

The EPFL logo is rendered in a bold, red, sans-serif font. It is positioned within a decorative frame consisting of two overlapping, thick, curved bands. The upper band is light blue and the lower band is light green, both with a slight gradient and a soft shadow effect.

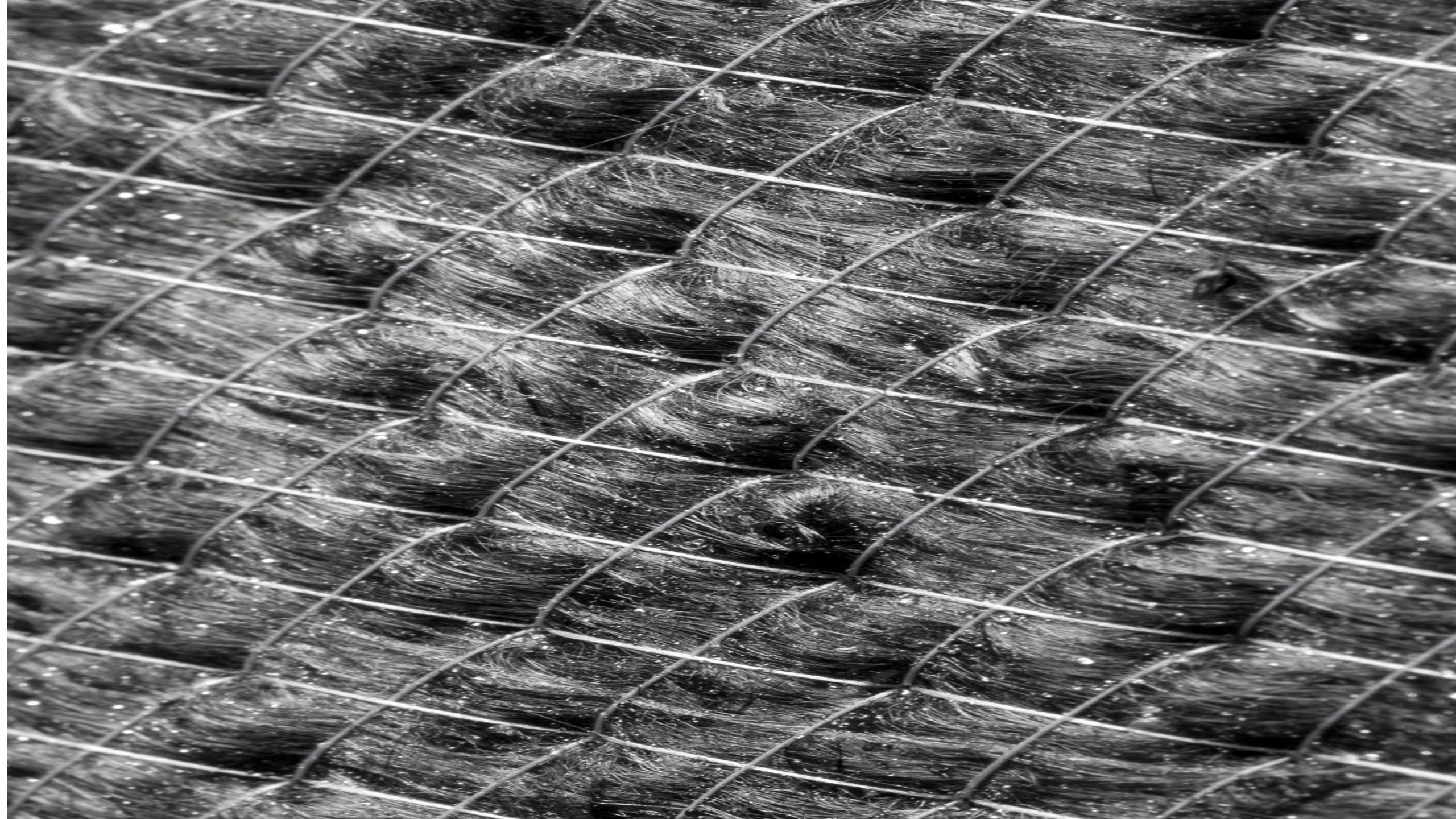
EPFL

Prof. Anastasios P. Vassilopoulos

Advanced composites in engineering structures

The GRMeC logo features the text 'GRMeC' in a bold, blue, sans-serif font. A small circular icon with vertical lines is placed between the 'R' and 'M'. Below this, the text 'Composite Mechanics Group' is written in a smaller, black, sans-serif font. The logo is set against a background of two overlapping, thick, curved bands, similar to the one in the top left, with the upper band being light blue and the lower band being light green.

GRMeC
Composite Mechanics Group



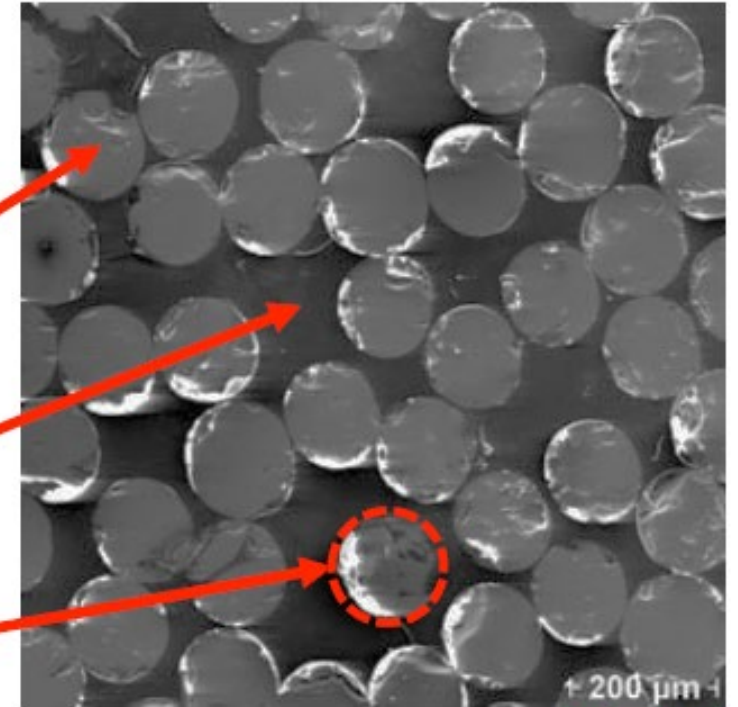
What is a composite material?

- The lexical meaning leads to any material that consists of more than two phases...
- Structural composite materials:
 - Materials having strong fibers (or other strengthening mean) surrounded by a weaker matrix material. The matrix serves to distribute the fibers and also to transmit the load to them.

What is an (advanced) composite material?

e.g. **glass fibres**
mixed into a
polymer resin

Fibre–matrix
interface



200 μm

Are they new?

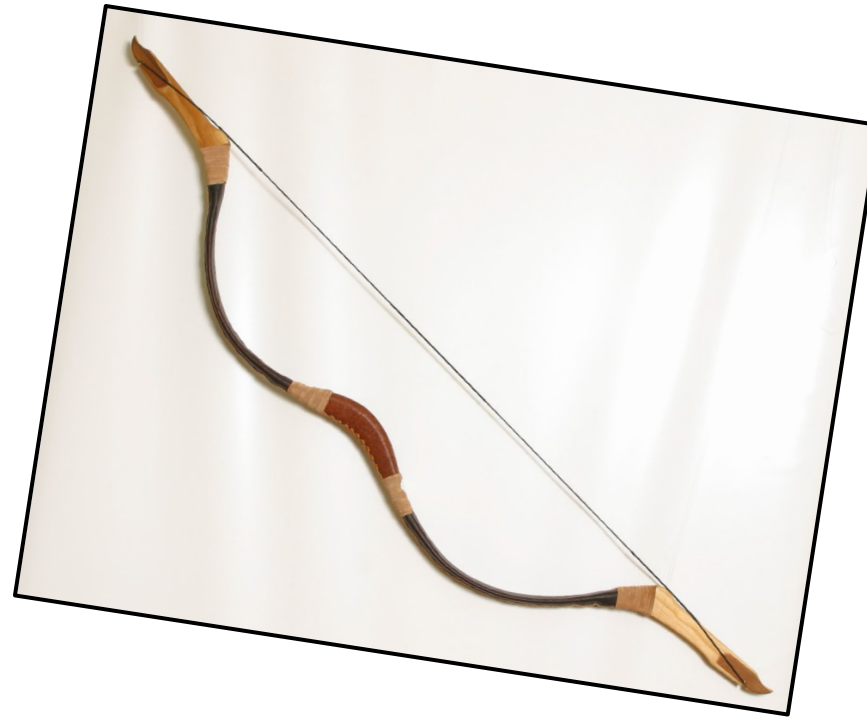
- Composites are used since the ancient times
- Mesopotamia (glued wood strips at dif. Angles to create plywood)
- Mongolian arcs
- Japanese swords
- Achilles buckler
 - more...



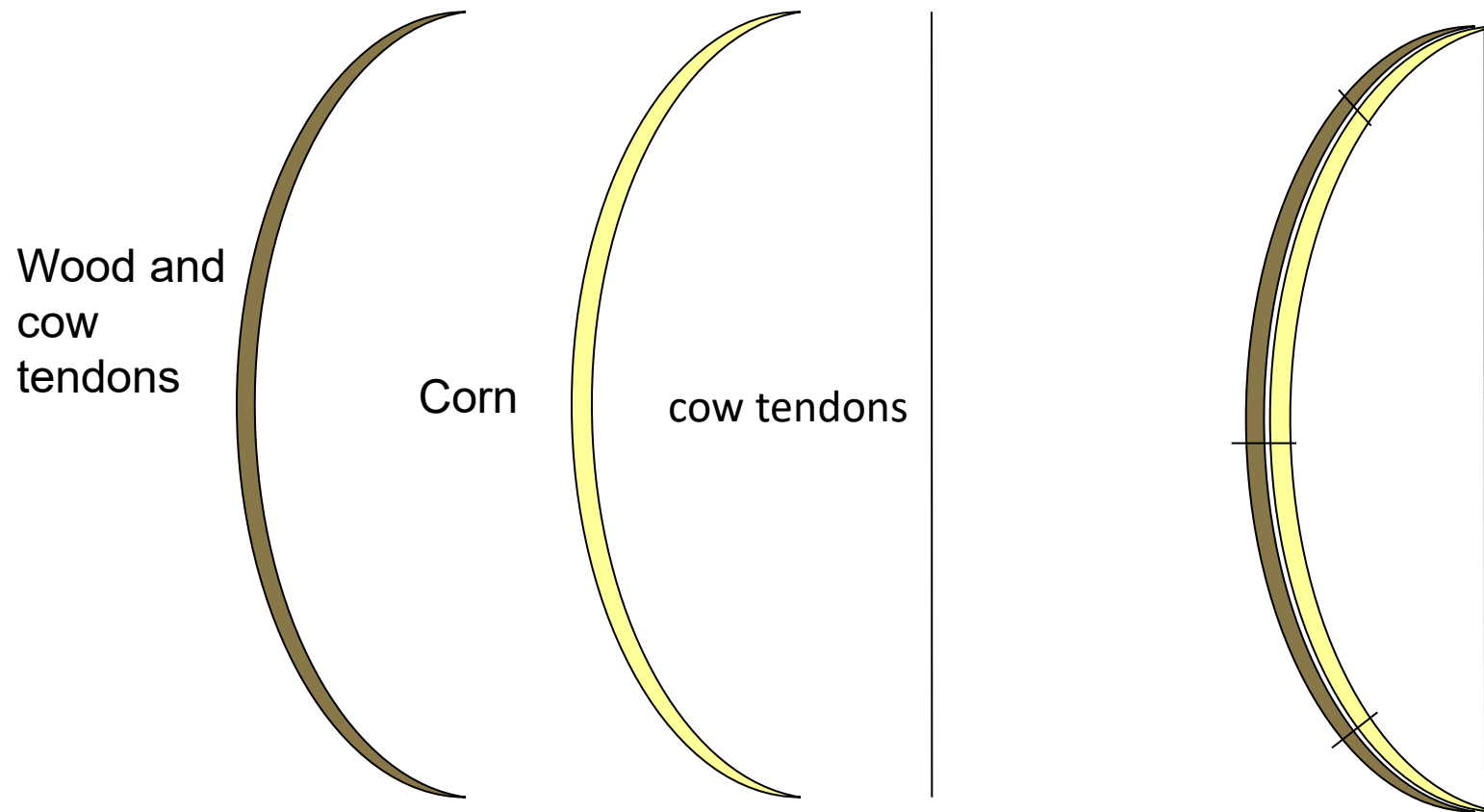
The Mongolian arcs



- Mongol Bow is a composite bow made of wood, tendons, and horn held together by a glue made from fish bladder, with the compressed parts made of corn,



The Mongolian arcs



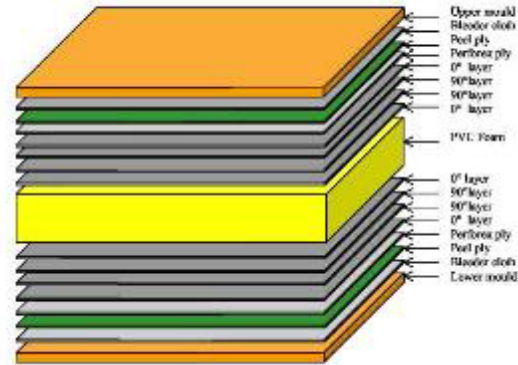
Papyrus (Egypt, <4000 BC)

- Laminated writing material from the papyrus plant (Bio!)



Japanese sword

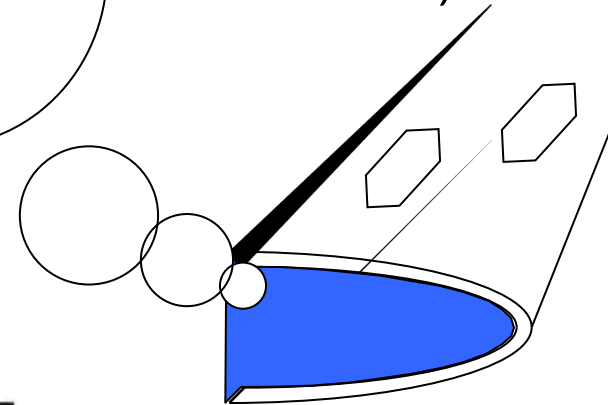
- Japan iron
of



Hard
Poor tensile resistance

Hard Defects
Poor tensile resistance

is made of steel and soft
paste, **with orientation**
n, then formed into a U
sword then has good
(wich structure)



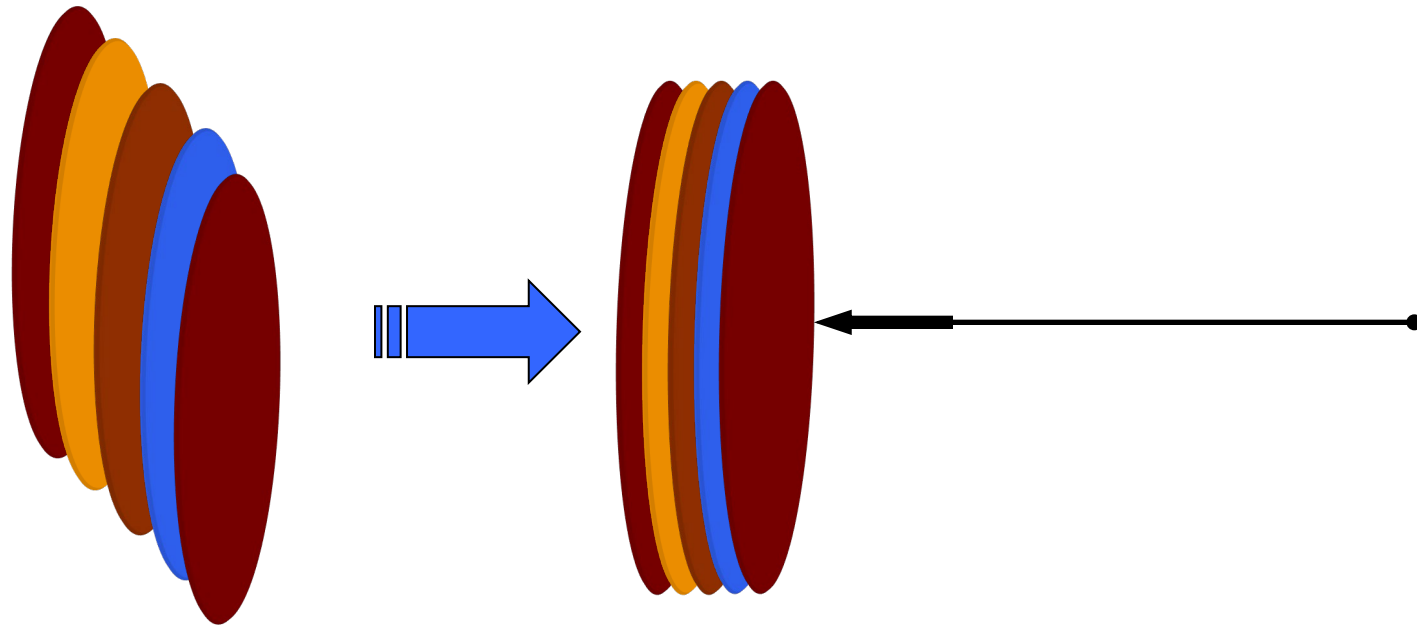
References in ancient text

- References to highly interesting structures exhibiting elements of almost modern technology can also be found in the Homeric epics. The shields of **Achilles and Ajax Telamonius** – son of Telamon, king of Salamis – are presented **as laminated structures consisting of successive layers** of different metals, and metal and leather layers respectively and are characteristic examples of the advanced knowledge of the science and technology of materials and structures possessed by the Mycenaean Greeks. Metals of particular interest in this respect were hard bronze, tin and pure gold (shield of Achilles) and hard bronze and calf's leather (shield of Ajax). The manufacture of Achilles' armor – by Hephaestus – is described in detail in the Iliad. The description refers to a laminated composite structure, consisting of five consecutive metal laminates with very different mechanical properties. In fact, **the shield consists of two external laminates of hard bronze, two internal ones of tin and a central one of pure (soft) gold**. This structure exhibits maximum penetration resistance, as proved by a complete numerical simulation of its elastoplastic behavior at large deformations, when impacted by the tip of a piercing element, an arrow or spear for example. The shield of Ajax presented a similar configuration, which according to Homer was a **multi-layered structure consisting of eight consecutive laminae** - an external lamina of hard bronze and seven layers of calf's leather underneath. The impressive impact properties of this structure are also praised in the Iliad:
 - **“...The spear struck the sevenfold shield in its outermost layer – the eighth which was of bronze – and went through six other layers but in the seventh hide it stayed...”** from Iliad's description of the duel between Ajax and Hector. These unique detailed descriptions, which also include the weapon's battle behavior, constitute the first known applications of laminated structures in human history*.
- Also in the Bible, Exodus 5.15-18 it is described how the people mixed straws with mud to fabricate bricks...

* A. P. Vassilopoulos, T. Keller, Fatigue of fiber-reinforced composites, Springer 2011

Achilles' buckler

- In ancient Greece (<1000 BC): Bucklers were made from different layers of metal, leather, wood and (soft) gold to provide shielding against impact.





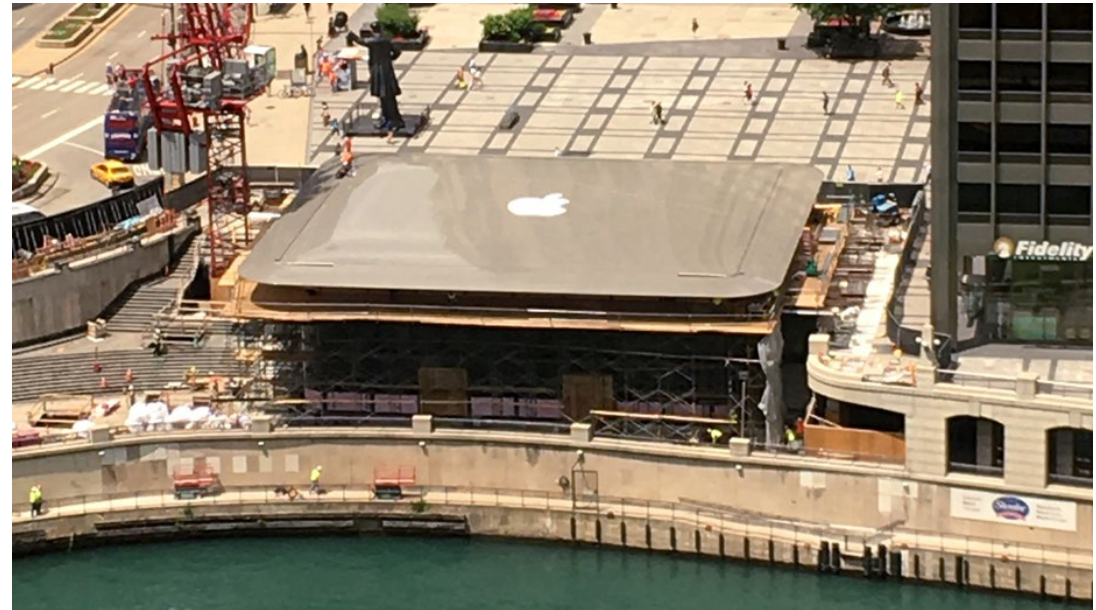
Contemporary composite structures



Composite projects in Switzerland and abroad



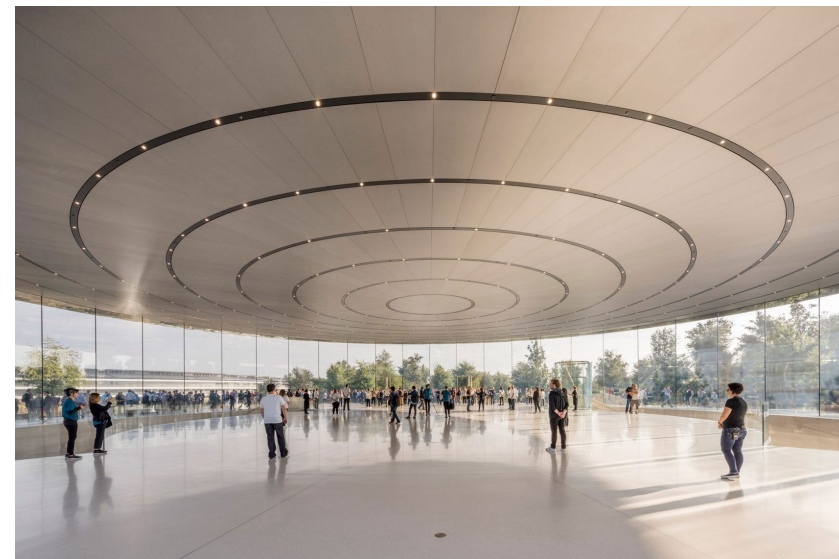
Foster + Partners - Apple's Steve Jobs Theater Pavilion (Cupertino, California)

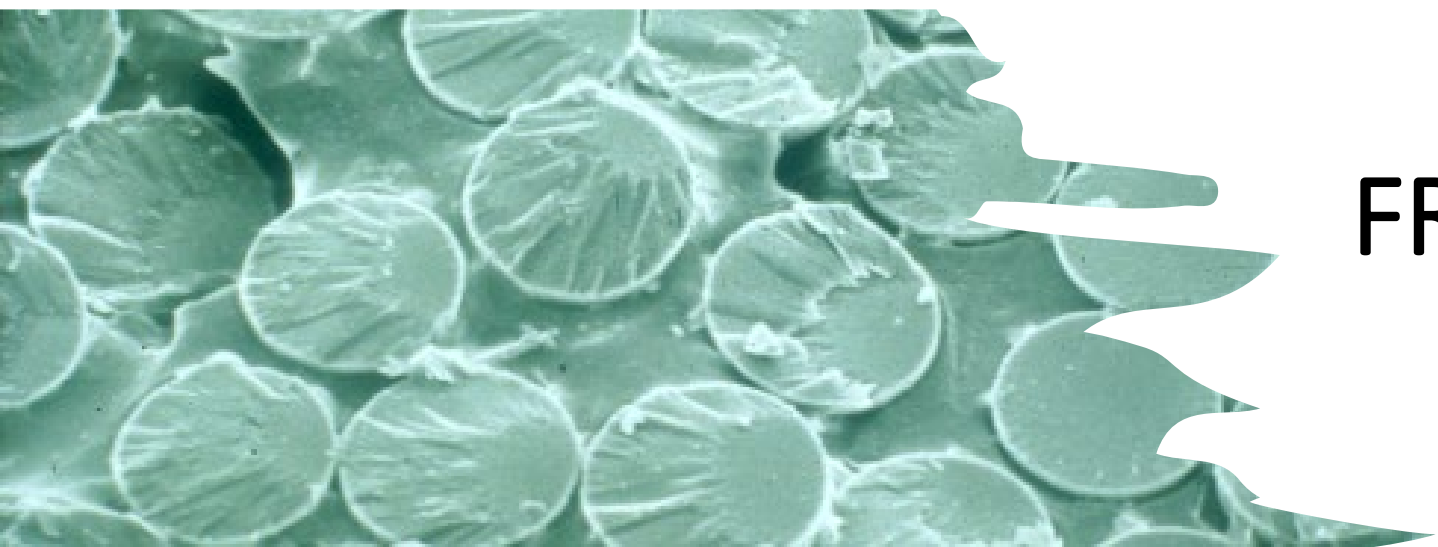
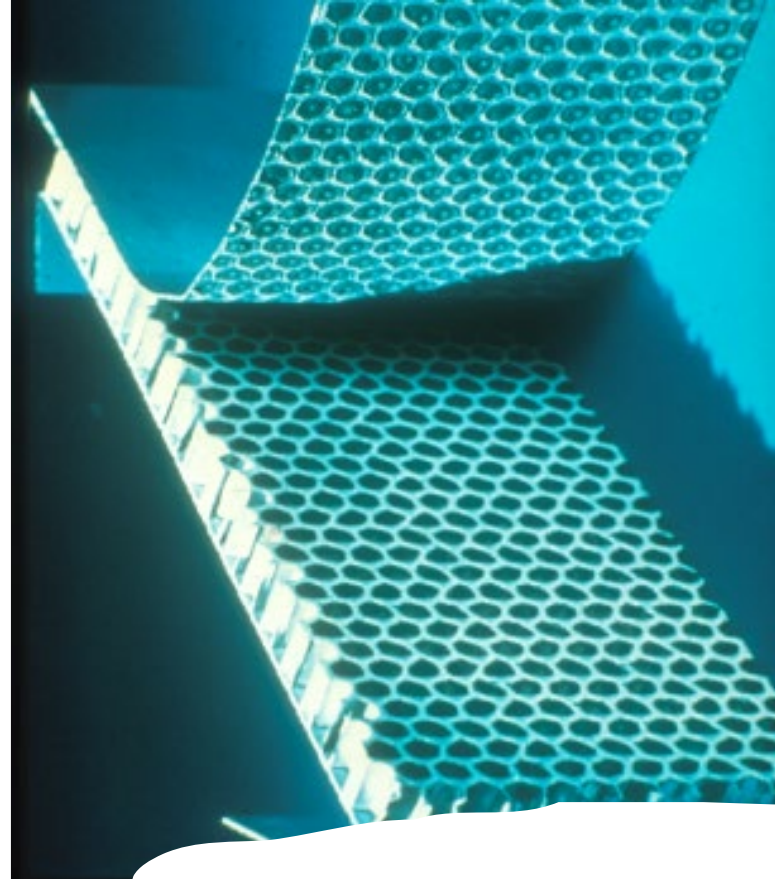


Apple shop - Chicago

Composite projects in Switzerland and abroad

- Weighing 80.7 tons (73.2 metric tons), the impressive roof structure is described by the design team as the "largest carbon-fibre roof in the world". It is made up of 44 identical radial panels, which were assembled on site and then lifted into place in one go on top of the 41m diameter pavillion.
- <https://www.dezeen.com/2018/11/21/steve-jobs-theater-pavilion-foster-partners-apple-park/>

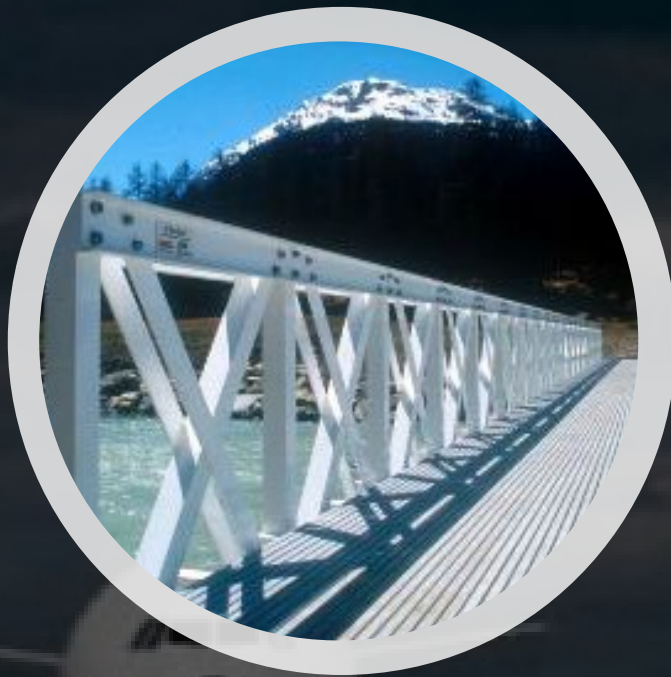
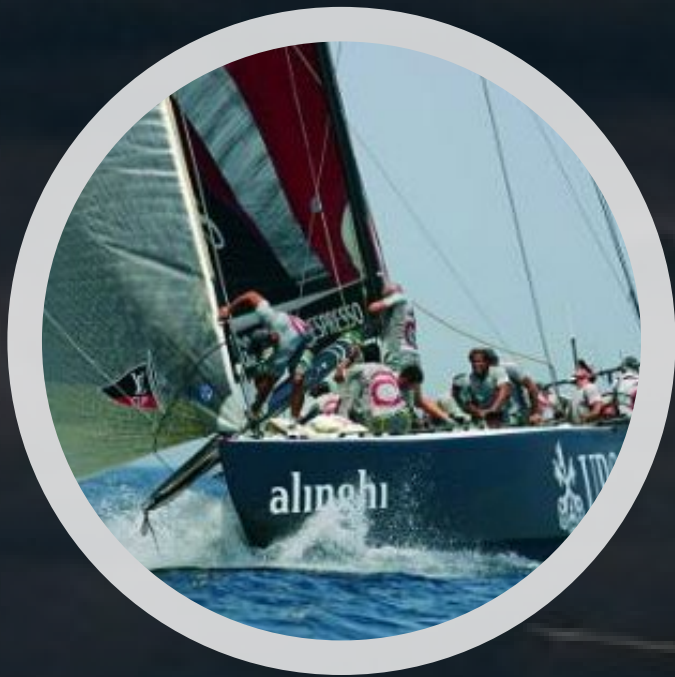




FRP Materials

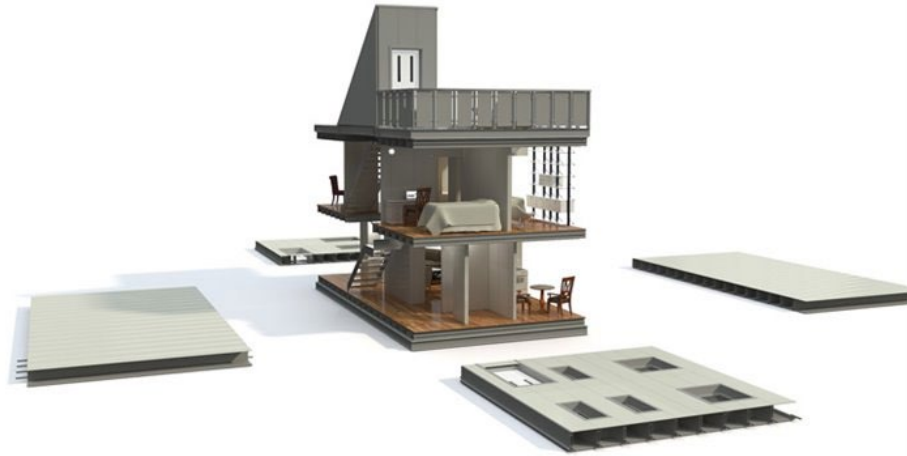


Applications



Applications

The Startlink - lightweight building systems



Composites profiles used in trains/trams



CFRP tubes - pavilion

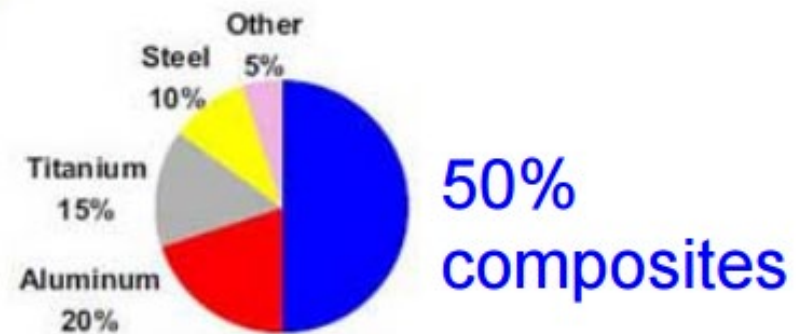
Trench shoring system



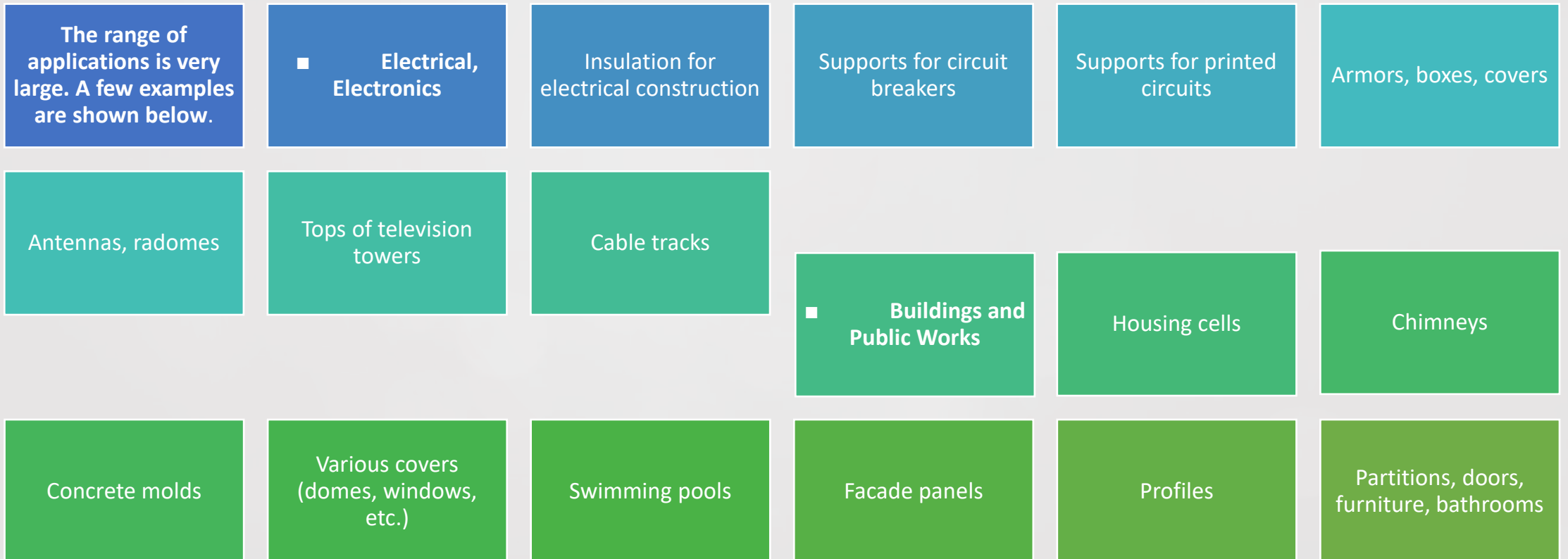
Boeing 787 Dreamliner



- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylons



WHAT CAN BE MADE USING COMPOSITE MATERIALS?



WHAT CAN BE MADE USING COMPOSITE MATERIALS?

Road Transports

Body components

Complete body

Wheels, shields,
radiator grills,

Transmission
shafts

Suspension
springs

Bottles for
compressed
petroleum gas

Chassis

Suspension arms

Casings

Cabins, seats

Highway tankers,
isothermal trucks

Rail transports:

Fronts of power
units

Wagons

Doors, seats,
interior panels

Ventilation
 housings

WHAT CAN BE MADE USING COMPOSITE MATERIALS?

Bridges

Wind energy (Wind turbine rotor blades)



WHAT CAN BE MADE USING COMPOSITE MATERIALS?

- **Space Transports**

- Rocket boosters
- Reservoirs
- Nozzles
- Shields for atmosphere reentrance

- **General mechanical applications**

- Gears
- Bearings
- Housings, casings
- Jack body
- Robot arms
- Fly wheels
- Weaving machine rods
- Pipes
- Components of drawing table
- Compressed gas bottles
- Tubes for offshore platforms
- Pneumatics for radial frames
- Sports and Recreation
- Tennis and squash rackets
- Fishing poles
- Skis

Based on
traditional
Design concepts



A composite fuselage section



The wing lower cover for Airbus' A350 XWB measures approximately 32 meters long by six meters wide, making it the largest carbon fiber part ever produced in civil aviation.



Eyecatcher Building

In the construction engineering field, composites have been initially used to replace conventional materials like steel, or concrete in order to achieve lightweight, easily assembled structures. A typical example of this concept is the Eyecatcher building in Basel, Switzerland. A 15-m-tall, five-story, mobile, lightweight building, it is the tallest multistory GFRP building in the world.



Location 1999: Basel-Mustermesse



Location 2002: Basel-Dreispietz

The pontresina bridge

- The Pontresina bridge is a temporary lightweight pedestrian bridge, installed each year in the autumn and removed in the spring. Two 2x12.50-m truss girder spans, with adhesively-bonded joints in one span (fully load-bearing) and bolted joints in the other span, were used and additional structural safety was provided by a redundant truss and joint configuration.



The pontresina bridge



The pontresina bridge



Free formability



Although for the above-mentioned examples and numerous other applications the substitution of conventional materials by FRP composites has been proved successful, **this practice prevents engineers from taking advantage of one of the most attractive characteristics of composite materials.** These “advanced” materials allow engineers to adopt a different approach to design problems, propose alternative design concepts (**based on the free formability and lightweight characteristics of composites**) and redesign structures. It is thanks to this free formability concept and the superior specific mechanical properties offered by FRP composites that the wind industry grew so rapidly during the last quarter of the 20th century and is still growing by using hybrid tailor-made materials in order to meet the requirements for today’s “huge” wind turbine rotor blades

Differentiating the perceptual design concept!



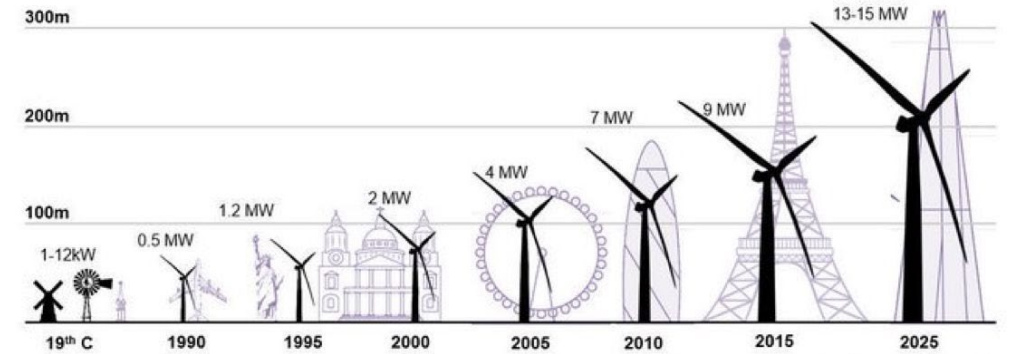
The world's largest wind turbine blade on the road



This is the world's largest wind turbine blade en route to the largest offshore wind turbine in the world, in Methil, Scotland. At an incredible 273.95 feet (83.5 meters) long by 13.7 feet (4.2 meters) wide, the blade had to be transported all the way from Denmark, [where it was manufactured](#) —a logistical nightmare.

It was installed on a 7-megawatt test offshore turbine made by Samsung Heavy Industries, which will start producing energy in 2015. Here's a video of the installation, from April 4:

Evolution of wind turbine heights and output



Sources: Various; Bloomberg New Energy Finance

32 September 19, 2017

Bloomberg New Energy Finance

Power system value enhancements

- Large rotors
- Storage hybrids
- Self-curtailment

Barriers

- Permitting
- Transportation
- Community concerns

Power system value enhancements

- Large rotors
- Balancing Services
- Connecting to high price and low curtailment points

Barriers

- Vessels
- Cranes
- Ports

Fixed-to-floating crossover

- > 60 m water depth

Use of floating

- 11-25% of projects

Onshore Wind Turbines



Offshore Wind Turbines



Characteristics in 2035



The longest wind turbine rotor blade (2020)



At 107 meters,
LM Wind Energy's blades
for the Haliade-X
12MW

Hybrid G/C composites



How to fabricate such big structures?

How to support such big structures?
The foundation in Rotterdam of the Haliade-X



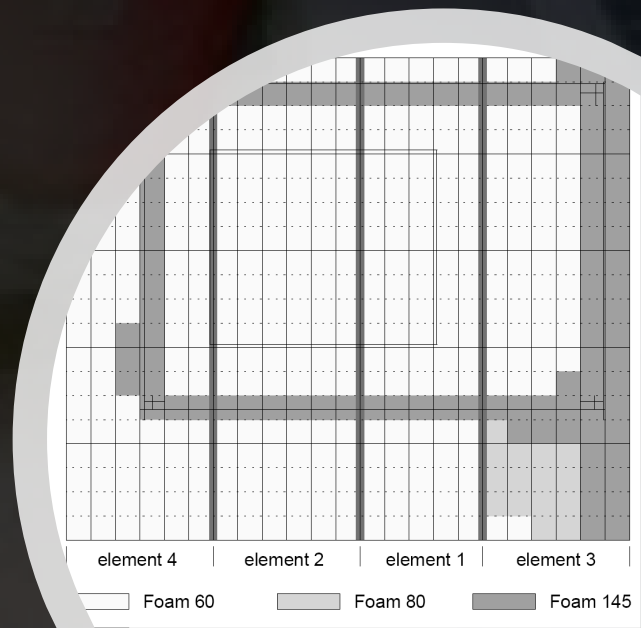


Novartis roof

- The sandwich roof construction integrates static, building physical and architectural functions, **allowing the prefabrication of the entire roof in only four lightweight elements that were easily transported to the site and rapidly installed.**
- The cutting of foam blocks with a computerized numerical control machine and adhesive bonding proved to be advantageous procedures for the fabrication of the complex roof shape, without the use of expensive molds.



CNC-cutting of 460
individual foam blocks





Adhesively
bonded joints



Roof installation on site:
simple transport and
installation of large-scale
elements



Prefabrication

The **degree of prefabrication** guaranteed a high-quality fabricated composite structural element, quality control of fabrication since it can be performed in well-controlled laboratory conditions, and results in reduced construction times compared to conventional building procedures. In special cases, **bridge structures for example, the advantage is even greater since prefabrication and fast installation also means reduced traffic interference.** The lightweight characteristic of composite materials can in this case also offer considerable **savings in dead loads** and therefore allow the bridge widening (on the same foundation) to accommodate more traffic.



Avançon Bridge, Bex, 2012: GFRP-balsa sandwich bridge deck



Old one-lane bridge



Bridge deck fabrication



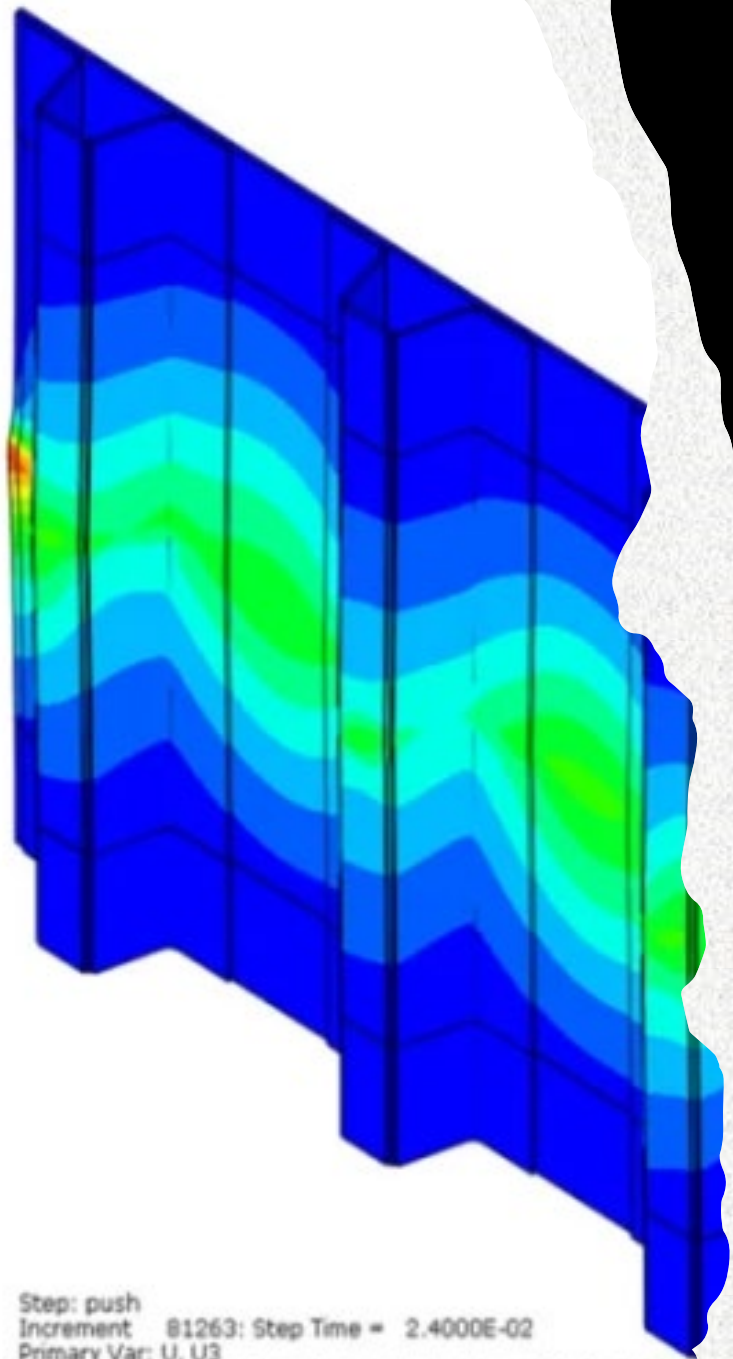
Installation

Pre-assembly on site

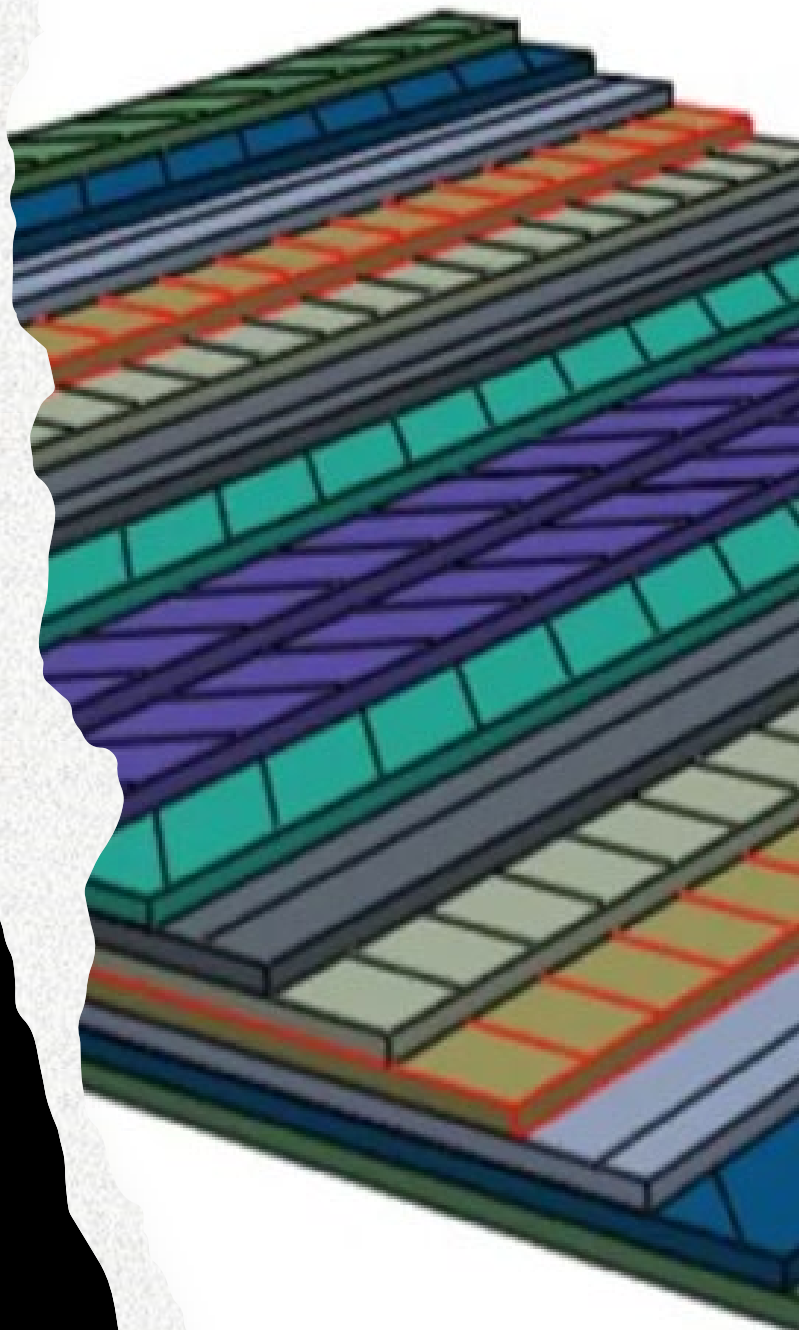




How do we analyze composite structures



Step: push
Increment 81263: Step Time = 2.4000E-02
Primary Var: U, U3
Deformed Var: U Deformation Scale Factor: +1.000e+00
Status Var: STATUS

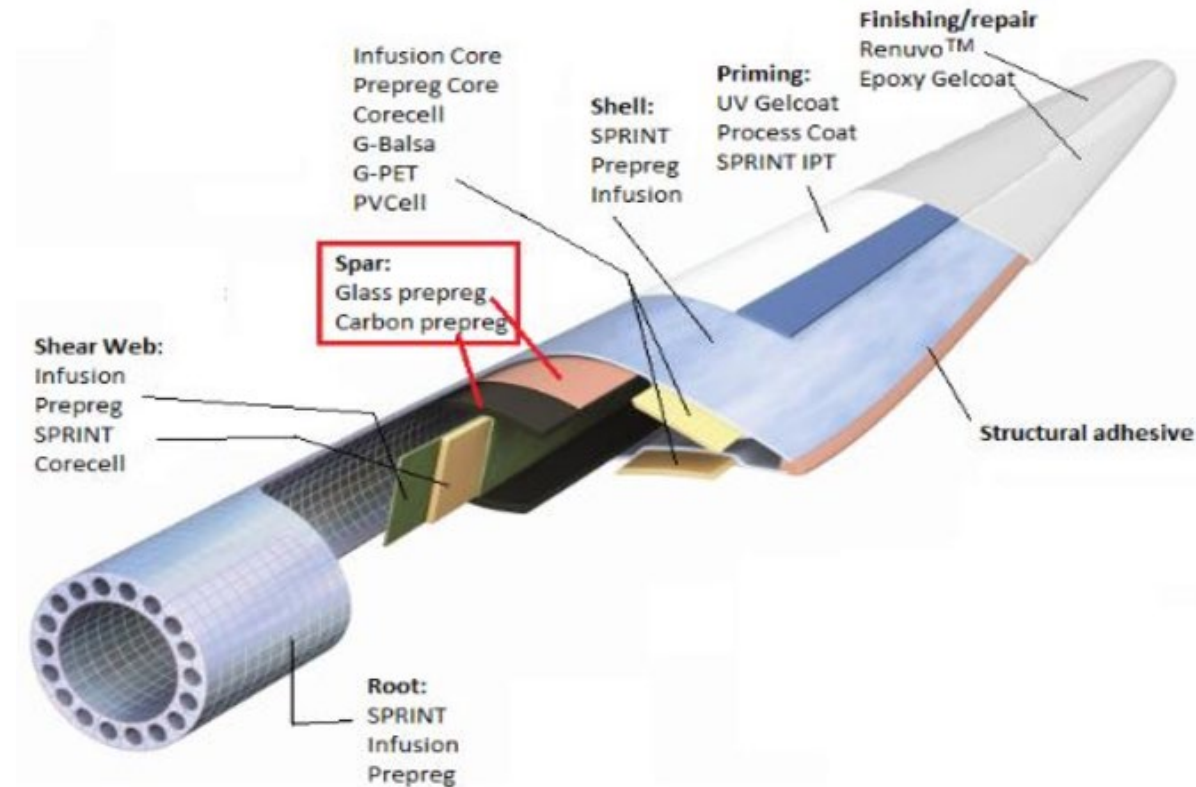


Life cycle of a composite structure

or else – from fibers and resin to composite structures



Concept

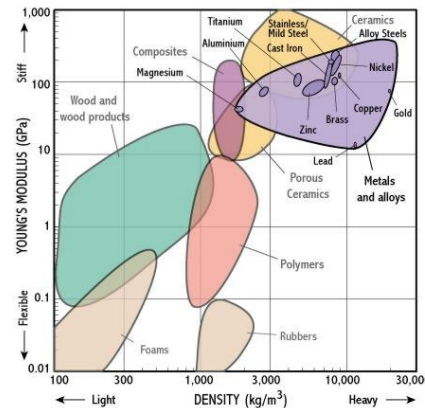


Life cycle of a composite structure

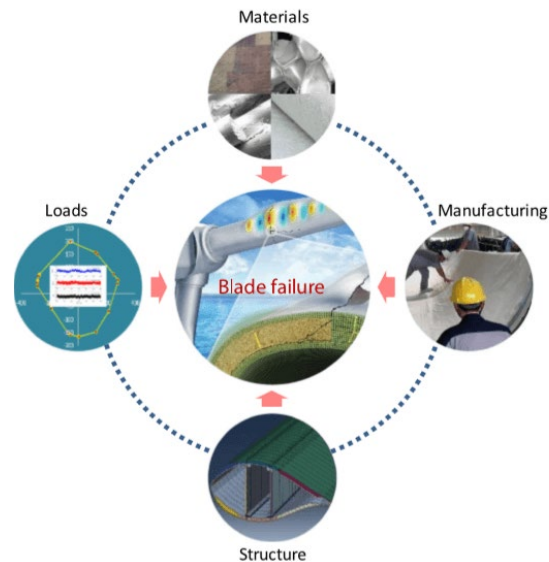
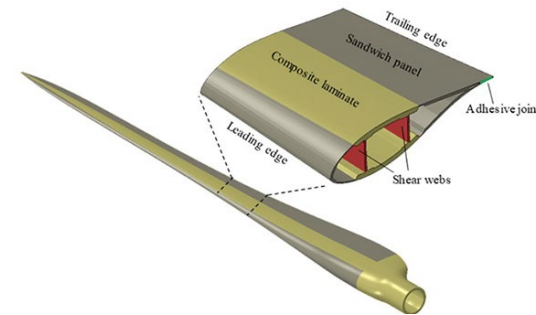
or else – from fibers and resin to composite structures



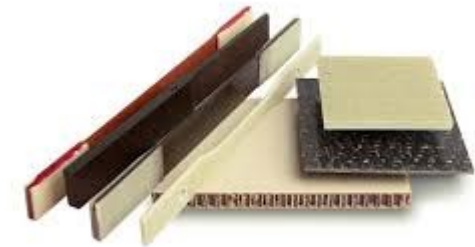
Concept



Design

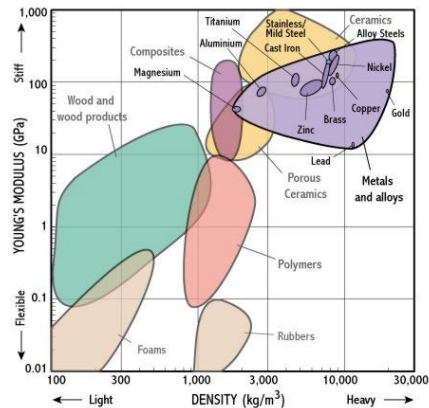


Material Testing



Life cycle of a composite structure

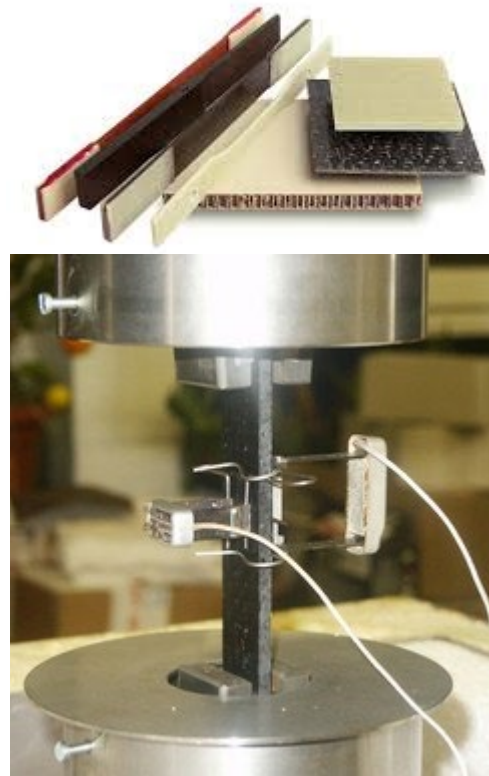
or else – from fibers and resin to composite structures



Design



Material Testing



Manufacturing



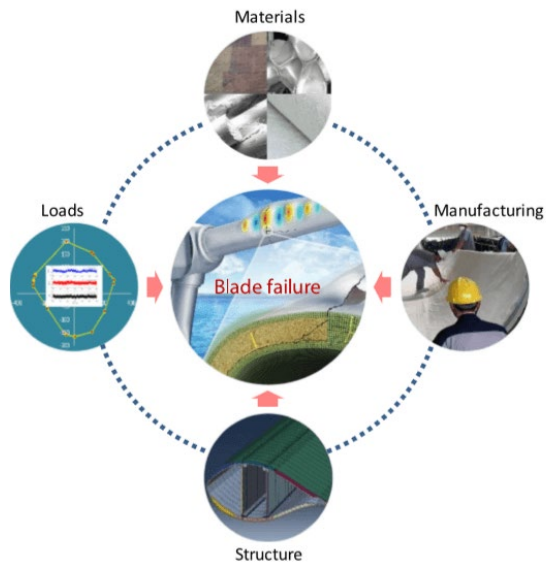
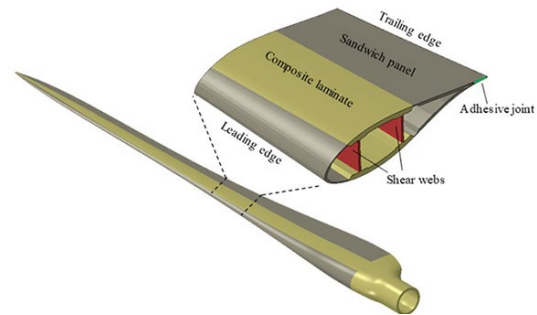
Design verification



Life cycle of a composite structure

End of life strategy
Reuse
Recycle

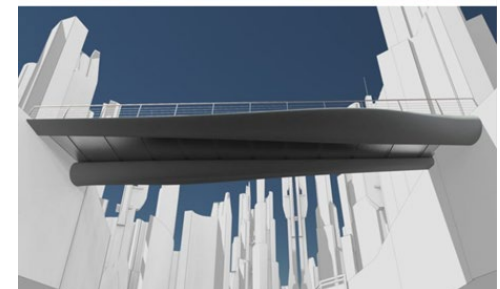
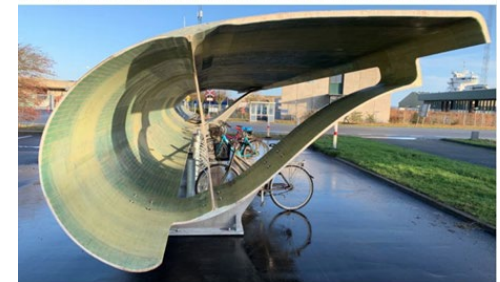
Material Testing



Manufacturing



Design verification



End of life scenario



Landfilling - <https://www.bloomberg.com/news/features/2020-02-05/wind-turbine-blades-can-t-be-recycled-so-they-re-piling-up-in-landfills>

Can composites be recycled?



The disposal of composite waste in cement kilns is widely believed to be an effective option, resulting in energy and materials recovery.

Co-processing is the simultaneous use of composite regrind as raw material and as a source of energy in cement manufacturing, to replace natural mineral resources (material recycling) and fossil fuels such as coal, petroleum and gas (energy recovery). In this process, the composites regrind used for co-processing is both an alternative fuel and raw material (AFR).



Fig.1 : Unloading of windmill blades at processing site



Fig.2 : Part storage prior to mechanical treatment



Fig.3 : Mobile sawing equipment to reduce transport costs



Fig.4 : Typical composite regrind, made from ground windmill blade

After their useful life saving energy and helping to reduce Eco-footprint in many applications, composite regrind can reduce Eco-footprint and CO₂ emissions of cement manufacturing.

Can composites be recycled?



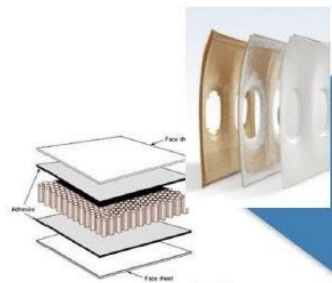
Carbon fibers can be recovered and recycled from carbon fiber reinforced polymers (CFRP) with around half a dozen companies around the world specializing in this work



Recycled and sorted carbon fibres



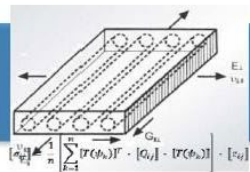
rCF veil production



rCF veil sandwich structure



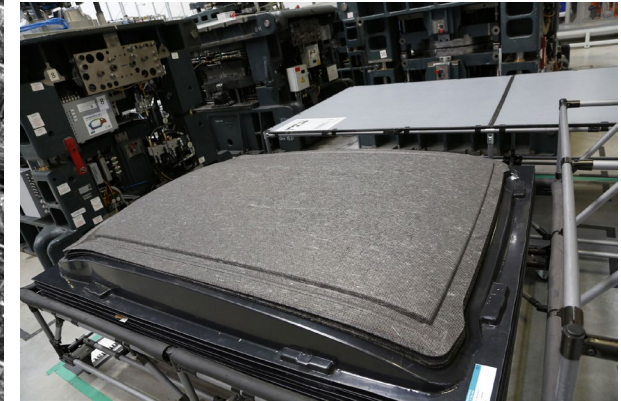
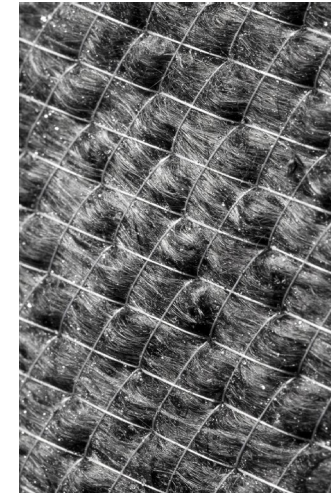
Processing



Characterization



Prepreg impregnation



Mechanical **carding** is used by SGL Automotive Carbon Fibers (Wackersdorf, Germany) to process CF scrap from weaving and preform kitting for the BMW i-series CFRP Life Module production into stitched nonwoven materials (left) which are then molded into the i3's rear seat structure and roofs for both the i3 and i8 (right). SOURCE: BMW

Do composites fail?



Course objectives



Learn about composites



Understand the advantages/disadvantages of composites



Learn about the use of composites, their placement in the market and their future



Learn how to design a composite structure



Design a simple composite structure

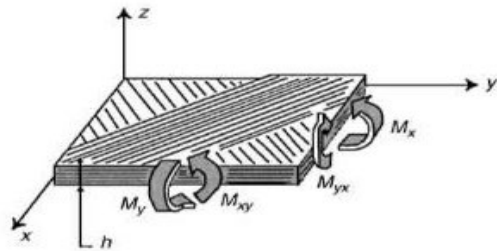


Obtain Transversal skills – Team/project management, writing a scientific report, hands on experience...

Practice

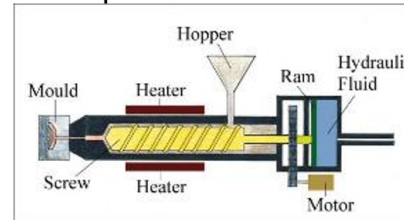
Applications and dimensioning

- Laboratory experience
- Present applications of composites
- Perform dimensioning of a structure



Introduction

- Types of composites
- Reinforcements
- Matrix materials
- Interfaces
- Macture procedures



Structural foam injection

Mechanics of composite materials

- Theory of elasticity for anisotropic media
- Classical lamination theory

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{21} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix}$$

Advanced Composites in Engineering Structures Course layout



Current Projects/GR-MeC activities

Potential for

Course projects

Semester projects

Master projects

Internship



Fancy Master Theses

Talk to me...

