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To cite this article: R Moceikis *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **251** 012028

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Workability of glass reinforced concrete (GRC) with granite and silica sand aggregates

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Abstract. Glass fiber reinforced concrete (GRC) opens the door for lightweight and complex shaped innovative construction, adding architectural value to buildings. With panel thickness down to 15mm, considerable amount of total loads and materials per square meter of facade can be saved, if compared to conventionally used 80 mm thickness outer layer in insulated precast concrete wall elements. Even though GRC is used for over 50 years in such countries as Great Britain, USA and Japan, there are very few examples and little research done in Eastern Europe with this building material. European Commission propagates sustainable design as commitment to energy efficiency, environmental stewardship and conservation. For this reason, GRC plays important role in moving toward these goals. In this paper, GRC premix recipes including fine granite and silica sands, reinforced with 13mm length alkali resistant glass fibers are investigated. Two CEM I 52,5R cements with different particle sizes were used and severe water dissociation noticed in one of concrete mixes. Cement particle size distribution determined with laser diffraction particle analyser Cilas 1090LD. To determine modulus of rupture (M.O.R.) and limit of proportionality (L.O.P), plates thickness 15 and 20 mm were produced and tested for flexural resistance according to 4-point bending scheme. Concrete workability tests were made according EN 1170-1.

1. Introduction

Architects and clients are ever more demanding in looking for something “different” and extraordinary. Possibility to make large scale, complex shape cladding panels from concrete are the key factors, making GRC an alluring material for facades. One of the best examples, a historical monument for GRC is The Credit Lyonnais Building, built in 1956, London. After 56 years (in 2012) the building was cleaned and GRC was found as good as the day it was erected. This building can be considered as inspiration for many engineers and architects for half a century not only for design, but also for all-round performance capability of the product. Since 1956 GRC industry has made significant steps forward, creating new GRC concrete formulations and production techniques, such as 3D moulding (ADAPA moulds, Denmark [1]) and 3D printing (WINSUN, China [2]). Design of complex shape GRC panels are well represented in recent projects, such as Nanjing Youth Olympic Conference Centre (China, [3]) and Masdar Institute of Technology (Abu Dhabi, [4]).

Glass fibre-reinforced concrete is a composite material that consists of cementitious matrix in which short glass fibers are dispersed. In this form, both fibers and concrete matrix retain their physical and chemical identities, yet resulting in a combination of properties that cannot be achieved by these



materials alone. In general, fibers are the key for flexural strength and the cementitious matrix acts as a load transfer medium between them.

First commercially applied fibers were introduced to the building industry in 1900's and were made from asbestos. After more than half a century of broad usage, asbestos was associated with health risks and fibers from new materials emerged. Examples of just a few of the fibre types are cellulose, carbon, Kevlar, polypropylene, polyolefin, polyvinyl alcohol, polyacrylnitril, ceramic, steel, glass, basalt, wood, etc. Although there has been (and still is) a tremendous thrust in research programmes to seek for more fibre alternatives, the fibre cement producers worldwide have used only a few of the fibre types researched for products produced for the market today. The reason for this is that choice of a particular fibre type is based on price, availability, compatibility with cement, durability and the reinforcing potential in the cement composite [5,6].

All above mentioned requirements for fiber- reinforced concrete are satisfied by alkali resistant glass fibers and this composite material is widely known as glass reinforced concrete or GRC which has a history in building industry for more than 50 years. GRC was first established in commercial form by Pilkington Bros. in 1956 and development work carried out by the Building Research Establishment in the UK. Since that time there has been a huge amount of research and development work carried out in the last 60 years and for that reason, GRC composite can be considered as a trustful building material for various applications [7].

As GRC is used mostly for flexural elements, bending characteristics such as limit of proportionality (L.O.P.) and modulus of rupture (M.O.R.) are the most important. It is very important to note, that glass fiber durability when placed in alkaline environment has been a main concern for many years [8-10]. AR fibers does not fully solve the issues and aged GRC have lower tensile strength and ductility than young GRC. Both reductions have been a major drawback when considering GRC as a material for load bearing structural elements. For these reasons, design values of L.O.P. and M.O.R. must be discounted for long term loss of strength.

There are three main areas, determining durability of GRC: the concrete matrix, fiber- concrete bond and the fibers themselves. The swelling and drying of porous concrete matrix can lead to large deformations or frost damage after considerable amount of freeze- thaw cycles. As for GRC production up to 3 times more cement is used when compared to typical concrete, it is much more favorable to alkali aggregate reaction (AAR). Some new test show, that the microstructure of the interface between matrix and fibers and densification of the matrix (e.g. due to calcium hydroxide precipitation) within and around the glass fiber strands has significant impact on GRC durability [11]. Last and probably most important factor for ageing of GRC is the corrosion of fibers in high alkaline cement matrix. For this reason only alkali resistant (AR) glass fibers with more than 13% ZrO_2 should be used [12].

One of the most common GRC production techniques is premix method, when mortar and precut fibers are previously mixed. The quantity of fibers added to the mortar is usually up to 3.5%, in terms of weight, and the length of the fibers is around 12 mm (longer fibers lead to an excessive reduction of the mix workability) [13]. Tests for workability and flexural capacity can be done according to European Standard EN 1170. Four- point bending scheme is used for bending tests and according to previous reports, 10 MPa flexural resistance is achieved without big complication [14]. Workability is determined by slump test, using a small cylinder, with diameter 57 mm and height 55mm.

Fine silica sand is the most frequently used filler in GRC for its good durability, workability and mechanical characteristics. Main disadvantages of silica sand in Lithuania is its higher price and low accessibility. For this reason, GRC premix with fine granite filler was investigated and results compared to silica sand further in this paper. Some researchers compared GRC flexural resistance using two cements- CEM II 32,5 and CEM I 52,5R. Conclusion was made, that due to higher early and matured strength, CEM I 52,5R should be preferred for GRC [15]. In Lithuania several manufacturers of CEM I 52,5R are offering their products with S.S.A. (Specific Surface Area, Blaine method) ranging from 520 to 590 m^2/kg . S.S.A. affects many characteristics of cement and one of the most important is workability. For this reason, two different CEM I 52,5R cements were used in this research.

2. Methods for investigation

Further on, four GRC mixes including fine granite and silica sand, reinforced with 13 mm length alkali resistant glass fibers are investigated. Two CEM I 52,5 R cements from different manufacturers are used and slump test results compared. Severe water separation found in some of the recipes and volume of separated water was measured. 15 and 20 mm thickness 28-day matured concrete coupons were tested for flexural capacity. Other general characteristics of concrete, such as early and matured compressive strength, density and entrained air are also presented.

2.1. Mix design and materials

GRC mixes were designed according to absolute volume method and composition is described in table 1. Ordinary Portland Cements (CEM I 52,5 R) are identified as OPC1, and OPC2. Compressive strength after 28 days is 63MPa for both OPC1 and OPC2.

Recipes with granite filler 0/2 are described as BGM and recipes with silica sand 0/1,25 (BSM) are made mixing together two fractions of silica sand (0/0,8 and 0,8/1,25). Alkali resistant glass fibers with 17,2% ZrO₂ content and 13,3mm length bundled 18,3 μ m filament diameter are used. In order to compare workability of concrete, quantities of all components except water are not changed. Water quantity is increased by three steps: W/C=0,40; W/C=0,42; W/C=0,44.

Table 1. Four mix compositions with different filler, cement and water- cement (W/C) ratio.

Recipe ID	Cement (C)	Aggregate (F)	Glass Fibers (GF)	Plasticizer (P)	C:F	GF, %	W/C	P, %
BGM1	OPC1	0/2 Granite	AR-13,3mm-17%Zr	Glenium ACE430	1: 1,37	2,2%	0,4...0,44	1%
BGM2	OPC2	0/2 Granite	AR-13,3mm-17%Zr	Glenium ACE430	1: 1,37	2,2%	0,4...0,44	1%
BSM1	OPC1	0/1,25 Silica	AR-13,3mm-17%Zr	Glenium ACE430	1: 1,37	2,2%	0,4...0,44	1%
BSM2	OPC2	0/1,25 Silica	AR-13,3mm-17%Zr	Glenium ACE430	1: 1,37	2,2%	0,4...0,44	1%

Commercially available polycarboxylate ether-based superplasticizer (*BASF* Master Glenium ACE430) is used. Raw material for granite filler is imported from Ukraine (*Selice* quarry) and crumbled into different fractions in Lithuania by company *UAB GRANITAS*. Silica sand is from local Lithuanian quarries (*AB Anyksciu Kvarcas*). Granulometric composition of aggregates are presented in figure 1.

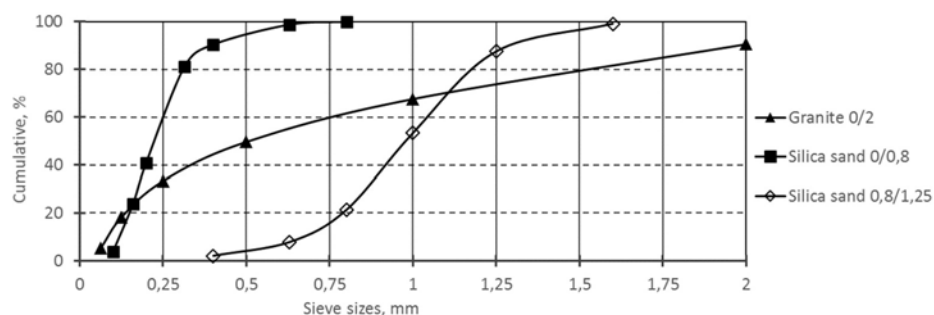


Figure 1. Granulometric compositions of used aggregates.

2.2. Test methods, specimen preparation

For identification of concrete workability, slump test according to EN 1170-1 [16] was chosen. Concrete sample is placed into steel tube Ø57 mm and h=55 mm, which is lifted after 30 s and spread circle measured.

Concrete water dissociation is measured with a 2,65l cylinder (Ø150, h=150mm). Concrete mix is placed into the cylinder for 2 hours and after this time has passed, water is pumped from the surface with a pipette and weighted.

Flexural capacity tested by 4-point bending scheme with a machine *Walterbay LMF 100*. Test coupons 120x300xh mm (h=15 and 20 mm) were used. Test scheme is showed in Figure 2.

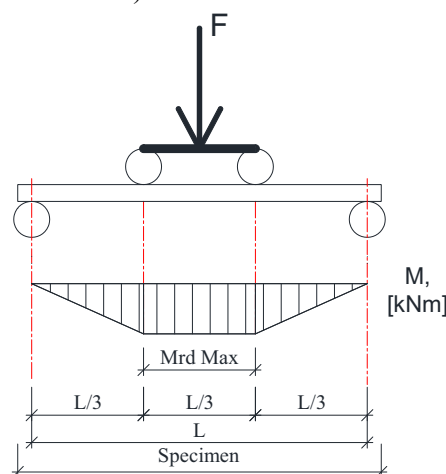


Figure 2. Flexural capacity bending scheme.

Concrete cubes 100x100 were made and tested for compression after 1 and 28 days. Entrained air is measured with *Testing* air entrainment meter for concrete.

Particle size distribution of two CEM I 52,5 R cements (OPC1 and OPC2) was tested with laser analyzer *CILAS 1090*.

3. Results and discussion

3.1. Cement particle distribution

Laser analysis (table 2 and figure 3) showed difference of particle size distribution between OPC1 and OPC2. OPC2 is finer, with bigger specific surface area. According to data, presented by manufacturers, S.S.A. (Specific Surface Area, Blaine method) is 520 m²/kg for OPC1 and 590 m²/kg for OPC2.

Table 2. Cement laser analysis results (CILAS 1090).

Cement	Diameter at 10%	Diameter at 50%	Diameter at 90%	Mean diameter	Density
OPC1	0,79 µm	7,69 µm	36,36 µm	13,51 µm	3,20 g/cm ³
OPC2	0,65 µm	5,04 µm	23,46 µm	9,29 µm	3,11 g/cm ³

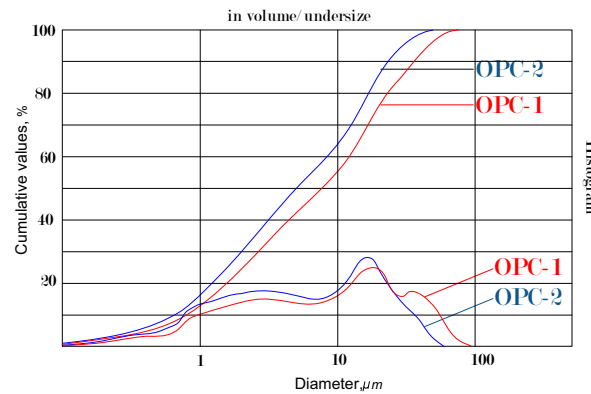


Figure 3. Cement particle size distribution (CILAS 1090).

3.2. Concrete workability

Slump test results are presented in figures 4-7. OPC 1 cement showed very poor workability, both for silica sand and fine granite. Severe water dissociation noticed in all W/C variations. OPC 2 and fine granite did not show any better slump characteristics, even though water dissociation was found to be smaller. OPC 2 and silica sand were the best combination, showing no water dissociation and good workability.

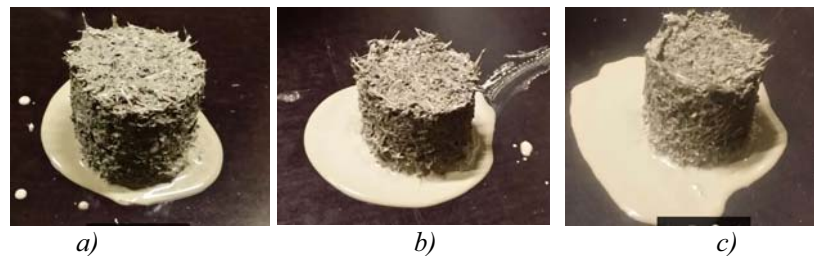


Figure 4. Slump test for BGM1 with OPC1:
a) $W/C=0,40$, b) $W/C=0,42$, c) $W/C=0,44$.

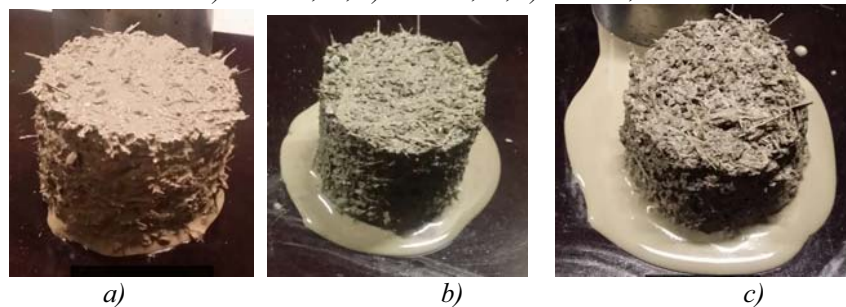


Figure 5. Slump test for BGM2 with OPC2:
a) $W/C=0,40$, b) $W/C=0,42$, c) $W/C=0,44$.

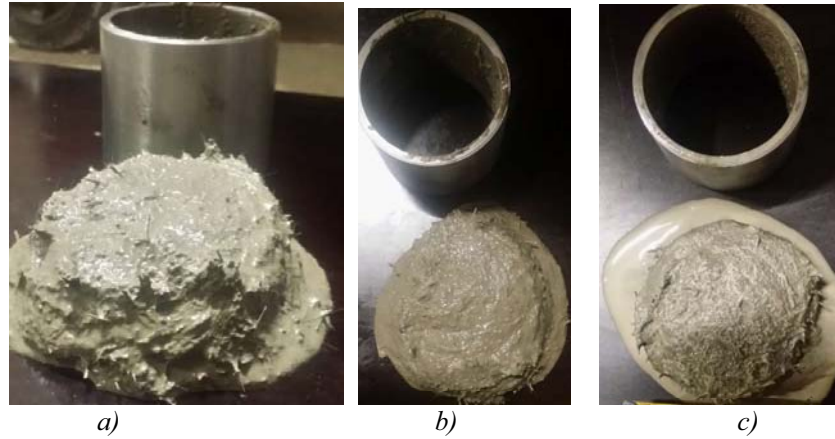


Figure 6. Slump test for BSM1 with OPC1:
a) $W/C=0,40$, b) $W/C=0,42$, c) $W/C=0,44$.

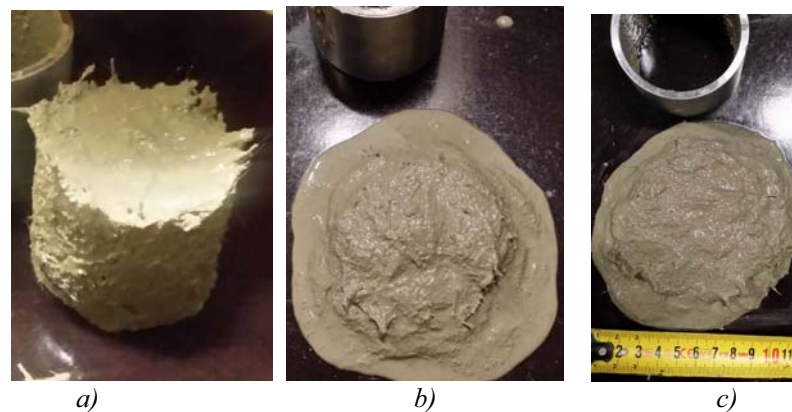


Figure 7. Slump test for BSM2 with OPC2:
a) $W/C=0,40$, b) $W/C=0,42$, c) $W/C=0,44$.

3.3. Water dissociation

For recipes BGM1 and BSM1 with $W/C=0,44$ and OPC1 water dissociation (concrete bleeding) was measured and results are presented in table 3. For recipe with granite and OPC1 cement, up to 18% of total water in concrete mix dissociated on the surface, and 36% for silica sand, respectively.

Table 3. Water dissociation measurements.

Recipe	W/C	Water dissociation, g	Part from total ^a
BGM1	0,44	156	18%
BSM1	0,44	307	36%

^a Calculated from total water content in recipe

3.4. Flexural capacity

For recipes BGM2 and BSM2 with $W/C=0,44$ and OPC2 test coupons with thickness 15 and 20 mm were produced and flexural capacity was measured after 28- day maturing in laboratory environment (+20°C, 60% rel. humidity). Test results are represented in reliance of MPa to specimen deflection in

mm and presented in figures 8-9. Generally, specimens with silica sand showed up to 20% higher flexural capacity, compared to fine granite.

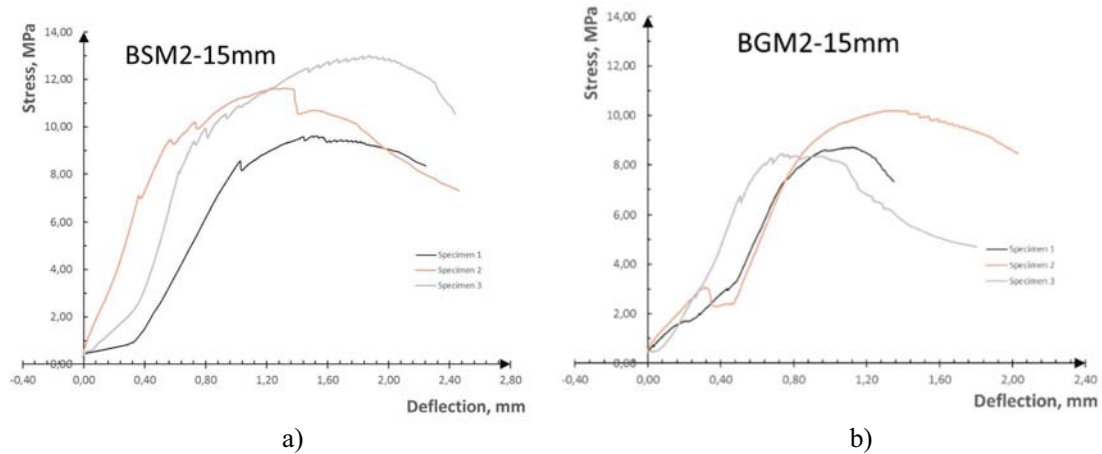


Figure 8. Bending curves for 15mm thickness specimens:
a) BSM2 with OPC2, b) BGM2 with OPC2.

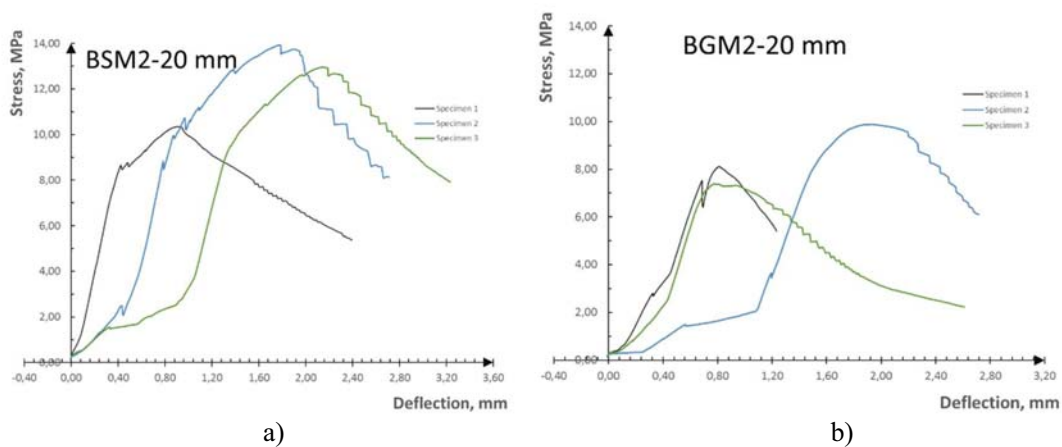


Figure 9. Bending curves for 20mm thickness specimens:
a) BSM2 with OPC2, b) BGM2 with OPC2.

3.5. Other characteristics

Other main concrete characteristics (compressive strength, density and air content) were also measured and presented in table 4. Recipes with silica sand tend to higher early and compressive strength after 28 days. Difference is up to 20%.

Table 4. Other main characteristics of concrete with OPC2 Cement.

Recipe	Compressive strength		Density (28 days)	Air content
	24hours	28days		
BGM2	23 MPa	45 MPa	2197 kg/m ³	2 %
BSM2	27 MPa	54 MPa	2176 kg/m ³	3.8 %

3.6. Discussion

Experimental results proved that granite filler is not suitable for premix GRC with CEM I 52,5 class cement due to severe water dissociation and very poor workability. This can be explained by the flat form of granite particles, which results to heavier friction in the cement matrix. Additional tests with quantity of superplasticiser did not give positive results and authors came to conclusion, that additional fine pozzolanic additives should be incorporated when granite is used as a filler for GRC.

4. Conclusions

Laser analysis showed different particle size distributions for two CEM I 52,5R class cements used for GRC concrete with granite and silica sand fillers. Cement OPC2 with specific surface area of 590 m²/kg showed significantly better workability than the one with 520 m²/kg (OPC1).

Granite 0/2 and silica sand 0/1,25 fine fillers we compared incorporating OPC1 and OPC2 cements. All recipes with granite filler showed poor workability and water dissociation. On the other hand, silica sand showed good workability and no water dissociation when used with finer OPC2 cement.

Flexure tests for coupons with silica sand filler showed better results sand than granite, L.O.P. equal to 8-9 MPa and 6-7MPa, respectively.

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