity, the dentist mixes several constituents, then places them in the prepared cavity to polymerize. For this procedure to be successful the viscosity of the mixed paste must be sufficiently low and the polymerization must be controllable.

Dental composites have a Young's modulus in the range 10 to 16GPa, and the compressive strength from 170 to 260 MPa. These composites are still considerably less stiff than dental enamel, which contains about 99% mineral.

The thermal expansion of dental composites, as with other dental materials exceeds that of tooth structure. Moreover, there is a contraction during polymerization to 1.2 to 1.6%. These effects are thought to contribute to leakage saliva, bacteria, etc. at the interface margins. Such leakage in some cases can cause further decay of the tooth. All the dental composites exhibit creep.

Fibrous Composites

Fibers incorporated in a polymer matrix increase the stiffness, fatigue life, and other properties. Fibers are mechanically more effective in achieving a stiff, strong composite than particles. Materials can be prepared in fiber form with very few defects which concentrate stress. Fibers such as graphite are stiff (Young's modulus is 200–800GPa) and strong (the tensile strength is 2.7– 5.5GPa). Composites made from them can be as strong as steel but much lighter.