Durability for FRP Composites in Construction

Overview

Fibre reinforced polymers (FRPs) have been used successfully over the past 60 years in a wide range of applications in the marine and civil engineering sectors. These include pipes, tanks, slabs, walkways, bridge decks, gratings, column reinforcing wraps and reinforcing bars for concrete. In many of these applications FRPs are exposed to one or more environmental influences. FRPs can be formulated to meet the durability requirements of even the harshest environment. FRPs are durable inasmuch as they are water resistant, thermally stable and cannot rust.

Performance Requirements

Most construction materials have a finite life. Whilst FRPs are no exception to deterioration, they can easily be designed to meet even the most challenging service environment. FRPs are being specified for applications in service environments ranging from the Middle East to Antarctica. In addition, there are continuous improvements in resin technology (new improved varieties of resin tend to be developed around every seven years).

All construction materials are subject to deterioration in service due to exposure to certain environmental elements. Material deterioration may begin through one or more of the following influences:

- Mechanical stresses, including static loading, fatigue, repeated minor impact, erosion (including water erosion) and abrasion
- Chemicals (water, solvents, fuels, oils, acids, cleaning liquids, atmospheric oxygen, oxidising agents, caustic alkalis etc)
- Radiation (including sunlight)
- Heat, including high temperatures and large and rapid fluctuations in temperature
- Biological attack from bacteria, fungi, insects and marine borers.

Outdoor weathering can involve all five factors simultaneously. Materials can often survive individual threats such as ultraviolet light or a specific solvent, but they can still succumb to a combination of influences.

Effects of Weathering

Resins on their own vary a great deal in their ability to withstand outdoor use for long periods. Poor performance can sometimes be completely transformed by trace additives, so the solution becomes one of using the right grade of resin and appropriate additives. The effects of outdoor use on structural FRPs such as glass/polyester or carbon/epoxy laminates are confined to the surface and do not often involve a serious threat to their structural integrity. The effects are mainly cosmetic including:

Fading and darkening - Colour fading or darkening without loss of gloss can be due to the use of unstable pigments or pigment combinations which change colour after exposure. This can be mitigated by the appropriate choice of pigment.

Yellowing - Yellowing is due usually to the darkening of the base gelcoat resin, especially in whites. This can be overcome by using a more UV-resistant resin and better UV additives, and by ensuring good cure of the resin. Surface Coatings also provide protection.

Blooming - Blooming is caused by migration of an incompatible pigment or additive to the surface of a gelcoat to give a mat, faded appearance.

Loss of gloss and chalking - Loss of gloss is normally brought about by erosion of the surface layer of the gelcoat due to chemical and/or physical damage.

The erosion of gelcoat after many years' service with no treatment or repair can bring about the eventual mechanical failure of a laminate by exposing the reinforcement underneath. It should be noted that the onset of loss of gloss or chalking does not presage the immediate disappearance of the gelcoat which normally lasts for many years longer.

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Prediction of Durability

Predicting the weathering performance of building materials (including FRPs) can be carried out based on artificially accelerated laboratory weathering experiments and field trials. The latter take several years and relatively few organisations have been able to generate large data banks. However, there are now sufficient case histories of FRP products to give us performance data extending over three decades or more. Accelerated methods can be undertaken indoors or outdoors.

All resins and organic reinforcing fibres (but not glass or carbon) absorb water to varying extents, usually at a very low level, and are water permeable. The effects of moisture, once absorbed, are complex. Changes in the appearance and properties of the FRP product may be slight or severe, chemical or physical, permanent or reversible. The more moisture absorbed, the more deterioration in properties is likely to be found and the less reversible are the changes on drying. Reductions in strength and modulus are observed. An initial increase in strength is possible, because of the relief in internal stresses, which is followed by a decline after further absorption.

Thick laminates are much less affected than thin ones in a given period and this explains the durability of many early FRP structures. It has been calculated that an epoxy-based FRP with a typical diffusivity towards moisture of 10-13m2s-1 would require 13 months to reach saturation if left in a tropical climate at 35C and 95% relative humidity (RH) if the thickness was 2mm, but a 90mm thick section would need 1342 years.

Despite these reported effects of moisture, careful selection of material and component design can overcome any potential problems. FRP components, being tailor-made parts, are designed to prevent moisture absorption. Cutting or drilling on site exposes fibre and resin which could affect the absorption properties of the component and is strongly discouraged. FRPs have been used in the marine industry for many decades with very few reports of moisture ingress problems.

Effect of Temperature on Performance

Maximum temperatures for use of FRPs are governed by two main factors: the resin's glass transition temperature (Tg) and the temperature at which chemical decomposition starts to become significant. Decomposition temperatures are seldom actually reached in service life. FRPs are pre-eminently loadbearing materials, and it is their temperature-dependent mechanical properties, such as Tg, or the closely related heat distortion temperature, that usually determine the maximum use temperature.

Minor Impact Damage

A common hazard for FRPs is minor impact damage resulting from scratching or collision with small objects. The resulting damage is often difficult to see with the naked eye, but it can include delamination, matrix cracking, fibre debonding and in severe cases, fibre fracture. Most impacts occur in practice at an oblique angle which tends to reduce the severity of normal incidence, no matter whether damage is measured by the damage area, indentation depth or residual strength. The fact that there is scope for on-site repair of impact damage in FRPs, even in remote areas, is an important favourable consideration in their durability.

Conclusions

FRPs offer the ability to tailor-make components with the properties needed to meet performance requirements of a particular situation. Correct material selection and design means that FRPs can perform in the most demanding of service environments.

FRPs offer good durability, their performance enhanced by incorporation of additives and correct maintenance procedures. FRP components have demonstrated service lives of over 40 years to date in construction applications in a variety of different environmental conditions with minimal maintenance requirements. Advances in resin and additive technology mean that design lives of 60 – 120 years are possible.

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