Specification for the manufacture, curing and testing of GRC products

Third edition

GRCA
GLASSFIBRE REINFORCED CONCRETE ASSOCIATION
INTERNATIONAL

CONCRETE SOCIETY

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SPECIFICATION FOR THE MANUFACTURE, CURING AND TESTING OF GRC PRODUCTS

CONTENTS

Forward

This Specification is designed to enable architects, engineers and specifiers to specify GRC. It covers all aspects of GRC production from raw materials, through production, curing and storage to quality assurance and testing. Grades of GRC covered are:

- General purpose cast premix GRC: Grades 8 and 8P
- Sprayed premix or high quality cast premix GRC: Grades 10 and 10P
- Normally sprayed GRC: Grades 18 and 18P

where 'P' refers to the use of acrylic polymer emulsion in the GRC mix design.

In consultation with a producer, the specifier should select the grade of GRC required. The specifier can then ensure that the product is manufactured and tested according to the specification.

The Specification is a material and manufacturing specification. An engineer should be consulted to ensure that the material grade selected is consistent with the engineering design of the product. This Specification supersedes all previous GRC specifications. It has been prepared by the GRCA Technical Committee.

In this Specification, the unit of force/area used is the Newton per square millimetre (N/mm^2) which is numerically equal to the Mega Pascal (MPa) and Mega Newton per square metre (MN/m^2).

1 Introduction

1.1 Scope

This specification covers the requirements for the manufacture, curing and testing of GRC products. It gives detailed requirements for grades of GRC manufactured by two different methods:

- '**Spray' Grades 18 and 18P**
- **'Premix' Grades 10 and 10P**
- **'Premix' Grade 8 and 8P**

'P' refers to the use of acrylic thermoplastic polymer emulsion in the GRC mix design. The specification covers mixes with and without polymers. Selection of the applicable grade should be made by the producer in consideration of the engineering design of the product. This choice should then be approved by the purchaser.

1.2 References

Standards and other publications referred to in this specification are listed in Appendix D.

1.3 Definitions

Uncured state
The stage in the manufacture of GRC when all 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.

Aggregate/cement ratio
The ratio of the mass of total dry aggregate to the mass of dry cement in the GRC.

Water/cement ratio
The ratio of the mass of total water to the mass of dry cement in the GRC in the uncured state. When pozzolanic fillers are used they can be considered as cementitious and the water/cement ratio can be expressed as a water/total binder ratio; examples of such pozzolanic fillers are fly ash, silica fume and metakaolin.

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.

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

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 may be a specimen of the product itself. It is more likely that a test board will 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 coupons
Specimens taken from a test board for the purpose of 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.

Test board mean
The arithmetic mean value for a property calculated from all the individual test coupon results from one test board. For statistical analysis, this mean is regarded as one result.

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.

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

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

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.

Dry curing
A method of curing which prevents early loss of moisture and allows curing to take place without keeping the GRC damp. Dry curing is carried out by adding an appropriate quantity of the polymer into the GRC mix. (See Section 4.5.)

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

'Bag' and 'bucket' tests
Methods for the calibration of GRC spray equipment.

Spray GRC
A method of manufacture in which GRC is produced by simultaneously spraying cementitious slurry and glass fibre which is chopped from roving within the spray gun.

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

Mist coat
An initial cementitious sprayed coating without glass fibre.

Facing coat
An initial layer without fibre but containing decorative
sands or aggregates and often pigment.

GRCA
The International Glassfibre Reinforced Concrete Association.

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.

Premix mixer
A two-stage or variable speed mixer designed to prepare fine sand/ cement slurries (stage 1) and to blend in chopped glass fibres (stage 2) in the premix process.

MFFT
Minimum film formation temperature (for acrylic polymers).

Limit of proportionality (LOP)
Also known as elastic limit. The stress in a flexural bending test where the stress/strain plot deviates from a straight line.

Modulus of rupture (MOR)
The highest stress on a stress/strain plot during a flexural bending test.

Top/bottom ratio
The ratio of the MOR results of samples tested with the mould face in tension to those with the trowelled face in tension.

2 Constituent materials

2.1 Alkali-resistant glass fibre

Glass fibre shall be an alkali-resistant continuous filament fibre developed and formulated to have high strength retention in hydraulic cement environments. The producer shall provide certification from the supplier to show that the glass fibre conforms to EN 15422:2008

2.2 Cement

Cement shall be supplied by a manufacturer of assessed capability, made to recognised standards and supported by suitable certification. Cement shall be correctly stored and kept dry to avoid deterioration.

2.3 Fine aggregates

Fine aggregate or sand shall be 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 shall be 1.2mm; for premix GRC, the maximum particle size shall be 2.4mm. In both cases the fine fraction, i.e. sand passing a 150 micron sieve, shall be less than 10% of the total weight of sand.

Silica sands are widely used and should conform to the specification in Table 1.

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.

Table 1: Specification for silica sand

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

2.4 Water

Water shall be clean and free from deleterious matter, see BS EN 1008, *Mixing water for concrete.*

2.5 Admixtures

Admixtures are permitted and their use is encouraged as they can enhance the properties of GRC. They should always be used strictly in accordance with the suppliers' recommendations and the producer must ensure that their use has no adverse effect on the product.

Calcium chloride-based admixtures must not be used if the GRC component contains steel reinforcement, fixing sockets or other cast-in devices.

2.6 Acrylic polymers

Acrylic thermoplastic polymer dispersions should be used in accordance with the manufacturers' instructions and should conform to the specification in Table 2.

Polymers with properties outside the above specification may be used with the agreement of the purchaser.

2.7 Pigments

Powder pigments or dispersions may be used to produce coloured GRC. The pigments should conform to international or national standards. The purchaser should recognise that colour variation may occur and must agree an acceptable range of variation with the producer.

Table 2: Specification for acrylic polymers.

Compound type	Aqueous thermoplastic polymer dispersion
Polymer type	Acrylic based
Solids	45–55%
Appearance	Milky white, creamy, free from lumps
Minimum film-formation temperature	7–12 °C
Ultraviolet resistance	Good
Alkali resistance	Good

2.8 Other component materials

Other component materials (e.g. silica fume, metakaolin, fly ash, reinforcing fillers), may be added to modify the properties of the mix. They must be used in accordance with the supplier's instruction and the producer must demonstrate that their use will not adversely affect the properties of the GRC.

3 Composition of GRC in the uncured state

3.1 Mix design

It is the responsibility of the producer to select a suitable mix design for the product. The mix design must be such that the mechanical properties of the GRC in Section 8 of this Specification are achieved and that these requirements are consistent with the engineering design of the product.

The mix designs in Table 3a, b and c are intended as a guide; designs falling outside these guidelines may be acceptable but should be scrutinised before use.

Table 3a: Guide mix designs – Grade 8

Premix Grade	Grade 8	Grade 8P
Description	General purpose premix	
Aggregate/cement ratio	0.5-1.50	0.5-1.50
Water/cement ratio	0.35 -0.40	0.35-0.40
Glassfibre content (% by weight of total mix)	2.0-3.0%	2.0-3.0%
Polymer solids content (% by weight of cement)	Nil	4-7%

Table 3b: Guide mix designs – Grade 10

Premix Grade	Grade 10	Grade 10P
Description	Sprayed premix or High quality cast premix	
Aggregate/cement ratio	0.5-1.50	0.5-1.50
Water/cement ratio	0.30-0.375	0.30-0.375
Glassfibre content (% by weight of total mix)	2.0-3.5%	2.0-3.5%
Polymer solids content (% by weight of cement)	Nil	4-7%

Table 3c: Guide mix designs – Grade 18

Spray Grade	Grade 18	Grade 18P
Description	Direct sprayed GRC	
Aggregate/cement ratio	0.5-1.0	0.5-1.0
Water/cement ratio	0.30-0.375	0.30-0.375
Glassfibre content (% by weight of total mix)	4.0-5.5%	4.0-5.50
Polymer solids content (% by weight of cement)	Nil	4-7%

4 Manufacture

GRC products manufactured by premix and spray production methods are covered in this Specification, but other manufacturing methods may be used providing agreement is reached between the producer and the purchaser regarding their use and control.

4.1 Manufacture by direct spray

4.1.1 Weighing/batching
Dry ingredients shall be batched by weight using calibrated weighing equipment capable of an accuracy of ± 2% of the stated batch weight. Liquids should be weighed, volume batched or automatically dispensed. The producer must demonstrate that the method employed will give an accuracy of ± 2%.

4.1.2 Mixing
The cementitious slurry should be mixed in a 'high shear mixer' in accordance with the manufacturer's instructions and using the stated mix design. The producer must demonstrate that this type of mixing system is to be used. The consistency of the mix should be tested by measuring the slump (see Appendix A) at the start of each shift and at agreed intervals during each shift.

4.1.3 Spraying
Spraying should be carried out using specialist equipment that allows the simultaneous deposition of known quantities of cementitious slurry and chopped glass fibre. Before starting production, the spray equipment must be calibrated to ensure that the specified glass fibre percentage is achieved. Calibration to measure the deposition rates of the glass fibre and cementitious slurry should be carried out using ‘bag and bucket tests’ in accordance with the methods in Appendices B and C.

These tests should be carried out at the beginning of each shift, after any alteration of the equipment controls and after any unsatisfactory ' wash out' test results (Section 7.1).

If the equipment used gives continuous readings of glass and slurry output these tests need not be carried out.

A mist coat without fibre may be sprayed; this coat should be as thin as practicable and should be followed immediately by the first GRC spray.

When a facing coat is used this may be sprayed or poured. This coat may be allowed to stiffen but the first GRC coat must be applied before initial set takes place.

The GRC materials must be sprayed and built up in thin layers of 3–4mm until the required thickness is achieved. The sprayed GRC should be compacted by a hand roller before spraying the next layer. After the final layer has been sprayed the thickness of the GRC must be checked using a template or depth gauge and compared to the design thickness.

Unless specifically stated in the agreed product manufacturing specification, the design thickness should be considered as a minimum and no part of the component should be below this thickness.

Over-thickness will be permitted and is to be expected particularly at corners or areas with a deep profile. It will not be permitted if:

1. Any flat areas exceed the design thickness by 4mm.
2. The weight of the component exceeds the maximum design weight as specified by the engineer.

After checking the thickness, any areas of under-thickness should be re-sprayed and areas of over-thickness removed and the material discarded. The specified finish to the ' back' of the unit should be applied using a float or roller.

4.2 Manufacture by premix casting

4.2.1 Weighing/batching
Dry ingredients should be batched by weight using calibrated weighing equipment capable of an accuracy of ± 2% of the stated batch weight. Liquids should be weighed, volume batched or automatically dispensed. The GRC manufacturer should demonstrate that the method employed will give an accuracy of ± 2%.

4.2.2 Mixing
The GRC should be mixed in a two-stage or variable speed premix mixer. The producer must demonstrate that the equipment is suitable for manufacturing premix GRC.

First the cementitious slurry should be mixed at high speed in an intensive shear mixer. The slurry is then transferred to a second mixer or the mixing action of the intensive shear mixer adapted so that the glass fibre is blended uniformly into the slurry.

The glass fibre may be added manually or automatically as chopped fibres or automatically as glass fibre roving using a fibre chopper.

4.2.3 Casting
The premixed GRC material should be pumped or carried in a holding vessel to the filling station. The material should then be poured or pumped into the mould ensuring that the method of filling expels the air from the product and planes of weakness are avoided. Compaction may be by internal or external vibration or by the use of a 'self-compacting' mix. The producer must ensure that the method chosen is consistent with the required surface finish and mechanical properties.

4.2.4 Sprayed Premix
The premixed GRC material may also be sprayed onto or into moulds using specialist sprayed premix equipment. A facing coat or a mist coat may be sprayed first. The GRC material should be sprayed in layers 4-6mm and compacted by roller before spraying the next layer. The thickness should be checked as in 4.1.3

4.3 Storage before demoulding

Filled moulds must be stored at temperatures between 5°C and 40°C. 'P' grades must be stored at a temperature higher than the MFFT but below 40°C.

Moulds must be stored on a level surface and supported in such a manner that they will not bow or twist.

Once the initial set has taken place the mould shall be covered with polythene of 500 gauge or above and should not be moved until demoulding.

4.4 Demoulding

The GRC component must not be demoulded until it has gained sufficient strength to be removed from the mould and transported without being over-stressed.

Demoulding must be carried out in such a manner that no damage occurs to the component. If a component is too large to be demoulded by hand special demoulding sockets or loops must be embedded in the component and demoulding should be done with a lifting frame.

Procedures to be used should be agreed with the engineer before starting production.

4.5 Curing

4.5.1 Moist curing (for non-polymer grades)
GRC components should be cured at controlled temperature and humidity. Ideally this should be for seven days at 20°C and 95% RH. This is not always practical and alternative curing regimes are satisfactory providing the producer demonstrates that the procedure:

1. Enables the component to achieve the physical properties given in Section 8.
2. Ensures that excess shrinkage caused by a too rapid drying of the product does not occur.
3. The curing method is acceptable to the purchaser and engineer.

4.5.2 Curing of polymer grades
Components produced using P grades of GRC should be dry cured after demoulding. Moist curing can be detrimental. Temperature above 35°C or below 5°C should be avoided for the first two days after manufacture.

4.6 Storage, handling and transport

GRC components must be stored, handled and transported in such a way that:

1. No part of the component is overstressed.
2. Bowing or twisting is not induced in the component.
3. No damage is caused to any part of the component, particularly edges and corners.
4. No permanent staining or discoloration is caused either by the storage conditions or the stacking/protection material.

For large components, the method of handling, storage, loading and transporting shall be agreed with the engineer.

5 Quality control and assurance

5.1 General

The manufacturer should demonstrate that an approved quality system is operated. This may be ISO 9001 or 9002, or similar. Reference should be made to EN 1169: 1999: *Precast concrete products: General rules for factory production of glass-fibre reinforced cement.*

6 Sampling

6.1 Sampling and sample boards

Tests may be carried out on coupons cut from the GRC components themselves. However this is not normally practical and it is standard practice to produce a sample board. This should be manufactured, demoulded and cured in the same manner as the component it represents. Its quality and thickness should be the same as the component, as far as possible.

Due to testing restraints the thickness should be limited to 12mm. Sample boards must be large enough for sufficient coupons to be cut to meet the testing requirements of this specification; 600 x 600mm is a commonly used size.

6.2 Frequency

The producer shall be responsible for sampling at a rate that will ensure compliance with this specification. This rate should be not less than 1 board per day per spray team initially to ensure compliance with the selected grade. Once a manufacturer has sufficient data (at least 40 results) and can demonstrate compliance then the frequency may be reduced, but it should not be less than one board per week.

7 Testing

The following tests are to be carried out and at 28 days and the required properties shall be as shown in Table 4. Earlier testing at 7 or 14 days is allowed provided the 28 day requirements are met.

Table 4: Minimum requirements at 28 days

Grade	8 or 8P	10 or 10P	18 or 18P
Minimum glass fibre content (% by weight)	As mix design	As mix design	As mix design
Characteristic LOP N/mm^2	6	7	7
Characteristic MOR N/mm2	8	10	18
MOR top/bottom ratio	0.8-1.25	0.8-1.25	0.8-1.25
Minimum bulk dry density kg/m^3	1800	1800	1800
Minimum bulk wet density kg/m^3	2000	2000	2000

7.1 Glassfibre content

The glassfibre content shall be determined in accordance with either BS EN 1170 Part 2 or *GRCA Method of testing glassfibre reinforced cement (GRC) material* Part 1. This test should be carried out on all Grade 18/18P sample boards

7.2 Limit of proportionality and modulus of rupture

The LOP and MOR shall be determined at 7 and/or 28 days in accordance with either EN 1170 Part 5 or *GRCA Methods of testing glassfibre reinforced cement (GRC) material* procedure A and B.

Additional information %Strain to LOP %Strain to MOR and Young's Modulus provided by modern test equipment should be recorded. This test should be carried out on all sample boards

7.3 Bulk density, water absorption and apparent porosity

These properties shall be determined in accordance with either BS EN 1170 Part 6 or *GRCA Methods of testing glassfibre reinforced cement (GRC) material*. These tests shall be carried out at least once per month

7.4 Other tests

Other tests of GRC may be carried out when required by the purchaser, including full-scale load tests of products and components, fire tests, etc. These tests should be supervised by the engineer.

8 Compliance

8.1 General

The constituent materials should comply with the requirements of Section 2 and the composition of the GRC shall comply with Section 3. The GRC should be produced and cured in accordance with Section 4.1 or 4.2. It should be sampled at a frequency complying with Section 6 and tested as Section 7. It should meet the requirements of Section 8.

8.2 Minimum values for compliance

Compliance is generally assumed to have been met if the strengths in Table 5 are attained at 28 days or before.

If other properties, e.g. density or porosity, are considered to be critical for an application compliance values should be agreed between the purchaser and the producer.

9 Non-compliance

9.1 Failure to comply

a. If any single test board fails to meet any of the compliance requirements, the GRC at risk shall be that produced between the previous complying test board and the next complying testboard. .

b. If failure to comply arises from consideration of consecutive groups of four boards the GRC at risk shall be that represented by the first and fourth test boards together with all intervening material.

9.2 Action in the event of non-compliance

The action to be taken over GRC products that do not comply with this specification should be agreed between the producer and the purchaser. In determining the action to be taken, due regard should be paid to the technical consequences of the kind and degree of non-compliance and to the economic consequences of adopting remedial measures or replacing the rejected products.

In estimating the quality of the sub-standard GRC and in determining the action to be taken, the following should be established wherever possible:

a. The validity of the testing shall be confirmed by checking that the sampling, testing and calculations have been carried out in accordance with this specification.

b. That the raw materials and mix proportions used in the GRC under investigation comply with both the specifications and/or with those agreed between purchaser and producer.

c. That the curing regime adopted before testing complies with the recommendations in this Specification. Re-testing of test boards may be appropriate when it is considered that the storage conditions of the product might result in improved properties because of extended curing.

d. The effect of any reduction in GRC properties on the strength and durability of the product.

   Two points should be considered:
   i. The safety factors adopted in the design.
   ii. The thickness of GRC produced compared to the design thickness.

Table 5: Minimum strengths

Grade numerically equivalent to the Characteristic MOR			
	8 or 8P	**10 or 10P**	**18 or 18P**
LOP N/mm^2			
Mean of 4 consecutive test samples	7.25	8.00	8.00
Minimum individual test sample	5.75	6.0	6.0
MOR N/mm^2			
Mean of 4 consecutive test samples	9.50	12.00	21.00
Minimum individual test sample	7.50	8.50	15.00

NOTE:
A more rigorous approach is to analyse overlapping groups of 40. The actual characteristic value for LOP or MOR can be calculated from the formula: *CHARACTERISTIC VALUE = AVERAGE VALUE – 1.64 x STANDARD DEVIATION.*

APPENDICES

A. SLUMP TEST

A1 Equipment

- A perspex plate scribed with concentric circles numbered 1 to 9, radii of: 65, 85, 105,125, 145, 165, 185, 205 and 225mm
- Metal tube of internal diameter 57mm and height 55mm

A2 Method

- Place the tube over the central ring of the plate.
- Fill the tube with slurry.
- Remove entrapped air by rodding and tapping the side of the tube.
- Screed the slurry level with the top of the tube.
- Lift the tube vertically away from the plate allowing the slurry to spread over the plate.
- Note the number of rings covered by the slurry.
- Record and compare to the required value.

B. BAG TEST

This test measures the delivery rate of a glass fibre chopper.

B1 Equipment

- Stop watch
- Balance capable of weighing at least 500 g accurate to ± 1g
- Plastic bag approximately 300 x 600mm

B2 Method

- Weigh the bag empty.
- Discharge glass fibre into the bag for 15 seconds.
- Weigh the filled bag.
- Subtract the weight of the empty bag.
- Multiply the weight of glass fibre by 4.
- Record as the glass output per minute.
- Compare with the required output.

C BUCKET TEST

This test measures the delivery rate of cementitious slurry.

C1 Equipment

- Stop watch
- Bucket
- Balance capable of weighing at least 10 kg accurate to ± 50 g

C2 Method

- Weigh the bucket empty.
- Spray slurry into the bucket for 30 seconds.
- Weigh the bucket and slurry.
- Subtract the weight of the empty bucket.
- Multiply the slurry weight by 2.
- Record as the slurry output per minute.
- Compare with the required output.

FURTHER READING

Standards

BS EN 1169: 1999: *Precast concrete products – General rules for factory production control of glass-fibre reinforced cement products.*
BS EN 1170: 1998: *Parts 1–8 Precast concrete products: Test methods for glass-fibre reinforced cement*

Part 1. Measuring the plasticity of the mortar – 'Slump test' method.
Part 2. Measuring the fibre content in fresh GRC, 'Wash out test'.
Part 3. Measuring the fibre content of sprayed GRC.
Part 4. Measuring bending strength – 'Simplified bending test' method.
Part 5. Measuring bending strength – 'Complete bending test' method.
Part 6. Determination of the absorption of water by immersion and determination the dry density
Part 7. Measurement of extremes of dimensional variations due to moisture content.
Part 8. Cyclic weathering type test

BS EN 14649:2005: *Precast concrete products – Test method for strength retention of glass fibres in cement and concrete (SIC TEST).*
BS EN 15422:2008 *Precast Concrete Products - Specification of glassfibres for reinforcement of mortars and concretes.*

Further standards are in preparation (2010) to cover
- *Classification of glassfibre reinforced concrete performance (future standard BS EN 15191)*
- *Design of GRC*

GRCA Publications

The Concrete Bookshop
Tel: 07004 607777 (UK only) or +44 (0)1276 607140
Email: enquiries@concretebookshop.com
Web: www.concretebookshop.com

Practical Design Guide for Glassfibre Reinforced Concrete, 2005.
Practical Fixing Guide for Glassfibre Reinforced Concrete parts 1 and 2, 2010
GRC in Action, full colour brochure 24 pages, 2006 (in revision).

In addition, the International GRCA holds a database of past GRCA Congress Proceedings and many other GRC related publications including some free downloads. Web: www.grca.co.uk.

Prestressed Concrete Institute (PCI) USA

Tel: +1 312 786 0300 Web: www.pci.org

Recommended Practice for Glass Fiber Reinforced Concrete Panels - Fourth Edition, 2001.
Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete Products, 1991.

National Precast Concrete Association of Australia (GRC Industry Group)

Tel: +61 (029890) 8853 Email: info@npcaa.com.au Web: www.npcaa.com.au

Design, Manufacture and Installation of Glass Reinforced Concrete (GRC), 1999 (in revision)