TFC – FRP STRENGTHENING SOLUTION FROM FREYSSINET

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ABSTRACT

TFC is a patented process of structural strengthening by bonding additional carbon fibres-based fabric onto the structures. TFC can be applied on reinforced and prestressed concrete, steel, wood or masonry. It can act to resist bending moment and shear force. It can provide a pier confinement and strengthen structures against earthquake. The process consists of material plating by the bi-directional carbon fibres fabric composite and is bonded advantageously onto the tensile stressed area of the part to be strengthened. In case of loss of strength to structures caused by corrosion, TFC can compensate the deficiency. In case of requirement for strengthening, addition of TFC can upgrade capacity of existing structure to new operating conditions. Design for the two above cases complies with various design standards. The performances of TFC have also been demonstrated in a large number of laboratory tests and were approved by authorities in several countries, even in the nuclear field. TFC has advantages over its own light-weight, it is insensitive to corrosion, Uvs, freeze-thaw, irradiation and immersion. The installation for TFC is easy: there is no need for plating pressure and the woven composite is flexible and can be reeled to roll of a small diameter which enables handling even in situations of difficult accesses and the perfect moulding with the discontinuous shape of substrate.

KEYWORDS
FRP product, strengthening, repair, confinement, seismic reassessment.

DESCRIPTION OF TFC

TFC is a patented system for structural strengthening by the gluing of additional strengthening elements, carbon fibres-based, developed in partnership with the Central Bridge and Road Laboratory (LCPC in French), ATOFINDLEY, SOFICAR and FREYSSINET, marketed and installed by FREYSSINET.

TFC Composite Fabric

Torayca carbon fibres are obtained by pyrolysis of an organic fibre (PAN) called a precursor. The latter is cross-linked and is oriented in controlled atmosphere. The carbon fibres come in the form of black tufts, containing 12000 monofilaments, 7 to 8 microns in diameter. They provide two application possibilities: firstly as carbon for the properties of that element, secondly as flexible fibre, suitable for all forms of finished products. For the TFC system, an industrial fibre was chosen among the broad range of Torayca carbon fibres for its perfect match with applications in Building and Public Works. This fibre has been tested in specialised laboratories, including the “Laboratoire Central des Ponts et Chaussées” (Central Bridge and Road Laboratory).
TFC composite fabric (please refer to figure 1) consists of carbon fibres oriented at 90° in the warp and in the weft in order to obtain a flexible and deformable weave that can accommodate the shapes of the substrate. The fabric is bi-directional with a strength direction concentrated in the warp (70% of the fibres along that direction and 30% of the fibres in the weft direction). The fabric comes in standard widths of 300 mm, 200 mm, 150 mm, 75 mm, 40mm and in roll. The fibres are coated with fibre oil which promotes the chemical link with the matrix.

Resin of the Composite's Matrix

TFC composite fabric shall be impregnated by resin in order to guarantee good bonding with the substrate to be strengthened. The rheological characteristics of the resin enable the application on vertical surfaces or on ceilings. It can be applied to substrates such as masonry, steel, dry or damp concrete at temperatures from 5 to 50 °C. The dual component glue of TFC is referenced “Eponal Resin” and “Eponal Hardener”. The standard thickness of Eponal adhesive shall be applied for each fabric layer, for instance for a fabric weighting 500 g/m², 1.2 to 1.5 kg/m² of adhesive shall be used for each fabric layer. After application, the hardening speed, related to the ambient temperature, governs the time before bringing it into service.

TFC Composite

TFC composite corresponds to the fabric impregnated with the synthetic resin. The mechanical characteristics are indicated in table 1: they correspond to the minimal guaranteed characteristics.

<table>
<thead>
<tr>
<th>Table 1. Characteristics of TFC composite</th>
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<tr>
<td><strong>Average Thickness</strong></td>
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<td><strong>Breaking Tensile Strength</strong></td>
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<tr>
<td><strong>Modulus of Elasticity</strong></td>
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<tr>
<td><strong>Breaking Tensile Stress</strong></td>
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<tr>
<td><strong>Warp 1 cm wide</strong></td>
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<tr>
<td><strong>Breaking tensile Stress</strong></td>
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<tr>
<td><strong>Weft 1 cm wide</strong></td>
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PLACING TFC

The placing of TFC shall be done by experienced workers. FREYSSINET carries out the control of both fabrication and application which guarantees the quality.

Substrate Preparation

The substrates whatever the material they are made of, shall be free of all materials that might have adverse effects on the bond stress of the TFC. A direct tensile test shall be carried out in situ by pull-off test in order to determine the substrate bonding characteristics before installation and confirm that it complies with the value taken into account in the design.
Although TFC has considerable capacities to accommodate the most diverse and even the most developable shapes (please refer to figure 2), it is not able to follow all local surface defects such as blisters, small spalls, protruding clumps of pebbles, convexities or other. It is therefore required, in some cases, to dress or re-shape the surface before applying TFC strips. With regards to concrete substrate, the gluing surface of concrete shall be prepared so as to create enough roughness and to ensure cohesion. The most common preparation is by sand blasting. (please refer to figure 3)

**Application of the First Layer of Resin**

The dual-component epoxy glue comes in pre-proportioned kits. Both bags shall be mixed together by means of mechanical tools such as a helical beater mounted on a drill. The two components have different colours. The mix is ready when the colour of the mixed product is uniform.

The first layer of epoxy glue (called the gluing layer) shall be applied with tools (like short bristle roller) that make it possible to “massage” the backing in order to allow the penetration of the resin within the substrate rugged cavities and then ensure a correct surface impregnation. (please refer to figure 4).

**Application of Carbon Fibre Strips**

The strips shall then be applied onto the wet resin. The strip shall be placed from one extremity to the other by smoothing down with the back of the hand on the gluing resin as the work moves forward (please refer to figure 5). Then, the strip shall be pressed flat (hand pressure sufficient) in order to impregnate the fibres with the glue and to eliminate any air bubbles, after pressing flat, the fabric shall be slightly sticky to hand touch.
Application of the Closing Layer of Resin

Once the strips have been placed and pressed flat, a last resin layer (named the closing layer) shall be applied in order to complete the impregnation of the fabric. It shall be applied immediately after the strips are placed by means of a spatula moved in the direction of the fibres with suitable pressure. The quantity of resin to be applied is 700 g/m². Afterwards, TFC can be covered by various systems for aesthetic or protection reasons: decorative painting, fire protection product… (please refer to figure 6)

STRENGTHENING WITH TFC

FREYSSINET’s experience is now more than ten years of industrial application. More than 80,000 m² of TFC have already been applied in the different examples of use listed here after.

Bending and Shear Force Strengthening

FRP are usually used for strengthening structures subject to bending moments or shear force deficiency. TFC is therefore of course compatible to such strengthening works. Design is carried out in accordance with the local standards and Owner’s requirements. Figures 7 to 9 show some examples of TFC strengthening with regards to bending moment or shear force capacity.
Confinement

FRP improves the mechanical properties of a column by confining it. The wrapping of a column by means of TFC induces an increment of its ultimate bearing capacity. Strips can be placed in a spiral or as closed hoops. TFC design for confinement is based on the Richart’s model (1928): Eq. 1, which is on the safety side with regards to more recent model (such as Mander’s formulae).

\[ f'_c = f_c + 4p \]  

(1)

With:
- \( f'_c \): concrete strength of the confined concrete
- \( f_c \): concrete strength of the unconfined concrete
- \( p \): confinement pressure induced by TFC wrapping

Confinement is more efficient for a circular section (whole section confined) than a square or a rectangular section (section partially confined as shown in figure 11).

Greater the equivalent radius of the section is, less the confinement is efficient. As a matter of fact, the pressure confinement induced by FRP wrapping is proportional to the inverse of the equivalent radius of the section.
TFC behaviour with regards to confinement has been tested several times in different laboratories. Figure 12 shows an example of the confinement of a circular column by means of TFC placed in a spiral (one layer).

**Seismic Retrofit**

Intensities of earthquakes vary from place to place. In many countries standards have been updated due to recent earthquake (Turkey, Taiwan, Mexico…) with greater intensity. Following this change, some buildings shall be retrofitted under seismic effects. The use of FRP for seismic retrofitting is effective and cheap in comparison with other methods. TFC can be used for seismic retrofit in the following cases:
- old structures not meeting the specifications of the earthquake regulations in place,
- structures require a strengthening following a change in the intended use or an increase in the loads.

A dynamic study of the structures shall be carried out by a competent engineering firm in order to determine the required seismic strengthening or the required repairs for a structure damaged by an earlier earthquake. The strengthening by TFC is able to satisfy the ductility requirement through the development of local mechanisms making it possible for the composite to accommodate major deformations of the substrate.

Figure 13 shows the facility to place TFC strips onto surfaces without dismantling existing ducts.

TFC has been used for strengthening tanks in steel subject to earthquake. A 3D model has been carried out without and with TFC strengthening in order to determine the buckling instability shown in figure 14. In a
further testing, 4 tanks (please refer to figure 15) have been built, one without any strengthening and the three others with TFC quantities determined by the calculations. Tests results were very close to calculations ones.

Figure 15. Tanks in steel strengthened by TFC strips – Tests

Seismic retrofit also can be applied to masonry structures. TFC can be used as a strengthening material for such structures as follows:
- application of TFC to improve the behaviour, outside the plane, of masonry walls, considered as secondary non-structural elements but it is necessary to prevent their falling in case of earthquake.
- strengthening of the capacity within the plane of the wall which brace a structure of strengthened concrete portal frames by transforming a portal type scheme with filler into a bearing masonry structure, tied and strengthened with TFC,
- adding ties to non-tied masonry walls or masonry walls with insufficient ties, particularly around openings, for medium or small residential buildings.

Figure 16. Masonry wall – 2 storeys – strengthened by TFC – subject to dynamic test  
Figure 17. Masonry wall – strengthened by TFC

TFC strengthening has been tested onto masonry walls subject to dynamic solicitations. Strips are anchored at their extremities either by means of metallic elements such as angles or by carbon braids (FREYSSINET’s patent). The results of the different tests were all satisfactory with a great ductility and 20% greater capacity under earthquake. In addition to this, it shall be pointed out that no block or part of block has been ejected far from the walls: all the chips of blocks have fallen close to the bottom of the walls: no risk of damages of equipments inside the room.

The above figure (figure 17) shows an example of TFC strengthening onto a masonry wall inside a building in France. TFC strips have been placed without dismounting the existing ducts and design has been carried out taking into account all the recesses.

PCCP Repair

Prestressed cylinder concrete pipe, PCCP is used commonly as underground pipeline for transporting mainly drinking water. There are two families of PCCP: the first one is a lined-cylinder pipe constituted by an inner concrete core inside a steel cylinder confined by means of high tensile wires (prestress) protected with a mortar coating; the second one is an embedded cylinder pipe (please refer to figure 18) constituted by an inner concrete
core inside a steel cylinder embedded in an outer concrete core confined itself by means of high tensile wires (prestress) protected with a mortar coating.

As such pipes are installed underground, they are subject to corrosion. Sometimes, wires break and a splash of water occurs. The classical repair method consists of excavating around the damaged zone and install new prestressing wires around the pipe. Nevertheless, sometime, it is impossible to excavate if the pipe is located under a main road of a city that could not be closed or the pipe is located close to building foundations excavation of which can induce damages into the building due to foundation displacements. In such cases, two options are possible. First option, the placing of an inner steel pipe within the existing pipe and the void between the new inner steel pipe and the old PCCP is filled up with mortar: this solution reduces the inner dimension of the pipe which can be critical for the water distribution network. Second option, the placing of carbon fibre strips from inside (Frey-Cwrap product from FREYSSINET for instance which is similar to TFC but unidirectional). Frey-Cwrap strips (figure 19) give structural strengthening of the pipe and watertight.

A numerical simulation has been carried out with Code ASTER software (Finite Element model software) in order to determine the required quantity of FRP against the internal pressure. Calculations taking into account the bedding and the backfill around the pipe have also been carried out. Frey-Cwrap is constituted by carbon fibres provided by Torayca (SIFICAR) or Teho Tenax, type UD (unidirectional) 300/500 g/m² or BD (bidirectional) up to 80/20 (means 80% along the warp direction and 20% along the weft direction). The width is fixed to 600 mm. The modulus and the minimum guaranteed breaking stress are the same as for TFC: 105 GPa and 1700 MPa respectively. It can be placed from 1 layer to 5 layers. Resins are provided by BOSTIK: type Eponal 382 & Eponal 385. This FRP product is approved for drinking water in both France and USA.

CONCLUSION

TFC is a patented product from FREYSSINET. It can be used in many fields: buildings, bridges, tanks, silos, nuclear plants, PCCP … It has been tested to bending, to shear force, to confinement, to dynamic solicitations (earthquake strengthening), to temperature effect, to ageing and to ionising radiation and decontamination which allows a huge field of application. The product is guaranteed by FREYSSINET from its conception (design included) to its placing on site. It can be applied onto various substrates such as reinforced or prestressed concrete, steel, wood, masonry. It does not need heavy tools for placing it: hand pressure is enough and it can be placed even if the substrate gets ducts network fixed on it: a small gap between ducts and the wall is sufficient to allow the crossing of the strips.