Cem-FIL® GRC Technical Data

Vetrotex

Cem-FIL®

CONDITIONS OF ACCEPTANCE

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1. INTRODUCTION

Glass Reinforced Cement (GRC) is a composite material consisting of a mortar of hydraulic cement and fine aggregate reinforced with Cem-FIL alkali resistant glass fibres. The GRC may contain additional filler materials, pozzolanic materials and admixtures. The fibre contents are typically 3% to 5% by weight depending on product application and production method employed. The properties of GRC depend on a wide range of variables. These include method of manufacture, mix formulation, fibre product type, length and orientation, admixtures used, etc. A GRC material may therefore be tailored to meet the particular requirements of a specific application. The information given in this publication mainly refers to GRC materials having an aggregate: cement ratio of up to 1:1, incorporating Cem-FIL AR glass fibre and made by the spray and premix processes. These GRC materials have been widely used for many years and their properties and characteristics studied extensively.

GRC is a family of composite materials that combine the high compressive strength properties of cement mortars with significantly increased impact, flexural and tensile strengths imparted by the fibre reinforcement.

GRC products are safe, have good chemical resistance and will not rot or corrode. GRC is made of inorganic materials and will not burn, has negligible smoke emission and offers good fire resistance. In some circumstances GRC is made containing polymer materials which may slightly affect some fire performance properties.

GRC is normally of relatively thin cross section, giving a low component weight which allows savings in handling, storage, transportation, and installation compared with traditonal concrete products.

There are two main methods of manufacturing GRC

- Spraying of fibre and slurry simultaneously onto a mould, by manual or mechanical means.

  Typical products made using the spray process include architectural cladding panels, channels, tanks, facade elements, ducting and permanent formwork.

- Premixing the fibre and slurry and then processing the mixture by vibration casting, extrusion, injection moulding, etc., to produce the end product form.

  Typical products made using the premix process are sunscreens, planters, electrical transformer housings, slates and tiles, junction boxes and drainage components.

2. RAW MATERIALS

2.1 Cem-FIL AR Glass Fibre

Cem-FIL AR Glass Fibre is a continuous filament, alkali resistant glass fibre with high durability in cement. The fibre composition lies within a critical region of the Na_2O CaO ZrO_2 SiO_2 system.

Some typical properties of Cem-FIL AR Fibre are as follows:

• Single filament tensile strength 3.5 GN/m^2	3.5 GN/m^2
• Strand tensile strength 1.7 GN/m^2	1.7 GN/m^2
• Young's Modulus of Elasticity	72 GN/m^2
• Specific Gravity	2.68
• Strain at breaking point (strand)	2.4%
• Filament diameter	14 or 20 µm

There are two product forms used in cement reinforcement. These are Chopped Strands, for use in premix GRC and as a reinforcement in renders and concretes, and Rovings, for use in the spray production of GRC or for continuous reinforcement.

Chopped Strands consist of continuous strands chopped to uniform length while maintaining the integrity of the original strand. They are available in lengths of 3mm to 35mm. Chopped Strands are normally designated by length, by the Tex (mass in grammes of a kilometre length) of the individual strands (bundle of filaments) and by reference to their size coating. The size coating on Chopped Strand products is designed to give resistance to mechanical damage in processing or designed to allow the strands to disperse into individual filaments on contact with moisture.

Chopped Strands are supplied packed either in boxes or bags, or in bulk shipments.

A Roving is a grouping of individual parallel strands wound as a bundle into a cylindrical shaped package containing typically 20 kg of fibre. It may be:

1) chopped in a 'gun' and sprayed simultaneously with the cement matrix material to provide composites which may be of complex profile.

2) chopped on-site to reduce transport costs, and allowing direct feeding into premix processes

Rovings are designated by the Tex of the whole Roving, the Tex of the Strand and the number of strands they contain and by reference to their size coating.

Rovings are normally shrink-wrapped in plastic film and packed in cardboard cartons.

2.2 Cements

The most widely used cements in GRC manufacture are Ordinary Portland Cement (OPC) and Rapid Hardening Portland Cement (RHPC) and should be to the relevant National or International Standards. RHPC is chemically very similar to OPC but is more finely ground and, because of this, develops strength more rapidly at early ages. It is often preferred for GRC for this reason. It should be noted that the term 'rapid hardening' has a different meaning to the term 'quick-setting'. GRC made with rapid-hardening cement stiffens and initially hardens at a similar rate to that of OPC: it is after the initial hardening that the strength increases more rapidly. It should be stored and used in the same way as OPC. RHPC is slightly more expensive than OPC.

White Portland cement is made from raw materials containing only a very small quantity of iron. It is used in GRC where a white or light coloured finish is required. Because of this and the fact that white cement costs more than OPC, extra care must be taken in handling the cement to avoid contamination, and in the batching, mixing, and transportation to ensure that all equipment is kept clean. It is equally important to make sure that the finished GRC is protected against discoloration. The setting and strength development properties are similar to those of grey OPC and, apart from the extra care necessary, there is no difference in the methods of using it or in storage.

Care should be taken when curing white GRC because it gets dirty very easily in the early stages of its life and is very difficult to clean later.

Other types of cement, such as High Alumina Cement, Sulphate Resistant and Rapid Setting Cements may be used in certain applications and should be to the relevant National Standard. Care should be taken that the choice of cement is appropriate and complies with statutory regulations.

It is important that cement is correctly stored. Cement must be kept dry, and damp air can be as harmful as direct moisture. Cement stored in bulk in a silo will be satisfactory up to about 3 months. Cement in normal 3-ply paper bags stored under good conditions can lose about 20% of its strength after 4 to 6 weeks. Therefore, bagged cement should be used soon after delivery.

2.3 Fillers

2.3.1 Sand

Silica sands to the following specification are readily available in most countries of the world

1. *All sand should be washed and preferably dried.* It will then contain less soluble matter and fine particles, and also allow easier control of water:cement ratio.

2. *Particle Shape and Surface Texture*
   Particle shape - rounded or irregular preferred.(Flaky and/or elongated should be avoided)
   Surface texture - smooth preferred. (Honeycombed should be avoided).

3. *Chemical Composition (%)*
   Sands of the following composition have been used in the UK. and have been found to be satisfactory.

Silica	>96
Moisture	<2
Soluble salts (i.e. alkalis)	< 1
Loss on Ignition	<0.5
Organic matter	- must not affect the setting of the cement
SO_3	0.4 (4000 ppm) max.
Cl	0.06 (600 ppm) max.

Other sands should be satisfactory as long as they are deemed suitable for good quality concrete.

The silica content of the sand need not necessarily be as high as 96%. There are good quality sands with much lower silica content that are suitable for GRC manufacture

The value for loss on ignition can be accepted up to 3%, providing the material is hard, non crushable, non-reactive and of similar shape and grading to that described below.

4. *Grading*

Sprayed GRC

a) Particle size

1.2 mm max. (i.e.100% passing BS 14 sieve, ASTM 16 sieve) for sprayed GRC 2.4 mm max. (i.e.100% passing BSS 7 sieve) for premix GRC

(b) Fine fraction

Max.10% passing 150mm (BSS100, ASTM 100 sieve).

Premix GRC

The maximum particle size is not critical but the quantity of fines should be limited because of the effect on water demand and hence the water:cement ratio.

2.3.2 Crushed Aggregates

Many varieties of aggregates used for concrete may be crushed to a suitable grading for use in GRC. Examples of such aggregates are marble, limestone and granite.

2.3.3 Pozzolans

1: PFA fly ash is a pozzolanic material and is the ash extracted from flue gases of boilers fired by pulverised coal. PFA should be to the relevant standard for PFA used in concrete. Blended PFA cements suitable for concrete manufacture are available in many countries. Typically they contain 25-35% PFA.

2: Silica Fume (or micro silica) is a very fine material and is an industrial by-product. It is often supplied in the form of a water based slurry. It is usually only used in specialist mix designs and processes.

3: Cem-Star is a particular grade of metakaolin which has very high reactivity with hydrating cement. It provides GRC with very good long term strength retention. (See Appendix A of Chapter 5)

2.4 Water

Water should be clean and free from deleterious matter and should meet relevant standards for water used to make concrete.

2.5 Admixtures

Standard concrete admixtures or those specially formulated for GRC manufacture may be used as appropriate to the particular process and to obtain the required properties of GRC. Admixtures are generally added to produce the following effects.

In manufacture of GRC

- increasing the workability without increasing the water/cement ratio
- improving the cohesion
- reducing segregation
- reducing bleeding
- retarding the setting (stiffening) process
- accelerating the setting (stiffening) process.

On properties of hardened GRC

- increasing the rate of early strength development
- increasing the strength
- decreasing the permeability
- improving fire resistance

Admixtures are added to mixes in small amounts and care must be exercised to ensure that only the correct dose as specified by the manufacturer is added.

Calcium chloride based accelerators are not normally acceptable.

2.6 Pigments

Pigments may be used to colour GRC. Special care is required to achieve uniformity of colour and the strong colours are not usually achievable without significant variation. Low quality pigments may lose or change colour with time.

2.7 Health Aspects of Raw Materials

2.7.1 Fibre

Cem-FIL fibres at 14µ and 20µ diameter are substantially above the range of respirable particles. Evidence to date has shown that these fibres cause no long term health hazard, although some temporary skin irritation may be experienced.

Reference: "Continuous Filament Fibre Glass and Human Health". APFE Brussels.

2.7.2 Other Component Materials

Relevant Codes of Practice and manufacturers' recommendations regarding the handling and use of these materials should be followed.

3. MANUFACTURING METHODS

3.1 Sprayed GRC

In the manufacture of GRC by the spray process, simultaneous sprays of cement/sand mortar slurry and chopped Cem-FIL AR glass fibre are deposited from a spray-head into or onto a suitable mould. The spray-head may be hand held or mounted on a machine. The mortar slurry is fed to the spray gun from a metering pump unit and is broken into droplets by compressed air. Cem-FIL AR fibre roving is fed to a glass fibre chopper/feeder, mounted on the spray head which chops the fibre to predetermined lengths, typically 25-40 mm and injects the chopped strands into the mortar spray so that a uniform felt of fibre and mortar is deposited on the mould. The slurry has typically a sand:cement ratio of up to 1:1 and a water:cement ratio of 0.33. The water:cement ratio should be kept as low as possible consistent with satisfactory spray and incorporation characteristics, as increasing the water:cement ratio leads to a reduction in the strength of the product. Admixtures may be used to obtain the required workability. The proportion of fibre to slurry is adjusted so that the resulting composite contains typically 5% by weight of glass fibre. Comprehensive detail is contained in the "Guide to Spray Manufacture" issued by Cem-FIL.

3.1.1 Manual Spray Method

The operator holds the spray-head in his hand and moves it to-and-fro across the mould, directing the stream of material perpendicular to the mould surface, until the required thickness of GRC has been built up. Roller-compaction ensures compliance with the mould face, impregnation of the fibre by the slurry, removal of trapped air and development of adequate density. The rolled surface may be finally trowelled smooth. Thickness control is achieved by use of pin-gauges. A typical output of a single hand-unit is 10-12 kg of GRC per minute. The process results in one surface of the product having an ex-mould finish and the other surface a rolled or trowelled finish. Products are covered with polythene sheet after spraying and normally demoulded the following day and then cured.

The process is labour intensive but is capable of producing complex shapes and is extremely versatile. The process is used for manufacture of a wide range of components including cladding panels, agricultural components, facade elements, formwork and ducting.

3.1.2 Mechanised Spray Method

The basic spray method described above is readily mechanised. For the production of components which are substantially flat or of shallow profile, moulds are propelled along a roller or flat conveyor passing beneath a transverse unit on which the spray-head is reciprocated. Outputs are up to 25-30 kg/minute. Forward and transverse speeds are balanced and feed sprays are accurately adjusted to ensure uniform laydown and correct fibre distribution through the composite. The finished product has an ex-mould finish on one side and a trowelled or rolled finish on the other.

Equipment of this type is used in the commercial production of single-skin and sandwich cladding and facade elements, formwork and sewer linings. Folding moulds may be used in the manufacture of shaped components such as ducts and channels.

3.1.3 Spray-Dewatering Process

This process utilises the principles of the mechanical spray equipment described above to form a continuous GRC felt which is then dewatered to consolidate it and to give a workable sheet material which may be allowed to set in the flat state: alternatively, it may be formed whilst still in the ‘green’ state to produce corrugated or profiled sheets, box sections, pipes, etc. With the dewatering technique it is possible to utilise a much wetter and more easily sprayable mix, up to 0.5 water:cement ratio. The GRC felt is subsequently dewatered to about 0.28 water:cement ratio and can give a material of higher density and higher initial strength than non-dewatered material. The finished product has a matt texture on one side. The other side may be given a trowel finish if required. Forming of complex shapes is carried out manually, but standard corrugations or profile forming may be mechanised.

3.2 Premixed GRC

All premix processes involve the blending together of the cement, sand, water, admixtures and chopped strands of Cem-FIL fibre in a mixer prior to being formed.

To produce a premix of the correct quality it is necessary to mix in two stages. The first stage is designed to produce a high quality slurry to achieve the necessary workability and allow for the uniform incorporation of fibre. The second stage is the blending of fibres into the slurry at a reduced speed.

It is more convenient to carry out both stages in the same piece of equipment, but separate mixers can be used for each stage.

The actual mix formulation used depends upon the type of product being made, but a typical mix has a sand:cement ratio of 2:3 and a water:cement ratio of preferably less than 0.35. It is essential to keep the water:cement ratio as low as possible consistent with maintaining workability of the mix, so admixtures are used.

Up to 4% by weight of chopped strands can be incorporated into the mix, but typical fibre content is 3%. The fibre length is normally 12 mm because above this length the mix becomes difficult to work. A fibre length of 25 mm is generally found to be the maximum useable.

Although the glass fibre strands are designed to withstand the mixing action, it is normal, as indicated above, to add the fibre at the end of the mixing cycle to minimise fibre damage. Comprehensive detail is contained in the "Guide to Premix Manufacture" issued by Cem-FIL.

3.2.1 Vibration Casting

This process is very similar to the vibration casting of pre-cast concrete. It involves pouring the wet GRC premix into an open or double-walled mould and vibration enables the slurry to flow and removes trapped air. Alternatively the premix may be pumped to the mould through a hose using a peristaltic pump.

For standard products a timed discharge can be used to produce constant product weights.

The process is extensively used to make large sunscreens or screen walling panels using polystyrene or rubber moulds which have sufficient flexibility to absorb the small shrinkage that takes place during setting.

Other products produced by this process include litter bins, electrical transformer housings, planters, junction boxes and decorative mouldings.

3.2.2 Sprayed Premix

This is a variation of the premix method whereby the mix (including chopped glassfibres) is blended in a mixer and the resulting material is then delivered by a suitable pump to a special spray head, which is used manually to deposit the material in an open mould. In this method the thickness of material is normally delivered in one layer and no vibration or other compaction is used. In comparison with vibration casting, the moulds may be less robust since they are not subject to vibration and also are open, without cores.

A glassfibre content up to a maximum 4% by weight can be incorporated but a content of 3%, usually in the form of 12mm chopped strands, is typical. The properties of the finished material are similar to those of vibration cast premix of equivalent glassfibre content.

The method is suitable for the production of small architectural components and decorative features such as cornices, corbels, columns, window sills and small cladding panels.

3.2.3 Pressing

Rapid production of relatively simple small components e.g. promenade tiles, lids etc. is possible by pressing techniques. The equipment may vary in complexity according to the output required, with fully automatic systems being possible for high volume production, but the basic pressing operation is performed on a charge of wet premix GRC with dewatering taking place.

3.2.4 Spraymix

This is a combination of premix and spray methods and uses normal spray equipment together with vibration casting.

A spray unit delivers glass fibre and slurry on to a baffle plate above a slot in a double-walled mould on a vibrating table and the vibration enables the wet GRC to slide from the plate into the mould. This eliminates the need to mix the glass fibre and slurry together in a mixer prior to mould filling and reduces fibre damage to a minimum. Normal chopping roving is used rather than the chopped strands used for premix processes.

3.3 Miscellaneous Processes

The application of Cem-FIL fibre to more conventional cement and concrete formulations is presented in this section, but it should be noted that the properties obtained in these applications are not those of GRC of the types previously described, and are not discussed subsequently.

3.3.1 Renders, Floor Screeds and Concrete

Formulations containing between 0.5% and 2.5% by weight of Cem-FIL AR fibre have been developed for rendering, applied by either spraying or trowelling to a thickness of 4-10 mm. The finished render has superior resistance to impact and shrinkage cracking and is less permeable to water than normal sand-cement render. Fibre reinforced render is also used in dry blockwall construction and external insulation systems.

Other formulations containing similar quantities of fibre have been developed for floor screeds. The superior impact and crack resistance of fibre reinforced screeds enables them to be laid more thinly than conventional screeds. They also provide a good surface for the final floor finish treatment.

3.3.2 Sprayed Concrete,Guniting and Shotcreting

Cem-FIL AR fibre at about 1% by weight of total mix can be added to normal sprayed concrete mixes, giving a crack resistant and impact resistant lining from a relatively thin cover compared with normal sprayed concrete. Both dry guniting and wet sprayed concrete processes can utilise Cem-FIL fibre reinforcement with the advantage of reduced rebound compared with steel fibres.

3.4 Curing of GRC Products

The hydration of cement is a relatively slow process at ambient temperatures and for this reason concrete products are usually allowed to hydrate or ‘cure’ for several weeks after casting to give full strength development.

GRC products are normally of comparatively thin section, manufactured with a lower water:cement ratio than most conventional concretes, and are prone to rapid drying. If this occurs before hydration is complete the cement never achieves its full strength and the properties of the GRC are adversely affected, so more attention to curing conditions is necessary.

3.4.1 Moist Curing of GRC Products

To ensure complete hydration it is essential that products are kept moist immediately after manufacture and during the curing period. Several methods of achieving this are currently in use, mainly: storage in a humidity chamber or fog room, sealing in polythene bags, or total immersion in water.

For all products the curing period can be divided into three parts:

(I) A pre-demoulding cure to give sufficient strength to the product for demoulding. This is important and is carried out by covering the component closely with polythene to minimise air flow across the GRC surface thus enabling the component to retain as much water as possible.

(ii) The main cure as described above.

(iii) Post-curing during which the product is normalised to the ambient conditions prior to storage or use, particularly in extreme hot or cold conditions.

The rate of hydration will be different in each of these periods, but at the end of the curing cycle the GRC should have been brought up to the final strength requirements. The particular curing regime will depend upon the product, manufacturing process and mix design, and must be such that the required level of properties is achieved.

During the curing period the strength of the GRC products will be building up from an initially low level and care is necessary in demoulding, handling and particularly in the main cure to ensure that products are not overstressed whilst in a relatively weak state since they could be permanently deformed or subjected to damage which may not be visible.

As with concrete, it is possible to use accelerated curing schedules, either by the use of chemical accelerators or by a higher temperature cure. This may be commercially attractive, but conditions must be carefully controlled to achieve consistent and acceptable strength levels.

A controlled post-curing regime is important where the conditions in storage or use will be substantially different, in either temperature or humidity, from the main cure conditions. In particular, the combination of direct sun and low humidity could cause problems with differential drying shrinkage even though the GRC strength is high at this stage in its life.

As a guide to practical curing regimes, Cem-FIL GRC products will achieve a substantial proportion of their ultimate strength when the main cure is carried out for 7 days, in a humidity of greater than 95% RH, and with a minimum temperature of 15°C. A suitable post-curing regime will allow the remainder of the strength to be realized.

3.4.2 Air Curing

An alternative method of curing the GRC is to incorporate polymeric materials into the GRC mix. The polymer formulation used must be capable of forming a film around the mix particles, thus allowing the moisture in the GRC to be retained and hydration to continue. The polymer materials are normally added at dosage rates of between 2% and 10% of polymer solids to cement weight. After demoulding the GRC product can be allowed to cure in ambient air conditions, but care must be taken to ensure that the air temperature is above the minimum film formation temperature of the polymer.

The properties of GRC cured in this way are similar to those of the same basic formulation (i.e. sand:cement ratio, water:cement ratio and glass content) made without polymer additions and moist cured as described in section 3.4.1.

However the addition of polymer materials to GRC may affect the fire performance properties.

4. PRINCIPLES OF GLASS FIBRE REINFORCEMENT

4.1 The Effect of Glass Fibres on the Strength of the Mortar Matrix

Fibrous materials have been used for many thousands of years to stabilise materials that are inherently unreliable. Straw in mud bricks and horse hair plaster are two old examples. Asbestos fibres in cement is a more modern example. The role of the fibrous material is to include small regions of high strength material which control the propagation of cracks from voids in the matrix and hence give a reliable tensile strength to an otherwise brittle material with an unreliable tensile strength and poor impact characteristics

Cem-FIL alkali resistant glass fibres perform this role in cement based materials such as mortars and concretes, which are inherently brittle and have unreliable tensile strength. The full strength of the materials can thus be developed because of the presence of glass fibres, and it can be shown (Refs. 1 and 2) that the presence of sufficient glass fibres will increase the mortar strength above the expected levels.

4.2 Tensile Stress-Strain Curves for GRC

When GRC is tested in tension, the load extension curve produced takes one of two forms, which are shown here schematically.

Curve Type A is representative of freshly made sprayed GRC or aged Cem-FIL star GRC which exhibits durable behaviour and Curve Type B is representative of premix GRC or of standard aged sprayed GRC.

Figure 4.2 (a)
Curve Type A:
Representative tensile load-extension diagram for GRC.

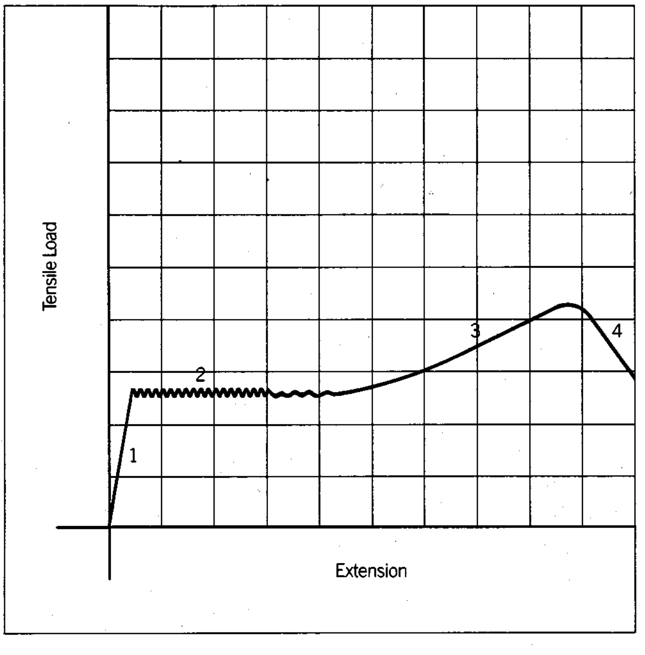
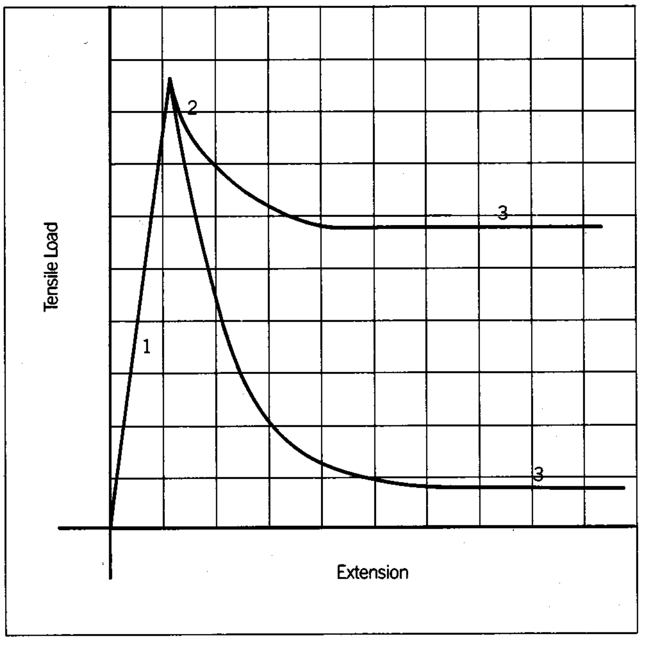


Figure 4.2 (b)
Curve Type B:
Representative tensile load-extension diagram for GRC.



In both of these diagrams, the initial linear portion of the curve, Region 1, is determined by the fibres and matrix acting together as an elastic composite, the stiffness and stress being given by the appropriate version of the 'Law of Mixtures'. Thus for example:

Equation 1 $E_c = k_1k_2k_3E_fV_f + E_mV_m$
and
Equation 2 $\acute{O}_c = E_c \Sigma_c = (k_1k_2k_3E_fV_f + E_mV_m) \Sigma_c$
i.e.
Equation 3 $\acute{O}_c = k_1k_2k_3\acute{O}_fV_f + \acute{O}_mV_m$

where
E = Young's Modulus
V = Volume fraction
∑ = Strain
Ó = Stress
k = Efficiency factor

(For a more detailed theoretical analysis see Chapter 5 of Ref. 12)

The subscripts c, f and m denote composite, fibre and matrix respectively. The fibre property terms in these equations are modified by 'efficiency factors' k_1, k_2, k_3, which may not be identical in both equations but are usually similar in value. They take account of the effects of the use of fibres infinite lengths (k_1), in bundles or strands (k_2) and oriented in different directions (k_3).

At about the mortar failure stress, cracks propagate around the glass fibres and the subsequent behaviour depends upon whether the fibres are sufficient to carry the load (type A) or not (type B). This transitional point of the curve is designated the bend-over point (BOP).

In GRC designated type A, the glass fibres act as reinforcing agents. Moving away from the crack face, load is transferred back from fibre to matrix, by shear forces at the fibre matrix interface and in the matrix, until the stress and strain in the matrix has again risen to failure level and a new crack is formed. This continues until the material is traversed by an array of very fine cracks - often difficult to see - at a spacing governed by the matrix strength, bond strength and fibre concentration (Region 2). On further loading the fibres slip and the existing cracks widen (Region 3). In these ways regions of considerable extension, and high energy absorption are introduced.

The Ultimate Tensile Strength (UTS) arises when the bridging fibres across one particular crack are either broken or pulled out of the matrix, although the failure is gradual rather than abrupt (Region 4).

The criterion for fibres breaking or pulling out of the matrix depends upon the length of fibre embedded in the matrix and the strength of the bond. There is a critical length of strand above which the strand will always break if the fracture plane is at the mid-point of the strand, but if the strand has shorter than half this critical length on either side of the fracture plane, the strand will always pull out. The critical length is proportional to the strength of the fibres and inversely proportional to the physical shear bond between the fibre and matrix. It also depends upon the strand geometry.

In GRC designated type B, the UTS occurs slightly above the level of the BOP, after which the load drops (Region 2) to a level which the fibres can sustain (Region 3), the fibres subsequently being broken or pulled out of the matrix. The values for load in Region 3 will depend on the amount, orientation, length and strength of the fibre.

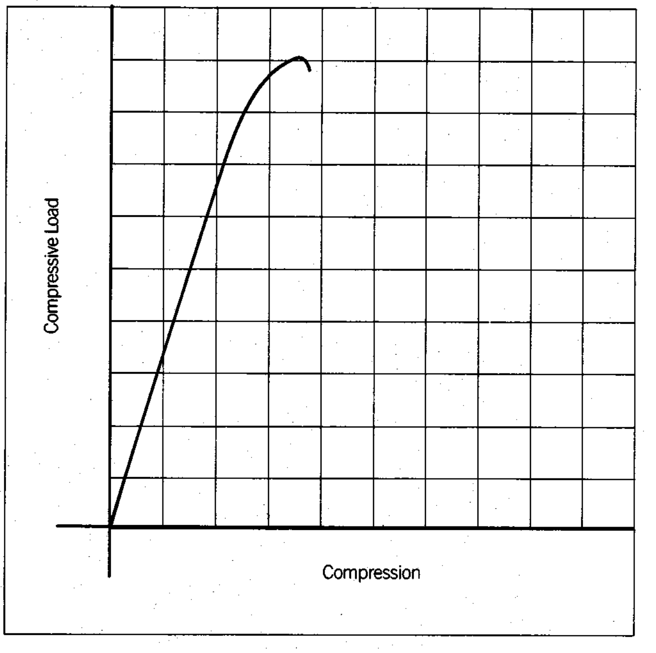
Practical tests (Ref. 10 and 11) demonstrate the features of types A and B up to the maximum loads, although the transition between Regions 2 and 3 of the type A is often difficult to detect. Type A GRC is characterized by visible multiple cracking of the sample whereas type B material often has only one visible crack.

Most testing machines are unable to detect the regions after the UTS, but these can be demonstrated (Ref. 3) by using special test equipment.

4.3 Compressive Stress-Strain Curves for GRC

The stress-strain curve of GRC when tested in compression is linear up to high stresses and is similar to the curve which would be obtained from testing the matrix without any fibre.

Figure 4.3
Representative load-compression diagram for GRC.



The effect of fibre depends on the orientation of the fibre relative to the direction of the compressive stress; fibres running parallel to the direction of compression create fracture planes which can reduce the compressive strength to about 70% of values obtained in testing across the plane of fibres (Ref. 4). The compressive strength of GRC is several times the tensile strength.

4.4 Bending Stress-Strain Curves for GRC

Considering a rectangular GRC beam subject to bending and assuming a linear strain distribution through the beam up to failure as in Simple Bending, the upper surface of the beam will be in compression and the lower surface in tension. For a given strain, the stresses in the GRC must follow the tensile and compressive stress-strain curves.

Figure 4.4 (a)
Schematic stress-strain curves for GRC

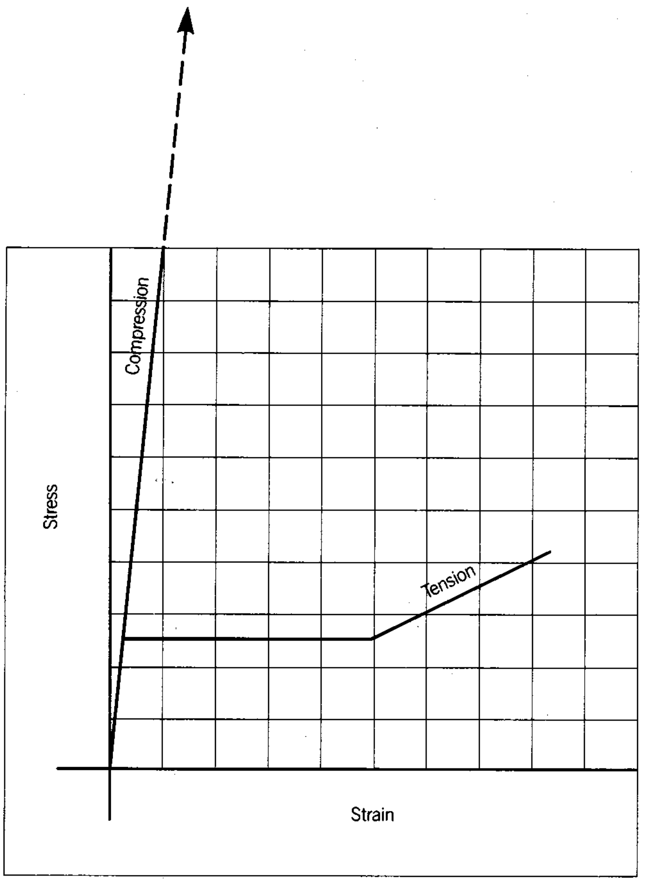
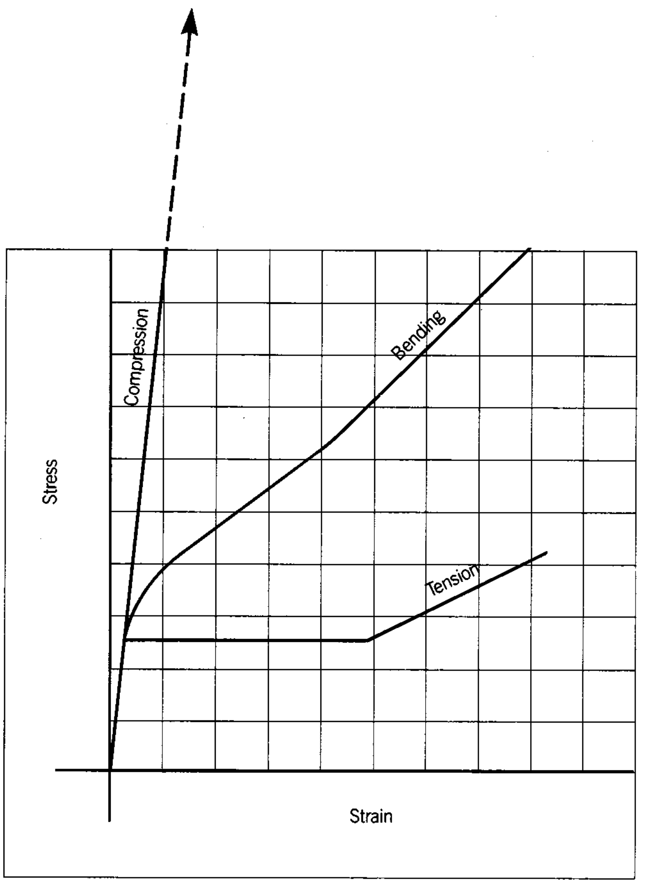


Figure 4.4 (b)
Schematic stress-strain curves for GRC.



Up to the tensile BOP strain the resulting stress distribution remains linear. Above the BOP strain the distribution of stress on the tensile side of the neutral axis changes, and to satisfy the law of force equilibrium (Total Tensile Force = Total Compressive Force) the neutral axis moves towards the compressive side, which again causes a redistribution of stress through the thickness.

If apparent stress and strain are calculated from simple bending theory, the resulting bending stress-strain curve lies between the compressive and tensile curves. It contains two points of interest, the elastic limit, commonly termed the Limit of Proportionality (LOP) and the highest calculated stress, termed the Modulus of Rupture (MOR).

If the tensile and compressive stress-strain curves for any particular specimen of GRC are known, the bending curve can be estimated (Ref. 3 and 5). (The reverse operation can also be performed, but with more difficulty). Such an estimate of the bending curve suggests the LOP is similar to the BOP, but practical tests show the LOP to be about 1.7 times the BOP. However, brittle materials often show higher strength in bending than in tension (Ref. 6) so this is not surprising.

The MOR is found to be about 2.5 times the UTS for most variations of GRC composition and this has been justified theoretically (Ref. 5).

4.5 Strain-to-Failure of GRC

This measure is usually associated with tensile or bending tests of GRC and is the strain at which the UTS or MOR is achieved.

4.6 The Effects of Orientation of Glass Fibre

The fibre is only able to provide strength and stiffness in the direction of the fibre. Fibres which are not aligned with the direction of stress act in a less efficient manner than those that are. Hence, a composite with the fibres all aligned in one direction will provide maximum resistance to stress in that direction. Apart from some specialist processes, it is not practically feasible to make use of this orientation property to its maximum effect.

In thin section products, the major stresses are normally in the plane of the section and advantage can be taken by using sprayed GRC which lays down the fibre in a random 2-dimensional array in the plane of the material. In this way the efficiency factor k_3 (Section 4.2) is about twice as high as for premix GRC where the fibres are randomly orientated in 3-dimensions and form GRC which is virtually isotropic. The use of Chopped Strand Mats in premix GRC enables the properties to approximate to those of sprayed GRC as long as there is sufficient glass fibre present.

A further effect of orientation is on the quantity of fibre that can be incorporated into the matrix. The packing density of the glass fibre strands is higher if there is some degree of alignment and this shows in the manufacture of GRC, where 5% by weight (4.1% by volume) is commonly used in sprayed GRC, but only 3.5% by weight (2.9% by volume) is used in premix GRC.

The effect of orientation also needs to be considered in a negative sense. If the fibres are assumed to be randomly orientated (in either 2 or 3 dimensions), then unintentional alignment of the fibres may give rise to planes of weakness. This can arise in the manufacture of premix GRC if the mix is badly placed. Machine sprayed GRC, and occasionally hand sprayed GRC, can be subject to preferential alignment of the fibres and it may be advisable to measure properties in two directions (Ref. 7).

The most obvious effect of orientation arises in the different shear properties of sprayed GRC.

4.7 Shear Strength of GRC

If the shear stresses are confined to the plane of the GRC, the measured in-plane shear strength is similar to the UTS. This follows logically if the material is assumed orthotropic or isotropic, because the shear stress should equal

$$\frac{\text{UTS}}{(1+\gamma)} \quad \text{where } \gamma \text{ is Poisson's Ratio}$$

However, if there is a shear stress out of the plane of sprayed GRC, there will be a complementary interlaminar shear stress which is not resisted by any contribution from the fibres. It can be postulated that the interlaminar shear strength of sprayed GRC will be similar to the matrix shear strength or to

$$\frac{\text{BOP}}{(1+\gamma)}$$

and practical results support this (Ref. 4).

4.8 Impact Resistance of GRC

Impact loads on GRC normally inflict damage over a localized area. The presence of the fibres in GRC restricts the propagation of cracks outside the zone of stressed material. This damage can often be repaired with no detriment to the GRC products.

Impact strength of GRC is normally measured using a modified Izod test machine, on samples 25-50 mm wide and 6-12 mm thick. The values obtained in such a test are of little use except for the purpose of comparison with samples of GRC and other materials subjected to the same test. Such comparisons show the impact strength of GRC to be higher than that of many similar materials.

The impact strength of GRC is high when many long fibres fail by being pulled out of the matrix, this process absorbing a great deal more energy than fibre breakage. However, this implies relatively low values for the factors k_1 an d k_2 in equations 1 and 2 (Section 4.2), indicating that the fibres are used somewhat less efficiently in terms of the GRC strength.

The impact strength of GRC is lower when few fibres are pulled out of the GRC. If the fibres have a very short critical length (see Section 4. 2) the GRC may exhibit brittle characteristics under impact loads.

4.9 Elastic Modulus and Poisson's Ratio of GRC

The Elastic Modulus of GRC usually quoted is the gradient of the initial linear part of the tensile stress-strain curve. While it should be possible to obtain values from bending tests, most commercial testing machines are too soft to give an accurate value without using some correction factor.

Although the “Law of Mixtures” (Section 4. 2) applies, it can be shown by the insertion of any reasonable values in equation 1 that the composite modulus is not significantly different from the modulus of the matrix. Practically measured values are not in disagreement with this.

The same reasoning applies to the value of Poisson's Ratio which is also similar to that of the mortar matrix.

4.10 Effect of Ageing on GRC

In common with many materials the properties of GRC can alter with time. The degree to which the properties can change depends upon the formulation of the GRC and its working environment.

Most GRC is made from a cement/sand matrix reinforced with strands of glassfibre which are composed of 100-200 filaments. Fresh GRC exhibits a high degree of flexural toughness (Impact Strength). This is partly due to the fact that the cement paste is surrounding rather than penetrating the strand. Crack energy is dissipated at the strand - matrix interface and also within the strand bundle itself. As the cement continues to hydrate over long periods of time the voids between the individual filaments in the strand become progressively filled with hydration products from the free lime and the composite becomes less capable of absorbing crack energy. There is also an effect arising from the reaction products building up on the surface of the fibres themselves. These create stress raisers on the surface of the fibre which results in a reduction in the fibre strength even though there is no significant reduction in the fibre diameter.

The micro-crack control mechanism as described in Section 4.1 is relatively unaffected since the fibre is always many times stronger than the matrix.

The net effect of ageing of standard sprayed GRC is some reduction in Flexural and Impact Strength accompanied by an increase in the elastic region up to the Limit of Proportionality as the bond between the fibres and matrix increases and the cement continues to hydrate. These changes are temperature and moisture dependent and use of this is made in accelerating the effect to determine long term behaviour (Ref. 9). Real time ageing tests in a variety of environments demonstrate that mechanical properties level out even under the most adverse conditions. The long term properties are stable.

The formation of hydration products is dependant on the matrix formulation. Modifying the mix design to include pozzolanic materials such as Cem-Star which react with the free lime has the effect of reducing the changes in mechanical properties by limiting the development of the bond between hydration products and fibres. The degree of improvement depends upon the amount and reactivity of the pozzolan used.

Matrix-dominated properties do not change significantly with time although conditions in service can affect properties such elastic modulus and LOP which are lower in dry conditions than in wet conditions. The mix design of most GRC formulations is characterised by higher cement contents and lower water/cement ratios than is common with mortars and concretes. These are factors which are known to improve the durability of cementitious products.

The general effect of ageing on the stress-strain behaviour of standard GRC can be illustrated by the figures 4.10 (a) and 4.10 (b). GRC which initially follows a type A curve (sprayed GRC, high fibre content) will exhibit a gradual decrease in UTS and strain-to-failure until it approaches the type B curve. GRC which initially follows a type B behaviour (premix GRC, lower fibre content) will only exhibit a change in the value of stress for the tail portion of the curve.

Figure 4.10 (a)
Curve Type A
Representative tensile load-extension diagram

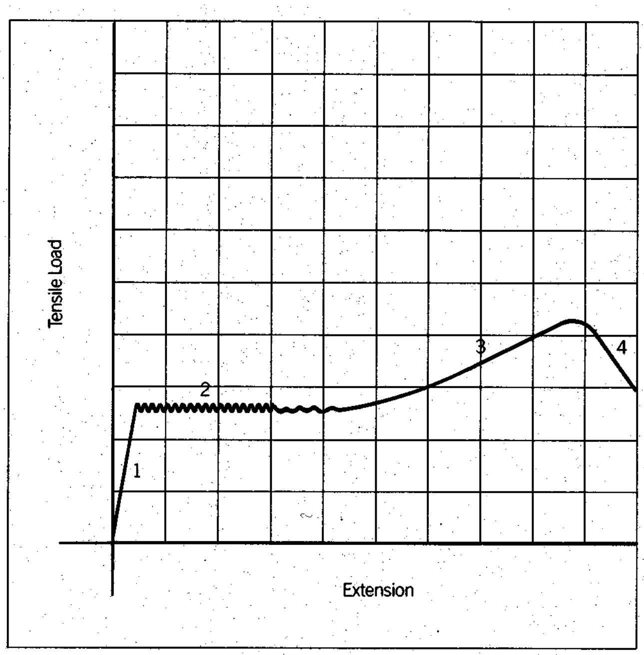
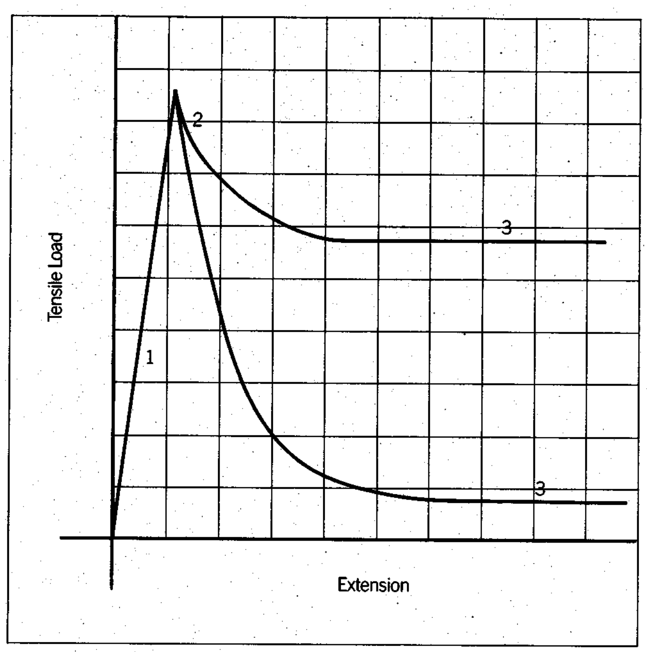


Figure 4.10 (b)
Curve Type B
Representative tensile load-extension diagram for GRC.



The following table gives a summary of the general effects of ageing on the various properties of GRC composites. Further indications of the magnitude of the effects and rates of change for specific formulations are given in Chapter 5.

Table 4.10
Properties of GRC Aged in Wet Conditions and following an Initial Stress-Strain Curve in Tension of:

	Type A	Type B
BOP	Little Change	Little Change
UTS*	Decreases to stable level	Little Change
Compressive Strength	Little Change	Little Change
LOP	Little Change	Little Change
MOR*	Decreases to stable level	Little Change
Strain-to-failure*	Decreases substantially	Little Change
In-Plane Shear Strength	Little Change	Little Change
Interlaminar Shear Strength*	Decreases to stable level	Decreases
Impact Strength*	Decreases substantially	Little Change
Modulus	Little Change	Little Change
Poisson's Ratio	Little Change	Little Change

**These changes will be smaller and take much longer to occur with modified matrices such as Cem-Star GRC.*

4.11 References

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3. Laws V. and Walton, P. L., RILEM Symposium, “The Tensile-Bending Relationship for Fibre Reinforced Brittle Matrices” Testing and Test Methods of Fibre Cement Composites, The Construction Press LW.,1978, pp 429-438.

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7. BS6432:1984, British Standard Methods for Determining properties of glass fibre reinforced cement material.

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9. GRCA Method of test for strength retention of glassfibre in cements and mortars. The Glassfibre Reinforced Cement Association GRCA S 0104/0184, January 1984.

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12. GRC Majumbdar A.J. and laws V., “Glass fibre Reinforced Cement” BSP Professional books’, Blackwell, 1991 ISBN 0-632-02904-8.

Note: Past Proceedings of the biennial Congresses of the Glassfibre Reinforced Cement Association are a useful source of additional information.

5. MECHANICAL PROPERTIES OF GRC

(See also Chapter 5 Appendix A for improved durability "Cem-FIL Star GRC")

The mechanical properties of GRC depend upon the mix formulation and the processing method used. This chapter gives initial property values for a few commonly used formulations, shows the effect of age upon these properties and gives indications of the effect of variations in formulation upon the initial and aged properties.

5.1 Typical Initial Property Values

The ranges of various mechanical properties are summarised in Table 5.1 for GRC formulations subjected to a satisfactory curing regime and tested at 28 days. It is important to realise that GRC is a relatively low w/c ratio material and because of its thin section, it can, and will, dry out prematurily if it is not kept in a humid environment.

An ideal curing regime for a GRC component is to cover the product in the mould immediately after manufacture with a polythene sheet until demoulding and then store it in a humid, preferably >95% RH, environment at 15-20°C for a further 7 days.

Alternatively, the use of air curing polymers, which will film form in the mix and seal in the moisture, will give similar results. All manufacturers should regularly check their products for mechanical properties.

Table 5.1
Typical Initial Mean Property Values of Cem-FIL GRC

Property	Units	Hand Spray [standard or Cem-FIL Star]	Vibration Cast Premix
Dry bulk density	(t/cu. metre)	1.9-2.1	1.9-2.0
Compressive strength	MPa	50-80	40-60
Elastic Modulus	G.Pa	10-20	10-20
Impact Strength	kJ/m^2	10-25	10-15
Poisson's Ratio		0.24	0.24
LOP	MPa	7-11	5-8
MOR	MPa	20-30	10-14
Direct Tension:			
BOP	MPa	5-7	4-6
UTS	MPa	8-11	4-7
Strain to Failure	%	0.6-1.2	0.2-0.6
Shear:			
In-plane	MPa	8-11	4-7
Interlaminar	MPa	3-5	N.A.

The values shown are those at completion of cure and are for guidance only. They encompass variability in quality and, in the case of machine sprayed GRC, the anisotropy (i.e. preferential orientation of the fibre in one direction) which may occur.

Achievement of these properties in practice requires adequate care, quality control and curing during manufacture.

Information on the test methods used to obtain these property values, including some discussion of the merits of the tests and the values obtained can be found in Ref. 1 to 5 and Ref. 15. (See also Chapter 11.2.)

5.2 Effect of Age on the Initial Property Values

The list of property given in Table 5.1 can be divided into those which are strongly linked to the quality of the matrix and those which are strongly linked to the glass fibre content.

5.2.1 Matrix Dependent Properties

Those properties which are more dependent upon the matrix are compressive strength, modulus, Poisson's ratio, LOP, BOP and the interlaminar shear strength.

These properties vary little with the age of the GRC, but may increase marginally in humid environments as the cement in the matrix continues to hydrate.

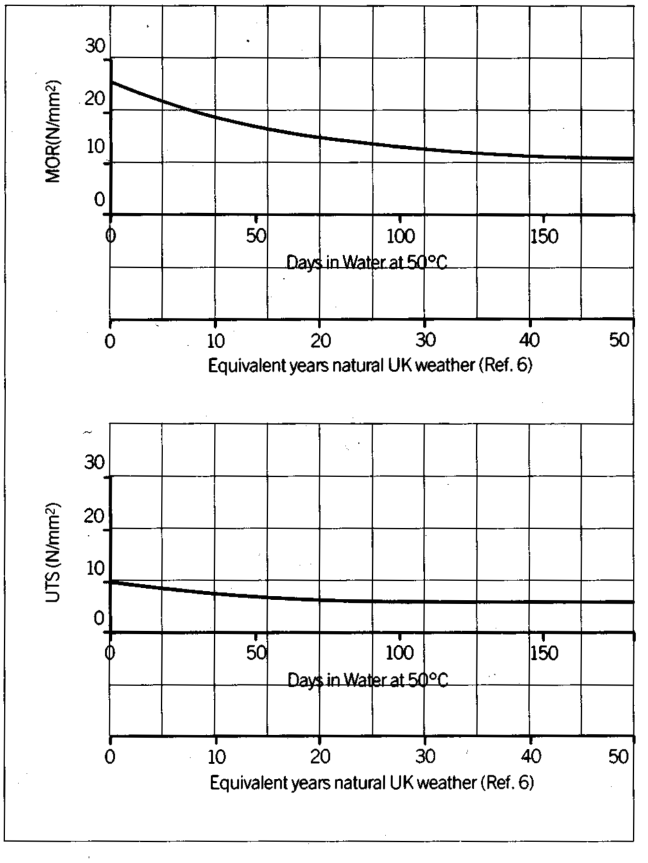
There is a more obvious variation between these properties depending on the moisture content of the GRC, dry GRC exhibiting property values lower than wet GRC.

5.2.2 Glass Fibre Dependent Properties

Those properties which are more dependent upon the glass fibre are the impact strength of all types of GRC and the MOR, UTS, strain-to-failure and in-plane shear strength of sprayed GRC.

Figure 5.2.2

Typical Variation with Time of Strength of standard 5% Cem-FIL Hand Spray GRC at Water: Cement Ratio 0.33-0.36.



Two curves are shown here, depicting the effect of hot water ageing (Ref. 6). These curves are shown for hand spray GRC (Table 5.1) and are scaled according to the time spent in hot water and the equivalent age (Ref. 6) in U.K. weather. The method of accelerating the ageing of GRC has been developed from research over a period of 25 years. It has been assessed by continuing correlation with real-time data from GRC exposed in many climates around the world for periods up to 20 years.

The relationship between "days in hot water" and natural weathering depends upon the mean annual temperature of the exposure conditions. Warm, humid environments will produce more rapid reductions in properties, leading to the same long term stable values.

The curves depict typical variations of MOR and UTS of this standard formulation of GRC made with Cem-FIL fibre.

For standard GRC, these curves show the properties depicted decreasing with time to a stable long term limiting value. It is obviously important in terms of design and confidence in GRC that the long-term properties are known and this has been the subject of much investigation and discussion (Refs. 6, 7, 8 and 9). Impact strength, strain to-failure and in-plane shear strength also show decreasing property levels over similar time periods, achieving stable values after about 150 days in water at 50°C. An estimate of the long term stable property values of the GRC formulations from Table 5.1 is shown in Table 5.2.

Table 5.2
Estimated Long Term Stable Property Values for standard Cem-FIL GRC

Property	Units	Sprayed - Classic	Sprayed Cem-FIL Star	Premix Cast
Compressive strength	MPa	75	90	60
Modulus	G.Pa	25	20	20
Impact Strength	kJ/m^2	4	>20	3
Poisson's Ratio		0.24	0.24	0.24
LOP	MPa	10	12	8
MOR	MPa	13	30	10
BOP	MPa	5.5	12	4.5
UTS	MPa	5.5	12	4.5
Strain to Failure	%	0.04	0.8	0.03
Shear strength				
In-plane	MPa	5.5	5	4.5
Interlaminar	MPa	4	5	N.A.

The reduction in properties is considerably reduced in dry environments (less than about 50% RH). (Ref.7) and also by the use of a Cem-FIL Star matrix.

Whilst the hot-water accelerated aging procedure is well-established, relatively simple and capable of predicting a minimum value for long term stable composite strength, there is growing support for the use of a cyclic weathering test as an alternative. This involves the repeated application of wetting, drying, heating and cooling according to a predetermined cycle. This procedure is embodied in current European Standards (CEN) documentation as ENV 1170-8.

5.3 Effects of Variations in Manufacture and Composition of GRC

The properties shown in Table 5.1 and the ageing effects discussed in Section 5.2 will be changed by the use of different mix formulations and variations in manufacturing technique. This section discusses some of these changes. (See also Ref. 16).

5.3.1 Curing

The property levels given in Table 5.1 assume that the matrix is well cured, i.e. to the equivalent of the curing regime given in Section 5.1. If the matrix is not well cured, this will reduce directly all those properties highly dependent upon the matrix, e.g. LOP, BOP, modulus and compressive strength. The effect upon those properties which are more dependent upon the glass fibre varies. MOR and UTS are reduced since the glass fibre is less effectively gripped by the matrix, but the impact strength may be increased since more and longer fibres can pull out. MOR may also be reduced by the failure of the matrix on the compression surface rather than by failure of the fibres on the tensile surface. The effect of curing upon the ageing characteristics depends on the history of the GRC. If the curing is simply insufficient in terms of time, this will remedy itself in a moist environment since the curing will continue. However if the GRC is allowed to dry out in an uncured or partly cured state, such as may happen if the GRC is not covered immediately after manufacture, re-wetting will not enable the potential properties to be achieved and will result in permanently low properties over the life of the GRC product. It can thus be seen that attention should be paid to the curing of GRC.

5.3.2 Compaction

The effect of compaction is to maintain the dry bulk density of the GRC at a sufficiently high level to obtain the required properties. If compaction is neglected or only partially effective, the reduction in density will reduce all those properties directly dependent upon the matrix and also MOR and UTS. This effect will be permanent over the life of the product.

5.3.3 Water:Cement ratio

GRC should normally be manufactured with a water:cement ratio of around 0.33. If this is allowed to become too high, the dry bulk density of the GRC will be reduced with consequent effects on the properties as discussed in Section 5.3.2.

5.3.4 Sand: Cement ratio

At low sand:cement ratios (0.33:1 or less) the properties of GRC which depend upon the matrix, e.g. LOP, BOP and modulus, may be increased above the levels shown in Table 5.2. At sand:cement ratios higher than 0.5:1, the properties are relatively unaffected by changes in sand:cement ratio; provided that the workability of the resulting mix can be maintained for manufacturing purposes (e.g. by the use of admixtures) without significantly increasing the water:cement ratio. If the workability is poor the compaction may suffer (see Section 5.3.2) and if a high water:cement ratio is used to obtain workability, it will affect properties adversely (Section 5.3.3). The use of superplasticisers is therefore strongly recommended so as to improve workability at low w/c ratios in 1:1 mixes.

Although it may appear advantageous, in terms of properties, to use low sand:cement ratios, it should be borne in mind that this will increase shrinkage, moisture movement and creep of the material.

5.3.5 Fillers

The effects of other fillers is similar to that of sand, provided that water:cement ratio, density and glass content can be maintained.

5.3.6 Glass Content (Ref.16)

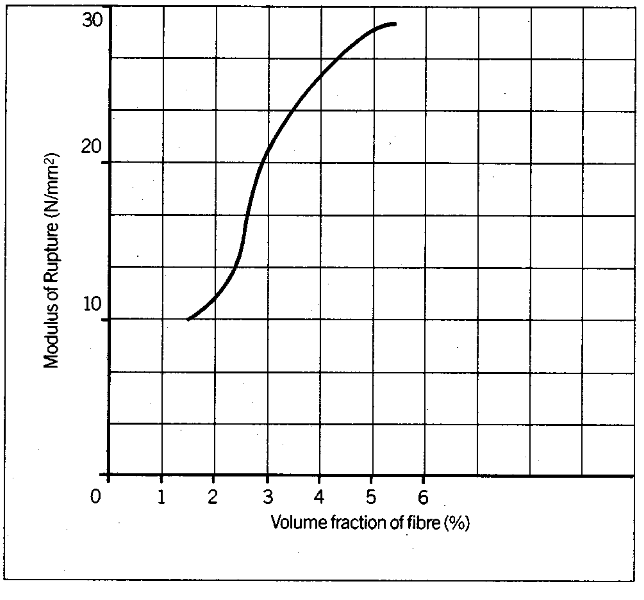
Although it is common practice to give glass content in terms of percentage by weight, it is the percentage by volume (or volume fraction, V_f) which determines the reinforcing effect. In low density GRC, 5% by weight may be as low as 2% by volume, whereas in GRC with a density about 2 t/m^3, 5% by weight is about 4% by volume.

$$V_f = \frac{\rho_{GRC} W_f}{\rho_{GLASS}}$$

V_f = Volume fraction
W_f = Weight fraction
ρ_{GRC} = Density of GRC
ρ_{GLASS} = Density of Glass Fibre

Sprayed GRC

Figure 5.3.6
Typical Variation of MOR with Fibre Volume Fraction for Hand Sprayed Cem-FIL GRC containing 37mm long fibres.



Increasing the volume fraction of fibre in sprayed GRC increases impact strength, MOR and UTS to levels roughly proportional to the increase in fibre content. A similar effect is found upon decreasing the fibre content, but below about 2% volume fraction, there is insufficient fibre to provide an effective reinforcing action. If the fibre content is reduced, there is a greater likelihood of obtaining areas of the GRC composite which have little or no fibre in them. Greater attention must be paid to fibre distribution during manufacture to avoid this possibility. Those properties mainly dependent upon the matrix show little variation with fibre content, although LOP and BOP may be increased detectably at levels of more than 5% by volume. Above about 6% by volume there is difficulty with processing leading to poor compaction and generally reduced properties (Section 5.3.2).

Premix GRC

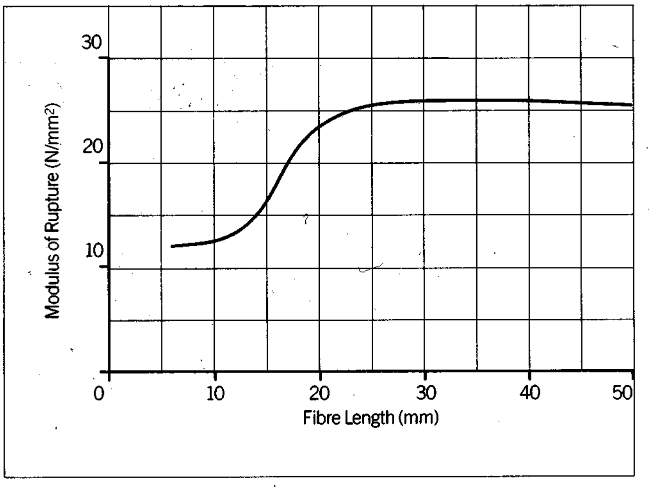
In premix GRC the random orientation of the fibres and the use of shorter fibres reduces the reinforcement efficiency considerably compared with sprayed GRC having the same fibre content. Since the incorporation of more than 3.5% by volume of fibre leads to severe processing difficulties, the range of fibre contents is usually limited to between 2% and 3.5% by volume. At lower glass contents the properties of the GRC are not generally attractive except for some applications, e.g. renders and screeds where its main benefit is crack arrest and increased toughness.

Within this range of glass contents, the only property that varies significantly is impact strength, which increases with increasing glass content.

5.3.7 Strand Length

The use of longer strands of glass fibre increases the effectiveness of them as reinforcing agents. The effect is not linear.

Figure 5.3.7
Typical Variation of MOR with Fibre Length for Hand-Sprayed Cem-FIL GRC Containing 5% by Weight of Glass Fibre.



For 4.1% volume fraction (5% by weight), hand spray GRC, the effect of changing the strand length between 25 mm and 50 mm is marginal for any property level except for impact strength, which shows an increase with increasing fibre length.

Below 25 mm fibre length, the reinforcing efficiency drops markedly and with 12 mm or shorter fibres the property levels achieved are not dissimilar to the values for premix GRC. Above 50 mm fibre length incorporation of the fibre becomes difficult and compaction problems (Section 5.3.2) are encountered in manufacture.

In premix GRC, the nature of the process makes it difficult to incorporate fibres longer than 25 mm, and the random distribution leads to reduced efficiency.

Variations in fibre length have only marginal effects on property levels other than impact strength, which increases with fibre length. However, longer fibres in thin sections may result in fibre orientation which could give improved properties in certain instances.

5.3.8 Cement Type

The effect of using cements other than RHPC or OPC and cement replacements (e.g.pozzolanic) can be considered in two ways. The obvious effect is to alter the characteristics of the matrix and hence the level of those properties which depend largely upon the matrix. The properties of different types of cement and of cement replacements are discussed in many texts (e.g. Ref. 10,11).

However, the type of cement can have a marked effect on those properties which depend largely upon the glass fibre. Although the initial properties will be little affected, some cements have lower alkali and lime contents than OPC and RHPC and the long term properties will be higher. (Ref. 12, 13,19).

5.4 Creep and Stress-Rupture Behaviour of GRC

GRC is quite capable of bearing load over prolonged periods. In common with other cement and concrete materials, the initial (elastic) deformation is followed by a further slow creep deformation when the load is maintained.

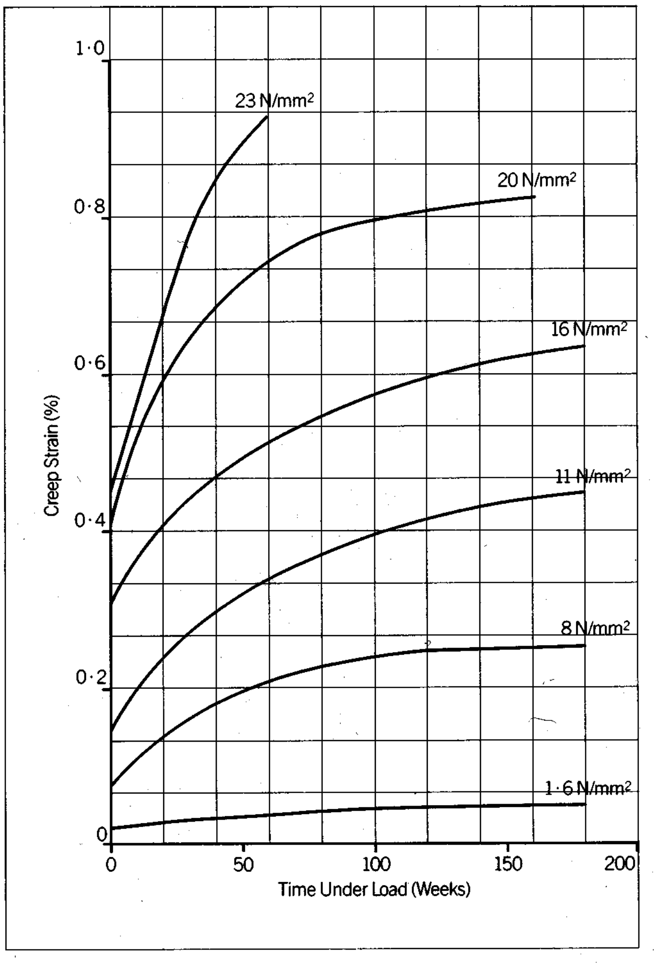
The Creep behaviour of GRC is very similar in general form to that of cement paste and sand/cement mortars. In direct tension creep strains are smaller than expansion-contraction strains due to humidity changes; in bending the creep rate decreases with time.

At bending stresses below the LOP (the normal working range of the material), the creep behaviour of GRC is identical to that of the matrix material. Creep strain is proportional to the initial strain and under long term loading will increase the initial strain by a factor between 2 and 4.

This means, for example, that a panel installed horizontally which exhibits some deflection under self weight would be expected with time to show a deflection of approximately three times the initial amount.

No stress rupture failures have been observed at up to twice the normal recommended working stress level, in experiments in which samples have been kept under a constant bending load in dry air, under water at 18/20°C, or in natural U. K. weather conditions for periods of about eight years.

Figure 5.4
Results of Tests to Measure the Flexural Creep of Dry Stored, GRC Samples Containing 5% by Weight of CEM-FIL fibre and a Water:Cement Ratio 0:33



5.5 Fatigue Performance

Repeated load fatigue tests have been carried out in bending and direct tension on samples of sprayed GRC.

A common form of S-N curve (stress versus cycles to failure) is obtained. Bending tests gave fatigue lives greater than 10^5 cycles at the LOP stress level and greater than 10^7 cycles at the normal flexural working stress levels.

Direct tension test results indicate lives in excess of 10^4 cycles at the BOP and over 10^7 cycles at the normal tensile working stress levels.

Figure 5.5(a)
Flexural Fatigue of Hand Spray GRC Containing 5% by Weight of Cem-FIL Fibre at a Water: Cement Ratio 0:33

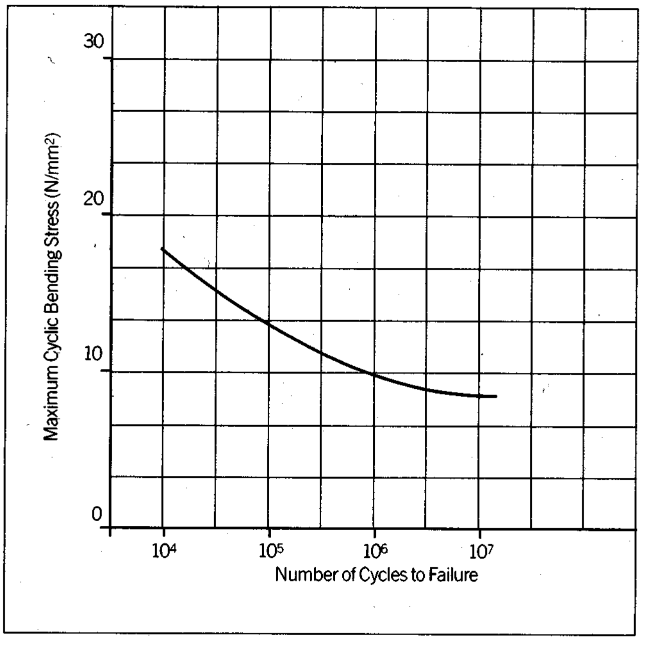
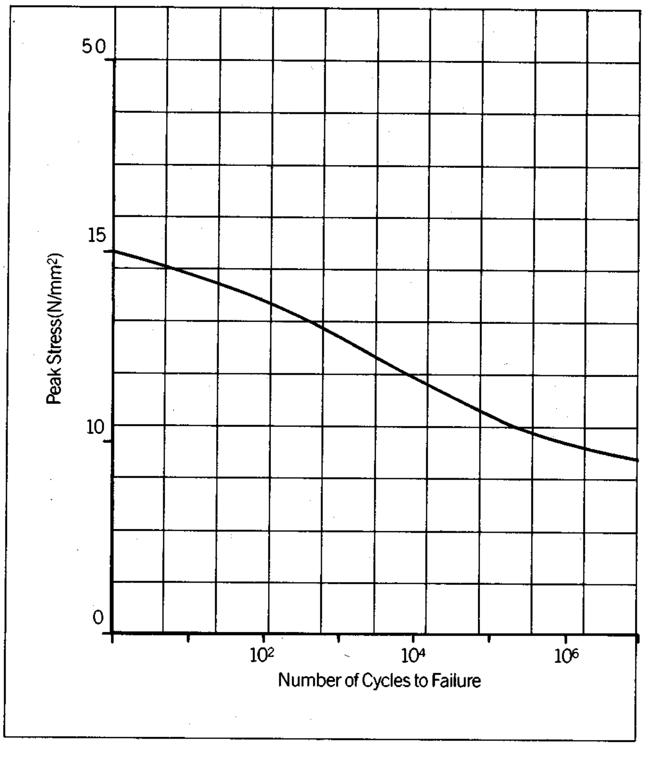


Figure 5.5(b)
Tensile Fatigue of Hand Spray GRC Containing 5% by Weight of Cem-FIL Fibre at a Water: Cement Ratio 0:33



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(See also Chapter 11.2 for future European standards).

Chapter 5, Appendix A :- Cem-FIL Star GRC

Standard GRC is known to lose some of its initial strength and become less ductile over long periods of time. Although the design process accounts for this change in properties, it is still perceived by some as being a disadvantage.

There is now strong evidence to show that, when Alkali Resistant fibres are used, this loss of strain capacity is not due to alkali attack on the fibre by the cement but to the development of lime crystals and Calcium Silicate Hydrates (CSH) around and within the bundles of glass filaments. The lime, calcium hydroxide, $Ca(OH)_2$, is a by-product of the cement setting and hydration processes and it is initially present as an aqueous solution. This solution is drawn by capillary action into the fibre bundle and later crystallises, filling the pores and locking the fibre into the cement matrix, thus preventing the slippage that exists in young GRC. It is this energy absorbing slipping of the fibres that gives GRC its remarkable toughness characteristics.

Research aimed at reducing the effects of calcium hydroxide crystal formation by the use of pozzolanic materials, which also reduces the matrix alkalinity, proved to be most successful. Exhaustive tests were carried out on a wide range of formulations in order to create a pozzolan which could be specifically tailored to meet the achievement of stable and predictable long term properties in GRC components.

Years of experience of working with GRC meant that the amount of lime and its rate of liberation typically produced in a GRC composite made with Portland cement is known. In Cem-FIL Star GRC, the rate at which the lime is produced is matched by the rate at which Cem-Star metakaolin reacts with lime. Matching lime consumption to lime production means that there is very little free lime available and consequently relatively few lime crystals form thus avoiding the above problem.

The addition of Cem-Star metakaolin results in significantly increased ultimate factors of safety and design flexibility for GRC components with excellent long term performance when subjected to a variety of ageing tests.

- accelerated ageing at 50°C water immersion [see Table 5.2]
- wet/dry cyclic ageing (modified NFB 51-263)
- freeze/thaw [ASTM C666]. No detrimental effect
- chemical resistance
- carbonation. No detrimental effect

The new "Cem-FIL Star GRC" is based on known cement technology specifically tailored for the unique requirements of GRC. No change has been made to the basic chemistry of the Portland cement hydration process. Therefore, it is reasonable to assume that the existing methods of accelerating ageing are still applicable but long term weathering tests under different environmental conditions are, nonetheless, on-going. In addition, it is a system that has already been extensively tested in real terms, including panels on buildings in Europe since 1986 and more recently in the Far East and the United States of America.

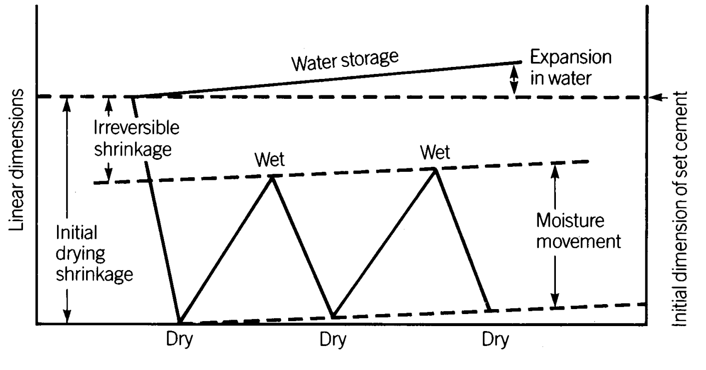
Full details are given in the brochure "Cem-FIL Star GRC" and associated reports (refs. 15, 16, 17, 18 and 19) available from Cem-FIL International Ltd.

6. PHYSICAL AND CHEMICAL PROPERTIES OF GRC

6.1 Shrinkage

All cement based materials are susceptible to dimensional changes as they are wetted and dried (Reference 1 and 2). After manufacture and cure, drying results in shrinkage from the original state. Re-wetting results in expansion but not to the extent of restoring the original size: there is therefore an initial irreversible shrinkage, which will be followed in subsequent service conditions by a reversible dimensional movement dependent on the moisture content of the cement. For GRC the irreversible shrinkage is one quarter to one third of the total possible shrinkage: typical figures for a 1:1 sand:cement ratio GRC mix are 0.03% irreversible shrinkage and a total ultimate shrinkage of about 0.12%. The shrinkage and moisture movement behaviour are represented diagrammatically in Figure 6.1(a).

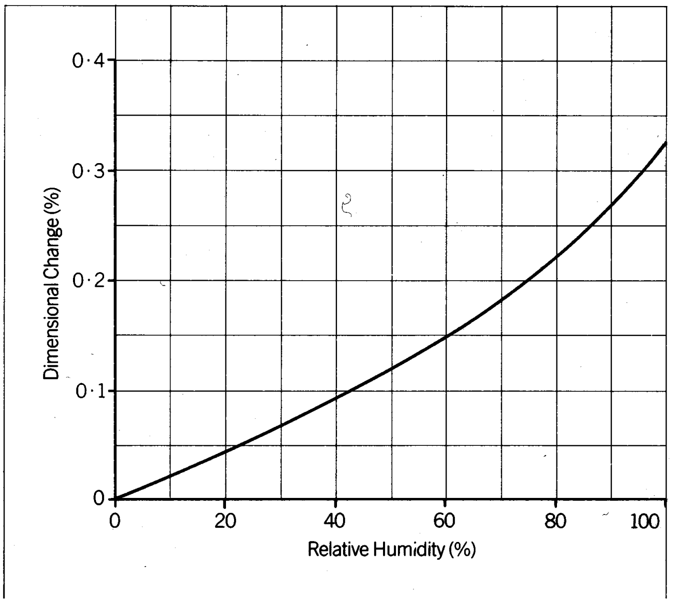
Figure 6.1 (a)
Diagrammatic representation of moisture movements.



It should be noted that the amplitude of reversible movement quoted above is between fully-dried and fully-soaked conditions, as in the laboratory. In practice these extremes may not be experienced in normal weathering conditions although there will be some cyclic movement about a mean level which is effectively shrunk relative to initial manufactured dimensions.

The moisture content of the material is related to the relative humidity of the surroundings, so it is convenient to express the dimensional change in terms of relative humidity. Figure 6.1 (b) shows the reversible shrinkage obtained when neat cement GRC is completely dried from equilibrium with any value of relative humidity (based on data from Reference 3).

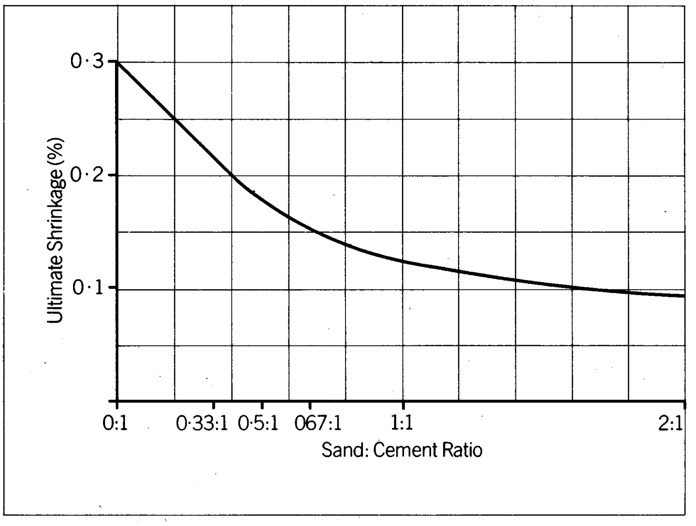
Figure 6.1 (b)
Shrinkage of Neat Cement GRC upon Complete Drying from Equilibrium with Air at any Relative Humidity.



The ultimate shrinkage of cementitious materials is highest when the matrix is based on pure cement. Shrinkage is reduced by dilution of the cement with aggregates not susceptible to moisture movement: this is standard practice for mortars and concretes and well-documented (Reference 1). Very early GRC employed pure cement as a matrix but it is now normal to add a proportion of good quality fine aggregate (typically silica sand) in order to reduce shrinkage. Figure 6.1(c) shows the effect of silica sand additions on the shrinkage behaviour of GRC, an effect very similar to that of increasing the aggregate content of mortar or concrete. (Reference 1).

The addition of a suitable acrylic polymer to the mix (as in the '5/5' mix) has a beneficial effect in moderating reversible shrinkage movements, typically giving a value of 80% of a standard non-polymer mix. More significant improvements can also be achieved by matrix modifications such as the inclusion of Cem-Star metakaolin. This has been shown to give a typical reversible shrinkage of 60% of a conventional sand-cement mix

Figure 6.1 (c)
Typical Variation of Ultimate Shrinkage with Aggregate Contents of GRC.

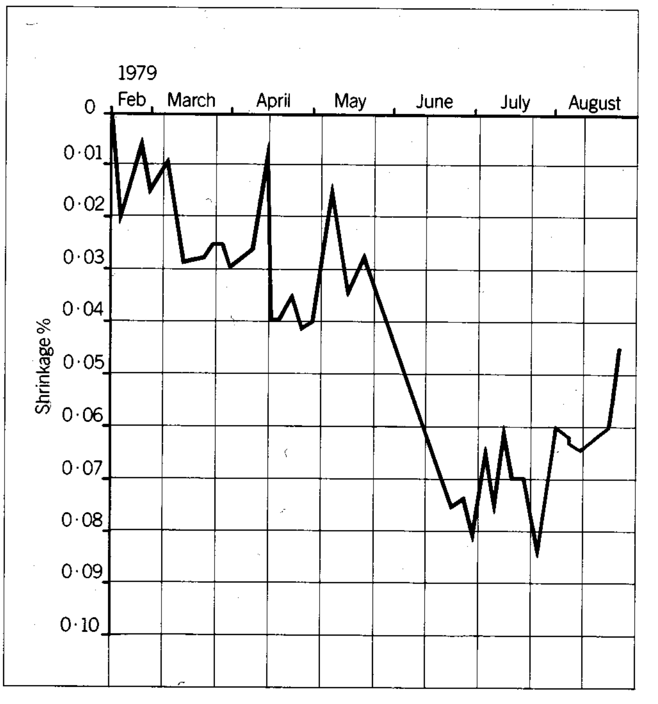


The mechanism of shrinkage in cementitious materials is complex and a number of factors affect both the magnitude of total shrinkage and the relative magnitude of irreversible drying shrinkage and reversible moisture movement. Total shrinkage is principally affected by the aggregate proportion and type, and water:cement ratio. The effect of alternative curing regimes is not conclusive for concrete but for GRC some experimental evidence suggests that GRC which has not received a sufficient moist cure undergoes increased initial irreversible drying shrinkage, up to 0.10%, and overall shrinkage is increased up to 0.25%.

Since GRC is a relatively impermeable material, changes in external humidity take a considerable period of time to affect the moisture content of the GRC. 10 mm thick sprayed GRC will take about 20 days to approach equilibrium with changes in external humidity, and thicker sections take even longer. GRC used in sandwich construction panels, particularly those with lightweight concrete cores, will react much more slowly, certainly in the sense of drying out after manufacture when it is likely that equilibrium will not be reached for many months in temperate weather conditions. This clearly has implications for the design and installation of components (see Chapter 7) in that shrinkage movement will need to be allowed freely in order to avoid undesirable stresses in the GRC.

The general pattern of behaviour is that GRC is not susceptible to transient changes in humidity, but moisture movement in natural weather follows a seasonal pattern. An indication of this is depicted in Figure 6.1(d) for the United Kingdom and similar information has been found elsewhere (Reference 3). Superimposed on the underlying moisture movements, there may be more rapid thermal movements.

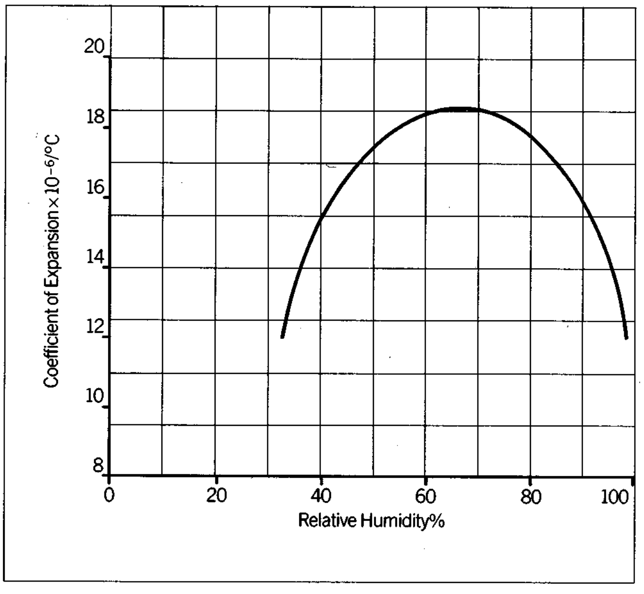
Figure 6.1 (d)
Results of Shrinkage Measurements in U. K. Weather of 10mm thick, 5% fibre content, Direct Spray GRC.
Sand: Cement Ratio 0.5:1
Water: Cement Ratio 0.33



6.2 Thermal Expansion

The coefficient of thermal expansion is in the range 10-20 x 10^{-6}/°C which is within the range of values for other cementitious materials. GRC, in common with cement paste and, to a less noticeable extent, mortars and concretes, exhibits an anomalous behaviour in that the thermal expansion coefficient varies with moisture content of the material. The coefficient has a value at the lower end of the range when the material is fully dry or fully saturated. At intermediate levels of moisture content (50%-80% RH) the upper value applies. The reason for this behaviour is that the thermal expansion coefficient is made up of two movements: the normal kinetic thermal coefficient and a swelling pressure, a complex effect caused by moisture transfer within the system (Reference 1). The behaviour for neat cement paste is shown in Figure 6.2. As with concrete the addition of aggregate will have an effect upon the absolute magnitude of thermal coefficient dependent upon the proportion and type of aggregate.

Figure 6.2
Relationship between linear coefficient of thermal expansion of cured cement paste with ambient Relative Humidity.



6.3 Chemical Resistance

The rate of chemical attack on cementitious materials depends largely upon the extent to which reactive elements in the cement are exposed to aggressive agents and this is a function of permeability. The permeability of GRC is lower than that of normal concretes, and consequently GRC shows good resistance to chemical attack. Cem-FIL fibre is itself resistant to both acid and alkali environments.

It is generally true that dewatered GRC offers slightly better resistance than non-dewatered GRC, due to its lower water/cement ratio and reduced porosity. GRC also benefits from having a high cement content, which is another factor determining the chemical resistance of concretes. Improved performance against chemical attack may be expected from the use of special cements e.g. high alumina cement or supersulphate cement. A further discussion of the chemical resistance of GRC may be found in Reference 4.

6.3.1 Sulphate Resistance

In the presence of moisture and sulphates a reaction takes place causing degradation of the cement, although GRC is less sensitive than most concretes.

Resistance to sulphate attack is increased by the use of sulphate resisting cement and it is usual practice to use this type of cement for the manufacture of GRC which may be in contact with sulphate solutions. Typical of such applications are silage tanks, drainage components, sewer linings and junction boxes which may be used in contact with sulphate bearing soils.

6.3.2 Acids and Alkalis

Portland cement releases calcium hydroxide during hydration and is highly alkaline (pH 12.5). Consequently, alkaline solutions present no particular hazard to GRC. Cem-FIL glass is relatively unaffected by acidic environments although OPC may be degraded after long term exposure to acids. Such conditions may arise due to the action of sour silage, under certain conditions in sewers where bacterial action has produced sulphuric acid and in certain types of soil, but can be countered by the use of sulphate resisting cement or high alumina cement.

6.3.3 Marine Environments

Seawater and seaspray exposure of GRC give mechanical property changes similar to those in fresh water exposure and natural weather at equivalent temperature. Some surface carbonation can occur which may detract from the appearance of the GRC but which is not detrimental to mechanical properties, unlike reinforced concrete where both the salts and carbonation result in increased attack on the reinforcement.

6.4 Freeze-Thaw Behaviour

In certain climates GRC may be subjected to long periods at sub-zero temperatures and to freeze-thaw conditions. Laboratory tests based on BS 4624 (1970) - Asbestos and Asbestos Building Products, and DIN 274 (1936) Asbestos Cement Sheets, Asbestos Cement Boards have been carried out on both dewatered and non-dewatered machine sprayed GRC containing 5% fibre and various sand contents. There was no visible change in the appearance of the samples after the tests and the mechanical property values of MOR, LOP, Young's Modulus and Impact Strength were unchanged. The general freeze-thaw behaviour of GRC is therefore very good.

A more severe test based on ASTM C666-73 Procedure A— Resistance of Concrete to Rapid Freezing and Thawing has also been performed on GRC and on fully compressed asbestos cement sheet as a comparison. This test involves freezing and thawing in water - a process unlikely to be encountered in actual use conditions. After 300 cycles between -20°C and +20°C GRC showed relatively little change in properties, LOP increasing by up to 20% while MOR, Modulus and Impact strength decreased by up to 20%. The mechanical properties of asbestos cement were much more seriously affected. Surface flaking and surface delamination were the signs of attack on GRC.

It must be remembered that freezing and thawing tests in the laboratory cannot duplicate natural exposure. The main function of laboratory tests is to try to assess the relative durability of materials. Care should therefore be taken in interpreting the results, particularly for those tests with 'artificially' severe conditions.

Many GRC composites have now completed over 20 years in a natural freeze-thaw environment in Toronto (average 65 freeze-thaw cycles per year) with no sign of damage.

In locations where sub-zero temperatures and frequent freeze-thaw cycles are experienced, it is also likely that the mean annual temperature will be low. This has the beneficial effect of retarding the rate of change of time-dependent strength properties (see Chapters 4 and 5). For instance after 10 years exposure at Toronto the MOR values were 20% higher than those obtained after 10 years exposure in the U. K.

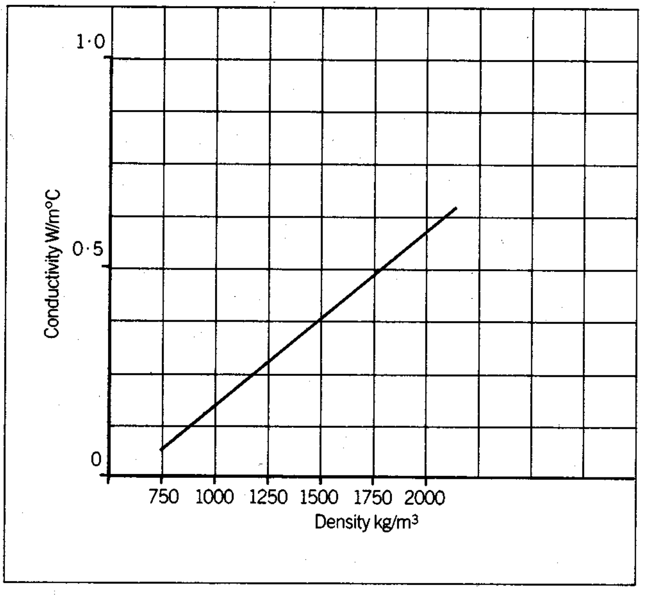
GRC containing Cem-Star metakaolin has been shown to perform equally if not better than standard GRC.

6.5 Thermal Conductivity

The thermal conductivity of GRC depends on the density of the material and the moisture content.

For dry materials, i.e. those used in internal environments, Figure 6.5 shows the variation of thermal conductivity with density. This graph will apply to most low density GRC products since these are normally used internally, but is an under-estimate for standard density GRC in the range 1900-2100 kg/m^3 which is more often used externally. For normal density GRC, dependent on the moisture content, the conductivity will be between 0.5 and 1.0 W/m°C.

Figure 6.5
Thermal Conductivity of Cem-FIL GRC.



6.6 Sound

The sound insulation of an homogeneous material depends on three physical properties.

- Surface mass (weight per unit area).
- Stiffness (dependent upon panel shape).
- Damping

Of these, the surface mass is the most important in determining the sound insulation at the lower frequencies.

There is a general curve relating the surface mass of material against sound reduction which is reasonably true for most homogenous materials. This 'Mass Law' curve is shown in Figure 6.6(a). The sound reduction figures shown are based on an average for frequencies from 100 Hz to 3150 Hz. For each doubling of surface mass there is an approximate 5 dB increase in sound reduction. Hence a typical 10 mm thickness of GRC which has a surface mass of 20 kg/m^2 will have an average sound reduction of about 30 dB. Increasing the thickness to 20 mm will increase the reduction to about 35 dB. Further increases in sound reduction will require a much higher overall surface mass and this may well be uneconomic using single skin GRC.

The relationship between the Sound Reduction Index and Frequency for a 9 mm (18 kg/m^2) panel is given in Figure 6.6(b).

Figure 6.6 (a)
Relationship of Sound Insulation to Mass.

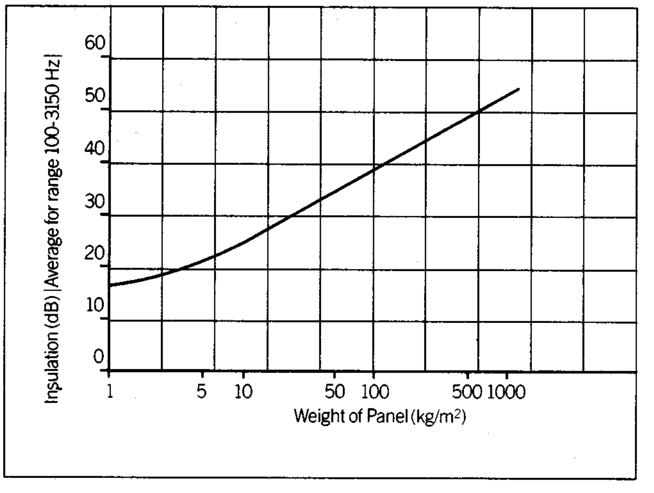
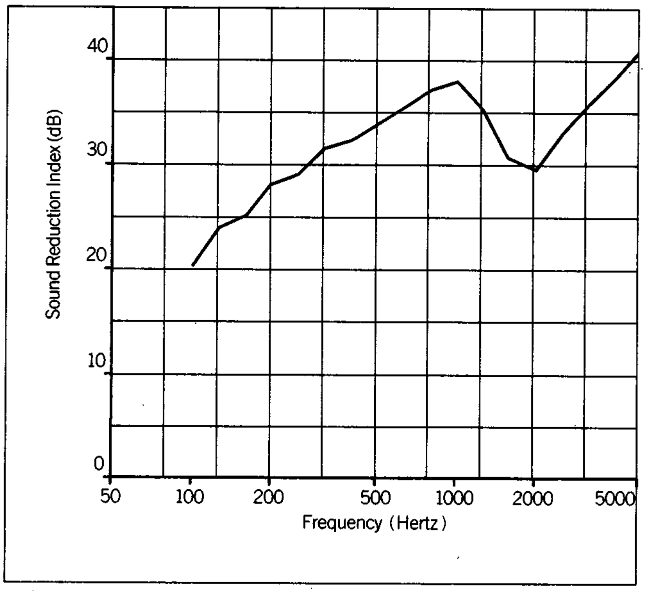


Figure 6.6 (b)
Relationship of Sound Reduction and Frequency for a 9mm (18Kg/m^2) Cem-FIL GRC panel.



6.7 Permeability

6.7.1 Water Vapour Permeability

The measured values of water vapour permeability are dependent on the water-cement ratio of the GRC, the degree of compaction, the age of the specimen when tested, and on the precise nature of the test. Measurements have been made to BS 3177 - Tropical Conditions (38°C, 90% RH).

A wide range of measured values have been reported. The lowest values are obtained with spray-dewatered material of low (0.25) water:cement ratio with higher figures for direct-sprayed material of water:cement ratio 0.35. In terms of water vapour permeance, the range of initial measured values is from less than 1 to more than 7 metric perms, for 10mm thick GRC material. Values reduce with time, and even with high starting value the long term permeance will invariably be below 3 metric perms.

A typical value of water vapour permeability may be taken to be 0.001 g.m/s.MN, corresponding to a water vapour permeance of 0.1 g./s.MN or approximately 1.2 metric perms for 10 mm thick GRC.

6.7.2 Water Permeance

Measurements made according to BS 473.550 on freshly made 8 mm thick GRC have shown results in the range 0.02-0.40 ml/m^{2}min.

As with water vapour permeability the water permeance tends to decrease after about 1 to 2 years natural weathering to the lower end (0.1 ml/m^2 min.) of the range.

6.7.3 Air Permeance

Air permeance for 10 mm thick GRC will be about 2 metric perms.

6.8 Abrasion Resistance

The resistance to abrasion or erosion of cementitious products can be assessed by various test methods. Care is necessary in making comparisons of the performance of materials since it is evident that a material may perform better, in a ranking sense, according to one test than to another. Test methods for concretes include the revolving disc test, steel ball abrasion test, dressing wheel test and shot-blast test (see Reference 1). Since there has been interest in the resistance of GRC to wind-blown sand, GRC has been tested according to a modified form of ASTM C418-68 which involves directing a jet of air-driven sand at the sample. Under this test the GRC samples performed well in comparison with concrete and asbestos-cement. The results of this work, expressed as volume-loss, are given in Table 6.8.

Table 6.8

Material	Total Dry Volume Loss (cm^3)
Neat cement (spray dewatered)	0.14
GRC (spray dewatered)	0.27
GRC (direct spray)	0.30
Concrete Paving Slab	0.32
Semi compressed a/c	0.37
Fully compressed a/c	0.52
Brick	0.88

Generally the literature (e.g. Reference 1) indicates that abrasion resistance tends to follow compressive strength, and is improved at low water-cement ratios: on this basis GRC appears well placed. It should be recognised, however, that under particular test conditions the presence of a high proportion of larger, hard, aggregate appears beneficial and in these circumstances a concrete meeting these requirements may rank higher.

6.9 Density

The density of standard Cem-FIL GRC materials is commonly around 2.0 tonne/m^3 which is slightly below that of conventional dense concrete. It gives rise to a convenient method of expressing the weight of GRC, namely that 10 mm thick GRC weighs 20 kg/m^2. GRC forms lightweight components by virtue of thin section, rather than by lightness of the material; although low-density versions of the material are possible.

The significance of density, however, goes beyond the simple concept of weight. Density is a good indicator of material quality, a high density meaning slightly greater fibre volume fraction but more significantly indicating well-compacted, well-made material of correct water:cement ratio. The more useful figure is the dry bulk density, and the normal values for good quality material are:

	Spray Dewatered GRC	Hand Spray GRC	Vibration Cast Premix GRC
Dry Bulk Density (t/m^3)	2.0-2.05	1.9-2.1	1.9-2.0

6.10 Water Absorption and Apparent Porosity

Water absorption and apparent porosity of GRC are determined as part of the routine Quality Control measurement of wet and dry bulk density. Typical values for hand sprayed GRC with a 0.5:1 sand: cement ratio are:

Water absorption : 12%
Apparent porosity : 24%

It will be noted that these figures are higher than those for typical concretes, which would normally exhibit a water absorption less than 10%. This is a direct result of the higher cement content in GRC and the presence of coarse aggregate in concrete. The permeability of the GRC, as discussed earlier, is however significantly lower than that of concrete.

6.11 Potable Water Approval

GRC samples have been tested by the National Water Council and classified under the heading “Items which have passed full tests of effect on water quality” (Reference 5). This indicates that drinking water may be passed through or stored in GRC without harmful effect, but official approval is only given for specific formulations.

6.12 Ultra-Violet Light

GRC is not susceptible to degradation arising from exposure to ultra-violet light.

6.13 Nuclear Radiation

The mechanical properties of samples of GRC subjected to gamma radiation at a dosage rate of 1.2 mega rads/24 hours over a period of 7 days were unaffected.

6.14 References

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7. DESIGN PRINCIPLES

As with any material, there are applications appropriate for Cem-FIL GRC and some which are not, and this judgement must be made in the particular circumstance based on the characteristics of the material. Generally, GRC components can be used in situations where the stresses can be evaluated at realistic safe levels, the resulting component is economic, and the consequences of failure are limited in extent.

Although GRC is a fibre reinforced composite, it is not necessary to use the complex composite analysis techniques required by high performance fibre reinforced plastics. GRC can be treated as a homogeneous isotropic material and the techniques used for the analysis of GRC stresses, strains and deflections are identical to those used with isotropic materials such as metals, provided the stresses are within the elastic limit of the material.

The process of designing a product can be broken down into three basic components.

(a) *Resistance to applied loads.* Mechanical design is the most commonly performed part of the design process, but other factors also merit consideration.

(b) *Resistance to environmental influences.* Physical design is often neglected, but the analysis of sound and thermal insulation and performance in fire is required for building components and, for GRC products, moisture and thermal movement may exert more influence upon the final solution than the applied loads.

(c) *Installation of the component.* The GRC component is often required to interact with some other structure or components and this should always be considered at the design stage.

7.1 Mechanical Design

The design of any product has to satisfy many requirements. Adequate strength against the specified loads is an obvious requirement, and therefore mechanical design will commonly be performed to ensure satisfactory performance. The loads to which a product may subjected during demoulding and handling should not be ignored.

This section covers mechanical design aspects, to give satisfactory performance in relation to the short and long term strength properties of GRC.

7.1.1 The Approach to Mechanical Design in GRC

As with other materials, it is normal practice to design at stresses below the elastic limit. The elastic limits of GRC in compression, bending (LOP), tension (BOP) and shear do not change significantly in most environments, so the initial property values can be used as a reference.

Design stresses are also selected with respect to long term strength values. In conditions where there is a reduction of ultimate strength, accelerated ageing tests (Reference 1) indicate that the strength stabilizes. Design stresses should be based on this stable value, allowing a suitable factor of safety.

In terms of the bending strength of a good quality hand sprayed GRC (formulation and properties are shown in Table 5.1 of Section 5), a typical design stress is 6 MPa, which covers both of these requirements.

Figure 7.1.1 (a)

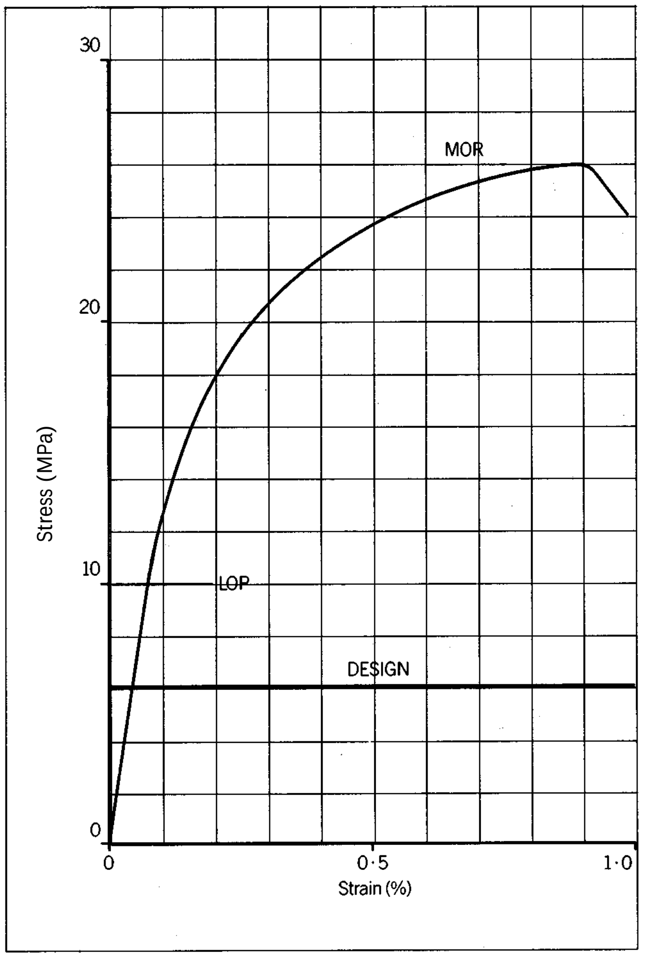
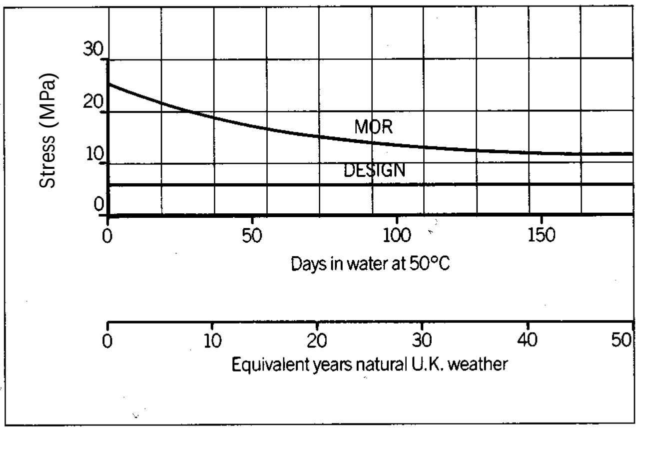


Figure 7.1.1 (b)



The high initial ultimate properties of the material are a bonus in the early life of the product, allowing the use of higher design stresses for structures such as formwork, which may require high strength only in the early life of the product.

7.1.2 Choice of Design Stress Levels

Since GRC is not one material, but a family of closely related materials, the design stresses to be used will depend on the choice of formulation and manufacturing process. Also each individual material will have several design stress levels because the material characteristics result in different strengths dependent upon the type of loading and the section being loaded.

The design stress chosen must also be related to the quality of manufacture, since the manufacturer is not just using the material to make GRC components, but also creating the material from its basic constituents.

7.1.3 Design Stresses

The normal test data available from a GRC manufacturer relates to bending tests on small coupons of GRC. The results can be statistically analysed to give characteristic values of the initial LOP and MOR. Other mechanical properties of GRC can be divided into those which are strongly dependent upon the matrix (compressive strength and inter-laminar shear strength), and are related to the LOP, and those which are strongly dependent upon the glass fibre content (UTS and in-plane shear), and are related to the MOR.

For instance:

Compressive strength	6-10 x LOP
Inter-laminar shear strength	0.4-0.5 x LOP
UTS	0.4 x MOR
In-plane shear strength	0.4 x MOR

Hence an estimate can be made of the characteristic values of these properties if the LOP and MOR are known.

Table 7.1.3 gives typical design stresses for the GRC formulations indicated in Table 5.1 (Section 5), provided that the characteristic strengths are not less than:

		MOR_k	LOP_k*
≠	Sprayed GRC	18 MPa	6.5 MPa
	Premix	8 MPa	5 MPa

Where subscript k indicates the characteristic value, i.e. that below which not more than 5% of the test results fall.

* The values are obtained by using a Testometric, J.J. Lloyd Instruments Ltd. test machine, or similar.

≠ Specification for the manufacture of Glassfibre Reinforced Cement (GRC) - GRCA S0110/October 1995 (Glass Reinforced Cement Association).

Table 7.1.3

		Design Stresses MPa	
Stress Type	Loading Example	5% spray Cem-FIL GRC	$3^1/_2$% premix Cem-FIL GRC
Compressive	Compressive	12	12
Bending	Bending solid beams or plates	6	4
Tensile	Cylindrical hoop stress	3	2
Tensile	Bending sandwich panels	3	2
Web Shear	In-plane shear of webs in box sections	2	1
Bearing Shear	Shear loading at bearing positions	1	1

These design stresses are obtained by applying a factor of approximately 1.8 to the long term elastic strength (e.g. LOP, BOP) of the GRC.

GRC is often used in constructions where the stress is neither pure bending nor pure tension. Bending of box-sections (often used to strengthen GRC products) is an example. In this case the design stress will be between the values for bending and tension. Taking Table 7.1.3, for example, 4 MPa for sprayed GRC and 2.5 MPa for premix GRC might be appropriate. However in case of doubt it would be advisable to use the lower values for tensile design stress or perform load tests to check the product behaviour.

The values of design stress may be increased where loads are of limited duration and occur early in the life of the material (e.g. permanent formwork), and reduced values (e.g. one third of the normal values) may be desirable when considering the stresses imposed by demoulding a product at an early stage in the curing cycle when the LOP of the material may be low.

Consideration may be given to reducing the design stresses if a permanent load is to be applied to the GRC in order to take account of the effects of creep.

7.1.4 Design Calculations

Design calculations are performed according to normal methods for a linear elastic isotropic material. The calculations allow material thickness to be determined to limit stresses to values given in 7.1.3 (or to check actual stresses for a given thickness).

7.1.4.1 Minimum Thickness

For normal applications of GRC the following minimum design thicknesses have been found satisfactory for handling and processing.

Premix (vibration cast or spraymix)	10 mm
Machine Spray	6 mm
Hand Spray	8 mm
Render	3 mm

7.1.4.2 Loads

The loads applied to the GRC may be subjected to load factors in accordance with local practice. For instance the U.K. BS CP8110 (Ref.2) would indicate the following:

(i) Dead and imposed load: 1.4 x dead load + 1.6 x live load.

(ii) Dead and wind load: 1.4 x dead load + 1.4 x wind load.

(iii) Dead, imposed and wind load: 1.2 x dead load + 1.2 x imposed load + 1.2 x wind load.

Dead load is defined as the weight of the GRC components and fittings, wind load is self defined and imposed load is any other applied load.

7.1.4.3 Analysis

GRC products can usually be subdivided into interacting parts, each of which can be tested individually as a beam or plate element and analysed accordingly using formulae available in standard texts (e.g. Ref.8).

The stresses and deflections for beams can be calculated using the following formulae.

Stress $f = \dfrac{WL}{k_1 Z}$

where W is the total load on the beam (N).

L is the length of the beam (mm).

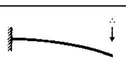
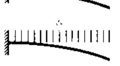
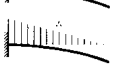
E is the modulus of the material (N/mm^2).

k_1 and k_2 depend on the beam support and the load type.

Z (mm^3) and I (mm^4) depend on the shape of the beam.

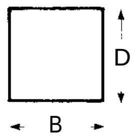
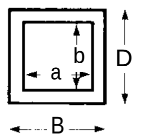
For some of the more common cases of load types and support conditions the following table gives values for k_1 and k_2

Table 7.1.4.3(a)

Load Type	Support Condition	Diagram	k1	k2
Point load	Cantilever		1	3
Uniform	Cantilever		2	8
Hydrostatic	Cantilever		3	15
Point load	End supports		4	48
Uniform	End supports		8	77
Hydrostatic	End supports		7.8	77

For two of the more common shapes of beam found in GRC construction the following values of Z and I can be calculated. Section properties of other shapes can be calculated by normal procedures.

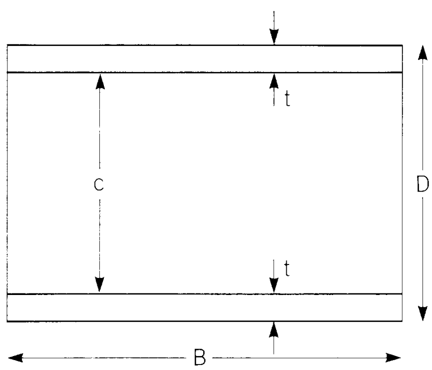
Table 7.1.4.3(b)

Beam Shape	Section Modulus Z	Second Moment of Area I
Solid 	$\dfrac{BD^2}{6}$	$\dfrac{BD^3}{12}$
Box Section 	$\dfrac{BD^3 - bd^3}{6D}$	$\dfrac{BD^3 - bd^3}{12}$

The formula for deflection gives an estimate of the short term deflection. For sustained loads or dead weight, the creep of the GRC should be considered. A simple method is to multiply the deflection due to sustained loads by a factor of 3 to obtain the long term deflection.

Sandwich Beams

The analysis of sandwich beams is slightly more complex than for normal beams, since the thickness of the relatively low modulus core material used allows an extra amount of deflection. (Ref.9)



Stress $f = \dfrac{WL}{K_1 Z}$ where Z = Bct

Deflection $y = \dfrac{WL^3}{k_2 EI} + \dfrac{WLc}{k_1 BD^2 G}$

where $I = \dfrac{BctD}{2}$

and G is the shear modulus of the core.

In the above equations the values k_1 and k_2 are those given earlier in Table 7.1.4.3(a).

This formula for deflection takes no account of the side walls which are usually built into a GRC sandwich structure. Hence the deflection calculated will be an overestimate. An alternative method of calculation assumes the beam to have a width B and length L, but only part of the width B is effective (Ref. 8, Article 7.1.2). As an approximation, the effective width B_e is given by

$\dfrac{B_e}{B} = 1 - 0.6 \dfrac{B}{L}$ (asuming $L \geq B$)

The sandwich beam can now be designed as a box section of width B_e and the deflection calculated accordingly.

Sandwich structures should also be checked for the shear load transmitted through the core material. The shear force, V, can normally be-taken to be equal to the maximum support load (in Newtons) and the shear stress is then

$$f_s = \frac{V}{Bc}$$

which should be less than 40% of the core shear strength.
The following table gives shear modulus and shear strength for PBAC (Styropor concrete) and high density foams.

Table 7.1.4.3(c)

Core Material	Shear Modulus	Shear Strength
Polystyrene Bead Aggregate Concrete (Styropor) 400 kg/m^3	230 MPa	0.34 MPa
High Density Polystyrene 25 kg/m^3	11 MPa	0.26 MPa
Polyurethane Foam 40 kg/m^3	2.3 MPa	0.32 MPa

The figures for PBAC are dependent upon the quality.

Selection of plastic foams as core materials will depend on operating conditions and the temperature stability of the foam. Polystyrene foam appears to work satisfactorily with sandwich panel surface temperatures up to about 80°C, and polyurethane foam has a superior resistance to high temperatures.

Design of sandwich structures assumes that the shear strength of the bond between the various layers of the sandwich is also greater than the shear stress. If this is not the case, the structure ceases to act as a sandwich and may be over-stressed. The shear attachment can take other forms including the use of GRC webs joining the two skins, and these should be designed so that the web shear stress is less than the web design stress.

Experience has shown that it may be advisable to limit the area of sandwich structures to a maximum of 6.5m^2 (approximately 3.6m x 1.8m). Although there is no justification for this from analysis of mechanical strength, it is apparent that more problems are experienced in production, handling, installation and use with sandwich structures larger than 6.5m^2 area, unless the manufacturing process and installation procedures are specifically developed to overcome these problems.

7.2 Physical Design

7.2.1 Thermal Movement

Thermal dimension changes in GRC can be calculated from the formula:

$$\Delta L = \alpha \Delta T L$$

where α is the coefficient of thermal expansion.

ΔT is the change in temperature.

L is the length over which the dimension change is measured.

and ΔL is the change in length.

Hence for a 2 m long GRC component undergoing a temperature rise of 30°C

$$\Delta L = 20 \times 10^{-6} \times 30 \times 2000 = 1.2 \text{ mm}$$

assuming a coefficient of thermal expansion of 20x10^{-6}/°C. Cladding panels on a building may experience surface temperatures varying from -10°C to 60°C (light colours) or 80°C (dark colours) over the period of a year in the U. K., so substantial expansion or contraction may take place, up to 1.8 mm per metre length.

7.2.2 Moisture Movement

Moisture movement in GRC comprises two components. These are irreversible shrinkage and reversible shrinkage. Both components are present at all times, but the relative amounts of each depend upon the conditions. Irreversible shrinkage will occur under all conditions, but more slowly if the GRC has a high moisture content. Reversible shrinkage depends only on fluctuations in moisture content.

Under service conditions, Cem-FIL GRC products are unlikely to be subjected to the full range of reversible shrinkage. In most climates, GRC in an external environment may be fully moistened for part of the time, but is unlikely to be fully dried.

Very arid conditions will need to prevail to completely dry GRC. These conditions provide limited opportunity to re-wet the GRC, so even in these conditions the full range of reversible shrinkage is unlikely to occur.

Wet-cured GRC with a sand: cement ratio of 0.5:1 will probably experience 0.05% dimensional change due to irreversible shrinkage and of up to 0.15% reversible moisture movement subsequently GRC with a sand : cement ratio of 1:1 will exhibit reversible movement of 0.1-0.12%.

Since shrinkage occurs at a greater rate immediately after cure it is sensible to allow GRC products to dry or acclimatize away from exposure to sun or winds for a period immediately after cure. In this way distortion (which may be permanent) should be avoided and a large portion of the irreversible shrinkage may take place prior to installation of a component.

The amount of shrinkage or moisture movement which may realistically be seen in service is up to 0.15% or 1.5 mm/metre length. Such an amount of movement requires design consideration in many ways, e.g. allowance for movement at fixing positions and selection of joint widths (see Section 7.3).

However it is also necessary to consider the effect of restraining this movement, either intentionally or unintentionally, and this is considered in Section 7.2.3.

7.2.3 Stresses and Deflections due to Moisture and Thermal Movement

Moisture and temperature gradients within GRC products will induce stresses and/or deflections in the product. Since GRC is normally made in relatively thin sections the possibility of significant differences in temperature through the thickness of the material is small, but moisture differentials can occur and the product will tend to bow out of the plane of the material. For instance, if a damp flat GRC sheet is placed upon a flat surface, the upper surface of the GRC will start to dry by evaporation while the lower surface will not. The resulting bow is usually a temporary state since the effect is normally reversible. If different areas of a product are subject to different conditions of temperature and moisture the product will tend to change shape to accommodate the induced movement, but under certain circumstances the product may be restrained, either by being fixed to another structure or by its own shape, resisting the change of shape. When restraint occurs stresses are induced and these stresses can exceed the failure stress of the GRC, resulting in what are termed "shrinkage" cracks.

The calculation of such stresses and deflections is complex in most cases and also inaccurate, since the conditions of moisture and temperature can only be estimated. However if all movement of the GRC is totally restricted then the stress which would be developed may be unacceptably high. For example restraint of 0.15% shrinkage could induce a stress

f = .0015 x 20,000 = 30 MPa assuming a value of 20,000 MPa for Modulus.

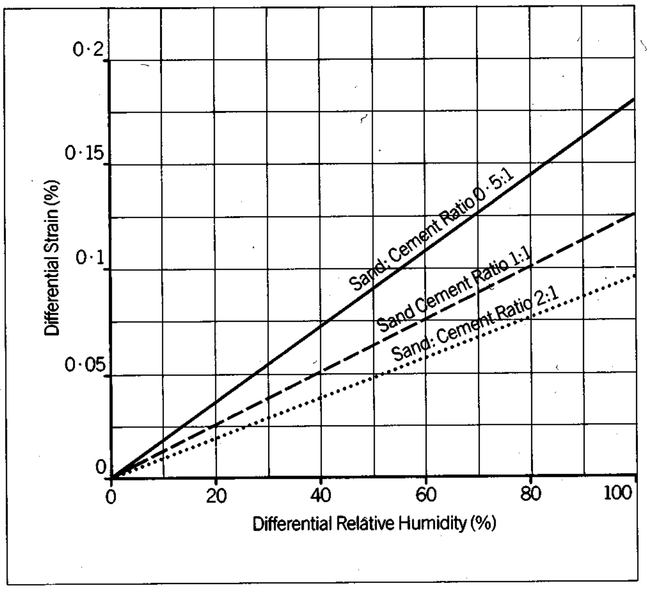
This is substantially higher than the tensile strength of most GRC formulations.

Good design of GRC products would include a minimal number of fixings, making sure that these allow movement in the plane of the GRC, and would also restrict the number of changes of section, ensuring those which are necessary are as smooth as possible.

However GRC is often made with built-in stiffening ribs formed round expanded foam, or in the form of sandwich structures. In both cases there is opportunity for the GRC on opposite sides of the core material to experience different conditions of temperature or moisture content. These different conditions create a tendency for bowing of the product, to a limited extent in ribbed GRC, but much more pronounced in sandwich structures.

For sandwich structures, Figure 7.2.3(a) gives a guide to the differential strain which can be generated by differences in relative humidity. The differential strain which can be generated by a temperature difference ΔT°C can be calculated from $\varepsilon = \alpha\Delta$ T where α is the coefficient of thermal expansion (see Section 5.2). The temperature difference between the two faces should be calculated from the known exposure conditions taking due account of solar gain. Solar gain is higher for dark coloured products (approximately 45°C above ambient as opposed to 25°C for light colours) so there is significant advantage to be gained from using light colours on GRC.

Figure 7.2.3 (a)
The relationship between differential RH and differential strain for various sand: cement ratios.

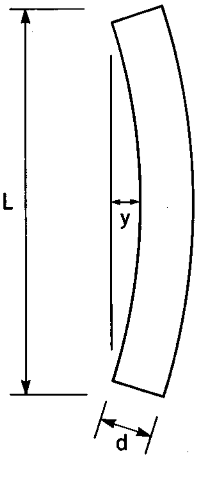


Whilst it may be sensible to design for extreme values of temperature variation, the slow reaction of GRC to moisture vapour movement makes it reasonable to design sandwich panels for values of relative humidity averaged over a long period. The differential strains developed by moisture and temperature may act in opposite senses and this can be taken into account.

The value of the deflection expected in a flat sandwich component which is free to bow is given in Figure 7.2.3(b).

Figure 7.2.3 (b)
The relationship between bowing deflection and panel dimensions.

$$y = \frac{\epsilon L^2}{8d}$$



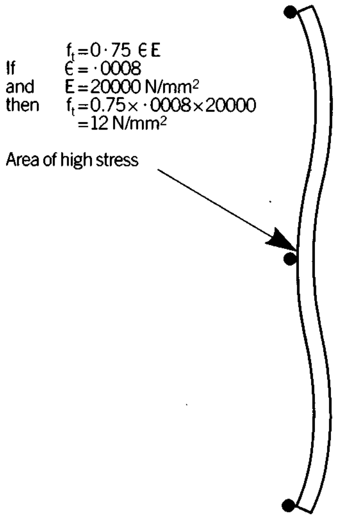
Where
ε is the diferential strain
L is the length of the product
d is the total thickness of the product
BS 8110 (Reference 2) suggests that a limit on deflection of

L/350 is suitable for cladding panel design purposes, so applying this to the case of a GRC sandwich cladding panel with ε = 0.08%, a value obtained from inspection of many contracts in the U. K., results in the requirement for d > 0.035L.

This thickness is generally greater than that required for resistance to normal cladding loads.

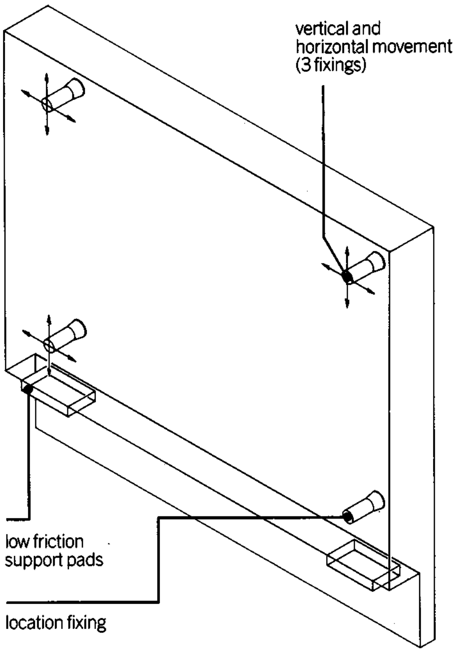
If a sandwich panel is prevented from deflecting, either by intermediate or continuous fixing of a flat sandwich or by the inherent resistance of certain shaped sandwich constructions to deforming in particular directions, then restraint of the differential strains will induce stresses in the GRC skins.

Figure 7.2.3 (c)
The effect of intermediate restraint of the bowing deflection.



On the other hand in the case of flat panels significant stresses are not produced provided that the panel is allowed to move and deflect freely (Fig. 7.2.3(d)). This dictates the avoidance of intermediate fixings and strongly suggests the use of fixings which allow for bowing and shrinkage movement.

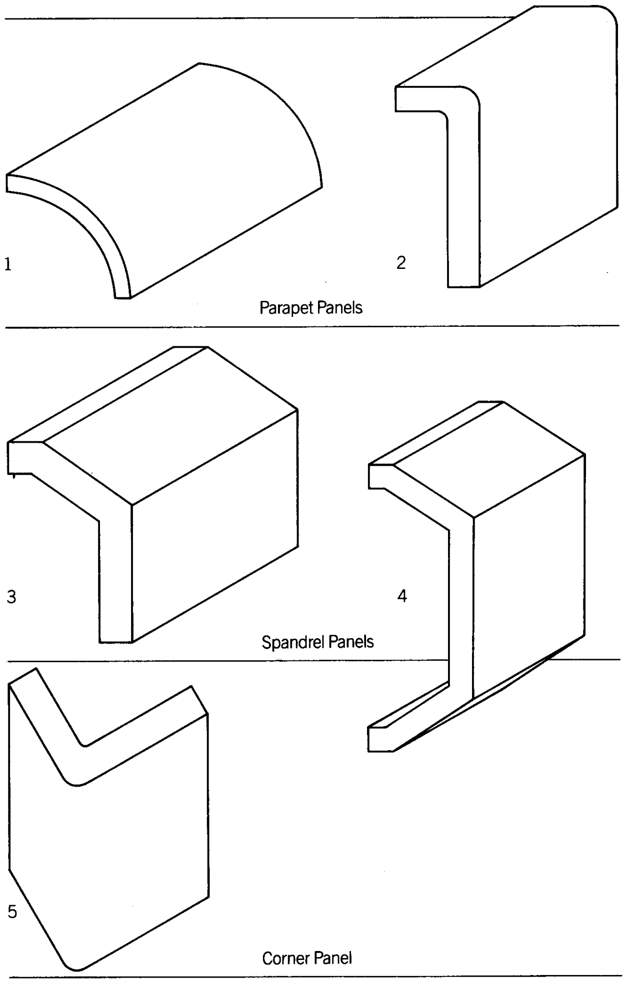
Figure 7.2.3 (d)
Fixings should allow freedom of movement.



Whilst significant skin stresses do not normally occur in simple flat sandwich panels free to move, in detail there can be stresses of greater magnitude where particular adverse strain gradients apply in conjunction with a rigid core material. Consideration should be given to this aspect and in the absence of detailed calculations it may be appropriate to include an allowance of 1 N/mm^2 for residual shrinkage stresses.

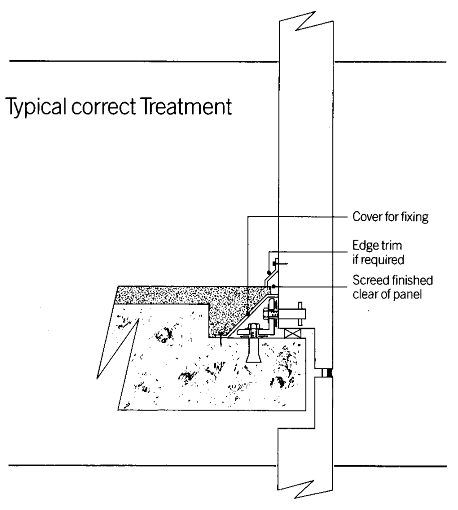
Sandwich panels which are corner shaped or curved (Fig. 7.2.3(e)) can be subject to tensile stresses irrespective of fixing condition. This is of particular significance in climates where variable weather conditions are prevalent, e.g. the U.K., and in such areas shaped sandwich panels should not be used. In these cases the panel shape should be simplified or single skin construction adopted. Where a shaped sandwich panel has sufficient bending stiffness to induce high stresses it will often have enough strength to be designed as a single skin. This may therefore be the preferred solution.

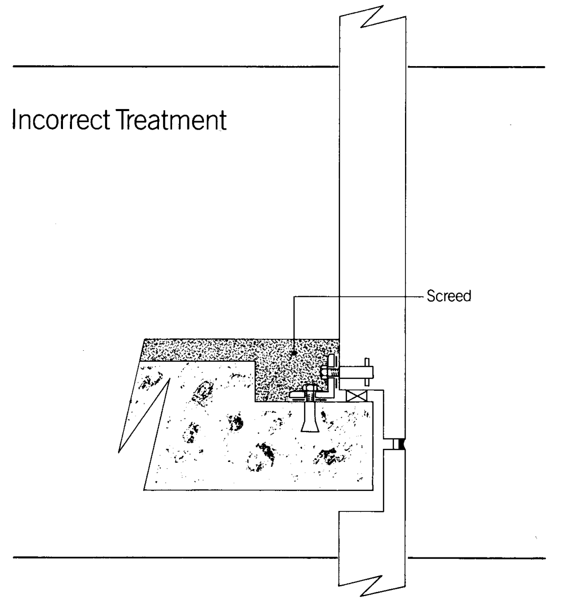
Figure 7.2.3 (e)
Examples of shaped panels where it is recommended that single skin construction is used.



In addition to providing allowance for movement at the fixing positions, the detailing of the areas of a structure surrounding a GRC component should ensure that movement of the GRC is not restrained. A typical example of restraint is provided by screeding a floor directly up to the back of a cladding panel, which may not only prevent the natural bowing, but may also lock fixings which are otherwise designed to allow movement.

Figure 7.2.3 (f)
Screeding up to the rear face of a GRC panel.





The presence of other members which may restrain movement should also be considered, and steps taken to ensure that restraint does not occur.

7.2.4 Thermal Insulation

The passage of heat through a structure is usually defined in terms of the overall thermal transmission or U-value. This is most often used in the context of buildings, but is also applicable to any other use where thermal insulation is required.

The U-value of a structure depends on the thickness and thermal conductivity of the materials of construction. Each layer of material has a thickness t metres and a thermal conductivity K W/m°C.

The thermal resistance of that layer of material is given by

$$R = \frac{t}{k} \quad m^2\ °C/W$$

and the thermal resistance of the structure is found by summing the material resistances and the surface resistances.

	Material A	B	C	
	t_A(m)	t_B(m)	t_C(m)	
	K_A(W/m°C)	K_B(W/m°C)	K_C(W/m°C)	
Resistances:				
R^1 Surface Res:	$R^2 = \frac{t^A}{K^A}$	$R^3 = \frac{t^B}{K^B}$	$R^4 = \frac{t^C}{K^C}$	R^5 Surface Res:

e.g. $R_0 = R_1 + R_2 + R_3 + R_4 + R_5$ for the diagram shown.

The U-value is obtained from

$$U = \frac{1}{R_0} \quad W/m^2°C$$

The values of the surface resistance R_1 and R_5 depend upon many variables, such as roughness, temperature and speed of flow across the surface. However, three main values can be taken to cover most cases adequately.

(i) Still air (internal surfaces) R = 0.123 m^{2}°C/W

(ii) Wind (external surfaces) R = 0.055 m^{2}°C/W

(iii) Liquid (still or moving) R = 0 m^{2}°C/W

This method of calculating the U-value can be extended to any number of material layers, and the designer should adjust thicknesses and types of material to obtain a suitable U-value.

Table 7.2.4

Material	Approximate density Kg/m^3	Thermal Conductivity W/m°C
GRC	1900/2100	0.5-1.0 (depending on moisure content)
PBAC	400	0.14-0.18 (depending on moisture content)
Polystyrene	20-30	0.0037
Polyurethane	40	0.023
Phenolic foam*	30	0.035
Glass wool*	12-50	0.035-0.040

* Phenolic foam and glass wool cannot be considered as structural infil materials.

In cases where different areas of a structure have different U-values, an average U-value can be obtained from:

$$\frac{U_1A_1 + U_2A_2 + U_3A_3 + \ldots}{A_1 + A_2 + A_{3+}\ldots}$$

where U_1, U_2, U_3,… are the U-values of sections of the structure with surface areas A_1, A_2, A_3,…

This is used to take into account such things as side walls or internal ribs in sandwich constructions, and areas of window in cladding panels.

7.2.5 Interstitial Condensation

Condensation within the fabric of a construction is possible when the materials used are permeable. This also applies to constructions containing GRC, although it is less permeable than other cementitious materials. The possibility of interstitial condensation can be predicted by a standard calculation (Ref. 3) and values of vapour resistivity (taken largely from Ref.3) for materials often associated with GRC are given in the following table.

Table 7.2.5

Values of Vapour Resistivity of Materials

Material	Resistivity MNs/gm
Moving Air	0
Still Air	5.5
Mineral Wool	
Expanded Polystyrene	100-600
Polyurethane Foam	30-1000
Concrete	100
Asbestos Cement	250-500
Plasterboard	60
Plaster	60
GRC	900-2000
PBAC (Styropor)	200

Most constructions, either by accident or design, separate environments containing different water vapour pressures and are thus subject to water vapour movement through the construction. It is important that the surface on the side of low water vapour pressure is at least as permeable as the surface on the side of high vapour pressure to reduce the risk of moisture build up in the construction. Hence caution should be used when considering surface finishes which may be relatively impermeable.

7.2.6 Fire Performance

The use of a building material is governed largely by its performance in a range of standard fire tests. These standard fire tests can be divided into two categories:

- Those which test the materials themselves.
- Those which test the performance of a particular structure.

The exact nature of the standard tests depends upon the country concerned but most tests are broadly comparable with the British Standard fire tests currently used by specifying bodies in the U.K.

Fire Tests

Table 7.2.6 gives the performance of Cem-FIL GRC to the relevant sections of BS 476: “Fire Tests on Building Materials and Structures” (Ref. 4). Material tests are unaffected by product density, fibre content or matrix composition; providing organic matter is present at levels no higher than 1% the product should pass the Non-combustibility test.

Table 7.2.6:
Example of the Performance of Cem-FIL GRC in fire tests.

	GRC Construction	Non Combustibility BS476 Part 4	Ignitability BS476 Part 5	Fire Propagation BS476 Part 6	Surface Spread of Flame BS476 Part 7	Fire Resistance BS476 Part 8			Notes
						Stability	Integrity	Insulation	
Single Skin	GRC–'Standard'Single skin 10-15mm thick	Non Combustible	P	Class 0	Class 1 Zero Spread	–	–	–	Class 0 rating can also be obtained with a wide range of organic based surface coatings
Single Skin	Cement/PFA/air entranment formulation 8-15 mm thick GRC	Non Combustible	P	Class 0	Class 1 Zero Spread	2h	2h	–	A specially formulated matrix for added fire protection
Single Skin	Cement/Perlite formulation 8-15 mm thick GRC	Non Combustible	P	Class 0	Class 1 Zero Spread	2h	2h	–	A low density product designed for ease of on-site cutting and drilling
Single Skin	Single skin GRC and fire protection insulant	Non Combustible	P	Class 0	Class 1 Zero Spread	1h	1h	–	The actual degree of resistance depends on the thickness and type of insulant
Sandwich Construction	Double skin GRC panel enclosing 50 mm of glass or mineral wool (minimum density 30 kg/m^3)	Non Combustible	P	Class 0	Class 1 Zero Spread	1h	1h	–	This type of construction will not act as a sandwich
Sandwich Construction	GRC 10 mm PBA Concrete† 50 mm GRC 10 mm	–	P	Class 0	Class 1 Zero Spread	2h	2h	2h*	* Determines fire rating of the construction.
Sandwich Construction	GRC 10 mm PBA Concrete† 100 mm GRC 10mm	–	P	Class 0	Class 1 Zero Spread	4h	4h	4h*	† PBA Concrete – Polystyrene Bead Aggregate Concrete.

Tests have been conducted in the United Kingdom according to the BS 476 Part 8 1972 test which determines the fire resistance of a given structure. This test has three criteria:

Stability:

The structure under test must not collapse.

Integrity:

Flames must not penetrate the structure.

Insulation:

The temperature on the protected side of the structure must not rise by an average of more than 140 deg. C above the initial temperature.

A single skin of GRC will not satisfy the Insulation criterion and the standard cement/sand mix cannot be relied on to maintain Integrity. To guarantee Integrity in single skin form it is necessary to use a cement/PFA/air entrainment mix, a low density perlite/cement mix or similar mix with reduced density and increased porosity.

The cement/PFA/air entrainment mix is only used for internal applications at present. A single skin of GRC can provide a 1 hour fire resistance to all three criteria if a suitable thickness of a fire resistant insulant, such as vermiculite/cement or gypsum is applied to the GRC.

Sandwich panels containing a lightweight polystyrene bead aggregate concrete (PBAC) core perform well in the fire resistance test: all three criteria are readily achieved with ratings of up to 4 hours. Table 7.2.6 indicates the constructions which can be used to achieve different fire ratings. It must be noted that the BS 476 Part 8 1972 test applies to the whole construction under test and therefore, in the case of a panel the joint and the fixing points are also tested.

Smoke Production

There is, at present, no British Standard or I.S.O. test for the smoke production of building materials.

GRC has been subjected to the AMINCO National Bureau of Standards Smoke Density Chamber Test (ASTM STP 422-67).

Test Result	THERMAL EXPOSURE Flaming	Non-Flaming
Average Maximum Value of Specific Optical Density	4	4
Obscuration Time (mins)	not reached	not reached

For comparison, timber products usually have Maximum Values of Specific Optical Density of the region of 150 (Flaming) and 300 (Non-Flaming) with an Obscuration Time of 2 to 8 minutes; polyester resin products have Maximum Values of Specific Optical Density in the region of 400 and an Obscuration Time in the region of 1 to 5 minutes. GRC, therefore, has negligible smoke production.

Certification

GRC is classified as “Class 0” according to Section E15 of the 1976 Building Regulations (U. K.).

GRC is listed as an Approved Lining Material in Schedule 8 of the Fire Offices’ Committee Rules (1978).

GRC meets the requirements for Non combustibility as specified in ASTM E 73 “Noncombustibility of Elementary Materials”.

7.2.7 Sound Reduction

The amount of sound reduction obtained with GRC is proportional to the surface mass (weight/unit area). This will apply to both single skin and sandwich construction. If larger reductions than 20-40 dBA are required it is generally uneconomic to increase the surface mass and specialized sound absorbing systems are required.

7.3 Installation Considerations

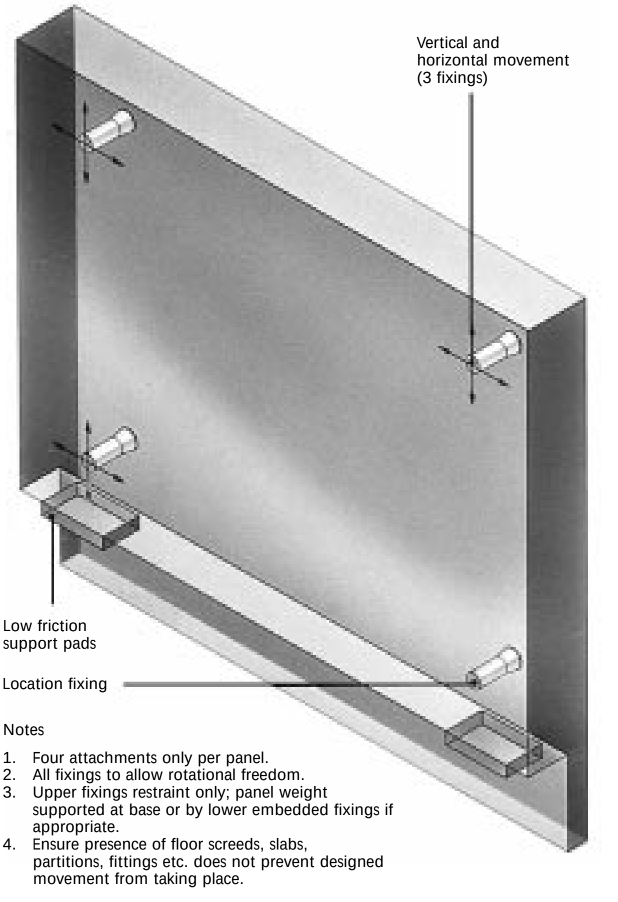
7.3.1 Fixing Systems

Many types of fixing commonly used with concrete, stone, asbestos cement, GRP or steel can be used directly or adapted to GRC, giving a wide range of possibilities.

In respect of the materials used for fixing components, GRC is no different to concrete and the choice of material is likely to be influenced by the local Statutory Authority. Austenitic stainless steel and non ferrous inserts are preferable. Galvanised mild steel may be used, however the coating weight will be dictated by the durability required. Unprotected. mild steel must not be used under any circumstances for cast in fixings. Where dissimilar metals are in contact there is a possibility of galvanic corrosion occurring. This can be avoided by the use of isolation materials such as neoprene and synthetic resin bonded fibres.
In all cases the fixing system should be designed so that the force transmitted through the fixing is transferred to a sufficiently large area of GRC. For example the fixing should be encapsulated in a block of GRC, or oversize washers or plates should be used to spread the load.

The fixing system should make allowance for site and manufacturing tolerances, for thermal and moisture movement of the GRC, and for movement of the structure. For instance one fixing can be used to locate the product while all other fixings allow movement relative to it. (Fig. 7.3.1(a)). Because of the occurrence of bowing with sandwich construction products, fixing systems for these should not restrict small rotational movements and should not be placed in positions which restrict the bowing of the product. (Section 7.2.3).

Figure 7.3.1 (a)
General principles of fixing for ribbed single skin or sandwich panels.



Allowance for movement cannot be achieved just by providing a slotted hole since a bolt system can be tightened sufficiently to eliminate sliding in the bracket. The following sections show various methods of allowing movement with manytypes of fixings. The fixing detail should ensure that subsequent site work, e.g. screeding, is not allowed to lock fixings which are supposed to allow movement.

Where possible, products of significant weight should be supported from below so that the weight of the product induces compressive stresses, thus leaving the full tensile strength of the product available to resist applied loads.

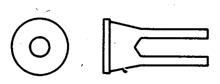
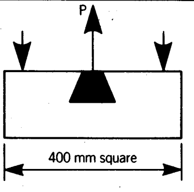
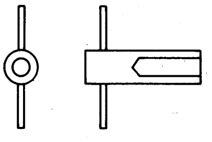
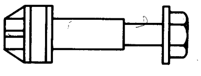
The state of serviceability expected from the fixing should be considered and a factor applied accordingly.

A full set of instructions on the assembly and use of the fixings (including advised bolt torques) should be provided with the drawings.

Encapsulated Fixings

This type of fixing includes cast in sockets and other major cast in concrete fixings.

Table 7.3.1.
Results of pull out tests on some types of cast in sockets.

Type	Illustration	Typical test method	Type tested	Thread size	Pin	Pull-out load kN Length *mm* 38	50	75
1. Cast-in sockets Cone type. Ferrous and non-ferrous.			'Harris & Edgar' HET 300 Series Aluminium Bronze	M10		25	25	30
				M12			30	50
				M16			30	60
2. Cast in sockets with cross pin anchor bar. Ferrous and non-ferrous.		(As above)	'Harris & Edgar' HET 27 Series	M10	6 x 50	Insufficient data but expected to be similar to cone type cast-in fixing		25
				M12	10 x 75			50
				M16	10 x 75			60
3. Cast-in socket Nut encased in plastic.		(As above)	Fischer BM12	M12				40

When used to carry high loads the fixing should be encapsulated in a block of good quality GRC with a minimum width of 100 mm and a minimum dimension of 50 mm between the fixing and the edge of the component. The detail of the fixing area should be such that it is easily accessible during manufacture. Good quality material must be used around the fixing. Waste material is not acceptable.

The results of pull out tests on encapsulated fixings in GRC show similar results to the same fixings used in concrete.

Three suggestions for allowing freedom of movement with cast-in fixings are shown in Figures 7.3.1(b) to 7.3.1(d), but any method of fixing capable of allowing in-plane translation in all directions, out-of-plate rotation and sufficient tolerance will suffice.

Figure 7.3.1 (b)
Flexible rod.

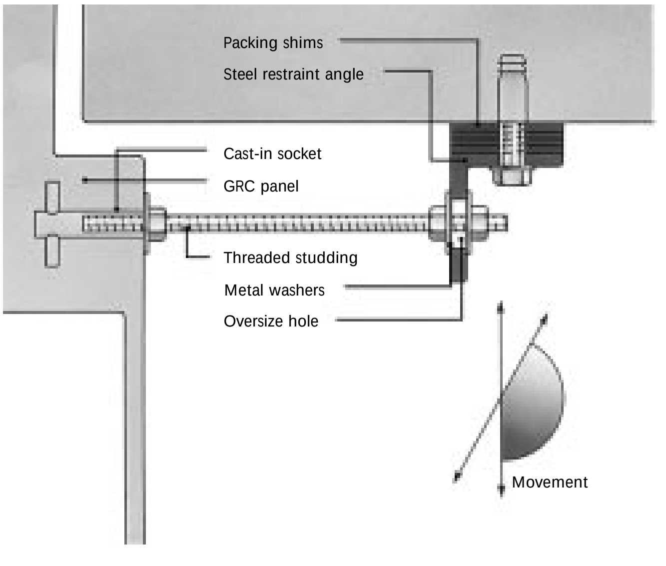


Figure 7.3.1 (c)
Sliding bracket.

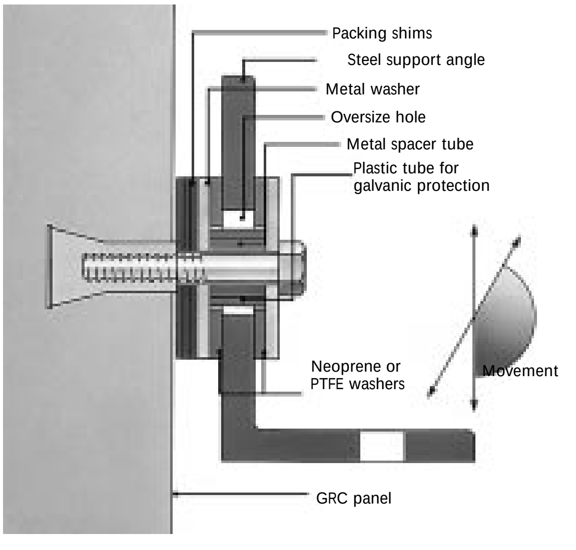
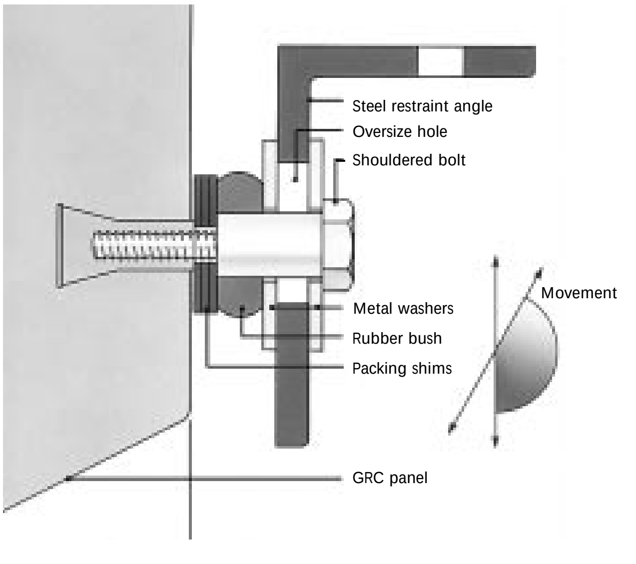


Figure 7.3.1 (d)
Resilient bush fixing.



The principles of Figures 7.3.1(b) to 7.3.1(d) also apply to cast-in channels or inserted fixings.

Cast-in Channel Fixings

If these are well incorporated, the loading values for concrete panels can be used, but it would be advisable to perform pull-out tests on an actual GRC component.

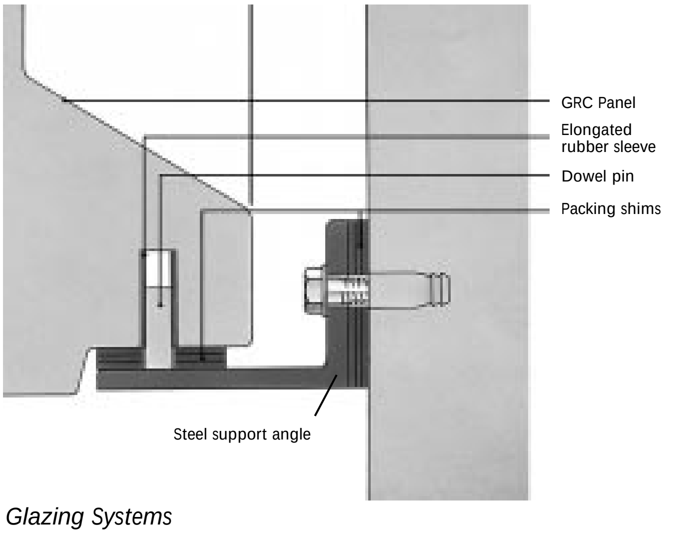
Inserted Fixings

This type includes expansion bolts and chemical anchors. These are not recommended for heavy duty fixings in GRC because of variability in test results.

Dowel Pin or Dowel Plate (Corbel) Fixings

If correctly detailed this system can allow for any amount of in-plane movement and tolerance, but at the same time gives ease of attachment with high resistance to lateral forces. This type of fixing should be designed for the dowel pin shearing through the GRC walls of the socket.

Figure 7.3.1 (e)
A dowel-type fixing.



Glazing Systems

Any system which is satisfactory for the fixing of glass will be satisfactory for flat sheet GRC of the same edge thickness.

A/C Fixings

All asbestos cement fixings can be used for fixing single skin GRC. Pull-through shear stresses should be checked.

Oversize Washers

Any form of fixing through the panel can be used with an oversize hole in the GRC and oversize washers or bearing plates to spread the load, e.g. nails, screws, bolts, pop rivets, blind fixings.

The washer should be at least 5 times the diameter of the fixing mechanism and of sufficient thickness (> $^{1}/_{16}$ washer diameter) to spread the load effectively. Tests have shown that the fixing can then be designed to the shear stress acting around the perimeter of the washer. Where bolts are used, tightening torque should be limited to avoid locking the fixing by distorting the oversize washer.

Cast-in Studplate

This type of fixing is similar to a cast-in washer, but has a stud welded to it. The same comments apply.

Screw Fixing

For minor fixings, screwing directly to the GRC can be a suitable method of attachment. This can be done using:

(a) Self tapping screws into pilot holes. Good attachment depends critically on the choice of pilot hole diameter.

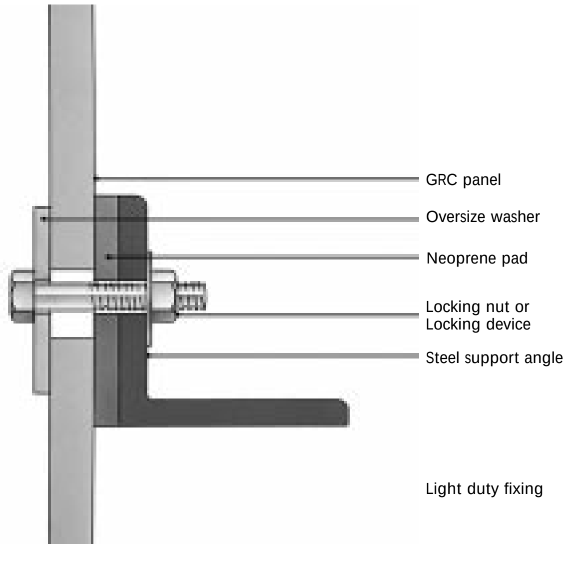
(b) Screws into masonry plugs.

(c) Screws into cast-in plastic block. Wood blocks can be used, but may swell with moisture during casting and curing of the GRC, subsequently shrinking away from the surrounding GRC.

Adhesives

Adhesives suitable for cement based materials can be used with GRC and will give joint strengths similar to those obtained with other cementitious substrates.

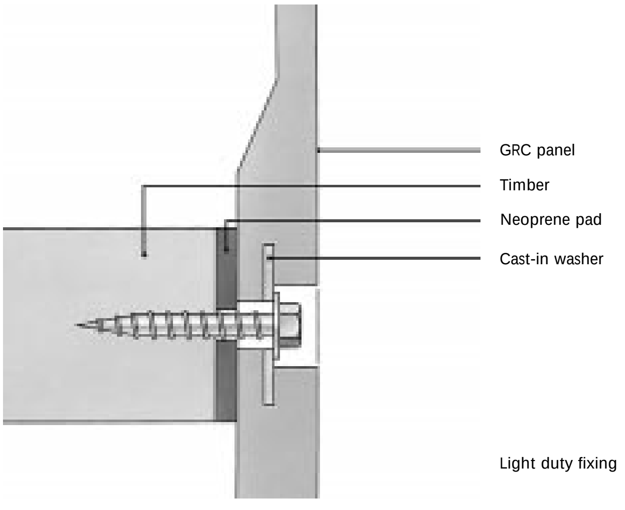
Figure 7.3.1. (f)
Single skin fixing system.



Cast-in Washers

The comments for oversize washers apply.

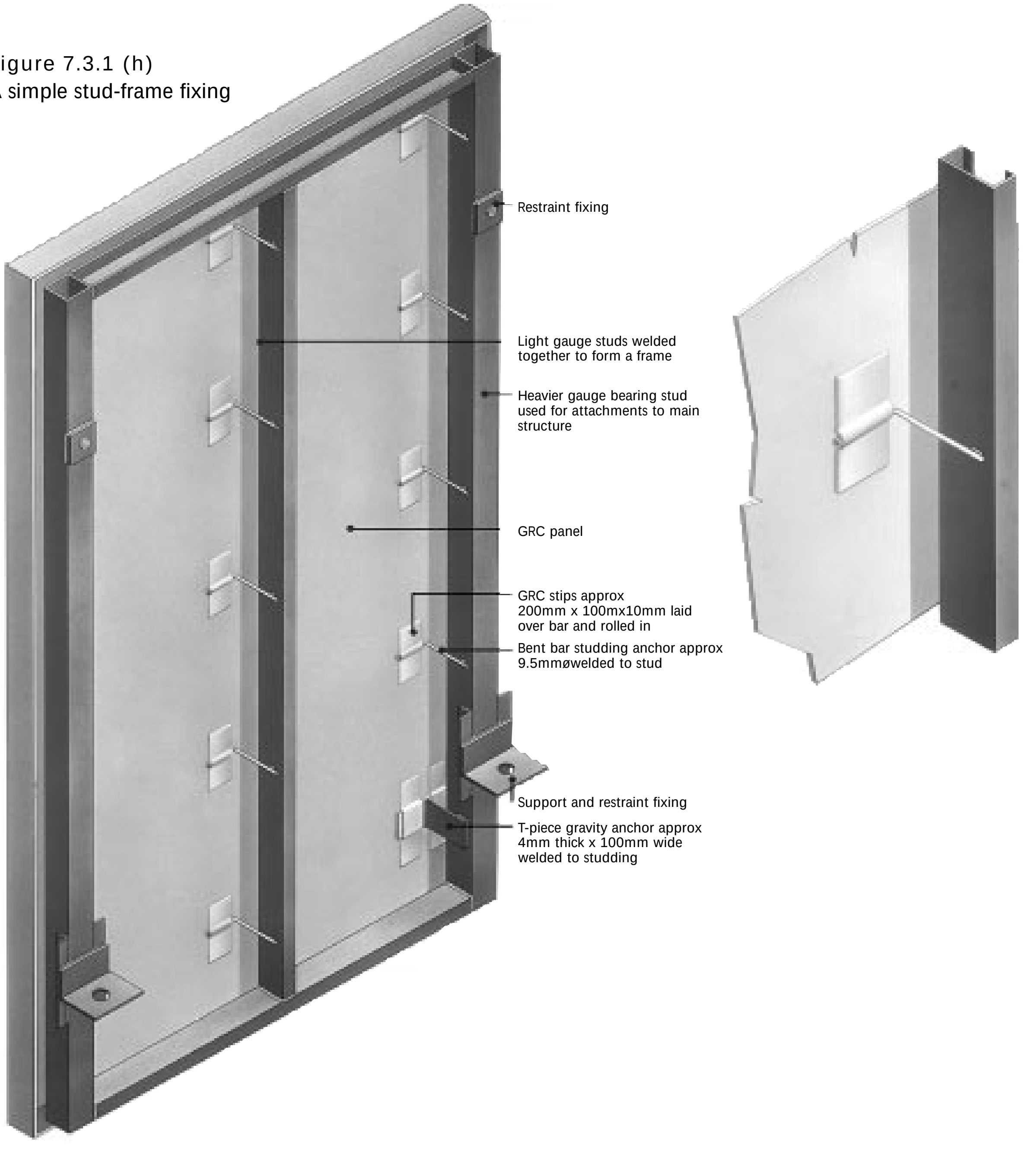
Figure 7.3.1 (g)
Cast-in washer detail.



Stud Frame

Single skin GRC is particularly suited for attachment to a wood or metal studding frame by overspray of attachments to the frame members. Although this system apparently conflicts with requirements for movement, there is normally sufficient flexibility in the system. The complete unit of GRC and frame is then attached by conventional means. The studding anchors should be at 600 mm centres.

Figure 7.3.1 (h)
A simple stud-frame fixing



7.3.2 Jointing and Sealing

The techniques used to “seal” joints between GRC components are similar to those used for natural stone, precast concrete or asbestos cement. The amount of “sealing” can vary from simple overlap joints (e.g. corrugated sheet), designed to resist rain penetration, to compression joints, designed to resist liquids under large hydrostatic pressures. A code of practice (Ref. 5) gives general guidance.

7.3.2.1 Unsealed Joints

Overlap Joint

This type of joint should be designed according to existing criteria for asbestos cement or other thin sheet materials.

Cover Strips

The upturn flanges of two adjacent GRC components are covered by an inverted channel of another material. This is essentially a version of the overlap joint and should be treated as such since forming an air-tight seal can be difficult.

7.3.2.2 Sealed Joints

These types of joint are expected to resist the flow of air through a joint. All involve some method of sealing the joint to resist the air flow and hence require some material to be always in contact with the components on either side of the joint. The contact is maintained by compressive forces or adhesion, but in either case, the joint needs to be carefully designed with regard to the relative movement of the components in order to maintain the seal under all conditions.

Sealing Compound

Joints filled with sealant do not need complex edge details, but the surface must be clean, dry, free from laitence and primed according to the sealant manufacturers instructions. Sealants must be flexible to allow for GRC movement and the joint design should anticipate this, ensuring that the expected joint movement in all three directions is within the capabilities of the sealant. (Ref. 6). For example a 3 m long component may experience up to 6 mm moisture and thermal movement. Sealants are readily available which have an allowable strain capacity of 25%, so to accept a movement of 6 mm the joint width will need to be a minimum of 24 mm. In order to maintain this, it has been suggested (Ref. 7) that the joint width be designed to be:

minimum allowable + expected movement which in this case would be 24 + 6 = 30 mm.

It is important that the design of the joint should take into account the component surface. Aggregate facing mixes can be porous, allowing water to penetrate behind the seal if this is wrongly positioned, and care must be taken to keep any applied finish clear of the sealing area since this could cause problems with adhesion. (Reference 6). Joints filled with sealing compound properly applied and well designed can resist hydrostatic pressure.

Figure 7.3.2.2 (a)
Sealing Compound joint.

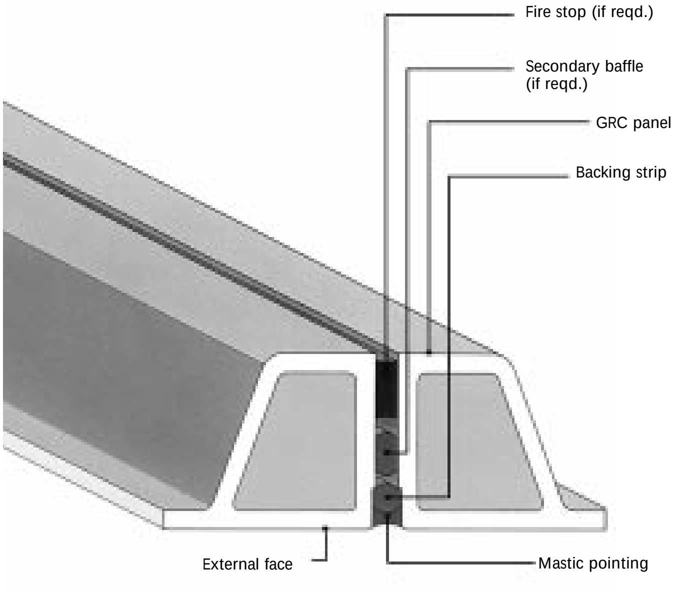
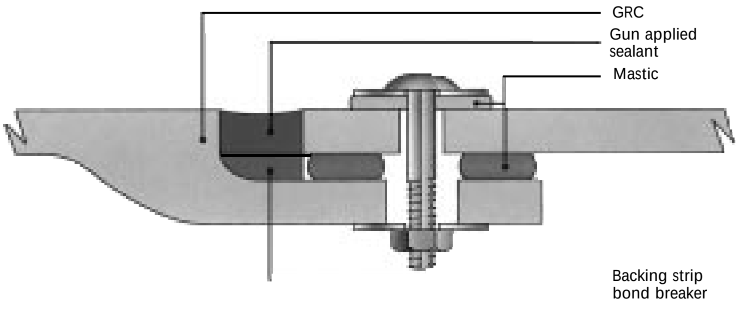


Figure 7.3.2.2 (b)
Sealing compound joint.



Gaskets

Gaskets joints do not need complex edge details to components, but the surfaces to which they match must be very smooth, accurate and defect free. Gaskets rely on permanent compression to remain effective sealing agents, so very tight joint tolerances and close attention to GRC thermal and moisture movement is necessary to design an effective gasket joint. Such a joint would then be air-tight and resist rain penetration.

Figure 7.3.2.2 (c)
Gasket Joint.

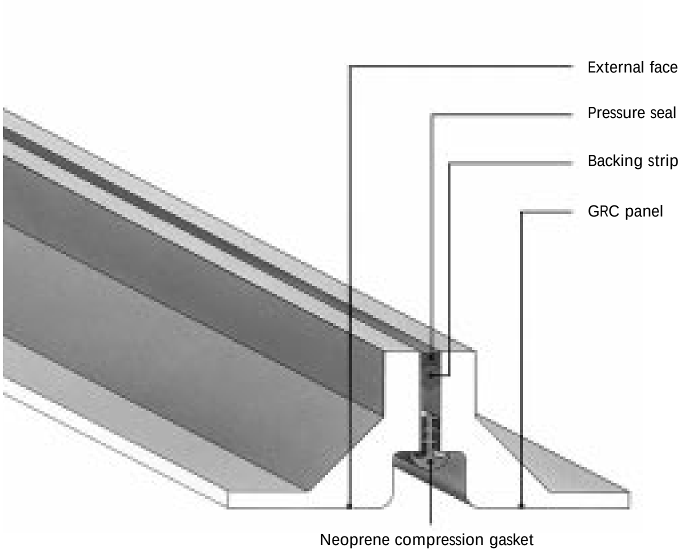
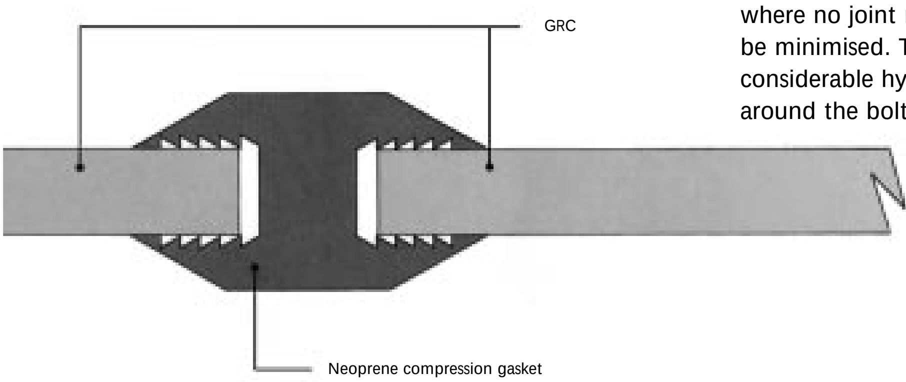


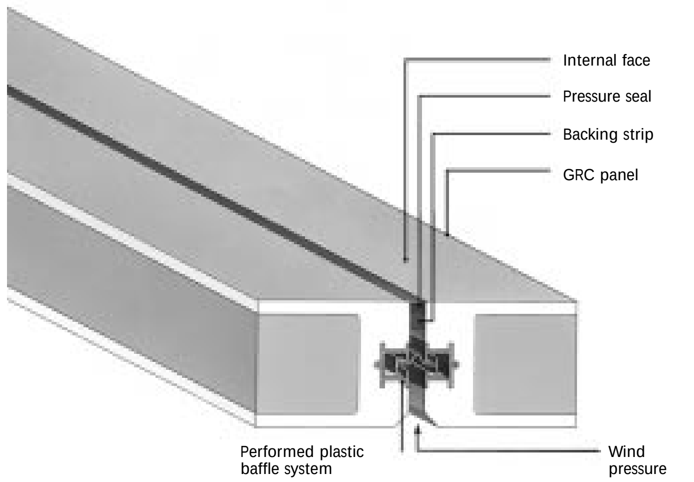
Figure 7.3.2.2 (d)
Gasket joint for small flat areas of GRC.



Open Drain Baffle Joint

This type of joint is only suitable for thick section GRC components with deep edge returns. It contains an air-tight seal which is protected from direct weathering by the baffle. Although the baffle can accept considerable variations in joint width and considerable movement, the presence of the sealant at the back requires the joint width to be designed as if it were a sealant joint.

Figure 7.3.2.2 (e)
Open drained baffle joint.



Compression Joints

This type of joint, where two flanges of GRC are bolted together with a layer of compressible material between, can only be used where no joint movement is expected and joint tolerances can be minimised. This type of joint will be capable of withstanding considerable hydrostatic pressure, although the joint detail around the bolt position is critical.

7.3.3 Handling

Some provision will be required for lifting, storage and transportation of the GRC. This should be considered at the design stage and the GRC component should be designed to resist handling forces. This is particularly important during demoulding, when the GRC is incompletely cured and will have a relatively low strength. An appropriate design stress value at demoulding stage would be 1 MPa which would cover most eventualities.

The incorporation of strategically positioned lifting points, the use of frames, both in handling and transportation, and the manufacture of properly designed storage racks may assist in reducing problems encountered during the handling of GRC, particularly large components. The consideration of these at the design stage will simplify problems which otherwise might produce severe difficulties.

7.4 References

1. Litherland K.L., Oakley D.R.+ Proctor B.A., “The Use of Accelerated Ageing Procedures to Predict the Long Term Strength of GRC Composites”. Cement and Concrete Research, Pergamon Press Ltd., 1981, Vol. 11, pp 455-466.

2. BS CP8110, Part 1: 1985, “The Structural Use of Concrete”

3. BS 5250: 1975,’Code of Basic Data for the Design of Buildings: The Control of Condensation in Dwellings”.

4. BS 476, “Fire Tests on Building Materials and Structures”.

5. BS 6093: 1981, “Code of Practice for the Design of Joints and Jointing in Building Construction”.

6. C.I.R.I.A./Sealant Manufacturers Conference, “Manual of Good Practice in Sealant Application”,1976.

7. Building Research Establishment Digest 223.

8. Roark R.J. and Young W.C., “Formulas for Stress and Strain” 5th Edition, McGraw Hill, 1975.

9. Allen H.G., “Analysis and Design of Structural Sandwich Panels” Pergamon Press,1969.

8. Design Examples

The design examples contained in this publication are for general guidance only. It is the responsibility of the user to ensure that any design is appropriate for any particular application and the user's attention is drawn to the warnings in the introduction.

Cem-FIL International hereby disclaim all and any liability for any error in or omission from this publication and for all consequences of relying upon it.

INTRODUCTION

These examples demonstrate the methods involved in the design of GRC components for various applications. The reader is reminded that the design parameters used in these examples are assumed and should not therefore be taken as correct for real applications.

A full design analysis should always be performed by a Chartered Engineer, though other persons with experience of GRC may be able to design components sufficiently well to enable them to provide quotations or estimates for potential contracts or products.

Although stud frame GRC cladding panels are being increasingly used, this document does not contain an example since this application is covered in detail in the 'GFRC Recommended Practice for Glass Fiber Reinforced Concrete Panels' published by the Precast/Prestressed Concrete Institute, U.S.A.

In each of these examples, the design process will consider the factors discussed in Section 7 of 'Cem-FIL GRC Technical Data' entitled 'DESIGN PRINCIPLES'. These include:

(a) Resistance to applied loads
(b) Resistance to environmental influences
(c) Installation of the component.

In certain areas it may also be necessary to design for seismic effects.

It must be emphasised that these examples are for use with Cem-FIL GRC and may not be appropriate for other fibre reinforced cement materials.

Note. In designing GRC components the calculation of self weight in these examples assumes a nominal ambient density of 2,000 kg/m^3 and g = 10 m/s^2.

8.1 FORMWORK

There is considerable variety in the use of GRC as permanent formwork and reference should be made to the publication “GRCA Handbook No. 1 - Permanent Formwork (Reference 1)”.

The most common use of GRC formwork is as a bridge deck soffit spanning between the beams of bridges. Flat sheet, corrugated sheet and ribbed sheet products are all used. The example shown here is for corrugated sheet.

8.1.1 Design Stresses

Assuming that the formwork is to be used within one year of manufacture and the consequences of failure are classed as ‘Normal Risk’, the standard design stresses for sprayed GRC formwork are taken from “GRCA Handbook No. 1” as:

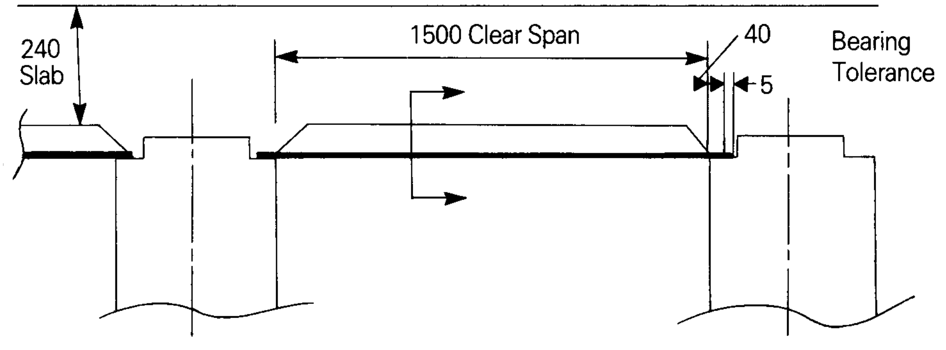
Compressive	20 MPa	
Bending	9 MPa	
Tensile/Bending	6 MPa	(for box sections or channels)
Tensile	4.5 MPa	
Web Shear	2.5 MPa	
Bearing Shear	1 MPa	

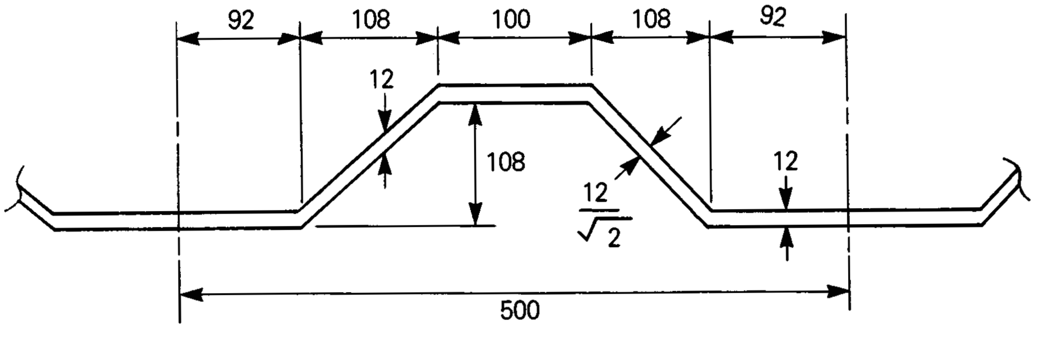
Some of these values are higher than those quoted in Table 7.1.3 of ‘Cem-FIL GRC Technical Data’. This is because formwork is subjected to the design loads only once (until the concrete hardens) and is loaded when unaged. Therefore these design stresses assume that the formwork is always used within one year of manufacture. Use of these design stress levels should give the product a factor of safety of at least 2x on the material properties, but this should always be checked by a representative load test.

8.1.2 Assumed Design Parameters

Clear Span	=	1.5 m
Bearing Width	=	40 mm (at each end of the span)
Panel Length	=	1.5 + (2x0.04) = 1.58 m
Design Span (L)	=	$\frac{1.5 + 1.58}{2} = 1.54$ m
Concrete Depth	=	0.24 m (above top of rib)

8.1.3 Section and Section Properties



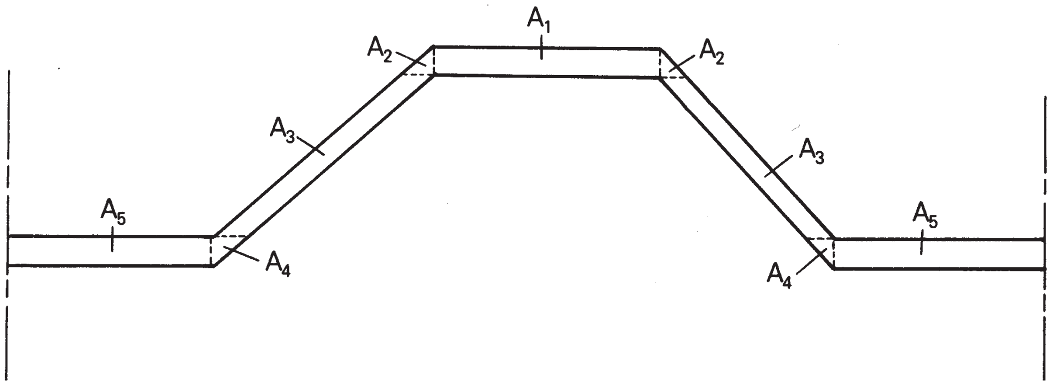


SECTION A-A

(All dimensions in mm)

For this complex section, numerical calculations can be tedious and would therefore normally be performed on a computer. However, in this case the section properties have been calculated by long-hand to show the method.

Considering one 500 mm wide section of formwork the GRC can be split into elements as shown below:



Where there are two similarly numbered elements (e.g. A_2) the two areas are added in the calculations.

The required section properties are:

y (distance from Base to Neutral Axis of Section)
I_{NA} (Second Moment of Area about its Neutral Axis)
a_y (First Moment of Area above or below the Neutral Axis)

Calculation of y

$$y = \frac{\text{Sum of Moment Areas about the base}}{\text{Total Area of GRC}}$$

(Each Moment Area is the area of that element multiplied by the distance from its centroid to the base of the section).

Element	Area (mm2)	Distance from Centroid of Element to Base of Section (mm)	Moment Area about base (mm3)
A1	1,200	114	136,800
A2	144	112	16,128
A3	2,304	60	138,240
A4	144	8	1,152
A5	2,208	6	13,248
Total Area	6,000 mm^2	Sum of Moments	305,568 mm^3

Therefore the distance from the base to the Neutral Axis of the Section is:

$$y = \frac{305,568}{6,000} = \underline{50.93\text{ mm}}$$

Calculation of I^{NA}

The Second Moment of Area of the Section about the Neutral Axis is given by

$I_{NA} = \Sigma\ (I_A + Ah^2)$

where Σ means 'the sum of',

I_A is the Second Moment of Area of each element
A is the Area of each element
h is the distance from the Centroid of each element to the Neutral Axis of the Section

Note:

The Second Moment of Area of a rectangle about a horizontal line through its centroid is given by

$$I = \frac{bd^3}{12}$$

where b = base width
d = depth

The Second Moment of Area of a triangle about a horizontal line through its centroid (parallel to its base) is given by

$$I = \frac{bd^3}{36}$$

where b = base width
d = depth

Element	I_A (mm^4)	Area (mm^2)	h^2 (mm^2)	I_{NA} (mm^4)
A_1	$\frac{100 \times 12^3}{12}$	1,200	$(114 - 50.93)^2$	4,787,790
A_2	$\frac{2(12 \times 12^3)}{36}$	144	$(112 - 50.93)^2$	538,206
A_3	$\frac{2(12 \times 96^3)}{12}$	2,304	$(60 - 50.93)^2$	1,959,010
A_4	$\frac{2(12 \times 12^3)}{36}$	144	$(50.93 - 8)^2$	266,542
A_5	$\frac{2(92 \times 12^3)}{12}$	2,208	$(50.93 - 6)^2$	4,483,796

Total $I_{NA} = 12.035 \times 10^6$ mm^4

Therefore, the Second Moment of Area of the Section about its Neutral Axis is

$I_{NA} = 12.035 \times 10^6$ mm^4

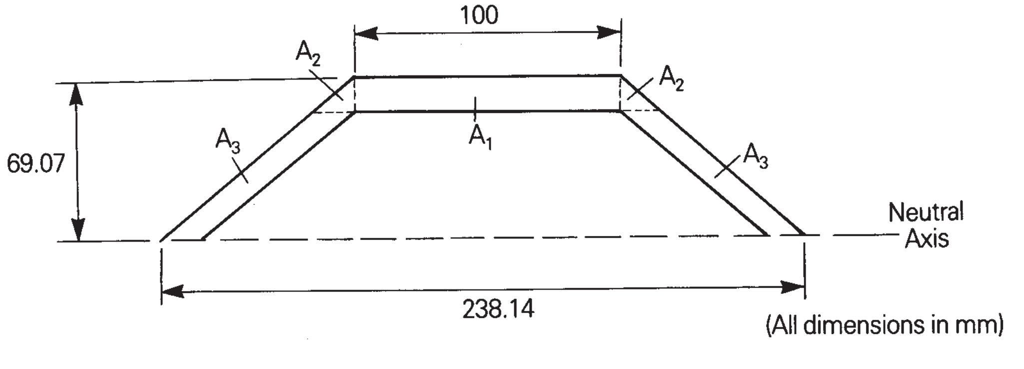
Calculation of a_y

The First Moment of Area of the section (a_y) can be calculated for either the area above or the area below the neutral axis. In this case the area above the neutral axis has been chosen.

$a_y = \sum Ah$

where $\sum$ means 'the sum of'
A is the area of each element
h is the distance from the Centroid of each element to the Neutral Axis of the section.

Considering only the area above the Neutral Axis the following diagram can be drawn.



Element	Area (mm^2)	h (mm^2)	Ah (mm^3)
A_1	1,200	63	75,600
A_2	144	61	8,784
A_3	1,368	28.5	38,988
			$\sum Ah = 123{,}372\ mm^3$

Therefore, the First Moment of Area above the Neutral Axis is

$\underline{a_y = 123.4 \times 10^3 mm^3}$

For a corrugated panel in bending we need to consider tensile and compressive stresses and shear stress in the webs.

Section Modulus for the tensile face:

$$Z_t = \frac{I}{y}$$

$$= \frac{12.035 \times 10^6}{50.93}$$

$$= \underline{236.3 \times 10^3 mm^3}$$

Section Modulus for the compressive face:

$$Z_c = \frac{I}{d - y}$$

$$= \frac{12.035 \times 10^6}{69.07}$$

$$= \underline{174.2 \times 10^3 mm^3}$$

8.1.4 Loading

The concrete load should be calculated according to accepted practice. For example, reference can be made to the Concrete Society Formwork Report “Formwork - A Guide to Good Practice”. (Reference 2)

Concrete slab 0.24 x 25		=	6.00 kN/m2
Concrete in Troughs, (92+92+108)x108x2x25x10^{-6}		=	1.58 kN/m2
Live Load		=	1.50 kN/m2
Panel Weight 0.012 x 20		=	0.24 kN/m2
Total Load	w	=	9.32 kN/m2

Hence, for a 500 mm wide section

Load, W = bwL
= 0.5x9.32x1.54
= $\underline{7.18kN}$

Maximum Bending Moment (M)

$$M = \frac{WL}{8}$$

$$= \frac{7.18x1.54}{8}$$

$$= \underline{1.382 kNm}$$

Shear force (S)

$$S = \frac{W}{2}$$
$$= \underline{3.59\text{kN}}$$

8.1.5 Stresses

Before considering the major span the ability of the GRC spanning between the webs to withstand the concrete load should be checked. This area can be considered as a clamped plate.

Bending Stress $f_b = \dfrac{M}{Z}$

Bending Moment $M = \dfrac{WL}{12}$

Section Modulus $Z = \dfrac{bt^2}{6}$

Therefore $f_b = \dfrac{0.5WL}{bt^2}$

W=wbL

Hence, $f_b = \dfrac{0.5wL^2}{t^2}$

$$f_b = \frac{0.5x(0.348 \text{ x } 25 + 1.5 + 0.24)x0.184^2}{0.012^2}$$
$$= \underline{1.23\text{MPa}} < 9\text{MPa} \quad \text{Therefore } \underline{\text{Acceptable}}$$

Major Span

Tensile/Bending Stress $f_{tb} = \dfrac{M}{Z_t}$

$$= \frac{1.382x10^6}{236.3x10^3}$$
$$= \underline{5.85 \text{ MPa}} < 6\text{MPa} \quad \text{Therefore } \underline{\text{Acceptable}}$$

Compressive Stress (f_c) $f_c = \dfrac{M}{Z_c}$

$$= \frac{1.382x10^6}{174.2x10^3}$$
$$= \underline{7.93\text{MPa}} < 20\text{MPa} \quad \text{Therefore } \underline{\text{Acceptable}}$$

Shear Stress (fs) in the side-wall of the rib is at a maximum at the neutral axis.

$$f_s = \frac{Sa_y}{Ib}$$ where b is the net width of section through the neutral axis, (i.e. b=2 x 12 = 24mm)

$$= \frac{3{,}590 \text{ x } 123.4 \text{ x } 10^3}{12.035 \text{ x } 10^6 \text{ x } 24}$$

$$= \underline{1.53 \text{ MPa}} < 2.5 \text{ MPa} \quad \text{Therefore } \underline{\text{Acceptable}}$$

Because of the parabolic distribution of shear through the panel thickness,

Maximum Shear at Bearing = $\frac{3S}{2bt}$ where b is the element width (i.e. 500 mm)

$$= \frac{3\text{x}3590}{2\text{x}500\text{x}12}$$

$$= \underline{0.90\text{MPa}} < 1.0 \text{ MPa} \quad \text{Therefore } \underline{\text{Acceptable}}$$

Note:

These calculations assume complete 500 mm sections only. Special consideration may be required in the vicinity of the joints between panels.

When the concrete is poured the GRC will be wetted and will consequently expand. The concrete and GRC will then gradually dry out together, though they may shrink at different rates. In practice, this differential movement has not appeared to be a problem, therefore, it has not been taken into account in this design.

The above example is typical for corrugated sections of relatively small dimensions. Where corrugated sections are of large size the analysis would be incorrect as consideration must be given to shear lag and buckling effects. Therefore, it is essential that specialist advice is obtained with larger sections.

8.1.6 Deflection

The deflection of the formwork should not be too large. As a general rule a limit of span/270 is considered appropriate, unless otherwise specified.

$$\text{Deflection } (\delta) = \frac{5}{384}\frac{WL^3}{EI}$$ for a simply supported beam

$$= \frac{5}{384} \text{x} \frac{7.18\text{x}1.54^3\text{x}10^6}{15\text{x}12{,}035}$$

$$= 1.89\text{mm}$$

$$1.89 = \frac{L}{815} \quad \text{Therefore } \underline{\text{Acceptable}}$$

8.1.7. Long term Considerations

The prime requirement of permanent formwork, after it has performed its immediate structural role, is that it should remain in place. This should not be a problem provided that the formwork is manufactured and installed in accordance with the recommendations of 'GRCA Handbook No.1', as the adequacy of the bond between GRC and concrete has been proven by tests. This assumes, of course, that the bond is not contaminated with dirt, etc.

Once the slab has been cast and the concrete has set, the GRC formwork and reinforced concrete deck will act together compositely (i.e. as the slab is loaded the GRC and concrete will deflect together).

Since the GRC is below the concrete (i.e. further from the neutral axis) the strain in the GRC will be greater than that in the concrete, for any given deflection. And as the GRC will have already been stressed by the imposed load of the slab being cast it is possible that under normal working conditions the GRC will be stressed past its LOP, thus causing micro-cracking (unless the GRC has had time for stress relaxation through creep).

It is accepted that fine cracks may occur in the formwork, since the concrete deck which it is bonded to is designed to crack in a controlled manner.

However, under loaded conditions no crack should at any time exceed 0.5 mm width and the GRC must remain bonded to the concrete. This crack width relates to a maximum permissible crack width in the concrete of 0.25 mm at the normal reinforcement cover.

Since a concrete deck is normally designed so that its neutral axis is in the top half of the slab the overall depth of formwork should not exceed one half the depth of the slab. (Note: This may not be the case with pre-stressed slabs).

8.1.8 Other Considerations

Wind loads should always be checked. If uplift is a problem then cleats are required to hold the panels down. If the bearing surfaces are wide, similar cleats could be used to prevent sideways movement.

Bearing surfaces should not produce point loads, therefore bedding onto the supports should be considered. Mortar or mastic is appropriate.

Panels will have a mould finish on the exposed underside and a rolled finish, for good bond, on the upper face in contact with the concrete.

Joints between panels should be sealed against grout loss.

8.2 CHANNEL LINER

Irrigation and land drainage projects commonly require different shapes, sizes and methods of installation of channels. They may be supported above the ground, free-standing on the ground, or lining channels in the ground.

This example considers small trapezoidal GRC channel liners which may be used for either irrigation or drainage.

8.2.1 Design Stresses

The typical design stresses for sprayed GRC used in irrigation and drainage products are taken from Table 7.1.3 of 'Cem-FIL GRC Technical Data' as:

Compressive	12 MPa
Bending	6 MPa
Tensile/Bending	4 MPa (for box sections or channels)
Tensile	3 MPa
Web Shear	2 MPa
Bearing Shear	1 MPa

8.2.2. Assumed Design Parameters

Channel Specifications

Effective Channel Length	(L)	=	3 m
Shape - Trapezoidal			
Discharge	(Q)	=	28.32×10^{-3} cumecs
Slope	(S)	=	1 : 1000
Freeboard	(F)	=	30mm

Soil Properties

Angle of Internal Friction	(Ø)	=	31°
Max. Dry Density	(ρ_d)	=	1,800 kg/m3
Cohesion	(C)	=	0

8.2.3 Channel Shape

Although the channel liner shape has been specified as trapezoidal the angle of the side walls and the ratio between width and depth has still to be decided.

The optimum channel shape for hydraulic purposes and economy of material is achieved when the hydraulic radius (R) is at a minimum.

$$\text{Hydraulic Radius (R)} = \frac{\text{Wetted Area (A)}}{\text{Wetted Perimeter (P)}}$$

Therefore, the optimum hydraulic shape would be a semi-circle, or failing that a trapezoidal shape which closely resembles a semi-circle, as will be used in this case (see Fig. 8.2.3).

It should be noted that this shape has been chosen on hydraulic grounds, but in some circumstances, for example where uplift from waterlogged soils is encountered, a very different profile may be required.

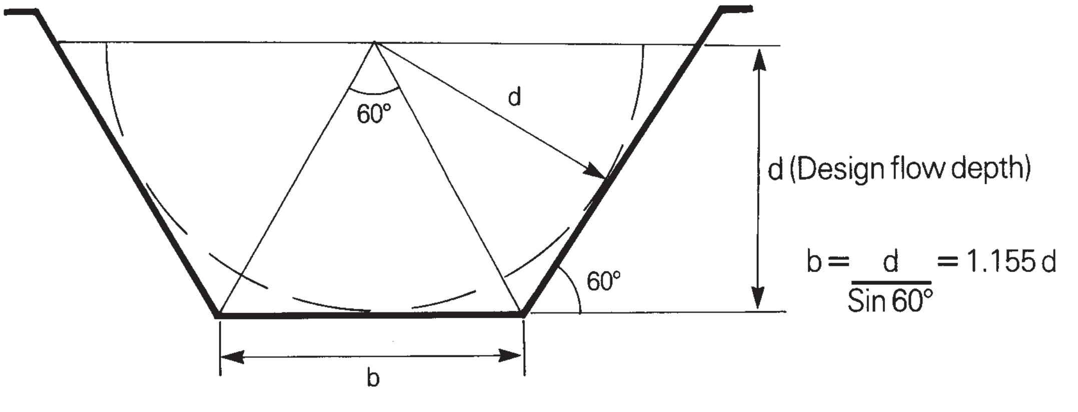


Fig 8.2.3 The Optimum Trapezoidal Channel Shape

All the internal dimensions of the channel liner can be expressed in terms of ‘d’ (the Design Flow Depth). It is therefore necessary to calculate the ‘design flow depth’ required to satisfy the channel specifications.

8.2.4 Calculation of the Internal Dimensions

With water flowing at the Design Flow Depth (d).

$$\text{Wetted Area (A)} = \frac{3}{2}bd \quad = 1.732d^2 \qquad \left(b = \frac{d}{\text{Sin}60°}\right)$$

Wetted Perimeter (P) = 3b = 3.464 d

Manning's Equation states:

$$Q = \frac{S^{1/2}}{n} \frac{(A^{5/3})}{(P^{2/3})}$$

where n is 'Manning's Coefficient of Surface Roughness'. Tests at Southampton University have revealed a value for GRC of n = 0.012 (Reference 3). This may alter with time if there is a build-up of algae or other deposits.

$$Q = \frac{0.0316}{0.012} \frac{(1.732)^{5/3}(d^2)^{5/3}}{(3.464)^{2/3}(d)^{2/3}}$$

= 2.873 $d^{8/3}$

Therefore, as the discharge requirement is 28.32 x 10^{-3} cumecs, we can equate:

2.873 $d^{8/3}$ = 28.32 x 10^{-3}

$$d = \left(\frac{28.32 x 10^{-3}}{2.873}\right)^{3/8}$$

Therefore in order to satisfy the channel specification d = 0.177m

Width of channel liner invert $(b) = \frac{0.177}{\text{Sin}60°}$

Therefore b = 0.204 m

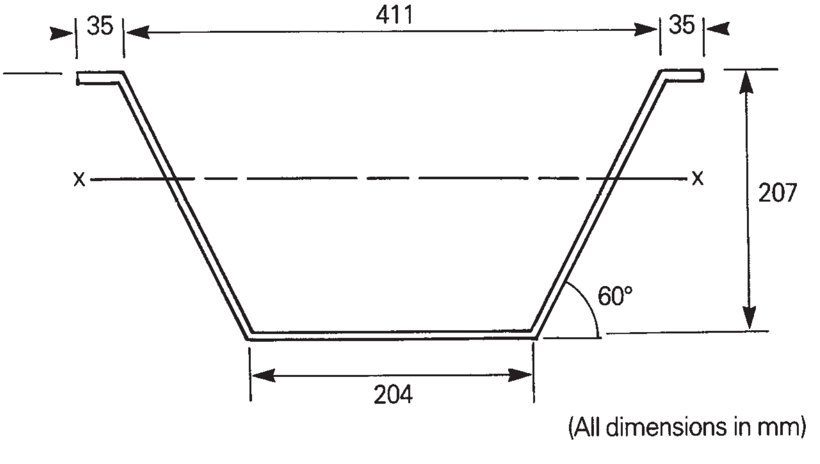
With Freeboard (F) = 30mm, the perimeter of the channel liner is

$P=3.464(0.177)+2x0.03 \left(\frac{2}{\sqrt{3}}\right)$

Therefore P = 0.682 m (excluding flanges)

Flanges - it is recommended that flanges are used to stiffen the channel sides, to ease handling and to help reduce any localised bowing caused by uneven back-filling, which could otherwise cause the joints to separate. The size of flange to a large extent depends upon the size of channel liner. In this case the flanges are to be 35 mm wide.

8.2.5 Determination of Channel Liner Thickness



Effective Channel Length = Span = 3 m.

It is assumed that the channel liner will be fully supported along its length when installed in the ground. However it may be prudent to consider the case where the channel liner is full of water and the back-fill providing the lateral support has been removed.

The Total Horizontal Force (F) being exerted on one side of the channel when full of water is given by

$$F = \frac{\rho g h^2}{2} = \frac{1000x10x0.207^2}{2}$$

= 214 N/m length of channel.

For the purpose of analysis this force can be considered to be acting one third of the way up the channel side (i.e. at a height above the invert of h = $\frac{207}{3}$= 69 mm.)

The Bending Moment (M) about the knee of the channel is therefore

M = Fh = 214 x 69 = 14766 Nmm

Assume a Channel Liner Thickness of 6 mm

The Section Modulus (Z) for a 1 m length of channel is therefore

$$Z = \frac{bd^2}{6} = \frac{1000x6^2}{6} = 6000mm^3$$

Bending Stress $(f_b) = \dfrac{M}{Z}$

$$= \frac{14766}{6000}$$

Therefore f_b = <u>2.46 MPa</u> < 6 MPa Therefore <u>Acceptable</u>

At this stage in the calculations it is recommended that handling stresses are checked.

8.2.6 Calculation of Handling Stresses

Using a computer programme or the method shown in Section 8.1.3 to analyse the section properties we get:

Distance of the neutral axis from the bottom face

y = 87.1mm

The Second Moment of Area about the neutral axis

I_{NA} = 26.18x $10^6 mm^4$

The First Moment of Area above or below the neutral axis

a_y = 153838 mm^3

The Net Width of section at the neutral axis is

$$b = 2 \text{ x } 6 \text{ x} \frac{2}{\sqrt{3}}$$

$$= \underline{13.9mm}$$

Total Channel Perimeter $= 0.682 + 2 \text{ x } 0.035$

$$= \underline{0.752 \text{ m}}$$

Therefore, assuming a wet density of 2200 kg/m³ for the GRC at the time of handling,

Weight per linear metre of liner = 22 x 0.752 x 0.006
= 0.099 kN/m (ignoring over-spray)

To allow for 'snatch' loading and lower early material strength during demoulding, handling stresses should be limited to one quarter of the normal design stresses (i.e. 1 MPa for tensile bending). This assumes careful handling.
Assume that the channel will be supported at its ends only

$$M = \frac{wL^2}{8}$$
$$= \frac{0.099 \text{ x } 3^2}{8}$$
$$= \underline{0.111 \text{ kNm}}$$

Highest tensile/bending stresses will occur when the channel is being carried upside down

$$f_{tb} = \frac{My}{I} = \frac{0.111 \text{ x } 10^6 \text{ x } (213 - 87.1)}{26.18 \text{ x } 10^6}$$
$$= \underline{0.53 \text{ MPa}} < 1 \text{ MPa} \quad \text{Therefore } \underline{\text{Acceptable}}$$

Shear stress (f_s) in the side walls is at a maximum at the neutral axis.

$$f_s = \frac{Sa_y}{Ib} \qquad (S = \frac{W}{2} = 149\text{N})$$
$$= \frac{149 \text{ x } 153{,}838}{26.18 \text{ x } 10^6 \text{ x } 13.9}$$
$$= \underline{0.06 \text{ MPa}} < 1 \text{ MPa} \quad \text{Therefore } \underline{\text{Acceptable}}$$

Therefore for handling purposes <u>6 mm thick sprayed GRC</u> should be sufficient.

Note

This example is typical for channel liners of relatively small dimensions.

Where channel liners are of large size the handling analysis would be incorrect as consideration must be given to shear lag and buckling effects. Therefore, it is essential that specialist advice is obtained with larger channel liners.

8.2.7 Soil Stability

Since channel liners are installed in the ground it is important to design the liner to withstand the soil pressures and to check that channel uplift will not occur.

It must be emphasised that the calculations being performed here are very simplified and consider the *non-cohesive* soil in a *dry* state only with no account being taken of friction between the soil and the channel sides. They also assume that the ground on either side of the channel is fiat and carries no surcharge.

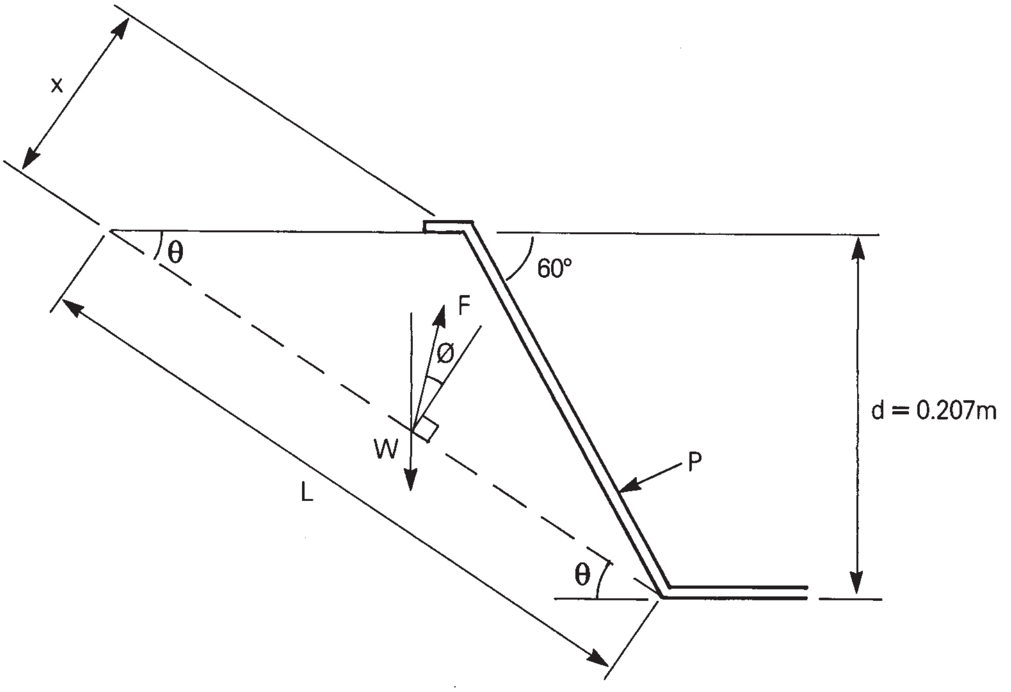
The presence of heavy traffic close to the channel or local water-logging of the soil after heavy rain would increase the pressure on the channel sides and the uplift. In practice soil conditions may vary considerably and it is therefore strongly recommended that expert advice is sought from a soils engineer when designing such channels.

It must be emphasised that a totally different approach would have to be taken if cohesive soils were being considered.

Calculation of the force {P) required to resist the Active Soil Pressure, by the Coulomb Wedge Method.

Active Soil Pressure would not normally be a problem for such small channel liners under these conditions, but the calculations are being performed as a proof.

Consider a wedge of soil with a slip surface at an angle Ø to the horizontal.



W is the Weight per linear metre of the soil wedge. F is the Resultant Force acting at an angle Ø from the normal, where Ø is the Angle of Internal Friction on the slip plane.

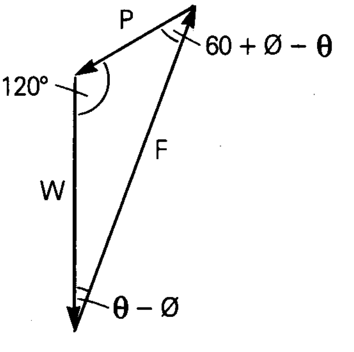
$$x = \frac{2d}{\sqrt{3}}\text{Sin}(60-\theta)\text{L} = \frac{d}{\text{Sin}\theta}$$

Area of soil wedge is given by $\dfrac{d^2\text{Sin}(60-\theta)}{\sqrt{3}\text{Sin}\theta}$

Therefore assuming the soil to be dry, the Dry Density $(\rho_d) = 1{,}800\text{kg}/\text{m}^3$

$$W = \frac{18d^2\text{Sin}(60-\theta)}{\sqrt{3}\text{Sin}\theta}\text{kN}$$

By constructing a force diagram it is possible to calculate P for different values of Ø.



$$P = \frac{W\text{Sin}(\theta-\varnothing)}{\text{Sin}(60+\varnothing-\theta)}$$

$$= \frac{18d^2\text{Sin}(60-\theta)\text{Sin}(\theta-\varnothing)}{\sqrt{3}\text{Sin}\theta\text{Sin}(60+\varnothing-\theta)}$$

In this case Ø = 31°
d = 0.207m

Therefore, by substituting various angles θ into the equation for P we get:

θ	P (kN/m length)
44°	0.054
45°	0.055
46°	0.055
47°	0.054

Maximum P = 0.055 kN/m length and occurs when $\theta = 45°$

P is concentrated 1/3 of the way up the channel side. The length of the channel side

$$= \frac{2(0.207)}{\sqrt{3}}$$
$$= \underline{0.239\text{m}}$$

The Bending Moment produced in the bottom corner of the channel when empty is given by:

$$M = \frac{0.239}{3}(0.055) = \underline{4.38 \text{ x } 10^{-3}\text{kNm}}$$ (ignoring self weight of the channel side)

$$f_b = \frac{M}{Z} = \frac{4.38 \text{ x } 10^{-3}}{6,000} = 0.73 \text{ MPa} < 6 \text{ MPa} \quad \text{Therefore } \underline{\text{Acceptable}}$$

Uplift

The vertical component of P is: Psin 30° (i.e. P/2). Therefore the total uplift due to soil pressure from both sides of the channel liner is 2 P/2 = P/m length.

So Uplift = 0.055 kN/m

The self weight of the channel liner is

w = 20 x 0.006 x 0.752
= 0.09 kN/m (when dry) > 0.055 kN/m.

Therefore the uplifting forces will be resisted provided that there is no ground water present.

Conclusion

A 6mm thick GRC channel liner should satisfy the channel specifications whilst withstanding the stresses due to handling and soil pressures.

8.2.8 Installation and Jointing of Channel Liners

These notes on installation and jointing are designed to be a guide to some of the points which need considering. They do not attempt to cover every eventuality. Different methods would be required if frost or clay heave is likely.

1. The trench should be excavated ‘over-sized’ and any rocks in the base of the trench should be removed.

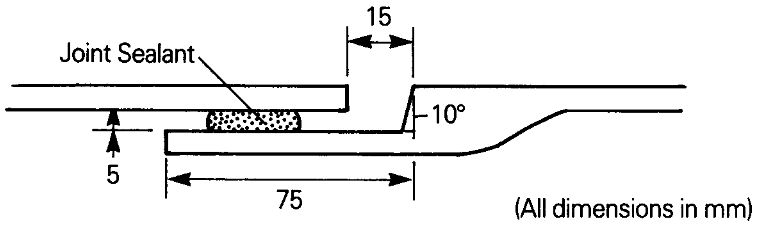
2. A thin layer of sand or similar granular material should be laid in the bottom of the trench and levelled, to provide a sound base for the channel liners and to help minimise any differential settlement.

3. The channel liners can then be installed one at a time.

4. Channel liners can be lined up using a string line or theodolite by sighting on a mark in the centre of the channel inverts. This mark may be a groove produced by the mould or a pencil line.

5. The flanges of each liner should be checked with a spirit level to ensure that no twisting of the channel line is taking place.

6. Once a channel liner has been correctly positioned the sealant material (e.g. polyisobutylene strip) should be applied to the lower flange of the overlap joint (the joint should be clean, dry and free from dust).



7. The next unit should be placed so that there is a gap between units along the channel invert to allow for linear expansion and contraction of the channels due to thermal and moisture changes.

8. Once the unit has been correctly positioned the joint should be firmly compressed, so that the sealant is well bonded to the two units.

9. Once the jointing is completed the channel liners should be back-filled with a granular material, taking care not to disturb the joints. This granular fill should be gently tamped to force it into the voids.

Note:

In some cases, and with larger channels it may also be advisable to bolt the channel liner flanges together to prevent joint separation during back-filling. This should be performed with oversized holes or slots being either cast or drilled in the flanges, and using a bolt with large washers to spread the load.

It is important to prevent the bolt being over-tightened and effectively restraining the joint. This can be done either by bolting through a spacer tube or using partially threaded bolts.

8.3 SUNSCREEN

This design is for 3 m x 1.49 m sunscreen panels for a 15 m high building on the outskirts of a city. The analysis considers the more severe case that the area behind the sunscreen is open (e.g. a car park) and is not blocked by a window.

Extensive reference is made to CP3: Chapter 5: Part 2 “Code of Basic Data for the Design of Buildings - Wind Loads”, published by the British Standards Institution. (Reference 4)

8.3.1 Design Stresses

The standard design stresses for premix GRC used in sunscreens are taken from Table 7.1.3 of ‘Cem-FIL GRC Technical Data’ as:

Compressive	12 MPa
Bending	4 MPa
Tensile	2 MPa
Web Shear	1 MPa
Bearing Shear	1 MPa

Building height	15 m
Building width	40 m
Building length	50 m
Panel height	3 m
Panel width	1.49 m
Sunscreen pattern	(see fig. 8.3.1)
Basic wind speed	40 m/s
Building class	A (see ref. 4)

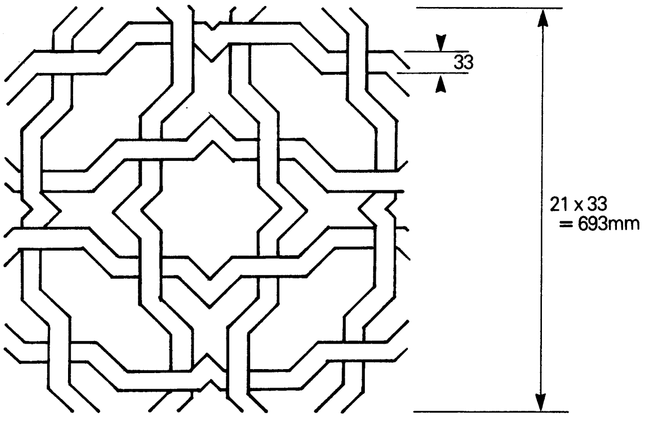


Figure 8.3.1
A Module of the Sunscreen Pattern

8.3.2 Calculation of Wind Load

Assumed basic wind speed (V) = 40 m/s
From CP3: Chapter 5: Part 2 the wind speed factors are:
S_1 = 1.0 (Topography Factor)
S_2 = 0.88 (Ground Roughness and Building Size Factor)
S_3 = 1.0 (Statistical Factor)
Design wind speed (V_s) = $VS_1S_2S_3$
Therefore V_s = 40 x 1 x 0.88 x 1 = 35.2 m/s
The Dynamic Wind Pressure (q) = KV_s^2 where K is a constant (CP3: Chapter 5: Part 2, Section 6 "Dynamic Pressure of the Wind ")
When calculating in SI units K = 0.613

Therefore q = 0.613 $(35.2)^2$
= $\underline{760\ \text{M/m}^2}$

It should be noted that the shape of a building can have a marked effect on the actual wind force exerted on a screen. Therefore pressure coefficients must be taken into account as outlined in CP3: Chapter 5: Part 2: Section 7.

In this case the Internal Pressure Coefficient Cpi is being ignored. Therefore the Wind Force (F) is given by:

F = $C_{pe}qA$ where C_{pe} = External Pressure Coefficient
A = Effective Area

The value for C_{pe} is taken from CP3: Chapter 5: Part 2, Table 7. In this case for a 15m high building with a 40m x 50m plan, the worst local value of C_{pe} = -0.8.

In this example we have considered that the wind load is proportional to the solid area of screen. Therefore the Effective Area (A) can be found by plotting one of the segments on squared paper and counting the squares (see fig. 8.3.2).

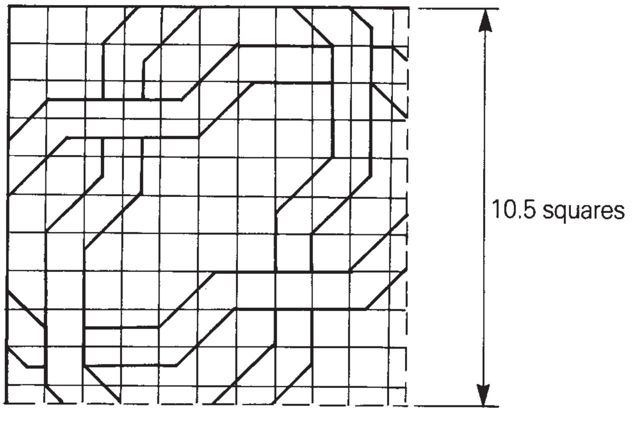


Fig. 8.3.2
Count the Squares to Determine the Effective Area A

For different patterns and shapes the effective area and consequential load will vary.

The Effective Area (A) = $\dfrac{\text{Number of squares containing solids}}{\text{Total number of squares}}$

$$\frac{45}{110.25} = 0.408$$

The Wind Force (F) per square metre of the screen pattern is given by:

F = $C_{pe}qA$

Therefore F = -0.8 x 0.408 x 1064

= - $\underline{347\ \text{N/m}^2}$ (negative sign indicates a suction load)

Note: It is important to ensure that the selected screen pattern fits symmetrically within the boundary of the screen. Small adjustments may be made by altering the width of the perimeter ribs.

E.g. If the width of an individual pattern rib is 33 mm, each complete pattern module as shown in fig. 8.3.1 would be 21 x 33 = 693 mm wide. Therefore the width of the sun screen could be made up of two complete pattern modules (1386 mm) plus two perimeter ribs, each 52 mm wide. Thus giving the required width of 1490 mm.

Likewise in the vertical direction, the screen could be made up of four complete pattern modules (2,772 mm) plus two extra pattern rib widths top and bottom (2 x 2 x 33 = 132 mm), leaving two perimeter ribs each of 48 mm (Total screen height = 3 m).

The presence of perimeter ribs in the design will have the effect of increasing the *overall* effective area of the screen.

The effective area used in any *particular stage* of the design analysis may vary depending upon the section of the screen being analysed.

E.g. If the screen is supported top and bottom only (i.e. spanning 3 m) then the effective area and effective width of the screen should include the side ribs for the purpose of load calculations.

If, however, the screen is supported along its side ribs only (i.e. spanning 1.49m) it is arguable whether or not the top and bottom ribs should be considered since their contribution towards the stiffness of the centre of the screen will be minimal because of their remoteness. For this reason when considering loadings on the screen it is recommended that *remote* end ribs of this kind are ignored.

8.3.3 Calculation of the Required Screen Thickness

The type of support method which is being assumed in this example is a continuous fixing down both sides of the sunscreen (e.g. the screen may be slotted between two inward-facing channels) with the weight of the screen being carried by a slab or other support under the lower rib. Therefore the span being considered is 1.49m maximum. The perimeter ribs at the top and bottom of the panel will have very little stiffening effect on the central portion of the panel, therefore for the purpose of this calculation they are being ignored.

Consider a 1 m wide strip across the screen in the centre of its long span.

The wind force per metre width = 347 N/m

$$M = \frac{wL^2}{8} = \frac{347 \text{ x } 1.49^2}{8}$$
$$= 96.3\text{Nm } (96.3\text{x}10^3 \text{Nmm})$$

The minimum effective width of the strip, (i.e. at the weakest point) is obtained from fig. 8.3.3.

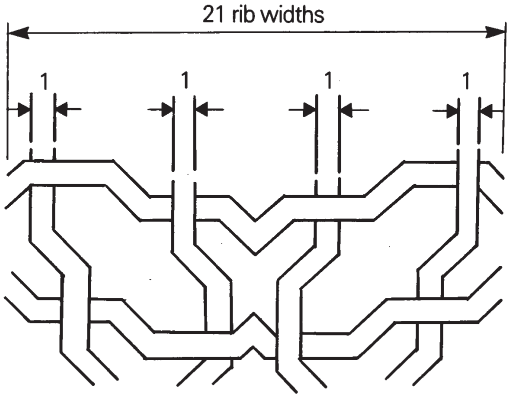


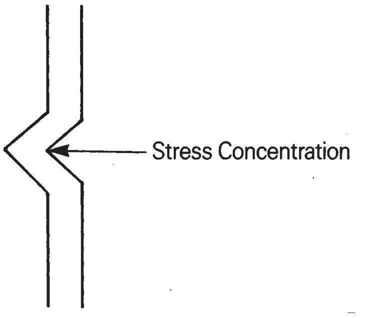
Fig. 8.3.3
Determination of the Effective Pattern Width.

The effective width of the 1 m strip is

$$\frac{4}{21} \text{x } 1000 = 190\text{mm}$$

It should be noted that in GRC sunscreens of complex pattern there may be stress concentrations at changes in direction within the GRC elements. This is true in this example.

In transmitting the load back to the supports, the forces must be transmitted around a sharp 90° bend as shown below. The result is a concentration of stress at the inside corner. Such concentrations can be reduced by rounding the corners, however, in this example the corner is considered as sharp.



In experimentation, when samples were loaded to failure cranked specimens failed at 2/3 the load of plain specimens. Therefore an additional load factor of 1.5 x should be used in stress calculations.

For premix GRC in bending the design stress f_b = 4 MPa. Therefore, with the additional load factor applied, the required Section Modulus (Z) is

$$Z = \frac{M}{f_b} \text{ x } 1.5 = \frac{96.3 \text{ x } 10^3 \text{ x } 1.5}{4} = 36{,}112\text{mm}^3$$

$$Z = \frac{bd^2}{6}$$ where b = effective strip width (190 mm)
d = required screen thickness

$$\text{Therefore } d = \sqrt{\frac{6Z}{b}} = \sqrt{\frac{6 \text{ x } 36{,}112}{190}}$$

$$d = 34\text{mm}$$

Check Deflection

Considering the screen to be Simply Supported and carrying a Uniformly Distributed Load, the Central Deflection (d) is given by:

Deflection (δ) $= \dfrac{5}{384}\dfrac{WL^3}{EI}$

W = 347 x 1.49 = 517N for a 1 m wide strip
L = 1490 mm
E = 15 x 10^3 MPa

$$I = \frac{190 \text{ x } 34^3}{12} = 622 \text{ x } 10^3\text{mm}^4$$

Therefore $\delta = \dfrac{5 \text{ x } 517 \text{ x } 1{,}490^3}{384 \text{ x } 15 \text{ x } 10^3 \text{ x } 622 \text{ x } 10^3} = 2.4\text{mm}$

i.e. deflection = L /621 < L /350 recommended as suitable for cladding by BS 8110. Therefore it is Acceptable.

8.3.4 Calculation of Handling Stresses

Since Premix GRC sunscreens generally have quite a high self weight compared to other GRC products it is important to check the stresses which would be induced by different handling conditions. It is then possible to make handling recommendations which should avoid any damage to the screens.

(a) Consider the screen being carried horizontally, supported by the ends (i.e. 3 m span).

The self weight per linear metre in the 3 m span direction (excluding the top and bottom perimeter ribs) is:

w = 0.034 (1.386 x 0.408 + 2 x 0.052) 20 x 10^3 = 455 N/m

To allow for 'snatch' loading and lower early material strength during demoulding, handling stresses should be limited to one quarter of the normal design stresses (i.e. 1 MPa for Premix in Bending). This assumes careful handling.

$$M = \frac{wL^2}{8} = \frac{455x3^2}{8} = 512Nm\ (512x10^3 Nmm)$$

Effective Width (b) = $\frac{4}{21}$ x 1386 + 2x52 = 368mm

Effective Section Modulus $(Z) = \frac{bd^2}{6}$

$$= \frac{368 \text{ x } 34^2}{6} = 70.9x10^3 mm^3$$

Bending Stress $(f_b) = \frac{M}{Z} = \frac{512x10^3}{70.9x10^3} = 7.22 \text{ MPa} > 1 \text{ MPa}$

Therefore TOO HIGH

(b) Consider the screen being carried horizontally supported by the sides (1.49 m span). The self weight per linear metre of a 1m wide strip across the centre of the screen in the 1.49m span direction (excluding remote end ribs and side perimeter ribs) is:

w = 0.034(1 x 0.408) 20x103 = 277 N/m

Again to take account of 'snatch' loading and lower early material strength during demoulding, the stress should be limited to 1 MPa.

$$M = \frac{wL^2}{8} = \frac{277x1.49^2}{8} = 76.9Nm(76.9x10^3 Nmm)$$

Effective Width $(b) = \frac{4}{21} x1000 = 190mm$

Effective Section Modulus $(Z) = \frac{bd^2}{6}$

$$= \frac{190x34^2}{6} = 36.6x10^3 \text{mm}^3$$

Bending stress $(f_b) = \frac{M}{Z} = \frac{76.9 \text{ x } 10^3}{36.6 \text{ x } 10^3} = \underline{2.1 \text{ MPa}} > 1 \text{ MPa}$

Thus the stress is still TOO HIGH.

In this case it would therefore be necessary to construct a handling frame to give extra support to the centre of the screen. This is common with many large sun screens.

In addition, since most handling failures occur during demoulding, extreme care must be taken when the screen is in its 'green' state.

8.3.5 Fixings

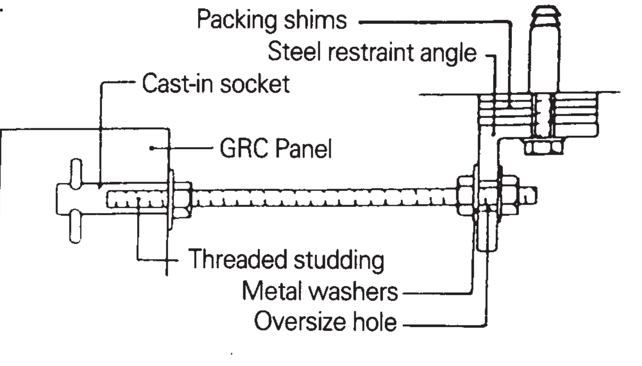
It has already been mentioned that in this case the panels have been designed to slot between vertical channels. These should be spaced to allow approximately 5mm either side of the edge perimeter ribs to allow for lateral expansion and contraction caused by thermal and moisture changes. It is recommended that when fixing methods of this type are used, self-adhesive rubber pads are fixed to the flanges of the channels at the top, middle and bottom to prevent vibration of the screens by the wind.

It is also advisable to place neoprene packing shims under the side perimeter ribs so that the weight of the screen is transferred down through the ribs to the support. This method of packing also allows screens to be designed for installation one on top of an other, with the packing transmitting the compressive loads down through the vertical side ribs.

An alternative method of fixing may involve bolting into cast-in sockets in the back of the side ribs. The fixings should be of austenitic stainless steel or non-ferrous, and would normally be located approximately one-fifth of the way in from the ends of the screens (thus keeping the magnitude of the bending moments to a minimum). The bolts should be of austenitic stainless steel threaded studding (see fig. 8.3.5), the length and diameter of which should be designed to allow for the necessary vertical and horizontal movement of the screen. This type of fixing would not be expected to support the weight of the sunscreens. This should be done by supporting the base of the side ribs on packing shims. The induced stresses on a panel supported in this way would be different to the case considered and would have to be taken account of in the design.

Note: Care must be taken to check the ability of the stud to resist buckling.

Fig. 8.3.5
Flexible Rod Fixing



8.3.6 General Note on Sunscreen Manufacture

When considering the design of a sunscreen mould thought must be given to the demoulding of the screen. It is common practice to build a taper into rubber moulds, in the order of 1 in 12 on either side of a rib, to aid demoulding. This will have a small effect on the properties of the screen and will increase the weight.

8.4 CLADDING PANEL - SINGLE SKIN

A common form of construction for a single skin GRC Cladding Panel includes stiffening ribs. This example considers one such panel with overall dimensions of 3 m height by 2 m width.

A number of manufacturers include polymers in their GRC mixes when producing cladding panels. This has the effect of reducing both the moisture induced movement and Elastic Modulus of the mix. This example, however, considers non-polymer GRC for consistency with the other examples.

For the purpose of this analysis it is considered that the panel is fixed at four positions close to its corners. Fixings must allow for thermal and moisture induced movement of the panel as outlined in Section 7.3.1. of “Cem-FIL GRC Technical Data”.

Note: For a ribbed panel of this type with some flexural stiffness no more than four fixings should be used.

8.4.1 Design Stresses

The standard design stresses for sprayed GRC used in cladding are taken from Table 7.1.3 of “Cem-FIL GRC Technical Data” as:

Compressive	12	MPa
Bending	6	MPa
Tensile/Bending	4	MPa (for box sections or channels)
Tensile	3	MPa
Web Shear	2	MPa
Bearing Shear	1	MPa

8.4.2 Assumed Design Parameters

Building height .	30 m	
Panel height	3 m	
Panel width	2 m	
Basic wind speed	40 m/s	
Location	City Centre	
Building class	A	(see ref. 4)

8.4.3 Calculation of Wind Load

Assumed basic wind speed (V) = 40 m/s

From CP3: Chapter 5: Part 2 (Reference 4) the wind speed factors are:

S_1 = 1 (Topography factor)
S_2 = 0.9 (Ground roughness and building size factor)
S_3 = 1 (Statistical factor)
Design wind speed (V_S) = $VS_1S_2S_3$
Therefore V_S = 40 x 1 x 0.9 x 1 = 36m/s

The Dynamic Wind Pressure (q) = KV_S^2 where K is a constant (CP3: Chapter 5: Part 2, Section 6 - ‘Dynamic Pressure of the Wind’)

When calculating in SI units K = 0.613

Therefore q = 0.613 $(36)^2$
= <u>794 N/m²</u>

It should be noted that the shape of a building can have a marked effect on the actual wind force exerted on a panel. Therefore pressure coefficients must be taken into account, as outlined in CP3: Chapter 5: Part 2: Section 7.

In this case the Internal Pressure Coefficient Cpi is being ignored. Therefore the Wind Force (F) is given by:

F = $C_{pe}q$ where C_{pe} = External Pressure Coefficient

The value for C_{pe} is taken from CP3: Chapter 5: Part 2, Table 7. In this case the worst value has been assumed (i.e. C_{pe} = -1.2).

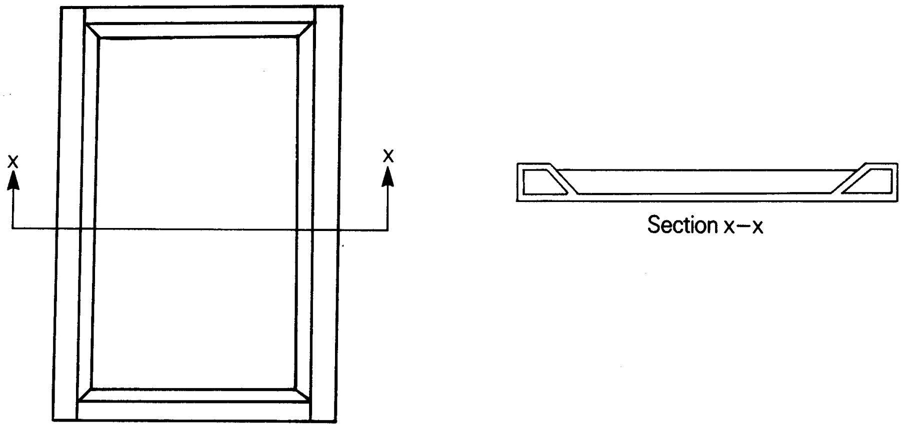
Therefore Wind Force (F) = -1.2 x 794 = -953 N/m^2
(Negative sign indicates a suction load).

8.4.4 Calculation of Rib Thickness

A cladding panel of this size requires ribs to strengthen the relatively weak flat face.

In order to assist with panel jointing it is necessary to have returns at the panel edges. Also it is preferable that ribs are positioned in a direct line between fixings. Therefore the ribs should be around the edge of the Panel (see fig. 8.4.4).

Fig. 8.4.4
Typical Ribbing of a Single Skin GRC Cladding Panel



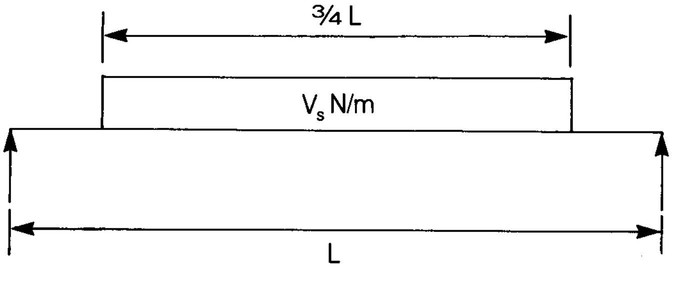
In order to design the ribs it is first necessary to determine what loads they are carrying. This can be performed by considering the ribs to be beams supporting a flat slab and by using the equations given in BS 8110: Part 1: 1985: Section 3.5.3.7. (Reference 5)

$V_{sy} = \beta_{vy} n l_x$

$Vsx = \beta_{vx} n l_x$

V_{sy} and V_{sx} are the Loads per linear metre being carried over the central $^3/_4$ of the span of the 3 m side and 2 m end ribs respectively (see fig. 8.4.4b).

Fig. 8.4.4b
Distribution of Load on a Rib



β_{vy} and β_{vx} are Shear Force Coefficients obtained from Table 3.16 of BS 8110.

n is the total Design Ultimate Load per unit area
l_x is the Length of the shorter side
l_y is the Length of the longer side

Therefore:

l_x =2m, l_y = 3m
l_y/l_x = 1.5, therefore from table 3.16 of BS 8110:

β_{vy} = 0.33 and, β_{vx} = 0.45 (using the case for four edges discontinuous)

n = 953 N/m^2 (calculated in 8.4.3)

Therefore, for the 3 m side ribs:

$$
\begin{aligned}
V_{sy} &= \beta_{vy} n l_x \\
&= 0.33 \times 953 \times 2 \\
&= 629 \text{ N/m}
\end{aligned}
$$

For the 2 m end ribs:

$$V_{sx} = \beta_{vx} n l_x$$
$$= 0.45 \text{ x } 953 \text{ x } 2$$
$$= 858 \text{ N/m}$$

Using fig. 8.4.4b, the Bending Moment (M) at the centre of the span is given by:

$$M = \frac{3}{4} V_s \frac{L}{2} \text{x} \frac{L}{2} - \frac{3}{4} V_s \frac{L}{2} \text{x} \frac{3}{4} \frac{L}{4}$$

$$= \frac{3V_s L^2}{16} - \frac{9V_s L^2}{128}$$

$$M = \frac{15}{128} V_s L^2$$

Therefore in the 3 m span rib:

$$M = \frac{15}{128} \text{x } 629 \text{ x } 3^2$$
$$= \underline{663 \text{ Nm}} \ (663 \text{x} 10^3 \text{Nmm})$$

In the 2 m span rib:

$$M = \frac{15}{128} \text{x } 858 \text{ x } 2^2$$
$$= \underline{402 \text{ Nm}} \ (402 \text{x} 10^3 \text{Nmm})$$

The bending of a box section rib results in tensile bending in one face and compression in the other. The limiting stress is normally that of tensile/bending, as in this case, since its permissible value is lower (i.e. 4 MPa)

Since we have a relationship for the Tensile/Bending Stress (f_{tb}) from the Theory of Bending, where

$$f_{tb} = \frac{M}{Z_{tb}}$$ (Z_{tb} is the Section Modulus for the tensile/bending face)

it is possible to calculate the minimum Section Modulus required for each of the ribs.

For the 3 m span ribs:

$$Z_{tb} = \frac{M}{f_{tb}} = \frac{663 \text{ x } 10^3}{4} = \underline{166 \text{ x } 10^3 \text{mm}^3}$$

For the 2 m span ribs:

$$Z_{tb} = \frac{M}{f_{tb}} = \frac{402 \text{ x } 10^3}{4} = \underline{101 \text{ x } 10^3 \text{mm}^3}$$

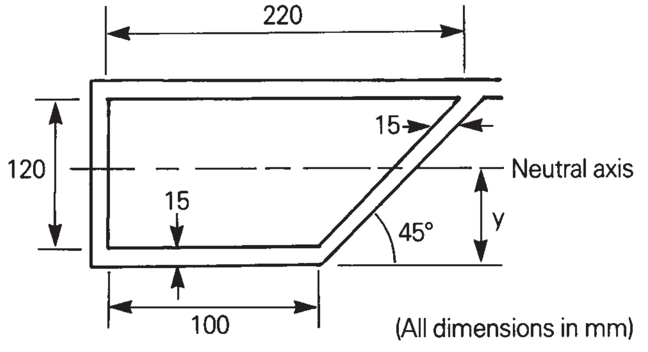
3 m SPAN RIBS

Consider a rib having GRC skins 15 mm thick, formed around 120 mm deep polystyrene ribs, which taper from 220 mm wide at the front face of the panel to 100 mm wide at the back face.

Provided the panel is symmetrical, with ribs on either side being the same size and shape, the neutral axis through the ribs can be considered as horizontal.

Torsional effects on the ribs should be negligible and have therefore been ignored.

Fig. 8.4.4 (c)



Computer analysis of this section (or use of the method shown in Section 8.1.3) gives:

$$I = \underline{296 \text{ x } 10^5 \text{mm}^4}$$
$$y = \underline{88.2\text{mm}}$$

The Tensile/Bending Section Modulus (Ztb) under suction wind loading is given by

$$Z_{tb} = \frac{I}{(150 - y)} = \frac{296 \text{ x } 10^5}{(150 - 88.2)} = \underline{479\text{x}10^3\text{mm}^3} > 166\text{x}10^3\text{mm}^3$$

Therefore Acceptable

This gives a Tensile/Bending Stress

$$f_{tb} = \frac{M}{Z_{tb}} = \frac{663 \text{ x } 10^3}{479 \text{ x } 10^3} = \underline{1.38 \text{ MPa}}$$

If normal wind loads of the same magnitude as the suction wind load are experienced the opposite face will be in tensile/bending, i.e:

$$Z_{tb} = \frac{I}{y} = \frac{296 \text{ x } 10^5}{88.2} = \underline{336 \text{ x } 10^3\text{mm}^3} > 166 \text{ x } 10^3\text{mm}^3$$

Therefore Acceptable

This gives a Tensile/Bending Stress

$$f_{tb} = \frac{M}{Z_{tb}} = \frac{663 \text{ x } 10^3}{336 \text{ x } 10^3} = \underline{1.97 \text{ MPa}}$$

Shear stress in the rib will be negligible and has therefore been ignored

Check Deflection

The Central Deflection (d) of a Simply Supported beam of length L carrying a Uniformly Distributed Load (w) over the central 3/4 of its span is given by

$$\delta = \frac{1205 \text{ x } 10^{-5} \text{wL}^4}{\text{EI}}$$

(w = the previously determined V_{sy})

$$= \frac{1205 \text{ x } 10^{-5} \text{ x } 629 \text{ x } 10^{-3} \text{ x } 3000^4}{15{,}000 \text{ x } 296 \text{ x } 10^5}$$

$$= \underline{1.38 \text{ mm}}$$

(i.e. L/2,174 which is less than the L/350 maximum limit recommended by BS 8110.
Therefore <u>Acceptable</u>)

Check Handling Stresses:

The weight of the panel per linear metre in the 3 m span direction is approximately

w = 2.9 x 1 x 0.015 x 2000 = 87 kg/m (i.e. 870 N/m)

To allow for 'snatch' loading and lower early material strength during demoulding, handling stresses should be limited to one quarter of the normal design stress (i.e. 1 MPa for tensile/bending). This assumes careful handing.

When supported at the ends with the ribs on the underside

$$\text{M} = \frac{\text{WL}^2}{8} = \frac{870 \text{ x} 3^2}{8} = 979 \text{ Nm } (979 \text{x} 10^3 \text{Nmm})$$

Considering the two side ribs only

Z_{tb} = 2 x 336 x 10^3 = 672 x 10^3 mm3

Therefore $f_{tb} = \frac{M}{Z_{tb}} = \frac{979 \text{ x } 10^3}{672 \text{ x } 10^3} = \underline{1.46 \text{ MPa}} > 1 \text{ MPa}$ Therefore <u>TOO HIGH</u>

This mode of handling should therefore be avoided unless the ribs are thickened.

2 m SPAN RIBS

For simplicity in manufacture consider that the 2 m span ribs have the same cross-section as the 3 m span ribs.

Therefore:

I = 296 x 10^5 mm^4
y = 88.2 mm

And under suction wind loading

$Z_{tb} = 479 \text{x} 10^3 \text{mm}^3 > 101 \text{x} 10^3 \text{mm}^3$ therefore <u>Acceptable</u>

This gives a Tensile/Bending Stress

$$f_{tb} = \frac{M}{Z_{tb}} = \frac{402 \text{ x } 10^3}{479 \text{ x } 10^3} = \underline{0.84 \text{ MPa}}$$

If normal wind loads of the same magnitude as the suction wind load are experienced the opposite face will be in tensile bending.

i.e. $Z_{tb} = \frac{I}{y} = \frac{296 \text{ x } 10^5}{88.2} = \underline{336 \text{ x } 10^3 \text{mm}^3} > 101 \text{ x } 10^3 \text{mm}^3$ Therefore Acceptable

This gives a Tensile/Bending Stress

$$f_{tb} = \frac{M}{Z_{tb}} = \frac{402 \text{ x } 10^3}{336 \text{ x } 10^3} = \underline{1.20 \text{ MPa}}$$

Shear stress in the rib will be negligible and has therefore been ignored.

Check Deflection

The Central Deflection (d) of a Simply Supported beam of length L carrying a Uniformly Distributed Load (w) over the central 3/4 of its span is given by

$$\delta = \frac{1205 \text{ x } 10^{-5} wL^4}{EI}$$ (w = the previously determined V_{sx})

$$= \frac{1{,}205 \text{ x } 10^{-5} \text{ x } 858 \text{ x } 10^{-3} \text{ x } 2{,}000^4}{15{,}000 \text{ x } 296 \text{ x } 10^5}$$

$$\delta = \underline{0.37 \text{ mm}}$$

(i.e. L/5405 < L/350 therefore Acceptable)

Check Handling Stresses

The weight of the panel per linear metre in the 2 m span direction is approximately

w = 3.9 x 1 x 0.015 x 2,000 = 117 kg/m (i.e. 1170 N/m)

To allow for 'snatch' loading and lower early material strength during demoulding, handling stresses should be limited to one quarter of the normal design stresses (i.e. 1 MPa for tensile/bending). This assumes careful handling.

When supported along its sides with the ribs on the underside

$$M = \frac{wL^2}{8} = \frac{1170 \text{ x } 2^2}{8} = 585 \text{ Nm} \;\; (585 \text{ x } 10^3 \text{Nmm})$$

Considering the two end ribs only

$$Z_{tb} = 2 \text{ x } 336 \text{ x } 10^3 = 672 \text{ x } 10^3 \text{mm}^3$$

Therefore $f_{tb} = \frac{M}{Z_{tb}} = \frac{585 \text{ x } 10^3}{672 \text{ x } 10^3} = \underline{0.87 \text{ MPa}} < 1 \text{ MPa}$ therefore Acceptable

The panels should therefore be handled by their sides, particularly during demoulding.

8.4.5 Calculation of Flat Sheet GRC

The perimeter ribs have been designed using 15 mm thick GRC. It is therefore necessary to check that the flat central area of the panel will suffice at this thickness. If 15 mm thickness is not enough on its own, the central area can be stiffened by cross-ribbing.

The flat sheet is considered to be rigidly supported around its perimeter, where it joins the perimeter ribs.

The dimensions of the flat sheet are:

Height (a) = 3,000 - 2 (220 + 15 + 15)
= 2,500 mm
Width (b) = 2,000 - 2 (220 + 15 + 15)
= 1,500 mm

Ratio of height/width (a/b) = 1.67

From "Formulas for Stress and Strain - Table 26 (8) by R.J. Roark and W.C. Young" (Reference 6) the maximum Flexural Stress (f_b) at the centre of the long edge is given by:

$$f_b = \frac{-\beta_1 q b^2}{t^2}$$

where q = load per unit area
b = width
t = GRC thickness
β_1 is a constant

For a/b = 1.67, β_1 = 0.4825

$$f_b = \frac{-0.4825 \text{ x } 953 \text{ x } 10^{-6} \text{ x } 1,500^2}{15^2}$$
$$= \underline{-4.60 \text{ MPa}}$$

The magnitude of this stress is less than 6 MPa, therefore acceptable. The sign is unimportant.

The maximum Flexural Stress (f_b) in the centre of the flat sheet is given by

$$f_b = \frac{\beta_2 q b^2}{t^2}$$ (β_2 is also a constant)

For a/b = 1.67, β_2 = 0. 2375

$$f_b = \frac{0.2375 \text{ x } 953 \text{ x } 10^{-6} \text{ x } 1,500^2}{15^2}$$
$$= \underline{2.26 \text{ MPa}} < 6 \text{ MPa}$$ Therefore Acceptable

The Deflection (δ) at the centre of the flat sheet is given by

$$\delta = \frac{\alpha q b^4}{E t^3}$$ (α is also a constant)

For a/b = 1.67, α = 0.0263

$$\delta = \frac{0.0263 \text{ x } 953 \text{ x } 10^{-6} \text{ x } 1,500^4}{15,000 \text{ x } 15^3}$$
$$= 2.51 \text{ mm}$$

This is equivalent to L/598 < L/350. Therefore Acceptable

Check Handling Stress

To allow for 'snatch' loading and lower early material strength during demoulding, handling stresses should be limited to one quarter of the normal design stresses (i.e. 1.5 MPa for bending of sprayed material). This assumes careful handling.

The self weight of the 15 mm thick skin will be approximately

w = 0.015 x 2,000 x 10 = 300 N/m^2

This represents $\frac{300}{953}$ of the design suction wind pressure, therefore the handling stress will be

$$f_b = \frac{300}{953} \text{ x } 4.6 = \underline{1.45 \text{ MPa}} < 1.5 \text{ MPa}$$ Therefore Acceptable

The panel will therefore be acceptable for handling provided that until it is cured it is handled by its side ribs and not by its ends.

8.4.6 Fixings

Fixing systems should be designed according to the recommendations of Section 7.3.1 of 'Cem-FIL GRC Technical Data'.

The fixings should make allowance for site and manufacturing tolerances, thermal and moisture movement of the GRC, and movement of the structure.

Reversible thermal and moisture movement combined may be as high as 0.15%. This must be accommodated by the fixings.

The panel should have its self-weight carried by supports near the base (e.g. on low friction support pads), and no more than four fixings should be used for each panel unless a stud-frame system is adopted.

8.4.7 Insulation

GRC has a relatively high thermal conductivity and therefore cannot itself provide more than a minimal degree of thermal insulation. For this reason it is necessary for insulation (normally glass or mineral wool) to be added to give the required U value for the wall of a building.

8.4.8 Other Considerations

This example is typical for panels where the box section ribs have relatively small dimensions.

Where box section ribs are of large size the analysis would be incorrect as consideration must be given to shear lag and buckling effects. Consideration should also be given to the possibility of thermal and moisture differentials between the front and back of the rib, as it is with the Sandwich Panel example. Therefore, the design of such elements should be performed by a professional engineer.

8.5 CLADDING PANEL - SANDWICH CONSTRUCTION

One of the strongest forms of construction for a GRC cladding panel is the sandwich. This consists of sprayed GRC skins formed around a core of polystyrene (or similar lightweight, low modulus material). Correct design of sandwich panels is essential as significant stresses can arise from thermal and moisture differentials across the panel.

The high strength of this product results from the GRC skins being positioned away from the neutral axis in areas of the highest tensile and compressive stress.

The polystyrene fills the area around the neutral axis where the bending stress is lower. It does however act as a shear link between the two GRC skins, assisting whole panels to act together as a composite, thus calculations should ensure that the shear strength of the core and the bond between core and GRC is adequate.

The Elastic Modulus of GRC varies with both the mix composition and age (tending to be between 15-20 GPa). In sandwich panel design the Elastic Modulus is important, not only in the determination of deflection, but also in the calculation of stress caused by differential movement. For this reason a low value of 15 GPa has been used in the deflection calculation and a higher value of 20

GPa has been used in the stress calculation. This should ensure conservative results.
Care must be taken in the design of sandwich panels to take account of likely thermal and moisture movement. The lightweight core acts as an insulator, therefore there may be a significant difference in thermal and moisture movement between one skin and another. This will result in the panel bowing. It is most important that this bowing is allowed to take place and it must therefore be taken into account when designing the fixings. Also, shaped sandwich panels should be avoided as their inherent stiffness can prevent the necessary bowing and lead to increased stresses in the GRC skins.

Over recent years an increasing number of manufacturers have included polymers in their GRC mixes when producing cladding panels. Generally, this is to be recommended since it has the effect of reducing both the moisture movement and Elastic Modulus of the mix. This example, however considers non-polymer GRC for consistency with the other examples.

In practice, it becomes more difficult to ensure good manufacturing quality and avoid some restraint of movement as the size of panels increases. For this reason it is considered that generally the size of a conventional sandwich panel should be restricted to about 3.6 x 1.8 m.

For the purpose of this analysis it is considered that the panel is fixed at four positions close to its corners. Fixings must allow for thermal and moisture movement of the panel as outlined in Section 7.3.1 of ‘Cem-FIL GRC Technical Data’.

No more than four fixings must be used on a sandwich panel.

8.5.1 Design Stresses

The standard design stresses for sprayed GRC used in cladding are taken from Table 7.1.3 of ‘Cem-FIL GRC Technical Data’, as:

Compressive	12	MPa
Bending	6	MPa
Tensile	3	MPa
Web Shear	2	MPa
Bearing Shear	1	MPa

8.5.2 Assumed Design Parameters

Building height	30 m
Panel height	3.6 m
Panel width	1.8 m
Basic wind speed	40 m/s
Location	City Centre
Building class	A (see ref. 4)

8.5.3 Calculation of Wind Load

Assumed basic wind speed (V) = 40 m/s

From CP3: Chapter 5: Part 2 (Reference 4) the wind speed factors are:

S_1 = 1 (Topography factor)
S_2 = 0.9 (Ground roughness and building size factor)
S_3 = 1 (Statistical factor)

Design wind speed (Vs) = $VS_1S_2S_3$
Therefore VS = 40 x 1 x 0.9 x 1 =36 m/s

The Dynamic Wind Pressure (q) = KV_s^2 where K is a constant (CP3: Chapter 5: Part 2, Section 6 - ‘Dynamic Pressure of the Wind’).

When calculating in SI units K = 0.613

Therefore q = 0.613 $(36)^2$ = 794 N/m^2

It should be noted that the shape of a building and any openings on its surface can have a marked effect on the actual wind force exerted on a panel. Therefore pressure coefficients must be taken into account, as outlined in CP3: Chapter 5: Part 2: Section 7.

In this case the Internal Pressure Coefficient C_{pi} is being ignored. Therefore the Wind Force (F) is given by:

$F = C_{pe}q$ where C_{pe} = External Pressure Coefficient

The value of C_{pe} is taken from CP3: Chapter 5: Part 2, Table 7. In this case the worst value has been assumed (i.e. $C_{pe} = -1.2$).

Therefore Wind Force (F) = -1.2 x 794 = -953 N/m² (Negative sign indicates a suction load-tension in outer skin).

8.5.4 Calculation of Panel Thickness

The recommended procedure is to determine the panel thickness required to satisfy the deflection criterion, then to check the associated stresses.

Considering Panel Deflection

The calculation of deflection of sandwich beams is more complex than that of normal beams for two reasons:

1. Deflection due to Wind Load

   The use of a relatively low modulus core material such as polystyrene results in additional deflection due to shear stresses in the core.

   This can be allowed for by using the deflection formula given in Section 7.1.4.3 of 'Cem-FIL GRC Technical Data' which incorporates shear deflection. Therefore, in this example the deflection due to wind load is given by:

$$\delta = \frac{5}{384}\frac{WL^3}{EI} + \frac{WLc}{8Bd^2G}$$

   where d is the overall panel thickness
   c is the core thickness (in this case d-20)
   B is the panel width
   G is the shear modulus of the core
   (= 11 MPa for high density polystyrene)

2. Deflection due to Differential Movement

   In a sandwich construction the two GRC skins can be in different regimes of temperature and humidity. This has the effect of causing differential changes in length of the two GRC skins which are accommodated by the panel bowing. The amount of movement experienced will depend to a large extent on the colour of the panel and its matrix composition (sand/cement ratio, acrylic polymer content, etc.)

For example, a dark coloured panel made from GRC with a sand/cement ratio of 0.5 is likely to experience greater movements, under the same climatic conditions, than a light coloured panel with a sand/cement ratio of 1. This is because both the thermal gain and the reversible moisture-induced movement of the darker panel with the lower sane/cement ratio will be greater. (This is explained more fully in Section 7.2 of 'Cem-FIL GRC Technical Data').

The amount of bow can be calculated from:

$$\delta = \frac{\varepsilon L^2}{8d}$$

where ε is the differential strain between the skins
L is the panel length
d is the overall panel thickness

Choice of the actual strain differential must be based upon the judgement of the engineer. This can be assisted by using the relationships given in Section 7.2 of 'Cem-FIL GRC Technical Data'. In this case 0.8 mm/m has been chosen for non-polymer GRC.

Calculation of Deflection

In order to determine the minimum thickness of panel required to satisfy the deflection criterion, it should be assumed that the deflections due to wind load and differentials are cumulative.

Maximum allowable deflection according to BS 8110 is:

$$\frac{\text{Span}}{350} = \frac{3{,}600}{350}$$

So, let the maximum deflection (δ) = 10 mm.

Therefore $$\delta = \frac{5}{384}\frac{WL^3}{EI} + \frac{WLc}{8Bd^2G} + \frac{\varepsilon L^2}{8d}$$

$$I = \frac{1{,}800\ d^3 - 1{,}780\ (d-20)^3}{12}$$

So, $$\delta = \frac{5}{384} \text{x} \frac{6{,}175 \text{ x } 3{,}600^3 \text{x } 12}{15{,}000\ (1{,}800\ d^3 - 1{,}780\ (d-20)^3)} + \frac{6{,}175 \text{ x } 3{,}600\ (d-20)}{8 \text{ x } 1{,}800 \text{ x } d^2 \text{x } 11} + \frac{8 \text{ x } 10^{-4} \text{x } 3{,}600^2}{8d}$$

By substitution, if d = 170 mm

δ = 1.06 + 0.73 + 7.62 = 9.41 mm (equivalent to $\frac{\text{Span}}{383}$, therefore Acceptable)

So, to satisfy the deflection criterion the panel should be at least 170 mm thick with 10 mm thick GRC skins.

Calculation of Stresses

Although a 170 mm thick panel with 10 mm thick skins will satisfy the deflection criterion it is imperative that the GRC skin stresses caused by the wind loading and differential movement are calculated. These should again be treated as cumulative.

Wind Loading

Under a uniform wind pressure the design total pressure is:

W = 953 x 3.6 x 1.8 = 6,175 N

The Bending Movement is given by:

$$M = \frac{WL}{8} = \frac{6{,}175 \text{ x } 3{,}600}{8} = \underline{2.779 \text{ x } 10^6 \text{ Nmm}}$$

In this particular example, the shear deflection within the core has a negligible effect upon stress within the GRC. Therefore, from Section 7.1.4.3 of 'Cem-FIL GRC Technical Data', the stress in the Tensile face is given by:

$$f_t = \frac{M}{Bct}$$

Where B is the panel width
c is the core thickness
t is the GRC skin thickness

Therefore $$f_t = \frac{2.779 \text{ x } 10^6}{1{,}800 \text{ x } 150 \text{ x } 10} = \underline{1.03 \text{ MPa}}$$

Differential Movement

A relatively high value of 20 GPa (20,000 MPa) has been used for the Elastic Modulus to ensure a conservative stress calculation for non-polymer GRC.

Consider shrinkage of 0.8 mm/m taking place in one skin relative to the other.

If the panel were to be restrained from moving in any way the un-relaxed tensile stress in the GRC skin would be:

$$\begin{aligned} f_t &= \varepsilon E \\ &= 0.0008 \text{ x } 20,000 \\ &= 16 \text{ MPa} \end{aligned}$$

However, since the panel is free to move stress relaxation will take two forms:

a) In-plane movement (as shrinkage occurs the core and the opposing GRC face will be put into compression).

b) Bowing.

These stress reductions can be considered separately.

a) In-plane movement.

Let P be the reduction in f_t caused by in-plane relaxation without bowing.

$$(f_t - P)t = P(t + c \text{ x } \frac{E_c}{E_f})$$

where t = GRC skin thickness
c = core thickness
E_c = Core Elastic Modulus (Assumed 22 MPa)
E_f = GRC Elastic Modulus

So for a unit width:

$$(f_t - P)10 = P(10 + 150 \text{ x } \frac{22}{20,000})$$

Therefore $$P = \frac{10 f_t}{20.165} = 0.496\ f_t$$

b) Bowing

Let P_1 be the reduction in f_t caused by bowing.

$$P_1 = \frac{My}{I} = f_t t \frac{(c+t)}{2} \text{ x } \frac{d}{2} \text{ x } \frac{1}{A}\left(\frac{2}{c+t}\right)^2$$ Where A is the sectional area of GRC skin.

(This ignores the stiffness of the polystyrene core in restraining natural bowing, however if other core materials with a greater Elastic Modulus are used these may have to be considered).

$$\begin{aligned} P_1 &= \frac{f_t \text{ x } 10 \text{ x } \frac{(150+10)}{2} \text{ x } \frac{170}{2}}{2 \text{ x } 10 \text{ x } 80^2} \\ &= 0.531\ f_t \end{aligned}$$

Therefore, the extreme stresses in the GRC skins will be:

$$
\begin{aligned}
f_t &= 16\ (1 - 0.531 - 0.496) \\
&= \underline{-0.432\ \text{MPa}}\ \text{(Compressive - In the outer face of the GRC skin)} \\
f_t &= 16(0.531 - 0.496) \\
&= \underline{0.560\ \text{MPa}}\ \text{(Tensile) - In the inner face of the GRC skin)}
\end{aligned}
$$

Cumulative Stresses

Therefore, if the worst case of the stresses acting cumulatively is considered, the maximum tensile stress in a skin will be:

f_t = 1.03 + 0.56 = 1.59 MPa < 3 MPa permissible, therefore <u>Acceptable</u>

The 170 mm thick panel with 10 mm thick skins will therefore satisfy both deflection and stress limitations based upon the assumptions given.

Note

The choice of core material and its Elastic Modulus can make a large difference to the finished result. For example, if a polystyrene bead aggregate cement (PBAC) core with a Modulus of 800 MPa had been used the tensile stress in the panel due to differential movement alone would have been 2.34 MPa.

8.5.5 Calculation of Core Shear Stress

Sandwich structures should also be checked for the shear load transmitted through the core material. The Shear Force (V) can normally be taken to be equal to the maximum support load

$$
\text{(i.e. } \frac{6{,}175}{2} = 3{,}088\ \text{N)}
$$

Provided that panels are unrestrained from bowing the shear stress in low modulus cores due to differential movement of the skins should be negligible.

The Shear Stress (fs) is then:

$$
f_s = \frac{V}{Bd} = \frac{3{,}088}{1{,}800\ \text{x}\ 170} = \underline{0.01\ \text{MPa}}
$$

The shear strength of high density polystyrene is 0.26 MPa (from Table 7.1. 4.3 (c) of ‘Cem-FIL GRC Technical Data’).

The shear stress in the core must not exceed the elastic limit of the core in shear or the shear strength of the bond between the core and the GRC.

As a guide, if the shear stress is less than 40% of the core shear strength the stress should be within the elastic limit of the core material.

This value should also be checked with test results for actual shear stress measured with the adhesives and other materials used in production. The bond between the core and GRC can be enhanced by applying a thin coat of mortar containing an acrylic polymer on to the core.

In this case the shear stress of 0.01 MPa is only 3.8% of the shear strength of the polystyrene core, therefore the stress is acceptable.

8.5.6 Calculation of Handling Stresses

Assume that the panel is being carried horizontally, supported by the ends (i.e. span = 3.6 m).

Self-weight per m^2 is:

GRC: $2 \times 0.01 \times 2{,}000 = 40$ kg/m^2

Polystyrene: $0.15 \times 25 = 3.75$ kg/m^2 (Assuming a Density of 25 Kg/m^3)

Total = 43.75 kg/m^2 i.e. (437 N /m^2)

To allow for 'snatch' loading and lower early material strength during demoulding, handling stresses should be limited to one quarter of the normal design stresses, (i.e. 0.75 MPa for sprayed material in tension).

$$M = \frac{wL^2}{8} = \frac{437 \text{ x } 3.6^2}{8}$$

$$= 708 \text{ Nm } (708{,}000 \text{ Nmm})$$

$$I = \frac{1{,}800 \text{ x } 170^3}{12} - \frac{1{,}780 \text{ x } 150^3}{12} = 236 \text{ x } 10^6 \text{mm}^4$$

$$y = \frac{170}{2} = 85 \text{ mm}$$

Therefore, the tensile stress is given by:

$$f_t = \frac{My}{I} = \frac{708{,}000 \text{ x } 85}{236 \text{ x } 10^6} = \underline{0.26 \text{ MPa}} < 0.75 \text{ MPa}$$

Therefore <u>Acceptable.</u>

8.5.7 Fixings

The panel should have its self-weight taken by supports near the base. The fixings are assumed to be for restraint only (see Section 7.3.1 of 'Cem-FIL GRC Technical Data').

The fixings should make allowance for site and manufacturing tolerances, thermal and moisture movement of the GRC, and movement of the structure.

No more than four fixings should be used for each panel.

Under suction wind loading the pull-out load on each fixing will be

$$\frac{953 \text{ x } 3.6 \text{ x } 1.8}{4} = 1{,}544 \text{ N}$$

Appropriate fixings can be chosen in accordance with section 7.3.1. of 'Cem-FIL GRC Technical Data'.

As a guideline, if cast-in fixings are used, the fixing socket should stand at least 10 mm proud of the back of the panel . This will prevent any roughness of the back GRC face from interfering with the fixing.

8.5.8 Insulation

The Thermal Resistance (R) of the panel can be calculated from:

$$R = R_E + R_I + \sum \frac{t_i}{k_i}$$

where R_E is the external surface resistance (0.055 m²°C/W)
R_I is the internal surface resistance (0.123 m²°C/W)
t_i is the thickness of material layer i (m)
k_i is the conductivity of material layer i (W/m°C)

For polystyrene K = 0.037 W/m°C
For GRC K = 1.0 W/m°C

Hence for a 170 mm thick panel with 10 mm GRC skins and a 150 mm polystyrene core:

$$R = 0.055 + 0.123 + \frac{0.01}{1} + \frac{0.15}{0.037} + \frac{0.01}{1} = 4.25 m^{2^\circ} C / W$$

The 'U-value' is given by $U = \frac{1}{R}$

Therefore $U = \frac{1}{4.25} = \underline{0.24 W / m^{2^\circ} C}$

8.5.9 General Comments

Selection of plastic foams as core materials will depend on operating conditions and the temperature stability of the foam. Polystyrene foam should work satisfactorily with sandwich panel working temperatures up to about 80°C, and polyurethane foam has a superior resistance to high temperatures.

Design of sandwich structures assumes that the shear strength of the bond between various layers of the sandwich is also greater than the shear stress. If this is not the case, the structure ceases to act as a sandwich and may be over-stressed. The shear attachment can take other forms including the use of GRC webs joining the two skins, and these should be designed so that the web shear stress is less than the web design stress.

Experience has shown that it may be advisable to limit the area of sandwich structure to a maximum of 6.5 m^2 (approximately 3.6 x 1.8 m). Although there is no justification for this from analysis of mechanical strength, it is apparent that more problems are experienced in production, handling, installation and use with sandwich structures larger than 6.5 m^2 area, unless the manufacturing process and installation procedures are specifically developed to overcome these problems.

If an aggregate facing mix is used for one side of a GRC sandwich panel it should be noted that the aggregate mix will probably exhibit different shrinkage and moisture movement properties. This may well result in bowing occurring soon after the panel is demoulded. It should be remembered that an aggregate facing mix is not reinforced with fibre and therefore plays no part in the structural thickness of the panel (as calculated in the design). However, it will naturally increase the self weight of the panel and it may therefore be necessary to check the handling stresses.

For further information on the Design and Manufacture of sandwich panels reference can be made to Cem-FIL Bulletin No. 44 - 'Behaviour of GRC in Architectural Cladding Panels'.

8.6 REFERENCES

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9. SURFACE FINISHES

9.1 General

Finishing techniques can vary considerably between individual plants and manufacturers should develop specific techniques supported by skilled operators or special facilities. Each plant should develop quality requirements for all architectural finishes prior to undertaking actual production of such finishes. Such requirements should include samples and production procedures. A finishing process should produce an acceptable uniform appearance without detriment to required material properties.

All finishes of GRC units should be stated on shop drawings. Reference samples or mock-up units should be available in the plant so that all concerned can be sure that standards of finish and exposure are being maintained. These samples should be protected during the course of the project to prevent any unwanted changes in appearance with time.

When choosing a particular surface finish it is important to understand and give consideration to the fact that the GRC backing may have different volume change characteristics. Whether the surface finish material is a face mix or a veneer material, the volume change characteristics should be compatible with those of the GRC backing or the difference should be accommodated.

Exposed aggregate surfaces may be achieved by removing surrounding paste through chemical processes, such as using retarder or acid etching, or mechanically through abrasive blasting, or honing and polishing. Each method will uniquely influence the appearance of the exposed surface. Different degrees of exposure by any of these methods are:

Light exposure. Where only the surface skin of cement and some sand is removed to expose the sand and the edges of the closest coarse aggregate. Sand colour will greatly influence the overall panel colour.

Medium exposure. Where further removal of cement and sand has caused the coarse aggregate to visually appear approximately equal to the matrix in area.

Deep exposure. Where cement and fine aggregate have been removed from the surface so that the coarse aggregate becomes the major surface feature.

The extent to which aggregates are exposed or “revealed” is largely determined by their size. Reveal should be no greater than one-third the average diameter of the coarse aggregate particles and not more than one-half the diameter of the smallest sized coarse aggregate.

A demarcation feature or a skin joint should be incorporated into the surface of a GRC panel having two or more different mixes or finishes. The different face mixes should have reasonably similar behaviour with respect to shrinkage in order to avoid cracking at the demarcation feature due to differential shrinkage.

Exposed aggregates can be brightened by washing with diluted muriatic acid [NOTE:- Manufacturers instructions and precautions must be followed]. This removes the dull cement film which remains when exposure techniques such as washing and brushing are used. The acid solution should not materially affect the remaining cement or aggregate. The acid normally is applied to a pre-wetted surface by brush or it can be sprayed. The surface should be pre-wetted to reduce acid penetration. Immediately after each washing with the acid solution, the GRC units should be thoroughly rinsed with fresh, clean water, to completely remove all traces of acid. Proper precautions should be taken to protect all exposed metal during cleaning operations.

The acid and brush should be kept clean. When acid is brushed onto the surface, the brush may build up a concentration of insoluble silica gel in the bucket that may then be picked up by the brush and smeared over the surface. Hydrofluoric acid is effective in removing deposits but is extremely dangerous for inexperienced personnel. Such cleaning should not be performed by plant employees unless trained and properly protected.

Face mixes containing a polymer will exhibit finishing characteristics substantially different than face mixes without a polymer. Finishing times will be increased for retarded and acid etched finishes. For this reason, it is desirable to use a face mix without a polymer for these finishes.

For finishes that do not involve removal of the matrix material, a face mix with a polymer may be advantageous because it is a denser mix and allows for a surface with fewer imperfections and reduced potential for surface crazing.

Consistency in apparent colour of all finishes can be enhanced by colour compatibility of materials. If the coarse aggregate, fine aggregate, and cement paste are similar in colour, the depth of exposure and localised densities of materials will not be as critical in maintaining colour consistency. In contrast, if material colours are quite different, panels may appear blotchy for the same reasons.

9.2 Smooth

When a glossy, ceramic-like finish is desired, plastic liners are normally used. Metal or highly polished wood produces a very smooth surface. Coated plywood produces a fairly smooth surface. In general , the joints of the materials used to construct the casting surfaces are difficult to hide.

Smooth finished units will normally have air voids on return surfaces. Samples should be used to establish acceptability of such voids with respect to frequency, size and uniformity of distribution. For maximum economy, units with smooth surfaces should be produced without additional surface treatment after stripping. This, in turn, demands the following precautions:

1. Attention to detailing with provisions for ample draft, proper edges and corners and suitable water drips and other weathering details.

2. Well constructed moulds, so that imperfections will not be mirrored in the units. The use of plastic moulds or liners with a matte finish or fibreglass overlaid plywood, which is smooth but not glossy, will help prevent crazing.

3. The mould release agent should be the same throughout production and is applied under as nearly identical conditions as possible each time. (Some release agents help reduce the crazing tendency, by breaking the contact with glossy surface of the mould.)

4. Mist coat or face mix designs that combine a constant, low water-cement ratio, high density and a polymer curing agent in order to minimise crazing, entrapped air voids and colour variations. The mix should be fully graded with aggregate fines below a No. 50 (300 µm) sieve not in excess of 5%.

5. Proper consolidation and curing to minimise non-uniformity which show easily on such surfaces. Uniform curing with minimum loss of moisture from the smooth surface will help minimise crazing tendencies.

6. Minimise chipping because smooth finish patches are difficult to perform in terms of texture and colour match.

9.3 Retarded

Retardation involves the application of a specialised chemical to the face mix surface that delays the cement paste from hardening within a time period and to a depth depending upon the type or concentration of retarder used.

Surface retarders being considered for a project should be thoroughly evaluated prior to use. A sample panel should be made to determine the effects on the mould or face mix. This involves using the particular type of cement, aggregate, and specific mix selected for the product. The effectiveness of the retarder will vary with changes in the rate of hydration due to different temperatures, humidity, or water content of the face mix. The depth of reveal or retardation will be deeper the wetter the mix, the lower the strength of the GRC face mix, and/or the higher the coarse or fine aggregate content ratio.

When using a retarder, the manufacturer's recommendations should be closely followed. Surface retarders can be applied by roller, brush or spray care should be taken to ensure uniform application of retarders to the mould surface.

The retarder should be dry before the face mix is placed. Some retarders are specially formulated for high abrasion resistance. Water should not contact the retarder on the mould surface before the face mix is placed to prevent activation of the retarder.

The finishing process should begin shortly after stripping before the matrix becomes excessively hard. The timing of the surface finish operation should be consistent each day as some retarders cease to delay the hardening process as the panel cures. The retarded surface should be exposed by removing the matrix material by water blasting, aided by use of brushes, or sandblasting.

Once a uniform exposure is obtained, the washing can cease when the flush water is clear and there is no noticeable cement film on the aggregate.

9.4 Sand or Abrasive Blasting

Sand or abrasive blasting of surfaces is suitable for exposure of either large or small aggregates.

Uniformity of depth of exposure between panels and within panels is essential in abrasive blasting, as in all other exposed aggregate processes, and is a function of the skill and experience of the operator. The diameter of the nozzle and nozzle pressure should be determined by experimentation. Different shadings and to some extent, depth of colour will vary with depth of exposure. The age of the panel at time of blasting will also affect the speed and depth of exposure. The age and strength of the face mix at time of blasting should be consistent throughout the project in order to achieve the desired uniform finish from panel to panel.

The type and grading of abrasives affect the surface finish and should remain the same throughout the entire project.

Sands used for blasting operations should be free of deleterious substances such as fine clay particles. If sand is used as the abrasive, a high silica content sand should be used rather than bank or river sand. Silica sand does not break down as readily, thus much less fine-sized dust is formed. The abrasive used should not cause any colour contamination.

9.5 Form Liners

Form liners may be incorporated in or attached to the surface of a mould to produce the desired pattern, shape or texture in the surface of the finished GRC units. A form texture can be of considerable influence in assisting as-cast surfaces to appear more uniform. Wood, steel, plastics and elastomeric materials are most commonly used as form liners.

The method of attaching the form liner should be studied for resulting visual effect. Liner panels should be secured in moulds by gluing or stapling, but, unless desired, not by methods which will permit impressions of nail heads, screw heads, rivets or the like to be imparted to the surface of the GRC.

9.6 Acid Etched

Acid etching is most commonly used for light or medium exposure. In cases where aggregates are to be exposed to considerable depth, only acid resistive siliceous aggregates such as quartz and granite should be used. Carbonate aggregates e.g., limestones, dolomites and marbles, will discolour or dissolve due to their high calcium content. The aggregates on an acid-etched surface present a cleaner or “brighter” look. In normal weathering, the aggregates will lose this brightness and look very similar to their original condition.

Acid etching may be accomplished by brushing the surface with a long handled stiff bristled fibre brush previously immersed in the acid solution. Speciality equipment is also available to acid etch by means of high pressure 24 MPa heated water 65 deg. C with acid metered in low volume (3 to 5%) at the end of the wand. This aids in the speed of the process and allows for better uniformity.

The face mix to be treated should have uniform temperatures and strength levels (preferably about 28 MPa when acid is applied.

The GRC unit should be well wetted with clean water prior to acid treatment because acids will penetrate faster and deeper into dry GRC. The water fills the pores and capillaries and prevents the acid from etching too deeply, and also allows all acid to be flushed after etching.

Acid should not be allowed to lie on the surface for any length of time (15 min. is considered a maximum). Deep etch should be achieved by multiple treatments. After completion of acid etching, the unit should be thoroughly flushed with water.

Prior to acid etching, all exposed metal surfaces, particularly galvanised metal, should be protected with acid-resistant coatings. These include vinyl chlorides, chlorinated rubber, styrene butadiene, bituminous paints and enamels and polyester coatings. If parts of the GRC surface are not to be acid etched they may be coated with an acrylic lacquer.

9.7 Honed or Polished

The grinding of GRC face mixes produces smooth, exposed aggregate surfaces. Grinding is also called honing and polishing depending on the degree of smoothness of the finish. In general, honed finished are produced by using grinding tools varying from about No. 24 coarse grit to a very fine grit of about No. 300. Polishing is accomplished after honing and may be done with a polishing compound.

Polishing consists of several successive grinding steps, each employing a finer grit than the preceding step. Air voids in the GRC surface should be filled before each of the first few grinding operations using a sand-cement mixture that matches the matrix in the GRC unit. Careful filling and curing are required and the next grinding operation should not be performed until the fill material has reached sufficient strength.

Compressive strength of the GRC face mix should be 35 MPa before starting any honing or polishing operations. If proper strength is not produced, grinding will cause dislodgement of aggregate particles and, if the face mix mortar is not hard, the surface will not grind evenly nor polish properly.

The stiffness of the skin and the panel frame, if used, should be considered to ensure that the finished surface will not deflect inconsistently under the pressure of the grinding units, especially with large multihead machines. This can cause uneven depth of grinding and thus a non-uniform appearance.

In choosing aggregates, special attention should be given to maximum size and hardness. The face mix should have a uniform and dense surface and consideration should be given to aggregate hardness. Softer aggregates such as marble or onyx are much easier to polish than either granite or quartz.

9.8. Veneer Facing Materials

Materials such as natural cut stone, (granite, limestone, marble,) thin brick, ceramic or quarry tile, and architectural terra cotta, provide a great variety of textures for GRC units. Quality requirements (design and production procedures) for these finishes should be based on previous records with the identical materials, or sufficient testing of sample and mock-up units to establish performance criteria under the service conditions. Particular attention should be paid to compatibility of materials with respect to differential expansion and contraction caused by thermal and moisture changes. It is necessary to consider the differential volume change of veneer facings and GRC backing. If materials do not have similar physical properties, the final design should include compensation for some interaction of the different materials.

A complete bondbreaker between natural stone veneer and GRC should be used. Bondbreakers should be one of the following: (1) a liquid bond breaker applied to the veneer back surface prior to spraying GRC. (2) a polyethylene sheet, or (3) a 3 mm polyethylene foam pad or sheet. Connection of the natural stone to the GRC should be with mechanical anchors which can accommodate some relative movement. Preformed anchors fabricated from stainless steel Type 302 or 304 should be used. The number and locations of anchors are based on the height, width, and thickness of the cut stone facing unit, and on the desired mechanical bond. Close supervision is needed during the insertion and setting of the anchors. If the anchor is placed in epoxy, it should not be disturbed while the epoxy sets. Care should be taken to ensure compaction of the GRC around the anchors.

The strength of the facing veneer material should be known or determined along with the anchor system to assure adequate strength to resist stresses during handling, transportation, erection, and service conditions.

Some cut stones are easily stained by oils and rust and require the moulds to be lined with polyethylene sheets or other non-staining materials. Veneer joints within a GRC element should be a minimum of 6 mm wide. Joints should be either taped over or filled with sand, a non-staining spacing material or a resilient sealant backup material which will not stain the veneer or adversely affect the specified type of sealant to be applied to the joints later. The gasket should be of such size and configuration as to provide a pocket to receive the sealant and also prevent GRC from entering any portion of the joint between the veneer units. This material should be removed after the panel has been removed from the mould (unless it is a resilient sealant backup or tape).

When considering clay products bonded directly to GRC (including thin brick, structural facing tile and architectural terra cotta), adequate testing and design analysis should be made to determine moisture and thermal movement compatibility of the clay product veneer and the GRC backing or measures should be taken to address the incompatibility. Ceramic glaze units may craze from freeze/thaw cycles or the bond may fail on exposure. Therefore, where required for exterior use, the manufacturers should be consulted for suitable materials and test data backup.

Care should be exercised in placing the mortar or GRC backing mixes to prevent movement of the individual facing materials and thus upset the finished surface.

After removal of the units from the mould the exposed surface should be cleaned.

9.9. Applied Coatings

Paints may be used for purely decorative reasons. Every paint is formulated to give certain performance under specific conditions. Since there is a vast difference in paint types, brands, prices, and performances, knowledge of composition and performance standards is necessary for obtaining a satisfactory GRC paint.

GRC is sometimes so smooth that it makes adhesion of some coatings difficult to obtain. Such surfaces should be lightly sandblasted, acid etched, or ground with silicon carbon stones to provide a slightly roughened surface.

Paint applied to exterior surfaces should be of the breathing type, (permeable to water vapour but impermeable to liquid water), or wall cavities should be well vented when a non-breathable coating is used. Typically, latex or fluorine paints are suitable for most exterior applications. The interior surface of exterior walls should have a vapour barrier (paint or other materials) to prevent water vapour inside the building from entering the wall. The paint manufacturer’s instructions regarding mixing, thinning, tinting, and application should be strictly followed.

Sealers, both clear and pigmented, can be used but they must be tested on reasonably sized samples of varying age, and their performance verified over a suitable period of exposure or usage based on prior experience under similar exposure conditions. Sealers should be applied in accordance with manufacturer’s written recommendations. Any sealer used should be guaranteed by the supplier or applicator not to stain, soil, darken or discolour the finish. Also, some sealers may cause joint sealants to stain the panel surface or affect the bond of the sealant. The manufacturers of both the sealant and the sealer should be consulted before application, or the material specified should be pretested before application.

Site applied surface coatings should not be applied until all repairs and cleaning have been completed. In cases where the panels have been coated at the manufacturing plant, and additional cleaning is required, it may be necessary to recoat those particular panels.

9.10. Repairs

9.10.1 Repairs in the Factory

A certain amount of product repair is to be expected as a routine procedure. Repair work requires expert craftsmanship, if the end result is to be structurally sound, durable and pleasing in appearance. Repairs are acceptable provided the structural adequacy, serviceability, and the appearance of the product are not impaired. Excessive variation in colour and texture of repairs from the surrounding surfaces may result in the panels not being approved until the variation is minimised. Major repairs should not be attempted until an engineering evaluation by the panel design engineer is made to determine whether the unit will be structurally sound.

Since the techniques and procedures of repairing GRC are affected by a variety of factors including mix ingredients, final finish, size and location of damaged area, temperature conditions, age of panel, surface texture, etc., precise methods of repairing cannot be detailed in this Standard.

Adequate curing methods for repairs should be implemented as soon as possible to ensure that the repair does not dry out too quickly and cause it to shrink away from the existing GRC. Moist curing the repair area for a minimum of 3 days is most effective, when possible. Corrosion protected materials should be touched-up upon completion of all intended curing and acid cleaning. All repaired products should be inspected by quality control personnel to ensure that proper repair procedures including curing have been followed and that the results are acceptable. Repairs should be evaluated when finished surface is dry.

9.10.2 Repairs at Site

GRC panels may be superficially damaged (minor chipping or spalling) during transport or erection and jobsite repair will be necessary.

Workers experienced in such jobsite repair must perform this work. Repairs should be done only when conditions exist which assure that the repaired area will conform to the balance of the work with respect to appearance, strength and durability.

It is important that all repairs be performed in advance of the final cleaning and joint sealing operation. The repair work must be fully cured, clean, and dry prior to caulking.

**** Acknowledgement***

Cem-FIL International Ltd. is grateful to the PCI of the USA for their permission to use extracts from their publications.

10. QUALITY ASSURANCE

Quality control procedures have been established to ensure correct operation of the manufacturing process, to ensure that correct material properties are being achieved and to assess the final product.

These procedures may be generally described as follows:

Process Control

Determination of:
(1) fibre output (from spray unit)
(2) slurry output (from spray unit)
(3) slump characteristics of slurry
(4) glass content of uncured GRC
(5) water/solids ratio of uncured GRC

Production of GRC is also controlled by keeping a check of such items as raw material usage, thickness of product and final product weight.

Product Control

Tests on cured GRC specimens taken either from product or a test board representative of the product.

Determination of:

(6) dry and wet bulk density, water absorption and apparent porosity

(7) limit of proportionality (LOP), modulus of rupture (MOR) and directionality ratios

Methods to determine the above are given in the Quality Control Test Booklet which Cem-FIL International Ltd. supplies to its customers and which is available to specifiers. British Standard BS 6432 details test methods for the items above numbered 4, 5, 6 and 7. European (C.E.N.) Standards in the series EN 1170-1 to -8 also refer and now supercede previous BS or other national standards. Test methods are also given in the GRCA, ASTM, PCI and RILEM publications noted in Section 11, and references 1 and 2 discuss the background to QC procedures.

Component Inspection and Testing

Final product inspection for surface flaws, colour, finish and overall product dimensions should always be carried out. In certain circumstances it may be necessary to mechanically test the finished product. The booklet “Guidelines for Testing” which Cem-FIL International Ltd. supplies to its customers and which is available to specifiers gives information on full scale testing of GRC cladding panels. Other methods appropriate to the particular product are given in BS 3445, BS 6171 and BS DD76: Part 1 or equivalent international standard.

References

1. Proctor B.A., “Principles and Practice of GRC - A Review” Composites, Vol. 9, No. 1, 1978, pp 44-48.

2. Ward D., and Proctor B.A., “Quality Control Test Methods for Glass Fibre Reinforced Cement” RILEM Symposium Testing and Test Methods of Fibre Cement Composites, The Construction Press Ltd., 1978, pp 35-44.

11. STANDARDS AND SPECIFICATIONS

11.1 Introduction

Standards for GRC are being developed steadily. In Europe, new C.E.N (Comité Européen de Normalisation) Standards are being generated which will cover aspects not previously addressed, and replace some existing national standards.

11.2 C.E.N.

Published:

BS EN 492:1994
Fibre-cement slates and their fittings for roofing - Product specification and test methods.

BS EN 494:1994
Fibre-cement profiled sheets and fittings for roofing - Product specification and test methods.

To be published 1998/9:

EN 1169
General rules for factory production control of glass-fibre reinforced cement.

Published 1998:

EN 1170-1
Test method for glass fibre-reinforced cement - Part 1: Measuring the plasticity of the mortar - “Slump test” method.

EN 1170-2
Test method for glass fibre-reinforced cement - Part 2: Measuring the quantity of fibre in fresh GRC - ‘Wash out test” method.

EN 1170-3
Test method for glass fibre-reinforced cement - Part 3: Measuring the rate of sprayed fibres.

EN 1170-4
Test method for glass fibre-reinforced cement - Part 4: Measuring bending strength - “Simplified bending test” method.

EN 1170-5
Test method for glass fibre-reinforced cement - Part 5: Measuring bending strength - “Complete bending test” method.

EN 1170-6
Test method for glass fibre-reinforced cement - Part 6: Measuring the absorption of water by immersion and measuring the dry density.

EN 1170-7
Test method for glass fibre-reinforced cement - Part 7: Measurement for dimensional variations in accordance with the water content.

ENV 1170-8:1997
Test method for glass fibre-reinforced cement - Part 8: Cyclic weathering type test

11.3 British Standards Institution

BS 3445:1981	Fixed Agricultural Water Troughs and Water Fittings
BS 6171:1982	Prefabricated Sectional Storage Bunkers for Domestic Solid Fuel
BS 6432:1984	British Standard Methods for Determining Properties of Glass Fibre Reinforced Cement Material
DD 76 1981 (Part 1)	Precast Concrete Pipes of Composite Construction. Part 1. Precast Concrete Pipes Strengthened by continuous alkali-resistant glass fibre rovings.

11.4 Glass Reinforced Cement Association (GRCA)

GRCA Methods of Testing Glassfibre Reinforced Cement (GRC) Material-GRCA S 0103

GRCA Method of test for strength retention of glassfibre in cements and mortars - GRCA S0104

Specification for Alkali Resistant Glassfibre Rovings and Chopped Strands for Reinforcement of Cements and Concretes GRCA S0105

Guide to Specification for Glassfibre Reinforced Cement Cladding GRCA S0106

GRCA Guide to the use of Acrylic Polymers in GRC GRCA G0109

Specification for the Manufacture of Glassfibre Reinforced Cement (GRC) GRCA S 0110

11.5 Deutsches Institut für Bautechnik

Cem-FIL fibre products are covered by the following approvals:
Zulassung no. Z-31.2-122
Zulassung no. Z-31.2-127

11.6 American Society for Testing and Materials (ASTM)

ASTM - C947-89 Standard Test Method for Flexural Properties of Thin Section Glass Fiber Reinforced Concrete (Using simple beam with third point loading).

ASTM - C948-81 Standard Test Method for Dry and Wet Bulk Density, Water Absorption, and Apparent Porosity of Thin Sections of Glass Fiber Reinforced Concrete.

ASTM - C887-79a Standard Specification for Packaged Dry Combined Materials for Surface Bonding Mortar.

11.7 Prestressed Concrete Institute

PCI Committee on Glassfibre Reinforced Concrete Panels, “Recommended Practice for Glassfibre Reinforced Concrete Panels” Third Edition 1993

PCI Committee on Glassfibre Reinforced Concrete Panels, “Manual for Quality Control for Plants and Production of Glassfibre Reinforced Concrete Panels” Publication number MNL-130-91, ISBN 0-937040-46-0

11.8 RILEM: International Union of Testing and Research Laboratories for Materials and Structures.
Rilem Technical Committee 49 TFR. Draft Recommendations.

“Testing Methods for Fibre Reinforced Cement - Based Composites” Matériaux et constructions (materials and structures) essais et recherches/research and testing, NovemberDecember 1984, No.102, pp 441-456.

11.9 British Board of Agrément

Certificate No. 88/2060
Fibrocem High Performance Renders

Certificate No.82/1016
Fibrocem Blockmix Glass Reinforced Rendering.

Certificate No.81/833
ARC Slimline Glass Reinforced Concrete Pipes.

11.10 CSTB (France)

Avis No.17/80-82
Avis sur le tuyau d’assainissement SLIMLINE (Société ARC Concrete Ltd.).

Avis No.7/83-235
Système d’isolation thermique par l ‘extérieur (Societe CIDE Paris, France)

Avis No.16/83-105
Bloc de Hauteur d’Etage (BHE) (Enterprise Brugeaud, Tulle, France)

Avis No.1/84-514
Beton Isolant Léger (BIL) (Entreprise Brugeaud, Tulle, France)

Evaluation Technique: Cem-FIL Star GRC Groupe Specialisé No1 (13.12.1996)

11.11 National Precast Concrete Association of Australia

GRC Committee of the NPCAA: Code of Practice for the design and installation of GRC Products (Draft - 1995).

11.12 South African Bureau of Standards

SABS - 1969 (Amendment No.4, 6th June 1979). Concrete non-Pressure Pipes.

11.13 National Swedish Board of Physical Planning and Building (Statens Planverk).

Type Approval Certificate No.2306/77 (renewed 21.2.83) - Siroc Grund GRC insulation units.

11.14 National Water Council, London

The publication “Water Fittings” lists water fittings and materials which have been examined, tested and found to comply with Water Byelaws. GRC is listed as follows:

“Water Fittings” November 1980 GRC Glass Reinforced Concrete Premixed GRC (79/12/1) Sprayed GRC (34/7911) 8002 MX CemFIL Marketing Department, Fibreglass Ltd.

“Water Fittings” Supplement No.6, December 1982 GRC Glass Reinforced Concrete Premixed CemFIL 2 GRC (115/80/2) Sprayed CemFIL 2 GRC (115/80/1) 8101 MX CemFIL Marketing Department, Fibreglass Ltd.

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