Composites in Construction

Frequently Encountered Misconceptions

The uptake of Fibre reinforced polymer (FRP) composites in the construction sector has trailed that of other industries, and has not been helped by a number of common misconceptions about the material. The following fact sheets address these common misconceptions and provide information to areas of key concern and confusion.

Common misconceptions have been addressed covering the following areas:

- **Effects of Alkaline Environments**
- **Moisture/Solution Effects**
- **Creep Behaviour**
- **Fatigue Effects**
- **Effects of Fire**
- **Thermal Effects/High Temperature Resistance**
- **Effects of Ultraviolet (UV) Radiation**
- **Vandal Resistance**
- **The Cost of Composites**
- **Recycling**

It is not the objective of these sheets to provide comprehensive design guidance, merely to raise awareness of some of the actions that can be taken to avoid negative effects of the above conditions.

The examples given may not all be directly related to the construction industry, the aim being to highlight the uptake and use of composite materials under conditions of concern, thus dispelling misconceptions and encouraging the uptake in other industries, namely construction.

Effects of Alkaline Environments

It is known that alkaline solutions, in some cases, can cause degradation to the main constituents of FRP composites. This is particularly the case with bare glass fibres, where a reaction with an alkaline solution forms expansive silica gels.

However, it is the performance of the composite *system* as a whole that should be the primary consideration when operating in this type of environment. When this is done, composites have been shown to exhibit superior performance and durability characteristics than more conventional construction materials. The use of a suitable polymeric resin is essential to protect the fibre and slow the diffusion process. Vinyl ester resin has been proved to reduce the alkali attack by providing a protective barrier.

The high level of performance consistently attained by composite structures operating in these conditions in countless field applications is unequivocal in the proof that composite materials can perform well in alkaline environments.

Design Considerations

- The resistance to alkali attack can be increased by designing the member to lower stress levels.
- Careful selection of the fibre and resin system is essential for optimum performance in the working environment presented.
- A suitable thickness of appropriate resin rich surface exposed to the alkaline environment should be a pre-requisite for these conditions.
- The resin system should be fully cured upon production.
- It is important that FRP equipment be fabricated in such a manner as to ensure the longest service life. Suitable veil tape and catalyst system design & fabrication techniques are required along with correct laminate lay-up sequence.
- Although higher in cost, carbon and aramid fibre composites are not susceptible to alkaline environment degradation and can be used in the most extreme cases. However, an appropriate resin must be selected to ensure good overall composite system performance (i.e. interface performance)
- An extensive amount of research addressing this subject has now been undertaken, and as a result more accurate and reliable predictive models for the behaviour of composite materials in alkaline environments are now available.
- A recent introduction by Saint-Gobain Vetrotex, *Arcotex* glass fibre, exhibits outstanding acid and alkaline resistance and good stress corrosion resistance, is suitable for reinforcing thermosetting resins.

Examples of Use

Concrete Reinforcing Bar

FRP concrete reinforcing bar is a prime example. Concrete is used extensively in construction, and is known to have a pore water pH level of 13.5, making it a highly alkaline environment. FRP reinforcement has been used successfully as an alternative to ferrous concrete reinforcement due to its superior alkaline and corrosion resistance, along with other related benefits.

Pulp and Paper Mill Equipment

Perhaps one of the most prominent examples of the use of FRP in these environments is in the Pulp and Paper industry. Under pressure from increasing environmental legislation, the industry is now recycling a greater amount of process streams. This, however, increases the industry’s already severe corrosion problems. The chemicals required for the production of paper are extremely alkaline and corrosive and a constant threat to production equipment. Even stainless steel is not satisfactory in many cases. Equipment manufactured from composite materials was one of the only viable options which met corrosion resistance requirements at affordable costs.

FRP composite systems can be built to meet the specific demands of corrosive, high temperature environments. Since their introduction, FRP tanks and stacks, piping, duct work, grating and polymer concrete have all provided satisfactory service in the harsh conditions of the pulp and paper mill.

Moisture/Solution Effects

Most FRP elements are likely to be exposed to rain, humidity, moisture or diffused solutions through other substrates during their service life. It is therefore important that the effects of moisture are properly understood. There remains conflicting views regarding the effect of moisture to individual constituents and FRP composite systems as a whole.

In some cases it has been observed that water accumulated at the fibre/matrix interface contributes substantially to the shear strength loss of the material. Water accumulation has been proven to contribute substantially to the shear strength loss of epoxy/E-glass fibre composites. It has also been shown that ingress of water through voids in a composite can cause plasticisation of the resin.

Conversely, certain evidence suggests that moisture absorption can be beneficial. It induces swelling of the resin matrix around the fibre and reduces the residual compressive stresses at the fibre/matrix interface caused by curing shrinkage. This results in release of the mechanical interlocking stresses between the fibre and the matrix which in turn can increase load carrying capacity. Some sources have also stated that although it is a common belief that glass fibres can be damaged by prolonged exposure to water, the most common forms of glass fibre, E, R and S glass are actually resistant to damage by water.

It is evident that further research is required to address the variability in opinion concerning the effect of moisture on FRP composites. However, these conflicting results all serve to highlight the need to primarily adopt a philosophy of selecting the correct fibre/resin combination, manufacturing technique and surface treatment to eliminate potential exposure to the fibre/matrix interface.

Hygrothermal Effects

Temperature influences the quantity, distribution and the rate at which water is absorbed into the composite material. As temperature increases, the amount and rate increase rapidly. Accelerated testing techniques have now been developed to assess this phenomenon.

Design Considerations

- The resin plays a critical role in protecting the fibre and also impedes the diffusion process. Preference must be given to the use of *appropriate* epoxies and vinyl esters. Appropriate unsaturated polyester resins should not be discounted as candidate materials. Isophthalic resins have demonstrated good service histories in applications such as tanks and pipes.
- In an aqueous environment a suitable thickness of resin rich surface should exist. This decreases the possibility of rapid ingress of moisture and other chemicals. This is augmented with the use of gel coats and surface scrim layers.
- The glass transition temperature (Tg) of the selected resin should be significantly higher (at least 20^{o}C) than the maximum service temperature of the component. In addition, to ensure that the resin achieves its full capability, the curing schedule employed during moulding should be in accordance with manufacturer's recommendations. It should also be noted that moisture absorption will affect the temperature resistance of a cured resin.
- The stress level in the composite should be minimised to combat degradation and enhance damage tolerance.
- Aramid fibres can also absorb large amounts of water, resulting in swelling. This type of fibre should be protected by coating ensuring sound bonding with the matrix and protection from water absorption.
- Moisture is not known to have a degrading effect on carbon fibre, but again the fibre/matrix interface may be affected if not fully compatible.
- It must be emphasised that the majority of test results are characteristic of environments created in laboratories under controlled conditions, and often result in degradation that is far more severe than would be seen in the field over equivalent periods of time.

Examples

Fibre reinforced composites are increasingly used in offshore and civil engineering structures. In these applications, composite materials are often exposed to harsh aqueous environments.

Investigation has revealed that although there is degradation in materials response, after specific periods of exposure it settles to asymptotic levels, indicating that designers can safely use composite materials if appropriate partial safety factors for strength are used.

It should be noted that a large number of applications in civil infrastructure are likely to be stiffness driven rather than dominated by strength requirements.

Pile encapsulation

Composite encapsulation systems consisting of fibre reinforced plastic jackets epoxy grouted to the substrate are an advanced solution to the problem of corrosion attack of seawater on structures such as marine piles, risers and platform legs. Concrete structures in the marine environment can suffer from cracks and spalling due expansion of reinforcement as corrosion takes place. Unprotected steel corrodes rapidly in the oxygen-rich splash zone. Alternative protection systems such as coatings, mastic wrapping or concrete encasement often prove unable to withstand wave forces and can deteriorate rapidly.

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 aggregate has the benefit of scouring the substrate further enhancing bond. The FRP jackets are translucent allowing the process to be monitored by diver. The encapsulation materials are robust, have very low permeability and are themselves durable in seawater. The systems are relatively straightforward to install and should provide maintenance free protection to the concrete structure for long periods. The system can also be used for H section steel piles, tanks, manholes and beams.

Polymer composite marine piles

Although composite piles do not have a long track record for use in civil engineering, their use can overcome problems with corrosion of steel and marine borer attack in timber piles. There are also environmental concerns over the use of tropical hardwoods or chemically treated softwoods. Composite piles have been used successfully in a number of large waterfront developments in North America.

Seapiles (TM) by Seaward International Inc. are made from 100% post-consumer recycled HDPE, coextruded with fiberglass or steel rods for strength. The piling has a high-density outer skin 5 mm thick and a lower-density foamed core. The standard product is 330mm in diameter and up to 32 m long, with eight 25 mm thick reinforcing rods. A square product called Seatimber(TM) for horizontal applications such as cross beams and fenders is also produced. Seapiles have been used by Hampshire County Council on the Hamble River, serving as channel markers. The piles were manufactured with green and red co-extruded outer skins, obviating the need to re-paint timber piles.

Creative Pultrusions Inc produce a circular section pile plus a composite sheet pile for bank protection and retaining walls.

Hardcore Composites produce large-diameter FRP monopiles in diameters up to 8 feet (2.4m) and continuous lengths in excess of 100 feet (30m), as alternative to multiple groups of timber piles, for higher loads and structural applications. The piles can be driven by standard impact, vibratory or jetting methods, either open-ended or with a driving shoe. Similarly with tubular steel piles, after installation they can be filled with concrete.

Thermal Effects

FRP composites are subjected to thermal cycles both during processing and throughout their service life.

Process related effects in conjunction with in service thermal exposure can have a significant effect on the overall response and durability of a composite structure or component.

In service thermal effects include:

- Temperatures above the cure temperature
- Freezing and freeze-thaw conditions
- Temperature variations and cycles

Low Temperature Effects
In FRP composites, a decrease in temperature causes the matrix to shrink. Relatively stiff fibres with a lower thermal expansion coefficient resist this shrinkage, and residual stresses arise in the material microstructure. However, except for severely cold environments, the induced stresses are of little concern. Generally, a steady increase in short term properties is seen down to -30^{o}C, at which point an increase of 8 - 16% is typical.

Significantly large temperature differentials can result in microcracking in the material. These microcracks can contribute to the degradation process by reducing stiffness and increasing permeability and water ingress through the fibre/matrix interface.

High Temperature Effects (Above processing temperature)
Initially, elevated temperature can be advantageous to composite components as it can result in an often-needed post cure. However, increased exposure has been known to cause degradation due to thermal effects, one being differing thermal expansion co-efficients and elastic properties between constituents. The long term effects of elevated temperature are still relatively unknown and this area has been highlighted for urgent further research.

It is reasonably well accepted that service temperature can be linked to the resin's *Heat Deflection Temperature* (HDT), provided that the composite is properly postcured. As a general rule, the HDT should be between 20 - 40^{o}C higher than the expected service temperature.

Freeze-Thaw Effects
Within the normal temperature range (+30 to -20^{o}C) freeze-thaw effects are insignificant unless a composite contains a large percentage of voids. A low voidage content does not allow frozen moisture to cause any appreciable damage. Severe thermal cycling (eg +60 to -60 ^{o}C) can cause microcracks to grow and coalesce to form matrix cracks. If prolonged, this can result in degradation of stiffness and other matrix dominated properties.

<u>Design Information</u>

- It is extremely important that the bond between laminates is of high quality and integrity. The greatest concern with temperature effects on composite structures is that freeze-thaw conditions can potentially result in debonding of laminates, either from concrete or other composite elements, particularly if there are gaps at the adhesive bond line.
- Room temperature curing epoxy resins have relatively low material operational limits, so particular attention should be given to the service environment of epoxy laminates.
- FRP composites should not be employed at temperatures above their glass transition temperatures (Tg). As a general design rule, Tg should be at least 20^{o}C above the maximum service temperature.
- Again the message is that although temperature and temperature cycling can affect the performance of a composite, consideration of the operating conditions at the design stage, along with careful selection of fibre and resin will ensure that performance and service life are not affected. Installation guidelines should specify surface preparation. New installations should be tap tested for unbonded regions.

Prepared by Trend 2000 Ltd and BRE (Partners in Innovation Project)
For further information please consult the project website: *www.polymercomposites.co.uk*

- Characteristic property changes in extreme temperatures must be understood for reliable structural design in cold regions. Hardening of the polymeric matrix at lower temperatures tends to decrease the unidirectional tensile strength of polymeric composites although the off-axis and transverse tensile strengths increase.

Examples

High Temperature FRP Composites in Flue Gas Scrubbers
FRP composites present an economic choice of material for parts exposed to the hostile environments found in gas scrubbers. A recently developed "high temperature" epoxy resin allows application under the aggressive conditions at approximately 200°C. The gaseous operating environment often contains highly corrosive mineral acids with water at ambient temperature also present. Therefore the vessel materials are subjected to a hot, wet corrosive atmosphere with thermal shock being caused by water cooling and heating by the gases. Various construction materials have been evaluated for the application and the combined beneficial properties of good temperature and corrosion resistance along with affordability made FRP composites an obvious choice.

FRP Tanks
FRP Tanks can be fabricated to withstand the corrosive attack of most acids and alkalis at a wide range of operating temperatures. FRP tanks retain their high strength properties at low temperatures, storing liquids with a minimum heat loss. Because they are lighter in weight than steel tanks, they are easier to handle and install.

Resins
A number of resins can be specified to withstand temperatures greater than 180°C, in combination with severe chemical environments. Other materials that could operate under these conditions, such as alloyed steel, are more expensive and have to be continually replaced due to corrosion.

Effects of Fire

A significant concern in any application utilising composite materials with organic based matrices is the possibility that the material may ignite and release potentially harmful toxic smoke. The resin component of most FRP's is undoubtedly combustible, and as this forms a significant proportion of the material, it must be taken seriously in any consideration of fire. Different resins exhibit various characteristics and a range of retarding low smoke additives are available to customise fire response still further.

The use of FRP composites in building structures, upon which stringent fire regulations are placed, shows they are in compliance as with other more conventional construction materials. Moreover, FRP composites are generally poor conductors and discourage the spread of fire. In fact, if a suitable filler is utilised, these materials can exhibit superior fire resistance than many conventional materials.

Another inherent safety aspect becomes apparent when the outermost layers of a composite lose their resin from heat exposure. They then act as an insulating layer, slowing heat penetration and internal evolution of gases.

Design Information

- Glass reinforced phenolic resins have inherent characteristics of low flame spread, low smoke generation and low heat release rate. This infers that they are less likely to be affected by a fire than more commonly available composite materials such as polyesters and vinylesters. The designer should take this into consideration from the outset in any new specification.
- Where a fire hazard exists, the fire hazard characteristics must be identified and the appropriate building and other fire code requirements determined and conformed to. These include: Intended use of the structure, potential ignition sources, potential mode of flame and smoke spread and means for detection (this could be an embedded smart fibre), suppression and extinguishment.
- GRP is virtually impossible to ignite when damp. If used with sprinkler/quench sprays which detect smoke, fire becomes much less of a likelihood.
- Surface fire spread can be reduced with a final surface coating of polyurethene. This enhances durability and surface finish, but consequently adds cost.
- Fire performance can depend heavily upon the method of fixing - especially the case for sandwich panels and wall cladding. An inner backup wall of incombustible material can provide the required resistance.
- Primary consideration should be given to the 'total fire behaviour' of the building/structure. However, there is a need for a greater understanding of this situation and its study continues (for all materials, not only composites).

Examples

FRPs are employed in a vast amount of small and large building structures, all of which have to meet stringent fire regulations. If the fire performance of composites was non-conforming then these materials could not be extensively used as they are.

ATS Ducting systems offer the combined advantages of high fire and corrosion resistance to hot exhaust gases. ATS uses a low smoke, fire safe resin to provide a rigid structural shell, which encloses the corrosion resistant liner.

Phenolics are used within firewalls and blast walls, where in combination with other desirable impact properties, the composite provides highly desirable characteristics for an application where reliable performance is critical.

Futura Composites in the Netherlands have recently commenced production of a carbon fibre ashtray!

Large offshore composite structures

In 1998 Norsk Hydro awarded a contract for the Heimdal 2000 riser platform to an alliance between ABB and Heerema T¿nsberg. The field development project is preparing the Heimdal Gas Centre for receiving and distributing the gas from the Oseberg field by 2000 and later from the Huldra field. ABB was awarded the supply of a module combining the local electric room, the local instrument room and the onboard workshop. The combined module is of a glass-fiber-reinforced sandwich construction weighing 65 tons. It marks a regulatory breakthrough for high-quality composite structures with respect to fire, explosion, noise and thermal insulation. The blast walls are designed to withstand a jet fire.

Apart from weight reduction, there is no need for additional thermal insulation as the composite itself is self-sufficient. Maintenance costs are negligible as no paint is required. The colour is built into the material. Similar technology and materials can be applied to all kinds of small structures and modules, shelters, living quarters and fire and blast walls.

Effects of Ultraviolet (UV) Radiation

Solar ultraviolet radiation has been shown to be deleterious to organic materials. UV radiation that reaches the Earth's surface comprises about 6% of the total solar radiant flux; wavelength 290 - 400nm, which coincides with the dissociation energy of most polymers. Polymers are thus greatly affected by exposure to UV radiation.

The effect of UV radiation on FRP composites is well documented from the extensive research and testing undertaken in this area. It is well known that with prolonged exposure to sunlight the matrix may harden and colour change or pigment loss may occur.

However, these effects of UV exposure are limited to the top few microns of the exposed surface, and are generally abated with the simple application of a UV resistant coating to the surface. Consequently, in thicker sections the UV degradation effect on structural properties is minimal, this being proved by numerous laboratory and field applications. The effects of temperature, moisture, wind-borne abrasives and other environmental conditions serve to complicate the sole influence of UV radiation and are not fully understood.

Highly light stable resins and pigments have now been developed which further enhance the long term stability of FRP composite structures.

Design Information

- Select an appropriate resin and fibre for the application. One concern is the degradation of aramid fibre. Therefore this should not be specified in structures to be exposed to prolonged sunlight, or those of thinner section.
- Common practice for outdoor applications is to apply a gel coat or other protective coating. This, however, still only serves as a self-sacrificing layer and may not give lifetime protection to a structure from UV induced damage. The protective coating will eventually be degraded by UV and periodic inspection and maintenance is required.
- Ultraviolet inhibitors can be included as an additive to the composite matrix to complement a gel coat in more severe exposures.
- It is known that the UV degradation in polymers is often magnified by the application of mechanical loads. Therefore it is imperative that loads are accounted for in any test procedure.
- A thorough knowledge of the service environment of the structure is important at the outset of the design stage. Sunlight exposure and intensity details should be obtained in order to select appropriate matrix and fibre materials and specify suitable section thickness' etc.
- Check for potential combined exposure regions to sunlight and moisture. The most damaging effect of UV exposure is probably not due to surface limited direct UV degradation, but to the increased potential for moisture ingress at the damaged regions.

Examples

Countless FRP composite structures which have long exposure to sunlight are currently in operation. Some of these are listed below. The success of these is based on the informed selection of materials and periodic inspection and maintenance of protective layers.

Building structures and fascias, bridges/parapets, utility poles/antenna/telecommunications, lighting columns and roadside safety equipment, tanks/storage vessels, external pipework/ducting, stairs & railing, doors, window/door frames etc. etc.

Some pleasure boats used in the Mediterranean and other tropical areas have a high proportion of GRP material in their structure. These boats must retain their appearance for many years, and the GRP materials have been shown to be capable of this.

With the correct combination of matrix resin and fibre, coating system and component thickness, all of these applications have been well proven in the field and shown not to suffer from UV degradation.

Creep Behaviour

Creep is the permanent deflection of a material under long term loading. Like most materials, FRP composites are prone to creep under sustained loading. It is important that this property is controlled to ensure long life expectancy. In composites, creep also depends on temperature (higher creep at higher temperatures) and operating environment, for example higher creep levels are seen when submerged in liquid than in air.

The effects of creep should be determined and included at the design stage. The addition of the fibre to the polymer matrix provides inherent resistance to creep in a suitably designed FRP component. Creep will not be a major concern if loading on the structure/component is kept below appropriate working stress levels.

<u>Design Information</u>

- In most cases, creep is resin dominated and can therefore be minimised with the appropriate selection and processing of resins - liason between suppliers and manufacturers is crucial at the design stage.
- Preferential orientation and suitable volume fraction of fibres in the composite serves to decrease any potential creep effect.
- In general, highly cross-linked thermosetting polymers exhibit lower creep rates than thermoplastic polymer composites. Commercial fibres such as glass and carbon do not exhibit high levels of creep under normal loads. Aramid is an exception and should be avoided where creep is a major issue.

<u>Examples</u>

Creep is only one of the properties that determines the overall durability of composite structures and components. However, it will be more influential in certain applications than others, particularly those where higher loads are involved. Two examples where good creep performance is required are wind turbines and aircraft rotor blades. These are subject to tight working tolerances and have to perform under constant high load cycles.

FRP's are utilised in many structures that need to exhibit favourable creep performance. These commonly include building structures, bridges, walkways etc. The successful long-term performance of these structures illustrates that creep is not a concern if given necessary consideration at the design stage.

Fatigue Effects

Fatigue characteristics represent the response of a material to cyclic loading. Repeated cyclic loading usually results in a decrease in strength properties of the material. The degradation and failure of bridges, highways and piping is nearly always associated with cyclic and dynamic loading. Composites are considered to have excellent fatigue response in comparison to metallics.

The loading characteristics need to be fully understood at the design stage; loading may be:

- Mechanical - eg. due to vehicle traffic etc.
- Thermal - due to variations in temperature
- Chemical - eg. seasonal road treatments, oxidation, water etc.

There now exists a reasonable amount of data for glass/vinylester, polyesters and epoxy composites. Thus, if the operating conditions are well defined, the service life of the system can be predicted with some degree of accuracy. However, with increasing service life and service condition complexity, reliable life prediction becomes more difficult. Uncertainty arises from the effect of several degradation processes that act on the constituents alone or in combination. These will control the service life of the structure.

Verification of service life via a "representative exposure" is highly desirable when specifying materials for intended service lives of 30-100 years. Existing life prediction techniques, for example the 'critical element approach' developed by Reifsnider, can be utilised to combine processes, sequences and severity to estimate life *under known conditions*. Computer based modelling can help identify critical service conditions and combinations of events influential on the durability of the structure.

Design Information

- Specify a limit service life below that of the fatigue limit. Below the fatigue limit (in No. of cycles) fatigue failure is highly unlikely and the component has essentially an infinite life, obviously not considering other degradation effects.
- Fatigue strength is directional in a composite. With off axis fibre orientation, fatigue strength is a function of load axis fibre ratio, stacking sequence and cycling parameters.
- Compressive fatigue performance is inferior to tensional performance in a composite. In flexural fatigue loading, initial damage usually develops on the compressive side of the specimen.
- The fatigue performances of carbon and aramid are known to be superior to those of E- & S-glass composites.
- Those measures recommended for protection against creep will also aid fatigue performance.

Examples

FRP Composite Bridges

Composite bridges exhibit excellent fatigue performance, and in many cases FRP material is purposely specified to combat this effect, where other traditional construction materials have failed in the past. The first FRP bridge was constructed in 1975, and consistent performance by this and other subsequent constructions has led to worldwide uptake of this material in bridges.

Vehicular bridges have been shown to resist all three of the aforementioned loading types, the thermal loading coming from daily temperature fluctuations, along with seasonal cycling, and chemical loading resulting from road treatments such as de-icing salts.

Composite bridges provide economical alternatives to steel structures which require constant maintenance and are still susceptible to rust and corrosion. The use of FRP composites in the primary structure also brings the further economic advantage of reduced traffic disruption due to the lighter weight and quicker installation times

Some of the most fatigue critical applications may be found within the aerospace industry. Wings and helicopter rotor blades (now predominantly FRP materials) are subject to intense cyclic loading, as are the blades on wind turbine machines. The FRP materials used in this type of application must have guaranteed performance as human safety is a priority.

Vandal Resistance

One of the major advantages of composite materials is their superior Strength-to-Weight and Strength-to-Stiffness ratios than most other conventional materials. They also have high energy absorbing characteristics. These properties make composite materials ideal for applications requiring impact resistance, including the resistance to malicious attack on a structure.

The reinforcement in a composite spreads the induced load over a wide area, thus increasing resistance to impact damage. Thermosetting resins also cannot be softened or made malleable with the application of heat, another tactic of vandalism.

The corrosion resistant properties of composites also ensure that structures do not become a target for attack due to degradation after long service.

Design Information

- Composite manufacturing techniques provide the ability to produce components and structures in single forms. This reduces the requirement for joints and seams, and acts as a deterrent to vandalism and potential burglary.
- Thermoset resins do not readily distort or ignite, and consequently offer higher resistance to impact damage.

Examples

Military Applications

The uptake of composites by the military, backed by extensive research and development, is a prominent example that they are capable of preferential performance in hostile or severe environments. Numerous Military components are manufactured from composite materials because of their light weight and high impact resistance. An example is portable communications and munitions carriers, the requirements for light weight and impact resistance being paramount.

Bicycle Stations

On the domestic side, a company in the US has recently started producing bike-parking stations out of FRP composites. The high impact resistance of the material, along with its light weight and consequently ease and speed of installation were major reasons for its choice in this application. The units could be manufactured in one piece with no external or internal frame and wall seams or joints. This reduced the cost of the structure whilst significantly improving its deterrence and resistance to vandalism in a product that will contain highly desirable items. A further benefit is that the UV stabilised gel-coat finish reduced maintenance requirements (it does not need painting or re-painting) and allows solvent removal of graffiti - a major problem with metallic units.

FRP Security Booths and Kiosks

Canadian company MNG Plastics manufacture booths and kiosks for security guardhouses and other uses exclusively from FRP materials. Demand for affordable, secure and functional booths for security guards has heightened following the September 11th terrorist attacks in the United States. The FRP materials offer the required strength, durability and cost effectiveness to meet these demands. The modular design can cater for a wide range of requirements and provides a quality, maintenance free appearance

The Cost of Composites

It is usually the case that the initial cost of composites is higher than conventional construction materials. However, it is the total Life Cycle Cost of the material that should be considered, and this is where composites offer significant economic benefits (and makes their use feasible in highly cost competitive construction sector). Particularly in the construction industry, it is the *installed* cost of the final component that is the important factor, which is often competitive with conventional construction materials.

Many *through-life* costs can be eliminated or radically reduced with the use of FRP composites:

- Inherent corrosion protection reduces maintenance costs. The costs associated with the periodic repainting of steel are eliminated.
- The cost of rehabilitating structures damaged by corrosion, such as the blast cleaning of steel, are removed with the use of composites.
- Replacement costs are delayed through the longer service life obtained from composite structures.

Construction and Transportation costs are also reduced with the use of lower density FRP composites:

- Charges for freight are usually based on weight - the low densities of FRP composites reduce shipping costs for a given volume
- There is less need for heavy construction handling equipment at construction/installation sites. Hire charges for this type of equipment are reduced.
- The ease of handling of components requires fewer personnel to manoeuvre or assemble components in the field. Significantly faster construction times are accomplished.
- Pre-assembly of certain components can reduce field assembly costs and times.
- In highway or bridge applications, the increased speed of location and fabrication of composite components minimises the costs associated with the disruption of traffic flow.

Historically, carbon fibre has been almost exclusively employed in aerospace and other very high performance applications, restricted by its high cost. However, the situation has changed largely and quickly. A number of the fibre suppliers have developed 'bulk' grades of fibre using a lower cost textile precursor, which accounts for 50-70% of the total fibre cost, bringing substantial savings.

Larger production facilities have ensured that the new materials can be produced in higher volumes at lower cost. The combined savings have led to a significant reduction, up to 70%, in the price of high strength carbon fibre. The improved economics of these fibres has led to their uptake across other industry sectors, including construction, where cost was the main inhibitor. Carbon fibre is now widely used for the repair and strengthening of structures such as bridges and concrete sections. The superior strength properties considerably extend the life of these structures and provide seismic protection.

Design Information

- The cost of composite materials can be broken down into five main areas: Fibres, resin, consumables, labour and machine. Fibre is the major costing element and must therefore be chosen carefully.
- The superior strength and stiffness properties and overall durability of composites allows structural design to be less conservative, meaning less raw material with associated cost saving.
- An FRP component may incorporate inherent benefits such as thermal insulation or rain water disposal, allowing off-set savings over conventional construction materials and design.

Examples

The Halgavor bridge installation in Cornwall, UK highlights the transportation, construction and through life cost savings that are gained form the use of FRP composite materials. The volume of traffic now seen in the UK implies that the costs of bridge construction and maintenance are strongly influenced by traffic management and delay costs resulting from lane or road closures. The need for rapid construction and easy maintenance lead directly to the selection of lightweight, self finished GRP materials that are durable and require little or no maintenance. Additional benefits arose from the pre-fabrication of the deck unit, which required no finishing, both minimising installation time and traffic disruption. The same benefits apply to bridge strengthening with composites, which has seen large uptake in recent years due to its cost effectiveness. Other more conventional options, such as steel plate bonding, require costly scaffolding and traffic management arrangements, and the greater weight of the components adds further safety implications.

Recycling

Fibre reinforced polymer composites (FRPs) are increasingly being used in construction due to their low weight, durability and tailor made properties. The UK composites industry produces 240,000 tonnes of composite products a year with 11% of this being for the construction sector. Although widely considered to be un-recyclable, several recycling options have been developed or investigated, including reintroduction of ground FRP waste into the production process, pyrolysis to generate fuel gas and fluidised bed recovery of glass fibres. Waste FRP has also been used experimentally in the production of wood/plastic composites, road asphalt and concrete. Incineration with energy recovery or in combination with the production of cement is also an option. The main barrier to the uptake of recycling, however, remains lack of market for waste material.

Unlike post consumer waste plastic such as polythene which can be melted and is relatively easy to reprocess, FRP is thermoset and contains a considerable fraction of glass fibre and filler such as calcium carbonate and sand. Polymer composite products are often highly engineered. However, generally, the value of the material constituents and hence any waste or recovered demolition material is low. Composite materials have high strength and stiffness, thus heavy machinery is required for shredding and grinding. Polymer composite products are also often bulky and lightweight, being engineered sections or profiles, which makes transport of non-ground waste uneconomic. There are no actual FRP recycling facilities in the UK and at present the most common disposal method is landfill.

Current and impending waste management legislation will put more pressure on the industry to address the options available for dealing with composites waste. EU waste management directives on landfill, incineration, construction and demolition waste, end-of-life vehicles, electrical and electronic equipment, and UK government policy such as the Waste Strategy 2000, the sustainable construction strategy, the landfill tax, and local government policy could all influence the composites industry. Such waste legislation focuses on dealing with waste through the waste hierarchy and will therefore put more pressure on solving fibre reinforced polymer composites waste management through recycling and reuse. The end-of-life vehicle directive is the most significant policy change relating to the use of FRPs and has some bearing on the composite industry concerned with vehicle component manufacture. Although it has no immediate bearing on the construction sector, it could negatively influence attitudes towards composites in purchasing policies and in future legislation. There are, however, often significant technical, environmental, safety and cost benefits in using polymer composite products. Polymer composite marine piles, for example, offer a low maintenance alternative to the use of tropical hardwoods such as greenheart, or the use of creosote/ copper-chrome-arsenic treated softwood. Polymer composite strengthening of structures such as bridges, silos and cooling towers, and wrapping of concrete columns, enables highly cost effective maintenance or upgrading of existing infrastructure.

Reuse of FRP waste

Seawolf Industries produce a waste FRP grinder designed to reduce breakage of the glass fibre reinforcement. The ground material is then mixed with a polyester based syntactic foam and the combined material re-applied using a specially designed spray gun.

RRECOM Project — Recycling and Recovery from Composite Materials

The aim of the research was to stimulate growth in the use of thermoset polymer composites through the development of technology for the recycling of scrap material. Two approaches were taken:

1. Brunel University focused on strategies and technology for the re-use of suitably comminuted (ground) thermoset recyclate as a functional filler for polymers leading to products with added value (especially suitable for recycling pure and uncontaminated scrap material). Important factors include reducing the size of the thermoset scrap to a form suitable for incorporation into the host polymer matrix; economics of the

comminution procedure; and identification of filler characteristics which may add value to the host matrix by influencing its physical or chemical properties. An integrated process technology was developed to combine necessary functional steps within a unified continuous conversion procedure. Moisture and volatiles were removed during the comminution stage aided by vacuum extraction. The recyclate was combined with the polymer matrix ensuring that effective dispersion and wet-out occurred. A range of polymer compositions were created containing fibre-reinforced polyester and phenolic recyclate derived from industrial scrap. The thermoset recyclate fillers have been successfully incorporated into polypropylene and it is possible to enhance mechanical properties relative to unfilled polymer, especially in the case of phenolic material which has a higher glass content and greater fibre integrity than the polyester waste used. Reinforced phenolic recyclate has been successfully incorporated into polyester resin and it is evident that the presence of this recyclate can increase fire performance (reduction of smoke emission) relative to unfilled polyester resin.

2. The University of Nottingham focused on the use of fluidised bed thermal processing techniques to recover energy and fibres in a form suitable for recycling into high value products (suitable for contaminated and mixed scrap material from end-of-life applications, e.g. from the automotive industry). Initial investigations were conducted using a typical industrial sheet moulding compound based on polyester resin. The optimum process temperature was 450 C as glass fibres suffer a reduction in strength during processing at higher temperatures. At 450 C the recovered fibres (in the form of short individual filaments) had the same stiffness but 50% of the strength of virgin glass fibres. The fibres were of good quality (purity over 80%) with little surface contamination thus the fluidised bed process effectively cleaned the fibres of the polymer matrix. Two opportunities for reuse of the recovered glass fibres in applications where they could obtain high value were demonstrated. In the production of a glass veil product and as a direct substitute for virgin glass fibre in a thermoset moulding compound. A key aim of the project was to demonstrate that the fluidised bed process was capable of recycling end-of-life components especially those of large volumes that may arise from the automotive industry. A painted car boot lid made from a double skin glass reinforced plastic, based on a polyester resin with a polyurethane foam core and metal inserts was processed in the fluidised bed at 450 C. This mixed and contaminated feed was processed in the same way as the other GRP materials and the recovered glass fibres were no different in quality to fibres recovered when pure composites were processed. The fluidised bed process has also been shown to be able to process scrap carbon fibre composites and yield good quality carbon fibres that are potentially of high value. An economic analysis of the fluidised bed recycling process showed that an operation recycling in excess of 10 000 tonnes per year of glass fibre composite material would enable the process to be commercially viable. These are quantities that do not exist in the UK at present. A carbon fibre recycling plant has the potential to be viable at much lower annual throughputs and may show a more favourable prospect of being viable in the short term.

RECOMP Project - Development of a Novel Recycling Process for the Recovery of Plastic Composite Materials

Pera Technology are leading the project management team consisting of representatives from each of the partners together with representatives of the DTI and EPSRC.
The project aims to address the problem of composites recycling by developing a process that combines pyrolysis to liberate the composite components with physical separation processes to achieve recyclable materials in their optimum form. The materials produced will be fully assessed for reuse in a range of applications. The overall aim of this research is to develop a recycling process that will give a commercially viable route towards sustainable manufacture of composite products.
The project and developed technology aim to raise the profile of composites as fully recyclable materials to enable them to continue to bring performance, cost and environmental benefits to a wide range of applications and products. The final benefit will be a substantial reduction in the quantity of composite waste being disposed of to landfill.
The evolving technology of pyrolysis can be considered to offer a potentially favourable route for the recovery and reuse of both the hydrocarbon and inorganic content of the composites with the capability of producing recovered streams in the optimum condition for reuse. In particular, the process temperature and subsequent separation stage can be tailored to liberate the component materials whilst minimising thermal degradation. It is anticipated that the pyrolysis-based recycle route would be applicable to all composite wastes. The materials recovered will be optimised and their recycling and reuse fully evaluated to achieve viable and sustainable recycle routes with the potential for commercial uptake

Recycled Thermoplastic Structural Panels

A recently launched Waste Resources and Action Project (WRAP) in the East Midlands has the specific objective of producing durable, high volume sandwich panels from recycled plastics. Techniques will be developed to convert plastic waste on a continuous basis into a variety of lightweight core materials. High strength/stiffness fibre reinforced thermoplastic skins will be laminated to the core to form high impact, lightweight structural panels. The project will also demonstrate that the panels themselves can be re-cycled into low grade fibre reinforced skins and/or core materials and be converted back into panels, thus sustaining the recycling route. The study will determine the recyclability of different types of reinforced plastics and exhibit the reformable characteristics of thermoplastics.

The concept overcomes the problem of high processing and recycling cost associated with polymers, sometimes making them more expensive than virgin plastic materials. The 'composite' solution allows a high proportion of low-grade waste to be used as a core, while the relatively thin thermoplastic skin significantly upgrades the mechanical performance whilst minimising cost.