DEKO

شركة ديكو مصر للإنشاءات الحديثة

GRC

Material properties
Mix Design
Casting Technique

with compliance to

GRCA
GLASSFIBRE REINFORCED CONCRETE ASSOCIATION
INTERNATIONAL

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INTRODUCTION

1.1 Scope

This Practical Design Guide has been prepared by the Technical Committee of the Glassfibre Reinforced Concrete Association (GRCA) . The purpose of this publication is to provide a useful reference for specifiers, designers, manufacturers and fixers of glassfibre reinforced concrete (GRC) products and to encourage the use of good design practices. It complements the other technical publications of the GRCA, namely:

- Guide to Fixings for GRC Cladding
- Specification for the Manufacture, Curing and Testing of GRC products
- Methods of Testing GRC Material

National and international standards relating to the testing of GRC and its constituent materials are also available and further standards will become available in the future. GRC is used extensively worldwide, both as a functional and decorative construction material in building and civil engineering. This Guide discusses the relevance of good design practice for typical products.

GRC is a composite material comprising a mixture of hydraulic cement, silica sand, alkali resistant (AR) glass fibres and water. The glass fibres effectively reinforce the mortar mix thereby improving its tensile and flexural characteristics. GRC is a particularly attractive and durable cladding material. It can be moulded into a wide variety of complex shapes and profiles and is ideally suited to the popular fast-track approach of using lightweight, prefabricated cladding panels for the exteriors of modern buildings. The main advantage of GRC panels over the corresponding precast concrete alternatives is the considerable saving in weight. This results in significant savings in the costs of transportation, handling and erection of the panels. If this weight advantage is considered at the design stage, it should be possible to effect substantial economies in the design of foundations and superstructures for high rise building constructions. Other notable advantages of GRC cladding are its durability, chemical resistance, non-combustibility and good sound/heat insulation properties.

GRC is used extensively in the architectural and civil engineering fields with the main products being:

- cladding
- permanent formwork
- slates/roof features
- cornices
- coping units
- canopies
- porticos
- walkway roofs/walls
- sunscreens
- artificial rocks
- drainage channels
- street furniture
- planters
- arches
- balustrading
- box beams
- cable trays
- conservatory walling
- domed roofs
- door surrounds
- gutter units
- sound barriers
- string course features.

The design elements of this publication are based on limit state theory whereby the GRC product is designed to satisfy the limit states of collapse and serviceability using appropriate partial factors of safety. Several worked examples are included to demonstrate the use of these partial factors of safety.

1.2 Terms and Definitions

Admixture - A material added to modify the properties of mortar or cement slurry.

Air Permeability - The rate of flow of air through a material.

Alkali Resistant (AR) Glass Fibre - Fibre made from glass having a high zirconia (minimum of 16%) content formulated to improve resistance to attack by aqueous alkaline solutions.

Ambient Temperature - The temperature of the air surrounding an object.

Anchor - Devices for the attachment of the GRC skin to the stud framing system; this includes gravity, flex and seismic anchors.

Artificial Ageing - A condition to which test specimens are subjected to to simulate their exposure to natural weathering (using accelerated testing).

Backing Coat - The layer of GRC comprising fibre and cementitious slurry ,the thickness of this layer must be equal or greater than the design thickness.

Bag and Bucket Tests - Very important methods for calibrating GRC spray equipment.

Bonding Pad - An additional covering of “GRC” material to secure anchors to the main element of “GRC” (typically cladding panels).

BOP - **B**end **o**ver **p**oint (tensile), namely, the stress at which the stress/strain curve deviates from a straight line variation when a sample of GRC is tested in direct tension.

Carbonation - The reaction between carbon dioxide and a hydroxide or oxide to form a carbonate, especially in cement paste or mortar; the reaction with calcium hydroxide to produce calcium carbonate. GRC offers an extremely high resistance to carbonation.

Characteristic Property - The value of a property above which 95% of the population of all possible measurements of that property are expected to lie.

Chopped Glass - Non-continuous multi-filament glass fibre strands; resulting from chopping the roving in a spray process.

Cladding Panel - A lightweight non-structural GRC prefabricated building component produced by a spray technique to form an exterior or interior wall/column panel.

Compaction - The process whereby the volume of the face mix or GRC backing is reduced to a minimum practical volume by the reduction of voids usually by vibrating, tamping, rolling or some combination of these.

Composite - A material formed by combining two or more materials; but so interconnected that the combined components act together as a single entity, eg GRC

Coupon - Specimen for testing.

Creep - The time dependant change in dimension or shape caused by a sustained load.

Curing - The process by which moisture is retained in the GRC product to allow full hydration.

Dry Curing - A method of curing carried out by the addition of the appropriate quantity of acrylic polymer to the GRC mix.

Dry density - The weight per unit volume of an oven dry specimen.

E-Glass Fibre - Borosilicate fibres widely used for the reinforcement of plastics, but not recommended for use with portland cement.

Efflorescence - A deposit of salts, usually white, formed on the surface of the skin. It is a substance that has emerged in solution from within the GRC backing or face mix and deposited by evaporation.

Engineer - The person or authority responsible for the design of the GRC product.

Facing Coat - An initial layer without fibre but containing decorative aggregates and often pigment.

Fibre - An individual glass filament with an average diameter of 13 to 20 microns and not less than 9 microns in diameter.

Fibre Content - The ratio, usually expressed as a percentage, of the glass fibre to the total composite; it can be by weight or volume.

Flex Anchor - A steel connection between the GRC panel and the supporting stud frame in stud frame construction. It is usually designed to provide lateral restraint only against the effects of wind forces and seismic loadings whilst allowing rotation perpendicular to the GRC facing.

Glassfibre content by weight (WF) - The ratio (expressed as a percentage) of the mass of glassfibre to the mass of GRC in the uncured state.

Gravity Anchor - A steel connection between the GRC panel and the supporting stud frame in stud frame construction. It is usually designed to support the full weight of the GRC panel and is positioned close to the bottom of the GRC panel.

GRC/GFRC Glass(Fibre) Reinforced Concrete.

GRCA - Glass Reinforced Concrete Association.

GRCA Approved Manufacturers Scheme AMS - The GRCA system of accreditation by assessment of the ability of a manufacturers to provide the necessary resources and equipment to meet the quality level required of GRC products.

High Shear Mixer - A mixer with a high shear action capable of the preparation of the fine sand/cement slurries required for the spray process.

LOP - Limit of Proportionality (flexural) ie the point at which the stress/strain curve deviates from a straight line.

Matrix - The cement paste into which various amounts of aggregate particles and/or glass fibres are incorporated.

MFFT - Minimum film formation temperature (for acrylic polymers).

Mist Coat - An initial cementitious sprayed coating without glass fibre.

MOR - Modulus of Rupture (flexural), the ultimate bending stress obtained from the four point bend test.

Premix GRC - A method of manufacture in which pre-cut glass fibres and the cementitious slurry are blended during the mixing.

Premix Mixer - A two stage mixer designed to prepare fine sand/cement slurries (Stage 1) and to blend in chopped glass fibres (Stage 2).

Polymer-Modified GRC - GRC which has been modified by the addition of an acrylic thermoplastic polymer dispersion either for 'dry curing' or for property enhancement.

Producer - The person or authority entering into a contract to manufacture a GRC product.

Purchaser - The person or authority entering into a contract to buy a GRC product.

Roving - A group of parallel glass fibre strands wound as a bundle with a cylindrical shaped package.

Roving Tex - The mass of "chopped" glass strands per kilometre length.

Sand/cement ratio - The ratio of the mass of the total dry sand to the mass of dry cement in the GRC

Sandwich Panel - A prefabricated panel which is a layered composite formed by attaching two skins separated by an insulating core or cores.

Scrim - A manufactured fabric having open area construction of over 4mm using AR glass fibre strands. It is laid up by hand to reinforce an area of the GRC backing.

Seismic Anchor - Bars or plates that transfer the seismic load on the skin back to the stud frame.

Serviceability Limit State - The condition of the GRC panel during use ie when in service. This usually refers mainly to allowable deflection limits when checking the conformance of GRC to this limit state.

Slump Test - A test for measuring the consistency of the cementitious slurry.

Spray GRC - A method of manufacture in which the GRC is produced by simultaneously spraying cementitious slurry and chopped glass fibre.

Stiffening Rib - A local thickening of the GRC skin to give the panel additional stiffness and strength.

Stud Frame - A structural framework, usually steelwork, to support a GRC panel by means of flex anchors and gravity anchors. This frame is attached directly to the supporting structure.

Superplasticizer - A high range water reducer admixture producing a cement slurry of significant higher slump without additional water.

Supplier - The person or authority entering into a contract to supply goods or services to the producer..

Test Board - A sheet of GRC manufactured during production for the purpose of assessing the quality of the GRC products being made. The test board should, if possible, be a specimen of the product itself. If this is not possible the test board should be made in the same way and at the same time as the GRC in the product so that it is representative of the quality and thickness of the GRC.

Test Board Mean - The arithmetic mean value of a property calculated from individual test results from one test board. For statistical analysis this mean is regarded as one result.

Test Coupons - Specimens taken from a test board for determining a property.

Test sample - The total number of coupons taken from a test board and tested to determine a property of that test board.

Tolerance - A specified permissible variation from stated requirements such as dimensions and strength.

Trowelled Surface - The surface of a panel away from the formwork or mould made by smoothing with a trowel.

Ultimate Limit State - The state of collapse. Conformance with this limit state is checked using a number of partial factors of safety applied to both the GRC mix and the applied loading.

Ultimate Tensile Strength - Stress at which GRC fails in pure tension.

Uncured state - The stage in manufacture of GRC when all the physical processes that could alter the composition of the material are complete but the fibre can still be separated from the matrix by the action of running water.

Water/cement ratio - The ratio of the mass of total water(including water contained in the polymer and plasticiser) to the mass of dry cement.

1.3 Types of GRC

The material properties, component design and method of manufacture of GRC products are interrelated

Glass Reinforced Concrete (GRC) is a composite material consisting of a mortar of hydraulic portland cement and fine aggregate reinforced with alkali resistant glass fibres. Within this broad definition, variations are possible in mix constituents and proportions, and manufacturing method, such as to produce materials with differing properties. The material properties, component design and method of manufacture of GRC products are interrelated.

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 guide mainly refers to GRC materials having an aggregate:cement ratio of up to 1:1, incorporating AR glassfibres in the range 2 - 5% and made by the spray and premix processes. The GRC may contain additional filler materials and admixtures. GRC materials have been widely used for a number of 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 is a composite with reinforcing elements randomly distributed throughout the matrix, unlike reinforced concrete where the reinforcing steel is placed primarily in tensile stress areas, at a predetermined distance from the surface to give the steel protective cover. This means that for practical purposes GRC is designed as a homogeneous material.

GRC products are safe, have good chemical resistance and will not rot or corrode. GRC is made of inorganic materials, will not burn and has negligible smoke emissions. It gives excellent stability and integrity resistance to fire. However, due to the thin nature of panels, it requires additional material to satisfy insulation requirements. 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, with thickness commonly in the range 10mm to 15mm. This gives a low component weight which allows savings in handling, storage, transportation, and installation compared with traditional concrete products.

There are two main methods of manufacturing GRC,
namely:

(i) **Spraying** the fibre and slurry simultaneously onto a mould, by manual or mechanical means, with subsequent compaction by roller and trowel. Typical products made using the spray process include architectural cladding panels, channels, tanks, facade elements, ducting and permanent formwork.

Figure 1.1

Initial spraying mould with a mist coat

Figure 1.2

Spraying GRC into mould

Figure 1.3

Compacting GRC using serrated roller

Figure 1.4

Gauging thickness of GRC

(a)

(b)

Figure 1.5

(ii) **Premixing** pre-chopped fibre in a mixer after thorough mixing of other components and then processing the mixture by vibration casting in a mould, extrusion, injection moulding etc, to produce the end product form (Figures 1.5(a) and (b). This method of production is very versatile and is ideal for producing small items of architectural product in short periods of time, by using multiple moulds.

1.4 Selection of Production Method & Raw Materials

The raw materials and mix design, and production method used, are decided according to the particular product and are inter-related with the engineering design.
In choosing the mix design the following may be varied: fibre content and type; sand/cement ratio; water/cement ratio; polymer content. By varying the composition of the cementitious slurry and the percentage of fibre a range of materials with differing mechanical and physical properties may be produced. These different mechanical and physical properties must be considered by the designer and manufacturer and the appropriate type of GRC selected for the application.

1.4.1 AR Glassfibre

AR (Alkali Resistant) glassfibre is specially formulated to have a high degree of resistance to alkali attack and high durability in cement. Cement solution is highly alkaline (typical pH12.9) which is a very aggressive environment for glass fibres. 'E' glass fibres, as used in plastics reinforcement, are rapidly destroyed. The special formulation of the 'AR' fibre , in particular the zirconia content, resists this aggressive environment. Laboratory testing shows that at least 16% zirconia content is required for adequate alkali resistance.

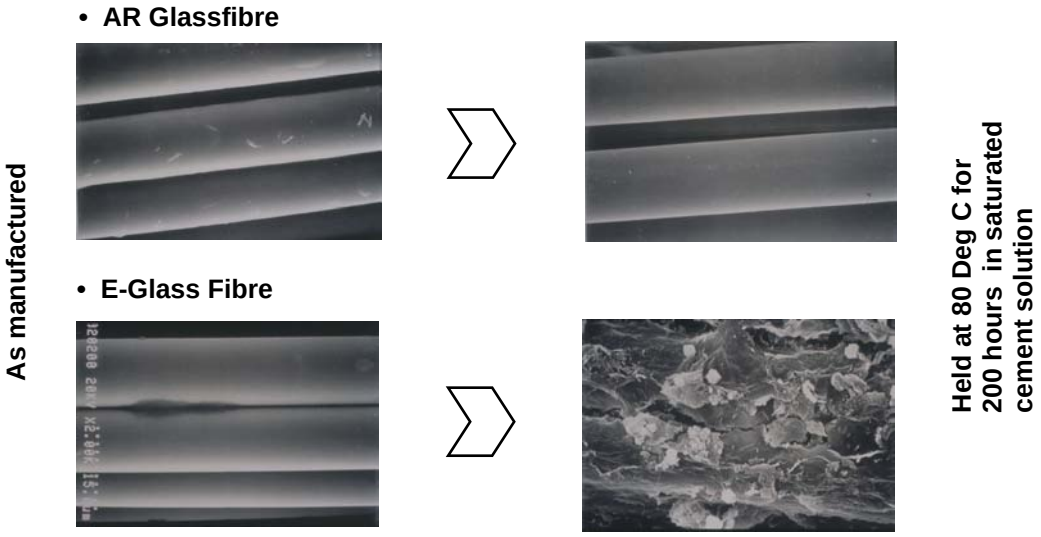

Figure 1.6 - Comparison of Alkali Erosive Attack in AR and E Glass Fibre

AR fibres are originally produced as continuous filaments typically 13 –20 microns in diameter and these filaments are gathered together to form strands. A coating or size is used to bind the filaments together. The number of filaments forming the strand and the type of size can be varied to produce a range of glass fibres to suit particular applications.

Typical AR Fibre Properties

•	Single filament tensile strength	3.0 - 3.5 GN/m2
•	Strand tensile strength	1.3 - 1.7 GN/m2
•	Young's Modulus of Elasticity	72 – 74 GN/m2
•	Specific Gravity	2.60 - 2.70
•	Strain at breaking point (strand)	2.0 - 2.5%
•	Filament diameter	13 - 20µm

Table 1.1 - Typical Specification

Property	Specification Value	Method of Test	Frequency of Testing
Zirconia Content	16% Minimum	X-Ray Fluorescence Analysis	Monthly
Density	2.7 +/- 0.3 G/cm^3	ASTM D 3800	Yearly
Tensile Strength (Strand)	1.0 - 1.7 GN/m^2	ASTM D 2343 Strand	Yearly
Filament Diameter	9 to 20 +/- um		Each 20 Tonnes
Roving Tex	+/- 10% from the nominal value stated by the Supplier	ASTM D 861	Each 20 Tonnes
Cut Length	+/- 3mm from the nominal value stated by the Supplier		Each 20 Tonnes
End Count	+/- 20% from the nominal value stated by the Supplier	Physical Count	Each 20 Tonnes
Loss on Ignition	+/- 20% from the nominal value stated by the Supplier, or +/- 0.3%, whichever is the greater		Each 20 Tonnes
Strength Retention by Strand in Cement	Minimum value 330 N/mm^2 after 96+/-1 hour in water at 80 deg C (+/- 1 deg C)	'Method of Test for Strength Retention of Glass Fibre in Cements and Mortars'. GRCA SO104/0184, Jan 1984	Monthly

The above tests are carried out by the glassfibre manufacturer.

There are two main product forms used for GRC production. These are Chopped Strands for use in premix GRC, and Rovings for use in the spray production.

Chopped Strands consist of continuous strands cut to uniform length while maintaining the integrity of the original strand. The size or coating on Chopped Strand products are designed to give resistance to mechanical damage in processing particularly during mixing.

Rovings are groups of individual parallel strands wound as a bundle into a cylindrical shaped package containing typically 18 to 20 kg of fibre. It may be:

1) chopped in a 'gun' and sprayed simultaneously with the cement matrix material onto or into a mould.
2) chopped on-site for use in the premix process.

Nets, scrims, chopped strand mat, and sewn fibre products are also available for applications where positioned or directional reinforcement is required.

1.4.2 Cement

The most widely used cements in GRC manufacture are Ordinary Portland Cement (OPC) Rapid Hardening Portland Cement (RHPC) and White Portland Cement. They should conform to the relevant National or International Standards. European equivalents to British Standard cements (CEM I to CEM V) have been recently issued. RHPC is chemically very similar to OPC but is more finely ground and, because of this, develops strength more rapidly at early age.

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. 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 Standard. Care should be taken that the choice of cement is appropriate to the product 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 and in order of age.

1.4.3 Sand

Fine aggregate or sand should be supplied washed and dried to remove soluble matter and permit accurate control of the water/cement ratio. The particle shape should be round or irregular and should have a smooth surface without honeycombing.

For spray GRC, the maximum particle size is generally limited to 1.2 mm; for premix GRC, the maximum particle size may be 2.4 mm. In both cases the fine fraction, i.e. sand passing a 150 micron sieve, is preferably less than 10% of the total weight of sand.

Silica sands are widely used, a typical specification being:

Silica content		> 96%
Moisture content		< 2%
Soluble salts		< 1%
Loss-on-ignition		< 0.5 %
Sulphate ion	maximum	4000 ppm
Chloride ion	maximum	600 ppm

Sands with a higher moisture content may be used provided the moisture content is known and the mix design is altered accordingly.

Sands other than silica sands may be used but the producer should provide evidence of their suitability. Soft building sands must not be used as they may lead to inferior mechanical properties. 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 (to obtain optimum mechanical properties and to preserve grading as a breakdown of particles would increase water demand), non-reactive and of similar shape and grading to that described above.

1.4.4 Sand/aggregate facing mixes

When a facing mix is used to produce an architectural finish special aggregates and sand may be required. The colour of the aggregate is particularly important as this contributes to the overall appearance. The grading differs from the sand used in the GRC mix with 0-3mm typically being used when the facing layer is sprayed and up to 10mm when the facing layer is poured and vibrated. Mix design may differ from the GRC backing layer but consideration should be given to potential differential shrinkage as a result of different cement content. Crushed and graded hard rocks like limestone, granite, spar, calcite or marble are particularly suitable.

1.4.5 Admixtures

The use of admixtures, such as plasticisers and superplasticisers, is encouraged as they can enhance the properties of GRC.
Standard concrete admixtures or those specially formulated for GRC manufacture may be used as appropriate. Admixtures are generally added to produce the following effects.

In the 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 the properties of hardened GRC :

- increasing the rate of early strength development
- increasing the strength
- decreasing the permeability

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 must not be used if the GRC product contains any steel components (or fixings) as there is a risk of corrosion of the metal.

1.4.6 Acrylic Polymers

Cementitious products should be moist cured to ensure that there is sufficient retained moisture for complete hydration of the cement. This is particularly critical for thin skin GRC products. The recommended curing regime is a wet cure at 95% relative humidity for 7 days. In many cases this is not practical as insufficient factory space is available.

Acrylic Polymers are added to the GRC mix to allow for a subsequent dry cure and for property enhancement, particularly the reduction of surface crazing.

When acrylic polymers are added to the mix at the recommended dosage a film is formed within the matrix during the first few hours of curing. The formation of this film significantly reduces the permeability and thus lessens the loss of water by evaporation ensuring that sufficient water is available for complete hydration.

Table 1.2 - Typical Polymer Specification

Compound Type	Aqueous thermoplastic polymer dispersion
Polymer Type	Acrylic based
Minimum Film Formation Temperature	7 - 12 deg C
% Solids	45 - 55%
Appearance	Milky white, creamy, free from lumps
Ultraviolet Resistance	Good
Alkali Resistance	Good

1.4.7 Water

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

1.4.8 Pozzolanic Materials

PFA ,GGBS, Metakaolin and Microsilica are a range of pozzolanic materials which have been shown to have a beneficial effect on the properties of GRC. They work by reacting with the free lime produced during the hydration process to form further hydration products.

1.4.9 Pigments

Powder pigments or dispersions may be used to produce coloured GRC . The pigments are normally iron oxide based and should conform to national or international standards. It is normally found that less intense, pastel shades are more successful and some variability is to be expected.

1.4.10 Paints, sealers and adhesives

Suitable paint coatings and adhesives may be used with GRC products. It is important to select a coating product which is appropriate: normally a product that is designed for use on concrete will perform adequately. As a general rule paint coatings used should be permeable to moisture vapour. Manufacturers' recommendations on the preparation of the GRC surface, and priming procedures, should be followed strictly.

1.5 Applications and Uses

GRC has many applications in both the architectural and civil engineering sectors of the construction industry, where both the functional and decorative qualities of the material are used. It is a particularly attractive and durable cladding material. GRC can be moulded into a variety of complex shapes and profiles, with a choice of attractive finishes, and is ideally suited to the popular fast-track approach of using lightweight, prefabricated cladding panels for the exterior of modern buildings. The main advantage of GRC panels over the corresponding precast alternatives is the considerable saving in weight. This results in significant savings in the cost of transportation, handling and erection of the panels. If this weight advantage is considered at the design stage, economies may be possible in the design of foundations and the superstructure of high rise buildings. Other notable advantages of GRC cladding are its durability, chemical resistance, good fire performance and good sound and heat insulation properties. A few examples can be illustrated as follows:

Figure 1.7
Architectural Cladding

Figure 1.8
Industrial Cladding

Figure 1.9
Architectural Features

Figure 1.10
Sunscreens

Figure 1.11
Renders

In civil engineering, agriculture and landscaping, many of the same properties are utilised, notably resistance to environmental conditions, adequate strength in thin section, ease of handling, and maintenance-free performance throughout service life.

Figure 1.12
Artificial Rocks

Figure 1.13
Noise Barriers

Figure 1.14
Ducts & Channels

Figure 1.15
Permanent Formwork

Figure 1.16
Agricultural Products

Figure 1.17
Street Furniture

Figure 1.18
Sewer Lining

Figure 1.19
Utility Boxes

The qualities of GRC can therefore be summarised as:

- Attractive and Versatile - Can reproduce fine surface details and finishes to complement any architectural style.
- Light Weight - Easier to transport and install
  - Reduces structural and foundation costs
- Good Chemical Resistance
- Will not Rot or Corrode
- Low Maintenance
- Unaffected by UV light or Hot Dry Conditions
- Suitable for any climate
- Freeze/Thaw Resistant