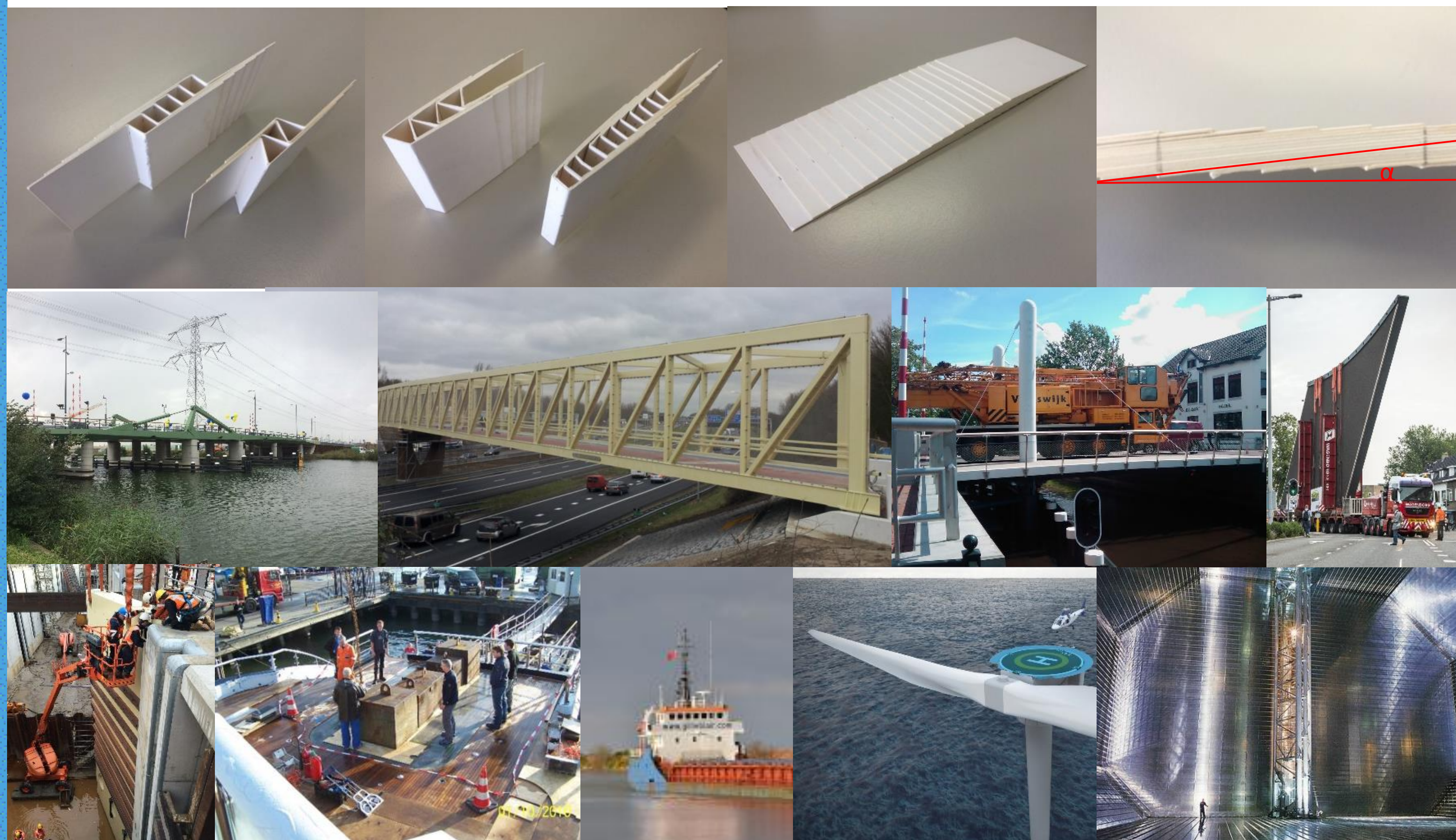
InfraCore® company

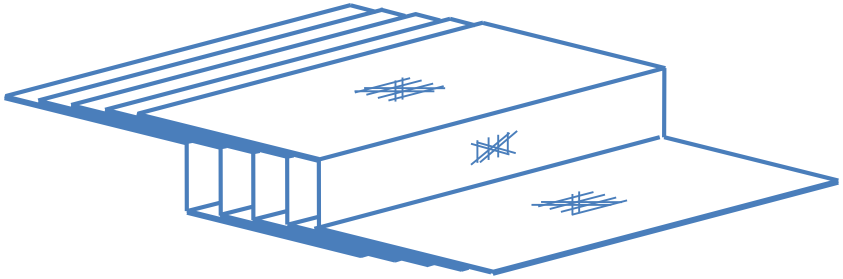
Oblique layered materials & structures®



1st mentioning of "Oblique layered composites" at SAMPE BENELUX on June 29th 2011 (Delft, NL)

Oblique layered materials & structures®

- Oblique layered materials
- Oblique layered structures®
- Theory of Oblique layered materials
- InfraCore Inside Technology
- InfraCore Institute
- OLM/InfraCore materialisations
- Conclusion



Oblique layered materials (OLM)

In traditional composite materials, the fabrics are plane-parallel to the overall outer surface of the laminate.

“Oblique Layered Materials are defined as multi layered laminates in which the fabrics partially overlay one another and which are interconnected in such a way that they form a structure in which the cross section shows layers which are at a slight angle through the thickness”.

In this definition, the oblique layers are interconnected to form a rigid laminate.

Oblique layered materials (OLM) in nature

Nature contains many Oblique Layered Materials.

For example:
the scales of fish are connected on one side to the body of the fish, the other sides are ‘free’ to move a bit, all overlap one another and they are at an oblique angle to the outer surface of the fish.

Together, they define the shape of the fish: oblique layered on a microscopic level, smooth on a macroscopic level.

This theme is repeatedly found, from fish to reptiles, to amphibians, to birds and butterflies, …
Even on a microscopic level: the scales of the surface of a hair.

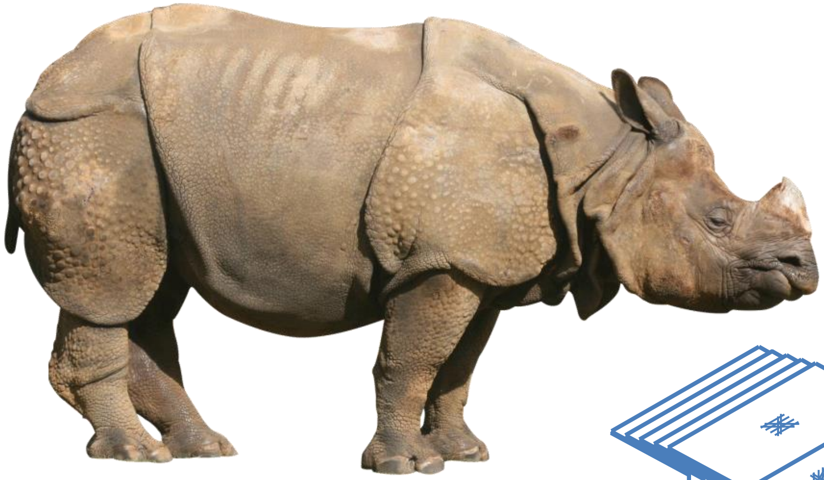
Oblique layered materials (OLM) in nature

Armadillo

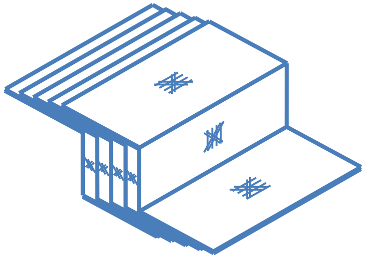
Sow bug

Millipede

Lobster



Indian Rhinoceros



Oblique layered materials (OLM) in nature

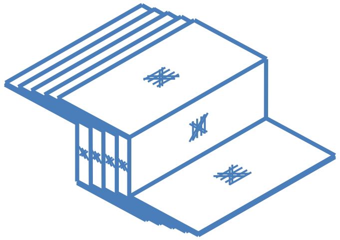
Fennel

Ravenala madagascariensis

Bamboo

Nautilus

Salmon



Oblique layered structures (OLS) in nature

In all these examples of nature, the layers are essentially not fully interconnected, but mostly stiff layers, plates or scales in oblique layered configuration, allowing for low in-plane and bending stiffness, for flexibility and for movement, expansion or growth.

We call these flexible structures ‘Oblique Layered Structures’ (OLS), as opposed to ‘Oblique Layered Materials’ (OLM), as they do not form one coherent interconnected rigid material.

In most OLS, the layers are connected to some substrate or base, in some they are connected to each other only.

Oblique layered materials (OLM) in man-made creations

Examples of man-made oblique layered structures are the armor of Mongol warriors, the harness of mediaeval knights, sequins and scaled necklaces, roof tiles and shingles, clinker built ships, wooden saloon doors, helical wrapped pipes, etc.

Also stacked interlocking items can look like oblique layered structures, e.g. stacked sheet piles, a row of interlocked shopping carts or some crash cushions at road junctions.

Oblique layers are everywhere around us.

Theory of Oblique layered materials

Literature contains no description of rigid ‘Oblique Layered Materials’, flexible ‘Oblique Layered Structures’ nor rigid ’Oblique Layered Composites’. This is an open research field, in essence a new material.

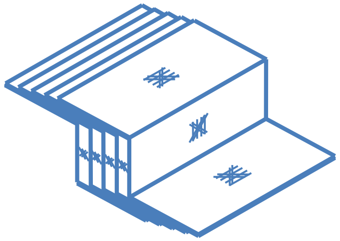
‘Plane-parallel’ FRP laminates can be described using the Classical Laminate Theory, which may be considered as an elaborate rule of mixtures. All stress and strain components can be linked using a 9 x 9 matrix of material stiffness or compliance constants. Often, these 81 material constants are reduced to 5 independent constants to describe transversely isotropic, orthotropic materials, by applying rules of symmetry.

In OLM however, symmetry is at least harder to define. It will translate in a more elaborate laminate theory description, involving many more than 5 independent material constants, which has not yet been properly modelled in these terms.

InfraCore Inside Technology
Oblique layered sandwiches

In nature, oblique layers are connected to a substrate, being e.g. the skin of a bird or the stem of a pinecone. The substrate for the layers in an OLM can also be another OLM, as each OLM surface contains many layer-ends , which can be extended and interconnected to a parallel OLM, thereby forming a sandwich-like structure.

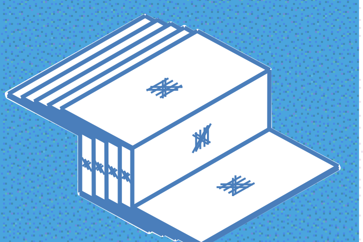
This is what InfraCore® actually is: two interconnected OLM's forming together a double-walled structure, with the layers forming the skin of one OLM, continuing through the 'core' to form the layers in the opposite skin, thereby fully interconnecting the skins and the core.



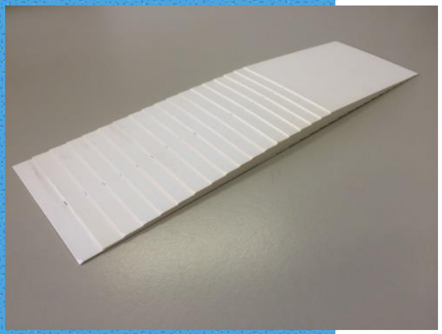
InfraCore Inside Technology
Oblique layered sandwiches

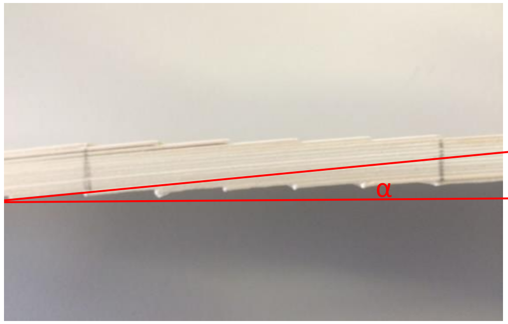
The two main variants to InfraCore® are Z- and U-InfraCore®.

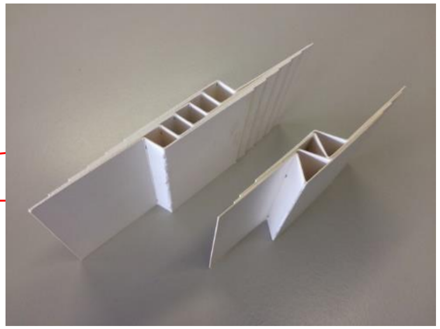
When loading both types of oblique layered sandwiches in bending, the webs are preferably directed in span direction.

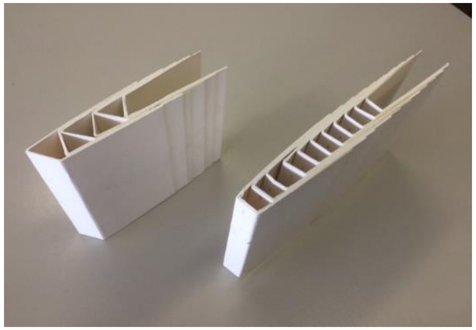


Bending stiffness in crosswise direction is increased by shaping the Z- or U-shape in such a way that a truss-like interconnection is formed perpendicular to the span, as shown here with triangular core cells.









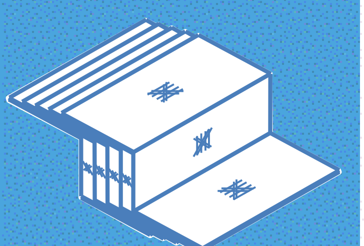
InfraCore Inside Technology
Oblique layered sandwiches

Without interlaminar damage, InfraCore® functions as any sandwich with the same laminate scantlings.

Each Z- or U-shaped layer from which the panel is composed, can be considered as a separate independent beam, with its own two flanges connected by a web, but without bond lines as it is one continuous fibre reinforced layer.

Even without resin or adhesive connecting the beams,
their Z- or U-shape functions as a shape-joint, interlocking and joining them together, just similarly to OLS.

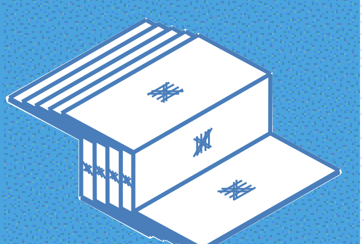
A badly (impact) damaged InfraCore® will show delamination between the layers composing the skin, however when loaded, the shear load transfer between the interlocking Z- or U-‘beams’ is minimal.



InfraCore Inside Technology
Oblique layered sandwiches

Initial delaminations in an InfraCore® bridge deck for 60-tonne traffic, made by impacting the deck with a heavy falling weight before the fatigue testing, did not grow under the simulation of 20 million vehicle passages. This test was witnessed by DNV-GL.

The structure would not even fail, even if all layers were fully delaminated, as one would still have a double-skinned plate, with each skin comparable to a natural oblique layered structure. The InfraCore® panel would be more flexible, especially perpendicular to the web direction, but it would be able to carry the full load.



Full delamination would transfer an InfraCore structure from an integrated sandwich to a set of independent beams with interlocking shape joints, or from an oblique layered material to an oblique layered interlocking structure, hence the robustness.

InfraCore Institute
OLM Fracture mechanics

In plane parallel composites, an interlaminar crack can initiate on all cross sectional edges, due to bending induced shear, or away from the edges, e.g. due to impact loading. The most vulnerable positions for crack initiation are the boundaries of the fibre layers in the laminate, where they protrude from the edges of a plate or where they are cut on the inside of a drilled hole.

In OLM, there are many more fibre layer ends protruding from the contours of a flat plate: both on the cross sectional edges as well as on the faces of the plate. There are more locations to initiate an interlaminar crack in OLM than in regular composites.

However, will this increased surface area which could initiate an interlaminar crack translate to a higher chance of actual crack initiation?

InfraCore Institute
OLM Fracture mechanics

If the crack initiation energy is higher in OLM, due to the obliqueness of the layers, it could be that this is offset by the larger potential crack initiation surface.

In a plane-parallel composite a crack can travel long distances between the layers, both lengthwise and crosswise.

In an OLM-plate, the crosswise crack propagation is limited to the width of the layer. Therefore, research into crack initiation and crack propagation in terms of fracture mechanics needs to be started. What are the critical stress intensity factors in OLM? How do these parameters relate to the obliqueness angle α? It is expected that where plane- parallel composites show one fracture surface, OLM will show multiple fracture planes, perhaps decreasing the overall propagation speed.

InfraCore Institute

OLM Interlaminar shear strength (ILSS)

ILSS is crucial for the performance of composite materials. ILSS samples fail in shear between the plane-parallel layers. What will happen in OLM, where the layers are not plane-parallel with the surface?
No systematic research has been performed yet to determine the ILSS-value of OLM depending on the obliqueness angle α.

With $\alpha = 0°$, regular plane parallel composite properties are expected.
With $\alpha = 90°$ no ILS failure will occur, depending on the definition of the in-layer fibre directions.

What will happen in between: for example in the range of typical InfraCore obliqueness, with $\alpha < 5°$? The expectance is that the ILSS of InfraCore will be higher than that of normal composites.
It is also expected that at higher α, multiple parallel shear fractures will initiate across the material.

OLM/InfraCore Materialisations

OLM and InfraCore® are not restricted to fibre reinforced organic polymers.

InfraCore® structures could be based on:

- thin layers of metal, with or without fibre reinforced polymer layers between them, e.g. steel or aluminium;
- fibre reinforced ceramics, with the fibres being a thermoplastic, glass or basalt, carbon or steel;
- even concrete, cardboard or rubber inflatables can be made using OLM or InfraCore®.

Conclusions

Oblique Layered Materials, Oblique Layered Structures and Oblique Layered Composites form a new category of materials and structures, worth investigating for their unique properties; some proven, some expected.

InfraCore® is a laminate technology which enables the benefits of classic sandwiches (light weight, high stiffness, high strength), without the drawbacks (skin-core debonding, dangerous delaminations).

All Oblique Layered materials and structures have parallels in nature.

We may learn to define better OLM by further studying the examples nature shows us.

InfraCore inside

FiberCore europe

> 700 structures with InfraCore inside

InfraCore inside

FiberCore europe

First FRP traffic bridge
conform Eurocode
NEN-EN 1991-2+C1/NB

Oosterwolde

dimensions : 12,5 x 12,5 m
span : 12 m
traffic class : class 600 kN / Eurocodes
year : 2010

InfraCore inside

FiberCore europe

InfraTech
Half-time award
2013

ProRail

heijmans

HILLEBRAND

Movares
adviseurs & ingenieurs

FiberCore europe

Traffic bridge Utrecht, crossing highway A27

dimensions	: 142 x 6,2m
span	: 6,2 m
traffic class	: class 600 kN, Eurocode
year	: 2011-2012

World record
resin injection
21 ton
'single shot'

Traffic bridge Muiden, 2014

dimensions	: 16,3 x 11,7 m
span	: 11,5 m
traffic class	: class 600 kN
year	: 2014

InfraCore® inside

FiberCore® europe

Traffic bridge Utrecht

traffic class : class 600 kN

year : 2015

InfraCore inside

FiberCore europe

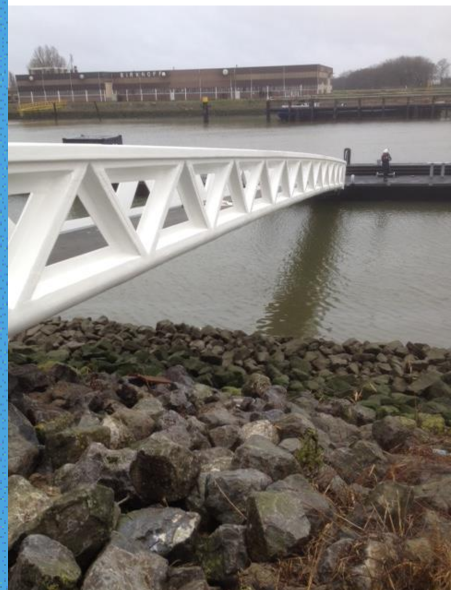
World's Largest FRP lock gates

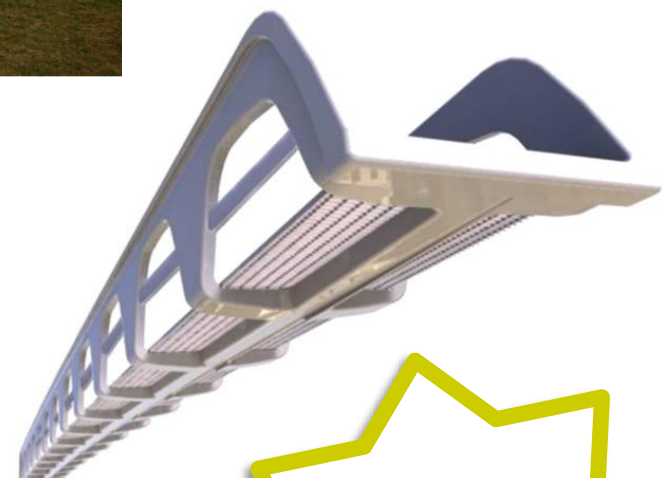
Lock gate IV

Tilburg

Year : 2016

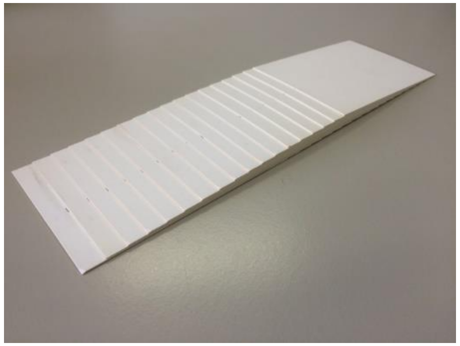
‘Harbour bridges’

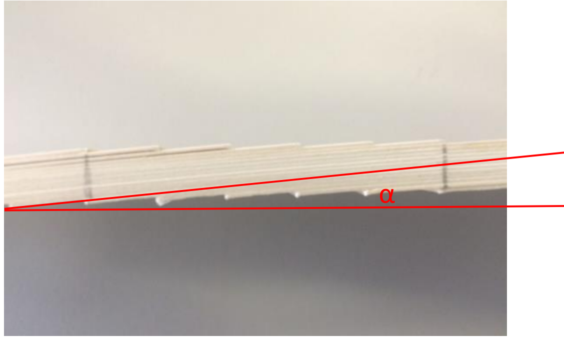


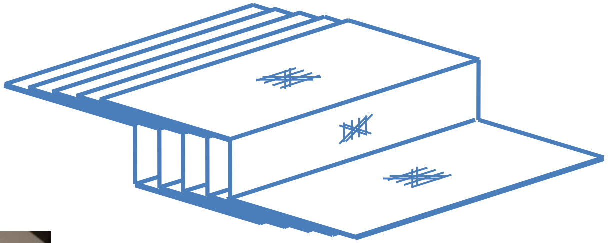


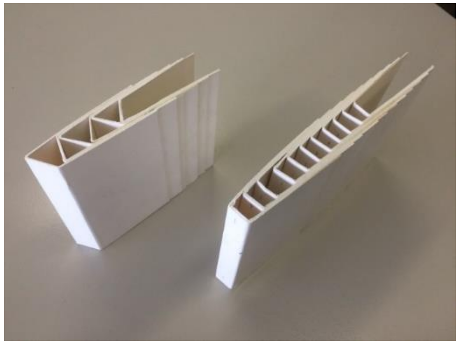
Span = 36 m

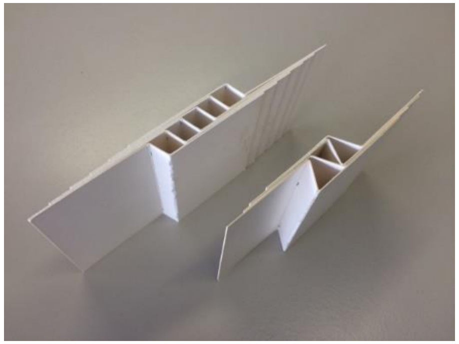
Company: FiberCore IP





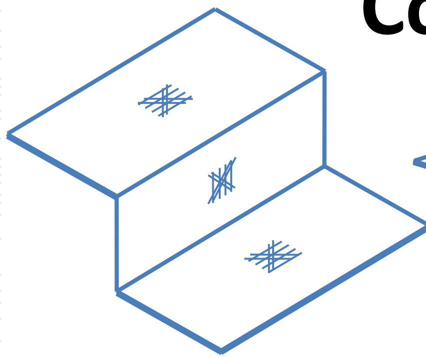


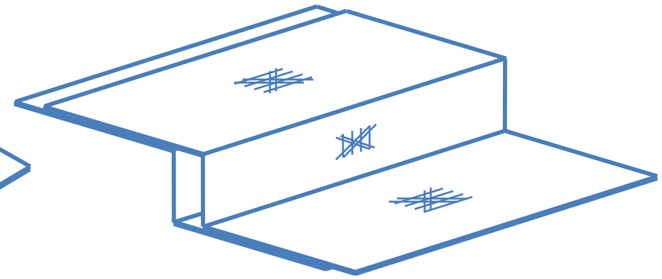




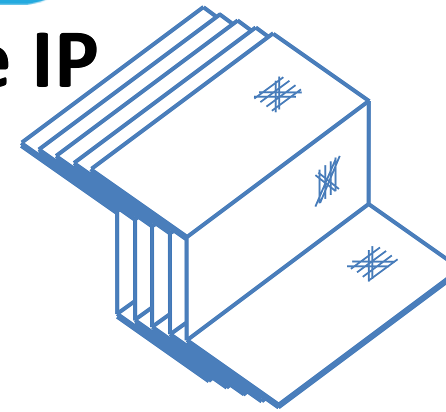
worldwide patent: Structural FRP technology InfraCore®
Development of 'Oblique Layered Material'

Company: FiberCore IP

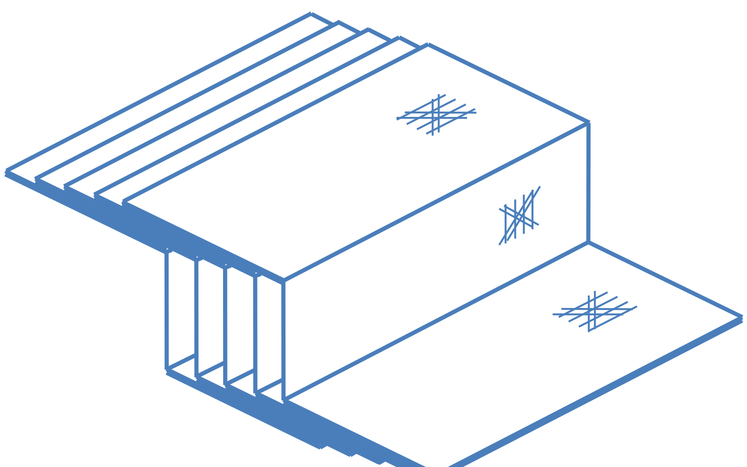




(Glass) Fibre Fabric beam box:
Flanges, connected by webs
Flanges 0°/ ±45° fabric, webs 90°/±45° fabric
Non-structural core



(Glass) Fibre Fabric multi-beam box
Beams are self-contained
Little shear transfer between beams
Impact damage = local delamination



(Glass) Fibre Fabric multi-beam box
Sandwich plate
Interlaminar cracking is inconsequential

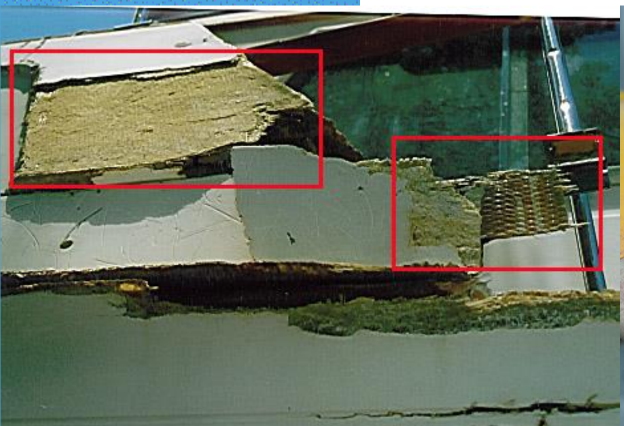
Multiple impact damage + fatigue
= local delamination, no damage growth

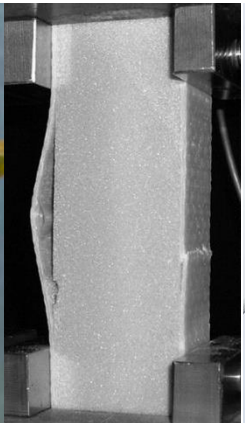
Extreme robustness

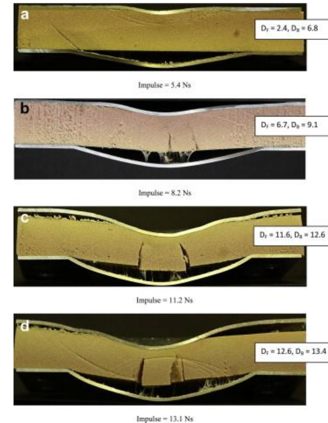
Company: FiberCore IP

Main problems in heavy duty FRP structures <u>solved</u>:

<u>Delamination, debonding and interlaminar cracking!</u>

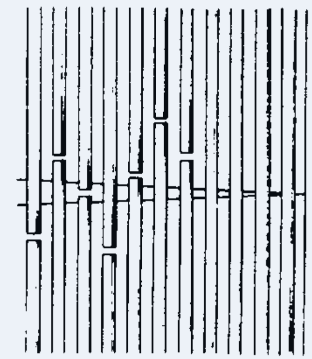




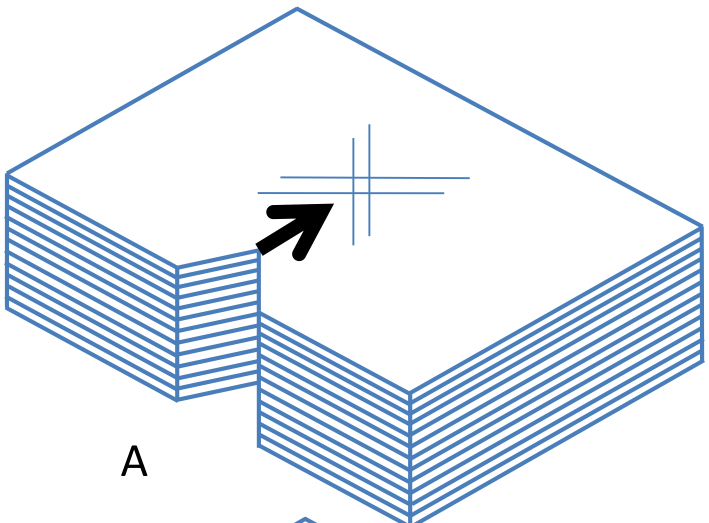


PROVEN DAMAGE TOLERANCE

FIT FOR OPERATION



Crack tip
in composites



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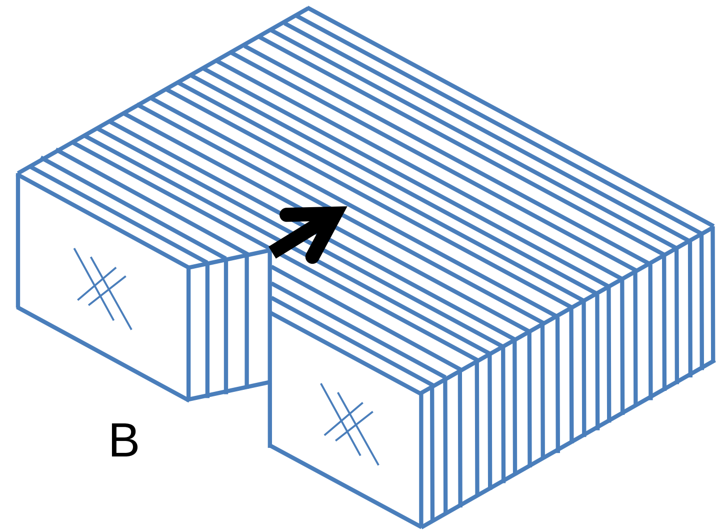

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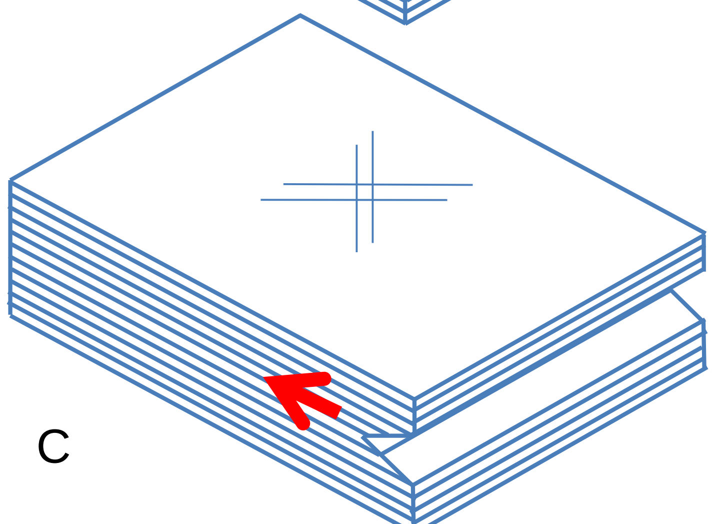
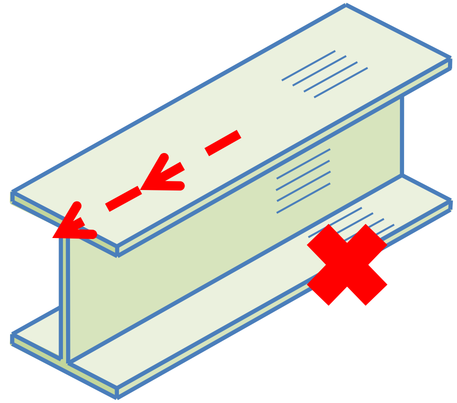
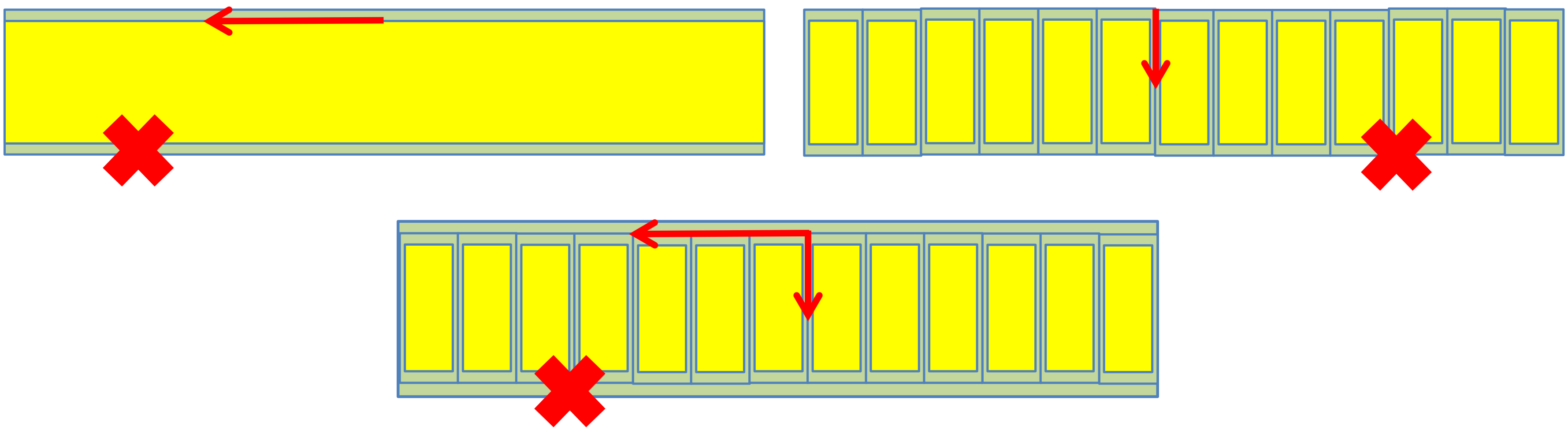
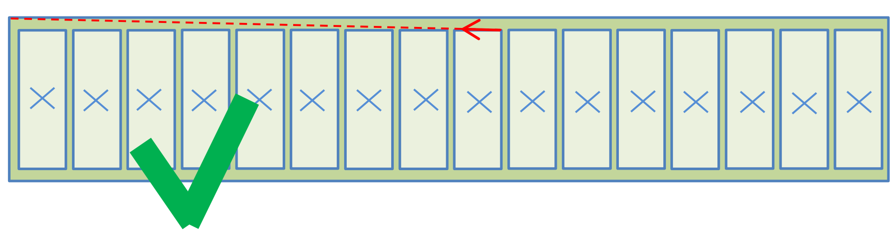


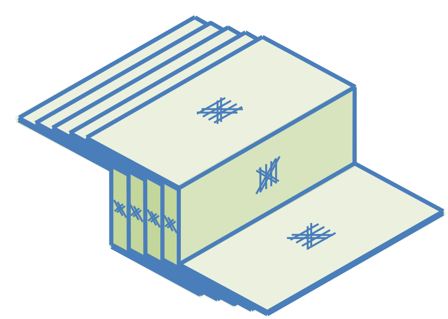
C

Fibre Reinforced Plastics
Inhomogenic, layered material
Fibres act as crack arrestors
Vulnerable to cracking <u>between</u> fibre layers
(“interlaminar cracking” or “delamination”)









Glass Fibre Fabric box beam:
Extreme robustness

InfraCore® inside

InfraCore® inside

PROVEN DAMAGE TOLERANCE

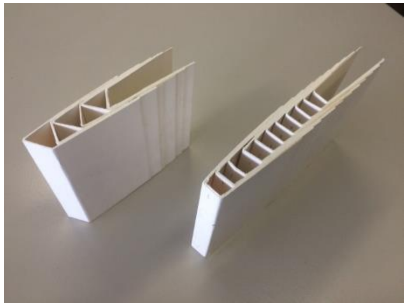
FIT FOR OPERATION

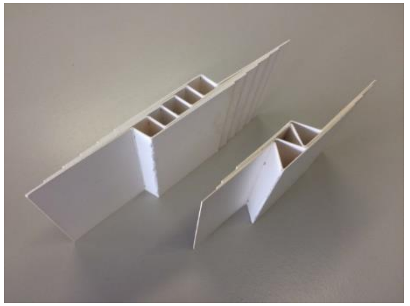
InfraCore® inside

The technology is fully compliant with the robustness requirements formulated in the Eurocode 0 (EN-1990), proven and patented worldwide.

InfraCore Company

Contact





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