Glass Fibre Reinforced Concrete as a material, its properties, manufacture and applications.

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Abstract.
This paper discusses the different types of GRC available in the Hong Kong Market. Several examples are illustrated as to where it has been used and how it has been produced. Latest developments in the durability problems of GRC are also discussed.
Key Words: GRC, AR Fibre, Materials, Processing, Quality Control.

1.0 Introduction

Glass reinforced concrete (GRC) used in Hong Kong is essentially a Portland cement-based composite with alkali-resistant (AR) glass fibres that are normally randomly distributed throughout the material. This paper will discuss about the properties and different types of GRC commercially available in Hong Kong.

2 Main Uses of GRC

2.1 Hong Kong

GRC has been used extensively in Hong Kong in recent years, typical examples of how it has been used include cable troughs, building facades and claddings, footbridge beams and architectural (ornamental) products

- **Cable Troughs**
  This is probably currently the most common usage for GRC in Hong Kong. GRC is mainly used for this purpose due to its strength and lightweight properties. Moreover it also has good electrical, fire and chemical resistance properties.

- **Building facades (as backing mix) and Lightweight architectural claddings.**
  It is used for these purposes mainly due to its lightweight nature and fire resistance properties.

- **Column protection covers** .
  GRC results in a product that is 5-10 times lighter than plain reinforced concrete and with an increase in impact resistance of approx. 20 times.

- **Footbridge beams**
  Beams made from GRC have been used on a footbridge in Tsim Sha Tsui. The lightweight nature , strength properties and bending properties of GRC made it ideal for this application.

- **Other architectural products such as ornamental fountains, banisters etc.**
  Due to the flexibility in moulding and surface appearance it is ideal for many architectural purposes.

2.2 Overseas

Overseas the use of GRC products has been more widespread, typical examples other than those mentioned previously include

- **Noise Protection Barriers.**
  GRC has been used for making noise protection barriers. The main reason is that theoretical values have been quoted that state panels with an thickness of 10mm and surface mass of 20kg/m^2 will achieve a sound reduction of about 30dB. Furthermore, barriers with a thickness of 20mm with the same surface mass will have a sound reduction of 35dB

- **Interior usages** such as kitchen counter tops, commercial and industrial tops etc. GRC is more stain resistant than granite and more scratch resistant than marble.
- **Exact Replicas** of historical buildings and extensions to old buildings using the same design features.
- **Others** such as roofs, slabs, piers, decking, parapets, earth retaining walls and channels, sewer relining, permanent formwork and floating pontoons for marinas.

3 Typical Properties of GRC

3.1 Physical Properties

Illustrated in the table below are some of the typical properties that are normally achieved with GRC. It should be noted that the final property is dependent not only on the mix design, materials and methods of manufacture but also the ambient conditions (the drier the conditions generally the lower the strength properties).

What can be clearly seen from this table is that firstly the sprayed mix samples are higher in strength properties than the premix samples and secondly that after long term storage, bending & impact strength properties do deteriorate slightly.

3.2 Advantages / Limitations

The main advantages of GRC in comparison to concrete, plastic or steel are as follows:

a) higher flexural strength, tensile strength and Impact Strength than plain concrete due to the presence of the glass fibre.
b) it is versatile with great design flexibility. It can be provided in many colours, textures, patterns and surface finishes. Nearly any shape product can be formed.
c) fibres are lightweight that minimizes the load added to existing structures.
d) improved Chemical Resistance for example it has better chloride penetration resistance than steel.
e) it does not rust or corrode.
f) improved shrinkage properties over plain concrete.
g) it is inorganic and does not add to the fire loading of a structure.
h) good acoustic properties.
i) low permeability that increases water or air pollution resistance; and
j) it is environmentally friendly.

2.2 Some of the main limitations of GRC are:

a) it is more expensive than plain concrete.
b) GRC can lose some of its initial strength over long periods of time and this has to be taken into consideration during the design stage.
c) it is manufactured as precast rather than on-site which means that forward planning is required.
d) at present in the Hong Kong market only a couple of suppliers are available

Property	Unit	Hand or Machine Sprayed	Premix	Hand or Machine Sprayed	Premix
		28 days at 20 °C	28 days at 20 °C	150 days at 50°C	150 days at 50°C
Modulus of Rupture (MOR)	MPa	20-30	10-14	12-22	7-11
Limit of Proportionality (LOP)	MPa	7-11	5-8	6-10	4-7
Interlaminar Shear Strength	MPa	3-5	N/A	3-5	N/A
In-Planar Shear Strength	MPa	8-11	4-7	4-6	4 –5
Compressive Strength	MPa	50-80	40-60	50-80	40-60
Impact Strength	KJ/m^2	15-25	10-15	4-20	2-5
Elastic Modulus	GPa	15-25	13-22	18-30	15-25
Strain to failure	%	0.6-1.2	0.1-0.6	0.04 - 0.1	0.03-0.5
Dry Density	Kg/m^3	1900-2100	1800-2000	1900-2100	1800-2000

4 Materials

The essential materials that are used to produce GRC for the Hong Kong market are;

4.1 **Cement** – normally OPC which for H.K. usage complies to the specifications laid down in BS12 (either 1989 or 1996 versions).

The cement can be either white cement (normally imported from SE Asia or China) or grey cement (normally either imported from China or Japan or within Hong Kong)

4.2 **Clean Dry and Well Graded Sand or crushed rock** mainly sourced from China. The sand (or crushed rock) is normally of maximum size 1.2mm for sprayed mixes and 2.4mm for premixes and with not more than 10% passing the 150µm test sieve.

4.3 **Admixtures** - typically superplasticizers which locally comply to the requirements of BS5075 or BS EN 480 (from Hong Kong).

4.4 **Water** – local potable water is used as this generally complies with the requirements of BS3148.

4.5 **Glass Fibres AR grade** (from Japan, China or France) with zirconium content of at least 16%.

4.6 **Other materials** may also be present these Include;

4.6.1 Polymers to act either as curing compounds or durability enhancers, which normally comply to the manufacturers specifications. Typical polymers commercially available are acrylic dispersions with a solids level of approximately 50%.

4.6.2 Pigments complying to the requirements of BSEN 12878 normally at a dosage of up to 5% in replacement of OPC (level depends upon colour requirement).

4.6.3 Other types of cement e.g. Rapid Hardening cements / High Alumina, but these for the Hong Kong market are insignificant.

4.6.4 Pozzolans – including PFA, Silica Fume and Metakaolin used as partial replacements of cement.

Since the material that is the most significant variant from concrete is the fibre, the fibre properties are now discussed in more detail.

4.7 Fibre

4.7.1 Glass fibre is commercially available in many shapes and forms. It has proven essential that not only the correct size and shape but also the correct type be used for the appropriate application.

Glass fibre types readily available include;

- E Glass
- R Glass
- D Glass
- C Glass
- AR Glass

The only type of glass that has been found to be suitable for use in GRC is the **AR GLASS**.

4.7.2 Why Use Glass Fibre and why specifically is AR Grade chosen ?.

4.7.2.1 Firstly, *why use Glass Fibre* ?.

There are several major benefits from using glass fibre most of these were highlighted earlier some of the others are as follows;

- mechanical strength – Glass Filament has a higher specific resistance than steel, therefore the filament can be used to manufacture strand and hence develop good high quality composites.
- compatible with organic matrices which enables it to be combined with resins as well as cement minerals matrices.
- low thermal conductivity this makes it possible to minimize thermal bridging and hence make considerable heat savings.
- good abrasion resistance.
- due to its size and shape, it is possible to manufacture composites with thin sections that have good bending strength; and
- able to be Recycled

Other types of fibres commercially available are Polypropylene, "Hybrid" (co-polymer) fibres and Steel which all have advantages and disadvantages in comparison with glass fibre.

Polypropylene fibres are cheaper, more readily available and have quite similar properties to Glass Fibre i.e. they lessen plastic shrinkage cracking, and help with restraint of thermal expansion. Their main disadvantage is that they do not significantly increase the flexural strength of the composite, hence, they have limited applications.

"Hybrids" (co-polymers) are similar to polypropylene but however have the advantage that more fibres can be added to the composite without "balling up". Therefore they give slightly better strength properties than polypropylene but again greatly inferior to glass fibre. Typical use for these hybrid co-polymers overseas has been for underground tanks and manholes.

Carbon and aramid fibres generally give much improved strength properties over glass fibres but however are significantly more expensive and not as good forming properties as glass which are the main reasons they are not extensively used for the Hong Kong Market.

For Applications where they there is a bending moment, steel fibres or glass fibres are the most appropriate as they give the greatest bending properties. For high bending moments steel fibre should be used but of course the limitation is that they are not easily formed into many shapes.

Glass Fibre Properties	Filament	Strand
Density	2.68	g/cm^3
Tensile Strength	3.0 GPa	1.7 GPa
Elastic Modulus	70-80	GPa
Elongation at Break	4.3 %	2.4 %
Moisture Content	< 0.1 %	
Coefficient of linear expansion (20 to 100°C)	5×10^{-6}	m/m/°K
Flammability	Non-	Flammable
Softening Point	773 to 860	°C
Filament Diameter	14 to	20μm

4.7.2.2 Secondly, why AR Grade ?.

Basically the matrix that comprises cement mortar is essentially alkaline in nature. This occurs due to the presence of free lime that is also alkaline. Therefore, there is a necessity that the fibre must be alkaline resistant.

Several years ago the BRE in the UK found that by adding zirconium whilst melting sand into glass at temperatures above 1500°C gave a suitable AR glass. Unfortunately however, zirconium is only available in limited places (e.g. Australia) and is therefore quite expensive. It was also found that the melting stage was highly susceptible to contamination, hence furnaces used for this process are limited in their usage, this again results in a cost increase.

Overleaf in figures 1 and 2 are some photomicrographs taken by Cem-FIL Corporation that clearly show the build up of lime inside a GRC composite and hence why AR glass fibre are required.

It should be noted that the lime is initially in solution and when the water evaporates lime crystal deposits remain. When these crystals are formed they do block up some of the voids present around the fibres, this can result in the fibres being more rigid as there are no gaps to move into, hence a reduction in the long-term strength of the composite may be observed.

In recent years, some methods for preventing this build up of lime crystals have been put forward. These methods shall be discussed in later.

Different forms of Fibres commercially available for the Hong Kong Market and used in GRC.

Currently the Fibres in Hong Kong are either,

1. Continuous Strands or rovings
2. Strands or rovings which have been cut into smaller pieces
3. Mats or mesh (both seldom used)

Fig 1: Open space around filaments after curing conventional GRC

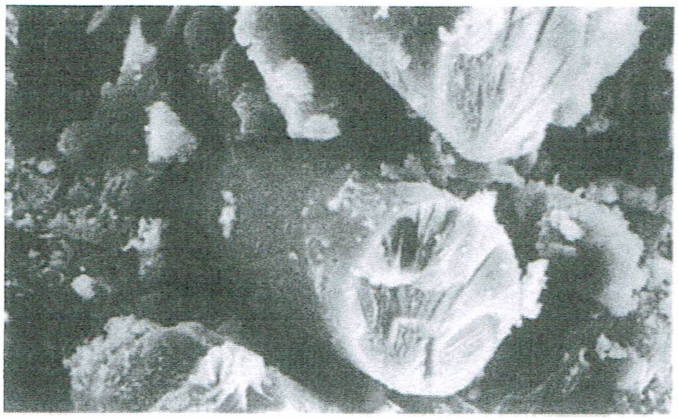
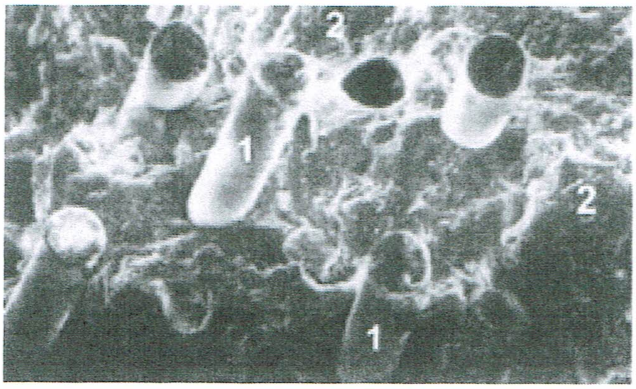


Fig 2: Dense lime deposits around filaments of conventional GRC after 1 year under water. 1- AR glass fibre 2- Lime crystals



Importance of Fibre Length and combination of fibre filaments into strands or rovings.

Fibres must not be too short – if they are it will lead to a significant reduction in strength and overall usefulness.

Fibres should not be individual filaments – individual filaments are nowhere near as strong as a several filaments combined. A good analogy comes from wool, a single filament of wool is not as strong as a strand of wool.

For certain applications fibres should not be too long, this may result in difficult management and forming properties. Hence strands or rovings maybe cut into smaller pieces.

For other applications chopped strands maybe made into mats, this is normally achieved by adding high molecular weight polymers at a level of approximately 10%.

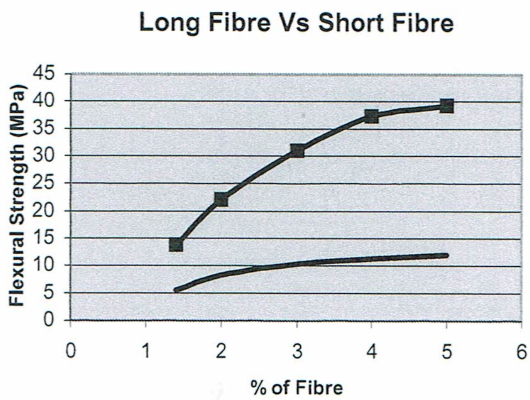
One of other important points to bring up, is that when fibres are incorporated into a composite, care has to be taken to ensure there properties are not diminished. A good example comes in the mixing process whereby if not properly handled they maybe cut into small pieces.

Content of Fibre within a composite.

Since Glass fibre is one of the major contributing factors to the cost of GRC, the content used within a composite has to be optimised. Hence the amount incorporated into a mixture is strictly controlled.

The strength increase of a composite when glass fibre is incorporated is illustrated in the graph below; it can be seen that when the fibre reaches a certain level the % increase in strength is optimised. Hence fibre contents are normally limited to the values previously stated (i.e. approximately 5%). It should also be noted from the graph that the strength of the longer fibre is significantly higher than the shorter one – an increase of around 250% is seen for the difference between a fibre strand approximately 1mm long and 3mm long.

Fig 3 Graph of Flexural strength variation with fibre length and fibre content.



5 MANUFACTURING OF GRC.

This section discusses the following; Moulds and Forms Used, Different Types of Mix (Face and Back Mix), Mixing/Spraying and Curing Processes, Fixings applied to GRC and the Finishing Process.

5.1 Moulds and Forms

The appearance of the finished product is directly related to the form material and the quality of the mould itself.

They can be made from various materials such as:

- steel,
- wood,
- plastic,
- rubber moulding compounds, (polyurethane or silicone)
- FRP(Fibre reinforced polyester resin) ; and
- GRC itself

For most applications the required stiffness, shape and surface finish can be achieved by a combination of materials. However for some complicated forms, moulds made of rubber, plastic, foam or other similar materials may be used.

It should be noted that the mould material should also be non-absorbent.

The mould design and its fabrication preferably should

- prevent any warping or buckling of the product. ; and
- ensure all corners have fillets, chamfers or rounded corners

In addition any mould release compounds used should be compatible with the mould material.

It should also be noted that generally moulds used for GRC are lighter than those used for precast concrete.

5.2 Typical Composition of GRC Products

Sprayed GRC

Material	Weight (kg)	(%)
Cement	100	42
Sand	100	42
Superplasticizer	1	0.4
Fibre	11	**5.0**
Water	32-34	13.5-14.5
Polymer (if req'd)	7-13	3-5

Premix GRC

Material	Weight (kg)	(%)
Cement	100	42
Sand	100	42
Superplasticizer	1	0.4
Fibre	4.5-8.0	**2.0-3.5**
Water	34-36	14.5-15.5
Polymer (optional)	7-13	3-5

5.3 Backing and Facing Mixes.

5.3.1 Difference between a Backing and facing Mix

A backing mix is where the GRC material is used as the backing material after a facing mix or veneer has been placed into the mould.

A facing mix is a GRC material that is either directly in contact with the mould or more commonly placed on top of a thin mist coat.

5.3.2 Mist Coats

A mist coat is a thin coat (thickness up to 5mm) of Cement/sand slurry, which is sprayed into the mould before the facing mix. It is similar in composition to the GRC except that it has no fibre.

The mist coat is exceedingly important as it "masks" the presence of fibres on the surface of the composite and enables a smooth product finish to be obtained.

5.4 Mixing and Curing Process

Stage1: Mortar mixing

Initially the cement, sand, water and plasticizer are mixed together using a mixer with a high shear action. A conventional concrete mixer sometimes is used but however mixing will take longer and the chance of damaging the fibre will increase.

Stage 2: Addition of Fibre

The fibres are added to the mortar mix immediately after the mixing is completed.

There are 3 different techniques that are used for addition of the fibre and these are dependent upon the production process being used, they are namely:

- premix, using pre-chopped fibre (normally approximately 10 to 35 mm)
- spray process using continuous rovings of fibre ; and
- hand lay up using a chopped strand mat or woven mesh

It should be noted that the hand lay technique is seldom used locally.

Premix
The pre-chopped strands are stirred into the mix at low speed, until they are dispersed with no dry bundles visible (normally 1 to 2 minutes is sufficient). The mix appears stiff but is easily cast, with vibration into moulds using a vibration table.

Spray
The continuous strand is fed into a chopping gun, this cuts the strand to approximately 25 to 40 mm. The chopped strand is simultaneously sprayed out with the cement mortar. The cement mortar is fed to the spray gun by pump, and is atomised by the spray gun using compressed air. The glass fibres and cement mortar are sprayed together onto a prepared mould where they are compacted in layers to produce the composite GRC using rollers. Normally several layers will be made and each layer will be approximately 3 to 6mm thick. Each layer will be compacted. The strands will be orientated in 2 dimensions. Spraying locally is applied by both manually spraying at a rate of around 10 to 12kg/min and by mechanical spraying at a rate of around 25 to 30 kg/minute.

Hand Lay-Up

The mortar mix is sprayed or painted onto the mould or form and the chopped strand mat or net placed on. The mortar is then forced through with the brush or a compaction roller. Excellent mechanical properties are achieved and no special equipment is needed.

Stage 3 Curing and Demoulding Process

The composites are either

a) left in the mould to harden and covered with damp hessian or polythene sheet to prevent moisture overnight. The next day they are demoulded. After demoulding the composite is cured under damp hessian or polythene sheet to prevent moisture loss for approximately 7 days.; or
b) If a polymer curing compound is used, they maybe exposed to the atmosphere preferably protected from direct sunlight and under cover for normally 1-2 days. The time duration and exposure conditions however should be referred to the curing compounds data sheet. N.B. Some curing compounds have been found to affect the fire resistance of GRC.

5.5 Fixing of anchors, inserts and embedment.

Wall panels, spandrels, column covers and other large units are generally connected to the structure through a metal frame consisting of either:

- light gauge metal studs,
- structural tubes,
- channels; or
- other metal item.

These fixings should achieve the necessary stiffness of the overall unit, inclusive of allowances for :

- demoulding,
- handling and transportation,
- erection; and
- loading after erection.

Smaller units can be connected by various fasteners designed to withstand the required forces. Examples include:

- cast in anchors,
- inserts,
- straps; and
- wires.

Sometimes (depending on application), small units can be attached with mortar, provided the mortar bond between GRC and the substrate is sufficient.

Connections to the building are basically the same as for other precast concrete products

5.6 Finishes

There are several different techniques to apply the finish to GRC products some of them used locally are stated below:

- smooth 'As Cast' surface,
- textured surface (using tools, acid etching or liners),
- retarded finish, using chemical retarding agents,
- abrasive blast finish,
- embedment finish.
- material finish,
- polished; and
- coated

The selected type of finish depends upon many factors, two important factors that are taken into consideration are:

- the presence and thickness of mist coat for facing mixes and the face mix composition for backing mix; and
- the exposure condition that the GRC will placed in. If the exposure condition is very severe, then of course GRC with strong acid etching or abrasive finishing will be inappropriate.

5.6.1 Smooth ' As Cast' Surface

This is where the GRC is placed against a mist coat in the mould to achieve "as cast" finish.

5.6.2 Textured Surface (using Light Sandblasting) to give 'natural stone' appearance.

This is where the concrete is placed in the same manner as 'smooth surface' with the exception that after about 7 to 28 days the product is given a gentle sandblast. A gentle sand blast removes the cement skin from the surface and results in a smooth sand-textured finish.

5.6.3 Textured Surface (using tools) to give 'broken ' appearance.

This is where the concrete is placed in the same manner as 'smooth surface' with the exception that after initial set the product is tooled. The tooling is either by machine or by hand tools (e.g. brushes with nails at the end). The tool removes the cement skin from the surface and results in a broken finish.

5.6.4 Textured Surface (using acid etching) to give 'shiny natural stone' appearance.

This is where the concrete is placed in the same manner as 'smooth surface' with the exception that after removal of the mould the product is inclined (to stop acid ponding) and washed with a dilute acid solution and subsequently hand scrubbed. The scrubbing removes the cement skin from the surface and results in a smooth sand-textured finish. After the scrubbing the surface is thoroughly washed with water to remove any residual acid.

5.6.5 Textured Surface (using forms) to give 'natural aesthetic' appearance.

This is where the concrete is placed in the same manner as 'smooth surface' with the exception that liners (made of bamboo, wood, rope or other material that is both compatible with the GRC and release agents and also temperature resistant up to at least 80°C) are placed onto the surface of the mould prior to casting. This will result in the surface of the product have a particular finish feature.

5.6.6 Retarded and sand blasted finish, using chemical retarding agents to give 'matt' appearance on the exposed aggregate.

This is where the concrete is placed in the same manner as 'smooth surface' with the exception that before casting a chemical retarder is painted onto the surface of the mould. After removal from the mould , the product is sand blasted to remove the retarder from the surface and this results in a product that has exposed aggregate.

5.6.7 Retarded and water washed finish, using chemical retarding agents (solvent or water based) to give 'shiny' appearance on the exposed aggregate.

This is where the concrete is placed in the same manner as 'smooth surface' with the exception that before casting a chemical retarder is painted onto the surface of the mould. After initial set (but before final set), the product is washed with high water pressure to remove the retarder from the surface and this results in a product that has exposed aggregate. It should however be noted that different retarders give varying finishes.

5.6.8 Abrasive or Sand blasted finish, to give appearance on the exposed aggregate to the required depth.

This is where the concrete is placed in the same manner as 'smooth surface' with the exception after final set up to 7 days after removal of the mould, the product is sand blasted to remove either the surface skin or cement matrix or fine aggregate from the surface and this results in a product that has the required degree of exposure.

The depth of the required abrasive or sandblasted finish will dictate the timing of the application of abrasion, the deeper the depth , the earlier the application.

5.6.9 Material Effects on Surface.

The constituent materials making up the concrete also have a significant effect on the surface finish. Surface finishes are regulated through the grading and colour of aggregates, colour of cements (white or different shades of grey) or through addition of pigments.

5.6.10 Embedment or Veneer Surface (using natural stone or brick or other material)

This is where the concrete is placed in the same manner as 'smooth surface' with the exception that embedment (natural stone, brick, tiles or other material) are placed onto the surface of the mould prior to casting. This results in the surface of the product having a natural finish. The embedment is not removed after casting.

It should however be noted, that the materials must be compatible with regards to shrinkage and expansion caused by thermal or moisture changes. Moreover, when using natural stones as the veneer a polythene sheet or foam pad is used and connection from the stone to the GRC is made via anchors that can accommodate the movement changes.

5.6.11 Polishing

Certain glass fibre products require polishing to get the required finish. Locally granite aggregates are highly polished by repeated grinding going from coarse to finer. Polishing compounds are normally used to aid the process and also during each grinding stage the surface air-voids observed are filled with a cement/sand mixture

5.6.12 Coatings

Coatings are occasionally applied to the surface of the GRC products. These coatings are normally applied to either protect against attack or for colour reasons. Typical coatings applied locally include polymer latex solutions and sealants.

6. Erection of GRC

The equipment and procedures used to erect GRC units are basically the same as for conventional precast concrete elements.

Some small, architectural pieces may not even need special equipment and many times can be installed by hand.

The lightweight nature of GRC means that it is easier to handle than plain precast concrete. The same care must however be taken with GRC as for plain panels to ensure that the units are not overstressed during handling, Otherwise cracking or other defects may occur.

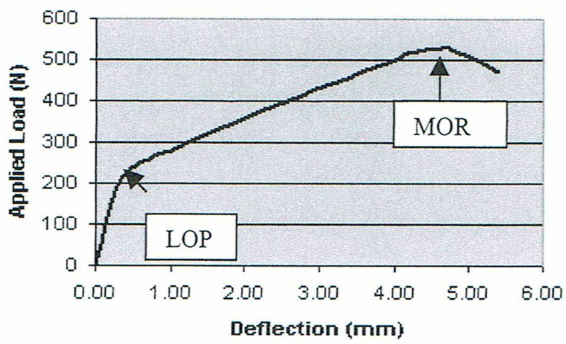
7. **Quality Control of GRC for the Hong Kong Market**.

Quality Control for the Hong Kong market basically consists of testing :

- the materials used
- the GRC production process; and
- the end product.

The materials being used are tested in accordance with the methods previously stated.
The tests performed during / after production are normally to the standards stated in BS6432:1984 and BSEN1170.

Fig 4 : Typical Load Deflection Curve of GRC.



Some examples of the tests being performed and the type of results obtained are as follows.

Slump Test. The principle of this test is similar to concrete slump, except that the sample is placed into a small cone on a table marked with circles. Once the cone is removed the diameter (circle number) is recorded.

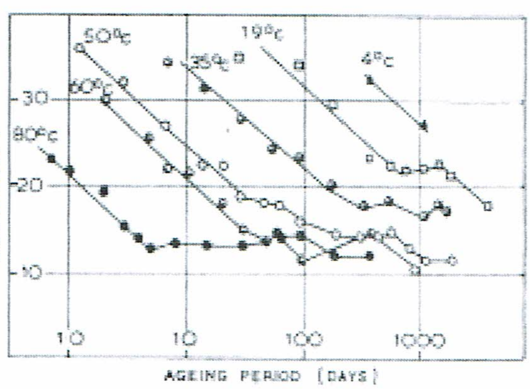
Glass Content. Samples are sprayed into pre-weighed baskets, weighed and washed. The resultant fibre content is calculated.

Flexural Tests. Samples are made from test panels that have been prepared with great care. Test samples 'coupons' are loaded in a UTM at 7 and 28 days of age. Examples of first Crack (LOP) and failure load (MOR) recorded can be seen from figure 4 below.

There have been other tests performed on GRC panels in Hong Kong and some of these include:

- water absorption and density,
- extreme dimensional variations according to water content,
- pull-out test for the cast in anchors,
- shear loading tests for the cast in anchors; and
- deflection measurement of panels under dead load.

Fig 5: Graph of MOR of GRC under different curing regimes.



8. Latest Developments in the search of improved durability for GRC

Some recent studies have been performed on GRC composites to see the effect of long term strength by accelerated ageing, an example was the work performed by K.L.Litherland et al at Pilkington in the UK(Ref 2) . They performed a series of tests under different conditions and the summary of their results can be nicely shown in the graph in figure 5.

Note that the bending strength does deteriorate from the initial stage but also observe how it stabilises over a period of time. It can also be observed that the strength is lower for the higher temperatures and that is basically consistent with the properties of concrete. Therefore bearing in mind these losses, designers can try to counteract this to ensure that the constant stress under the exposed weather conditions can be suitable.

There are currently several potential sources for increasing the long-term durability of GRC these include:

- use of additives such as metakaolin and other polymer materials,
- use of sulphoaluminate rapid-hardening cement and other additives,
- use of granulated blast furnace slag and a super low shrinkage admixture (NSR); and
- use of carbon-dioxide to promote super-critical carbonation.

Results obtained using metakaolin which is produced by superheating kaolin (a reasonable common mineral mainly used in the paper processing industry) at temperatures of around 700 to 800 °C has been promising.

Several papers have been published showing that metakaolin when used as a partial replacement of cement can be effective in increasing the long - term durability of GRC. Metakaolin achieves this by reacting with the free lime produced and thus there is little free lime available to form crystals (Ref3). Unfortunately however, metakaolin adds to the cost of the GRC unless it is locally available.

The use of sulphoaluminate rapid hardening cements and additives with at least a 5% reduction in the cement content has been found in the US to increase long term durability.

One of the problems with this system however is that the panels must be kept wet during the initial set process and polymer curing admixtures can not be used as they interfere with the curing of the cement.(Ref 4)

The use of NSR and granulated blast furnace slag has been found to also increase long-term durability and also has the added advantage of being compatible with polymer curing admixtures. The main drawback however is cost increase and availability of NSR is limited.(Ref 5)

The latest development is the use of carbon dioxide to promote a super-critical carbonation is at the moment still in the research stage. A paper has published with very promising results showing a substantial increase in the durability (Ref 6). The principal of this super-critical carbonation is basically that the carbonation process can be completed within several hours rather than several months or years thus mitigating the precipitation of lime crystals.

The main drawback at this stage, is that to do this, samples are currently placed in a pressure vessel at approximately 100bar and at a temperature of around 60^{0}C and to achieve this would be very costly from an production point of view. However, since research is still being carried out there is a great possibility that this problem maybe overcome in the near future.

9. Conclusion.

It can be clearly seen that GRC has many uses and applications within Hong Kong. Provided that all appropriate measures are taken in selection of materials, manufacture and fabrication, good high quality products maybe achieved.

One final word of caution is however in the durability whereby further studies are still required to find the most effective means for retention of strength.

References:

Cem-Fil Corporation – Study on alkalinity of GRC composites.

K.L.Litherland et al at Pilkington (UK)- The Use Of Accelerated Ageing Procedures To Predict The Long Term Strength Of GFRC Composites

Ambroise et Al - Metakaoline Blended Cements – 6th Biennial Congress of GRCA.:1987

Molloy , H.J. and Jones J. – Application and Production using Rapid Hardening Cement Composites -- 9th Biennial Congress of GRCA.:1993.

K.Iami et al. GFRC using super low contractile admixture. – ACI 549 Committee symposium.:1999

Short N. et Al – Super-Critical Carbonation of Cements – 5th International Symposium on Cement and Concrete 2002.