Complimentary Solutions - a review document on the role of polymer composites.

Polymer composite materials have the common advantages of high strength and stiffness, low weight, good durability and the ability to be self-coloured. This lends their usage to many applications in construction.

Although polymer composite materials can and have been used entirely on their own, in, for example, radar domes and all-composite bridges, there are many examples where FRPs are used in conjunction or *synergistically* with conventional or traditional building materials. There is, of course, an inherent synergy within the fibre and matrix combination of FRP materials themselves, similarly with polymer composite reinforced concrete and steel reinforced concrete. The pace of construction product development is such that there is no real definition of a "traditional" building material - aerated blocks, punched metal plate trussed rafters and extruded uPVC window frames all being examples of once quite innovative technologies which are now commonplace.

In considering the possible synergy of polymer composites with other materials it is important to make a distinction between the use of FRP merely in conjunction with other materials (i.e. compatibility), examples where the FRP is simply a better replacement material with advantages such as corrosion resistance or low weight, and true synergistic behaviour. That FRPs are often used in conjunction with other materials in building is no more remarkable than for other, perhaps more familiar materials, such as timber, glass, metal and brick.

Examples where FRP is used in conjunction with conventional materials include permanent formwork for concrete structures and timber cored FRP cladding. The transoms of FRP boats are often formed with a core of plywood. Timber may also be used as the frame or structural core of hand lay-up or spray-up FRP architectural features. Honeycombed resin impregnated paper and honeycombed aluminium foil are also used as core material.

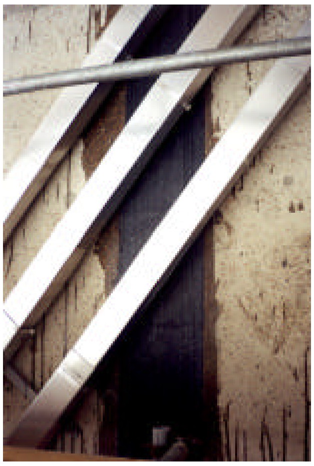
Carbon Fibre and Fibre Reinforced Polymer Strengthening

The most obvious and by far the most important example of the apparent synergy of FRP materials with conventional building materials is in the role of strengthening, either of existing structures or in new composite "hybrid" elements such as CF reinforced timber/glulam beams. The use of FRP materials in strengthening structures such as beams, floors, bridges, columns, silos, cooling towers and chimneys has rapidly gained acceptance worldwide since the development of the technique in the 1980's. For beams and bridges, generally, the technique involves bonding either unstressed or pre-stressed carbon fibre reinforced polymer (CFRP) plates to the underside (soffit) or bottom flange of the beam.

Strengthening of a bridge

Strengthening of beams in a building

This has the effect of increasing the capacity of the lower part of the beam which is under tension. For materials such as reinforced concrete and cast iron, which are strong in compression but weak in tension, this is usually the most critical area. Pre-stressing the CFRP plates has the effect of further reducing the tensile stress on the bottom flange, hence the load capacity is increased. CFRP plates can also be bonded to the sides of beams near to the supports to increase the shear capacity. For structures such as columns, silos and cooling towers the reinforcement is applied cross-wrapped or in bands, with the tensile capacity of the carbon fibres acting as confinement.



Strengthening of Tower at Nuclear Power Station

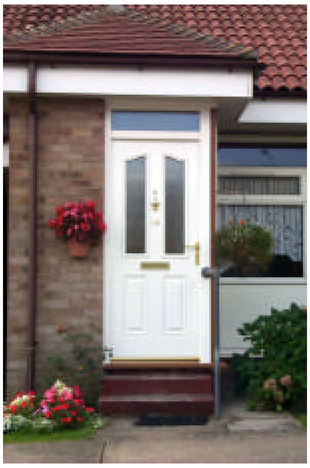
The most obvious advantage of the use of CFRP plates over the more traditional use of bonded steel plates is the reduction in dead load on the structure. Carbon fibres have much higher tensile strength than steel but with much less weight. They are also non-corroding. Glass fibre reinforcement is a lower cost alternative to carbon fibres. The bonding between the CFRP plates and the structure is of great importance for the technique to be successful. Non-destructive test methods for the detection of voids indicating bond failure such as the use of ultrasonic and transient pulse thermal imaging have been developed. Infrastructure repair is a multi-billion pound problem worldwide, in particular for reinforced concrete highway bridges damaged by de-icing salts. Strengthening of structures to resist earthquakes and to conform to new seismic design codes is another major application (eg bridge columns). Bridge columns can also be strengthened to improve resistance to vehicle impacts.

Key advantages of polymer composite strengthening:

- Highly cost effective method of maintaining or upgrading existing structures.
- Quick application results in lower disruption and shorter contract periods.
- The technique may allow continued usage of structure or facility during strengthening works.
- CFRP plates are an alternative to other forms of strengthening such as use of steel plates, provision additional support members, jacketing of columns with additional reinforced concrete, or complete replacement of structure.
- May enable preservation or upgrading of heritage structures (eg Hythe Bridge)
- Increases the capacity with minimal addition of dead load to the structure.
- Materials are easy to transport and handle - no lifting gear required.
- Ability to work in confined areas and in situations with difficult access (eg tunnels, basements).
- The technique is relatively quick - reduced disturbance and installation time.
- Minimal plate preparation required - by use of peel ply plates
- Plates may be any length with no lap joints needed.
- For wall strengthening overlaps are simple.
- Plates may be thinner than alternative steel - less reduction in headroom.

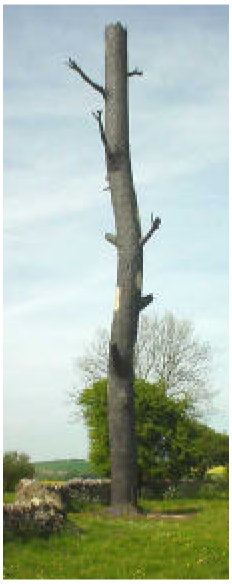
FRP as a replacement material

There are many instances where polymer composites because of their superior properties or relative cost are used as direct replacements to conventional materials. Complex stone fascias, for example, can be inexpensively replicated in lightweight FRP. Steel-framed buildings can be clad in FRP as an alternative to profiled steel. In a significant number of applications it is man's oldest building material, timber, which is being replaced. Examples of the direct replacement of timber by FRP include ladders, scaffold boards, cladding, fascia boards, bridges and bridge decks, cabins, marine piles, cooling towers, doors and windows, utility poles and flag poles, concrete formwork, and boats. Even FRP phone masts have been designed to look like trees.



GRP Door

GRP flagpoles



Lightening 'tree'

Ironically both timber and polymer composites suffer from the same unfounded prejudices of a susceptibility to creep, lack or durability, lack of fire and vandal resistance, and also a perceived difficulty with design - especially of connections.

There are also a number of applications where no suitable traditional material alternative to FRP exists, the most obvious examples include:

- Radomes
- Radar transparent fencing
- Non conductive and chemical resistant access platforms, ladders and decking
- Non conductive, radio transparent I beams, columns, sections and trusses for military and telecommunications applications.

Radome

Non-magnetic structure

One of the primary advantages of FRP components is the ability to pre-fabricate and tailor-make. There are numerous examples of applications where FRP offers a highly cost effective and practical alternative:

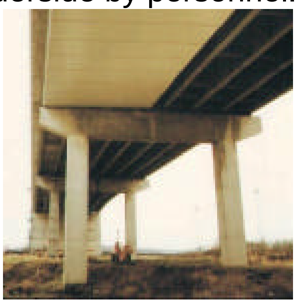
- Septic tanks
- Swimming pools and spa baths
- Water tanks
- Motorway sign gantries
- Pipework and ducting

Tank cover

Sign Gantry

Although FRP cladding has an obvious weatherproofing function, in the following applications the protective role of the material is more specific:

- Bridge enclosure systems (examples include Rogiet Bridge, Gwent and A19 Tees Viaduct Middlesborough). Bridge enclosure systems are advanced cladding systems for the sides and underside of bridges which fulfil two main purposes - protection of the structure from corrosion (eg salt water spray) and to allow safe inspection and maintenance of the bridge underside by personnel. They can also be used for aesthetic reasons.

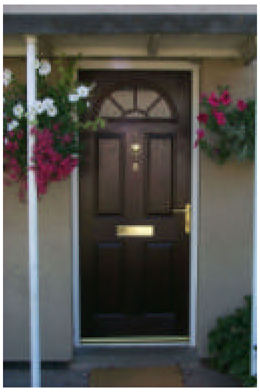


Bridge Enclosures

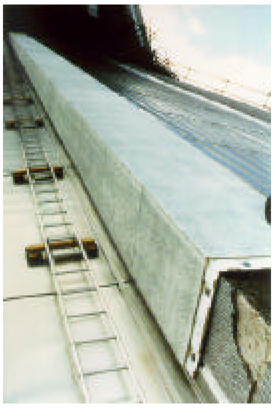
- Pile encapsulation. Composite encapsulation systems consisting of fibre reinforced plastic jackets epoxy grouted to the substrate are a solution to the problem of corrosion attack of seawater on both concrete and steel structures such as marine piles and platform legs. The encapsulation system consists of a moulded FRP jacket which is placed around the abraded and cleaned pile. Epoxy grout and aggregate mix is then pumped from the bottom up, displacing seawater. The FRP jackets are translucent allowing the process to be monitored by diver.

The ability to easily pigment or colour FRP items is yet another advantage of FRP materials, with examples including:

- cladding and roofing
- ladders
- doors and windows
- small buildings such as gatehouses
- sea markers (piles)
- buoys
- swimming pools


Dark wood effect

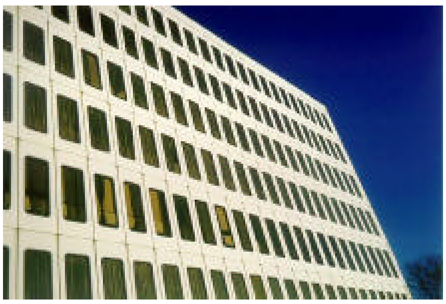

Fake Stone


Granite effect

The dual structural and cladding roles of FRP materials is apparent in the following applications:

- Sewage tank covers
- Bridge decks
- Cooling towers

Examples of buildings clad with FRP include the Canada Life Building in Stevenage and the Natwest Media Centre at Lord's. The formability and colour-ability of FRP in conjunction with the ability prefabricate allows architects to use the material in a wide variation of features and styles.




GRP Cladding of buildings

Although FRP has been used for the construction of whole structures, the Severn Visitors Centre, Aberfeldy Bridge, and Eyecatcher building in Basel, Switzerland, being examples, traditional building techniques and materials are still favoured in some markets, particularly housing.

Eyecatcher Building

Severn Visitors Centre

The majority of new build housing in the UK is presently quite conservatively styled in the manner of the Victorian and Georgian era. There is probably prejudice against plastic materials for the major elements of homes such as roofs and exterior panels. This may be based on a perception of poor UV durability, and an association of plastic with the disposable, imitation or fake. This is coupled with a desire for familiar materials such as brick, timber and slate. One notable exception to this aversion to plastic building materials is uPVC for window frames and doors, where the benefits of low maintenance over painted timber are readily apparent to the homeowner. The uptake of FRP materials may also be limited by moves towards sustainable, "ecological" construction and concerns over recyclability. Ironically one of the difficulties with reprocessing polymer composites is the very robustness of the material itself.

One of the most remarkable developments in the use of FRP materials has been for bridge building. FRPs offer bridge designers the advantages of high stiffness-to-weight and high strength-to-weight ratios when compared to conventional construction materials such as steel and reinforced concrete. FRP can be pre-formed into complete structural units, reducing construction time. In addition, FRP's have excellent corrosion resistance particularly against de-icing salts. There has been considerable recent development worldwide in the use of FRP's for bridge building, resulting in numerous successful examples of both pedestrian and highway bridges worldwide. Examples in the UK include the Bonds Mill Lift Bridge, Gloucestershire; Parsons Bridge, Dyfed, and of course the Aberfeldy Bridge, Scotland.


Aberfeldy Footbridge


Bonds Mill Lift Bridge


Parsons Bridge

Conclusion

In the role of strengthening, FRPs show distinct synergy with traditional and conventional building materials such as timber, brick, reinforced concrete, steel and iron. FRPs are also used in combination with these more familiar materials in a number of applications (see Summary Table, below). However, most building materials are used in combination with other types and it is often the case that there is no particular or special compatibility of polymer composites when compared with combinations of these materials.

Polymer composites exhibit useful properties such as corrosion resistance, high strength and stiffness, and can be tailor-made in a cost-effective manner - thus frequently FRPs are quite simply better replacement materials. FRPs because of their greater durability are used as protective elements - the main examples being pile encapsulation and bridge enclosures. In a number of specialist applications such as radomes and non-conductive structures FRPs offer the only practical alternative.

Summary Table:

Application	Material replacing	Reason for use of FRP	Material combinations and synergies
Cooling towers	In small cooling plant, as a direct replacement for timber (US in particular)	Prefabrication of modular units. Better durability than treated softwood timber. Concerns over the use and disposal of treated timber.	Compatibility with other plastic pipework.
Swimming Pools	Direct replacement for insitu concrete, also other types of plastic liner.	Lower cost, prefabrication.	FRP compatible with service pipework. Used in combination with stainless steel fixings, steps, grillages etc.
Wind Turbines	Direct replacement for steel	Lower weight, high strength and fatigue resistance.	
Ducting	Direct replacement for galvanised steel	Corrosion resistance, durability	

Walls and partitions	Alternative to blockwork /plaster/plasterboard internal walls or timber stud/plasterboard partitions	Modular, prefabricated construction. Weatherproof exterior.	FRP used in combination with insulating materials such as expanded polystyrene, phenolic foam, rock wool etc Internal skin of plasterboard. Compatible fixings to rest of structure . Building materials such as profiled steel, plywood, brick, block and cement bonded particleboard are also using in conjunction with these insulation materials.
Blast walls	Replacement for steel	Lower weight, durability	
Small building structures and cabins	Replacement for conventional building techniques including blockwork /cavity walls, timber and timber frame buildings, aluminium/steel insulated panels. Structural Insulated Panels (SIPS). Portakabins.	Modular, prefabricated construction. Low weight. Durable, weatherproof exterior. Ability to apply textures and colours.	FRP used in combination with insulating materials such as expanded polystyrene, rock wool. Internal skin of plasterboard. Compatible fixings to rest of structure. No particular synergy.
Doors, windows, lintels	Direct replacement for timber, aluminium and PVC. Competing alternative materials are modified timbers, wood derived products also eco-composites.	Durability, formability, cost	In combination with insulating materials, standard fixings, hinges etc. No particular synergy.

FRP Dowel Bars	Direct replacement for steel bar	Corrosion resistance	Compatibility with concrete
Telecommunication and utility poles	Direct replacement for timber poles, galvanised or painted steel masts and pylons	Non-conductive, Radio transparent, Durability	FRP used in conjunction with concrete foundations
Pipes	Direct replacement for conventional spun concrete and steel pipes, also traditional clay and brickwork liners. Competing materials are polythene and other thermoplastics (including recycled waste plastics).	Durability, Ease of handling	
Airport fencing	No direct alternative in terms of radar transparency, except perhaps timber.	Radar transparent	
Column Wrapping	Alternative forms of strengthening are encasement in concrete or steel	High strength, low weight. Ease of application, cost effectiveness	FRP used to strengthen conventional materials
Reinforcing bar	Direct alternative to steel	Corrosion resistance, strength, ease of cutting, lower weight, also makes concrete easier to recycle	Compatibility with concrete. Hollow tubes may be used to inject grout in strengthening schemes (case study: Chatham Dock Wall Reinforcement/Weldgrip)
Lighting columns	Direct alternative to painted or galvanised steel, pre-cast reinforced concrete	Impact safety, Durability	

Piles	Direct alternative to tropical hardwood timbers such as greenheart and treated softwood, also steel section and tube, pre-cast reinforced concrete. Competing technologies are PVC coated timber piles, plastic coated steel piles, non-ferrous reinforced concrete.	Durability. Environmental concerns over treated timber and use of tropical hardwood. Composite piles can be made from waste plastic. Piles can be coloured (sea markers)	Hollow FRP piles can be filled with concrete to improve capacity. FRP piles may be used in conjunction with timber for decks, handrails, fenders etc. Plastic lumber may also be used. Compatibility with metal fixings, brackets etc. Ease of drilling and sawing on site.
Pile encapsulation	FRP used to protect existing steel and concrete marine structures. Competing technologies include mastic wrapping, concrete encasement, underwater painting and coating.	Durability and impact resistance, also transparency when observing grout flow.	FRP used to protect conventional materials (concrete and steel)
Strengthening (existing structure and composite beams)	CF used to strengthen existing structures. Alternative technologies include use of steel plates, provision of additional supports, load reduction.	High strength, low weight. Ease of application, cost effectiveness	CF used to strengthen existing reinforced concrete, cast iron, brick, timber structures. CF used to increase tensile capacity of lower flange of composite beams, increasing span or load carrying ability.
Bridges	FRP may be used as a direct replacement (i.e. all composite bridge) or form part of the bridge (such as the deck)	Formability of sections, low weight, high strength and stiffness, durability	FRP bridges may have timber handrails, steel suspension cables, rubber decking. Concrete ballast may be incorporated to lightweight FRP bridges to improve dynamic performance. Use of timber for decking and

			handrails would add to the aesthetic appeal.
Bridge decks	Alternative to hollow welded steel box sections or UB's, plate girders etc, pre-cast concrete sections and planks, insitu reinforced concrete. Stress laminated timber bridges	Formability of sections, low weight, high strength and stiffness, durability	FRPs are compatible with surface coatings such as asphalt and other non-slip surfaces such as epoxy compounds. Able to bolt FRP beam elements to support steelwork etc.
Rock anchors	Direct replacement to steel	Corrosion resistance Less loss of pre-stress on system relaxation. Flexibility. Ease of handling. Cuttability.	Compatibility with epoxy grout. Compatibility with other plastic fittings (end plates, couplers, nuts)
Synthetic lumber (wood fibre reinforced plastic)	Alternative to timber (tropical and temperate hardwoods, treated softwood)	Lower maintenance, durability	Compatibility with metal fixings such as screws and brackets. Able to saw and drill like natural wood.
Timber resin repairs	FRP bar used as direct replacement for stainless steel or epoxy coated steel	Durability not really an issue. Ease of cutting on site and ability to bend. Lower weight (transport). Ease of preparation.	Compatibility with epoxy grout

Bridge enclosure systems	FRP cladding - no direct alternative	Durability and lightness. Colour, surface texture.	Used to protect steel support beams of bridges and provide safe access for inspection and maintenance. Also to improve bridge aesthetics.
Fascias, decorative mouldings	Direct replacement for traditional materials such as stone, brick, tiles, lead, zinc and other roofing materials	Cost, durability and lightness. Colour, surface texture	FRP fixings compatible with support structure such as steel frameworks, trussed rafters etc. Some decorative mouldings have timber cores
Industrial access platforms, stairs and ladders	Alternative to coated steelwork, timber and aluminium.	Corrosion and chemical resistance, durability and lightness, non-conductive. Ladders may be coloured.	No significant material combinations
Timber dowel connections	Alternative to steel and stainless steel	Compatibility with the mechanic performance of timber. Also lightness, corrosion resistance.	Timber connections
Monitoring	Monitoring and testing is especially important to innovative materials and applications on grounds of reliability and effective design.		FRP materials can incorporate fibre optic cables (Bragg sensors). Carbon Fibres can be used as in built strain transducers.

Eco-composites	The drive towards sustainable construction has made the use of alternative, bio-derived materials attractive, replacing petroleum-based matrix materials such as polyester and non-organic fibres such as glass in FRP materials.	Sustainable materials. Biodegradability	An eco-composite may contain natural fibres such as hemp, sisal, jute or flax, or consist of a natural polymer matrix derived from cashew nut shell liquid (CNSL).