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European Standardisation of Glassfibre-reinforced Cement (or Concrete)

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Summary

The characteristics of finished products depend to a large extent on the procedures followed at the time of their manufacture. To help glassfibre-reinforced cement/concrete (GRC) manufacturers organise their quality assurance, the technical committee of CEN has produced a series of standards for which it is advisable to refer to define the key points of the production control and the corresponding testing methods.

The European Standards available to date are:

- EN 1169 (General rules for factory production control of glass fibres reinforced cement)
- EN 1170 Parts 1 to 8 (Test method for glass fibres reinforced cement)
- EN 14649 (Test method for strength retention of glass fibres in cement and concrete (SIC TEST))
- EN 15422 (Specification of glass fibres for reinforcement of mortars and concretes).

Under development:

- prEN 15191 (Classification of glass fibre reinforced concrete performances)
- Future standard (Design of the components in GRC).

Introduction

One of the objectives of the European Economic Community was the creation of an internal market similar to a national market; that is, in which the people, the services, the capital and the goods would circulate without obstacles. This flexibility of the market aims to:

- improve the productivity and competitiveness of the European industry, by facilitating economies and by reducing the expensive formalities in time, workers and currency;
- widen the range of choice for consumers;
- stimulate the competition between companies;
- facilitate innovation, by moving research teams closer to the point of research.

The barriers to free circulation are numerous and varied. However, they are generally categorised under three headings: physical, technical and fiscal. With regard to technical barriers it is a matter of various rules in the broad sense, which are effective in a state and which impose themselves upon the persons, upon the firms and upon the goods. It concerns legislation, rules, standards, controls, etc.

To raise the technical barrier, the CEN Committee TC 229 (precast concrete products) was in charge of elaborating European standards. Representative experts from various European countries and relevant organisations from both the industrial (e.g. APCCV, GRCA, FVF) and the scientific sectors (CERIB, CSTB, Polytechnic Faculty of Milan) participated in the elaboration of European Standards.

The first stage was to adopt a common language: a general standard (EN 1169) was produced concerning the definition of the vocabulary and the rules of production control. Then to establish a set of test method standards for overseeing the process of manufacturing (EN 1170 Parts 1, 2 and 3) and thus evaluation of the performance of GRC material (EN 1170 Parts 4, 5, 6, 7 and 8). It was completed by works on constituents: specification of glass fibres for reinforcement of mortars and concretes (EN 15422), and a standard on test method for strength retention of glass fibres in cement and concrete (SIC TEST) (EN 14649).

Under development

The next stage aims at establishing a standard of classification of GRC performance, based on a European test campaign. This draft was subjected to the advice of National members of CEN, the majority of whom approved that this draft should become a European Standard.

This European Standard (prEN 15191) deals with the classification of glass-fibre reinforced concrete. This classification conforms to the needs of the design process of GRC. This European Standard applies only if EN 1169 is followed. This standard does not include the design methods.

GRC performance

GRC using spray or premixing processes

Manufacturing technique		**Spray processes**	**Premix processes**	**Test method**
Dry density	kg/m^3	1900^{+300}_{-200}	1900^{+300}_{-200}	EN 1170 - 6
28 day bending strength LOP MOR Ultimate strain (ε) at MOR	 MPa MPa %	 8 ± 2 20 ± 5 0,8 ± 0,2	 7 ± 2 9 ± 3 ≥ 0,1	EN 1170 - 5
Strength after ageing (50 immersion/drying cycles): MOR Ultimate strain (ε) at MOR	 MPa %	 16 ± 4 ≥ 0,1	 8 ± 2 ≥ 0,05	 EN 1170 - 8 EN 1170 - 5
Water absorption at 24 hours	%	11 ± 3	11 ± 3	EN 1170 - 6
Shrinkage/swelling	mm/m	1,2 ± 0,3	1,2 ± 0,3	EN 1170 - 7
Modulus of elasticity at 28 days in the long term	MPa	 10000 to 20000 15000 to 25000		
NOTE: Tensile strength is typically 50 % of LOP in absence of any information.				

Table 1: Performance of GRC using spray processes and premix processes (above values are average values)

		Performance	Test method
Impact resistance Dead impact Sharp impact	joules	 > 1000 > 10	
Fatigue strength		Similar to concrete	
Abrasion resistance		Similar to concrete	EN 1338
Compressive strength	MPa	40 to 70	EN 196-1
Thermal expansion For dry GRC	µm/mK	10 Up to 20 in humid condition	
Thermal conductivity	W/mK	0,8 to 1	EN ISO 6946
Permeability to air and water		Equal or less than concrete	
Freeze-thaw resistance		Equal or greater that of concrete	Pr EN …..
Chemical resistance		Similar to concrete	EN 196
Fire resistance		Non-combustible – Euroclass A1	EN 13501 - 1
Sound attenuation For an 8 mm thick sheet	dbA	30	

Table 2: Additional characteristics

GRC with oriented fibres

Processes using oriented fibres may result in mechanical properties that differ from the above and depend on the:

- geometry of the product;
- direction of the oriented fibres;
- position and cross-section of the oriented fibres in the product.

In the case of oriented fibres, the position of the test pieces according with EN 1170-5 is defined by the orientation of the fibres. The classification is related to the direction of the fibre.

Classification of GRC

Classification according to mechanical properties

GRC is classified in accordance with EN 1170-5 with limit of proportionality (LOP) and modulus of rupture (MOR) values as its material specific properties.

Application-specific values

Depending on the application, the MOR value of GRC exposed to natural weathering may change in the long term. This fact is taken into account by the application factor k_2.

For each formula in use, the corresponding *k*MOR factor is determined by type-test in accordance with ENV 1170-8.

For GRC products exposed to natural weathering during their service life:

$$k_2 = \frac{\text{MOR long-term value}}{\text{MOR 28 days}} \qquad \text{with} \quad 1.0 \geq k_2 \geq \frac{\text{LOP}}{\text{MOR}}$$

For GRC products not exposed to natural weathering, there is no time-related change of MOR to be expected. For this application $k_2 = 1.0$.

Material classes

Classification parameters

The material class of GRC is defined on the basis of the following characteristic values:

- limit of proportionality (LOP);
- modulus of rupture (MOR).

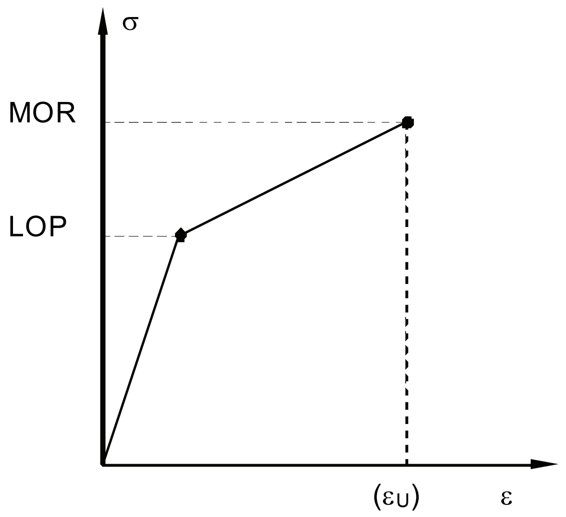

Figure 1: Stress–strain diagram

The general ranges of these characteristics values are as shown in Table 3.

LOP (MPa)	**MOR (MPa)**							
5	5	8	10					
6		8	10	12	14	16		
7			10	12	14	16	18	20
8				12	14	16	18	20

Table 3: Range of characteristic values for the classification of GRC

Specification of the parameters

The characteristic values correspond to the 5% fractile values with a probability of 75%. The values are related to tests performed on specimens at the age of 28 days.

The characteristic values (f_c) are defined by the producer; refer to the manufacturer's factory production control. According to statistics, the values refer to the formula: $f_c = f - ks$.

where s = standard deviation and f = arithmetic mean value.

Coefficient k is used for estimation of the fractile when the population standard deviation (s) is known (see Table 5 of ISO 12491:1997 with $\gamma = 0.75$ and $p = 0.95$; n = size of the samples). See Table 4.

n	3	4	5	6	10	30	50	100
k	2,0 3	1,9 9	1,95	1,92	1,86	1,77	1,74	1,71

Table 4

Examples of GRC denomination:

1 GRC 8/18 corresponding to LOP = 8 MPa and MOR = 18 MPa

2 GRC 7/10 corresponding to LOP = 7 MPa and MOR = 10 MPa

Application-specific parameter

With the application-specific parameter k_2 the conditions to which the GRC components will be exposed at the place of use are considered.

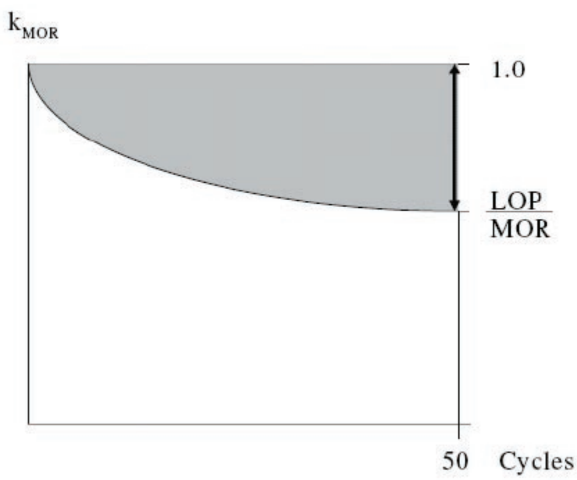

Figure 2: Value-range of k_2

Special properties

When further requirements are imposed on a glassfibre-reinforced concrete and/or a component made thereof, in addition to the materials and application-specific requirements, for example:

- resistance to fire;
- resistance to frost;
- impermeability to water;

then appropriate proof shall be given. This applies equally in the case of other special requirements.

Proof

The following is required:

- proof of the application class;
- proof of the application-specific coefficient γ_a shall be performed in accordance with ENV 1170-8 *Cyclic weathering type test*.

Requirements of glass fibre

The glass fibre test shall be performed in accordance with EN 15422 *Specification of glass fibres for reinforcement of mortars and concrete* and the test method for strength retention of glass fibres in cement and concrete (SIC TEST) is defined in EN 14649.

Future standard (Design of the components in GRC)

A working paper for a European design standard is actually in preparation. On the basis of this working paper it is planned to establish the standard.

Because the work on this standard is under progress, the presented design rules do not have the status of a standard but are an invitation to participate with contributions.

Design Code for GRC

1. The purpose of a European Design Standard for GRC

The standard defines the design rules for GRC corresponding to the design concept of the Eurocodes. The standard is based on the relevant characteristic values of the material according to Standards 1170-1 to 7, prEN 1170-8 and on prEN 15191 (*Classification of glass fibres reinforced concrete performances*).

The standard is not limited to specific production techniques and includes glass reinforcement in defined oriented directions. It covers the material-related design rules. Requirements that are not material-specific in general are defined in product standards.

2. The specific design – concept of the Eurocodes

Specific to the design concept of the Eurocodes is the design according to the ultimate limit state and the design according to the serviceability limit state.

The basis of the ultimate limit state is the resistance of the component or the system; with regard to the serviceability limit state it is the behaviour under service conditions. All design parameters for GRC have to be defined in accordance with this concept.

3. Adaptation of the design concept for GRC

For the adaptation of this design concept, the design parameters for the ultimate limit state are the characteristic values defining the resistance of GRC elements. For GRC elements exposed to bending this is the MOR value, while in many cases, currently the design rules are based on admissible stresses and often based on the LOP value.

The design concerning serviceability limit state does not differ from the present rules.

The actions on a building component are defined in:

- EN 1991: Actions;
- product-specific standards.

4. Ultimate limit state

4.1. Ultimate limit state design concept

The design concept with regard to the ultimate limit state is based on the resistance of the material. Safety factors relate to material-specific properties and actions. To consider conditions in use and time-dependent reduction, the GRC-specific factor *k* is introduced.

For design in terms of the ultimate limit state, the general formula is:

$$S_d \leq R_d$$

where: S_d is the design load $= \gamma_S\, S$

R_d is the characteristic resistance $= (k_1\, k_2) \times R\, /(\gamma_{tv}\, \gamma_c\, \gamma_m\, \gamma_b)$

where: S is the action resulting from external loads and secondary effects

R is resistance

γ_i is the safety factor for actions and resistance

k_i is the reduction factor.

4.2. Calculation of stresses

Actions on the GRC element result from external loads and as well from secondary effects (e.g. stresses due to temperature or moisture movements). The stresses are generally calculated on the basis of a linear elastic behaviour of the GRC.

4.3. Reduction factor k

- Reduction factor concerning climatic conditions in use

Products for use in water are permanently saturated. The reduced resistance under this condition is concerned by reduction factor k_1:

$k_1 = 1.0$ Products under natural weathering and inside use

$k_1 = 0.9$ Products under water (saturated material) (see values from *Practical Design Guideline GRCA*, 2004)

Values have to be based on test data.

- Reduction factor concerning time-related change of material properties

1. Products exposed to natural weathering

Products exposed to natural weathering undergo a change concerning MOR and ultimate strain. This change does not occur to the LOP value.

The corresponding characteristic reduction factor k_2 for MOR results from cyclic weathering type test prEN 1170-8:

$LOP/MOR < k_2 < 1.0$ (see figure 3)

2. Products not exposed to natural weathering

With regard to inside use, where products are not exposed to natural weathering, there is no change of material properties during service life.

$k_2 = 1.0$ For inside use

4.4. Partial safety factors for actions

For actions the partial safety factors are defined in EN 1991 and in the relevant product standards.

4.5. Resistance

For calculation of the resistance of a GRC element, the characteristic values for the material related to the type of stress have to be considered. In most cases, the significant stress for the design of GRC elements is stress due to bending. The significant value to define the bending resistance is the MOR.

Modulus of rupture: MOR = 28-day value according to EN 1170-5.

In the existing design rules (see values from *Practical Design Guide GRCA*, 2004) stresses due to tension and shear are defined in terms of function of the MOR.

Ultimate tensile stress: LOP = 0.5 MOR (Value = function of MOR)

Resistance to shear:

Resistance to compression: characteristic value based on prism testing.

(Note for prism testing reference to test standard is needed. Not confined to sprayed GRC, values depending on the orientation.)

4.6. Safety factors for resistance

The resistance on the design level R_d consists of the theoretical resistance R subject to reduction and partial safety factors.

Partial safety factors concerning resistance are:

- γ_{tv} production tolerances in dimensions (e.g. thickness);
- γ_c mode of collapse;
- γ_m material specific safety factor;
- γ_b difference between test coupon and product, if test coupon produced separately.

γ_{tv}	γ_c	γ_m	γ_b
1.05–1.2	In discussion	1.3	1.0–1.1

Table 5: Value range for partial safety factors for resistance

4.7. Fixings

For GRC-specific fixings, test data are needed and fixings have to be tested as a fixing system.

Figure 3: Gravity anchor

Figure 4: Inserts

5. Serviceability limit state

With regard to the serviceability limit state the design is based on the service loads.

5.1. Criteria of serviceability limit state

The criteria for serviceability limit state are:

- deformation
- risk of cracks
- product-specific properties

5.2. Limitation of deformation

Deformation under service loads is limited to product-specific values. For the calculation of deformation, effects due to humidity, temperature and creep have to be considered.

5.3. Safety against cracks

Under real dead load and 50% of live load the resulting stress should not exceed the LOP value reduced by a safety factor against cracking of the building. To take 50% of live load in consideration is a matter of contention.

$$\sigma_S \leq LOP/\gamma_{Rs}$$

where in general $\gamma_{Rs} = 1.2$ γ_{Rs} = safety factor concerning cracking of the building.

5.4. Fixation allowing stress-free movement

To avoid stresses due to secondary effects, components should be fixed allowing stress-free movements. This way movement does not create internal stresses.

In cases where stress-free movement is not possible, the stresses caused by these movements have to be considered in the design.

6. Product-specific requirements

Product-specific requirements may also be defined in the corresponding product standards. Usually in these standards the test methods are also defined.

7. Example with data of an inspection after ten years

In 1993 we produced cladding elements for the renovation of a building in Zürich. An inspection concept was part of the contract. The inspection after ten years was ordered by the owner (city of Zürich) and the data of this inspection are used for the following example.

Figure 5: Renovated building in Zürich

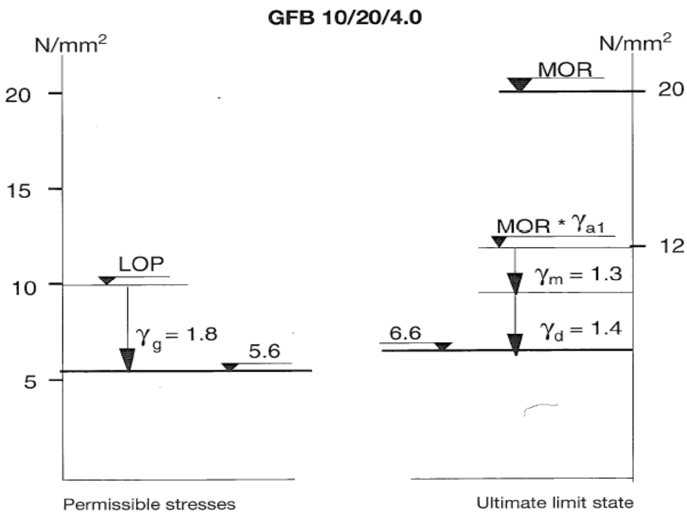

Figure 6: Admissible stresses and ultimate limit state design

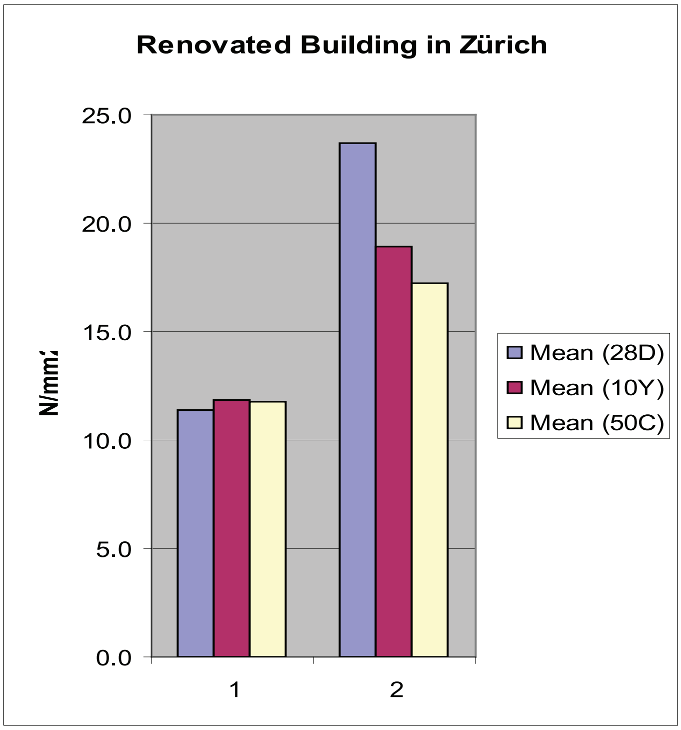

Figure 7: Data of quality control, inspection and cyclic weathering type test

The data show that the ultimate limit state design yields a reliable approximation of the real situation and also confirms the data of the cyclic weathering test.

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