UNIVERSITÀ DI PISA

COMPOSITE MATERIALS SCIENCE AND ENGINEERING

ANDREA LAZZERI

Anno accademico	2021/22
CdS	MATERIALS AND NANOTECHNOLOGY
Codice	738II
CFU	6

Moduli	Settore/i	Tipo	Ore	Docente/i
COMPOSITE MATERIALS SCIENCE AND ENGINEERING	ING-IND/22	LEZIONI	48	LAURA ALIOTTA ANDREA LAZZERI

Learning outcomes

Knowledge
After the completion of the course, the students will:

- Know the mechanical behaviour of composite materials.
- Know the processing and fabrication of different types of composites and understand the influence of fabrication and environment on the properties of composites.
- Know the wide design flexibility that composites can afford.

Assessment criteria of knowledge
Knowledge will be assessed via:

- ongoing assignments
- final oral exam.

Skills
Upon completion of the subject, students will be able to:

1. Demonstrate a good understanding of types and properties of composites;
2. Possess knowledge in processing and fabrication of structural composites;
3. Understand mechanical behaviors of composite materials;
4. Analyze composite laminates using classic laminate theory and apply failure criteria to assess composite structures subject to various types of loading.

Assessment criteria of skills
Behaviors will be assessed via:

- ongoing group assignments
- final oral exam.

Behaviors
After the completion of the course, the students will be able to:

- predict composite properties from fiber and matrix properties and volume fractions for both long and short fiber composites.
- understand how anisotropic elasticity differs from isotropic elasticity.
- compute the properties of a composite laminate with any stacking sequence.
- predict the loads and moments that cause an individual composite layer and a composite laminate to fail.
- compute hygrothermal loads in composites.
- understanding of how composites are used in the design of structures.

Assessment criteria of behaviors

Behaviors will be assessed via:

- ongoing group assignments
- final oral exam.

Prerequisites

Having attended the course Mechanical Behaviour of Materials, 738II or equivalent.

Teaching methods

Lectures are used to deliver the fundamental knowledge in relation to advanced composite materials (outcomes a to d).
Tutorials are used to illustrate the application of fundamental knowledge to practical situations (outcomes a to d).
Experiments are used to relate the concepts to practical applications and students are exposed to hand-on experience, proper use of equipment and application of analytical skills on interpreting experimental results (outcomes a and b).

Syllabus

1. Definition of composite material, Classification based on matrix and topology, Constituents of composites, Interfaces and Interphases, Distribution of constituents, Nano-composites.
2. Reinforcements for composites. Fibres. Basic properties of fibres and engineering materials. Fibre types. Fibre finishes. Fabrics. Fabric types. Core materials for sandwich panels. Foam Cores. Honeycombs. Fillers.
3. Polymer matrices I. Thermosetting polymer matrix. Types of resins. Gelation, curing and post-curing. Chemorheological behavior of thermosets, time-temperature-transition relationships in thermosets.
4. Unsaturated polyester resins. Different types of resin prepolymer. Vinyl ester resins. Various reactive diluents. Mechanism of curing: free radical chain polymerization. Initiators/Catalysts: Benzoyl peroxide (BPO), Dicumyl peroxide (DCP), Methyl ethyl ketone peroxide (MEKP), Cumene hydroperoxide (CHP). Inhibitors and Retarders: Benzoquinone, Hydroquinone, Chloranil, Diphenyl amine, 2,4 Pentanedione (acetylacetone). Promoters and Accelerators: Cobalt naphthenate and Dimethyl aniline. Additives: Thixotropic; Pigment; Filler; Chemical/fire resistance.
5. Epoxy resins. Mechanism of cure: step polymerization. Diglycidyl ether of bisphenol A (DGEBA). Multifunctional epoxies. Rubber toughened epoxies. Epoxy novolacs, Glycidyl amine epoxy resins. Amine curing agents: Diethylene triamine (DETA), Aminoethyl piperazine (AEP), Meta-phenylenediamine (MPDA), Methylene dianilene (MDA). Anhydride curng agents: Nadic methyl anhydride (NMA), Phthalic anhydride (PA). Phenolics, cyanate esters (CEs), bismaleimides (BMIs), benzoxazines and polyimides.
6. Polymer matrices II. Thermoplastic polymer matrixes. Engineering and high performance thermoplastics. Bioplastics. Comparison of resin properties.
7. Metal Matrices, Basic Requirements in Selection of constituents. Ceramic Matrices for Ceramic Matrix Composite Materials (CMC).
8. Fibre architecture. Fibre packing arrangements, Clustering of fibres and particles. Long fibres. Laminates, Woven, braided and knitted fibre arrays, Characterisation of fibre orientations in a plane. Short fibres. Fibre orientation distributions in three dimensions, Fibre length distributions, Voids, Fibre orientation during processing.
9. Elastic deformation of long-fibre composites. Axial stiffness. Rule of Mixtures.Voigt model. Transverse stiffness. Reuss model. Halpin-Tsai equation. Eshelby method. Shear stiffness. Poisson contraction effects.
10. Elastic deformation of laminates. Elastic deformation of anisotropic materials. Off-axis elastic constants of laminae. Engineering constants. Loading of a stack of plies. Stresses and distortions. Stacking sequence. Balanced laminates, Stresses in individual plies of a laminate, Coupling stresses and symmetric laminates.
11. Stresses and strains in short-fibre composites. The shear lag model. The stress transfer length. Transfer of normal stress across fibre ends. Prediction of stiffness. Onset of inelastic behaviour. Critical aspect ratio. The equivalent homogeneous ellipsoid and the Eshelby method. The background stress and the Mori-Tanaka mean-field approximation. Tandon and Wang equations.
12. The interface region. Bonding mechanisms. Adsorption and wetting. Dupre equation. Interdiffusion and chemical reaction. Electrostatic attraction. Mechanical locking. Residual stresses. Experimental measurement of bond strength. Single-fibre pull-out test. Single-fibre push-out and push-down tests. intralaminar shear strength.
13. Coupling and surface agents. Organofunctional silicon compounds. Silane coupling agents. Surface treatments for carbon and kevlar fibres. Toughness-reducing coatings. Non-coupling surface treatments for particulate fillers: long chain (C16-20) fatty acids. The interphase region.
14. Strength of composites. Failure modes of long-fibre composites. Axial tensile failure. Crack-blunting mechanism. Transverse tensile failure. Shear failure. Failure of laminae under off-axis loads. Maximum stress criterion. Tsai-Hill criterion. Strength of laminates. Tensile cracking. Interlaminar stresses. Edge effects.
15. Toughness of composites. Matrix and fiber fracture. Interfacial debonding. Work of fracture. Frictional sliding and fibre pull-out. Sub-critical crack growth. Fatigue. Stress corrosion cracking.
16. Thermal behaviour of composites. Thermal expansion and thermal stresses. Thermal cycling of unidirectional composites. Thermal cycling of laminates. Creep. Axial creep of long-fibre composites. Transverse creep and discontinuously reinforced composites. Conductivity of composites. Interfacial thermal resistance.
17. Fabrication of polymer matrix composites. Lay-up methods. Filament Winding. Pultrusion. Resin Transfer Moulding (RTM). Infusion processes. Secondary bonding. Science of adhesion. Pre-treatment prior to bonding. Adhesive selection. Joint design. Core materials. Core formats. Thermoforming. Sandwich construction. Wet laminating and infusion. Pre-impregnates.
18. Fabrication of Metal Matrix Composites: solidification processing of composites - XD process, Spray processes - Osprey Process, Rapid solidification processing, Dispersion Processes - Stir-casting & Compocasting, Screw extrusion, Liquid-metal impregnation technique - Squeeze casting, Pressure infiltration, Lanxide process), Principle of molten alloy infiltration, rheological behaviour of melt-particle slurry, Synthesis of In

situ Composites.
19. Fabrication of ceramic matrix composites - Various techniques of vapour deposition, Chemical Vapour Infiltration (CVI), Polymer Impregnantion and Pyrolysis (LSI) Liquid phase method, Liquidi Silicon Infiltration (LSI) and Hot pressing. Non-oxide ceramic matrix composites: C/C, C/SiC, SiC/SiC composites. Oxide ceramic matrix composites.
20. Secondary Processing and Joining of Composite: Forging and extrusion of composites – critical issues, dynamic recovery and dynamic recrystallization, mechanical properties; Induction Heating, Fusion Bonding, Ultrasonic welding, Gas tungsten arc welding, Gas metal arc welding, Resistance spot & seam welding, Resistance brazing, Resistance spot joining, Resistant spot brazing, Resistance welding of thermoplastic-graphite composite, Weld bonding, Brazing of MMC.
Laboratory Experiments
Typical experiments:
1. Manufacturing of composites
2. Tensile test of composites
3. Inspection of composites
4. Repair of a composite structure

Bibliography

Hull, D.; Clyne, T.W. *An introduction to composite materials*. 2nd ed. New York: Cambridge University Press, 1996. ISBN 521381908.
Matthews, F.L.; Rawlings, R.D. *Composite materials: engineering and science*. Boca Raton: Cambridge: CRC; Woodhead Publishing, 1999. ISBN 0849306213.
Chawla, K.K. *Composite materials: science and engineering*. 3rd ed. New York: Springer, 2012. ISBN 9780387743646.

Non-attending students info

Contact the teacher for the didactical material and course information.

Notes

Although synthetic composites have existed for thousands of years, the high technology of advanced composites has been used in the aerospace industry only for the last fifty years. The applications are becoming diverse - from aircraft structures and missile canisters to tennis racquets and fishing rods. The objective of this course is to analyze and design structures made of fiber reinforced composite materials.

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