The Train the Trainers handbook in 6 different languages

TECONAUT
USING DEEP TECH TO FACILITATE THE ECO TRANSITION IN THE NAUTICAL SECTOR

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A digital handbook in English, Spanish, French, Greek, Polish, German and Turkish.

Project number	**101139940**
Title of the document	The Train the Trainers handbook in 6 different languages
Date	12 January 2026
Document type	Guidelines
Distribtuion	NTUA
Dissemination level	Public
Version	1

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1 Introduction

1. Introduction

This handbook has been prepared as a practical reference tool for trainers participating in the EU-funded project **TEcoNaut** – a European initiative designed to strengthen collaboration between higher education providers, VET institutions, and the boatbuilding industry. The project aims to identify emerging skills needs, address existing skills gaps, and support long-term cooperation across the sector.

Focusing on vocational education and training in sustainable materials for boatbuilding, TEcoNaut supports the industry's transition to innovative, environmentally responsible technologies.

More specifically, the TEcoNaut project aims to achieve its main objective through:

- the development of a Deep Tech materials course for VET, focusing on the use and application of Deep Tech materials, together with a Train the Trainers programme.
- conducting an in-depth "skills gaps" identification phase, the results of which will be connected to ESCO and will make use of the new EU Green Taxonomy.
- awakening an entrepreneurial mindset among students and future workers in the "eco" nautical sector, enabling them to see future business opportunities in the use of sustainable materials and the circularity of boat-building materials, while fostering their resilience skills.
- designing a traineeship programme for HE students with hands-on approaches, allowing them to work on the application of Deep Tech skills within companies. The highly necessary Deep Tech green wave in boat building can only be successfully developed through collaboration among Higher Education institutions researching deep-tech materials, companies building boats in a sustainable, environmentally friendly way using these materials, and VET centres providing qualified staff.

This handbook is intended to complement the **TEcoNaut Course: *Sustainable materials in the boat-building sector***. It provides guidance, recommended practices, and structured resources to support effective delivery of the learning modules and to help trainers achieve defined learning outcomes.

2

The Role of this Handbook

2. The role of this handbook

2.1 Purpose

The purpose of this handbook is to act as the primary reference guide for trainers delivering the **TEcoNaut course**. It provides practical guidance on teaching methodologies, resources, and supplementary materials to support effective learning and ensure consistent delivery of the course's modules.

In addition, the handbook offers "level-up" information on several course topics to provide further context for trainers to respond to more advanced learner questions. By integrating instructional tools, reference materials, and practical insights, the Teacher's Handbook aims to support teachers in delivering a high-quality learning experience in an engaging, interactive environment.

More specifically, the handbook assists trainers in:

- Applying efficient and learner-centred training approaches
- Managing classroom activities and group dynamics
- Monitoring progress against defined learning objectives
- Addressing student questions that extend beyond the core course material.

This handbook is not intended to be restrictive. Trainers are encouraged to adapt and extend the material based on their professional judgement and the needs of their learners.

2.2 Users and Audience

This handbook is primarily intended for trainers involved in **Vocational Education and Training (VET)** and focuses on sustainable boatbuilding. It may also be used as a reference by:

- Educators in higher education institutions
- Training specialists within the maritime and boatbuilding industries
- Professionals involved in supporting or delivering VET activities under the TEcoNaut course.

2.3 Context

This handbook provides a comprehensive framework designed to support trainers in delivering the TEcoNaut course. The framework corresponds to **EQF Level 4** qualification requirements, ensuring consistency with recognised European standards for vocational training (See https://europass.europa.eu/en/description-eight-eqf-levels).

The main content of the Teacher's Handbook is presented below. It is organised to offer teachers/trainers clear guidance, practical tools, and structured support throughout all phases of the training process.

3 Course outline and Support Info for Lessons

4 Training Guidance

5 List of Materials and Equipment

Annex Supporting Presentations and Videos

Briefly, Section 3 provides the course outline for each unit, complemented by level-up information for several topics within each unit's content and tips for conducting the activities described in the course outline. Section 4 serves as a guide to teaching methods and to conducting an engaged. Section 5 presents the list of equipment and materials needed for hands-on activities and for a better understanding of the terminology related to boatbuilding. At the end, Annex includes the presentations delivered at a workshop held in France as part of the TecoNaut project, providing insights into deep-tech materials and mechanical properties.

3 Course Outline and Support Info for Lessons

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3. Course Outline and Support Info for Lessons

In this section, the course's overall framework is presented, outlining how the learning content is organized into units, modules, sub-topics, corresponding activities, and supporting course information. Each unit addresses a key thematic area, ensuring an appropriate balance between theoretical knowledge and practical application. The accompanying tables (see the relevant ***Course Outline*** tables) provide essential information for developing the course material, including topics, intended learning outcomes, estimated duration, and proposed teaching and training methods, to support trainers in planning and delivering the course effectively. These tables also offer learners a transparent overview of the course content and expectations. Activities instructions (see the relevant ***Activities Instructions*** tables) and level-up information (see the relevant ***Level-up Information*** tables) are provided for each unit, organized in tables to facilitate the trainer.

The course structure consists of **five (5) units.** Learners will be trained across the following:

Unit 1: Introduction to sustainability in boat building
Unit 2: Sustainable materials, properties, and performance
Unit 3: Application techniques in manufacturing and repair work
Unit 4: Life Cycle Assessment & Business case
Unit 5: Career planning, opportunities, and challenges

These topics collectively support the development of both technical competence and broader sustainability awareness within the boatbuilding sector.

The descriptions below explain the purpose and scope of each column included in the ***Course Outline*** tables, ensuring consistent interpretation and use across all training contexts.

Module

The column presents the each module of the respective unit.

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Sub-topic

This column refers to each sub-topic of the module.
Note: Text highlighted in bold in the “Sub-topic” column indicates that more detailed information and related activities for the respective sub-topic are provided in the respective ***Activities Instructions*** table.

Sub-topic Breakdown

This column provides detailed information on the subjects and subtopics presented within each unit, reflecting the content defined in the course syllabus. It offers a structured overview of what will be taught under each topic, supporting logical sequencing and comprehensive coverage of the material.

The topic breakdown helps trainers plan and organise their lessons effectively, while also guiding learners through a clear, step-by-step exploration of the subject matter.

Note: Text highlighted in bold in the “Sub-topic breakdown” column indicates the availability of level-up (advanced) information, which is presented in the respective ***Level-up Information*** table.

Learning Outcome

The Learning Outcome column specifies the knowledge, skills, and attitudes that learners are expected to acquire or develop through each activity. These outcomes have been defined to align with the overall curriculum objectives for each unit of the course.
Learning outcomes serve as key indicators for both trainers and learners, ensuring that each activity contributes meaningfully to the intended competence development.

Duration

This column indicates the planned time allocation for each lesson or activity. The duration listed should correspond to the timings specified in the programme syllabus, helping trainers manage session planning and ensure consistency across all training environments.

Teaching and Training Method(s)

This column proposes appropriate teaching and training method(s) for the respective sub-topic.

The ***Activities Instructions*** tables present all activities that can be carried out in class to help students gain a thorough understanding of the basic concepts and knowledge taught in the curriculum. The activities are shown in a table format, providing a structured overview for each unit, with clear instructions and guidance for teachers to organize tasks and guide students effectively.

The ***Level Up Information*** table provides trainers with an expanded overview of the advanced concepts, reference materials, and supplementary resources that complement the main curriculum. Its purpose is to support educators in deepening learners' understanding of sustainable materials, manufacturing methods, regulatory frameworks, and industry developments related to modern boatbuilding. By offering structured access to scientific publications, technical standards, professional tools, and real-world case studies, this section equips teachers with the contextual knowledge needed to confidently guide learners beyond the essentials and into a wider professional and environmental landscape.

Unit 1 gathers comprehensive resources that introduce students to sustainability frameworks, natural material innovations, and environmental assessment methods relevant to marine and coastal industries. It includes reference materials on sustainable marina management, the European Green Deal's long-term climate strategy, advanced research on wood and polymer-based smart materials, and standards such as ISO 12215 that define material properties used in boat structures. Additional content highlights the importance of Life Cycle Assessment (LCA) in reducing environmental impact throughout a vessel's lifespan, together with circular-economy perspectives on waste management and resource efficiency.

Unit 2 focuses on fibers, resins, composite structures, recycling technologies, and mechanical behaviour in modern boatbuilding. The references include scientific publications with comparisons of fiber properties, testing results, and the influence of resin chemistry on performance and durability. The unit also covers essential ISO standards, practical resources on composite mechanics, and detailed case studies on material defects, additive use, compatibilizers, and sandwich structures. A strong emphasis is placed on circularity, with numerous sources exploring thermal, mechanical, and chemical recycling methods, the energy requirements of different processes, and current industry initiatives centred on bio-based alternatives, natural fibers, and sustainable composite materials.

Unit 3 provides teachers with practice-oriented materials related to composite manufacturing processes, fibre architecture, and quality assurance in production. Through technical guides, provider websites, scientific articles, and demonstration videos, this unit explains lamination methods, resin infusion, defect prevention, and steps involved in constructing natural-fiber or hybrid composite components. It also introduces learners to new sustainable manufacturing approaches, examples of retrofitting and re use, repair methods, and industry perspectives on environmental impacts across boat construction.

Quality control, waste management solutions, and opportunities for recycling production offcuts are also covered.

Unit 4 compiles the most relevant regulatory frameworks, environmental footprint methodologies, and ongoing European initiatives aimed at decarbonising the boating sector. The references include official ISO standards, Product Environmental Footprint (PEF) documentation, LCA guidelines, industry studies, and policy-level reports. Together, these resources help teachers contextualise sustainability within the broader legal and industrial landscape, presenting how regulations shape material choices, manufacturing processes, end-of-life responsibilities, and the transition toward low-impact vessel design.

Unit 5 highlights the policy context, funding opportunities, labour market insights, and evolving skill requirements that shape the future of boatbuilding. It integrates materials on the EU Green Deal, Fit for 55, waste-shipment regulations, and financial mechanisms such as NextGenEU. The unit also presents case studies of shipyards adopting innovative sustainable practices, videos and guides on traditional craft and modern techniques, and a range of resources that introduce relevant professions, networking strategies, professional events, and new technological competencies emerging in the sector.

In the following tables, all abovementioned information is presented in detail for each unit of the TEcoNaut course material.

Unit 1: Introduction to sustainability in boat building

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
1.1 Fundamentals of sustainability in the maritime industry	**1.1.1 Principles of sustainability in the maritime industry**	**1. Introduction to the three pillars of sustainability 2. Specific challenges in maritime contexts: emissions, resource use, material waste** 3. Application of sustainability in vessel design, construction, and maintenance.	LO 1: Understand the fundamental concept of sustainability. LO 2: Identify the main environmental, social, and economic challenges in the maritime sector. LO 3: Skill of classifying actions and decisions based on the three pillars of sustainability. LO 4: The awareness of the long-term effects of engineering decisions on people and the environment	2 ½	Problem-based learning
	1.1.2 Historical evolution: Bio-based materials vs. fiberglass	**1. Introduction to material development in boatbuilding: a) Overview of traditional boatbuilding materials** b) Introduction of early composites 2. Timeline o f material evolution: a) Key historical milestones in boatbuilding materials b) ransition from traditional to futere (synthetic) materials c) Bio-based alternatives **3. Comparison of materials (examples) a) Environmental impact b) Mechanical properties c) Costs and availability in the market / industry.**	LO 1: Knowledge about the historical development of boatbuilding materials. LO 2: Skill of comperition traditional, sythetic and bio-based materials, in general. LO 3: Evaluate material choices based on historical context, technical needs, and sustainability criteria.	2 ½	Classroom-based learning (interactive lecture with material samples)

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
1.1 Fundamentals of sustainability in the maritime industry	1.1.3 Regulatory framework: Certifications and regulations	**1. Overview of international and regional maritime regulations (e.g., IMO, ISO 14001, EU directives)** **2. Introduction to certifications for sustainable materials and vessels** **3. The role of regulation in enforcing and encouraging sustainable practices.**	LO 1: Introduction to maritime regulations. LO 2: verview of relevant regulations and directives. LO 3: Role of regulations in sustainable practices.	1	Classroom-based learning (case-based lecture)

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
1.2 Environmental impact and waste management	**1.2.1 Life Cycle Analysis (LCA) in the boat industry**	**1. Introduction to Life Cycle Analysis (LCA) - definition and purpose** **2. Stages of a boat's life cycle:** **a) Manufacturing and construction** **b) Transport and distribution** **c) Use/operation phase** **d) End-of-life: disposal, recycling, or reuse** **3. Identification of emissions, waste, and resource consumption at each stage.** 4. Carbon footprint and its components in boat production and use. 5. Comparison of environmental impacts between	LO 1: Concept of LCA LO 2: Identify and describe the main stages of a boat's life cycle. LO 3: Recognize typical environmental impacts associated with each life cycle stage.	2	Classroom-based learning
	1.2.2 Waste management strategies: Circular economy principles and 3-R framework	1. Introduction to waste in the boatbuilding industry: a) Types and sources of waste during production, maintenance, and end-of-life stages. b) Environmental risks and consequences of improper waste handling. **2. Understanding the 3R Framework:** **a) Reduce – minimizing waste generation through smart design and resource efficiency.** **b) Reuse – extending product or component life through repair and repurposing.** **c) Recycle – material recovery and transformation into new products.** **3. Introduction to the Circular Economy?** **a) Definition and contrast with the traditional linear model ("take–make–dispose").** **b) Root principles: design for durability, keeping materials in use, regenerating natural systems.**	LO 1: Understand the principles of the 3R concept waste hierarchy LO 2: Understand the Circular Economy LO 3: Identification of common types of waste in the boatbuilding process. LO 4: Understanding of 3R and circular economy principles	2	Classroom-based learning

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
1.2 Environmental impact and waste management	**1.2.3 Limits of sustainability: Challenges in recycling vs. renewable raw materials**	1. Introduction to Sustainable Development. 2. Challenges of Recycling: a) Technical difficulties of recycling composite materials (e.g., fiberglass, carbon fiber). b) Economic barriers: cost of recycling vs. cost of new material. c) Limited infrastructure and technology for marine waste recycling. 3. Renewable Resources – Pros and Cons 4. Recycling vs. renewable resources	LO 1: Understand the environmental and technical limitations of both recycling and renewable materials. LO 2: Differentiate between recyclable and renewable materials in practical applications. LO 3: Knowledge of sustainability constraints and apply them responsibly.	2	Classroom-based learning

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
1.3 Innovations and future perspectives	**1.3.1 Future trends: Emerging materials, waste-free manufacturing**	1. Innovations and future perspectives **2. Concept of waste-free manufacturing**	LO 1: Knowladge of new new sustainable materials and technologies in the boatbuilding sector. LO 2: Understand the concept of waste-free (zero-waste) manufacturing.	1 ½	Classroom-based & problem-based learning
	1.3.2 Supply chain challenges and regulatory hurdles.	1. Introduction to the supply chain in boat building sector 2. Logistical challenges **3. Regulations and standards**	LO 1: Understand the structure and function of the boatbuilding supply chain.	1 ½	Classroom-based & problem-based learning

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Sub-topic	Activity	Description
1.1.1 Principles of sustainability in the maritime industry	*Sustainability Compass Mapping*	**Objective**: Help students classify sustainability challenges into environmental, social, and economic pillars. **How:** Present students with real-world scenarios in maritime contexts (e.g., oil spills, labor exploitation, fuel efficiency). Task: In small groups, map each scenario onto a Sustainability Compass (E/S/Ec/So). **Outcome:** Understand sustainability as a holistic framework.
1.1.2 Historical evolution: Bio-based materials vs. fiberglass	*Material Timeline Challenge*	**Objective:** Explore material transitions in boatbuilding over time. **How:** Provide cards with boat materials (wood, fiberglass, flax, carbon fiber), historical events, and their first marine uses. **Task**: Groups place cards on a timeline; discuss which innovations were sustainability-driven. **Outcome:** Recognize the evolution of materials and emerging sustainable alternatives.
1.2.1 Life Cycle Analysis (LCA) in the boat industry	*Lifecycle Puzzle*	**Objective**: Understand different stages in a boat's lifecycle and their impacts. **How:** Provide cut-out cards representing stages (raw material extraction, transport, use, EoL) and types of impact (carbon emissions, toxicity, water use). **Task:** Teams build a lifecycle flowchart, then link each stage with its impact. **Outcome:** Visualize how design choices influence a boat's total environmental footprint.

Sub-topic	Activity	Description
1.2.3 Limits of sustainability: Challenges in recycling vs. renewable raw materials	*Recycling vs. Renewables Debate*	**Objective:** Examine pros and cons of different sustainable strategies. **How:** Split students into two sides: Team A: Advocates for recycling composite materials. Team B: Supports renewable alternatives like flax or bio-resins. **Task:** Each team prepares arguments based on performance, costs, limitations, and infrastructure. **Outcome:** Deepened understanding of trade-offs and challenges in real-world material sustainability
1.3.1 Future trends: Emerging materials, waste-free manufacturing	*Future of boatbuilding – 3D printing debate*	**Objective:** Explore how modern technologies, e.g., 3D printing, could transform boat design, materials and construction methods. **How:** A structured classroom debate or discussion based on the question: “Will 3D printing revolutionize the way boats are built in the future?” Introduce key pros/cons, split students into groups with different future scenarios (optimistic, cautious, critical). **Task:** Students argue or present different future outcomes (fully printed boats, hybrid models, limitations), and discuss implications for materials, sustainability, regulations, skills. **Outcome:** Futures thinking, critical discussion skills, deeper understanding of innovation impacts.

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
1. Introduction to the three pillars of sustainability 2. Specific challenges in maritime contexts: emissions, resource use, material waste	https://europeanboatingindustry.eu/images/Introduction%20to%20Sustainability%20in%20Marinas/Introduction-to-Sustainability-in-Marinas---2nd-Edition.pdf?_t=1688484739 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en	Text about best practices for sustainable management, including energy efficiency, waste management, and environmental protection measures in coastal infrastructure. Content about The European Green Deal is the EU's strategic roadmap aiming for climate neutrality by 2050, promoting circular economy principles, sustainable industry transformation, and biodiversity protection.	Public available, best practices document
1. Introduction to material development in boatbuilding: a) Overview of traditional boatbuilding materials 3. Comparison of materials (examples) a) Environmental impact b) Mechanical properties c) Costs and availability in the market / industry.	A special issue of Forests (ISSN 1999-4907): Transforming Wood into Smart Materials: Innovations in Processing and Application (https://www.mdpi.com/journal/forests/special_issues/3K75GD42HU) Pagnotta, L. Sustainable Netting Materials for Marine and Agricultural Applications: A Perspective on Polymeric and Composite Developments. Polymers 2025, 17, 1454. https://doi.org/10.3390/polym17111454	This Issue is devoted the latest advances in processing techniques, material modification strategies, and the functional applications of wood or bamboo, aiming to offer readers a comprehensive understanding of how these natural materials can evolve in response to technological progress. This paper provides a comprehensive and up-to-date overview of polymeric and composite materials used in netting systems for marine and agricultural applications, and to evaluate their mechanical performance, environmental behavior, and suitability for sustainable development.	Publication, public available

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
1. Overview of international and regional maritime regulations (e.g., IMO, ISO 14001, EU directives) 2. Introduction to certifications for sustainable materials and vessels 3. The role of regulation in enforcing and encouraging sustainable practices.	ISO 12215 parts 1-:-4	These parts of ISO 12215 define material properties (e.g., laminates, cores, wood, metals).	Paid, standard / requirement document
1. Introduction to Life Cycle Analysis (LCA) - definition and purpose 2. Stages of a boat's life cycle: a) Manufacturing and construction b) Transport and distribution c) Use/operation phase d) End-of-life: disposal, recycling, or reuse 3. Identification of emissions, waste, and resource consumption at each stage.	LCA handbook. https://www.europeanboatingindustry.eu/eu-affairs/lca-blue-boat-horizon	A reference on Life Cycle Assessment (LCA) methodology, covering impact assessment, system boundaries, data interpretation, and decision-making tools in environmental analysis. The content promotes the use of LCA in the recreational boating sector to assess and reduce environmental impact throughout the design, construction, and operation phases of vessels.	Website, public available

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
2. Understanding the 3R Framework: a) Reduce – minimizing waste generation through smart design and resource efficiency. b) Reuse – extending product or component life through repair and repurposing. c) Recycle – material recovery and transformation into new products. 3. Introduction to the Circular Economy? a) Definition and contrast with the traditional linear model ("take–make–dispose"). b) Root principles: design for durability, keeping materials in use, regenerating natural systems.	"Enhancing Waste Resource Efficiency: Circular Economy for Sustainability and Energy Conversion"; Hadad Elroi, Grzymala Z., WójcikCzerniawska A., Szewczyk P. (2023)	A sample text examining how circular economy strategies and the 3Rs (reduce-reuse-recycle) approach can improve waste treatment energy efficiency and resource use in sustainable waste management systems.	Publication, public available
2. Concept of waste-free manufacturing	https://teconaut.eu/en/ - LEARNING CONTENT ON EXISTING AND POTENTIAL DEEP-TECH MATERIALS	Project platform providing insights into advanced and innovative materials for marine and other industries, focusing on technical properties, sustainability, and practical applications.	Website, public available

Unit 2: Sustainable materials, properties and performance

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Unit 2: Sustainable materials, properties and performance / Course Outline

Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
2.1 General material properties and performance	2.1.1 Material properties: Characteristics and applications	1. Introduction to material used in boatbuilding. 2. Overview of main material groups: natural fibers, recycled fibers, mineral fibers, and polymeric matrices. **3. Key material properties: mechanical (tensile, bending, compression), physical (density, moisture uptake), chemical durability (UV, saltwater resistance), and processability**. 4. Matching material characteristics with application areas (e.g., hulls, decks, interior structures). 5. Basics of sustainability assessment: life cycle thinking, renewability, recyclability.	LO 1: Evaluate the general properties and performance of sustainable materials; LO 2: Examine the chemical properties of composite components; LO 3: Identify basic criteria for selecting sustainable materials used in boat building.	1	Interactive lecture with real samples
	2.1.2 Mechanical performance: Tension, bending, compression, torsion, impact resistance	**1. Review of key mechanical property terms: tension, bending, compression, torsion, impact resistance. 2. Explanation of how fiber orientation, resin type, and lay-up affect mechanical performance. 3. Introduction to the composite structure: interaction of fiber and matrix. 4. Practical examples: how mechanical demands differ between hulls, bulkheads, and panels. 5. First contact with basic mechanical test methods (e.g., flexural test setup, hand deflection). 6. Interpreting mechanical performance data in simplified form.**		2	Lecture with demonstration

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
2.1 General material properties and performance	**2.1.3 Chemical resistance: Moisture, saltwater, UV exposure, degradation**	**1. Introduction to chemical and environmental stress factors: UV radiation, moisture, saltwater, temperature**. 2. Differences in degradation behavior between natural fibers and synthetic composites. 3. Typical damage symptoms: blistering, delamination, discoloration, fiber breakdown. **4. Influence of resin type on durability (e.g., polyester vs. epoxy vs. bio-based).** 5. Basic strategies for prevention and protection. 6. Simple tests that can be done outside of a test lab (e.g., soaking, UV aging with lamp).	LO 1: Evaluate the general properties and performance of sustainable materials; LO 2: Examine the chemical properties of composite components; LO 3: Identify basic criteria for selecting sustainable materials used in boat building.	1	Interactive lecture with photos & samples
	2.1.4 Material selection and sustainability in individual life cycle	**1. Sustainability dimensions in material selection: environmental, health/safety, technical, and economic. 2. Life cycle stages: raw material extraction, production, use, maintenance, disposal or recycling. 3. Overview of environmental impacts: emissions, energy consumption, transport. 4. Requirements and challenges of recyclability in composites. 5. Trade-offs: balancing performance, longevity, and ecological footprint. 6. Introduction to qualitative decision matrices or comparison tables.**		2	Guided group discussion

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
2.1 General material properties and performance	**2.1.5 Common manufacturing defects.**	1. Overview of common composite manufacturing defects: - Air bubbles (voids) - Dry spots - Fiber misalignment - Resin-rich areas - Delamination 2. Typical causes during hand lay-up and vacuum infusion. 3. Impact of defects on mechanical and chemical performance. 4. Visual inspection techniques and basic classification of defect severity. 5. Link between process control and part quality.	LO 1: Evaluate the general properties and performance of sustainable materials; LO 2: Examine the chemical properties of composite components; LO 3: Identify basic criteria for selecting sustainable materials used in boat building.	1	Lecture with demonstration

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Unit 2: Sustainable materials, properties and performance / Course Outline

Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
2.2 Raw materials and sustainable components	**2.2.1 Raw material categories: Natural fibers, recycled fibers, basalt, regenerated cellulose**	1. Introduction to reinforcement fibers used in sustainable composites. 2. Key types: flax, hemp, jute, basalt, recycled PET (rPET), regenerated cellulose. 3. Distinction between technical vs. non-technical fibers (e.g., strength, uniformity, processing). 4. Physical characteristics: strength, stiffness, moisture uptake, density. 5. Environmental impact: renewability, recyclability, energy in production. 6. Typical applications in boatbuilding: interior panels, hull sections, stringers.	LO 1: Identify and describe raw materials and sustainable components used in composites.	2 ½	Exploratory group activity with samples
	2.2.2 Textiles: Textile architectures in composites	**1. Overview of textile architectures in composites: - Woven fabrics (e.g. plain, twill) - Nonwovens (mats, felts) - Unidirectional (UD) reinforcements - rovings etc. 2. Influence of fiber orientation on strength and stiffness. 3. Drapability: how flexible a fabric is and how well it conforms to curved surfaces.** 4. Typical applications for each textile type in boatbuilding. 5. Link between architecture, lay-up complexity, and mechanical performance.		2 ½	Interactive demo with samples

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
2.2 Raw materials and sustainable components	2.2.3 Polymeric matrices: Thermoplastics, thermosets, bio-based resins	1. Functional role of the matrix in composites. 2. Thermosets vs. thermoplastics: - Properties (e.g., curing behavior, toughness, repairability) - Processing characteristics 3. Introduction to bio-based resins (e.g., bio-epoxy). 4. Recyclability of matrix options. 5. Material selection logic: mechanical demands vs. sustainability goals.	LO: Identify and describe raw materials and sustainable components used in composites.	1	Short presentation with comparison chart
	2.2.4 Additives & compatibilizers: Their role in sustainability	1. What are additives? (Basic definition: substances added to plastics to improve performance.) 2. Common additive types: - Fire retardants - UV stabilizers - Plasticizers (for flexibility) **3. What are compatibilizers? - Agents that help fiber and resin bind better 4. Why they matter: - Better bonding, longer part life, safety features** 5. Environmental aspects: - Additives can reduce recyclability or raise toxicity 6. Basic idea of ""green"" additives (bio-based or non-toxic alternatives).		½	Input presentation with sample testing

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TECONAUT

Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
2.2 Raw materials and sustainable components	**2.2.5 Sustainable sandwich cores: Balsa wood, cork, recycled PET, wood, paper honeycomb**	1. Introduction to sandwich construction in composites. 2. Common sustainable core materials: - Balsa wood - Cork - Recycled PET foam - Paper honeycomb - Plywood and other wooden cores 3. Core property comparison: - Stiffness - Weight - Moisture resistance 4. Processing aspects: cutting, bonding, compatibility with resin systems. 5. Environmental impact: - Renewable vs. recycled - Sourcing, energy in production, reuse potential.	LO: Identify and describe raw materials and sustainable components used in composites.	1 ½	Input presentation with sample testing
	2.2.6 Recycled elements: Use of repurposed composite materials.	**1. What can be reused or recyceled? 2. Challenges in using recycled materials.** 3. Practical reuse stategies in boatbuilding 4. Designing for reuse 5. Environmental benefits.		2	Classroom-based learning

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TECONAUT

Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
2.3 Bio-based and eco friendly composite solutions	2.3.1 Case studies: Boats built using natural fibers	1. Introduction: Why use natural fibers in boatbuilding? **2. Presentation of selected case studies: - Boat types (e.g., dinghies, sailing boats, components) - Used fibers and resin systems - Manufacturing methods 3. Motivation behind each project (e.g., CO_2 reduction, marketing, regulations)** 4. Lessons learned and encountered challenges (costs, durability, scaling) 5. Transfer to learner's context: what can be applied or avoided?	LO: Understand bio-based composite solutions and their applications.	3	Instructor-led presentation with group comparison
	2.3.2 Eco-friendly solutions: Bio-based polymers, adhesives, recyclable composites, cradle-to-cradle design.	**1. Bio-based materials in focus: - Bio-resins and adhesives (plant-based, low VOCs) - Differences between bio-based and biodegradable** 2. Recyclable vs. recycled composites: - Design and material selection implications 3. Sustainability philosophies: - Cradle-to-cradle (circular) vs. cradle-to-grave (linear) **4. Circular design strategies: - Design for disassembly - Material separation - Modular repairable components** 5. Practical relevance: where these concepts are emerging in the marine sector.		2	Interactive group design task (project-based learning)

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Sub-topic	Activity	Description
2.1.2 Mechanical performance	*Hands-on laminate comparison – Understanding fibre orientation and mechanical behaviour*	**Objective:** Students explore how fibre orientation and laminate lay-up affect mechanical behaviour, observing stiffness, flexibility, torsional response. **Teaching Notes:** Activity outline may be adapted depending on workshop resources. **Preparation:** Prepare 3–4 small composite laminates with same matrix but different fibre arrangements (unidirectional, cross-ply, ±45°, optionally woven natural fibre). A5 size or smaller. **Group Work:** Students manually test bending, twisting, compression; document behaviours; discuss which laminates suit which boat parts. **Learning Outcomes:** Recognize fibre orientation influence; connect tactile experience with mechanical terminology; apply lay-up understanding to real boat components.
2.1.2 Mechanical performance	*Failure Modes – A Closer Look*	**Objective:** Students observe actual failure examples of composites to identify failure modes. **Teaching Notes:** Designed for deeper understanding through tactile observation; adaptable to availability. **Preparation:** Collect pre-broken composite samples showing fibre breakage, matrix cracking, delamination. Label for instructor reference only. **Structure:** 1) Hands-on observation of failed samples. 2) Group discussion linking visual cues to failure type and causes. 3) Contextual link to boat parts. **Learning Outcomes:** Recognize composite failure modes; understand links between stress, material structure, and breakage; relate failure to risks in boatbuilding.

Sub-topic	Activity	Description
2.1.2 Mechanical performance	*Hands-on Testing – Feel the Performance*	**Objective:** Make mechanical terms tangible through physical testing. **Teaching Notes:** Requires simple pre-prepared material samples. **Preparation:** Samples: PET foam sandwich laminate, marine plywood, solid fibre laminate (e.g., flax+epoxy). Optional steel ball for drop test. **Part 1:** Manual Deflection Test: Students observe flex, rebound, sound clues. **Part 2:** Drop Test: Observe bounce, cracks, internal damage risk. Safety glasses required. **Part 3:** Logs: Students record behaviours and inferred properties. **Learning Outcomes:** Link behaviour to mechanical terms; experience differences between core materials; reflect on implications for safety and durability.
2.1.2 Mechanical performance	*Stress–Strain Behaviour – Seeing and Interpreting Material Data*	**Objective:** Help learners interpret stress–strain curves and connect them with real material behaviour. **Teaching Notes:** Bridges physical testing and engineering data; no advanced maths needed. **Preparation:** Print simplified stress–strain curves for flax composite, glass composite, carbon composite, foam/plywood compression curves. Optional blank diagrams. **Part 1:** Walkthrough of stress–strain curve regions (elastic, yield, ultimate, fracture). **Part 2:** Compare curves across materials; relate to earlier observations. **Part 3:** Discuss limitations of data and unpredictability (directionality, impact vs slow loading). **Part 4:** Mini project selecting materials for fictional boat part. **Learning Outcomes:** Understand stress–strain curves; compare materials analytically; see link between data and physical experience.

Sub-topic	Activity	Description
2.1.5 Manufacturing defects	*Manufacturing Defects Identification Activity*	**Objective:** Help learners identify typical laminate defects and understand causes and consequences. **Teaching Notes:** Many learners observe defects but do not understand formation. **Preparation:** Provide samples/photos of defects: air bubbles/voids, dry spots, fibre misalignment, delamination. Provide worksheet with defect chart: signs, cause, impact, prevention. **Part 1:** Rotate inspection stations; learners fill worksheet and hypothesize causes. **Part 2:** Group discussion on defect visibility, long-term impact, workshop experiences. **Optional:** Create sample defects intentionally; show infusion failure video. **Learning Outcomes:** Identify visual signs; understand production causes; learn defect prevention; strengthen QA mindset.
2.2.1 Raw material categories	*Exploration of fibres (Natural, Mineral, Recycled)*	**Activity Goal:** Students explore and compare reinforcement fibre types through hands-on inspection and analysis, linking fibres to marine applications and sustainability. **Preparation:** Provide samples of flax, hemp, jute (natural), basalt (mineral), recycled PET (rPET), regenerated cellulose. Provide fibre ID cards containing origin, properties (density, stiffness, durability), marine applications, environmental considerations. Provide matching worksheet (fiber type, common use, sustainability benefit/trade-off). Optional tools: magnifying glass, microscope, scale. **Part 1:** Fibre Station Rotation. Students rotate through stations, touch/inspect fibres, read fact sheets, complete worksheet. **Part 2:** Whole-class reflection; sorting fibres into Natural/Mineral/Recycled groups, discussion on strength, sustainability, surprises. **Optional:** Blind guess identification; application debate for choosing fibres for deck panel etc. **Learning Outcomes:** Recognize fibres; match to marine applications; assess sustainability profiles.

Sub-topic	Activity	Description
2.2.2 Textiles	*Workshop on textile forms: woven, nonwoven, UD (unidirectional)*	**Activity Goal**: Students understand how textile forms behave in composite lay-ups through hands-on testing and draping exercises. **Preparation:** Provide woven fabrics (plain, twill), unidirectional fabrics, nonwoven mats, plus small moulds (hemisphere, corner, trays), tape, scissors, markers, spray adhesive (optional). Worksheets for ID and draping notes. **Part 1 –** Orientation & Anisotropy Demo: Students mark fibre direction on UD fabrics, pull along and across fibres to observe anisotropy. Discussion on implications for load paths in boatbuilding. **Part 2 –** Draping Challenge: Students attempt to lay fabrics over curved moulds, observe folds/wrinkles, make relief cuts, compare drape behaviour, record which fabrics drape best. **Learning Outcomes:** Identify textile forms; understand relationship between weave/fibre direction and draping; recognize significance of orientation in strength and sustainability.
2.2.5 Sustainable sandwich cores	*Workshop: Comparing core materials*	**Learning Goal:** Students compare sustainable core materials (balsa, cork, rPET foam, paper honeycomb, optional PVC for reference) through inspection, weight comparison, deflection tests, and sustainability reasoning. **Materials Needed:** Sample plates of each core; profile cards; worksheets for structure/weight/stiffness; deflection test setup (books + dowel); scale; ruler or load. **Procedure:** 1. Introduction: Review sandwich core function; pose question "What makes a good core material?" 2. Group Rotation: Students handle each core sample, perform basic tests, note observations. 3. Comparison & Reasoning: Students fill decision matrix: best use-case per core, trade-offs (stiffness, water resistance, cost, sustainability). 4. Discussion: Which material surprised them, where to use cork/honeycomb, trust in balsa below waterline. **Learning Outcome:** Understand material differences through tactile comparison; recognize sustainability implications; practice structured material selection.

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Sub-topic	Activity	Description
2.2.6 Recycled elements	*Workshop: Reuse of composite offcuts*	**Learning Goal:** Learners develop practical reuse strategies, understand limitations of recycling, and reflect on sustainability in workshop routines. **Materials Needed:** Box of workshop leftovers (laminate offcuts, unused fibre mats, expired prepregs, resin cups, core cutouts, broken jigs). Worksheets for reuse brainstorming. Visual on waste hierarchy. **Procedure:** 1. Set the Scene: Introduce concept “not throwing away but rethinking”; highlight environmental impact of composite waste. 2. Group Exploration: Students sort leftovers, identify valuable items, propose reuse ideas (structural, tooling, packaging, training, creative). Consider safety risks and waste avoidance. 3. Documentation: Groups create reuse plan for 2–3 items, list limits, and discuss whether waste could have been avoided. 4. Presentations (optional): Groups present their ideas. **Learning Outcome:** Understand recycling limits; develop practical reuse strategies; integrate sustainability thinking into daily workshop decisions.

Sub-topic	Activity	Description
2.3.2 Eco-friendly solutions	*Circular Design Component Workshop*	**Learning Goal:** Students apply circular thinking in a practical design task. Focus is on understanding systems: material sourcing, use, end-of-life, sustainability trade-offs, manufacturing implications. **Materials Needed:** Design prompt sheets (sample components or self-defined); flipcharts or large paper; material cards/data sheets (bio-epoxy, polyester, thermoplastic; flax, glass, basalt, rPET; balsa, rPET foam, cork, honeycomb); optional videos/case studies of circular marine designs; worksheet for documenting materials and circular strategies. **Workshop Procedure:** 1. Kickoff – What does "circular" mean? Introduce cradle-to-cradle vs. cradle-to-grave; examples of boats designed for disassembly, modular reuse, low-impact materials (e.g., flax composites). 2. Task Briefing – Circular Component Design: Groups design a small boat component applying circular principles. Choose materials, consider production and repair, define reuse/recycling plan. 3. Group Design Phase: Brainstorm, sketch, research. Produce an A3/flipchart presentation including material choices, circular strategies, compromises, and second-life options. 4. Team Presentations: Groups present design; peers/instructor feedback. **Learning Outcome:** Students understand sustainability trade-offs; apply life cycle thinking to composite parts; demonstrate circular design strategies beyond recycling; communicate ecological reasoning. **Trainer Tips:** Link to real company practices or invite guest speaker; encourage "thinking backwards" from end-of-life.

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
3. Key material properties: mechanical (tensile, bending, compression), physical (density, moisture uptake), chemical durability (UV, saltwater resistance), and processability	Beckman, I. P., Lozano, C., Freeman, E., & Riveros, G. (2021). Fiber Selection for Reinforced Additive Manufacturing. Polymers, 13(14), 2231. https://doi.org/10.3390/polym13142231 (https://www.mdpi.com/2073-4360/13/14/2231)(table 4...)	Scientific publication about properties of different fibrers (with table, charts,...)	Public, scientific publication
1. Review of key mechanical property terms: tension, bending, compression, torsion, impact resistance. 2. Explanation of how fiber orientation, resin type, and lay-up affect mechanical performance. 3. Introduction to the composite structure: interaction of fiber and matrix. 4. Practical examples: how mechanical demands differ between hulls, bulkheads, and panels. 5. First contact with basic mechanical test methods (e.g., flexural test setup, hand deflection). 6. Interpreting mechanical performance data in simplified form.	https://eoceanic.com/sailing/tips/8/187/understanding_composites_for_larger_boat_projects/ ISO 12215-5:2019 ; ISO 12215-7:2019 ; ISO 12215-8:2019 ; ISO 12215-9:2019 ; ISO 12215-10:2019 https://www.sciencedirect.com/science/article/abs/pii/B9780081022924000011	Presentation with many charts and explicit figures about mechanical properties and characteristics of materials (fibers, resins,...) Building norms for small boats Scientific publication about mechanical tests for composites	Website, standard documentation, scientific publication, public (ISO is paid)

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
1. Introduction to chemical and environmental stress factors: UV radiation, moisture, saltwater, temperature. 4. Influence of resin type on durability (e.g., polyester vs. epoxy vs. bio-based).	Ali, Dr-Ahmed & Mohamed, Hamdy & ElSafty, Adel & Benmokrane, Brahim. (2017). INFLUENCE OF RESIN TYPE ON PHYSICAL, MECHANICAL AND DURABILITY PERFORMANCE OF GLASS-FRP BARS.	Conference paper about experiments on glass fiber reinforced polymer bars with different types of resin (isopolyester, vinyl-ester, polyuretan, and epoxy)	Conference paper, available upon permission by authors
1. Sustainability dimensions in material selection: environmental, health/safety, technical, and economic. 2. Life cycle stages: raw material extraction, production, use, maintenance, disposal or recycling. 3. Overview of environmental impacts: emissions, energy consumption, transport. 4. Requirements and challenges of recyclability in composites. 5. Trade-offs: balancing performance, longevity, and ecological footprint. 6. Introduction to qualitative decision matrices or comparison tables.	https://as-proceeding.com/index.php/icaens/article/download/1035/971 Xianhui Zhao, Katie Copenhaver, Lu Wang, Matthew Korey, Douglas J. Gardner, Kai Li, Meghan E. Lamm, Vidya Kishore, Samarthya Bhagia, Mehdi Tajvidi, Halil Tekinalp, Oluwafemi Oyedeji, Sanjita Wasti, Erin Webb, Arthur J. Ragauskas, Hongli Zhu, William H. Peter, Soydan Ozcan, Recycling of natural fiber composites: Challenges and opportunities, Resources, Conservation and Recycling, Volume 177, 2022, 105962, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2021.105962. (https://www.sciencedirect.com/science/article/pii/S0921344921005711) Chapter 5 of Eco-Boat building guide	Short scientific publication about recycling methods : mechanical, thermal and chemical Scientific publication about recycling impact on quality and mechanical properties of natural fibers Overview of LCA methodology	Public, scientific publications

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
	https://www.addcomposites.com/post/defects-and-damage-in-composite-materials-and-structures#headline2	Explicit, simple and turned to practice guide about composites, defects and impact, with many ramifications to other related and relevant topics	Public, Website
	https://www.marineshift360.org/#lcatool https://www.openlca.org/	Presentation of the free tool MarineShift360, access to the tool by creating an account, especially to "Educational Light" license Access to the free and professional tool of LCA OpenLCA by downloading it (open source software)	Free, Browser based application, Open-source LCA software
	https://www.youtube.com/watch?v=yn9UScW_YJc https://www.youtube.com/watch?v=3Lt87LKaZUU	Presentations about fibers showing samples and characteristics, origin, environmental impact, repartition	Public,YouTube videos
1. Overview of textile architectures in composites 2. Influence of fiber orientation on strength and stiffness. 3. Drapability: how flexible a fabric is and how well it conforms to curved surfaces.	Amit Rawal, Abhijit Majumdar, Vijay Kumar V, The Author(s) 2023. Published by Oxford University Press : Textile architecture for composite materials : back to basics (https://www.diva-portal.org/smash/get/diva2:1808412/FULLTEXT01.pdf) Yasser S. Mohamed, Ahmed Abdelbary, Theoretical and experimental study on the influence of fiber orientation on the tensile properties of unidirectional carbon fiber/epoxy composite, Alexandria Engineering Journal, Volume 67, 2023, Pages 693-705, ISSN 1110-0168, (https://www.sciencedirect.com/science/article/pii/S1110016822008420)	Scientific publication simply reviewing woven, nonwoven, knitted and braided textiles Scientific publication about experiments on different samples of composite with different orientation of the fiber	Public, scientific publications

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
	https://www.youtube.com/watch?v=yQo4ucV3jfA	Remember PSA and safety instructions Presentation of different types of matrices	Public, YouTube video
3. What are compatibilizers? - Agents that help fiber and resin bind better 4. Why they matter: - Better bonding, longer part life, safety feature	Sakshi Shantharam Kamath, Ravi Kumar Chandrappa, Additives used in natural fibre reinforced polymer composites-a review, Materials Today: Proceedings, Volume 50, Part 5, 2022, Pages 1417-1424, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2021.08.331. (https://www.sciencedirect.com/science/article/pii/S221478532105776X) https://www.sciencedirect.com/topics/materials-science/compatibilizer https://www.youtube.com/watch?v=4zpQwirFsbk https://www.youtube.com/watch?v=tiS8ArzEA58 https://www.youtube.com/watch?v=TNM8-pPPk-M https://www.youtube.com/watch?v=Bqb7iA6AG-g	Scientific review of additives used with natural fibre Several articles about compatibilizers Lecture course about sandwich construction (high level, calculation of mechanical parameters, ...) Presentation of advantages of sandwich construction with simple but explicit demonstrations and pomotion of balsa as a really efficient core Construction of IY Open60AAL with focus on balsa and lamination	Scientific publications, require permission by authors
1. What can be reused or recycled? 2. Challenges in using recycled materials.	https://www.youtube.com/watch?v=ynGKEYlYXQo Daniele Tortorici, Yi Chen, Leon Mishnaevsky, Susanna Laurenzi, Recycling carbon fibers by solvolysis: Effects of porosity and process parameters, Composites Part A: Applied Science and Manufacturing, Volume 190, 2025, 108667, ISSN 1359-835X, https://doi.org/10.1016/j.compositesa.2024.108667. (https://www.sciencedirect.com/science/article/pii/S1359835X24006651)	Circular economy project for composites Scientific publication about solvolysis Scientific publication comparing energy issues between pyrolysis and solvolysis Scientific publication about recycling methods and issues for composites	YouTube video, scientific publications, website article, Public except the scientific publications

Topic for level-up information	Reference Link	Briefing of Reference Content	
1. What can be reused or recyceled? 2. Challenges in using recycled materials.	Kooduvalli, K., Unser, J., Ozcan, S., & Vaidya, U. K. (2022). Embodied Energy in Pyrolysis and Solvolysis Approaches to Recycling for Carbon Fiber-Epoxy Reinforced Composite Waste Streams. Recycling, 7(1), 6. https://doi.org/10.3390/recycling7010006 https://www.mdpi.com/2313-4321/7/1/6 Yongxiang Yang, Rob Boom, Brijan Irion, Derk-Jan van Heerden, Pieter Kuiper, Hans de Wit, Recycling of composite materials, Chemical Engineering and Processing: Process Intensification, Volume 51, 2012, Pages 53-68, ISSN 0255-2701, https://doi.org/10.1016/j.cep.2011.09.007 . (https://www.sciencedirect.com/science/article/pii/S0255270111002029)		Scientific publication, website article, public
2. Presentation of selected case studies: - Boat types (e.g., dinghies, sailing boats, components) - Used fibers and resin systems - Manufacturing methods 3. Motivation behind each project (e.g., CO_2 reduction, marketing, regulations)	https://www.youtube.com/watch?v=uD7UxlwumWU https://www.proboat.com/2022/05/greenboats-flax/ https://www.compositesworld.com/news/alliance-for-european-flax-linen-and-hemp-reports-increasing-flax-fiber-adoption-in-marine https://www.metstrade.com/news/sustainability/bio-based-and-recyclable-materials-prove-themselves	ANT ARCTIC LAB project (volcanic fibre) Report about Greenboats achievements Article about various projects with different fibre and different boats Article about various project with different sustainable concepts	YouTube video, website articles, public

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
1. Bio-based materials in focus: - Bio-resins and adhesives (plant-based, low VOCs) - Differences between bio-based and biodegradable 4. Circular design strategies: - Design for disassembly - Material separation - Modular repairable components	https://entropyresins.com/bioinfusion/ https://greenpoxy.org/ Durmisevic, Elma & FIKKERT, Rick & Otheguy, Mariano. (2013). DfD as a Methodology to Improve the Sustainability of Offshore Accommodation. Technology Review 2013. (https://www.researchgate.net/publication/258837862_DfD_as_a_Methodology_to_Improve_the_Sustainability_of_Offshore_Accommodation)	Website of one of the rare bio-based epoxy producers (Entropy Resins) Website of one of the rare bio-based epoxy producers (Greenpoxy - Sicomin) Scientific publication about DfD	Public, website, scientific publications

Unit 3: Application techniques in manufacturing and repair work

Co-funded by the European Union

ERASMUS-EDU-2023-PI-ALL-INNO

Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
3.1 Sustainable manufacturing methods	**3.1.1 Tools, equipment, surface preparation**	**1. Introduction to hand tools and equipment for composite processing: - Scissors, rollers, peel plies, brushes, vacuum bags, infusion pumps 2. Surface preparation basics: - Cleaning, sanding, degreasing - Importance of surface quality for bonding 3. Safety considerations when handling tools and chemical**s 4. Differences in tool use with sustainable vs. conventional materials **5. Visual indicators for "ready-to-laminate" surfaces**	LO: Learners identify and safely use basic tools and equipment for composite manufacturing. They understand and carry out simple surface preparation steps.	4	Hands-on demonstration with equipment. Short instructor-led input.
	3.1.2 Textile structures: Working with natural fiber textiles	1. Introduction to natural fibre textiles used in composites: - Flax, hemp, jute, kenaf **2. Fabric forms: - Woven fabrics, non-wovens, unidirectional mats 3. Key characteristics of natural textiles: - Drapability, thickness, fibre alignment, moisture sensitivity 4. Influence of textile structure on mechanical performance and processability 5. Application areas in boatbuilding: interior panels, non-structural elements, etc.**	LO: Learners identify textile types made from natural fibres and describe how their structure affects the manufacturing process and the part's performance.	8	Hands-on material handling session supported by instructor input.

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
3.1 Sustainable manufacturing methods	**3.1.3 Laminating techniques: Applying bio-based resins with natural fibers**	**1. Introduction to basic laminating steps: - Cutting fibres, mixing resins, applying resin with roller or brush 2. Material specifics: - Handling of flax or basalt textiles - Wet-out behaviour of bio-based resin systems 3. Key process aspects: - Working time, fibre shifting, layer placement 4. Practical tips for successful open lamination** 5. Curing and post-processing (brief overview) 6. Preparation for comparison in next session (3.1.4): panels will be damaged and repaired later	LO: Learners demonstrate a basic hand lay-up process using natural fibres and bio-based resins. They follow the key process steps and produce a laminate panel suitable for visual inspection and comparison.	11	Guided hands-on task
	3.1.4 Challenges: Processing difficulties and optimizing sustainable materials.	Group A: Natural fibres, hand lay-up (open process) Group B: Glass fibres, hand lay-up Trainer demonstration: Natural fibres with vacuum infusion (closed process) Topics addressed: 1. Material handling and wetting behaviour 2. Observed processing difficulties: resin absorption, fibre fraying, working time 3. Visual laminate quality: bubbles, dry zones, wrinkles 4. Importance of closed processes for some natural fibres 5. Learner discussion: Which process was easier? What issues appeared? 6. Trainer input: Summary of advantages and limitations of each combination	LO: Learners experience key challenges in working with sustainable materials and compare their ease of processing and visual quality to conventional composites. They recognize the importance of suitable processing techniques for different fibres.	12	Group comparison & discussion

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
3.2 Retrofitting and repair strategies for boats	**3.2.1Retrofitting strategies: Integrating sustainable materials into existing boats**	Replacing nonstructural parts: inner boat shell, showers, sinks, floor panels, galley.	LO: Learners learn to anlayze a broken laminate, to prepare it for lamination / reparation and to set it in place	15	Guided hands-on repair task
	3.2.2 Repair techniques: Standardized repair methods for sustainable composites.	1. Analyze damage (size, material, way of reconstruction) 2. Removing damaged material 3. Grinding and Sanding **4. Reconstruction.**		15	Guided hands-on repair task

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
3.3 Waste reduction and efficiency in composite processes	**3.3.1 Quality assurance: Monitoring material and energy flow efficiency**	**1. What is quality assurance (QA) in composite manufacturing? - Role of QA in sustainability and durability 2. Simple QA techniques for small-scale composite production** 3. Material flow indicators: - Resin use per panel, fibre offcut rate 4. Energy-related factors: - Process time, heating tools, lights 5. Documentation tools: - Tracking sheets, visual inspection, photo logs 6. Reflection: How does documentation help improve efficiency and reduce waste?	LO: Learners understand the concept of quality assurance in composite manufacturing. They are able to monitor basic indicators of material and energy flow during fabrication and reflect on how efficiency can be improved.	5	Demonstration + guided group activity
	3.3.2 Waste reduction methods: Precision cutting, material repurposing, bio-based consumables.	1. What causes waste in composite processes? - Common sources: trimming, over-mixing, disposable tools **2. Material repurposing: - Ideas for using offcuts: filler material, mould backing, prototype pieces** 3. Bio-based consumables: - Recyclable mixing cups, compostable gloves, biodegradable release films (discuss is that really an option?!) **4. Good practice examples from industry** 5. Group task: Minimize waste while planning and preparing a small part 7. Reflection: What worked? Where did waste still occur?	LO: Learners apply basic strategies to reduce material waste in composite manufacturing. They plan work to optimize material use, explore reuse of offcuts, and identify sustainable consumable alternatives.	5	Group planning task & reflection

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Sub-topic	Activity	Description
3.1.1 Tools, equipment, surface preparation	*Workshop – Tool identification and lamination steps*	**Description:** Students work in groups. Each group receives several tools. On a whiteboard, the main steps of lamination and the main watch points and safety rules are written. Groups must identify which step and/or which safety rule or specification corresponds to their assigned tools and explain why. **Equipment**: Common tools used for lamination; whiteboard or similar **Objective:** Students become familiar with basic tools and understand their proper use relating to safety and lamination efficiency. **Expected Outcome:** Students know which tool to use, when and how, with respect to safety and effective lamination.
3.1.2 Textile structures	*Samples comparison*	**Description:** Students receive several fabric samples made of different fibres. They compare them, note characteristics and behaviour. **Equipment:** Various fabric samples. **Objective:** Students become familiar with lamination fabrics and able to recognise them. **Expected Outcome:** Students can recognize which fibre composes each fabric and understand fabric characteristics.
3.1.2 Textile structures	*Charts comparison and association*	**Description:** Display charts showing fabric resistance, without revealing fabric identity. Students must match charts to fabric samples based on observed characteristics. **Equipment:** Fabric property charts. **Objective:** Make students link fabric properties to behaviour. **Expected Outcome:** Students can choose appropriate fabrics according to final part requirements.

Sub-topic	Activity	Description
3.1.3 Laminating techniques	*Practical hand lay-up lamination*	**Description**: Each student receives a mould and materials (fabrics, tools, PPE, resin, hardener, consumables) to perform a hand lay-up lamination. **Equipment:** Moulds, fabrics, tools, resin, hardener, PPE, consumables. **Objective:** Teach students how to laminate and understand critical points in the process. **Expected Outcome:** Students are able to laminate properly using an open-mould hand lay-up process.
3.1.3 Laminating techniques	*Collaborative vacuum infusion*	**Description:** Trainer demonstrates a complete lamination via vacuum infusion. Students participate; key points are observed and discussed. **Equipment:** Mould, fabrics, resin, hardener, tools, PPE, consumables, vacuum pump. **Objective:** Introduce vacuum infusion and highlight critical watch points. **Expected Outcome**: Students understand how to laminate using vacuum infusion.
3.1.4 Challenges	*Lamination comparison (conventional vs sustainable)*	**Description:** Students laminate a small part using conventional materials and again using sustainable materials, noting remarks and observations throughout both processes. At the end they compare their experiences and present a synthesis. **Equipment:** Fabrics, resin, hardener, tools, PPE, consumables. **Objective:** Have students experience both material types and form their own comparisons. **Expected Outcome:** Students understand pros and cons of each material type.

Sub-topic	Activity	Description
3.2.1 Retrofitting strategies	*Group presentation on retrofitting projects*	**Description:** Students work in groups to research retrofitting or sustainable material integration projects. They present a 5-minute synthesis using their preferred format (slides, poster, video, pictures, etc.). Trainer distributes subjects to avoid duplication. **Equipment:** Computers, whiteboard, projector. **Objective:** Explore retrofitting and associated challenges. **Expected Outcome:** Students understand retrofitting methods, recognize challenges, summarise and extract main ideas.
3.2.2 Repair techniques	*Game with sanding papers and discs*	**Description:** Students match sanding papers/discs (mixed types) with grit labels and arrange them in order. Trainer then explains which grit suits which surface, tool, and task. **Equipment:** Sanding papers/discs, grit labels. **Objective:** Familiarize students with grits and types of sanding papers/discs. **Expected Outcome:** Students understand grit scale and appropriate usage.
3.2.2 Repair techniques	*Practical repair exercise*	**Description:** After demonstration, each student receives a deliberately damaged laminated sample. They choose a repair method, explain it, obtain teacher approval, and perform the repair. **Equipment:** Damaged composite sample, raw materials, resin, hardener, fabrics, lamination tools, PPE, consumables. **Objective:** Develop students' ability to analyse repair situations and apply correct methods. **Expected Outcome:** Students can repair damaged composites and select appropriate repair strategies.

Sub-topic	Activity	Description
3.3.1 QA in processes	*Reflection & QA techniques planning*	**Description:** Students analyze a given process in groups and plan implementation of QA techniques and indicators. They produce a diagram showing steps and proposed improvements. **Equipment:** Computers. **Objective:** Encourage adaptation of QA tools for process improvement. **Expected Outcome:** Students can implement and analyse QA methods based on process characteristics.
3.3.2 Waste reduction	*Waste brainstorming*	**Description:** Trainer presents examples of waste during boatbuilding, including numbers and statistics. Students propose waste reduction strategies. Class compiles a list of viable proposals. **Equipment:** Whiteboard. **Objective:** Raise awareness of waste and its impact; highlight the importance of early planning. **Expected Outcome:** Students view waste management as essential in company organisation.
3.3.2 Waste reduction	*Process planning with integrated waste reduction*	**Description:** Groups receive a final product. They create a full task plan with descriptions explaining how to minimise waste at each step. Output: a folder with a task table and detailed task sheets. **Equipment:** Computers. **Objective:** Encourage holistic process planning with waste reduction as a central goal. **Expected Outcome:** Students integrate waste reduction considerations into all process steps.

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
1. Introduction to hand tools and equipment for composite processing: - Scissors, rollers, peel plies, brushes, vacuum bags, infusion pumps 2. Surface preparation basics: - Cleaning, sanding, degreasing - Importance of surface quality for bonding 3. Safety considerations when handling tools and chemicals 5. Visual indicators for "ready-to-laminate" surfaces	https://aerospaceengineeringblog.com/composite-manufacturing/ https://compositeslab.com/composites-manufacturing-processes/ https://aerospaceengineeringblog.com/composite-manufacturing/	Website with articles which provide guides for different steps in composites boat building processes (turned to practice redaction, some videos, friendly way to explain) Website with short explanations of processes, materials, tools (well organised) Website with description of processes with simple and explicit schemes	Public, websites
2. Fabric forms: - Woven fabrics, non-wovens, unidirectional mats 3. Key characteristics of natural textiles: - Drapability, thickness, fibre alignment, moisture sensitivity 4. Influence of textile structure on mechanical performance and processability 5. Application areas in boatbuilding: interior panels, non-structural elements, etc.	https://www.isomatex.com/tenron/ https://www.circular-structures.com/ https://www.techniques-ingenieur.fr/actualite/articles/ecotechnilin-des-solutions-a-base-de-fibres-naturelles-au-service-de-lindustrie-134081/ (+ EcoTechnilin) S. Maiti, M. R. Islam, M. A. Uddin, S. Afroj, S. J. Eichhorn, N. Karim, Sustainable Fiber-Reinforced Composites: A Review. Adv. Sustainable Syst. 2022, 6, 2200258. https://doi.org/10.1002/adsu.202200258 (https://advanced.onlinelibrary.wiley.com/doi/full/10.1002/adsu.202200258)	Websites of fabrics providers Article about a company which produces mats with several natural fibres and tries to develop a recycling industry too Scientific publication about sustainable composites	Public, corporate websites and scientific article

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
1. Introduction to basic laminating steps: - Cutting fibres, mixing resins, applying resin with roller or brush 2. Material specifics: - Handling of flax or basalt textiles - Wet-out behaviour of bio-based resin systems 3. Key process aspects: - Working time, fibre shifting, layer placement 4. Practical tips for successful open lamination	https://www.addcomposites.com/post/what-are-the-fundamental-steps-of-composites-manufacturing https://www.youtube.com/watch?v=tE6KDNvyTuU	Explicit, simple and turned to practice guide about composites, defects and impact, with many ramifications to other related and relevant topics Video about a canoe construction in flax fibre and balsa with focus on specific steps	Public, Blog and YouTube video
	https://www.youtube.com/watch?v=RrVy7jaSABM https://www.youtube.com/watch?v=AD98L9XlCTU https://www.youtube.com/watch?v=Q09ZFVA6nR8	Presentation of lamination techniques with comparisons Video about using flax fiber and resin infusion Video about laminating glass fibre (with insights about crucial points (time of all process, ...))	Public, YouTube videos (demonstrations)
	https://www.imoca.org/en/news/news/lifting-the-lid-on-boat-build-impacts-for-a-more-sustainable-industry	Not retrofitting, but report about sustainalble materials implementation in a race boat (Imoca), with a explicit video	Public, Articles on sustainable retrofitting and hull reuse

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
4. Reconstruction.	https://www.sciencedirect.com/science/article/pii/S0264127523008614	Scientific publication about potential new way to repair composites	Public, scientific paper
1. What is quality assurance (QA) in composite manufacturing? - Role of QA in sustainability and durability 2. Simple QA techniques for small-scale composite production	https://www.addcomposites.com/post/quality-assurance-and-quality-control-in-composites-manufacturing	Description of topics to be invastigated for quality assurance	Public, Blog post about Quality Assurance and Control (QA/QC) methods for composite manufacturing
2. Material repurposing: - Ideas for using offcuts: filler material, mould backing, prototype pieces 3. Bio-based consumables: - Recyclable mixing cups, compostable gloves, biodegradable release films (discuss is that really an option?!) 4. Good practice examples from industry	https://compositesuk.co.uk/industry-support/environmental/what-can-i-do-with-my-waste/	Non-exhaustive list of solutions for waste composites and offcuts	Public, Industry article listing waste management and recycling options

Unit 4:
Life cycle assessment and business case

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
4.1 Evaluating environmental impact through LCA	**4.1.1 Life Cycle Assessment (LCA): Basics of LCA**	**1. Introduction to Life Cycle Assessment (LCA) 2. Environmental Impact Categories in LCA** 3. Applying LCA to Boatbuilding Materials 4. Identifying Environmental Hotspots in the Product Lifecycle 5. Using LCA for Informed Design and Procurement Decisions 6. LCA as a Tool for Business Strategy and Regulatory Compliance	LO: "Define what a Life Cycle Assessment (LCA) is and describe its four main phases. Identify the purpose of using LCA in the boatbuilding industry. List and describe key environmental impact categories as defined in the PEF method. Explain how LCA supports decision-making by comparing product or material options based on lifecycle impacts."	2	Classroom-based learning
	4.1.2 Environmental footprint: Carbon emissions, energy consumption	1. Carbon Emissions in Boatbuilding 2. Energy Consumption Across the Boat's Lifecycle 3. Material Comparison Using Carbon and Energy Data **4. Case Study: Recycling Glass Fibre Composites 5. Using ISO and PEF Standards in LCA**	LO: "Distinguish between carbon emissions and energy consumption and explain their roles in environmental impact assessment. Identify common sources of carbon emissions and energy use in boatbuilding. Interpret basic environmental data such as CO_2-equivalent emissions and energy use in megajoules (MJ). Compare the environmental footprint of two boat types or material configurations using simplified data."	3	Classroom-based learning

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
4.1 Evaluating environmental impact through LCA	**4.1.3 Identifying hotspots: Key areas of material, energy, and waste concerns**	1. What Are Environmental Hotspots in LCA? 2. Material-Related Hotspots in Boatbuilding 3. Energy Use as a Critical Impact Area **4. Waste Generation and End-of-Life Challenges** **5. Strategies for Reducing Environmental Hotspots** **6. Case Study: Hotspot Analysis from the ICOMIA Propulsion Decarbonisation Study**	LO: Define what a hotspot is in the context of Life Cycle Assessment. Identify typical material, enery, and waste-related hotspots in the boatbuilding lifecycle. Explain how hotspot analysis helps prioritize sustainability improvements. Interpret findings from real-world case studies to assess where environmental impacts are concentrated.	3	Classroom-based learning

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
4.2 Economic feasibility of sustainable materials	**4.2.1 Economic analysis: Comparing costs of sustainable vs. conventional materials**	1. Key Cost Factors in Material Selection for Boatbuilding 2. Lifecycle Cost Breakdown: From Purchase to End-of-Life 3. Case Comparison: Battery-Electric vs. Renewable Fuel Propulsion 4. Targeted Sustainability Investments and Economic Efficiency **5. Beyond Price: Incentives, Branding, and Long-Term Value** 6. Making Informed Choices Through Lifecycle Cost-Benefit Analysis	LO: Identify the key cost components involved in material selection (e.g., initial cost, maintenance, end-of-life). Compare the economic implications of using sustainable materials versus conventional ones. Apply a basic lifecycle cost framework to assess material choices. Recognize how environmental and economic factors can intersect to inform smart material decisions.	1 ½	Classroom-based learning
	4.2.2 Return on investment: Long-term financial benefits of sustainable choices	1. Understanding ROI in Sustainable Boatbuilding 2. Evaluating Long-Term Benefits of Sustainable Materials 3. Economic and Strategic Drivers Beyond Upfront Cost 4. Challenges and Uncertainties in ROI Calculation 5. Using LCA to Support Investment Decisions 6. Case Study: ROI from Material Switch in a Small Boatyard	LO: Define return on investment (ROI) and apply it to sustainable design decisions. Describe how sustainable materials can generate long-term savings or added value. Identify non-financial benefits (e.g., branding, customer appeal, regulatory readiness) linked to sustainability. Analyze a case study to determine whether a material switch delivers both environmental and financial returns.	1 ½	Classroom-based learning

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
4.3 Business models for sustainability in boatbuilding	**4.3.1 Circular business models: Linear vs. circular economy in boatbuilding**	1. From Linear to Circular: Rethinking Boatbuilding Systems 2. Core Strategies of the Circular Economy in Boat Design **3. Case Study: APER and the Circular Recycling of Boats in France 4. Applying the PEF Method to Circular Material Choices** 5. Circular Design in Practice: Second-Life Use and Modular Components 6. Circular Models as a Strategic Response to Regulation and Market Demand	LO: Describe the difference between linear and circular economic models. Identify circular strategies relevant to boatbuilding (e.g., modularity, take-back schemes, reuse). Explain the importance of lifecycle accountability and regulations like Extended Producer Responsibility (EPR). Interpret how circular business models can reduce waste, cut costs, and support market competitiveness.	1 ½	Classroom-based learning
	4.3.2 Design for Disassembly (DfD): Maximizing material recovery at end-of-life	1. What Is Design for Disassembly (DfD) in Boatbuilding? 2. DfD in Practice: Examples of Disassembly-Friendly Design 3. DfD and Its Role in Regulations and Eco-Labels **4. Planning for End-of-Life from the Design Phase 5. Benefits of DfD for Sustainability, Safety, and Resale Value**	LO: Explain what Design for Disassembly (DfD) means and why it is important. List practical DfD strategies used in boat design and construction. Describe the purpose and components of a material passport. Recognize how DfD and material tracking support recyclability, safety, and compliance with EU regulations.	1 ½	Classroom-based learning

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Sub-topic	Activity	Description
4.1.1 LCA: Basics	*Lifecycle Explorer Stations* *Students rotate through material-focused stations (e.g., fiberglass, flax, aluminum). They identify key life cycle phases and related environmental impacts, matching materials with PEF impact categories.*	**Assessment:** Matching exercise on LCA terminology and phases; mini quiz on the four LCA stages; case-based question on burden shifting. **Objective:** Introduce LCA methodologyand help students recognise how materials influence life cycle impact. **Expected Outcome:** Students can explain the four LCA stages, identifyimpact categories, apply lifecycle thinking to compare materials.
4.1.2 Environmental footprint	*Comparative Carbon Challenge* *Teams analyze two vessel profiles and estimate carbon emissions and energy use. They discuss trade-offs between propulsion systems and materials.*	**Assessment:** Calculations of MJ and CO_2-eq (using simplified data); written comparison of two materials or fuel types; short group discussion on energy/environment trade-offs. **Objective:** Help students understand energy and emissions contributions to environmental footprint across life cycle stages. **Expected Outcome:** Students can define carbon footprint and energy use, interpret environmental data, and compare configurations.
4.1.3 Hotspots	*Hotspot Detective Game* *Students receive LCA snapshots showing impacts across stages and components. They identifyhotspots and propose improvement strategies.*	**Assessment:** Worksheet on hotspot identification; small group presentation of a hotspot case; optional test question on hotspot categories. **Objective:** Develop the ability to locateand analyse environmental hotspots and prioritise interventions. **Expected Outcome:** Students can identify material, energy, and waste hotspots and suggest improvements.

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Sub-topic	Activity	Description
4.2.1 Economic analysis	*Boat Budget Breakdown* *Students compare cost breakdowns of traditional vs. sustainable materials. They analyse upfront, maintenance, and disposal costs.*	**Assessment:** Lifecycle cost worksheet; identify three cost drivers in discussion; short written explanation of trade-offs. **Objective:** Show how financial considerations influence material choices and demonstrate total cost of ownership. **Expected Outcome:** Students can identify economic trade-offs and support decisions using cost analysis.
4.2.2 Return of Investment (ROI)	*Case Study Role Play – Blue Horizon Boats* *Using the Blue Horizon Boats case, students act as stakeholders evaluating a material switch and its ROI.*	**Assessment:** ROI template; group presentation of stakeholder perspectives; reflection on tangible and intangible benefits. **Objective:** Help students evaluate ROI in practical scenarios involving sustainable materials. **Expected Outcome:** Students can calculate simplified ROI, identifybenefits, and communicate them clearly.

Sub-topic	Activity	Description
4.3.1 Circular business models	*Circular Makeover Workshop* *Students redesign a linear boat component (e.g., hatch, hull module) to align with circular principles (reuse, recyclability, modularity).*	**Assessment:** Group sketch/diagram; written explanation of circular principles applied; peer feedback. **Objective:** Engage students in rethinking marine products through circular economy. **Expected Outcome:** Students can explain circular principles and redesign components for improved recovery, reuse, and durability.
4.3.2 Design of Disassembly (DfD)	*DfD Design Lab* *Students redesign a boat component (storage hatch, deck module, bench structure) using DfDprinciples. They sketch/model the redesigned part, identify fasteners and explain material separation strategies.*	**Assessment:** Annotated design sketch; group presentation; written explanation of end-of-life improvements. **Objective:** Introduce Design for Disassembly and how it lowers environmental impact at boat end-of-life **Expected Outcome:** Students apply DfDstrategies (fasteners, modularity, separation) and demonstrate how these support sustainability.

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
1. Introduction to Life Cycle Assessment (LCA) 2. Environmental Impact Categories in LCA	(https://eplca.jrc.ec.europa.eu/LCDN/developerEF.html), https://www.iso.org/home.html, Blue Boat Horizon LCA project, EC PEF method, ISO STANDARDS https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html https://www.iso.org/standard/37456.html https://propellingourfuture.com/ Environmental Footprint Methods - European Commission Life Cycle Assessment for the circular economy https://www.lifecycleinitiative.org/ https://www.marineshift360.org/ https://www.recyclermonbateau.fr/l-aper-association-pour-la-plaisance-eco-responsable/ https://europeanboatingindustry.eu/images/Reports/A144650-R20241613a-UHo-EuCIA%20final%20report%20-%20summary-signed.pdf?_t=1728385417 GREC HANDBOOK https://europeanboatingindustry.eu/images/EU%20affairs/Roadmap-for-decarbonisation-vessels_Final.pdf	Official webiste of the Commission and ISO regulations.	Technical document (ISO), Guide (Grec Handbook), Report (Roadmap for the Decarbonisation of the European Recreational Marine Craft Sector), website (all), Free (only ISO is paid)
4. Case Study: Recycling Glass Fibre Composites 5. Using ISO and PEF Standards in LCA	ICOMIA - RICARDO study, Propelling our future, Blue Boat Horizon LCA project, EC PEF method, https://glassfibreeurope.eu/resource-type/report-study/,	Studies on decarbonisations and LCA methodology	Free, Website

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
4. Waste Generation and End-of-Life Challenges 5. Strategies for Reducing Environmental Hotspots 6. Case Study: Hotspot Analysis from the ICOMIA Propulsion Decarbonisation Study	ICOMIA - RICARDO study, Propelling our future, Blue Boat Horizon LCA project, EC PEF method, ISO standards, https://glassfibreeurope.eu/wp-content/uploads/2023/02/GFE_LCA-report-2023-February-2023.pdf	Studies on decarbonisations and LCA methodology	Free, Website
	ICOMIA - RICARDO study, Propelling our future, Blue Boat Horizon LCA project, EC PEF method, https://data.europa.eu/en/news-events/news/eus-digital-product-passport-advancing-transparency-and-sustainability	Studies on decarbonisations and LCA methodology	Free, Website
5. Beyond Price: Incentives, Branding, and Long-Term Value	ICOMIA - RICARDO study, Propelling our future, Blue Boat Horizon LCA project, EC PEF method	Studies on decarbonisations and LCA methodology	Free, Website
	ICOMIA - RICARDO study, Propelling our future, Blue Boat Horizon LCA project, EC PEF method	Studies on decarbonisations and LCA methodology	Free, Website

Topic for level-up information	Reference Link	Briefing of Reference Content	Notes
3. Case Study: APER and the Circular Recycling of Boats in France 4. Applying the PEF Method to Circular Material Choice	ICOMIA - RICARDO study, Propelling our future, Blue Boat Horizon LCA project, EC PEF method, https://www.recyclermonbateau.fr/, https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html	Studies on decarbonisations and LCA methodology	Free, Website
4. Planning for End-of-Life from the Design Phase 5. Benefits of DfD for Sustainability, Safety, and Resale Value	ICOMIA - RICARDO study, Propelling our future, Blue Boat Horizon LCA project, EC PEF method, https://data.europa.eu/en/news-events/news/eus-digital-product-passport-advancing-transparency-and-sustainability	Studies on decarbonisations and LCA methodology	Free, Website

Unit 5: Career planning, opportunities and challenges

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
5.1 Industry demand for sustainable boatbuilding expertise	**5.1.1 Industry landscape: Labor market trends, demand for green solutions**	**Learn about the current context of the nautical sector from a sustainability perspective, and identify the trends shaping the evolution of the labor market and the demand for new technical solutions, materials, and processes.**	LO: Understanding of the structural transformation of the sector towards sustainability and its drivers and obstabcles. Enhance teamwork, analytical thinking and public speaking of learners that can help their future careers.	2 ½	Classroom-based learning/direct instructions, workshop/debate
	5.1.2 Career paths: Roles in design, engineering, production, sales, marketing	**Exploring professional career paths within the sustainable nautical sector, understand emerging roles, the evolution of traditional profiles, and the skills needed to thrive in a technical, interconnected, and environmentally responsible environment.**	LO: Provide a comprehensive picture of the main job profiles and needed skills and competences to be able to find career in these poisitions.	2 ½	Classroom-based learning/direct instructions, groupwork

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Unit 5: Career planning, opportunities and challenges / Course Outline

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Module Title	Sub-topic	Sub-topic Breakdown	Learning Outcome (LO)	Duration (hrs)	Teaching and Learning Method(s)
5.2 Career paths and training in sustainable maritime industries	**5.2.1 Key skills: Technical and soft skills required for success**	**Presentation of key skills and competences in sustainable boatbuilding, Identification of challenges and opportunities to purse a career in the sector. Match transversal skills and competences relevant in sust. boatbuilding and carry out career planning excercises.**	LO: Identify interdisciplinary technical and soft skills, Evaluate current gaps in training, career pathways and industry practices.	2 ½	Classrroom-based learning/direct instructions, workshop, group discussion
	5.2.2 Professional development: Training, certifications, networking opportunities	**Evaluation of training gaps and current industry practices, Identify practical steps and methods to advance careers. Discover certifications, trainings, relevant netowkring events and career portals in the sector to enhance employability.**	LO: Explore practical strategies to enhance employability and advance career. Clear, self-created career roadmaps with relevant identified skills and competences. Identification and list creation of relevant trainings, events locally and internationally.	2 ½	Classrroom-based learning/direct instructions, workshop, group discussion

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Sub-topic	Activity	Description
5.1.1 Industry landscape	*1: Structured debate — Is the nautical sector ready for an accelerated green transition?*	**Description:** Students will engage in a structured debate exploring whether the nautical sector is prepared for an accelerated green transition. Divided into two teams — Pro (ready) and Con (not ready) — they will analyze and present arguments based on environmental, economic, technological, and regulatory factors. The debate will highlight key drivers (e.g., innovation, policy support, consumer demand) and barriers (e.g., high costs, lack of infrastructure, resistance to change). A short reflection will follow to consolidate learning and encourage critical thinking on sustainability in the maritime world. **Objectives of the Debate:** 1. Enhance critical thinking by evaluating complex sustainability challenges. 2. Develop argumentation skills through evidence-based reasoning. 3. Promote awareness of the environmental impact of maritime activities and the urgency of green transitions. 4. Encourage collaboration and respectful dialogue by listening to opposing views and responding constructively. 5. Foster systems thinking by identifyinginterconnected drivers and barriers. **Expected Outcomes:** -Students gain a deeper understanding of the sustainability challenges and opportunities within the nautical sector. -Students can identify and articulate key drivers and barriers to green transition. -Improved communication and teamwork skills through structured debate. -Increased motivation to explore sustainable solutions.

Sub-topic	Activity	Description
5.1.1 Industry landscape	*2: Sustainable Boatbuilding Around the World – Research Challenge*	**Description:** Students work in teams to investigate how different countries approach sustainable boatbuilding. Each team will choose or be assigned a country and explore its practices, innovations, materials, regulations, and industry trends related to eco-friendly boat construction. Findings will be presented in visual or oral format (poster, slideshow, video). **Objectives:** -Promote research and analytical skills. -Deepen understanding of sustainable materials and technologies. -Highlight global perspectives and differences in maritime environmental challenges. -Encourage teamwork and project management. -Develop presentation and communication skills. **Expected Outcomes:** -Students describe sustainable boatbuilding practices in at least one country. -Students gain awareness of global disparities and leadership in maritime sustainability. -Improved collaboration and organizational skills. -Improved presentation abilities. -Students reflect on how global best practices may be applied locally.

Sub-topic	Activity	Description
5.1.2 Career paths	*1: Career Pathway Mapping (group work)*	**Description:** Students receive cards with professional roles in sustainable boatbuilding. They must place them into a table relating each role to: -Required technical skills -Soft/transversal skills -Recommended education/training -Typical work environment (shipyard, supplier, consultancy, etc.)
5.1.2 Career paths	*2: Create Your Professional Persona*	**Description:** Students understand different professional profiles in sustainable boatbuilding by developing a full persona. Each group is assigned a professional role, such as: -Naval engineer (sustainable materials) -Shipyard manufacturing technician -Purchasing manager -Environmental consultant -Eco-efficient boat designer -Quality and certification manager -VET trainer in sustainable nautical construction **Students create a professional character, including:** -Name, age, experience -Background -Motivations and challenges -Technical skills -Soft skills -Education and training -Typical work environment -Their contribution to sustainability **Presentation:** Groups give a 5-minute presentation showing how the character fits in the sustainable boatbuilding value chain.

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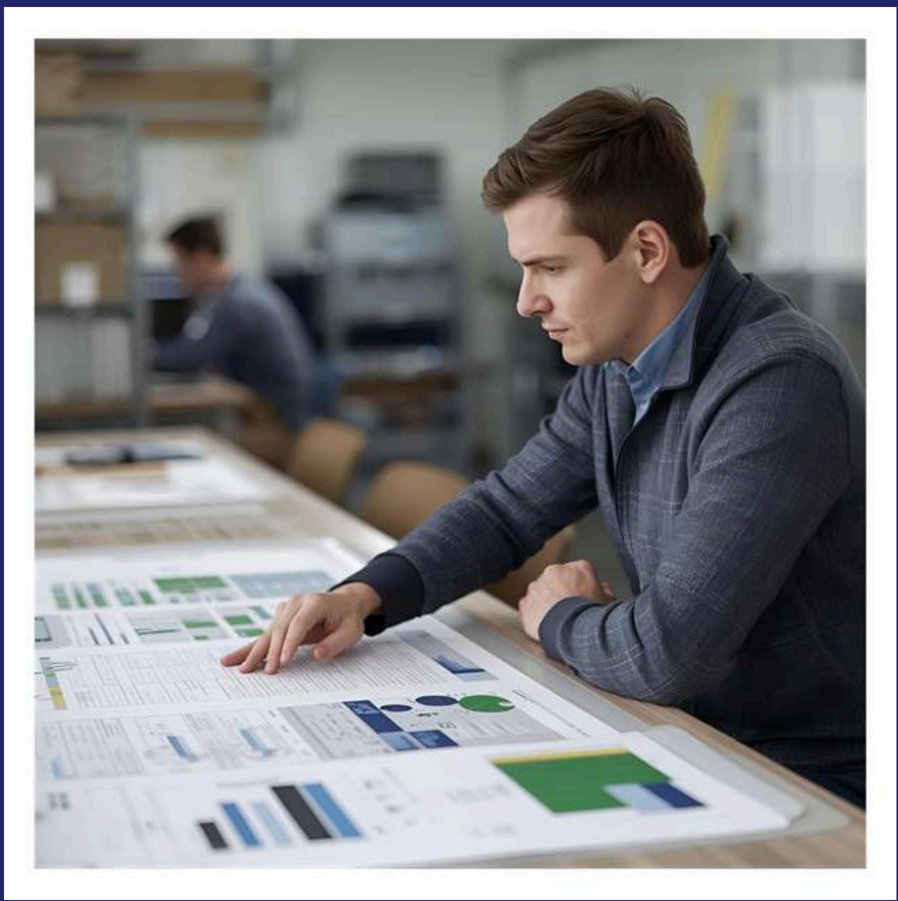
Sub-topic	Activity	Description
5.2.1 Key skills	*Designing Eco-Friendly Yacht Components Using Biocomposites* *Activity Overview: Teams create a conceptual design for an eco-friendly yacht hull component using biocomposites (flax fiber, bio-resin). Includes material selection, CAD layout, LCA basics, waste minimization, and filtration system design.*	**Target Group:** Vocational students specializing in deep tech and sustainable materials in the yacht industry. **Learning Objectives:** Understand how technical skills integrate into yacht design, apply CAD, LCA, and material optimization, develop awareness of sustainability challenges, collaborate in teams to solve design problems. **Step-by-Step:** 1. Team setup & role assignment. 2. Scenario briefing. 3. Design phase (material selection, CAD planning, LCA review, waste minimization, filtration system). 4. Presentation and discussion. **Assessment Criteria (optional):** Clarity, feasibility, discipline integration, creativity, team collaboration. **Discussion Questions:** Why biocomposites? Environmental challenges in traditional yacht production? Role of CAD & LCA? Trade-offs of replacing traditional materials?
5.2.2 Professional development	*Career Planning*	**Description:** Students design their career roadmap entering sustainable boatbuilding. Using a large sheet of paper map: -Short-term steps (skills, subjects) -Mid-term goals (internships, training, certifications) -Long-term vision (specific green-yacht careers) **Students also identify:** Key industry players (companies, NGOs), Events (fairs, workshops, conferences), Networking paths (LinkedIn, alumni, mentors) **Outcome:** Students present their roadmap & receive feedback.

Topic for level-up information	Reference Link	Briefing of Reference Content
EU Green Deal, Fit for 55 Package Waste Shipment regulation (EU) NextGenEU funds 3 countries (France, Germany, Netherlands) leading the way Current obstacles towards sustainability detailed Ocean Race article is a more general overview on obstacles and way forward Interview on green transition in the sector - casestudy of Benetau Case study of Benetauin video	https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en https://www.consilium.europa.eu/en/policies/fit-for-55/ https://environment.ec.europa.eu/topics/waste-and-recycling/waste-shipments_en https://next-generation-eu.europa.eu/index_en https://www.yacht.de/en/shipyards/boatbuilding-ecolution-these-shipyards-are-working-on-sustainable-concepts/ https://teconaut.eu/en/downloads/ (New deep tech skills document) https://www.theoceanrace.com/en/racing-with-purpose/sustainable-sports-and-innovation/sustainable-boat-building https://no-frills-sailing.com/sustainability-boatbuilding-beneteau-erwan-faoucher-interview/ https://www.youtube.com/watch?v=ynGKEYlYXQo	Official EU website for Green Deal, Fit for 55 package and Waste shipment regulation with the key points, aims, objectives in different languages Detailed information on NextGenEU funds Presenting 3 successful case studies who are implementing sustainable materials and practices, and shares insights and experiences. 3 companies are: Beneteau, The Ecoracer from Eco Yachts, Windelo, Bestevaer and Vaan. Detailed research on deep tech materials, their application, required skills and knowledge, obstacles and projection collected from a wide-scale interview series made with 120+ experts. The Ocean Race has held four Sustainable Boat Building Innovation Workshops since 2017, uniting industry leaders and racing teams to co-create an ambitious 2030 roadmap focused on materials, waste reduction, energy efficiency, and enablers like regulations and lifecycle analysis to cut greenhouse gas emissions by 50% . These workshops have yielded a detailed Industry Roadmap 2030, plus practical guidelines and reports spotlighting immediate steps that boat builders can take now to accelerate the transition to a more sustainable future . Presenting case study of Beneteau is making serious, tech-driven sustainability efforts—developing ecoresins like Elium®, increasing natural fibre use, rolling out electric/hybrid propulsion, and implementing lifecycle analysis and recycling programs—while balancing innovation with customer readiness and costs. + video interview

Topic for level-up information	Reference Link	Briefing of Reference Content
Jobs in shipyards & boatbuilding (in general)	https://www.marineinsight.com/careers-2/different-jobs-in-a-shipyard-shipbuilding-industry/ https://no-frills-sailing.com/sustainability-boatbuilding-beneteau-erwan-faoucher-interview/	Showcasing mainstream positions/jobs in the boatbuilding sector such as welders, fabricators, plumbers, electricians, carpenters, riggers, quality controllers etc.
Wooden boat building in video New technologies in traditional boatbuilding How to build a traditional wooden dinghy - video Sustainable sailboat building - video	https://www.youtube.com/watch?v=cXkBA-h0IlU https://www.youtube.com/watch?v=YbpcJiikP44 https://www.youtube.com/watch?v=xiE0n9lhk4g https://www.youtube.com/watch?v=De8E4YS6nNM	Short videos presenting traditional boatbuilding processess, and required skills and competences to work with wood and prepare dinghy or sailboat.

Topic for level-up information	Reference Link	Briefing of Reference Content
Relevant skills needed in the sector, status-quo of curriculum and imporvementneeded Video presentation on building a career List of UK and international events for boatbuilders, shipyards, also great occassions to network Tips on how to do networking Metstrade Young Professionals Linkedin Group Networking opportunities, preparation for international events, success stories	https://teconaut.eu/en/downloads/ https://www.youtube.com/watch?v=g34Vk5ehGHY https://marineindustrynews.co.uk/marine-industry-events/ https://www.youtube.com/watch?v=OVf5c7NthSw https://www.linkedin.com/groups/12717817/ https://fastercapital.com/content/Boating---Yachting-Networking-Event-Navigating-Success--How-Boating-and-Yachting-Networking-Events-Can-Boost-Your-Career.html	Curricula Assessment Research Report, Skills Identification & Assessment Guidelines, New deep tech skills set Boatbuilding jobs, expert interview and case studies presented. Extensive list of UK and international boatshow, fairs, exhibitions to search for job, network, learn about innovation and sustainability. Tips from professionals on how to master networking and make lasting impact. Private group on Linkedin for young boatbuilding professionals or workers in the sector to exchange, learn and network. Importance of netwoking principally in boatbuilding sector, what are the benefits, success stories, how to prepare for international boat trades and trends and innovations to look out.

4 Training Guidance



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4. Training Guidance

This section provides practical, application-focused guidance for trainers delivering the TEcoNaut course.

The aim is to support them in:

- Applying the recommended teaching and learning methods
- Adapting instructional approaches to different educational or operational contexts
- Facilitating interactive and effective learning experiences
- Ensuring that the intended learning outcomes, particularly those related to sustainable boatbuilding, are achieved consistently across all training environments.

Sections 4.1 and 4.2 present the training approach and guidance for trainers, with Section 4.1 providing an overview of selected and complementary teaching methods while Section 4.2 offers practical tips to support effective, learner-centred, and competence-based delivery of the TEcoNaut course. Through this guidance, trainers are equipped to provide high-quality instruction that reflects the programme’s emphasis on innovation, sustainability, and practical competence development.

4.1 Training Approach and Guidance

Guidance for trainers

When preparing and delivering lessons, trainers should:

- **Select appropriate teaching methods** from Section 4.1, considering the intended learning outcomes described in the tables of each Unit in Section 3, available resources, and the learner's prior experience.
- **Balance theory and practice** to ensure that each concept is explained and applied, so that learners gain a hands-on understanding.
- **Facilitate feedback and reflection** after every session to consolidate learning and encourage self-evaluation.
- **Adapt methods to the delivery format** – in-person, online, or hybrid – while maintaining inclusivity and engagement (*See Section 4.1: “Synthesizing Methods” for detailed guidance.*)

Overview of the methods selected

TEcoNaut employs a combination of five complementary teaching approaches, forming the pedagogical backbone of the programme. These methods are designed to ensure that training remains **interactive, competence-oriented and closely aligned with workplace realities**:

1. **Hands-on Learning** – Active participation through practical exercises that allow learners to perform real or simulated tasks and directly apply the taught concepts.
2. **Classroom-based Learning** – Structured, instructor-led sessions introducing theoretical foundations and creating opportunities for guided discussion.
3. **Online Training** – Web-based or self-paced activities offering flexibility and access to digital learning materials.
4. **Experiential Learning** – Learning through reflection on personal or collective experiences, linking real-life situations with new knowledge.
5. **Project-based Learning** – Team-based investigation of authentic problems that require combining theory and practice to produce tangible outcomes.

Together, these approaches empower trainers to deliver **engaging and effective learning experiences**, promoting the development of both technical and sustainability-related competencies critical to the boatbuilding sector.

Additional and complementary methods

Trainers can flexibly integrate the following approaches to address different learning objectives, participant profiles, or delivery modes:

- **Hybrid Learning**, combining online and in-person delivery to balance flexibility and interaction.
- **Workshops**, focusing on hands-on, peer-to-peer practice within small groups.
- **Group Discussions and Collaborative Learning**, encouraging teamwork and shared problem-solving.
- **Direct Instruction**, short theoretical inputs or demonstrations used before practice sessions.
- **Flipped Classroom Approach**, assigning preparatory self-study so classroom time is used for application.
- **Game-based Learning**, integrating playful or competitive elements to enhance motivation.
- **Scenario-based and Simulation-based Learning / Role-Playing**, allowing learners to experiment safely with realistic cases.
- **Problem-based Learning (PBL)**, where learners work collaboratively to resolve open-ended, real-world challenges guided by the trainer.

These additional methods provide trainers with **flexible tools to adapt the course** to different contexts, enhancing learner engagement and the effectiveness of training delivery.

Synthesizing methods

Training methods can be **strategically combined** to improve learning outcomes. For example:

- **Job Rotation and Cross-Training** – Expose learners to different functions, broadening their practical experience.
- **Collaborative Projects with Problem-Solving Sessions** – Merge teamwork with innovation, encouraging application of knowledge to real-world challenges.

Trainers are encouraged to apply similar combinations to **reinforce the connection between theoretical understanding and practical performance**, adapting approaches to the specific needs of learners and the training context.

4.2 Practical Tips for Trainers

This subsection offers practical recommendations to help trainers plan and deliver TEcoNaut sessions effectively. Its purpose is to support high-quality instruction, strengthen learner engagement, and promote consistent implementation of the training course.

Before the Session – Preparation

- Define learning outcomes clearly. Determine what participants should be able to do by the end of the lesson rather than focusing only on theoretical knowledge.
- Prepare materials in advance. Check that tools, samples and digital files are functional and available.
- Organise the learning environment. Arrange seating and equipment to encourage participation and ensure safety.
- Select and combine methods deliberately. Plan which approaches from Section 4.1 will best support the intended outcomes.
- Establish a positive atmosphere. Begin with a short introduction or question that links the topic to real-life work situations.

During the Session – Delivery

- Encourage active participation. Use questions, short discussions, and practical tasks to keep learners engaged.
- Distribute responsibility. Invite participants to demonstrate procedures or summarise key points.
- Alternate theory and practice. Provide concise explanations followed by interactive or experiential activities.
- Use visual and tangible aids. Demonstrate with physical examples, diagrams, or short videos to support understanding.
- Stimulate creativity. In project-based or problem-based activities, reward innovative solutions and collaboration.

After the Session – Reflection and Follow-up

- Conduct a brief debriefing. Discuss what participants learned and how they can apply it in their work.
- Gather quick feedback. Use short written or verbal evaluations to identify strengths and areas for improvement.
- Summarise and connect. Review the main takeaways and highlight links to upcoming modules.
- Record practical examples. Keep photos or notes of activities that can be reused or shared in later sessions.

Digital and Hybrid Delivery

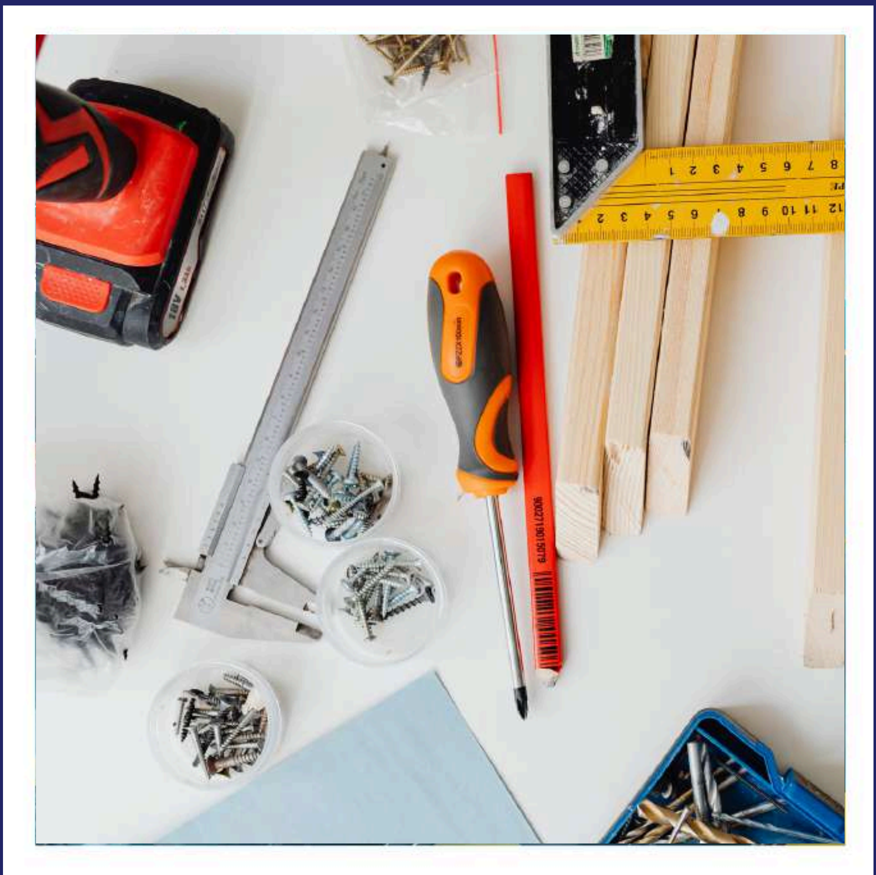
- Test technology in advance. Confirm that audio, video, and presentation tools function correctly. See Section 8, "Training Equipment".
- Maintain interaction. Alternate between short presentations and participant activities to prevent screen fatigue.
- Encourage collaboration online. Use group exercises or shared documents to promote teamwork.
- Provide self-paced resources. Offer recordings or digital materials for learners who need additional review.

Sustainable and Inclusive Teaching

- Model sustainability. Reuse demonstration materials and minimise printed handouts by using digital alternatives.
- Ensure accessibility. Adapt explanations and pacing to accommodate diverse experience levels.
- Promote respectful participation. Create an environment where all learners feel comfortable contributing.
- Highlight relevance. Use examples from different maritime sectors to connect with varied learner backgrounds.

These recommendations serve as a flexible checklist rather than a fixed procedure. Teachers /Trainers are encouraged to adapt them to the specific learning environment, available resources, and participant needs, ensuring that every TEcoNaut session remains experiential, inclusive and aligned with sustainable practices.

5 List of Materials and Equipment



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5. List of Materials and Equipment

Effective teaching in VET training centres relies on well-chosen, hands-on training equipment that allows learners to see, touch, compare, and apply materials and processes used in real production environments. The equipment described in this section supports a practice-oriented approach, helping students understand the properties, applications, and processing challenges of sustainable composite materials. By combining physical samples, visual aids, worksheets, and guided practical tools, trainers can bridge theory and practice and prepare learners for the sustainable boatbuilding tasks.

Unit 2 - Sustainable materials, properties and performance

Sub-topic 2.1.1: Material properties: Characteristics and applications

Training equipment for this topic focuses on enabling learners to compare and understand different reinforcement materials commonly used in sustainable composites. Material samples such as flax, basalt, recycled PET (rPET), and glass fibre should be available in small, manageable pieces so learners can examine texture, flexibility, fibre structure, and surface appearance.

Property comparison charts or handouts support structured learning by visually summarising key characteristics such as stiffness, weight, moisture behaviour, recyclability, and typical use cases. PowerPoint presentations or whiteboard visuals can be used to explain concepts such as tensile strength or fibre orientation, while images of real boat components help learners connect abstract material properties to practical applications in hulls, decks, interiors, or secondary structures.

List of essential material and equipment

- Material samples (e.g., flax, basalt, rPET, glass fiber)
- Property comparison charts or handouts
- PowerPoint or whiteboard visuals
- Application images of real boat components.

Indicative pictures of the required material and equipment

Volcanic rock – basalt powder

Volcanic pellet

Sub-topic 2.2.1: Raw material categories: Natural fibers, recycled fibers, basalt, regenerated cellulose

For this topic, clearly labelled fibre sample cards or small bundles allow learners to distinguish between different raw material categories. Labels should include fibre type and basic sustainability information. A comparison chart of technical and non-technical fibres helps learners to visualise performance ranges and limitations.

Short, fibre data sheets provide quick reference information, while a matching worksheet or cut-and-paste exercise enhances learning by asking students to connect fibre types with properties or applications. Images showing the use of these fibres in boatbuilding components further underline their relevance in modern, sustainable production.

List of essential material and equipment:

- Fiber sample cards or bundles (labeled)
- Comparison chart (technical vs. non-technical fibers)
- Fiber data sheets (short, visual)
- Matching worksheet or cut-and-paste exercise
- Images of fiber applications in boats.

Indicative picture of the required material and equipment

Volcanic fibres (chopped)

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Volcanic fibres

Sub-topic 2.2.2: Textiles: Textile architectures in composites

Teaching textile architectures requires visual training equipment. Samples of woven, nonwoven, and unidirectional (UD) textiles allow learners to physically explore differences in structure and handling behaviour. Fibre direction arrows applied directly to samples or shown on diagrams help explain load paths and structural performance.

A small model part, such as a foam shape, enables learners to practice draping textiles and observe how different architectures behave on curved surfaces. Worksheets with textile-to-application matching tasks support reflection and help learners link textile choice to real boatbuilding requirements.

List of essential material and equipment:

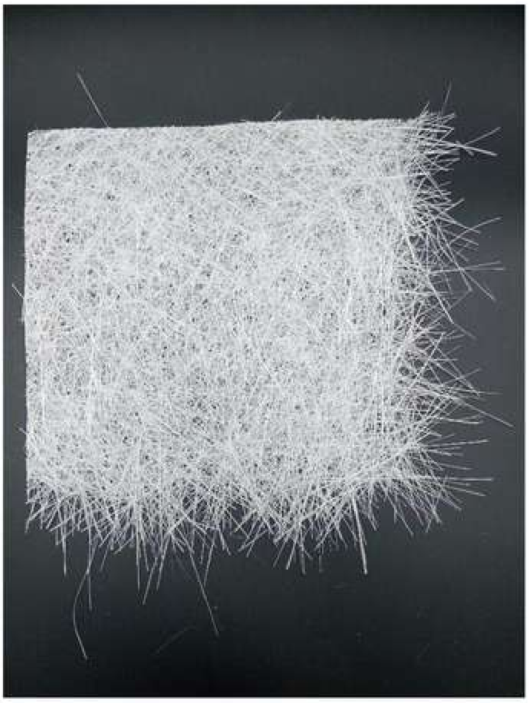
- Textile samples (woven, nonwoven, UD)
- Fiber direction arrows (on samples or diagrams)
- Model part to drape over (e.g., small foam shape)
- Worksheet with textile-to-application matching task.

Indicative picture of the required material and equipment

Fiberglass biaxial fabric

Fiberglass triaxial fabric

Indicative picture of the required material and equipment



Chopped strand mat

Volcanic biaxial fabric

Volcanic triaxial fabric

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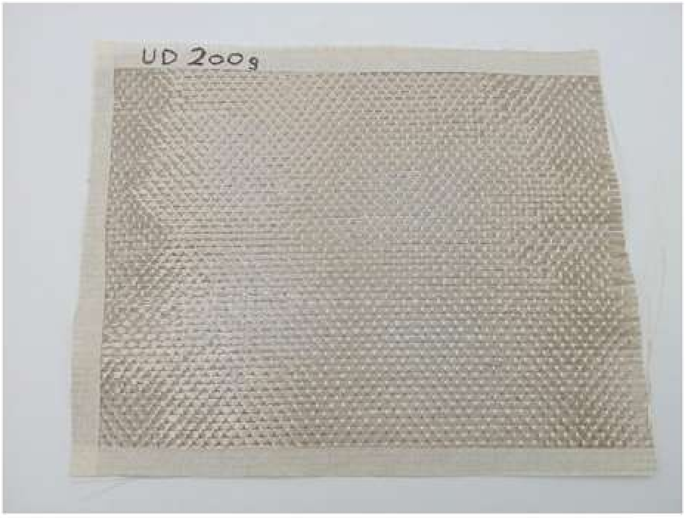


Volcanic unidirectional fabric

Sub-topic 2.2.5: Sustainable sandwich cores: Balsa wood, cork, recycled PET, wood, paper honeycomb

This topic benefits strongly from physical core material samples. Small blocks or cuttings of balsa, cork, recycled PET foam, wood, and paper honeycomb allow learners to compare weight, stiffness, surface texture, and internal structure. A simple datasheet or overview table summarizes key properties such as density, compressive strength, and sustainability aspects.

An optional weight scale can be used to demonstrate differences in density, while safe cutting tools allow learners to feel resistance and internal structure under supervision. A handout featuring a core material selector matrix supports decision-making exercises where learners choose appropriate cores for specific boat components.

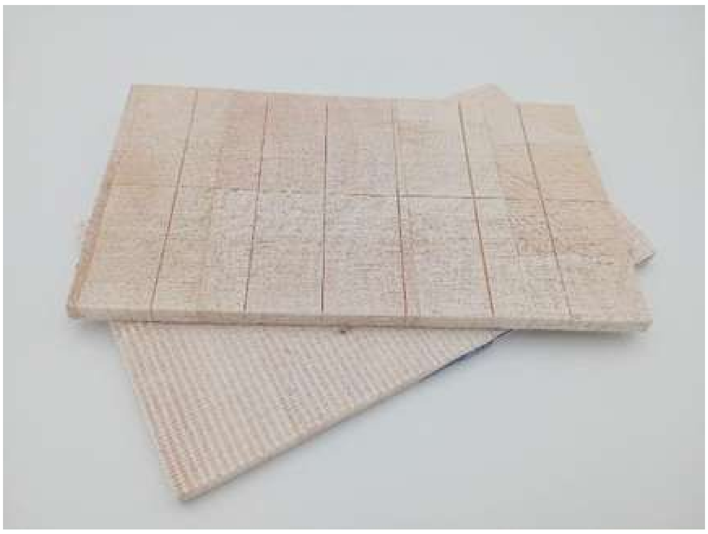
List of essential material and equipment:

- Sample blocks or cuttings of core materials (balsa, cork, rPET foam, etc.)
- Simple datasheet/overview table
- Weight scale (optional)
- Knife or cutting tool for feel (if safe)
- Handout: core material selector matrix.

Indicative picture of the required material and equipment

Grooved Foam Core

Rigid Foam Core



Balsa Core

Unit 3 - Application techniques in manufacturing and repair work

Sub-topic 3.1.1: Tools, equipment, surface preparation

This topic introduces learners to the tools, equipment, and preparatory steps required before any composite laminating or repair work can begin. Sample hand tools such as scissors, rollers, and sanding pads should be provided for hands-on familiarisation. Surface samples prepared from different materials (e.g. cured laminates, gelcoat surfaces, or core materials) are essential for practising preparation tasks. Acetone or an appropriate, safer substitute is used to demonstrate surface cleaning and contamination removal. Safety gear such as gloves, goggles, and masks must be available and consistently used during all preparation activities. This reinforces safe working practices and highlights the health and environmental risks associated with dust, solvents, and fibres. A printed checklist outlining surface preparation steps provides structured guidance, helping learners internalise correct sequences, quality checks, and safety measures.

List of essential material and equipment:
- Sample tools: scissors, rollers, sanding pads, acetone or substitute
- Surface samples for prep tasks
- Safety gear (gloves, goggles, masks)
- Printed checklist for surface prep steps.

Indicative picture of the required material and equipment

Wood spatulas

Sandpaper for deck sanding (various grits)

Sandpaper (various grits)

Sub-topic 3.1.3: Laminating techniques: Applying bio-based resins with natural fibers

Practical laminating exercises require realistic workshop equipment. Natural fibre fabrics, such as flax fibres, combined with bio-based resins allow learners to focus on correct processing rather than material preparation errors. Brushes, rollers, and mixing tools support hands-on application, while a mould or steel plate provides a controlled laminating surface.

Protective equipment reinforces safe working practices. A laminating instructions checklist guides learners step by step through the process, helping them develop consistent, repeatable techniques aligned with industry standards.

List of essential material and equipment:

- Natural fibre fabric (flax, technical fibres)
- Bio-resin (pre-measured)
- Brushes, rollers, mixing tools
- Mould or steel plate
- Protective equipment
- Laminating instructions checklist.

Indicative picture of the required material and equipment

Brush

Roller

Consolidation roller

Mixing pot

Mixing sticks

Sub-topic 3.1.4: Challenges: Processing difficulties and optimizing sustainable materials

To illustrate processing challenges, learners should work with materials such as flax twill and glass fibre twill of similar weight, alongside both bio-based and standard epoxy resins. This setup allows direct comparison of handling behaviour, wet-out characteristics, and surface quality.

Laminating boards or moulds support practical trials, while a vacuum infusion demo kit, operated by the trainer, demonstrates more advanced processing methods. Sample defect images (e.g. dry spots, fibre distortion, resin-rich areas) help learners identify common issues. An inspection and reflection worksheet encourages analysis and discussion on how to optimise sustainable material use.

List of essential material and equipment:

- Flax fabric (twill), glass fibre (twill), similar weight
- Bio-based and standard epoxy-resins
- Mixing tools, brushes, rollers
- Laminating boards or moulds
- Vacuum infusion demo kit (trainer use)
- Sample defect images for comparison
- Inspection & reflection worksheet for learners.

Indicative picture of the required material and equipment

Polyester resin (standard)

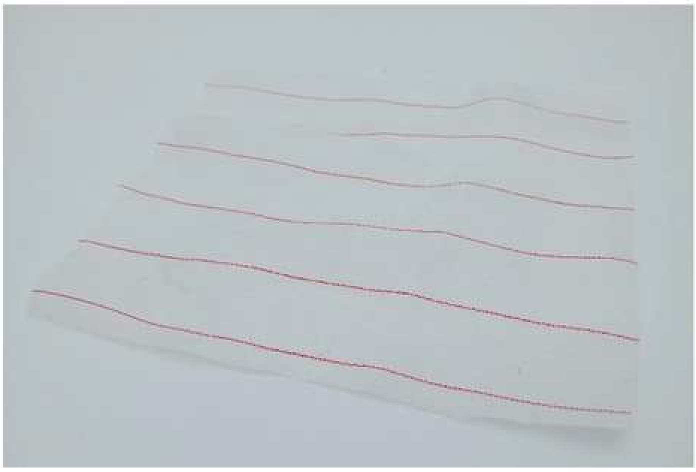
Brushes

Rollers

Mixing pot

Mixing stick

Vacuum pump



Peel ply

Vacuum bagging film

Sealant tape

General consumables for composite vacuum lamination

Resin trap

Sub-topic 3.2.2: Repair techniques: Standardized repair methods for sustainable composites

Repair training requires realistic damage scenarios. A damaged laminated plate serves as the base for repair exercises using natural or volcanic fibre fabrics and bio-resins. Brushes, rollers, and mixing tools support controlled application, while grinding and sanding equipment allows learners to prepare repair areas correctly.

Protective equipment is essential to reinforce safety standards. A laminating instructions checklist ensures repairs follow a structured, standardised method, helping learners understand quality requirements in sustainable composite repair work.

List of essential material and equipment:

- Natural fibre fabric (volcanic fibres)
- Bio-resin (pre-measured)
- Brushes, rollers, mixing tools
- Damaged laminated plate
- Grinding and sanding equipment (paper, grinder etc)
- Protective equipment
- Laminating instructions checklist.

Indicative picture of the required material and equipment

Brushes

Rollers

Mixing pot

Mixing sticks

Sandpaper for deck sanding (various grits)

Sandpaper (various grits)

Annex

Supporting material :

- Videos from Skills Shadowing Workshops
- Presentation on Deep-tech materials (in English)
- Presentation on Materials Mechanical Properties (in English)

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Videos from Skills Shadowing Workshops

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The following videos have been created as part of the European project TecoNaut. Specifically, the material was filmed during the skills shadowing workshops at the Astondoa shipyard, as well as at the facilities of Innovation Yachts and Green Boats.
The material covers the entire production spectrum, ranging from eco-friendly raw materials to the practical application of specialized manufacturing techniques, such as vacuum resin infusion.

Video 1: Composite materials manufacturing using recycled fibers and vacuum techniques
https://www.youtube.com/watch?v=CxCg8OJMKFI

Copyright © ASTONDOA

What does the video include?
The video demonstrates the practical application of sustainable materials in the **fabrication of composite panels (laminates)**. It begins with theoretical training on **recycled carbon fibers** and proceeds to hands-on application, covering the **vacuum resin infusion process**. For the first specimen, **thermoplastic resin** and r**ecycled carbon fibers** are used. It includes critical stages of the process, such as **leak testing the vacuum bag and testing the final panel's resistance to acetone**. In the second specimen, a composite panel is fabricated using bio-epoxy resin, cork, and flax fibers. It is ideal for demonstrating the transition from theory to production and comparing different infusion systems under real-world conditions.

Video 2: Hand lay-up followed by vacuum resin infusion techniques with mineral fibers and a Balsa wood core

https://www.youtube.com/watch?v=qMBLFOvja0M

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What does the video include?

The video is a detailed, step-by-step lamination guide for boat construction. The process begins with **cutting the layers** and **preparing the surface** of the mold, which already features a gelcoat layer. This is followed by the application of the **first resin layer**, with special attention paid to the corners, and the gradual placement of **three fiber layers**. A significant part of the video is dedicated to the preparation and positioning of balsa wood in the appropriate areas. The process concludes with the **vacuum phase**, utilizing materials such as **peel ply, release film, draining fleece, and a vacuum bag**, with the final stage involving the inspection and **sealing of any leaks**.

Video 3: Innovation and sustainability in boatbuilding: Materials and Applications
https://www.youtube.com/watch?v=6fjG-WgYI6Y

What does the video include?

This video includes a discussion on the use of **polyester materials** and **epoxy resins**, analyzing the challenges and advantages of each option. **Samples of certain bio-based materials** are presented, followed by the **practical application of the hand lay-up lamination technique** on an actual boat section. The video demonstrates the use of **hand lay-up tools** and **specialized shears for cutting fibers and fabrics**, as well as **vacuum preparation**. The video concludes with the successful **demolding process** of the final product.

Video 4: Natural flax fibers in sustainable pleasure craft boatbuilding
https://teconaut.eu/en/downloads/skills-shadowing-videos/

Copyright © GREENBOATS

What does the video include?

The video focuses on the use of **flax fibers** as a sustainable alternative to traditional reinforcement materials. The advantages of flax, such as its **low CO2 footprint** and excellent **mechanical properties**, are presented alongside a comparison with glass and carbon fibers. The process includes an explanation of the **plant's cultivation and processing** up to its conversion into **woven fabrics**. In the practical section, their application in **sandwich structures** and their compatibility with **bio-resins** are demonstrated, highlighting the potential for **recycling** and waste reduction in the pleasure craft sector.

Video 5: Visit and overview of sustainable materials in a boat shipyard
https://teconaut.eu/en/downloads/skills-shadowing-videos/

Copyright © GREENBOATS

What does the video include?
The video documents a visit to an actual production facility, focusing on visual contact with materials and equipment. Close-up shots present **rolls of natural fibers** stored on racks, while a **core material** that has already undergone vacuum processing is demonstrated. The student can observe the process of applying **sealant tape** to a mold for **vacuum bag** preparation. Additionally, the final result of a **boat under construction** is showcased, displaying the texture of the n**atural fibers** after lamination.

Video 6: Expanding shipbuilding technical skills through the use of sustainable materials in vehicle manufacturing

https://teconaut.eu/en/downloads/skills-shadowing-videos/

What does the video include?

The video demonstrates how expertise in **natural fibers** and **composite materials** can be transferred from the shipyard to other manufacturing applications. It focuses on the use of **lightweight structures** for creating cabins and **outfitting motorhomes (campervans)**. The trainee can observe the practical application of **composite panels** in vehicle interior design and insulation, proving that skills in handling these materials offer solutions to any sector requiring **durability**, **low weight**, and **sustainable construction**.

Video 7: Seven-Step Guide to Vacuum Resin Infusion
https://teconaut.eu/en/downloads/skills-shadowing-videos/

What does the video include?

The **vacuum resin infusion process** is presented in seven stages, utilizing **flax fibers**. **Cutting tools** are used to prepare the fabrics, alongside **sealant tape** and **specialized flexible hoses** for resin transfer and connection to the v**acuum pump**. The video shows the use of a **vacuum gauge** to detect leaks and monitor pressure during the resin infusion. The process includes the use of **resin mixing cups** and **hose clamps** to regulate the flow, while the final inspection is conducted on a **flat-plate specimen**.

Presentation on Deep-tech Materials

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SEA TEACH
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TECONAUT
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An Overview of the Deep Tech Materials Landscape
Artur Karczewski, PhD. Eng.
Gdańsk University of Technology
Gdańsk, Poland


TECONAUT
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Presentation overview
Deep Tech Materials definition?
Why is there a need to use deep-tech materials?
Deep Tech materials overview
Group work and discussion


TECONAUT
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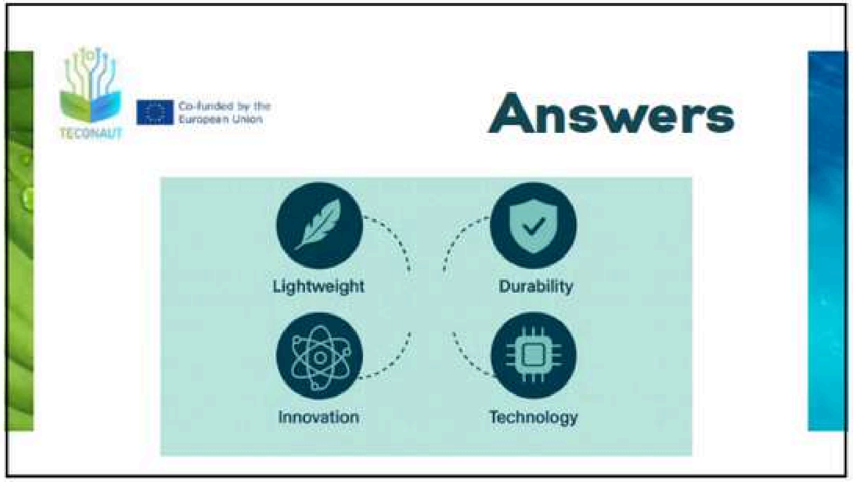
Question
When you hear the term Deep tech material, what do you think of?
Scan and answer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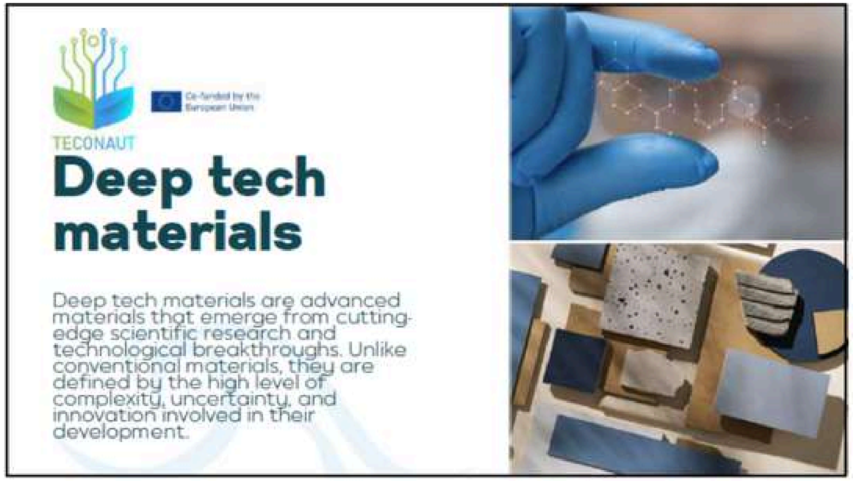
Answers
Lightweight
Durability
Innovation
Technology


TECONAUT
Uncertainty
technical
(will it work outside the lab?)
regulatory (can it meet safety
and certification standards?)
market-based
(will there be demand?)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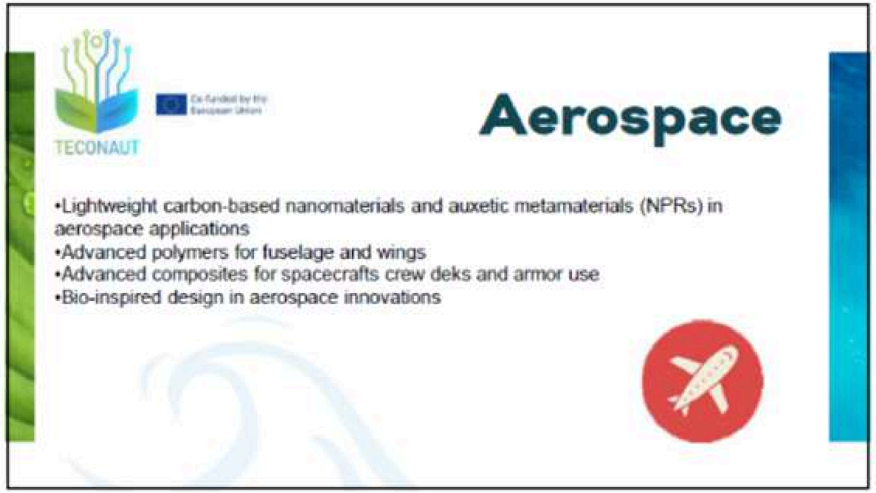
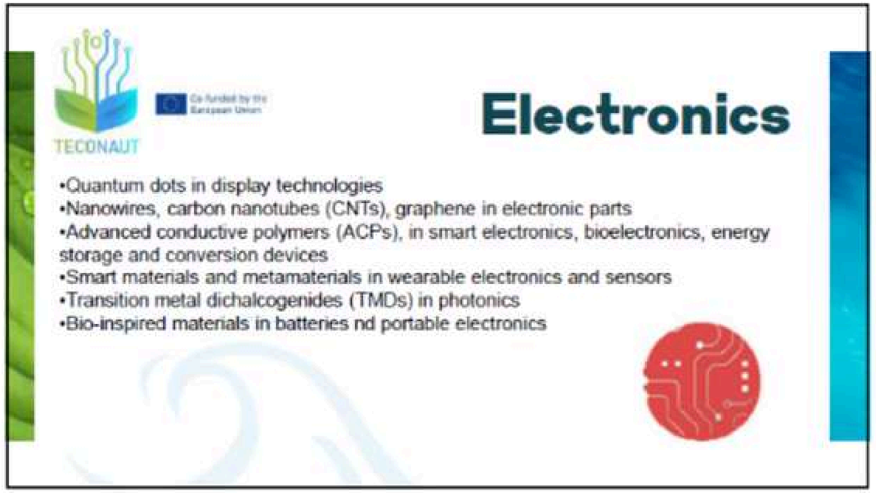
Deep tech materials
Deep tech materials are advanced materials that emerge from cutting-edge scientific research and technological breakthroughs. Unlike conventional materials, they are defined by the high level of complexity, uncertainty, and innovation involved in their development.


TECONAUT
Why do they matter?
Deep tech materials aren't just new– they're changing the rules of how we design, produce, and use materials across industries.
They are transforming: automotive, aerospace, electronics and medicine.


TECONAUT
Automative
•Advanced high-strength steels (AHSSs) in body structures and chassis
•Natural-fiber-reinforced c
omponents
•Graphene and carbon na
ts
Office on the web Frame
•Metamaterials for radar, antennas, and electromagnetic shielding for electric vehicles
•Piezoelectric materials in sensors and actuators
•Shape Memory Alloys (SMAs) in structural components and safety applications
•Man-made honeycomb structures in automobile components


TECONAUT
Aerospace
•Lightweight carbon-based nanomaterials and auxetic metamaterials (NPRs) in aerospace applications
•Advanced polymers for fuselage and wings
•Advanced composites for spacecrafts crew deks and armor use
•Bio-inspired design in aerospace innovations


TECONAUT
Electronics
•Quantum dots in display technologies
•Nanowires, carbon nanotubes (CNTs), graphene in electronic parts
•Advanced conductive polymers (ACPs), in smart electronics, bioelectronics, energy storage and conversion devices
•Smart materials and metamaterials in wearable electronics and sensors
•Transition metal dichalcogenides (TMDs) in photonics
•Bio-inspired materials in batteries nd portable electronics


TECONAUT
Healthcare
•Biocompatible materials and electromagnetic metamaterials for wearable flexible hybrid electronics
•Polymer-based composites for tissue engineering and dru delivery
•Carbon nanotubes, nanowires, nanoparticles, quantum dots and graphene in diagnostics, drug and alcohol sensing, drug delivery, biosensors and bioelectronic devices
•Bio-inspired innovations in reducing disease transmission


TECONAUT
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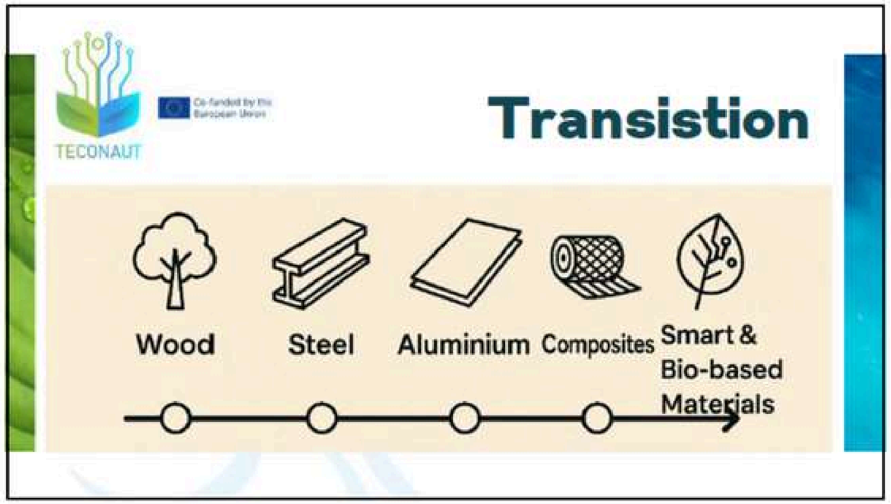
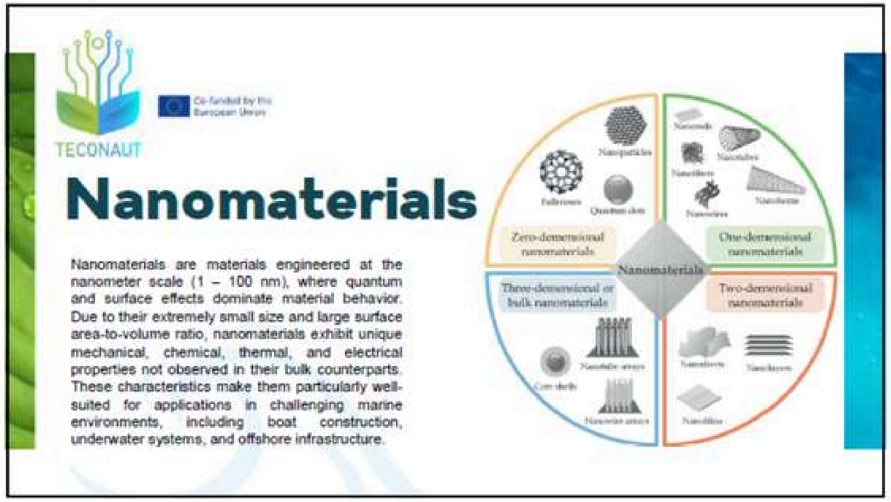
Question
Why is there a need to search for new materials in boatbuilding?
Office on the web Frame
Scan and answer


TECONAUT
Co-funded by the European Union
Transistion
Wood
Steel
Aluminium
Composites
Smart & Bio-based Materials


TECONAUT
Co-funded by the European Union
Comparison
Deep-Tech
Traditional Materials
Weight
Lightweight
Heavier
Strength
Higher
Lower
Corrosion Resistance
High
Limited
UV Resistance
Strong
Needs Coating
Recyclability
Varies
Lower
Repairability
Easier
Easier


TECONAUT
Co-funded by the European Union
Nanomaterials
Nanomaterials are materials engineered at the nanometer scale (1 – 100 nm), where quantum and surface effects dominate material behavior. Due to their extremely small size and large surface area-to-volume ratio, nanomaterials exhibit unique mechanical, chemical, thermal, and electrical properties not observed in their bulk counterparts. These characteristics make them particularly well-suited for applications in challenging marine environments, including boat construction, underwater systems, and offshore infrastructure.
Zero-dimensional nanomaterials
One-dimensional nanomaterials
Nanomaterials
Three-dimensional or bulk nanomaterials
Two-dimensional nanomaterials

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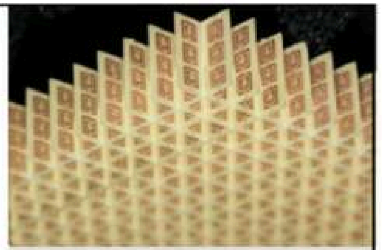
Nanomaterials

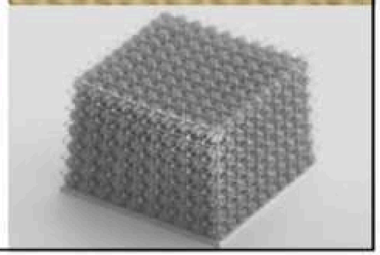
Category	Details
Material Classification	Nanostructured materials (e.g., nanoparticles, nanotubes, nanocomposites)
Mechanical Properties	High strength-to-weight ratio, fracture resistance, fatigue life enhancement
Surface Functions	Corrosion resistance, anti-fouling, UV protection, self-cleaning
Thermal/Optical Properties	UV blocking, heat dissipation, thermal insulation
Applications in Yachts	Nano-reinforced hulls, anti-fouling coatings, nanostructured UV-protective finishes, advanced sensor systems, nanocoatings on mechanical parts
Emerging Uses	Smart coatings, nanogenerators, lightweight energy storage (batteries, supercapacitors)

TECONAUT

Metamaterials

Metamaterials are artificially engineered materials designed to exhibit physical properties not found in nature. By carefully structuring their internal geometry, these materials can control acoustic, thermal, and electromagnetic waves in ways conventional materials cannot. While metamaterials have been widely explored in aerospace, defense, and telecommunications, their potential in the field of boat construction is increasingly recognized.





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Metamaterials

Category	Details
Material Classification	Advanced Engineered Materials (subset of functional materials)
Division into Groups	• Mechanical Metamaterials – optimized for strength, flexibility, etc. • Acoustic Metamaterials – control of sound waves; • Thermal Metamaterials – manipulation of heat flow; • Electromagnetic Metamaterials – control of EM/radar waves; • Optical Metamaterials – light wave control (cloaking, lenses)
Mechanical Properties	• High strength-to-weight ratio • Auxetic behavior (negative Poisson's ratio) • High stiffness or controlled deformability

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Metamaterials

Category	Details
Mechanical Properties	• Energy absorption • Tuneable elasticity and density depending on geometry
Application Cases	• Boat hulls: lightweight, impact-resistant structures • Noise insulation: cabins with acoustic metamaterials • Radar stealth: reduced detectability of military vessels • Thermal management: optimized interior climate control • Hydrodynamic coatings: drag reduction, anti-biofouling • Energy harvesting: from wave or vibration-induced deformation

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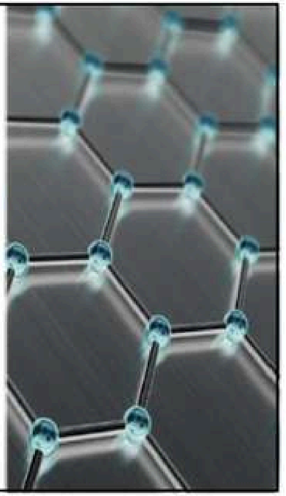
Quantum materials

Quantum materials, defined by properties like entanglement, topological states, and strong electronic correlations, represent a new frontier in advanced materials. Their application can be already encountered particularly in the healthcare industry and electronics. Though their current use in the maritime sector—particularly the yacht industry—is limited, their potential is significant. These materials could revolutionize marine systems through ultra-sensitive sensors, efficient energy subsystems, and high-performance composites tailored for demanding oceanic environments.



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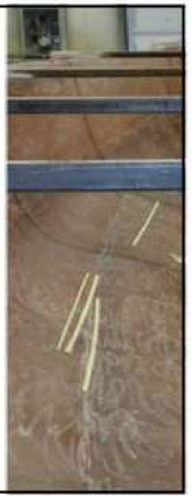
Quantum materials

Category	Details
Material Classification	Topological insulators, Weyl and Dirac semimetals, Mott insulators, heavy fermion systems, unconventional superconductors, spin liquids
Division into Groups	• Topological states • Strong electronic correlations • Quantum spin and entanglement phenomena
Mechanical Properties	• Generally brittle and sensitive to defects • Low ductility and mechanical strength • Not suitable for structural or load-bearing use • Often require encapsulation or substrate stabilization

TECONAUT

Advanced polymers & composites

Polymers and composites are some of the most widely used materials in modern boatbuilding. Unlike traditional materials such as wood or steel, composites are made by combining a polymer resin (the glue or matrix) with reinforcing fibers (like glass, carbon, or flax). This combination creates materials that are light, strong, and versatile, making them ideal for both structural parts of a boat and interior features.



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Advanced polymers & composites

Category	Details
Material Classification	Polymers / composites are a composition of at least two materials, with different physical and chemical properties, in this case: 1. Polymer plastics, the resin 2. Organic and / or inorganic fibre reinforcements

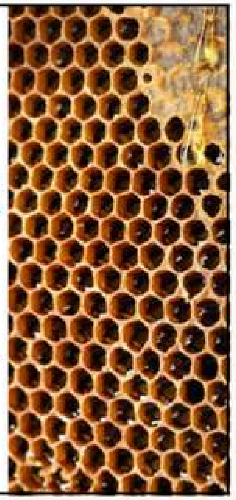
Division into Groups	They are grouped by manufacturing qualities and origins:
	• Resins / Matrixes / Plastics / Glue:
	  ○ Thermosets / Thermosetting polymer (e.g. Epoxy, Polyester)
	  ○ Thermoplastics (e.g. Acrylics)
	• Fiber reinforcements:
	  ○ Inorganic - Mineral (e.g. Volcanic, Basalt, Glass)
	  ○ Organic: Plant fibres (e.g. Flax, Hemp, Bamboo); Synthetic fibres (e.g. Carbon, Aramid)

Advanced polymers & composities

Category	Details
Mechanical Properties	• Lightweight • High-strength & high-stiffness • Versatility in application & in design • Resistance to environment • Low manufacturing costs
Application Cases	• Hull and deck structure • Inner hull • Shower trays • Interior arrangement

Bio-inspired & smart materials

Bio-inspired & smart materials can be grouped by their functional analogy to natural systems, while smart materials are typically classified by their response to external stimuli such as temperature, pH, light, or mechanical stress. These two categories overlap in function but differ in conceptual origin: bio-inspiration derives from observed biological strategies; smart materials focus on stimulus-triggered reactions. Smart materials are typically classified by the external stimulus they respond to.

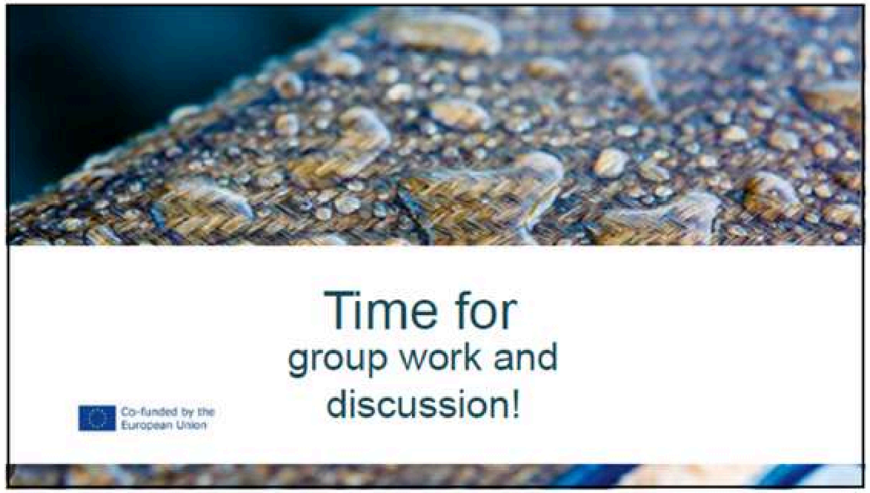


Bio-inspired materials

Category	Description
Material Classification	Bio-inspired (functionally nature-derived) / Smart (stimuli-responsive)
Division into Groups	Bio-inspired by surface (e.g., lotus, sharkskin), structure (e.g., fibres, cuticle), or function
Mechanical Properties	Varying: often not load-bearing; some materials offer vibration damping, wear and impact resistance
Limitations	Durability, lack of certification, limited structural applications, scalability
Application Cases	Anti-fouling coatings, composites, sensor-embedded laminates, self-healing coatings

Sustainability materials

Sustainable materials—such as recycled PET cores, bio-based resins and recycled carbon fibers—are emerging as viable alternatives in marine construction. Offering solid structural performance and environmental benefits, they are increasingly used in hulls, decks, and non-critical components of energy-efficient vessels.


Time for
group work and
discussion!
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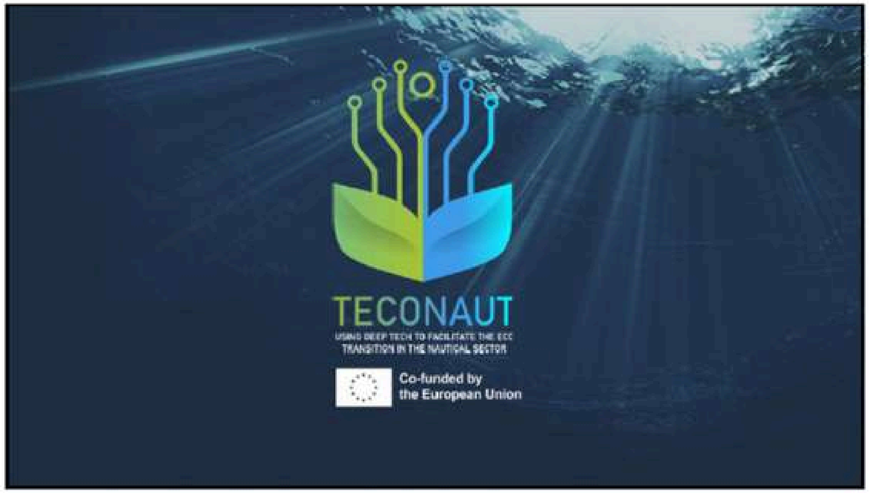
TECONAUT
USING DEEP TECH TO FACILITATE THE ECO
TRANSITION IN THE NAUTICAL SECTOR
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SEA TEACH
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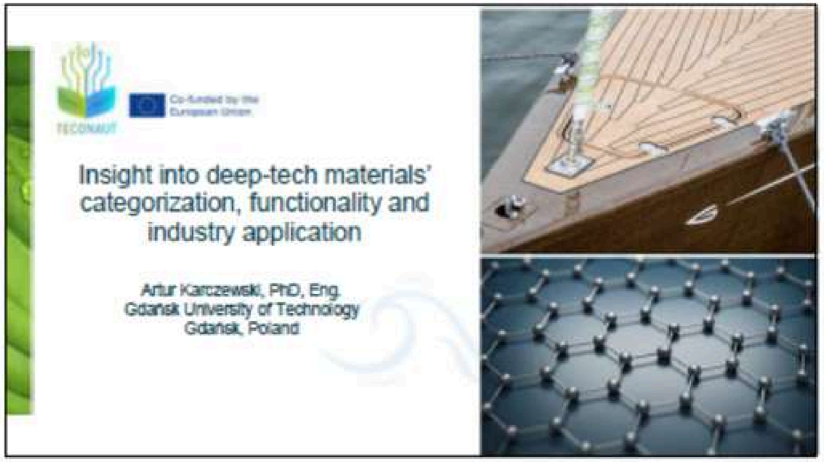
EBI
INNOVATION


TECONAUT
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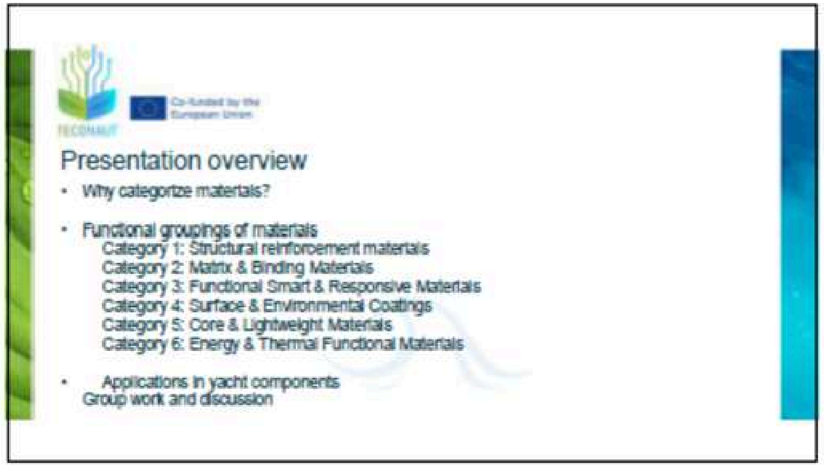
Insight into deep-tech materials' categorization, functionality and industry application
Artur Karczewski, PhD, Eng.
Gdańsk University of Technology
Gdańsk, Poland


TECONAUT
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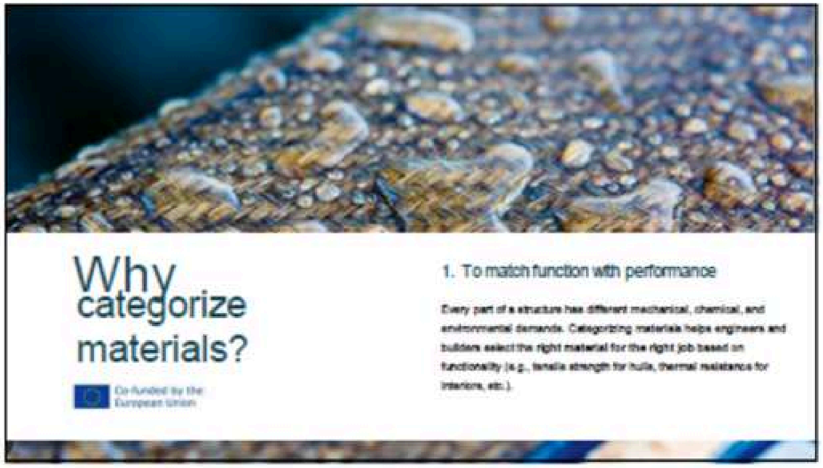
Presentation overview
• Why categorize materials?
• Functional groupings of materials
Category 1: Structural reinforcement materials
Category 2: Matrix & Binding Materials
Category 3: Functional Smart & Responsive Materials
Category 4: Surface & Environmental Coatings
Category 5: Core & Lightweight Materials
Category 6: Energy & Thermal Functional Materials
• Applications in yacht components
Group work and discussion


Why categorize materials?
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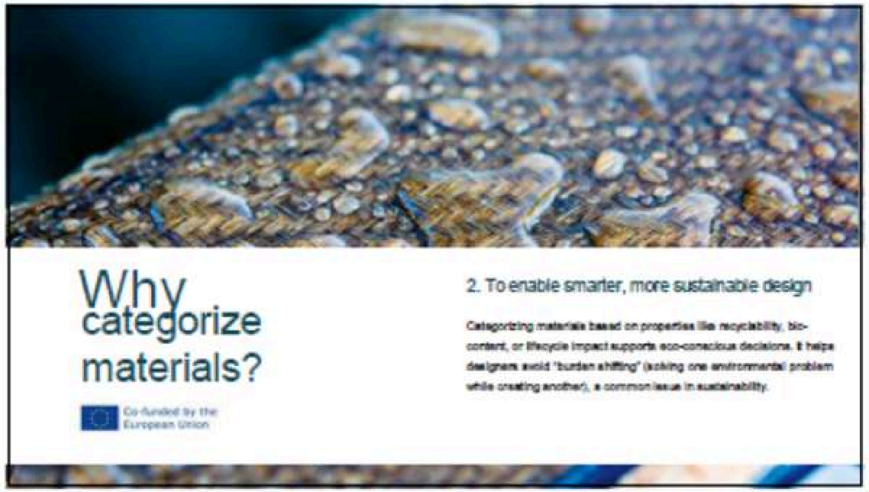
1. To match function with performance
Every part of a structure has different mechanical, chemical, and environmental demands. Categorizing materials helps engineers and builders select the right material for the right job based on functionality (e.g., tensile strength for hulls, thermal resistance for interiors, etc.).


Why categorize materials?
2. To enable smarter, more sustainable design
Categorizing materials based on properties like recyclability, bio-content, or lifecycle impact supports eco-conscious decisions. It helps designers avoid "burden shifting" (solving one environmental problem while creating another), a common issue in sustainability.
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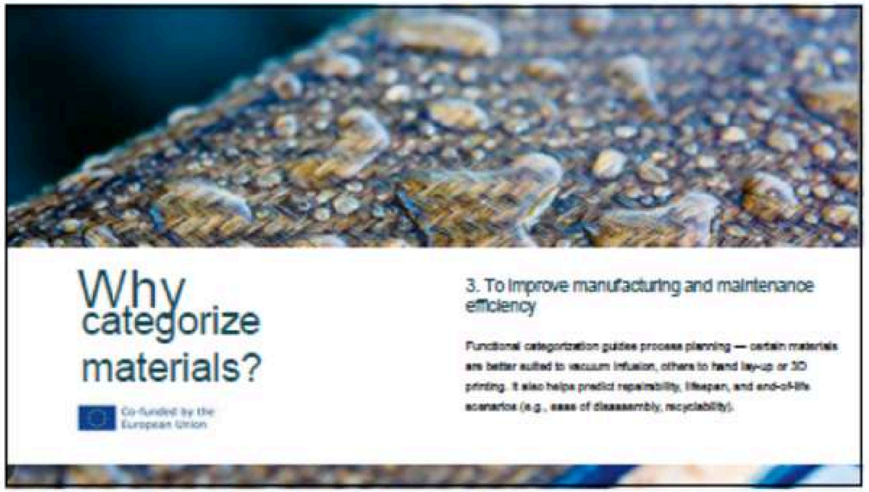
Why categorize materials?
3. To improve manufacturing and maintenance efficiency
Functional categorization guides process planning — certain materials are better suited to vacuum infusion, others to hand lay-up or 3D printing. It also helps predict repairability, lifespan, and end-of-life scenarios (e.g., ease of disassembly, recyclability).
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Why categorize materials?
4. To align with regulatory and certification requirements
5. To support innovation and integration of new technologies
6. To enhance communication across teams
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Importance
of material categorization in yacht design, sustainability, and performance
1. Yacht design: engineering for purpose:
Categorizing materials based on their mechanical properties (tensile, flexural, impact, etc.) and functional roles helps naval architects and designers:
Select optimal materials for each part
Design lighter, stronger, and safer boats
Balance cost vs. performance in a rational way
TECONAUT
Hulls
Impact and Water Resistance
Decks
Slip Resistance and Strength under Compression
Interiors
Weight and Aesthetics

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Importance

of material categorization in yacht design, sustainability, and performance

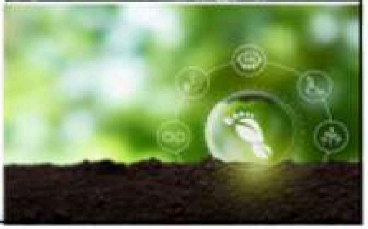
2. Sustainability: Smarter Material Choices

Functional categorization includes environmental metrics such as:

- Renewability
- Recyclability
- Life cycle emissions
- End-of-life options (reuse, biodegradability)

This enables builders to:

- Reduce carbon footprint (e.g., by choosing flax over fiberglass)
- Avoid toxic resins and coatings
- Improve circularity through modular construction and recyclable cores



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Importance

of material categorization in yacht design, sustainability, and performance

3. Performance: Getting the best out of the boat

Materials influence the speed, durability, and comfort of a yacht.

Categorizing by performance allows:

- Strategic layering and lay-up design
- Better resistance to marine threats (UV, osmosis, corrosion)
- Enhanced hydrodynamics through advanced coatings (e.g., sharkskin-inspired)

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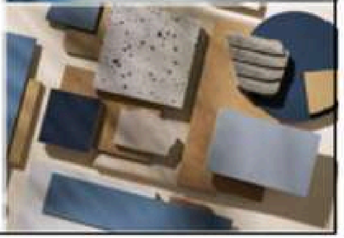
Deep – tech materials

Deep-tech materials are advanced materials that emerge from cutting-edge scientific research and technological breakthroughs. Unlike conventional materials, they are defined by the high level of complexity, uncertainty, and innovation involved in their development.



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Key features

Complexity - Engineered at the molecular, nano, or multi-functional level. Often involve hybrid systems (e.g., bio-based + smart).

Innovation-Driven - Born from frontier science (nanotech, AI-driven materials discovery, quantum chemistry). Often protected by patents or require IP strategies.

Long R&D Cycles - Years (sometimes decades) from lab to commercial use. Require high investment and iterative testing.

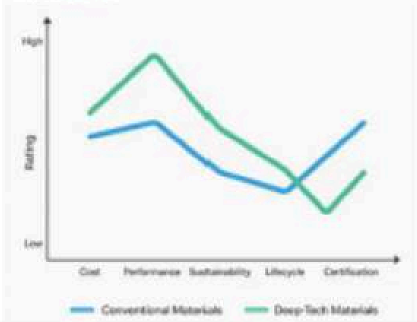
Key features

Uncertainty - Technical (performance in real-world), regulatory (compliance), and market-related (adoption and scale) risks.

High Entry Barriers - Require specialized knowledge, infrastructure, and certification. Not easily commoditized.

Lab discovery → Prototype testing → Pilot production → Yacht integration

Key features



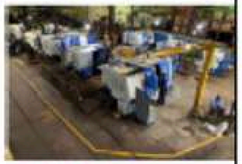
- Higher strength-to-weight ratios
- Improved fatigue, thermal, and chemical resistance
- Custom-engineered at nano or molecular levels (e.g., carbon nanotubes, graphene)
- Enable multifunctional applications (e.g., structural + sensing + self-healing)

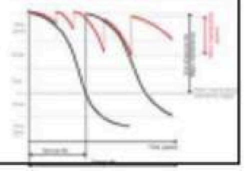
Question

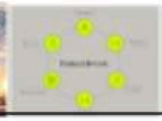
In your opinion, what is the greatest barrier to implementing modern materials in real-world structures?

But also…

- High initial cost
- Lack of certification and regulatory approval
- Limited manufacturing infrastructure
- Resistance to change in industry culture
- Unknown long-term durability or performance
- Insufficient training or workforce skills
- Supply chain and sourcing limitations
- Lifecycle data and recyclability gaps







Category 1: Structural reinforcement materials

Natural fibers (Flax, Hemp, Jute)

- High tensile strength with low weight
- Bio-based and renewable
- Biodegradable or recyclable
- Lower environmental impact than fiberglass
- Good compatibility with bio-resins and vacuum infusion

Category 1: Structural reinforcement materials

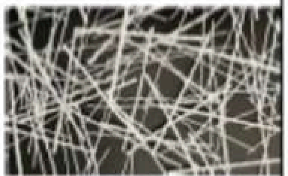
Natural fibers (Flax, Hemp, Jute)

- Moisture absorption must be managed
- Variability in fiber quality
- Needs surface treatments for durability

Category 1: Structural reinforcement materials

Basalt & recycled fiber reinforcements

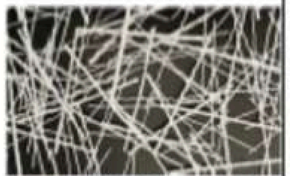
- High thermal and fire resistance (Basalt > Fiberglass)
- Lightweight with excellent mechanical properties
- Made from abundant or waste resources
- Resistant to moisture, corrosion, and fatigue
- Enables reuse of industrial waste and lower embodied energy



Category 1: Structural reinforcement materials

Basalt & recycled fiber reinforcements

- Basalt is more expensive than fiberglass
- Recycled fibers can have variable quality and limited certifications
- Mechanical properties are often slightly below virgin carbon/glass



Category 2: Matrix and binding materials

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Resins: The "Glue" of Composites

Bio-based thermoset resins
- Derived from plant oils, lignin, starch, or sugar
- Often used as drop-in replacements for epoxy or polyester
- Renewable

Thermoplastic resins
- Can be melted and reformed (vs. thermosets which are irreversible)
- Enable recyclability and modular construction (heat – formable)

Category 2: Matrix and binding materials

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Resins: The "Glue" of Composites

- Cost of bio-resins still higher than petro-based
- Thermoplastics require different processing equipment
- Certification lag for marine use

Category 3: Functional smart and responsive materials

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Smart polymers

- self-healing
  - Automatically repairs micro-cracks or surface damage without manual intervention
  - Increases lifespan and reduces maintenance
- thermo-Responsive (change stiffness, shape, or adhesion based on temperature)
- pH or moisture responsive (useful in bilge protection, humidity control, or corrosion prevention)

Category 3: Functional smart and responsive materials

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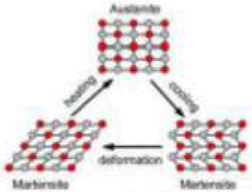
Smart polymers

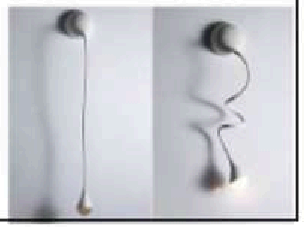
- Most applications still in R&D or prototype phase
- Need for marine-specific validation (saltwater, wear, etc.)
- Cost currently high for large-scale components

Category 3: Functional smart and responsive materials

Shape memory alloys

- Shape recovery after deformation - No external motors or hydraulics needed
- thermo-responsive actuation - React to heat, electric current, or magnetic field
- Silent and compact motion control - Ideal for tight spaces with no room for mechanics

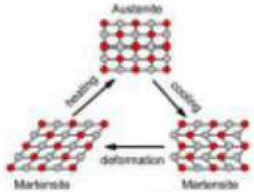




Category 3: Functional smart and responsive materials

Shape memory alloys

- High material cost (e.g., NiTi/Nitinol)
- Needs precise temperature control
- Long-term fatigue in marine environments still under study
- Complex design integration (not plug-and-play)

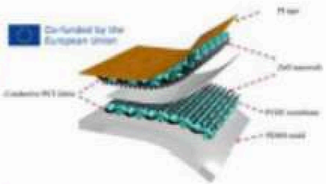


Category 3: Functional smart and responsive materials

Piezoelectric & sensor materials

Materials that generate electrical signals when mechanically stressed, or change shape when voltage is applied.

- Real-time stress and vibration monitoring – structural health monitoring
- Wave impact & pressure detection - Adaptive behavior or alerts in rough seas
- Leak or bilge water sensors - Automatic pump activation, early warnings
- Position & strain sensing - smart sail adjustment or trim feedback

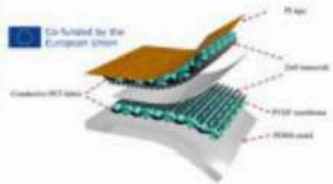


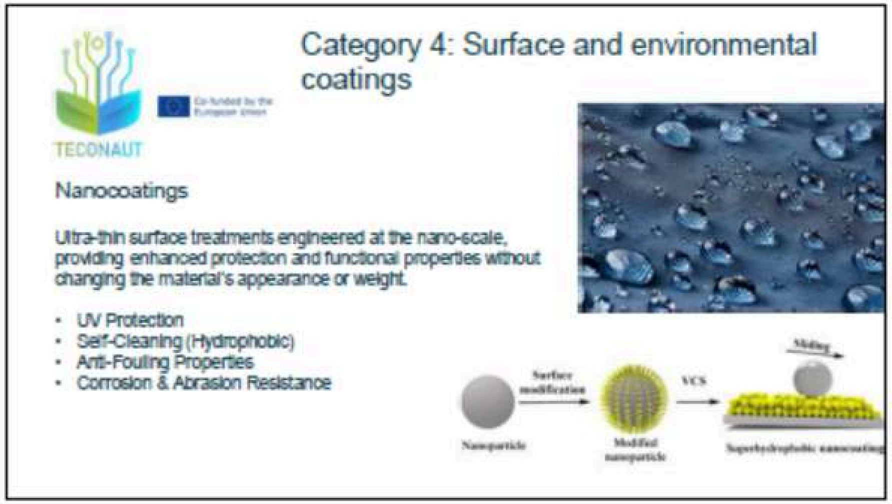
Category 3: Functional smart and responsive materials

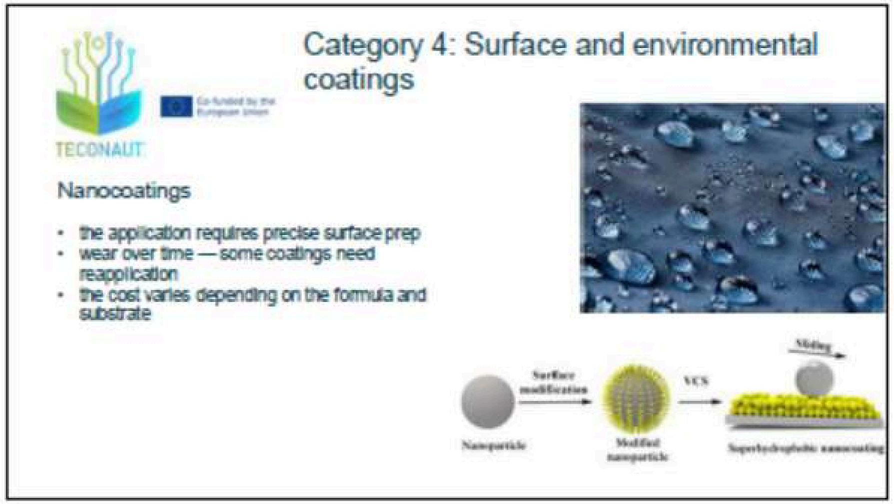
Piezoelectric & sensor materials

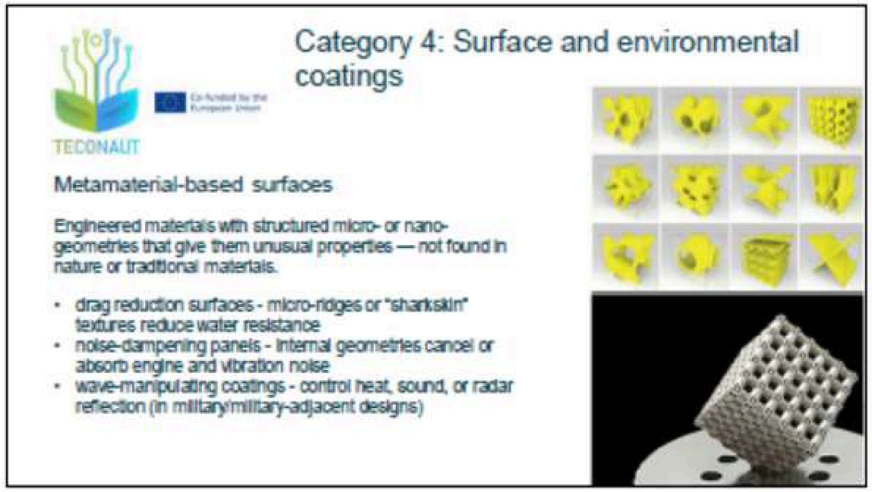
Materials that generate electrical signals when mechanically stressed, or change shape when voltage is applied.

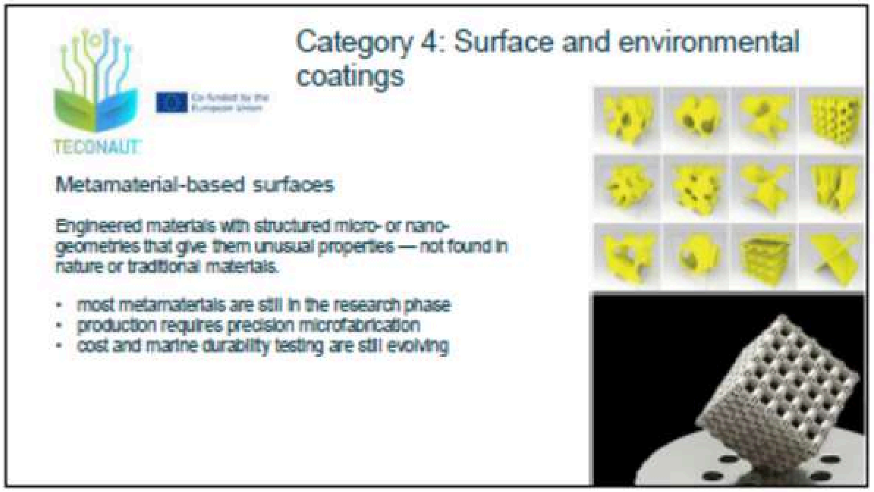
- requires integration into design phase
- saltwater corrosion protection needed
- must avoid false positives due to motion/vibration (typical problems of SHM systems but in the case of sea enviroment it is even more difficult to manage)




Category 4: Surface and environmental coatings
TECONAUT
Nanocoatings
Ultra-thin surface treatments engineered at the nano-scale, providing enhanced protection and functional properties without changing the material's appearance or weight.
• UV Protection
• Self-Cleaning (Hydrophobic)
• Anti-Fouling Properties
• Corrosion & Abrasion Resistance
Nanoparticle
Surface modification
Modified nanoparticle
VCS
Sliding
Superhydrophobic nanocoating


Category 4: Surface and environmental coatings
TECONAUT
Nanocoatings
• the application requires precise surface prep
• wear over time — some coatings need reapplication
• the cost varies depending on the formula and substrate
Nanoparticle
Surface modification
Modified nanoparticle
VCS
Sliding
Superhydrophobic nanocoating


Category 4: Surface and environmental coatings
TECONAUT
Metamaterial-based surfaces
Engineered materials with structured micro- or nano-geometries that give them unusual properties — not found in nature or traditional materials.
• drag reduction surfaces - micro-ridges or "sharkskin" textures reduce water resistance
• noise-dampening panels - internal geometries cancel or absorb engine and vibration noise
• wave-manipulating coatings - control heat, sound, or radar reflection (in military/military-adjacent designs)


Category 4: Surface and environmental coatings
TECONAUT
Metamaterial-based surfaces
Engineered materials with structured micro- or nano-geometries that give them unusual properties — not found in nature or traditional materials.
• most metamaterials are still in the research phase
• production requires precision microfabrication
• cost and marine durability testing are still evolving


TECONAUT
Category 5: Core and lightweight materials
Sandwich core materials
Lightweight materials placed between two strong outer skins (like a composite laminate), creating a stiff, durable, and low-weight structure — much like an I-beam or honeycomb. Core materials in deep-tech yachts:
• recycled PET (rPET) foam
• balsa wood
• cork


TECONAUT
Category 5: Core and lightweight materials
Sandwich core materials
• recycled PET (rPET) foam
○ lightweight, moisture resistant, and consistent
○ fully recyclable and available in various densities
• balsa wood
○ natural, ultra-light, excellent compressive strength
○ biodegradable, but vulnerable to moisture if not sealed
• cork
○ renewable, biodegradable, impact-absorbing
○ Naturally anti-slip
○ Lower strength than balsa, but very sustainable


TECONAUT
Category 5: Core and lightweight materials
Paper honeycomb & foam alternatives
Lightweight, low-cost core structures used in non-structural or low-load areas, offering strength, flexibility, and sustainability — especially for yacht interiors.
Paper honeycomb cores:
• Made from recycled paper or cardboard
• Ultra-light, strong under compression, low cost
• Fully recyclable and biodegradable

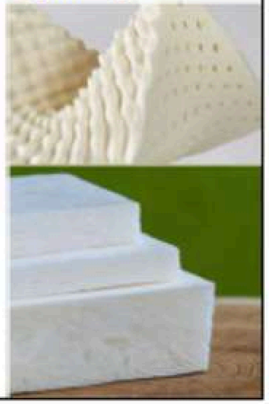

TECONAUT
Category 5: Core and lightweight materials
Paper honeycomb & foam alternatives
Lightweight, low-cost core structures used in non-structural or low-load areas, offering strength, flexibility, and sustainability — especially for yacht interiors.
Foam alternatives (bio-based or recycled):
• made from bio-resins, soy-based polyurethanes, or rPET foams
• used where lightweight filler or shape is needed
• often closed-cell = resistant to moisture
• non-toxic options replacing petroleum-based foam

Category 5: Core and lightweight materials

Paper honeycomb & foam alternatives

Lightweight, low-cost core structures used in non-structural or low-load areas, offering strength, flexibility, and sustainability — especially for yacht interiors.

- not suitable for high structural loads
- paper honeycomb needs sealing against moisture
- limited long-term performance data in marine settings

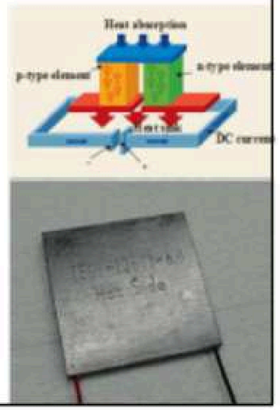


Category 6: Energy and thermal functional materials

Thermoelectric & Energy-Storing Materials

Thermoelectric materials - Materials that convert heat directly into electricity — without moving parts, wires, or batteries.

- Generate power from engine heat, sunlight, or surface temperature differences
- No fuel, no emissions, no moving parts
- Can power sensors, navigation beacons, micro-devices

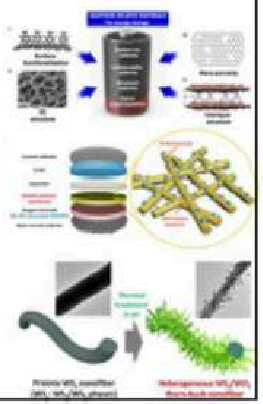


Category 6: Energy and thermal functional materials

Thermoelectric & Energy-Storing Materials

Energy storing materials - functional materials that can store and release energy — either integrated into boat structures or embedded in systems (e.g., supercapacitors, carbon fiber batteries).

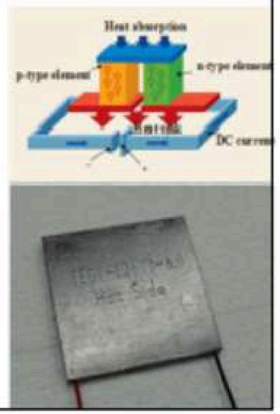
- carbon fiber or composites infused with energy storage capacity
- panels or hull sections that store power like a battery
- potential to power lights, sensors, or small electronics



Category 6: Energy and thermal functional materials

Thermoelectric & Energy-Storing Materials

- Still in R&D or early prototype stages
- Low power output — only suitable for small loads
- High cost for energy-storing composites
- Needs custom integration into design phase



Category 6: Energy and thermal functional materials

Solar integration with deep-tech layers

The embedding of solar energy harvesting into yacht components using thin, flexible, and smart photovoltaic materials — beyond traditional sola panels.

- flexible, lightweight, and can follow curved surfaces
- Transparent or semi-transparent films applied to glass, sails, or deck
- combine solar capture with UV protection, anti-fouling, or structural roles
- enables off-grid and silent operation
- powers lights, navigation systems, fridges, and winches

Category 6: Energy and thermal functional materials

Solar integration with deep-tech layers

The embedding of solar energy harvesting into yacht components using thin, flexible, and smart photovoltaic materials — beyond traditional sola panels.

- efficiency still lower than rigid silicon panels
- vulnerable to abrasion, UV, and saltwater
- integration into curved composites requires advanced bonding techniques
- cost and durability under marine conditions still under

Which materials are ready now?

TRL	Stage	Example materials
1-3	lab research	Shape-memory alloys, metamaterials
4-5	prototype testing	Smart polymers, energy-storing composites
6-7	pilot production	Thermoplastics, thermoelectrics
8-9	commercial use	Flax fiber, rPET foam, bio-resins, nanocoatings

Time for group work and discussion!

Presentation on Materials Mechanical Properties

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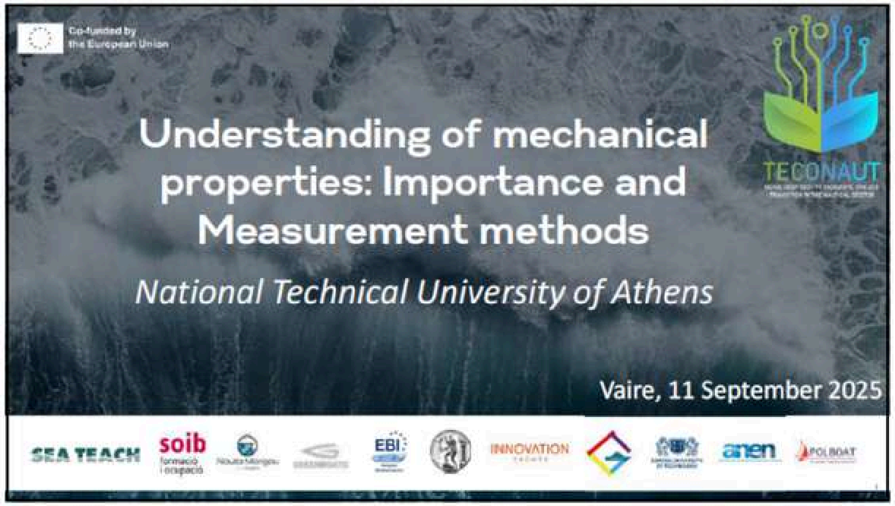
Co-funded by the European Union
Understanding of mechanical properties: Importance and Measurement methods
National Technical University of Athens
TECONAUT
Vaire, 11 September 2025
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Part 1
Introduction
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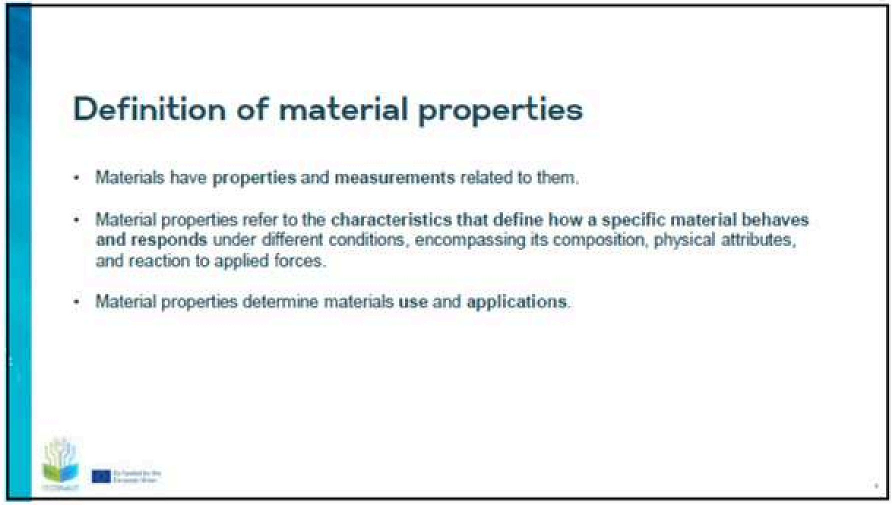
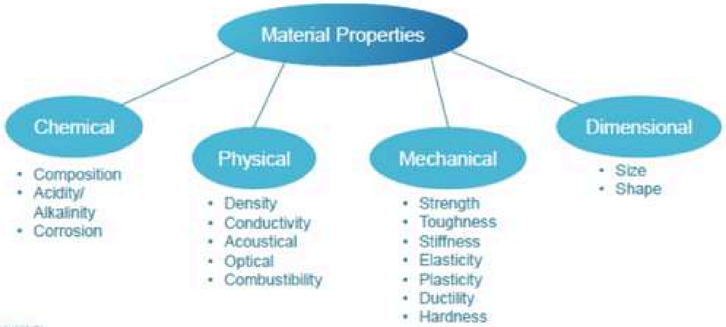
Topics
Definition of material properties
Categories of material properties
Definition of mechanical properties
Why study mechanical properties
Boatbuilding applications and mechanical properties' demands
Objectives
Introduction to material properties
Understanding of connection with boatbuilding applications


Definition of material properties
Materials have properties and measurements related to them.
Material properties refer to the characteristics that define how a specific material behaves and responds under different conditions, encompassing its composition, physical attributes, and reaction to applied forces.
Material properties determine materials use and applications.

Categories of material properties



Definition of mechanical properties

- Mechanical properties refer to the characteristics of a material that describe its **behavior under the action of external forces**, such as tension, compression, bending, or torsion.
- These properties **determine how a material responds to mechanical loads.**
- They affect the **mechanical strength** and **ability of a material to be molded in suitable shape** and the **ability to resist mechanical forces.**
- They include attributes like **strength**, **ductility**, **hardness**, **toughness**, **elasticity**, and **fatigue resistance**.

Why study mechanical properties?

- Development and **design of material applications** for maximized efficiency.

  *Choosing the appropriate materials for specific applications is essential to ensure **optimal performance** within their intended environments.*

- More efficient manufacturing process.
- **Limitations awareness** and management.
- **Handling awareness** for safety and accident prevention.
- Support the **development of advanced materials** for various applications in the boatbuilding industry.

Boatbuilding applications and mechanical properties' demands

- Understanding mechanical properties is essential as they determine the **quality and functionality of the final product**.
- Apart from quality and functionality, the mechanical properties influence **durability**, **performance** and **damage vulnerability**.
- Materials undergo **testing** and **evaluations** to ensure durability, resilience and finally suitability for applications.
- **Challenge**: Mechanical properties which contribute to operational performance optimization usually makes manufacturing process more difficult.
  ⟹ **Close cooperation** between the designer and the manufacturer is the key element to overcome the challenge. Compromises always need to be made!

Part 2
Mechanical Properties

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Topics

- Mechanical properties
- In-plane tensile strength
- In-plane shear strength
- Compressive strength
- Stiffness
- Interlaminar shear strength (ILSS)
- Interlaminar fracture toughness
- Fatigue resistance
- Impact resistance
- Young's modulus
- Poisson's ratio
- Thermal expansion
- Moisture absorption

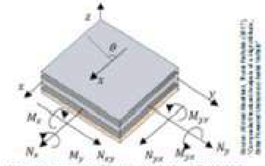
Objective

- Familiarization with mechanical properties

Mechanical properties

The mechanical properties of composites describe **how they react to applied forces, moments, torque and changes in environmental conditions** such as temperature and humidity.

- ✓ In-plane tensile strength
- ✓ In-plane shear strength
- ✓ Compressive strength
- ✓ Stiffness
- ✓ Interlaminar shear strength (ILSS)
- ✓ Interlaminar fracture toughness
- ✓ Fatigue resistance
- ✓ Impact resistance
- ✓ Young's modulus
- ✓ Poisson's ratio
- ✓ Thermal expansion
- ✓ Moisture absorption

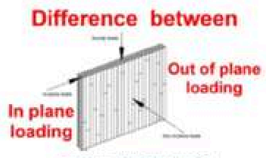


Coordinate system, Resultant forces and moments for laminated plate

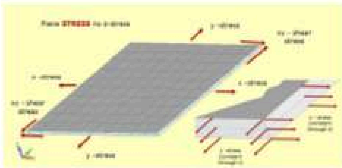
In-plane tensile strength

It is the maximum tensile stress that a composite material can withstand within the plane of its laminate layer before it breaks.

Because composites are fiber direction-dependet, in-plane tensile strength is measured in specific directions and is higher along the direction of fibers.



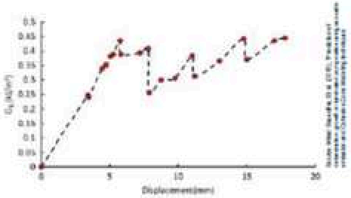
In plane vs. Out of plane loading


Stress on xy plane, zero stress on z plane

Interlaminar fracture toughness

It is a measure of a composite material's **resistance to crack growth between its layers under deferent types of loading.**

Compared to ILSS that measures stress, this one indicates how much energy the material can absorb before a crack between its layers grows.



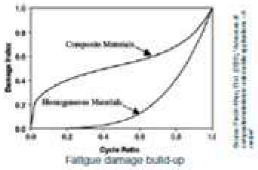
R-curve of the interlaminar fracture toughness

Fatigue resistance

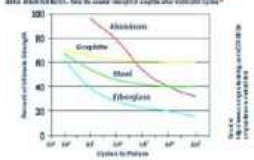
The ability of a composite material to withstand repeated cyclic loading (tension, compression, bending, or shear) **without failing.**

Fatigue occurs when a material is subjected to repeated or fluctuating stress, usually below its ultimate strength, causing progressive damage that can lead to sudden failure.

In composites fatigue is more complex, because the material is anisotropic and multiple failure mechanisms interact over time.



Fatigue damage build-up

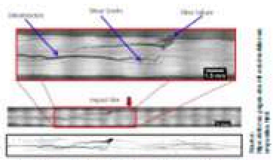


Impact resistance

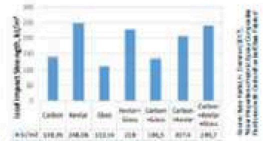
The ability of a composite material to absorb and dissipate energy from a sudden force or impact (drop, strike, or collision) **without catastrophic failure** like cracking, delamination, or fiber breakage.

Importance:

- Composites are strong but often brittle (e.g., compared to Grade A/CK45 steel)
- Impact can cause internal damage that is not visible but severely weakens the structure



Damage mechanisms of composites under impact



Izod impact strength properties of composite specimens

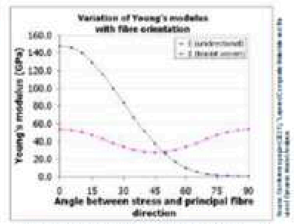
Young's Modulus, E

Young' modulus or modulus of elasticity, E, in composites is a measure of stiffness, that is, **how much a composite resists deformation when a tensile, or compressive force is applied.**

Higher E ⟹ stiffer material

Because composites are anisotropic, E depends on fiber orientation and laminate layup.

E_1 (along the fiber direction) > E_2 (perpendicular the fiber direction)



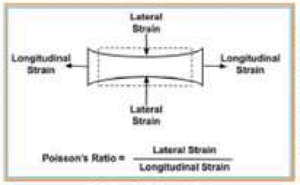
Variation of Young's modulus with fiber orientation

Poisson's Ratio, ν

It is the ratio of **transverse strain to axial strain** when the material is under **tensile or compressive load**.

Key point:

When a material is under tension in one direction, it shrinks in the perpendicular direction.
Poisson's ratio measures the degree of shrinkage that occurs in a material in relation to its stretching.



Definition of Poisson's Ratio

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Thermal Expansion

It refers to **how much a composite changes in size** (expansion or contraction) **when the temperature changes.**

The rate of this change is the coefficient of thermal expansion (CTE), denoted as α [μm/m°C] in literature.

Moisture Absorption

It refers to the **uptake of water or humidity from the environment into the matrix material** (usually a polymer).

This occurs over time and can change the composite's properties (strength, stiffness, dimensions, and durability.

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Quiz Time ?

Why is high stiffness an important mechanical property of composite material?

a) It makes the material heavier and more durable.

b) It allows the material to stretch easily easily under force.

c) It helps the material resist bending or deformation under load.

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Quiz Time ?

Why is high stiffness an important mechanical property of composite material?

a) It makes the material heavier and more durable.

b) It allows the material to stretch easily easily under force.

c) It helps the material resist bending or deformation under load.

Part 3

Measurements and Specifications

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Topics

- Why do we need quality control?
- ASTM and ISO Standards
- Tensile testing
- Compression testing
- Flexural testing
- Interlaminar shear strength
- Shear testing (±45°)
- Impact testing
- Fatigue testing
- Environmental resistance testing

Objectives

- Material quality control procedures and standards
- Getting to know standardized material tests

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Why do we need Quality Control?

- ✓ To ensure materials **meet safety** and **performance standards**.
- ✓ To **detect** manufacturing **defects** early.
- ✓ To **guarantee** long-term **durability** and **reliability**.

Essential for critical industries like **boatbuilding, aerospace, and automotive**

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ASTM & ISO Standards

- **ASTM**: American Society for Testing and Materials (US-based).
- **ISO**: International Organization for Standardization (global).

Property of ASTM

Property of ISO

They provide **standardized testing methods** to **compare materials** fairly.

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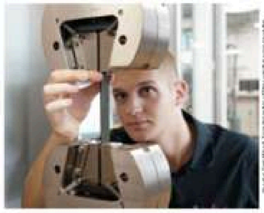
Tensile testing

Purpose: Measures how much force is needed to pull a composite material apart until it breaks.

- **ASTM** D3039 and **ISO** 527-4 are standard methods for testing fiber-reinforced composites.
- A flat rectangular specimen is pulled lengthwise until failure.
- Results help determine **tensile strength, modulus of elasticity, and strain** at break.



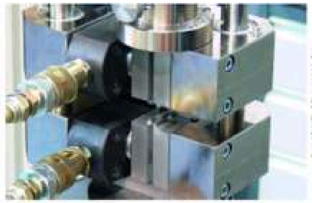
Preparing a composite sample for tensile testing

Crucial for understanding how composites behave under stretching forces, important for structural parts in boatbuilding like hulls, decks, or masts.

Compression testing

Purpose: Measures how much force a composite material can withstand when compressed before it buckles or fails.

- **ASTM D6641** and **ISO 14126** are standard methods for testing compressive strength of fiber-reinforced composites.
- The specimen is loaded lengthwise in compression using special fixtures (e.g., combined loading or shear loading).
- Evaluates **material behavior** under **squeezing forces**, including strength and stability.



Composite specimen placed in a fixture for compression testing

Crucial for assessing how composites perform in boat structures like hulls, frames, and panels that face compressive loads during service.

Flexural testing

Purpose: Measures how much force is needed to bend a composite material until it breaks or deforms.

- **ASTM** D790 and **ISO 14125** are standard methods for testing the flexural strength and stiffness of composites.
- The sample sits on two supports and is pressed down in the middle (3-point bending).
- Results show how well a **material resists bending** — indicating its rigidity and durability.

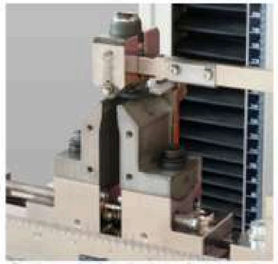
Set up for flexural testing using a 3-point bending fixture.

Essential for boat parts like decks, beams, and panels that face bending loads during operation.

Interlaminar shear strength

Purpose: Measures how strongly the layers (plies) in a composite are bonded together.

- **ASTM D2344** is the standard method used to test ILSS through a short beam bending test.
- A small beam is loaded in the center until the layers slide or separate.
- Helps **assess the adhesion between layers**, critical for avoiding delamination.



Short beam setup for testing the bonding between the composite layers.

Important for composites in boats, where strong bonding between layers ensures durability under repeated stress and vibration.

Shear testing (±45°)

Purpose: Measures how well a composite resists sliding forces between internal layers.

- **ASTM D3518** is the standard method for testing in-plane shear strength and stiffness using ±45° laminate specimens.
- The test pulls a specimen cut at ±45° angles to create a pure shear condition.
- Results show how the **material handles twisting** or **diagonal forces**.

The test machine used to apply shear force on angled composite specimens.

Important for composite parts in boats like hulls and panels, where angled loads from waves or torsion can cause shear stress.

Impact testing

Purpose: Simulates accidental hits or drops to see how a composite material absorbs and resists sudden impact.

- **ASTM D7136** is the standard for impact testing using a falling weight method on composite panels.
- The test creates controlled damage, and then a Compression After Impact (CAI) test checks how the material performs afterward.
- Evaluates the material's **damage resistance** and **ability to keep its strength after being hit.**

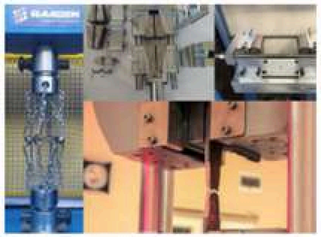
Device for testing the response of composites to sudden impact.

Essential for real-world situations in boatbuilding — dropped tools, floating debris, or collisions can cause unexpected impacts.

Fatigue testing

Purpose: Measures how a composite behaves under repeated or fluctuating loads over time.

- **ASTM D3479** is the standard method for determining the tension-tension fatigue behavior of fiber-reinforced polymer matrix composites.
- A specimen is repeatedly pulled and released at a controlled frequency until failure.
- Results help determine **how many cycles a material can endure before it cracks or breaks.**



Equipment used to test composite performance under repeated loading.

Important for predicting the lifespan of composite parts in boats exposed to wave forces, engine vibrations, or cyclic loading.

Environmental resistance testing

Purpose: Assesses how composite materials perform under harsh environmental conditions like moisture, salt exposure, and fire.

- **ASTM D570** – Water Absorption:

Measures how much water a material absorbs during immersion. Affects **weight, strength, and stability in wet conditions.**

- **ASTM B117** – Salt Spray (Corrosion):

Simulates long-term saltwater exposure. Evaluates **corrosion resistance** of materials and protective coatings.

- **IMO FTP Code** – Fire & Smoke Toxicity:

Tests flame spread, smoke density, and gas toxicity. Ensures **fire safety compliance** for marine applications.

Critical for boatbuilding, where materials must resist moisture, corrosion, and fire hazards over long service life.

Part 4

Factors affecting Mechanical Properties

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Topics

- Factors affecting material properties

Objective

- Getting to know which factors may affect material properties and how.

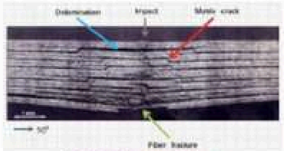
Factors affecting mechanical properties

- Grain size
- Temperature
  - ✓ significant properties reduction in high temperatures
  - ✓ reduction of 10%, 50%, 90% in temperatures 90ºC, 150ºC, 200ºC.
- Heat treatments
- Liquid environment presence
  - ✓ properties reduction
  - ✓ satisfactory protection through the use of gel coats.
- Atmospheric/ weather exposure
  - ✓ little impact
  - ✓ exposure to light, ultraviolet radiation, rain, frost.

Vessel's exposure to frost

Factors affecting mechanical properties

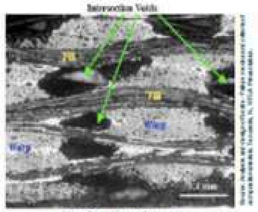
- Fiber properties
- Construction method
  - ✓ advanced methods ⟶ small changes in properties
  - ✓ simple methods (hand lay-up) ⟶ restricted quality and big changes in properties.
- Laminates' separation
- Polymerization rate



Depiction of mechanical failures

Factors affecting mechanical properties

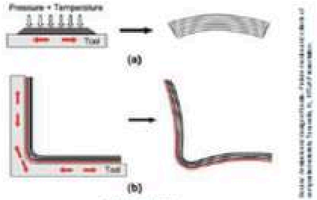
- Conditions of storage
- Human factor
  - ✓ craftsman skill
  - ✓ fiber misalignment
  - ✓ poor resin distribution
  - ✓ air voids
  - ✓ ply wrinkling – foreign inclusions.



Air voids, rits and wraps

Factors affecting mechanical properties

- Remaining tensions
  - ✓ during the solidification process
  - ✓ different coefficient of thermal expansion of fibers and resin
  - ✓ possible rejection of the entire structure due to excessive deformations.



Deformations

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Quiz Time ?

What is the nature of the factors affecting the material mechanical properties?

a) Mainly external, including handling procedures, human factor and weather

b) Inherent material factors concerning the fibers orientation and structure

c) A combination of internal and external elements, acting in multiple ways and dynamically.

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Quiz Time ?

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a) Mainly external, including handling procedures, human factor and weather

b) Inherent material factors concerning the fibers orientation and structure

c) A combination of internal and external elements, acting in multiple ways and dynamically.

Part 5

Types of Material Failures

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Topics

- Types of material failures
- Failure in tension
- Modes in failure in tension of a unidirectional layer
- Examples of tensile failures
- Failure in compression
- Failure in bending
- Examples of failures in bending
- Shear failure
- Creep failure
- Fatigue

Objective

- Familiarization with material failures

Types of material failures

What is 'failure'?

- ✓ Failure in tension
- ✓ Failure in compression
- ✓ Failure in bending
- ✓ Shear failure
- ✓ Fatigue
- ✓ Creep failure
- ✓ Impact

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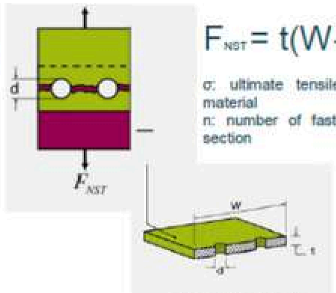
Failure in tension

Failure in tension occurs when the net section area reaches the ultimate strength of the sheet material

Failure mode in tension

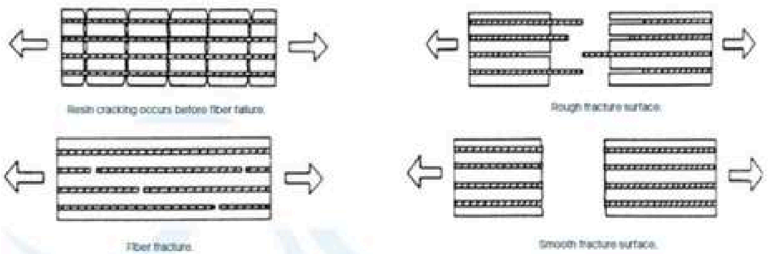


Net section tension failure

$$F_{NST} = t(W-n\,d)\,\sigma$$

σ: ultimate tensile strength of sheet material
n: number of fasteners along the net section

Modes of failure in tension of a unidirectional layer



Resin cracking occurs before fiber failure.

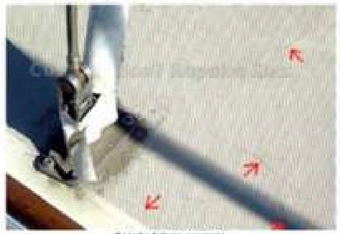
Rough fracture surface.

Fiber fracture.

Smooth fracture surface.

Examples of tensile failures

Tensile failure example.

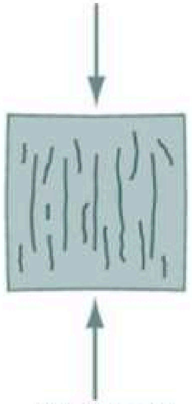


Tensile failure example.

Failure in compression

Compression failure usually occurs **due to the development of compressive stresses greater than the allowable stresses.**

When a load is applied to a material, it exerts a force on the material's molecules, causing them to move closer together. As more force is applied, the molecules become increasingly compressed until they reach a point where they can no longer move any closer together. At this point, the material has reached its maximum compressive strength and will begin to deform or fail if additional force is applied.

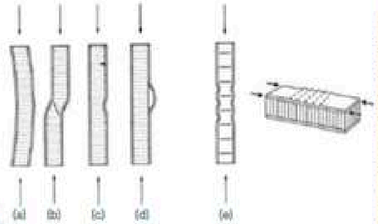


Failure mode in compression

Failure in compression

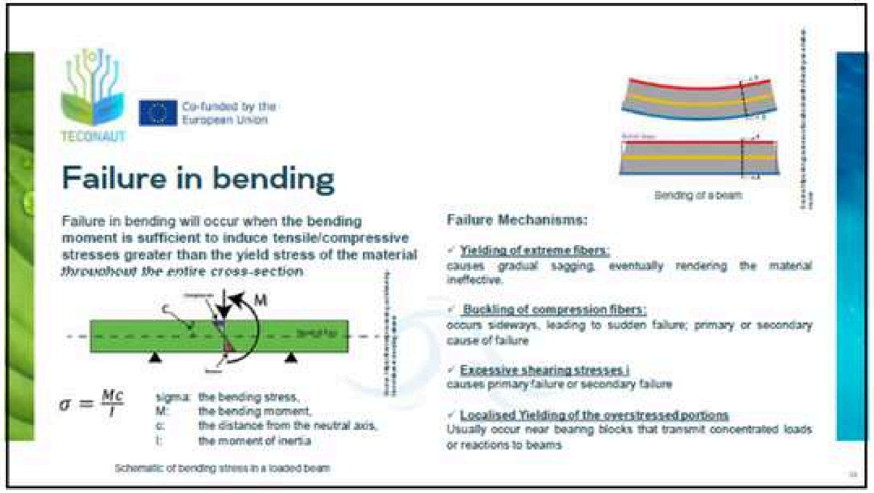
Factors affecting such failure:

- ✓ Non-complete fiber alignment, fiber adjacency
- ✓ Non-complete fiber–resin bonding
- ✓ Voids (entrapped air)



Failure modes in compression

(a) Total compression
(b) Shear crimping
(c) Skin wrinkling
(d) Skin wrinkling
(e) Dimpling



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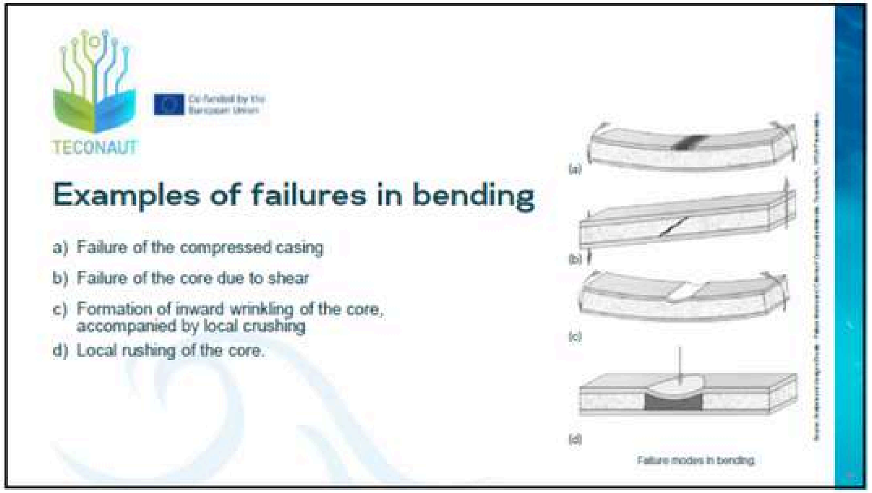
Failure in bending
Failure in bending will occur when the bending moment is sufficient to induce tensile/compressive stresses greater than the yield stress of the material throughout the entire cross-section
M
$\sigma = \frac{Mc}{I}$
sigma: the bending stress,
M: the bending moment,
c: the distance from the neutral axis,
I: the moment of inertia
Schematic of bending stress in a loaded beam
Bending of a beam
Failure Mechanisms:
Yielding of extreme fibers: causes gradual sagging, eventually rendering the material ineffective.
Buckling of compression fibers: occurs sideways, leading to sudden failure; primary or secondary cause of failure
Excessive shearing stresses: causes primary failure or secondary failure
Localised Yielding of the overstressed portions Usually occur near bearing blocks that transmit concentrated loads or reactions to beams



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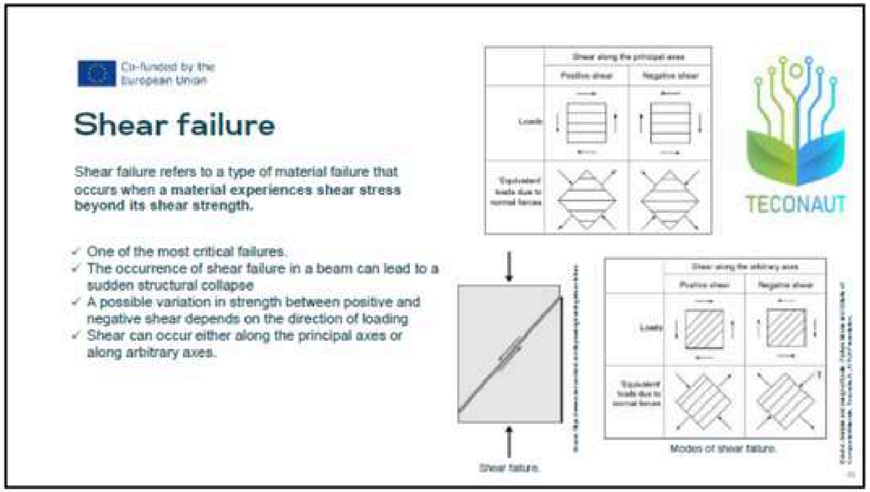
Examples of failures in bending
a) Failure of the compressed casing
b) Failure of the core due to shear
c) Formation of inward wrinkling of the core, accompanied by local crushing
d) Local rushing of the core.
(a)
(b)
(c)
(d)
Failure modes in bending



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Shear failure
Shear failure refers to a type of material failure that occurs when a material experiences shear stress beyond its shear strength.
One of the most critical failures.
The occurrence of shear failure in a beam can lead to a sudden structural collapse
A possible variation in strength between positive and negative shear depends on the direction of loading
Shear can occur either along the principal axes or along arbitrary axes.
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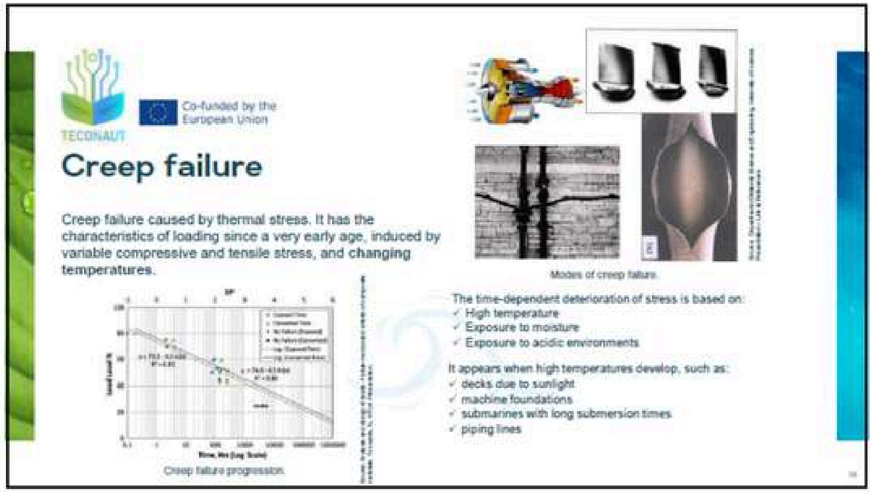
Shear failure.
Modes of shear failure.



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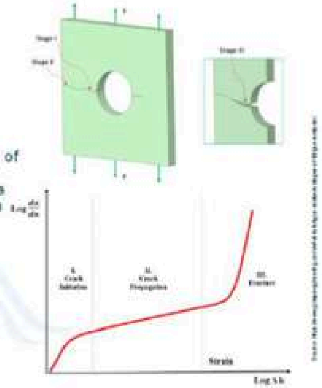
Creep failure
Creep failure caused by thermal stress. It has the characteristics of loading since a very early age, induced by variable compressive and tensile stress, and changing temperatures.
Modes of creep failure.
Creep failure progression
The time-dependent deterioration of stress is based on:
High temperature
Exposure to moisture
Exposure to acidic environments
It appears when high temperatures develop, such as:
decks due to sunlight
machine foundations
submarines with long submersion times
piping lines

Fatigue

Fatigue is a failure mechanism that involves the cracking of materials and structural components due to **cyclic** (or fluctuating) **stress**. While applied stresses may be **tensile** compressive or torsional, crack initiation and propagation are due to the tensile component.

3 stages of fatigue failure:

Stage I: Crack Initiation
Stage II: Crack propagation
Stage III: Failure



Stages of fatigue failure.

Part 6

Mechanical Properties, Failures and Deep Tech Materials

Topics

- Recap: why mechanical properties matter
- Typical failures in composite boat structures
- Engineering response to failure
- Mechanical properties, failures and deep-tech materials
- Potential of deep-tech materials in boatbuilding to prevent failure
- Deep-tech materials: Nanomaterials in boatbuilding
- Deep-tech materials: Metamaterials in boatbuilding
- Deep-tech materials: Quantum materials in boatbuilding
- Deep-tech materials: Advanced polymers and composites in boatbuilding
- Deep-tech materials: Bio-inspired and smart materials in boatbuilding
- Deep-tech materials: Energy and sustainability materials in boatbuilding
- Deep-tech materials: High-value added metals and materials in boatbuilding

Objective

- Exploring the application of knowledge about material mechanical properties, especially in the context of deep-tech materials.

Recap: why mechanical properties matter

- **Performance and safety:**
  Mechanical properties like strength, stiffness, and toughness determine how a composite performs under load and stress—critical for safety in demanding environments like marine applications.
- **Durability and reliability:**
  Understanding fatigue resistance, impact behavior and mechanical failures helps ensure long-term durability and consistent performance.
- **Design optimization:**
  Knowledge of mechanical behavior enables engineers to design lighter, more efficient structures retaining integrity.
- **Material selection:**
  Matching the right mechanical properties to the application ensures the composite will perform as expected.
- **Cost Efficiency:**
  Reducing overengineering and selecting the right materials for the right job can lower manufacturing costs while maintaining quality.

Typical failures in composite boat structures

- **Delamination**
  - ✓ Separation between composite layers due to poor bonding or repeated loading.
  - ✓ Often caused by impact, fatigue or manufacturing defects.
- **Matrix cracking**
  - ✓ Cracks form in the resin matrix between fibers.
  - ✓ Reduces load transfer and can lead to further damage.
- **Fiber Breakage**
  - ✓ Occurs when individual fibers exceed their tensile or compressive limits.
  - ✓ Common in areas under high stress or impact.
- **Debonding**
  - ✓ Loss of adhesion between fiber and matrix or between composite and core material.
  - ✓ Weakens structural integrity.

Typical failures in composite boat structures

- **Core shear failure (in Sandwich structures)**
  - ✓ The core material fails under shear loads, especially in high-impact or high-load zones.
  - ✓ Can lead to face sheet separation or crushing.
- **Buckling**
  - ✓ Compressive loads cause structural instability in thin laminates or unsupported panels.
  - ✓ Often seen in hull bottoms or deck panels under pressure.
- **Fatigue failure**
  - ✓ Progressive damage from repeated loading/unloading cycles.
  - ✓ Can initiate matrix cracks or delamination over time.

Engineering response to failure

- **Identification of the problem**
  Definition of the failure type and location.
- **Understanding of the cause**
  Answering the question: "Was it design, material choice, loading or manufacturing?"
- **Refining the design**
  Adjustment of fiber direction, laminate thickness or structures support.
- **Improvement of material use**
  Choice of tougher resins, stronger fibers or more resilient core materials.
- **Improvement of processes**
  Use of alternative processes which are more suitable.
- **Monitoring and maintenance**
  Use of frequent inspections to detect issues early and extend the boat's life.

Mechanical properties, failures and deep-tech materials

Towards the future of composites in maritime design

- **What are deep-tech materials?**
  Deep-tech materials are advanced materials that emerge from cutting-edge scientific research and technological breakthroughs. Unlike traditional materials, which are often well understood and widely used, deep-tech materials are defined not just by their composition or application, but by the high level of complexity, uncertainty, and innovation involved in their development.
- **Why they matter in boatbuilding?**
  Deep knowledge of mechanical properties and failures builds confidence in boat construction. By combining this knowledge with emerging material technologies, we open the door to creating more advanced composites tailored for marine performance.
- **How sustainability and impact are addressed?**
  Choosing the right material for a boat is about much more than just strength or weight. Each decision has an impact – on the environment, on health, on recyclability, and on cost. Sustainability is a core part of responsible boatbuilding. Responsible boatbuilding means prioritizing materials that reduce environmental impact while meeting performance demands.

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Potential of deep-tech materials in boatbuilding to prevent failure

- **Stronger, tougher composites**
  Increased resistance to cracking, impact and delamination.
- **Improved fatigue performance**
  Withstand repeated loads over time.
- **Smart damage detection**
  Materials with built-in sensors enable early issue detection.
- **Tailored properties**
  Advanced design allows materials to meet specific load and performance needs.
- **Greater environmental resistance**
  Better protection against moisture, salinity, UV and temperature changes.

Deep-tech materials: Nanomaterials in boatbuilding

Mechanical Properties	High strength-to-weight ratio, fracture resistance, fatigue life enhancement
Surface Functions	Corrosion resistance, anti-fouling, UV protection, self-cleaning
Thermal/Optical Properties	UV blocking, heat dissipation, thermal insulation
Applications in Yachts	Nano-reinforced hulls, anti-fouling coatings, nanostructured UV-protective finishes, advanced sensor systems, nanocoatings on mechanical parts
Emerging Uses	Smart coatings, nanogenerators, lightweight energy storage (batteries, supercapacitors)

Deep-tech materials: Metamaterials in boatbuilding

Material Classification	Advanced Engineered Materials (subset of *functional materials*)
Division into Groups	• **Mechanical Metamaterials** – optimized for strength, flexibility, etc. • **Acoustic Metamaterials** – control of sound waves; • **Thermal Metamaterials** – manipulation of heat flow; • **Electromagnetic Metamaterials** – control of EM/radar waves; • **Optical Metamaterials** – light wave control (cloaking, lenses)
Mechanical Properties	• High strength-to-weight ratio • Auxetic behavior (negative Poisson's ratio) • High stiffness or controlled deformability • Energy absorption • Tunable elasticity and density depending on geometry
Application Cases	• **Yacht hulls**: lightweight, impact-resistant structures • **Noise insulation**: cabins with acoustic metamaterials • **Radar stealth**: reduced detectability of military vessels • **Thermal management**: optimized interior climate control • **Hydrodynamic coatings**: drag reduction, anti-biofouling • **Energy harvesting**: from wave or vibration-induced deformation
Material Classification	Advanced Engineered Materials (subset of *functional materials*)

Deep-tech materials: Quantum materials in boatbuilding

Material Classification	Topological insulators, Weyl and Dirac semimetals, Mott insulators, heavy fermion systems, unconventional superconductors, spin liquids
Division into Groups	Grouped by dominant quantum effects: • Topological states • Strong electronic correlations • Quantum spin and entanglement phenomena
Mechanical Properties	• Generally brittle and sensitive to defects • Low ductility and mechanical strength • Not suitable for structural or load-bearing use • Often require encapsulation or substrate stabilization
Application Cases	• Quantum sensors (e.g. NV centers) for environmental monitoring or inertial navigation • Superconductors for high-efficiency energy subsystems in electrified propulsion • Thermoelectric quantum materials for onboard waste heat recovery

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Deep-tech materials: Advanced polymers and composites in boatbuilding

Material Classification	Polymer composites are a composition of at least two materials: 1. Polymer plastics, the resin 2. Organic and / or inorganic fibre reinforcements
Division into Groups	• Resins / Matrixes / Plastics / Glue: ◦ Thermosets / Thermosetting polymer (e.g. Epoxy, Polyester) ◦ Thermoplastics (e.g. Acrylics) • Fibre reinforcements: ◦ Inorganic - Mineral (e.g. Volcanic, Basalt, Glass) ◦ Organic: Plant fibres (e.g. Flax, Hemp, Bamboo)/ Synthetic fibres (e.g. Carbon, Aramid)
Mechanical Properties	• Lightweight • High-strength, High-stiffness • Versatility in application and in design • Low manufacturing costs
Application Cases	Hull and deck structure, Inner hull, Shower trays, Interior arrangement

Deep-tech materials: Bio-inspired and smart materials in boatbuilding

Material Classification	Bio-inspired (functionally nature-derived) / Smart (stimuli-responsive)
Division into Groups	Bio-inspired by surface (e.g., lotus, sharkskin), structure (e.g., fibres, cuticle), or function
Mechanical Properties	Varying: often not load-bearing; some materials offer vibration damping, wear and impact resistance
Limitations	Durability, lack of certification, limited structural applications, scalability
Application Cases	Anti-fouling coatings, composites, sensor-embedded laminates, self-healing coatings

Deep-tech materials: Energy and sustainability materials in boatbuilding

Material Classification	Recycled PET cores, bio-based epoxy resins, recyclable thermoplastic resins, recycled carbon fibers
Division into Groups	• Core materials: recycled PET foams for sandwich structures • Resin systems: bio-based and recyclable thermoplastics • Reinforcements: reclaimed fibers used in composites
Mechanical Properties	• Good structural stiffness and insulation (PET core) • Low viscosity and infusion compatibility (resins) • Recyclable or reusable through thermal recovery (thermoplastics) • Comparable strength to virgin carbon fiber (recycled fibers)
Application Cases	• Use of PET cores in hull and deck sandwich panels • Infusion of structures with recyclable or bio-based resins • Non-critical components made from recycled carbon fibers • Integration in energy-optimized yachts with solar, hybrid, or biofuel systems

Deep-tech materials: High-value added metals materials in boatbuilding

Material Classification	Aluminium alloys : aluminium-magnesium alloys and aluminium-magnesium-silicon alloys; graphene added alloys (experimental)
Division into Groups	• Aluminium alloys • Wrought alloys • Strain hardening • Age hardening • Casting alloys • Silicon alloys • Magnesium alloys • Graphene added alloys (still experimental)
Mechanical Properties	• Good corrosion resistance • High weldability • Easy to cut and form • Good strength/weight ratio
Application Cases	Hull, Frame, Pillars, Propeller

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