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Composite Materials Technologies in Constructions Structural Retrofitting: New Developments and Applications in Historical Buildings and Applications in Seismic Zone

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Abstract. *Application of composite materials to construction started in Italy at beginning of the '90's and was generally accepted as one of the most important technologies for retrofitting and structural recovery of buildings. In 2004 the Italian National Research Council (CNR) issued the guideline for design and applications of composite materials in constructions and in 2009 it has been officially adopted for reconstruction at " L'Aquila" after the earthquake of April 6, 2009.*

The big advantage offered by Composites, mainly based on carbon fibres, is attributed to the special properties of the reinforcing fibres. Applications of composites range from concrete structures to masonry, bricks, steel and wood structures and more specifically reinforcement of beams, columns, vaults, arches, walls, concrete slabs, floors and total building belting.

Since 1993 many important original solutions and know how on materials, design and applications have been developed: reinforcing fabrics produced by an original patented process of thermo welding; connection systems based on Ardfix innovative technology, to prevent delamination; technology for wood beams reinforcements; cables technology and anchoring systems, new water base matrix systems with high fire resistance and good permeability to humidity and water.

A large experience in new solutions, and an important know how in applications has been developed.

New thermo welded mashes produced with alkali resistant zircon glass fibres, have been developed for direct application in concrete or calcium based mortar matrices. This special mesh grade is produced avoiding traditional induction process with plastic coating, leaving the surface of the fibre free from polymer and preserving the good capacity of adhesion to cement or calcium.

Many applications example of the above concept are reported, mainly related to retrofitting historical building.

1-INTRODUCTION

Application of composite materials in construction started in Italy in 1993 with laboratory tests at University of Bologna , and in just ten years reached a very large diffusion and was generally accepted as one of the most important technologies for retrofitting and structural recovery of buildings [1]. The important role of this technology has been generally recognized. In 2004 the Italian National Research Council (CNR) issued the guideline for design and applications of composite materials in construction [2-4] and in 2009 it was officially adopted as one important technology for rehabilitation and recovery of buildings damaged by earthquakes and largely used in seismic situation like in " L'Aquila" after the earthquake of April 6, 2009.
It is well known that the great advantage offered by composites , mainly based on carbon fibres is attributed to the special properties of the reinforcing fibres: very high mechanical properties, high chemical resistance, low weight, low thickness and low invasiveness.

Properties of Composites

- **High mechanical properties:** Carbon fibers are five time more resistent compared to steel.
- **Lightness:** Carbon fiber density is 1,8g/cm3, steel density is 8 g/cm3.
- **No invasive:** Reinforcements are generally applied externally, in very low thickness , easily covered by plaster in final coating.
- **No corrosion and high environmental resistance:** no maintenance in the time.
- **High fatigue resistance**: Vibration dumping.
- **Reversibility of the application:** External applications are easily removed.
- **Easy application**: Very simple application technology without need of important equipments

Tab. 1- Main Properties of Composites Applications in Constructions

Reinforcement effect is obtained without addition of mass and rigidity, that means a big advantage in seismic zone applications.(Tab.1)

Technology Solutions of Composite Materials

- **Fibers:** ***Carbon, Aramid, LCP, Glass, AR-Glass.***
- **Reinforcement Grade:**
  - Textile : Unidirectional , Biax-fabrics, Multiax, Net - fabrics.
  -Preimpregnated reinforcements : Pultruded lamina, Bars and Rods or Special shapes, properly designed.
- **Application Technologies :** ***External Lamination of dry textile, External Adhesion of pultruded lamina, Internal reinforces by Pultruded Bars, Lamina and Cables***
- **Delamination and failure mode control -** ***Connectors***

Tab.2 - FRP- Technical Possible Solutions

Applications of composites range from concrete, masonry, brick, steel and wood and more specifically reinforcement of : beams, columns, vaults, arches, walls, concrete slabs, floors and total building belting.

The large development of technology leads to many different solutions in terms of fibre type and variety of applications. Engineering and architectural criteria to select the appropriate technology among different possibilities should be considered. Products, material and technology optimization is also an important consideration for designers, applicators and end users (Tab.2).

2-FRP: MATERIALS AND TECHNOLOGY DESIGN

In our work, taking advantage of a large experience in composite applications on construction, starting in 1993, many important innovative solutions and 'know how' on materials, design and applications have been developed. In the following paragraphs several criteria for structural reinforcement design and solution selection, among the different opportunities offered by the market are presented [5-9].

2.1 - Fibre Selection

Carbon Fibres: They are the most important fibres used in construction. The high level of crystallinity, over 99 %, and the high packed crystal structure of graphite makes this fibre very stable in respect to corrosion, even in high alkaline conditions, chemically stable at pH variations and with high thermal resistance, even over 1000° C. (Fig. 1). Besides the high mechanical properties, the special structure and morphology of this fibre make carbon fibres the most stable and safe with respect to environmental durability and for applications under severe conditions. Creep is also an important property when the reinforced structure is subjected to permanent loads. It is well known that carbon fibres show no significant creep under permanent loads.

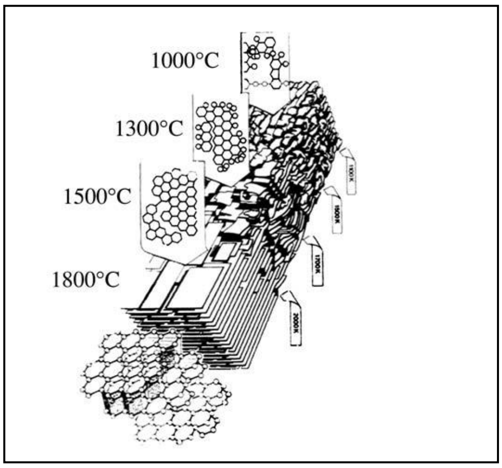


Fig. 1- The packed crystal structure of carbon fiber under thermal treatment process, in production [10].

Aramid Fibres: aramid fibres, are based on organic polymers, characterized by high mechanical properties, thermal resistance , and unusual capacity of vibration energy absorption

However this fibre lacks in resistance to humidity, to pH variation and UV radiation. Creep resistance of the fibre may be a property that designers should take in consideration with attention.

The high capacity of vibration dumping of Aramid fibre make this material very attractive to apply to earthquake rehabilitation construction, or application to constructions near high traffic roads, in order to prevent vibrations. A combination of aramid fibres as vibration energy dumping elements and carbon fibres as perfectly elastic elements can be a very good solution with excellent synergistic effects.

In practice, when aramid fibres are used, a good protection of the fibre, to humidity, environmental corrosion and UV radiation, should be warranted by the impregnation of resins.

Glass Fibres: glass fibres, largely used in traditional composites applications for a long time, are very cheap products, but they lack in terms of mechanical properties and weight (fibre density is 2,5g/cm3). For this reason the use of this fibre is usually limited to large surface applications when the role of the mechanical properties are not very important.

AR- Glass Fibres: AR- glass fibres nets are easily found in the market and used directly in combination with mortar, mainly for masonry or brick walls reinforcement. This special glass grade is based on composition containing a minimum amount (16%) of zirconium oxide, that provides superior performance under alkaline conditions.
Commercial glass nets based on A.R. fibres, are obtained by traditional waving process which includes an induction process with plastic coating to fix the fibre. So any adhesion between the fibre and the mortar is prevented, adhesion is extremely poor and generated only by mechanical bonds.

2.2- Reinforcements alternatives

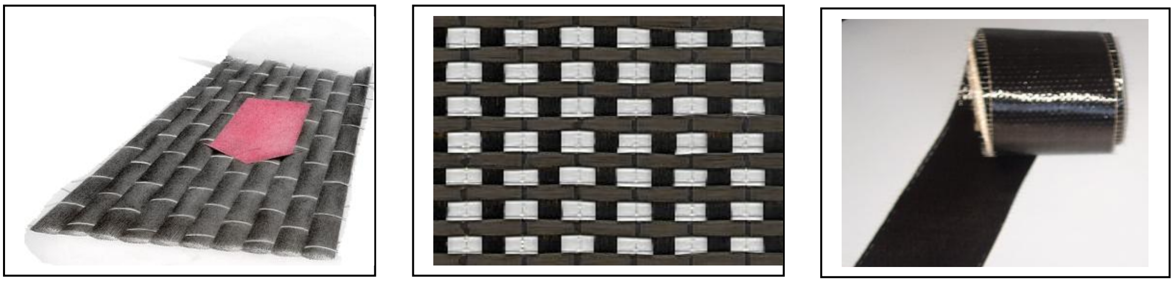
The **market** of fibre reinforcements offer a variety of solutions that can be selected by designers. Several alternatives are listed in Table 3.

Fibre Reinforcement
▪ **Woven fabrics : Unidirectional tape , Biax and Multiax Fabrics and Biax-Nets for in situ lamination :** very simple application , may be easily adapted to the shape of support, it is the only solution for columns wrapping. ▪ **Pultruded Lamina :** important fibre sections may be applied in only one shot . Lamina cannot permit bending and wrapping. ▪ **Pultruded Rods and Connectors:** for inside concrete reinforce and connections. ▪ **Cables :** building belting, connections and walls reinforcement.

Tab.3- Different reinforcement solutions are available

Fabrics and woven tapes can permit an easy application by direct lamination. Woven fabrics are characterized by very good draping properties and reinforcement may take any shape and perfectly follow the substrate profile, for example when the reinforcement should be applied to columns by wrapping to increase confinement

Betontex reinforcing fabrics (Fig.2) are produced by an original patented process of thermo-welding, with high efficiency in reinforcement effects [5]. This special process has been developed by Ardea technology and comprise the use of a special thermo welding of the warp and the weft by means of a thin glass fibre coated by a hot melted adhesive [5,6].



a-Unidirectional Thermo Welded Tape

b-Thermo Welded Net

c-Unidirectional Fabric Roll

Fig.2- Thermo welded carbon reinforces based on Betontex® technology.

Industrial production comprise unidirectional tapes , thermo welded biax- fabrics and nets, using different fibres, and weights and different fibre orientation. Reinforcements produced with this technology present very good handling properties, very good impregnation capability and perfect linearity of the fibre. Betontex reinforcements are easily applicable using optimized epoxy resins systems in all different conditions.

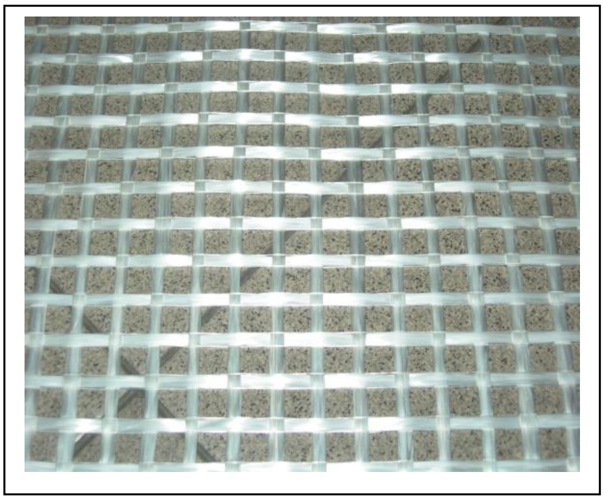


Fig.3.Betontex Thermo welded Net produced with AR- glass. Without plastic coating over the fiber.

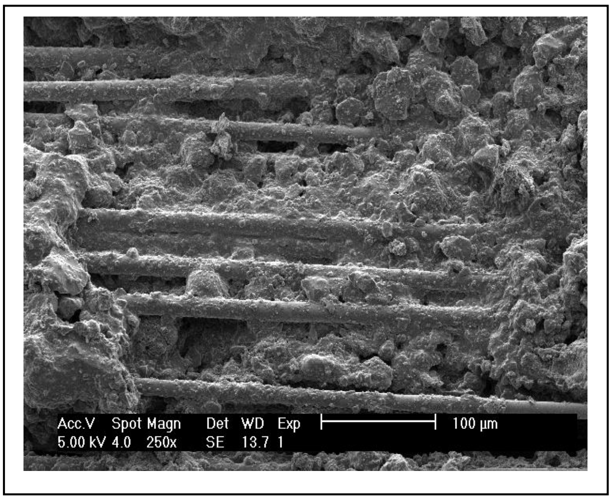


Fig.4.SEM view of interface between AR- .glass fiber surface and concrete, adhesion of the fiber is improved by Betontex IPN promoter.

New thermo welded nets produced with high zircon A.R. glass fibres, have been developed for direct application in concrete or in calcium based mortar matrices.

This special net grade is produced avoiding traditional induction plastic process , leaving the surface of the fibre free from polymer coating and preserving the good capacity of the fibre surface of adhesion to cement or calcium matrices. The free surface of the fibre can develop a good interaction with the concrete by direct physicochemical bonds formation (Fig.3-4).

In order to improve adhesion properties a special adhesion promoter has also been developed. This special adhesive system is based on a new concept of matrices with an IPN (Interpenetrated Polymer Network) structure, derived by a combination of two water based resins , one of which is supported over an active inorganic matrix. In fig.4 a view of the interaction between the fibre and the concrete is clearly shown.

Lamina may be used mainly in beam reinforcements whena significant amount of fibre sections should be applied, instead of using many layers of woven fabrics . Banding is a limitation in lamina applications thus, they are generally used only as beam reinforcements for straight on linear shape.

Pultruded rods, generally based on E-glass fibres and vinyl ester resins are very low prices materials, traditionally used for internal reinforcement of concrete.

Pultruded rods made of carbon fibres are primarily used to enhance mechanical properties in many cases and when there is a need to improve adhesion of carbon fibre reinforcements to the structure.

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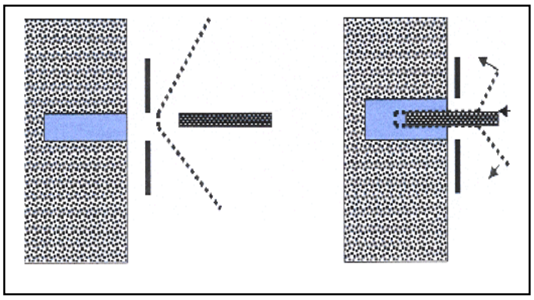

Fig.5**.** Schematic drawing of Ardfix connection system**:** a carbon bar push inside the wall a strip of unidirectional carbon fabric.

Connectors are very important for the general technology of composite materials applications in construction. The use of connectors made of carbon rods is extending and many alternative solutions have been proposed. In our research we have developed a very effective and easy to apply connection system that combine the application of carbon rods and unidirectional carbon strips.

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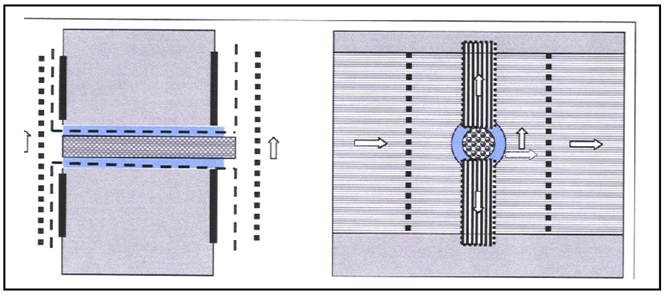

Fig. 6. Ardfix connecting the two faces of a wall. Loads are transferred through a net work structure.

Connectors should be used to improve adhesion of reinforcement to substrate, and are recommended when the quality of concrete or substrate is very poor.

Connectors may be very useful to prevent delamination, to transfer the tension from the reinforcement to the substrate and, also, to create a connection between the two sides of a structure, as in slabs or walls.

The use of high performance connectors, removes uncertainties related to substrate quality in terms of delamination resistance and allow designers to use the complete strength properties of the reinforcement without limitations induced by delamination phenomena.

The connection system, optimized in our work and described in reference [7], combines the application of a carbon fibre rod with a strip of tape and is represented in Fig.5 and 6. This system, after its introduction in the market with the name of Ardfix®, has been widely applied in many diverse applications.

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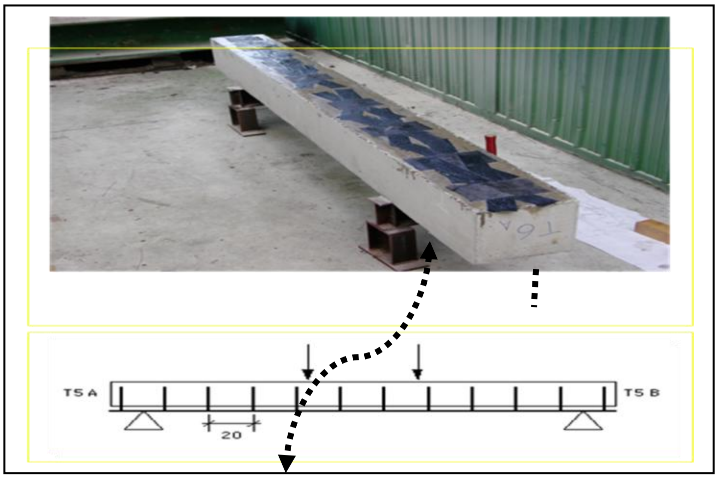

Fig.7.Application of Ardfix connectors on the intrados side of a concrete beam .After application of unidirectional reinforcing tapes, the beam is subjected to a flexural four points test.

A large number of laboratory tests have been carried on concrete beams reinforced with unidirectional carbon fibre, using Ardfix connectors. In fig.7 a beam reinforced with Ardfix connectors and unidirectional reinforcements is shown.

Fig.8a.Four point Flexion test on a concrete beam reinforced with n°3 layer of 300g/m^2 of high modulus (E=390 GPa) carbon fibre. No delamination has been detected during test.

Regarding the application, connectors are applied first, then, over connectors terminations, a unidirectional carbon tape is applied to reinforce the intrados of the beam.

With the Ardfix in all four-point flexural tests (Fig. 8a), no delamination of the reinforcement was observed and, at the ultimate load, the beam collapsed following the breaking of the carbon fibre at the centre of the beam, at the maximum moment (Fig.8b). Under such conditions, the ultimate bending resistance of the beam is governed by the ultimate tensile strength of the fiber.

Fig.8b.Breaking of carbon fibre at the centre of the beam at the ultimate strength, without delamination. Calculated tension on the fibre at break was equal to 3500 MPa.

The calculated values of strength for the carbon fibre, detected at the ultimate braking load of the beam, was equal to 3500 MPa, compared to the nominal tensile strength of 4200 MPa of the original fibre, Tenax HM grade.

Cables made of high modulus fibres, can be successfully used to many construction rehabilitation applications. Cables, based on a combination of aramid, glass and carbon fibres are new products developed by Ardea research, and can be used in connections, as ties, walls reinforcement, building belting and pre-stressing.

Fig.9. Application of Betontex Aramid Tie 85 HM on the tambour of “ *Anime Sante* “ Cathedral , L’Aquila, damaged by earthquake of 2009. The Tambour was put in security to proceed with further works.

An interesting application of aramid-carbon cable was the securing of the tambour of the Cathedral of “Anime Sante” -L’Aquila, damaged by earthquake of April 2009.

Cables made on aramid fibre, with a weight of 85 g per linear meter and a tensile resistance over 12 tons, were applied by specialized technicians, lowered by an helicopter around the damaged tambour (Fig.9). An important task was the connection at the ends of the cable in order to apply the desired tension. In order to do that, a special ring coated with Dynema fibres was prepared at the ends of each cable. The 38 m long cables were pre-stressed by standard jacks.
A new and challenging application of cables is the reinforcement of historical walls or façades made of either stones or bricks, when the external old appearance should be preserved. Cables may be introduced in very thin slits applied in courses of breaks or stones, avoiding any modification of the external surface.

Fig.10. Historical City Walls in stones (Bassano- Italy), reinforced with hybrid aramid – carbon fibres cable, prestressed and impregnated with epoxy resins. Courses among stones will be filled by traditional mortar.

Fig.11. Bricks walls reinforced with carbon fibres cable coated with aramid fibres, prestressed and impregnated with epoxy resins. Courses among bricks will be closed by traditional plaster.

Figures 10 and 11 show the cable application on stones and bricks walls. The examples refers to the City Walls of Bassano (Italy) and to a facade wall of an historical Cathedral in Bologna. In both cases cables have been pre-stressed and impregnated with special high fluidity epoxy resins and filled with traditional mortar.

2.3- Wood rehabilitation.

Wood-beam retrofitting is an important task that may be easily resolved by using FRP. Many different solutions have been proposed and described in literature [4] using: lamina , rods and unidirectional fabrics. However, all these solutions lack of a good reinforcing effect.
The low external surface compression resistance of wood, compared to the high tensile force of composites at internal surface, is a strong limitation on the strengthening effect.

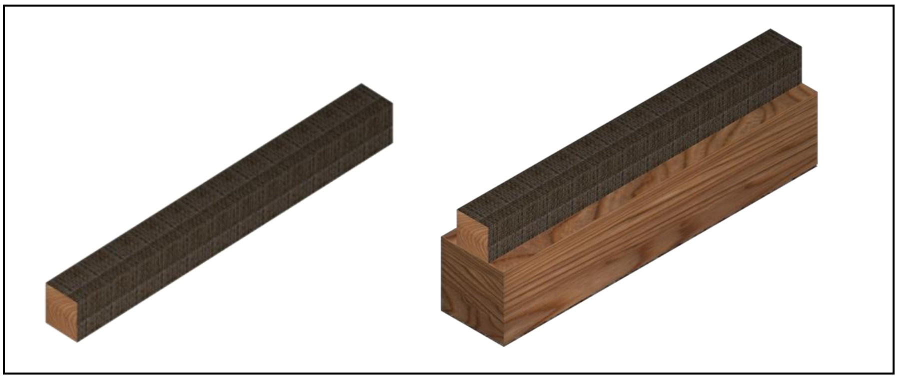

Fig.12-a. Ardwood, a wood element confined by carbon fibre net. Application of confined element to the extrados of wood beam.

This problem was resolved by applying a parallelepipedon of wood of square section, confined by a carbon fibre net, on the upper part (external surface) of the beam. This phase is followed by the application of carbon unidirectional fabrics or a lamina at the internal surface side of the beam.

Fig.12-b. Ardwood application on a beam, lateral view and section. Connection between Ardwood element and beam is made with Ardfix connectors. The intrados of the beam is reinforced with a carbon fibre lamina or a fabric.

The confined wood at the external surface of the beam be subjected to compression forces, equilibrating the high tensile force of the carbon fibre at internal surface side.
The system has been used for many years with the trade name Ardwood [8]. The schematic drawing of the Ardwood system for the rehabilitation of wood beams is shown in Fig 12(a-b).

3-MATRICES

Matrices are the second components of composite systems, the first being fibres. Matrices play a very important role in composite applications: impregnate the fibres, give shape to the reinforcement element, create a good adhesion to the building structure and transfer stresses from the structural element to the fibres

3.1 – Epoxy Matrices

Many types of matrices can be used in composite technology ranging from polymeric to ceramic and metal matrices.

Resin Grade	RC01	RC02	RC02/3 Tixo	RC30	RC30/3 Tixo
Functionality	Primer, surface preparation	Tixotropic Impregnating and adhesive	High tixotropic Impregnating and adhesive.	Tixotropic epoxy mortar	High tixotropic epoxy mortar
Resin A / Catalyst B ratio	2:1	2:1	2:1	4:1	4:1
Mixing ratio by weight	100:50	100:50	100:50	100:25	100:25
Gel Time at 20°C	50-60 (min.)	50-60 (min.)	50-60 (min.)	40-45 (min.)	40-45 (min.)
Hardening Time at 20°C	180-240 (min)	180-240 (min)	180-240 (min)	120-180 (min)	120-180 (min)
Total Hardening Time at 20 °C	14-16 (hrs)	14-16 (hrs)	14-16 (hrs)	12-14 (hrs)	12-14 (hrs)
Application Temperature range (°C)	From +5°C to 30°C	From +5°C to 30°C	From +5°C to 30°C	From +5°C to 30°C	From +5°C to 30°C

Tab. 4- Betontex Two Components Epoxy Resins Systems

Properties	methods	RC01	RC02	RC02/3 Tixo	RC30	RC30/3 Tixo
Adhesion to concrete	ACI 440.3R-04	≥ 3,00 MPa (*)	≥ 3,00 MPa (*)	≥ 3,00 MPa (*)	≥ 3,00 MPa (*)	≥ 3,00 MPa (*)
Tensile Strength	ASTM D 638	≥ 35,00 MPa	≥ 35,00 MPa	≥ 35,00 MPa	≥ 45,00 MPa	≥ 45,00 MPa
Tensile Modulus	ASTM D 638	≥2,50 GPa	≥2,50GPa	≥2,50 GPa	≥3,00	≥3,00
Tensile Elongation	ASTM D 638	≥ 2,80 %	≥ 3,00 %	≥ 3,00 %	≥ 2,0 %	≥ 1,50
Shear Resistance	ASTM D 2344	≥ 25,00 MPa	≥ 25,00 MPa	≥ 25,00 MPa	n.d.	n.d.
Density 25 °C	ASTM D 792	1,10 g/cm^3	1,10 g/cm^3	1,12 g/cm^3	1,50 g/cm^3	1,60 g/cm^3
HDT	ASTM D 648 A	≥ 70,0 °C	90-100 °C	90-100 °C	90-100 °C	90-100 °C

(*) with concrete delamination

Tab. 5- Betontex Two Components Epoxy Resins Systems : Mechanical Properties.

In most structural applications a two component epoxy resin system is used**,** they are formulated at different viscosity grades: *primer resin:* a low viscosity resins for surface preparation, *impregnation and adhesion resin:* a medium viscosity resin to impregnate fibres, *epoxy resins mortar:* a high viscosity resin, for surface adjustment, and for lamina and Ardfix bar application (tab.4)

Epoxy resins show the best properties (Tab.5) for application of composites to constructions in terms of mechanical properties, aging resistance, and durability in every condition. In construction epoxy resins have been introduced many years for applications of steel bars and plates, as *" beton plaque",* and engineers are familiar and confident with their use. Nevertheless some caution should be taken regarding: the distortion temperature (HDT) (Tab.5) , a property strictly related to the second order transition temperatures *Tg*, which is in the range between 90-100 °C. In general applications the usual coating with traditional plasters or protective paints may be sufficient to protect FRP. In case of high temperature applications or when fire resistance is required, a protective coating should be applied, as for steel structures.

3.2 – Concrete matrices,

Some applications of carbon fibre fabrics reinforcements, directly dipped in special cement mortar, have been reported in the market. These systems may have the advantage to partially overcome some lack of properties of epoxy resins, but also exhibit some other problems that should be considered.

Carbon yarn, used in waving, is generally composed by a number of basic fibre ranging from 3.000 to 24.000. Polymeric matrices have the capacity to impregnate the single basic fibres, that is to enter inside the yarn, between the single fibres, generating a real "*composite material"*. Cement particles do not have the capability to impregnate the single fibres, but can only coat the yarn externally, leaving the single basic fibres unbounded. For this reason the carbon fibre, in terms of strength, develop very low results, ranging between 25-40 % of the strength of composites impregnated with epoxy resins.

Furthermore there is no bond formation between carbon fibre, surface and cement, so the incorporation of carbon fibres in cement matrices do not generate a *"composite material"* but only a mechanical blend with poor mechanical properties.

3.3- New water based resin system.

Considering the above described problems related to matrices, both of epoxy type or

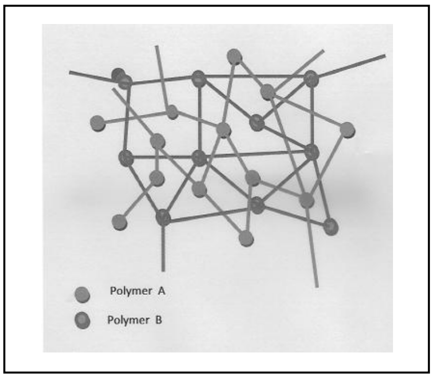

Fig.13 –IPN resins concept

cement mortar based matrices, we have investigated and optimized new resins system based on the IPN (Interpenetrated Polymer Network) concept, commercialized with the trade name of Betontex IPN Resins (Fig.13).

This type of matrices is based on a new formulated resin in water solution or dispersion, supported over special micronized mineral filler. After mixing and hardening the two components, an IPN structure is obtained.
Similar to epoxy resins, this new type of resins is used in different grades as: IPN primer of low viscosity, IPN impregnation resins of medium viscosity, or IPN mortar of high viscosity.

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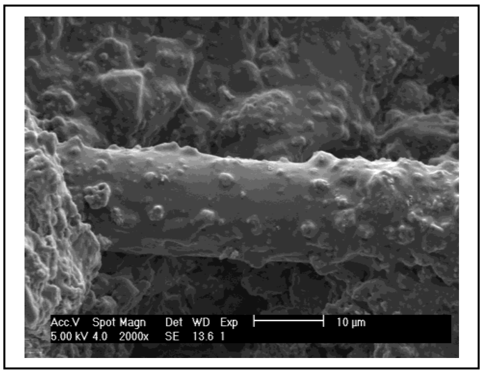

Fig. 14- Interface between IPN matrix and the reinforcing fibre, SEM x 2000 view ..

Betontex IPN resins may be used to applications with carbon fibres nets or AR Zirconglass nets, over concrete or over bricks or stone masonry structures.

The resins show very good adhesion capacity and very good mechanical properties; in tensile tests with carbon fibres 70-80% of epoxy resin properties are reached.

Temperature resistance is very good, no thermodynamic transition is observed until 180 °C, and degradation temperature may be observed over 300 °C, without melting.
Betontex IPN resins show a good burning resistance (class 1; following UNI 9176 D), can permit water vapour transmission, may be used over humid surfaces without any problem, and demonstrate very good aging properties even under also in severe conditions.
Many applications have been successfully carried out for reinforcement of walls and vaults and new tests are in progress for beam and plate reinforcement with unidirectional fabrics

4-APPLICATIONS EXAMPLES AND CONCLUSIONS.

Many application examples of the described technology are reported.
The most important are related to historical building retrofitting, among them we will refer to:
a) “Venaria Reale”, a Royal Palace in Venaria near Turin.

In Venaria the large arcades were reinforced with unidirectional hybrid carbon-aramid fibres, partially overlapped in the central area of the arcades to increase the fibre section.

b) Basilica of S.Antonio in Padua where the Vaults of convent were reinforced with aramid and carbon unidirectional strips. The walls of the tympanum of Library, were

Fig. 15- Venaria Royal Palace –Turin.

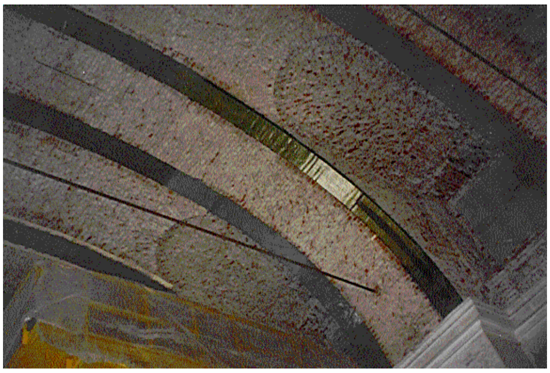

Fig. 16- Intrados reinforcement of arcades - Venaria Royal Palace –Turin. (1999)

reinforced with unidirectional carbon and hybrid carbon-aramid fibres in both sides of the walls and connected by Ardfix connectors in order to create a tridimensional network structure.

Fig.17 – The Basilica f S. Antonio in Padova- Italy (2001-2004).

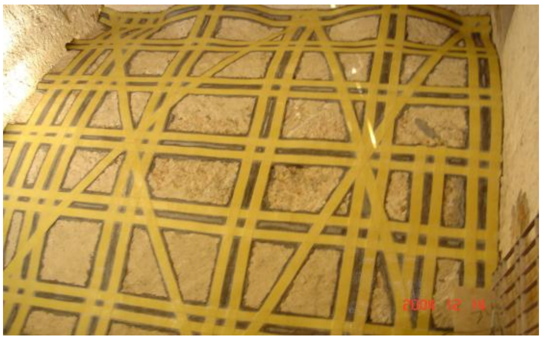

Fig.18 – The Basilica f S. Antonio in Padova- Italy . Vaults reinforcement of monastry cells.

Fig. 19 -Outside walls reinforcement of Tympanum of Library .

Fig. 20 -Inside walls reinforcement of Tympanum of Library.

We can also mention many other important churches and basilicas such as: Basilica of Vico-forte and Alba near Cuneo, Basilica of S. Petronio and S. Pietro in Bologna that have been subjected to rehabilitation works by using carbon fibres strips with the design and technology concepts described in this paper.

Fig.21- Example of extrados vaults reinforcement by carbon fibres tapes,
(S. Giorgio Church, near Bologna-Italy)

Fig.22- Example of walls reinforcement using Ardfix connectors, at Alba Cathedral in Cuneo- Italy.

A representative example of carbon fibre application with unidirectional strips, at the exterior of church vaults, is shown in figure 21. This reinforcement configuration presented is generally applied to many retrofitting works of old historical buildings and churches in Italy.

Application of connectors on the sides walls of the Alba Cathedral (Cuneo-Italy) is presented in photo 22. Over the connector ends two strips of unidirectional carbon fibre reinforcement is applied in orthogonal direction to the fibres (shown in the picture) and over them, a unidirectional reinforcement strip is placed. All laminations are made using, fresh resins at the same time. In such a way a connection of superior behavior is obtained.
Applications on old concrete buildings, retrofitting of bridges and old industrial building have been performed from many years and are now widely applied.

Fig.23- Example of old concrete rehabilitation using thermo welded Betontex unidirectional carbon reinforces.

Picture 23 shows the rehabilitation of an old concrete structure. The Beams are reinforced toincrease shear and flexure, while columns are reinforced for bending, compression by confinement and shear. Connectors are used to avoid debonding.
New solutions have been developed for seismic zones. In picture 24 an example of internal belting of an old Villa, damaged by earthquake of 1996 in Reggio Emilia, is shown. A similar reinforcement was applied at the external side of the wall. The strengthening is applied to avoid both out of plane and in plane failure of the masonry walls. Both sides have been connected with Ardfix.

Fig.24- Example of building complete belting (inside and outside) , at Villa Bertani- Reggio Emilia damaged by earth quake of 1996 , using thermo welded Betontex unidirectional carbon reinforces.

Fig.25a-25b- Concrete rehabilitation in a civil building at L'Aquila- Italy, damaged by earthquake of April 2009. Joint Column-Beam reinforcement. and Columns confinement.

Recent reinforced concrete industrial constructions damaged by the "L'Aquila-Italy" earthquake in April 2009 have been rehabilitated using Betontex carbon fibre reinforcements (Fig.25a-b). Reinforcement of old traditional bricks and masonry buildings, damaged by the same earthquake, are in progress, following the technical solutions and using the design concepts and materials reported in this paper.

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