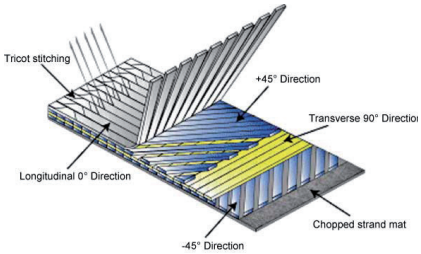
Technical datasheet

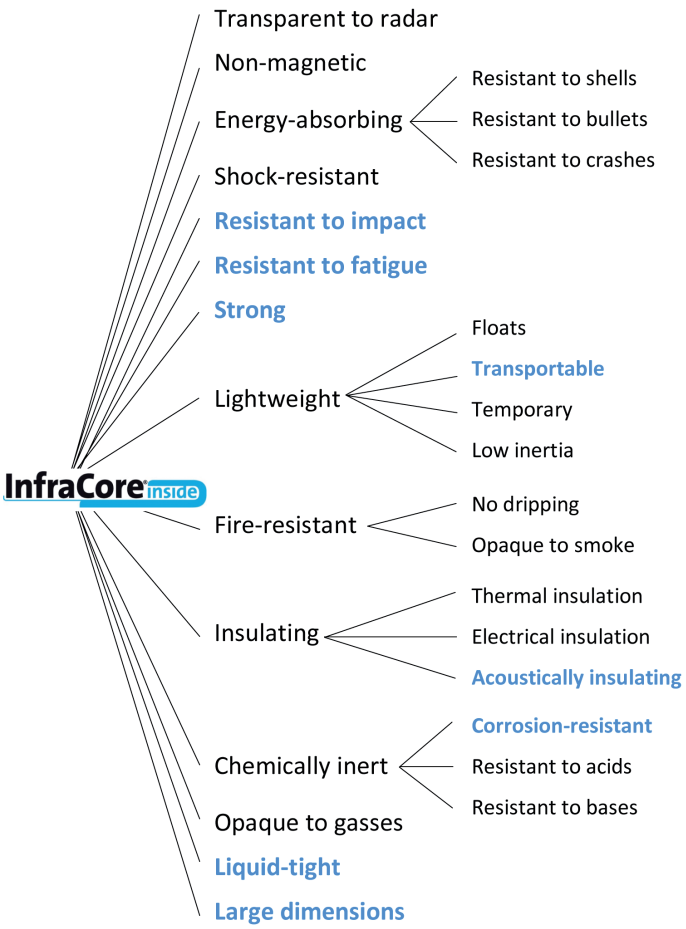
The FRP-material

Fiber reinforced polymers (FRP or composites) are a composite material of structural fibres set in a matrix of thermoset resin. The resin restrains the fibers against buckling and enables transfer of shear stress between fibers. Thermoset resin does not get soft at elevated temperatures, unlike thermoplastic material in coffee cups and many household plastics.

The fibers in FRP are typically glass fibers, although also superior, generally more costly, carbon or aramid fibers can be used. Glass fibers have a strength of 2800N/mm^2 (or: MPa) thus are stronger than steel (~355N/mm^2). Glass fibers are available as roving or as mats, either with fibers in one direction or combining a number of different directions. The fibers are like the reinforcement in reinforced concrete structures, yet at a much more refined level and entirely dispersed over the structure.



Rolls of glass fibres and an example of a glass fibre fabric comprising multiple fibre directions.



Overview of the properties of InfraCore® Inside, with those applicable to civil engineering structures highlighted

FRP and InfraCore inside

FRP is a structural material that cannot rot, is resistant to moisture and UV and does not decay over time. These are very attractive properties for usage in outdoor structures such as those in civil engineering, and for that reason InfraCore® Inside has been developed. However it is the right design that eventually makes that the properties come to full bloom. Therefore: InfraCore® Inside is always FRP, but not all FRP is InfraCore® Inside.

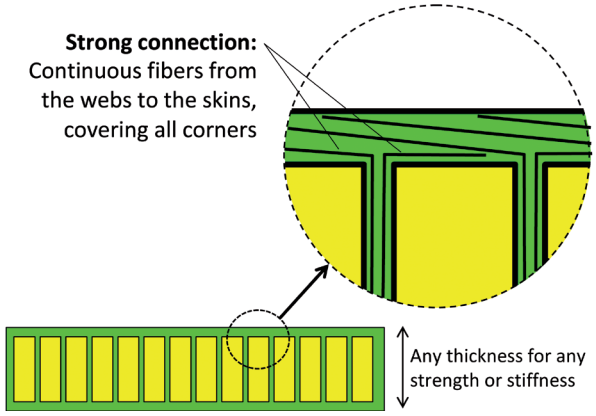
InfraCore® Inside is a dedicated technology to realise the potential of FRP in load-bearing structures. Invented at FiberCore Europe, its development towards even higher performance and for applications other than bridges and lock gates is continuously ongoing.

InfraCore inside *-technology*

InfraCore® Inside is FiberCore Europe's proprietary technology to construct strong, lightweight and durable structures in FRP. The technology comprises the design, the way the fibres are laid out and, and the method of fabrication. While a range of degrees of freedom exists to tune the technology for each specific application, the fabrication follows a modular construction. The dimensional constraints are due to handling and transportation, but not due to the technology in itself.

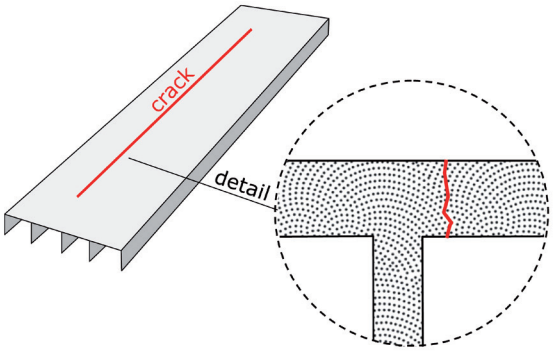
Structures in InfraCore® Inside are fully prefabricated and integral, with no internal bonding or bolting. The strength therefore fully relies on the fibers, which in themselves are stronger than steel.

InfraCore® Inside mechanically behaves like a highly efficient sandwich structure. In such structures, two skins are spaced in order to create a lever arm. The space in between is filled with lightweight material that only transfers shear stresses. The significance of InfraCore® Inside is that it incorporates a continuous structural connection between the two skins. This eliminates the brittle failure as a result of debonding between skin and core.

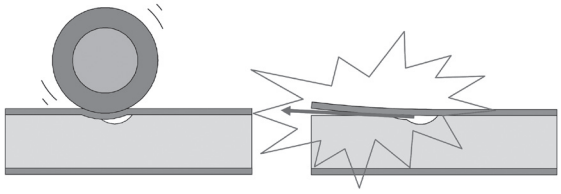


The principle of InfraCore® Inside: no skin-core debonding.

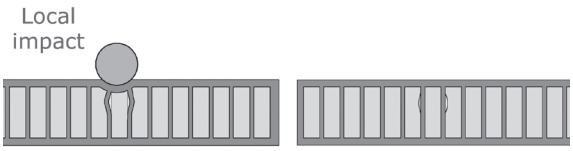
The importance of strength being dominated by fibers means that a resin-dominated fracture path should be avoided, and it is demonstrated below:



In structures with fibres predominantly in one direction, cracks eliminate the load distribution, and then propagate until failure. Fibres in cross-direction are essential to avoid this.



In conventional sandwich structures, initial damage is propagated by rolling wheels, leading to skin-core debonding and total failure.



In InfraCore® Inside, local damage can not lead to catastrophic failure modes. Moreover, the core-material (foam) is not part of the load-bearing structure, but only acts as a placeholder during construction.

Quality

The InfraCore® Inside technology was invented, developed and promoted from FiberCore Europe. It took a significant amount of time to come up with a structure that is cost-effective to build, efficient in use, and best in bringing the potential of FRP to clients in the world of infrastructure. FiberCore Europe is still the only fabricator of InfraCore® Inside.

FiberCore Europe operates an ISO9001-certified quality control system. The system ensures that products are built as specified and meet high quality standards.

It includes everything from the supply of raw materials to verification of individual stages in the fabrication process. Any future licensees will need to deliver the same quality.

Design and engineering

The properties of composite materials depend on the type, orientation and amount of fibres. Typical values, based on experience and economy, are as follows:

- Strength, span direction: 550N/mm^2 (or MPa)
- Strength, transverse: 150N/mm^2 (or Mpa)
- Stiffness, span direction: 39000N/mm^2 (or 39GPa)
- Stiffness, transverse: 11000N/mm^2 (or 11GPa)

InfraCore® Inside technology is a modified and improved sandwich, significantly improved to eliminate the debonding between the core and the skins that is normally critical and fatal in sandwich construction. For preliminary design purposes it is usually sufficient to consider InfraCore® Inside as a sandwich typology, and ignore the contribution of the interior foam and webs.

InfraCore® Inside has so far been used to support vehicles of up to 60 tonnes. It can withstand concentrated loadings of 2000000kg/m^2(!).

The density of infused rigid solid FRP (thus: not InfraCore® Inside) varies with the proportion of resin and fibres, but is normally between 1600 and 1800kg/m^3. The bare core material, which has no structural role and only serves as a lost mould during construction, weighs 35kg/m^3.

Codes and standards

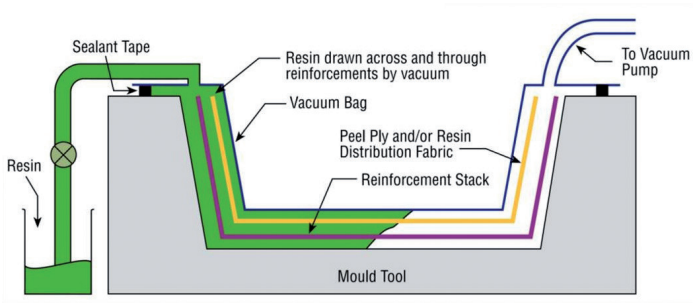
While the design of FRP structures is not covered by the Eurocodes, the material-independent parts of these codes can be used. The use of FRP is well-established in naval and aerospace construction and abundant design experience is available. Design guidance that considers the specifics of FRP in civil engineering applications is available, the most advanced being the Dutch design guideline CUR-96.

Following the limit state design methodology of Eurocodes, it proposes reduction factors on theoretical material properties, depending on the application, the method of construction and the environment where it is applied.

For the design of its InfraCore® Inside structures, FiberCore Europe follows the loadings as set out in Eurocodes, and the checking as per the CUR-96 guideline.

Fabrication

InfraCore® Inside is constructed with the vacuum infusion technique. This method allows fabricating integral structures in a structurally efficient way, in bespoke geometries. The process involves transporting resin through a stack of glass fibers and foam blocks. The process takes place inside an airtight bag, with no emissions.

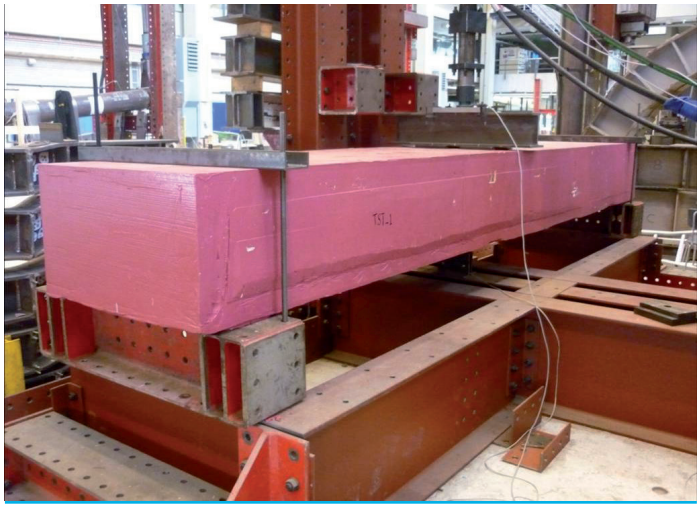


Schematic view of the vacuum infusion technique.

Since InfraCore® Inside is a technology with always the same principles at its core, it combines the fabricational efficiency of a system-based approach, with the flexibility of a customised fabrication method. The dimensions of the biggest element that can be produced are dictated by logistics, not by the technology itself. Currently the maximum length is 26m, the maximum width 8m.

Resistance to fatigue

When FRP is used in bridge-construction, the design is most often governed by stiffness requirements. In such stiff structures, the levels of strain are so low that the material is well outside the domain where it would be sensitive to fatigue. FRP is also used in windmill blades. These endure much higher levels of stress and strain. From this application a large body of knowledge is available on fatigue behaviour. The resistance of InfraCore® Inside against fatigue has been comprehensively tested at Delft University of Technology. In the tests, a sample was subjected to a loading equivalent to a design life of 150 years.

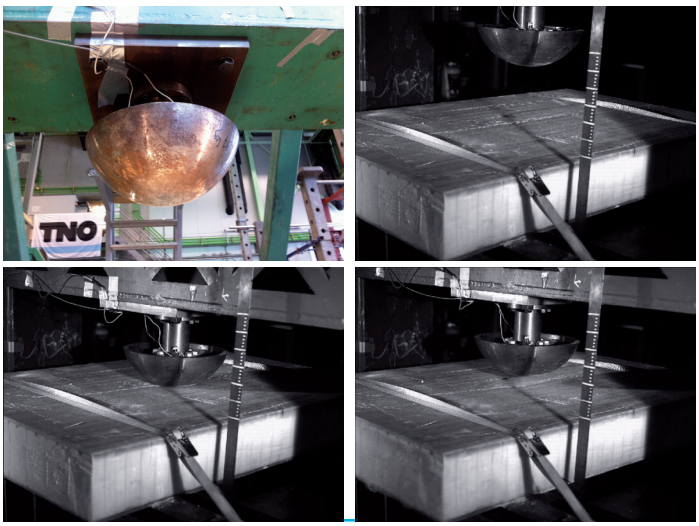


Fatigue-testing at Delft University of Technology.

Resistance to impact

In infrastructural applications not only the loading distribution as prescribed by design codes, but also the resistance to impacts is essential. Impacts could come from stones being stuck in the profiling of tyres, from lading falling off trucks, or from horses' hooves. Furthermore, no unsafe structures or progressive collapse is allowed following accidental situations.

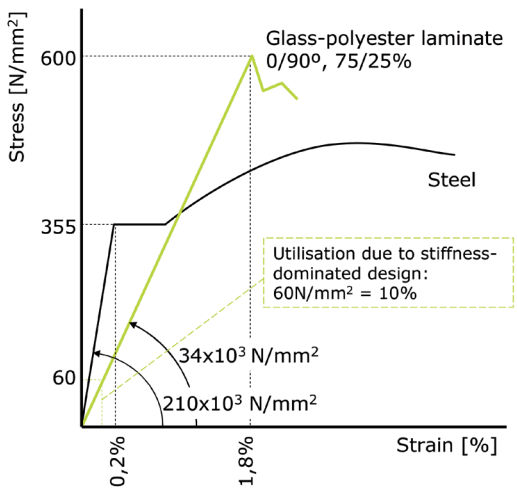
To demonstrate the resilience of InfraCore® Inside against impacts, panels were subjected to a mass in freefall at the laboratories of TNO. The test showed FRP's significant strain-capacity, as the applied mass bounced back



Images made with a high-speed camera show no panel failure, and elastic response instead.

Safety

In isolation glass fibres show a linear elastic behaviour until failure. However when constructed together as a multi-directional laminate through the infusion method, the failure behaviour is gradual as the fibres fail one by one, rather than all at the same time. Also, fibres in cross-direction will be virtually unaffected by failure in the span direction. For this reason, the bespoke fibre-layout of infusion is the key to safe FRP structures.



Stress-strain diagrams of FRP and steel.

In the deck of this 142m viaduct the thermal expansion properties of the InfraCore® Inside deck were modified. This allowed the deck to be integrally connected with the steel trusses.

Thermal behaviour

InfraCore® Inside is normally based on glass fibres and a polyester resin. These materials undergo shortening and expansion like most other materials, but the magnitude varies with the orientation and proportion of the fibres. Typical values for the coefficient of thermal expansion are:

- span direction: $7x10^{-6}$/K
- transverse direction: $50x10^{-6}$/K

Since the coefficient of thermal expansion can be tweaked, it can be matched with that of steel ($12x10^{-6}$/K), which enables integrally connected hybrid structures with minimal build-up of thermal stresses. It is worthwhile noting that in case carbon fibres are used, the thermal expansion is near zero.

Fire

In case FRP or InfraCore® Inside are set to fire, the resin will char but flames are self-extinguished as soon as the external heat source is taken away. The structural fibres are resistant to very high temperatures and will withstand the fire without any adverse effect. The material's response to fire can be optimised with additives that release water from within the material. Local damage as a result of fire can be repaired by re-infusion.

Climate

The structural fibers inside FRP are based on silicon (effectively sand) and are fully resistant to both hot and low temperatures.
InfraCore® Inside has been exposed to liquid nitrogen (-196°C), and has come out of the test fully functional.
On a more practical level: the wear surface that is installed on InfraCore® Inside bridge decks can withstand spiked wheels. However since the wear surface is thin, long-term exposure should be avoided and instead a layer of tarmac (asphalt) should be be applied.
In hot climates, exposure to temperatures over 90°C should be avoided. However anywhere in Europe, even on a hot day and with a dark coloured surface, such temperatures will not be reached.

Sustainability

Due to FRP structures' low self-weight, their low maintenance, long design life and the ability to recycle them and regain the embodied energy after use, FRP structures have very positive sustainability credentials. Comparisons with other materials should be performed on a case-by-case basis, and include all the project characteristics, including the foundations, maintenance and after-use.
Sustainability is a very broad subject and depending on the location and the client's ambition, also the following positive contributions could be considered:

- reduced noise emission during construction and in-use;
- fast construction, shorter disruption, less detours being made by ongoing traffic;
- less and lighter movements by transportation and crane-operations.

InfraCore inside *in use*

Since its market introduction in 2007 in the Netherlands, InfraCore® Inside has established itself as an accepted major new construction material for infrastructure. More than 250 projects have been realised in the Netherlands and the world. Please visit our website to see where our projects are located. Our products have an expected design life of more than 100 years, and come with a 50 year warranty.

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