Module 3: An Introduction to Composite Materials

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Topics Covered in Module 2

Induced Strain Actuation (ISA) – Uniform Strain Model

ISA – Euler-Bernoulli Model

ISA Model for Magnetostrictive Mini Actuator

Active Fibre Composite Actuation
Organization of this Lecture

- What is Composite Material?
- What are Laminated Composites?
- Various Fibres for Composite Reinforcement.
What is Composite?

- Natural or artificial mixtures of two or more distinct phase/constituents
- Primary engineering goal is to achieve a better balance of properties from the combination of materials
- Mixtures may consist of metals, polymers or ceramics
Types of Particulate/Whisker Reinforcement

- Spherical
- Irregular
- Angular and crystalline

- Off-axis aligned whiskers
- Randomly oriented whiskers
- Axial aligned whiskers
Types of Composite

- Particulate composite
- Flake composite
- Fiber reinforced composite
- Laminated composite
Fabrics

Random short fibers
Oriented short fibers
Continuous fibers

Plain Fibrous Layers

plain weave
tri-axial weave
bi-plane weave

Woven Fabrics
Glass Fibre

- Generic Name, available in three forms: E-Glass (Insulating), C-Glass (Anti corrosive) and S-Glass (High Silica - higher temperature application)

- Major Constituent SiO₂ (55-65%) & Al₂O₃ (8-25%), other constituent: CaO, Na₂O etc.

- Manufacturing - Molten Glass, fed through Platinum Bushings

- Pure crystalline glass melts at 1800°C breaking Si-O bond, impurities substitute some of the bonds and hence reduce Tₘ.
Glass Fibre contd..

• Nextel Fibres of 3M uses relatively low-temperature Sol-Gel technique
• Filaments susceptible to surface damage - hence *sizing* is necessary
• E-glass density-2500 kg/m³, Tensile strength - 1750 Mpa, E-70 Gpa
• susceptible to moisture absorption, strength decreases
• Used in roofing, frames, tanks, etc.
Boron Fibre

- Properties borderline between metals and non-metals. A good conductor at high temps. Chemically closer to silicon. Crystalline boron is inert chemically.
- First synthetic fibre, used since 1960 (Space Shuttle), very brittle to directly draw.
- Deposited through CVD on fine (10-12μm) Tungsten wire / some times on Carbon core.
- Hydrogen Gas used to reduce Boron Trihalide:
  - \[ 2BX_3 + 3H_2 \rightarrow 2B + 6HX \]
Boron fibre contd..

- High temperature around 1000°C req. - hence Tungsten base is required - resistive heating of wire.
- Temperature to be controlled during CVD - beyond 1300°C unwanted crystal-form occurs
- Core diffusion forming WB₄, W₂B₅ etc causes unwanted increase in core thickness - hence SiC coating is used
- Density 2340 Kg/m³, Tm-2040°C, expensive - used in F14, F15, space shuttle
Carbon Fibre

- Generic Term, Ex-PAN, Ex-Cellulose, Ex-Pitch
- Density -1700-1600 -2200 Kg/m\(^3\), E - 230 - 390 - 340,690 Gpa

Manufacturing steps -
- Fibearization - to make a precursor fibre - wet,dry or melt spinning
- Stabilization (to prevent from melting)
Carbon Fibre contd..

- Carbonisation - to remove impurity
- Graphitisation to enhance strength etc.
- Pan - ladder polymer, Polyethylene with a nitrile CN group in every alternate carbon atom
- PAN stabilisation 250°C, carbonisation 1000-1500°C, Graphitisation up to 3000°C
Carbon Fibre ..

- Ex-Cellulose from Cotton, Rayon etc. expensive not commonly used
- Ex-pitch, source PVC, Coal-Tar etc. quite cheap
- Anisotropic, Liquid Crystalline Mesophase could be directly spun
- Due to high alignment/orientation, high E is possible
- Used in shuttle booster, turbine & compressor blades, prosthetics
Organic Fibre: Kevlar

- Aramid Fibre – Generic Term, commercial form Kevlar & Nomex (Dupont), Technora (Teijin), Twaron (Akzo)
- Processed from the solution polycondensation of diamines and diacid halides at low temperature
- Mesophase order (random – liquid crystalline – nematic) controls mechanical property
Kevlar contd..

- Strong covalent bond axially, weak hydrogen bond transversely
- Density 1440 Kg/m$^3$, Tensile Strength (2.8 Gpa), Modulus (65-125 Gpa)
- Negative Coeff. of expansion due to kinks
- UV sensitive – degrades
- Kevlar – rubber reinforcement, K-29 – ropes, cables etc., K-49 aerospace & automotive applications
Org Fib: Polyethylene

- Molecular chain extension coupled with orientation
- HDPE 90-95% crystalline
- Melt crystalised polyethylene is drawn to a very high ratio (200)
- Surface treatment necessary to for bonding (involving cold gas plasma – Amonia or Argon)
- Density 970 Kg/m³, Tensile Strength 2.7 GPa, Modulus 119 GPa
Ceramic Fibre

- Alkyl Aluminium or Alkoxy Aluminium polymerised to form Precursor fibre in sol phase
- Extruded and coagulated to form gel fibres
- Dried and Calcined to form final fibre (3-5 micron) Hazardous for health!
- Inviscid melt technique is often used to reduce cost and draw fibre at low temperature – trade off high fibre dia >100 micron
Ceramic Fibres ..

- Density 2000-3000 Kg/m$^3$, Tensile strength – 2Gpa, E- 150-370 Gpa
- Use as refractory materials, reentry vehicle, shuttle etc
- Fine fibres have the best thermal insulation properties and good thermal shock resistance, and do not crumple up when heated and cooled over and over again.
Basalt Fibre

- Raw material for producing basalt fibre is a rock of the volcanic origin.
- Fibres are received by melting basalt stones down at the temperature of 1400°C. Melted basalt mass passes through the platinum bushing and is extended into fibres.
- Because of its wide range of temperature resistance from –260°C to 800°C basalt fibre products will outperform GFRP!
References


END OF LECTURE 12