Smart Materials, Adaptive Structures, and Intelligent Mechanical Systems

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Lecture 13

Introduction to Composites

References for this Lecture

1. Analysis and Performance of Fiber Composites, Agarwal, B.D. and Broutman, L. J., John Wiley & Sons.

2. Mechanics of Composite Materials, Jones, R. M., Mc-Graw Hill

3. Structural Analysis of Laminated Composites, Whitney, J. M., Technomic

4. Nonlinear Analyis of Plates, Chia, C., McGraw-Hill International Book Company

Lecture Overview

- What are “composites”?
- Importance and areas of application
- Classification
- Advantages of fiber-reinforced composites

What are “composites”?

- Composite: Two or more chemically different constituents *combined macroscopically* to yield a useful material.

- Examples of naturally occurring composites
  - Wood: Cellulose fibers bound by lignin matrix
  - Bone: Stiff mineral “fibers” in a soft organic matrix permeated with holes filled with liquids
  - Granite: Granular composite of quartz, feldspar, and mica

What are “composites”?

- Some examples of man-made composites
  - Concrete: Particulate composite of aggregates (limestone or granite), sand, cement and water
  - Plywood: Several layers of wood veneer glued together
  - Fiberglass: Plastic matrix reinforced by glass fibers
  - Cemets: Ceramic and metal composites
  - Fibrous composites: Variety of fibers (glass, kevlar, graphite, nylon, etc.) bound together by a polymeric matrix

These are not composites!

- Plastics: Even though they may have several “fillers”, their presence does not alter the physical properties significantly.
- Alloys: Here the alloy is *not macroscopically heterogeneous*, especially in terms of physical properties.
- Metals with impurities: The presence of impurities does not significantly alter physical properties of the metal.

Where are composites used?

- Automotive industry: Lighter, stronger, wear resistance, rust-free, aesthetics
  - Car body
  - Brake pads
  - Drive shafts
  - Fuel tanks
  - Hoods
  - Spoilers

Where are composites used?

- Aerospace: Lighter, stronger, temperature resistance, smart structures, wear resistance
  - Aircraft: Nose, doors, struts, trunnion, fairings, cowlings, ailerons, outboard and inboard flaps, stabilizers, elevators, rudders, fin tips, spoilers, edges
  - Rockets & missiles: Nose, body, pressure tanks, frame, fuel tanks, turbo-motor stators, etc.
  - Satellites: Antennae, frames, structural parts

Where are composites used?

- Sports: Lighter, stronger, toughness, better aesthetics, higher damping properties
  - Tennis
  - Bicycles
  - Badminton
  - Boats
  - Hockey
  - Golfing
  - Motorcycles …

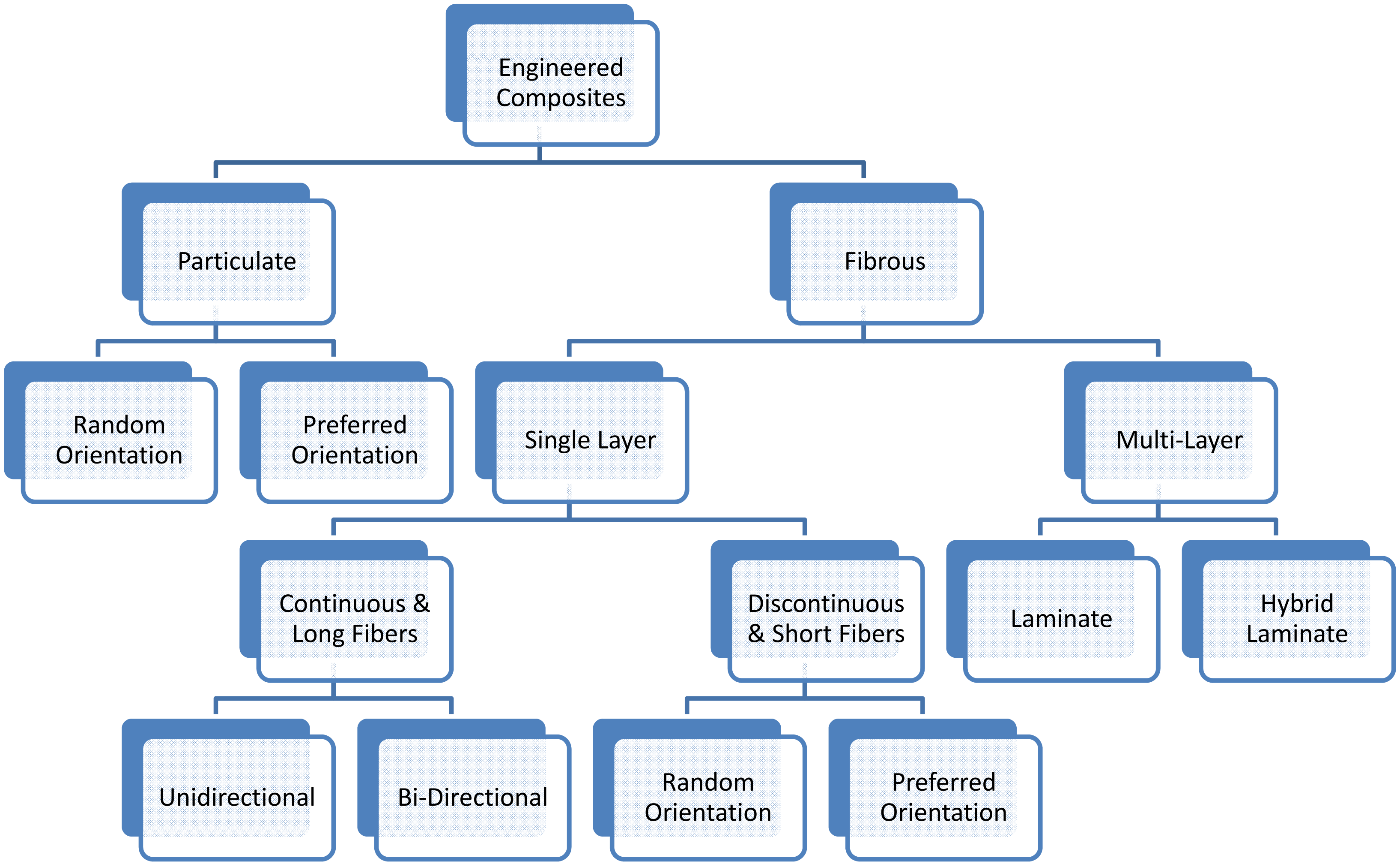
Where are composites used?

- Transportation & Infrastructure: Lighter, stronger, toughness, damping
  - Railway coaches
  - Bridges
  - Ships and boats
  - Dams
  - Truck bodies and floors
  - RV bodies

Where are composites used?

- And many more industry sectors
  - Biomedical industry
  - Consumer goods
  - Agricultural equipment
  - Heavy machinery
  - Computers
  - Healthcare

Classification of Composites



Classification of Composites

- *Particulate composites* have one or more material particles suspended in a binding matrix. A *particle* by definition is not “long” vis-à-vis its own dimensions.

- *Fibrous composites* have fibers of reinforcing material(s) suspended in binding matrix. Unlike particles, a fiber has high length-to-diameter ratio, and further its diameter may be close to its crystal size.

Classification of Composites

- Particulate composites:
  - Random orientation: Orientation of particle is randomly distributed in all directions (ex: concrete)
  - Preferred orientation: Particle orientation is aligned to specific directions (ex: extruded plastics with reinforcement particles)

Note: *Particulate composites in general do not have high fracture resistance unlike fibrous composites. Particles tend to increase stiffness of the materials, but they do not have so much of an influence on composite's strength. In several cases, particulate composites are used to enhance performance at high temperatures. In other case, these composites are used to increase thermal and electrical properties. In cemets, which are ceramic-metal composites, the aim is to have high surface hardness so that the material can be used to cut materials at high speeds, or is able to resist wear.*

Classification of Composites

- Fibrous Composites: In general, materials tend to have much better thermo-mechanical properties at small scale than at macro-scale. This is shown in the following table.

Material	Fiber Tensile Strength (GPa)	Bulk Tensile strength(GPa)
Glass	3.5 to 4.6	0.7 - 2.1
Tungsten	4.2	1.1 - 4.1
Beryllium	1.3	0.7
Graphite	2.1 to 2.2.5	Very low

At macro-scale, imperfections in material have an accumulated effect of degrading bulk mechanical properties of materials significantly. This is one reason why fibrous composites have been developed to harness micro-scale properties of materials at larger scales. Man-made fibers, have almost no flaws in directions perpendicular to their length. Hence they are able to bear large loads per unit area compared to bulk materials.

Classification of Composites

- Fibrous Composites:
  - Single-layer: These are actually made of several layers of fibers, all oriented in the same direction. Hence they are considered as "single-layer" composites. These can be further categorized as:
    - Continuous and long fibers: Examples include filament wound shells. These may be further classified as:
      - Unidirectional reinforcement
      - Bidirectional reinforcement

Classification of Composites

- Fibrous Composites (continued):
    - Discontinuous and short-fibers: Examples include fiber glass bodies of cars. These may be further classified as:
        - Randomly oriented reinforcement
        - Reinforced in preferred directions
  - Multi-layer: Here, reinforcement is provided, layer-by layer in different directions.
    - Laminate: Here, the constituent material in all layers is the same.
    - Hybrid laminates: These have more than one constituent materials in the composite structure.

Advantages of Composites

- Composites are engineered materials. We can engineer them specifically to meet our needs on a case-to-case basis. In general, following properties can be improved by using composite materials.
  - Strength
  - Modulus
  - Weight
  - Fatigue
  - Vibration damping
  - Resistance to wear
  - Electrical conductivity
  - Thermal conductivity
  - Behavior at extreme temps.
  - Acoustical insulation
  - Aesthetics
  - Resistance to corrosion

Limitations of Composites

- Like all things in nature, composites materials have their limitations as well. Some of the important ones are:
  - Anisotropy: A large number of composites have direction dependent material properties. This makes them more difficult to understand, analyze and engineer, vis-à-vis isotropic materials.

  - Non-homogenous: Further, these materials by definition are not homogenous. Hence their material properties vary from point-to-point. This factor as well makes them difficult to model, and analyze.

Limitations of Composites

– Costly: Composite materials are in general expensive. Thus, they are used only in applications where their benefits outweigh their costs.

– Difficult to fabricate: Further, fabricating structures from such materials is difficult, time taking, and expensive.

– Sensitivity to temperature: Laminated composites are particularly sensitive to temperature changes. They come in with residual thermal stresses, because they get fabricated at high temperatures, and then cooled. Such a process locks in thermal stresses into the structure.

– Moisture effects: Laminated composites are also sensitive to moisture, and their performance varies significantly when exposed to moisture for long periods of time.