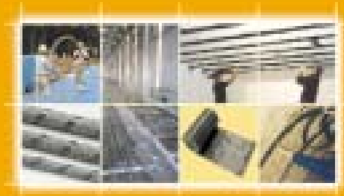
# Civil engineering

sireg



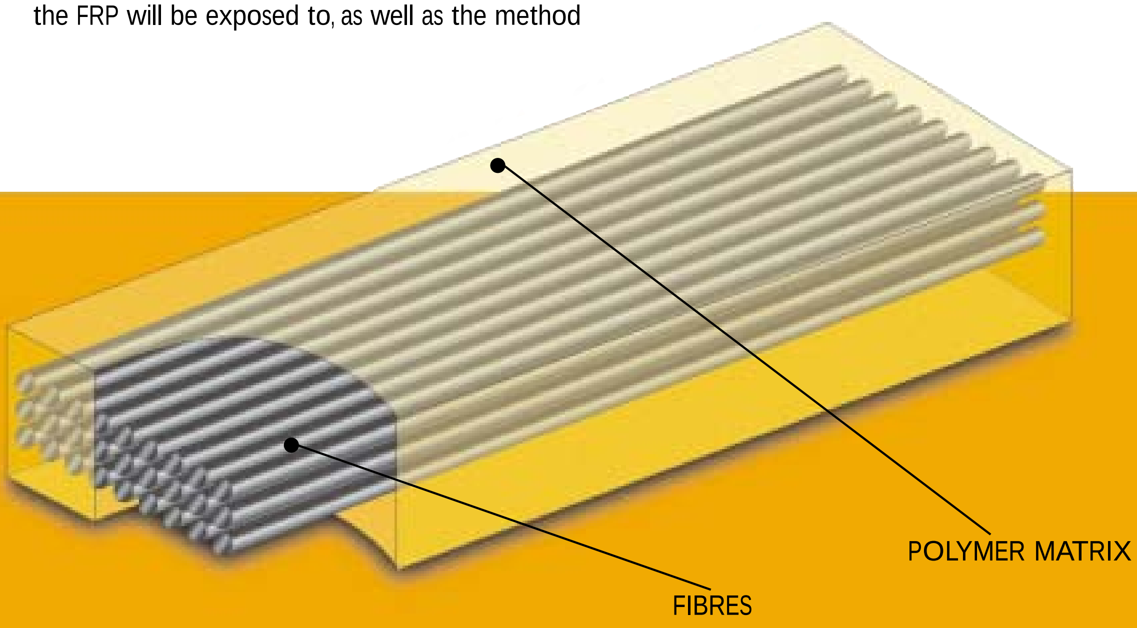
# *Did really Ramses II invent FRPs?*

The idea of combining two different materials to obtain a single, superior composite material is not new. Some of the earliest building materials were composite materials. The ancient Egyptians reinforced their mud bricks with straw to make them stronger. Fiber Reinforced Polymers (FRPs) are just the latest version of this very old idea (Iyer and Sen, 1991).

Fiber reinforced polymer (FRP) materials are composite materials consisting of high strength fibres immersed in a polymer matrix. The fibres in an FRP composite are the main load-carrying element and exhibit very high strength and stiffness when pulled in tension. An FRP laminate will typically consists of several million of these thin, thread-like fibres. The polymer matrix protects the fibres from damage, ensures that the fibres remain aligned, and allows loads to be distributed among many of the individual fibres in the composite. There are a variety of fibre types and resins that may be used to create an FRP composite. Fibres are selected based on the strength, stiffness, and durability required for the specific application, and the resins are selected based on the environment the FRP will be exposed to, as well as the method by which the FRP is being manufactured. Among several possibilities, the fibre types that are typically used in the construction industry are carbon, glass, and aramid.

Aerospace engineers have always searched for ways to reduce the weight of aircraft structures. They developed FRPs as lightweight materials with features of strength and stiffness similar to materials that they were accustomed to. The automotive, naval, defense, and sporting goods industries (to name a few) have adopted, since different years, the use of advanced composite materials on a widespread basis. FRP is now being used in civil industry sector to strengthen concrete, steel and masonry structures. They compete directly with traditional strengthening techniques like section enlargement, external post-tensioning and steel plate bonding. Steel plate bonding is a method of strengthening a structure by bonding steel plates to the concrete surface in the areas of high tensile stresses.

FRP original application began about 20 years ago in Japan and Europe as a low cost, low maintenance alternative to steel plate bonding.



# Carbon, Aramid and Glass FRP systems for civil engineering

FRP systems in the concrete repair industry are used to strengthen existing structures. Structures may need strengthening due to deterioration, design/construction errors, a change in use or loading, or for a seismic upgrade. FRP essentially works as reinforcement in concrete and provides strength where concrete is weakest in tension. FRP may be used on beam or slab soffits to provide additional flexural strength, on the sides of beams to provide additional shear strength, or wrapped around columns to provide confinement and additional ductility (a primary concern in seismic upgrades). Among many other applications, concrete and masonry walls may be strengthened to increase resistance to seismic and wind loads, concrete pipes may be lined with FRP to support higher internal pressures, and silos and tanks may be strengthened to support higher pressures.

Applications where existing FRP systems may not be useful include correcting punching shear problems in slabs or footings, correcting vibration problems, and providing greater compression strength to walls. In cases where FRP is useful, it should be recognized that there are reasonable limits to the additional strength afforded with FRP. Typically, increases in strength up to 50% are reasonable.

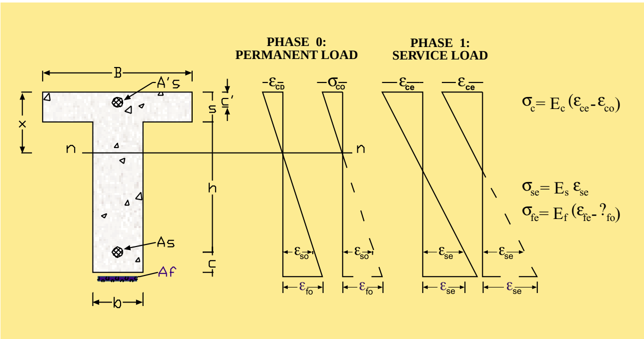
In selecting the type of fibre to be used for an application, there are few things to be considered: Glass (GFRP) and aramid (AFRP) are excellent for seismic upgrades where the seismic loads only temporarily engage the FRP. In cases where stresses are sustained in the FRP (such as in bending and shear strengthening), GFRP should be avoided (or service stresses maintained at a minimum level) because of creep rupture effects. Carbon is much more suitable in these applications. Similarly in exterior applications, Carbon (CFRP) will be much more durable.

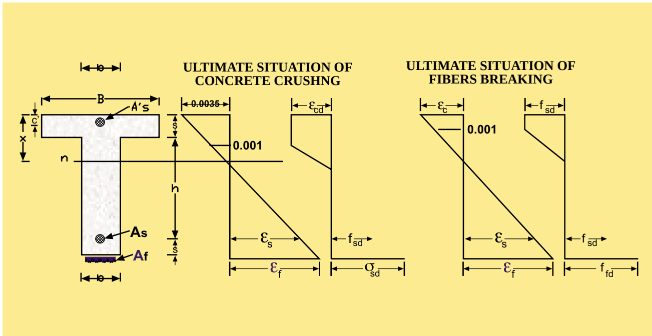
The steel plate bonding technique has been developed in 1960 in France by Hermite and Bresson. It consisted to gluing steel plates to the tensile face of RC and PC beams by epoxy resins adhesive. In the ‘80 a lot of experimental results and researches were published. In the meantime the applications started and have been rapidly growing up in any part of the world and now the technology has been introduced in standard code and recommendation for design.
The technology, even if efficient at structural level, has some problems in field application and in the durability side:

- the weight of the steel plate requires a lot of work for the installation, including sustaining device during the polymerization of the resin;
- the corrosion of steel during time requires paint and cost for maintenance.

The availability of FRP products with low weight, flexibility, high tensile stress, and high durability has solved the previous problems and transformed the entire plate bonding technique.
The main effects of the FRP plate bonding are:

- reduction of deflections (increment of stiffness);
- limitation of cracking phenomena (increment of durability);
- increment of the load capacity;
- increment of failure load (increment of safety).



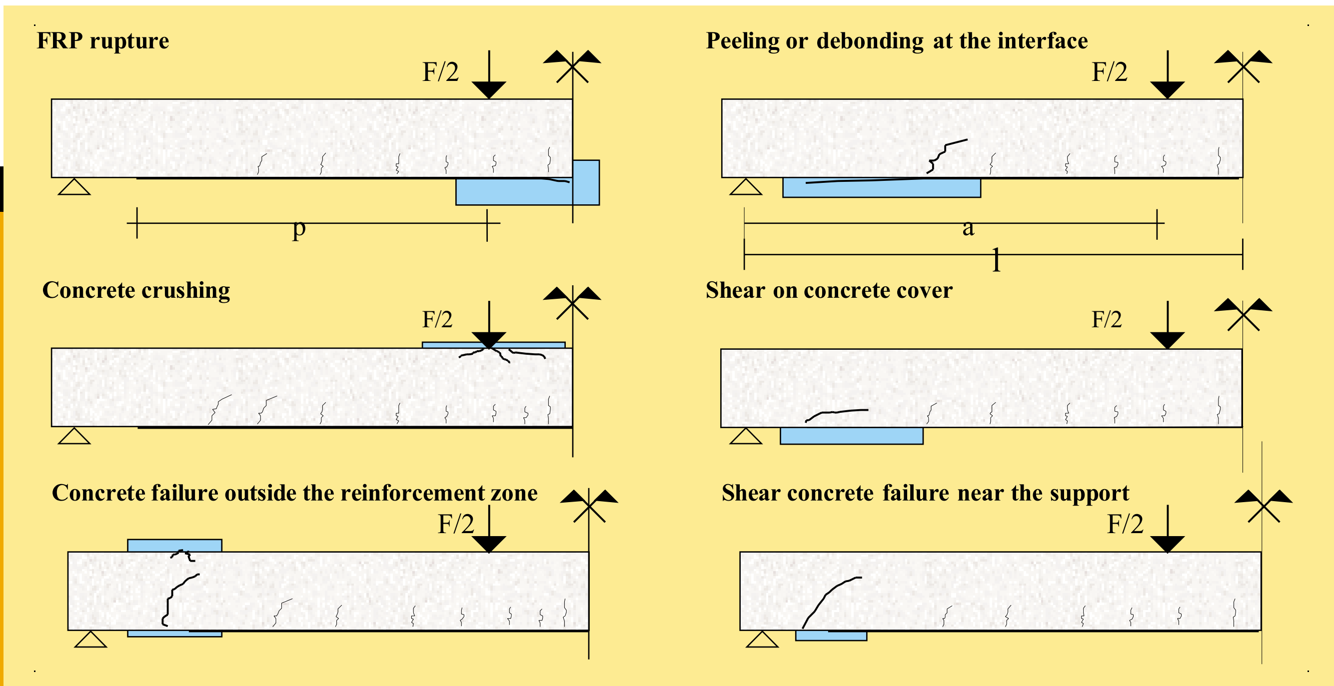




In order to obtain one or more of the previous effects, the designer could select a lot of parameters: length, thickness and orientation of the reinforcement, adhesive type, surface preparation etc.

The combination of these parameters is very important key-factor in the design. For example a specific reduction of mid-span deflection at service load could be obtained with many types of FRP just changing the thickness and/or the length of the reinforcement. But the ultimate load could be very different due to the fact that the failure mechanism changes from one more "ductile" to other more "brittle".

It's a fact that the failure mechanisms that could be generated in RC or PC concrete beams are at least 6 and all the designers must pay attention to properly consider them in their calculations !

Carbopree Software (ask for it) considers the whole engineering concept of the structural strengthening as well as the key performances of the materials used (concrete, steel re-bars, polymers, FRP rods, FRP sheets and FRP plates, interfaces properties and long term behavior ).



# *Externally bonded Carbopree plates for flexural strengthening*

Carbopree Plate is a family of unidirectional carbon fibers laminates. The application procedure is based on Carbopree Plate Adhesive, epoxy putty particularly designed to glue Carbopree Plates on concrete beams or slabs.


**Tensile performances of Carbopree High Strength Plates**

| | Carbopree Plate HS 50/1,2 | Carbopree Plate HS 100/1,2 | Carbopree Plate HS 50/1,4 | Carbopree Plate HS 100/1,4 |
|---|---|---|---|---|
| tensile strength, ASTM D3039 | 3000 MPa | 3000 MPa | 3000 MPa | 3000 MPa |
| tensile modulus of elasticity, ASTM D3039 | 165 GPa | 165 GPa | 165 GPa | 165 GPa |
| Ultimate deformation, ASTM D3039 | 1.8 % | 1.8 % | 1.8 % | 1.8 % |
| ultimate load, ASTM D3039 | 180000 N | 360000 N | 210000 N | 420000 N |
| Thickness | 1.2 mm | 1.2 mm | 1.4 mm | 1.4 mm |
| Width | 50 | 100 | 50 | 100 |



**Tensile performances of Carbopree High Modulus Plates**

| | Carbopree Plate HM 50/1,2 | Carbopree Plate HM 100/1,2 | Carbopree Plate HM 50/1,4 | Carbopree Plate HM 100/1,4 |
|---|---|---|---|---|
| tensile strength, ASTM D3039 | 2750 MPa | 2750 MPa | 2750 MPa | 2750 MPa |
| tensile modulus of elasticity, ASTM D3039 | 200 GPa | 200 GPa | 200 GPa | 200 GPa |
| Ultimate deformation, ASTM D3039 | 1.4 % | 1.4 % | 1.4 % | 1.4 % |
| ultimate load, ASTM D3039 | 165000 N | 330000 N | 192500 N | 385000 N |
| Thickness | 1.2 mm | 1.2 mm | 1.4 mm | 1.4 mm |
| Width | 50 | 100 | 50 | 100 |

# External wet lay up bonded Carbopree sheets for shear and flexural strengthening

Carbopree Sheet is a family of unidirectional high strength and high modulus carbon fibres sheets.

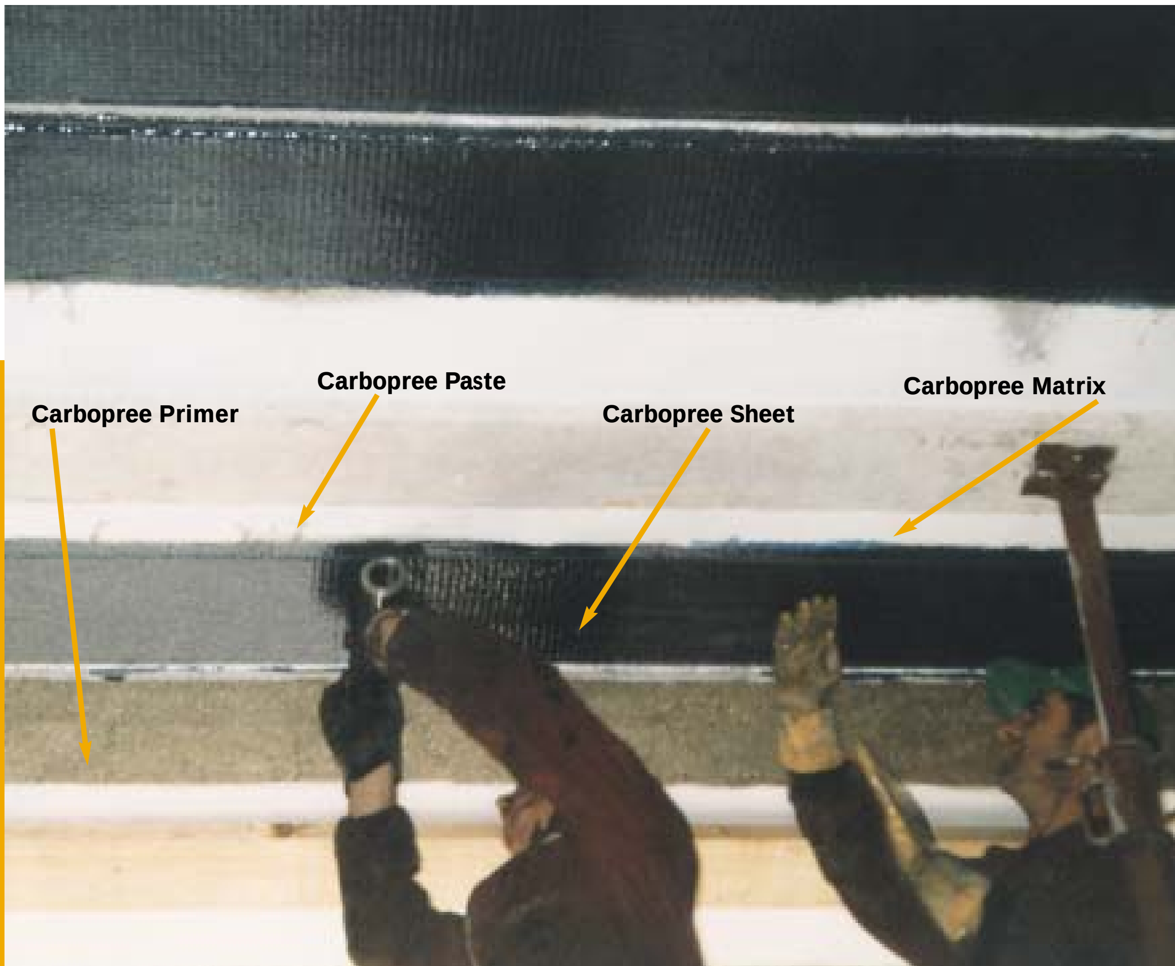
**Tensile performances of externally bonded wet lay-up applied Carbopree sheets for shear and flexural strengthening**

| | **Carbopree Sheet HS 300** | **Carbopree Sheet HM 300** |
|---|---|---|
| Type of fibre | High strength carbon | High modulus carbon |
| Tow sheet shape | Unidirectional | Unidirectional |
| Area density | 300 $g•m^{-2}$ | 300 $g•m^{-2}$ |
| Effective thickness, mm | 0.165 mm | 0.165 |
| tensile modulus of elasticity, ASTM D3039 | 230000 MPa | 390000 MPa |
| Ultimate deformation, ASTM D3039 | 1.5 % | 0.8 % |
| tensile strength, ASTM D3039 | 3000 MPa | 3000 MPa |
| tensile strength per mm width, ASTM D3039 | 495 $N•mm^{-1}$ | 495 $N•mm^{-1}$ |

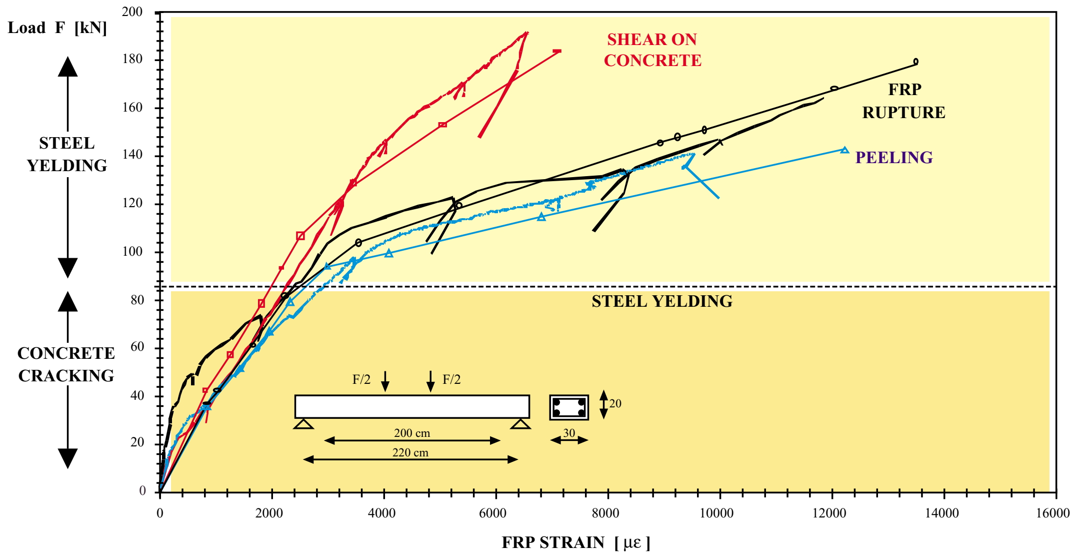


The standard wet lay up technique procedure foresees:

- **Carbopree Primer**: it penetrates deeply the concrete pores in order to provide full bond to the concrete elements;
- **Carbopree Paste**: it evens remaining surface irregularities before the application of Carbopree sheets. Leveled surface optimize the performance of the entire FRP system due to the perfect flat orientation of the fibres.
- **Carbopree Matrix:** it impregnates Carbopree Sheets, maintain the alignment of the fibres and hold them in place while the system cures. Its viscosity allows easy handling and overhead applications for many layers of CFRP sheets.
- **Carbopree Sheet**: CFRP reinforcement of the whole system



Load-CFRP strain: experimental result by using Carbopree Sheets HS 300 compared to numerical (FEM) models

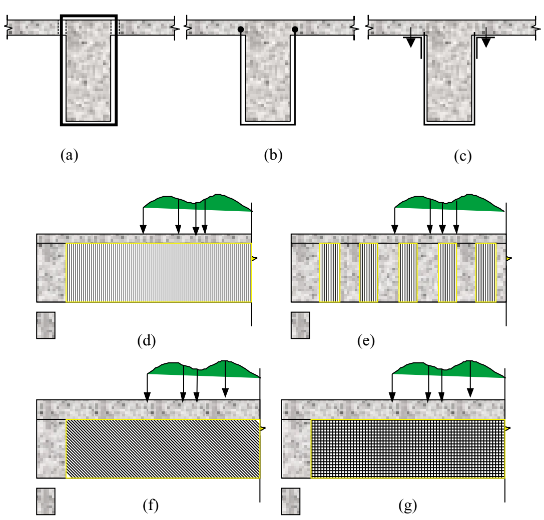



The most effective method of shear strengthening with FRP sheets is to wrap the entire cross section of the beam with FRP. Typically, this is not feasible from a job site standpoint. The presence of monolithic slabs or other supported elements often precludes wrapping the sheet around the top of the section. One option might be to drill holes through the slab and wrap strips or bands of FRP around the section. However, this method is often too complicated and expensive.

The most common method of shear strengthening is to wrap the sides and bottom of the section. This method, referred to as a "U" wrap, is typically feasible and is fairly effective in increasing the section's shear strength. The use of the "U" wrap is, however, only highly effective in positive moment regions. In negative moment regions, shear cracking starts from the top of the section near the slab. Due to its location below the slab, the FRP may not be able to control the start of these cracks. Once these cracks open, there is the potential for the crack to drive through section without any reinforcing effect from the FRP.

The transverse FRP reinforcement may be in the form of evenly spaced strips or it may be a continuous jacket. The use of strips may be effective in optimizing the amount of material used. Furthermore, if the entire length of the beam has to be wrapped, the use of strips may allow better moisture migration through the concrete.

Various schemes for wrapping transverse FRP reinforcement.




a) FRP wrapped entirely around the beam;
b) FRP "U" wrap mechanically anchored with Carbopree Rods;
c) FRP "U" wrap mechanically anchored with bolted steel L profile;
d) FRP "U" continuous wrap;
e) FRP "U" wrap placed in strips;
f) FRP 45° wrap;
g) FRP 0°/90° wrap.

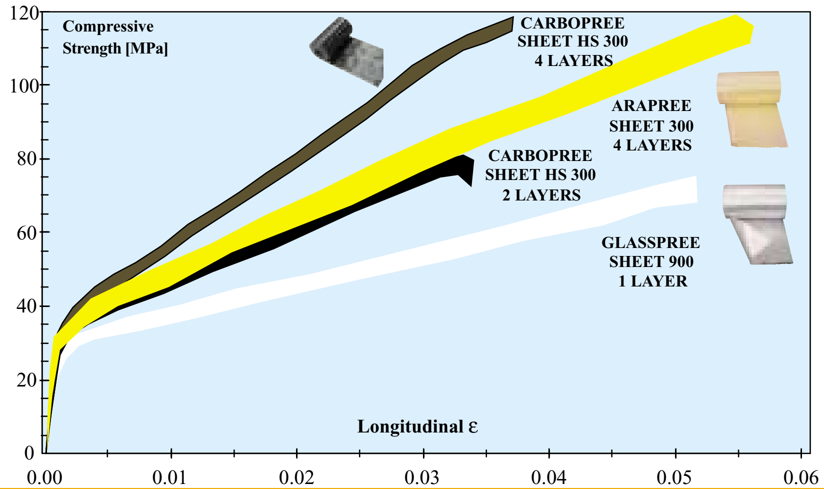
# *Carbopree Arapree and Glasspree for confinement*

The use of steel stirrups to enhance the ductility of RC columns is a well-known technique. Unfortunately this type of confinement is only localized in the narrow zone where the stirrups are located. The use of Fiber Reinforced Polymer FRP jacket reinforcement to enhance the axial compressive performance of concrete members has major effect due to the fact it generates a continuous confinement along column, without dramatic change in weight. By wrapping a concrete column with an FRP jacket, the shear, moment, and axial capacity are improved. In addition, the ductility of the member may be significantly improved. The FRP jacket is formed by wrapping the column with the FRP fibres oriented in the transverse (hoop) direction. Sometimes in the FRP jacket, fibres in axial direction are present for flexural strengthening. The jacket provides significant confinement to the concrete, which leads to the mechanical performance improvements.

Carbopree, Arapree and Glasspree sheet systems are very effective in enhancing the axial performance of concrete columns. When columns are subjected to axial and flexural loads the use of 0/90 degrees Carbopree sheet is recommended.

The significant problem with glass FRP, creep rupture, is not a concern with column wrapping because under sustained loads, the FRP jacket remains virtually stress free. The strength improvements afforded with glass FRP are lower than those achieved with carbon. However, the ductility of a column wrapped with GFRP or AFRP sheets is superior to that of a carbon jacketed column.

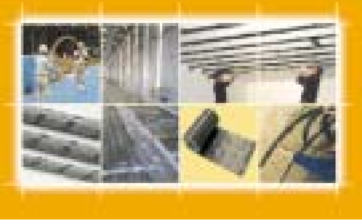
**Range of constitutive law in compression for concrete cylinders wrapped by Carbopree, Arapree and Glasspree Sheets**






**Tensile performances of externally bonded wet lay-up applied Carbopree, Glasspree and Arapree sheets for confinement**

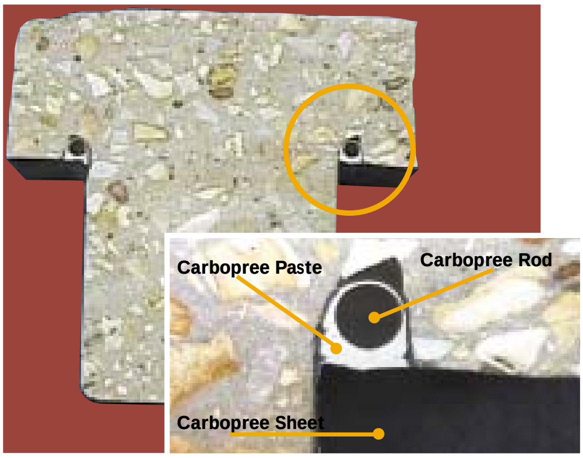
| | Carbopree Sheet HS 300 | Glasspree Sheet 900 | Arapree Sheet 300 |
|---|---|---|---|
| Type of fibre | High strength carbon | Alkali resistant glass | High modulus Aramide |
| Tow sheet shape | Unidirectional | Unidirectional | Unidirectional |
| Area density | 300 g•m$^{-2}$ | 600 g•m$^{-2}$ | 300 g•m$^{-2}$ |
| Effective thickness, mm | 0.165 mm | 0.23 mm | 0.214 |
| tensile modulus of elasticity, ASTM D3039 | 230000 MPa | 80000 MPa | 105000 MPa |
| Ultimate deformation, ASTM D3039 | 1.5 % | 2.8 % | 2 % |
| tensile strength, ASTM D3039 | 3000 MPa | 1700 MPa | 2000 MPa |
| tensile strength per mm width, ASTM D3039 | 495 N•mm$^{-1}$ | 390 N•mm$^{-1}$ | 438 N•mm$^{-1}$ |



# Internally bonded Carbopree, Arapree and Glasspree rods for structural strengthening

Typically FRP rods are produced by pultrusion, which is a well known manufacturing method used to produce FRP products with constant cross section. Generally speaking FRP rods offer excellent corrosion resistance (in particular for carbon fibres rods), as well as the advantages of high stiffness to weight ratio when compared to conventional construction materials. Other advantages of FRP include good fatigue properties, damage tolerance, easy of transportation and handling, low energy consumption during fabrication of raw materials and the potential for real-time monitoring.

Carbopree Rods, unidirectional carbon fibres based, are used mainly for flexural strengthening of concrete members especially where aggressive environment produce high steel corrosion, lightweight is an important design factor, or transportation cost increase significantly with the weight of the materials.




performances of Carbopree Rod HS (High strength)

| | Carbopree Rod HS 5 | Carbopree Rod HS 7,5 | Carbopree Rod HS 10 | Carbopree Rod HS 12 | Carbopree Rod HS 16 |
|---|---|---|---|---|---|
| tensile strength | 2300 MPa | 2300 MPa | 2300 MPa | 2300 MPa | 2300 MPa |
| tensile modulus of elasticity | 130 GPa | 130 GPa | 130 GPa | 130 GPa | 130 GPa |
| ultimate deformation | 1.8 % | 1.8 % | 1,8 % | 1,8 % | 1,8 % |
| Nominal diameter | 5 mm | 7,5 mm | 10 mm | 12 mm | 16 mm |
| Nominal area | 19 $mm^2$ | 44 $mm^2$ | 78 $mm^2$ | 113 $mm^2$ | 200 $mm^2$ |
| Ultimate load | 44 KN | 101 KN | 180 KN | 260 KN | 460 KN |
| Linear weight | 40 $g \cdot m^{-1}$ | 75 $g \cdot m^{-1}$ | 130 $g \cdot m^{-1}$ | 195 $g \cdot m^{-1}$ | 340 $g \cdot m^{-1}$ |

performances of Carbopree Rod HM (High Modulus)

| | Carbopree Rod HM 5 | Carbopree Rod HM 7 | Carbopree Rod HM 10 |
|---|---|---|---|
| tensile strength | 3000 MPa | 3000 MPa | 3000 MPa |
| tensile modulus of elasticity | 200 GPa | 200 GPa | 200 GPa |
| ultimate deformation | 1.5 % | 1.5 % | 1.5 % |
| Nominal diameter | 5 mm | 7 mm | 10 mm |
| Nominal area | 19 $mm^2$ | 38 $mm^2$ | 78 $mm^2$ |
| Ultimate load | 57 KN | 114 KN | 234 KN |
| Linear weight | 40 $g \cdot m^{-1}$ | 65 $g \cdot m^{-1}$ | 130 $g \cdot m^{-1}$ |

The use of Near Surface Mounted (NSM) FRP rods is a promising technology for increasing flexural and shear strength of deficient RC and PC members.

Advantages of using NSM FRP rods with respect to externally bonded FRP laminates are the possibility of anchoring the rods into adjacent members and minimal installation time. Furthermore, this

technique becomes particularly attractive for flexural strengthening in the negative moment regions of slabs and decks, where external reinforcement would be subjected to mechanical and environmental damage and would require protective cover which could interfere with the presence of floor finishes. A groove is cut in the desired direction on the concrete surface and is then filled halfway with Carbopree Paste; after an FRP rod is placed into the groove and lightly pressed. This operation forces the paste to completely surround the rod and to fill the groove, which is than filled and levelled with more paste.
Carbopree Rod can also be used for anchoring externally bonded Carbopree sheets in the case of shear strengthening of reinforced concrete members.

Arapree Rods, unidirectional non-magnetic and non-conductive aramid fibres based, are particularly designed for prestressing of concrete members, structural repointing of masonry structures, repair of historical buildings such us churches and ancient monuments, structural rehabilitation of cracked masonry columns.

## performances of Arapree Rods

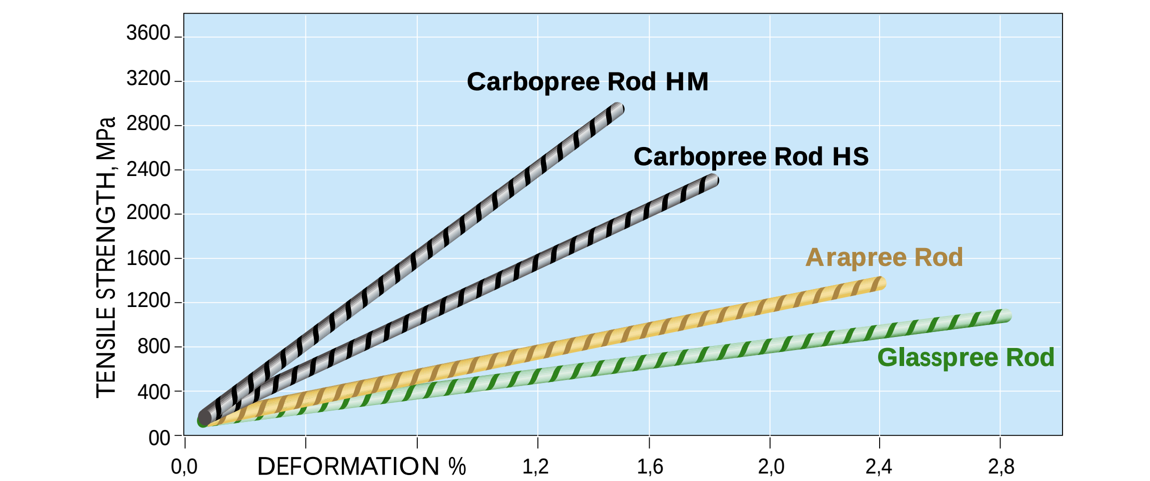
| | Arapree Rod 5,5 | Arapree Rod 7,5 | Arapree Rod 10 |
|---|---|---|---|
| tensile strength, MPa | 1200 | 1200 | 1200 |
| tensile modulus of elasticity, GPa | 50 | 50 | 50 |
| Ultimate deformation, % | 2.3 | 2.3 | 2.3 |
| Nominal diameter, mm | 5,5 | 7,5 | 10 |
| Nominal area, $mm^2$ | 23 | 44 | 78 |
| Ultimate load, KN | 27 | 52 | 93 |
| Linear weight, $g•m^{-1}$ | 40 | 75 | 130 |

Glasspree Rods, unidirectional non-magnetic and non-conductive glass fibres based, are particularly designed for strengthening of ordinary masonry structures or, in special cased, concrete structures.

## performances of Glasspree Rods

| | Glasspree Rod 12 | Glasspree Rod 16 | Glasspree Rod 20 | Glasspree Rod 25 | Glasspree Rod 28 |
|---|---|---|---|---|---|
| tensile strength, MPa | 1000 | 1000 | 1000 | 1000 | 1000 |
| tensile modulus of elasticity, GPa | 40 | 40 | 40 | 40 | 40 |
| Ultimate deformation, % | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| Nominal diameter, mm | 12 | 16 | 20 | 25 | 28 |
| Nominal area, $mm^2$ | 113 | 200 | 314 | 490 | 615 |
| Ultimate load, KN | 113 | 200 | 314 | 490 | 615 |
| Linear weight, $g•m^{-1}$ | 200 | 330 | 535 | 815 | 1022 |





# *Special applications:*

**Reinforcement for structures built erected nearby to the seaside:**
One of most important problem of the structures erected nearby the seaside is the corrosion of the steel reinforcement. Some examples of possible applications are:
retaining walls, piers, quays , jetties, piles , decks, caissons, bulkheads, floating structures, canals, roads and buildings offshore platforms, swimming pools and aquariums.

**Reinforced concrete treated with deicing salts:**
The use of our FRP bars can eliminate the corrosion problems where massive quantities of deicing salts are used every year or roads and pavements. Some examples of applications are: , bridge decks, jersey barriers, parking structures parapets, curbs, roads and slabs on grade, retaining walls and foundations.

**Electromagnetic neutrality and non-conductive applications:**
The application of our Arapree and Glasspree bars is requested where it is necessary a non-conductive electricity or electromagnetic neutrality .
Some possible applications are: manholes for electrical and telephone communication equipment, structures supporting electronic equipment such as transmission towers for telecommunications, airport control towers, magnetic resonance imaging in hospitals, railroad crossing sites and military structures with requirement for radar invisibility.

**Prestressed applications:**
Our Carbopree and Arapree rods can be used in prestressed concrete thanks to their features such as slightness and resistance to the corrosion. They can be tensioned through normal lines for steel strands using special adaptors.

**Post-tensioning applications:**

The Carbopree rods can be used to replace steel cables in unbounded post-tensioning applications when it is needed a higher resistance to environmental aggression.

**Temporary reinforced concrete structures in geotechnic:**

The applications of our FRP products in the geo-technical field are needed when it is requested to cut trough the concrete without damaging the cutting equipment after a temporary reinforced concrete structure has been built.
For example in the diaphragh walls in under-ground structures.

**Ground anchors and soil nails :**

The carbon bars can be used as permanent ground anchors or permanent soil nails without using any corrosive protections.
The most important European project where our Carbopree has been used was the Sunderland Metro.
The advantages of using our Carbopree bars are lightness, easily handling for the laying and they can also be used in some places difficult to get to (i.e. by climbing).