Durability of GRC

Introduction

Glass-fibre reinforced concrete (GRC) – a composite of a cement/fine aggregate matrix with glass fibres – is one of the most versatile building materials available to architects and engineers, and has been used since the early 1970s for a wide variety of applications worldwide, including cladding, façade renovation, noise barriers and permanent formwork.

During 35 years of use careful attention has been paid to the durability of the material, in terms of its performance in aggressive environments, and also its mechanical properties. The Alkali Resistant glass fibres used in GRC contain > 16% zirconia and a coating on the glass to maximise long term performance. Materials engineers have studied the performance of GRC and the interaction between the Alkali-Resistant glass fibres and the matrix for over 35 years. As a result, probably more is known about how the behaviour of GRC varies with time than with any other composite material.

This durability research has been incorporated into design guidelines for GRC, ensuring that specifiers should have confidence in the durability of GRC which has been designed, manufactured and installed according to GRCA guidelines. The purpose of this report is to give a brief explanation of the issues surrounding GRC material durability.

Properties of GRC and Design

GRC is a cement-rich low permeability composite, and as such has a high chemical resistance and a very low rate of carbonation, giving a high degree of durability. It will normally contain no steel reinforcement, and therefore does not have the same durability concerns and cover requirements as steel reinforced concrete.

The combination of high modulus glass fibres and a high quality cement matrix leads to a composite with predictable properties which are well understood and well documented.

Although many GRC formulations have a high ultimate failure stress and a ductile failure mode, the design of GRC products adopts a conservative approach and the design is performed within the elastic limits of the material (i.e. the design stress will be below the critical stress level at which the first cracks appear in the GRC matrix). This is best demonstrated with reference to a typical flexural stress / strain curve (Figure 1). This approach is different from the design of steel reinforced concrete, which is designed to crack, but in a manner controlled by the steel reinforcement.

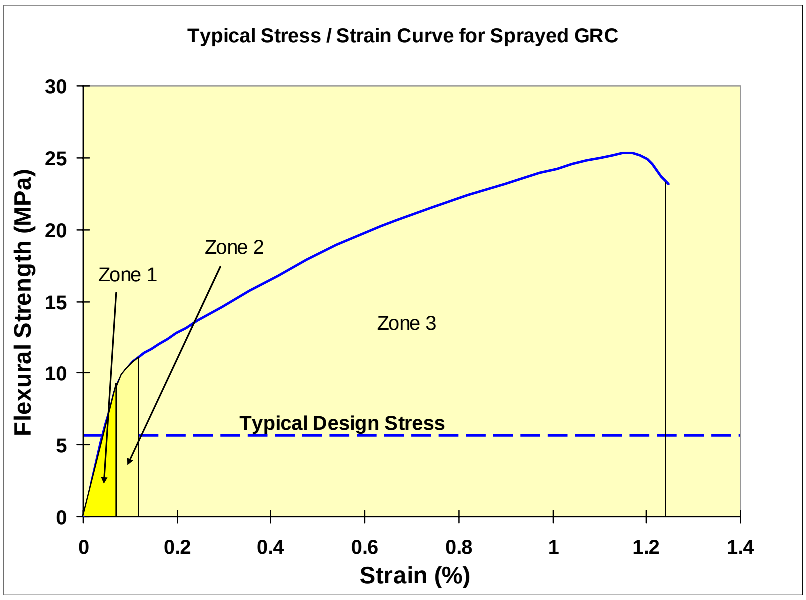
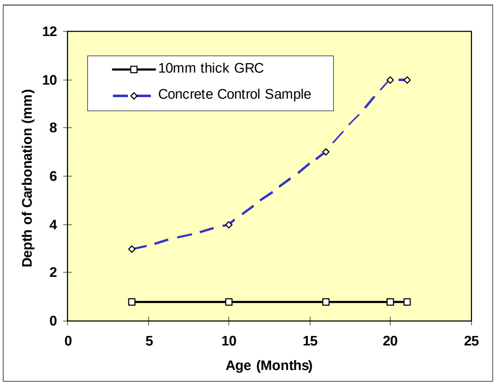


Fig. 1 Typical Flexural Stress / Strain Curve at 28 days

Credit Lyonnais Bank, London (1975)
Standard GRC

Heathrow Express Station (1998)
9,000 GRC panels with polymer addition



Comparative Depth of Carbonation in Accelerated Testing

San Francisco Towers, USA
155,000 GRC elements with polymer addition

In Zone 1, the fibres and matrix work together, with the high modulus glass fibres preventing cracking; in Zone 2, the load is gradually transferred to the fibres as the matrix begins to crack; in Zone 3, the fibres alone carry all the load. GRC components are normally designed so that the stresses and strains a component experiences stay in Zone 1. Zones 2 and 3 provide ductility which gives added safety so that accidental localised overloads will not cause the whole component to break.

Zone 1 is not generally affected by ageing (except there will normally be an increase in the elastic strength as hydration of the matrix continues): thus the **design** properties of GRC do not decrease with time, and in fact the factor of safety against cracking would normally increase. In this respect the service lifetime of a GRC component may be considered indefinite. In normal outdoor environments, as GRC ages, Zone 3 is slowly reduced in magnitude, and eventually, Zone 2 will also be reduced, but this does not affect the design life of the product, since the design does not make use of these ductile properties.

Mechanisms and Modification

There are two reasons why the ductility associated with Zones 2 and 3 is slowly reduced. The cement in GRC continues to hydrate – react with water – for months or years after casting. This causes calcium hydroxide (CH) crystals to build up around the fibres. This is both highly alkaline and also abrasive, and its build-up locks the fibres into the matrix, preventing fibres from slipping after the GRC cracks. The surface coating on AR glass fibres helps to prevent the build-up of CH crystals around the fibres.

If required the ductility of GRC (Zones 2 and 3) can be retained for longer by the use of matrix modification. Although this can make the GRC ductile for longer, it has little impact on Zone 1, and therefore would not normally affect the design stress levels. Matrix modification can take different forms:

1. Standard GRC made using OPC can be modified with the addition of an acrylic polymer and / or a highly active pozzolanic additive (e.g. metakaolin).
    a. Acrylic polymer impedes the moisture movement within the GRC, which assists curing, and is also found to have some benefit in improving ductility through its presence at the fibre / matrix interface.
    b. Metakaolin reacts with the CH as it is produced, resulting in a lower alkalinity and less CH to crystallise around the fibres.
2. Calcium sulpho-aluminate cements have also been developed to replace the OPC use in GRC. These create no CH during hydration, and result in a lower-alkalinity matrix.

Conclusions

The durability of GRC is proved by the wide variety of contracts which have used it worldwide over the past 35 years. In many applications it is used in preference to other materials (FRP, precast concrete, timber, terracotta, etc) because of its superior durability.

The normal design properties of GRC do not degrade with time. The change in ductility with time will depend on the matrix type, but is well understood and is factored into the design. For good quality GRC, ductile lifetimes of at least 60-80 years can be confidently expected in UK weathering conditions.

Project References

Emirates Palace, UAE
120,000m^2 Standard sand blasted GRC

Shepard Hall, City College New York (1990's)
75,000 GRC elements with metakaolin and polymer addition