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Research Article

GLASS FIBRE REINFORCED PRECAST CONCRETE CONTAINING HIGH CONTENT POZZOLANIC MATERIALS

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ABSTRACT

Glass fiber reinforced concrete (GFRC) is a composite construction material widely used as a precast exterior element in the construction industry. GFRC is generally composed of mixture of cement, sand, water and glass fiber. Cement production causes high energy consumption and CO_2 emissions, which has negative impacts on the environment. Therefore, in this study, the effect of using high amount of fly ash and blast furnace slag from industrial waste materials instead of cement is investigated. The cement was replaced by fly ash and blast furnace slag in different ratios and the fresh, physical and mechanical properties of 6 different GFRC mixes were investigated. In addition, SEM micrographs were taken after the bending test to analyze the microstructure of GFRC. Test results showed that the workability of mixtures was modified by pozzolan addition. Fly ash improved the workability of GFRC matrix, however synergistic effect of fly ash and slag tend to insignificantly affect the workability. The water absorption of mixtures was found as 11±3% and the densities varied between 1910 and 2000 kg/m^3. Substitution of cement with fly and slag reduced the early age flexural strength of the mixtures, the increase in fiber content resulted in improved flexural strength and the highest strength was observed in C100F0S0G4 mix as 12.2 MPa.
Keywords: Glass fiber reinforced concrete, fly ash, slag, sustainability, microstructure.

1. INTRODUCTION

Glass fiber reinforced concrete (GFRC) is a material composed of cement based matrix and glass fiber reinforcements dispersed in this matrix. Glass fiber and cement based matrix preserves their physical and chemical properties and different physical and mechanical properties are obtained by combining these materials [1,2]. The characteristics of GFRC depend on different variables such as production, mixing ratio, type, length and orientation of glass fiber and additives used. In general terms, fibers play a role in improving the bending strength, while cement based matrix provides the load transfer between the fibers [1]. The standard GFRC mixture consists of sand, cement, water, and glass fibers. Chemical additives, acrylic polymers and other mineral admixtures are used to modify the properties and increase durability of GFRC. GFRC combines the high compressive strength of the cement based matrix with the bending and tensile strength imparted by the fibers. GFRC is usually produced in thin thicknesses in the range of 10-20 mm.

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Due to its low weight compared to traditional concrete, it provides convenience in transportation, storage and inst allation.

GFRC was first used by Pilkington Bros in England in 1956 as a building material, but E-Type glass fibers used in that period failed to yield successful results due to chemical corrosion in the cement matrix [1,2]. Glass fibers generally became fragile over time due to the alkalinity of the cement mortar. For this reason, alkali resistant (AR) glass fiber was developed in 1977 [3]. AR glass fiber is used as micro reinforcement in concrete-like composites due to its stability in high alkaline environments [4]. The main purpose of using AR glass fibers is to improve the mechanical properties of the matrix, such as tensile and flexural strength. The use of glass fiber contributes to the tensile strength of the matrix and provides a controlled development of cracks. Thus, by improving the toughness of the material, it allows the failure to occur with first fiber pull-out instead of fracture [4]. The durability of GFRC decreases over time when exposed to weather conditions, even the stability of the fibers is affected [5].

The main binding material used in concrete structures is Portland cement. It is also used intensively as binder in GFRC. Cement production causes high energy consumption and CO_2 emission, which has negative impacts on the environment. For this reason, many studies have been carried out to reduce the use of cement without increasing the cost. One of these methods is the substitution of cement with environmentally friendly pozzolanic materials in certain proportions. The proper use of pozzolanic materials improves the concrete properties especially at later ages. Calcium silicate hydrate (CSH) gel is produced by the reaction of pozzolans with calcium hydroxide (CH) which occurs due to the hydration of cement [5,6]. Most importantly, pozzolans improve the durability properties, workability and reduces the hydration temperature of the cement based materials [4].

Generally, the GFRC is manufactured by two different techniques for different uses, including spray and premix methods [3,7]. Both grades of GFRC require different physical and mechanical properties. Compared to the premix class, high-fiber sprayed GFRC provides higher tensile strength and shows a more ductile behavior. In the spraying technique, the mortar is produced in a separate place without the addition of glass fiber. The glass filament is cut within the spray gun and then sprayed into the mold with the mortar to manufacture GFRC panels with desired geometry.

The aim of this study is to determine the effect of fly ash and blast furnace slag on the workability and the physical and mechanical properties of GFRC. Therefore, Portland cement was replaced with combinations of fly ash and blast furnace slag at a fixed content of 50% by weight.

2. EXPERIMENTAL PROGRAM

2.1. Materials and Mix Design

The materials used to manufacture GFRC panels are white Portland cement (CEM I 52.5R), fly ash, blast furnace slag, sand and superplasticizer. Chemical composition and physical properties of binders are presented in Table 1. The mean particle size of cement, fly ash, slag and sand were determined as 15.45 μm, 23.19μm, 10.43μm and 561 μm respectively, and the particle size distribution of the solid materials are shown in Fig. 1. Density, tensile strength, young's modulus and strain to failure of glass fibre is 2800 kg/m^3, 1500 N/mm^2, 74000 N/mm^2 and 2% respectively. In the experimental study 6 mixtures were produced and the mix design is shown in Table 2. The water to binder ratio was set constant as 0.34 and the sand to binder ratio by weight is fixed as 1.0 in all mixes. Melamine based superplasticizer was used at varying proportions to achieve a desired workability. The glass fiber content was set as 3% and 4% and in some mixes the cement was replaced with varying combinations of fly ash and slag by 50% by weight. Sample panels with a nominal thickness of 20mm were manufactured for each mix by spraying method. The mixes are coded according to the composition of the GFRC (Table 2), where the number following the "C" letter represents the percent mass of cement in the binder, the number following the "F" and "S" letters indicates the percent mass of the fly ash and slag in the binder. "G3" and "G4" represents the percent mass of glass fiber in the mix.

Table 1. Chemical composition and physical properties of binders

Oxide % by mass	Cement	Fly ash	Blast Furnace Slag
SiO_2	21.6	52.6	40.6
Fe_2O_3	0.3	5.8	1.2
Al_2O_3	4.1	25.0	12.6
CaO	65.7	3.3	35.1
MgO	1.3	2.1	5.8
SO_3	3.3	1.0	0.1
Na_2O	0.3	0.3	0.8
K_2O	0.3	4.1	0.7
Specific Weight, g/cm^3	3.06	2.21	2.91
Specific Surface Area, cm^2/g	4600	4860	4976

Table 2. Mix proportions

	Sample ID					
Material	C100F0S0G3	C50F50S0G3	C50F25S25G3	C100F0S0G4	C50F50S0G4	C50F25S25G3
Cement	1.0	0.5	0.5	1.0	0.5	0.5
Fly Ash	-	0.5	0.25	-	0.5	0.25
Blast Furnace Slag	-	-	0.25	-	-	0.25
Sand/binder ratio	1.0	1.0	1.0	1.0	1.0	1.0
Superplasticizer/binder ratio	0.0154	0.007	0.0121	0.0154	0.007	0.0121
Water/cement ratio	0.34	0.34	0.34	0.34	0.34	0.34
Glass Fiber ratio (%)	3	3	3	4	4	4

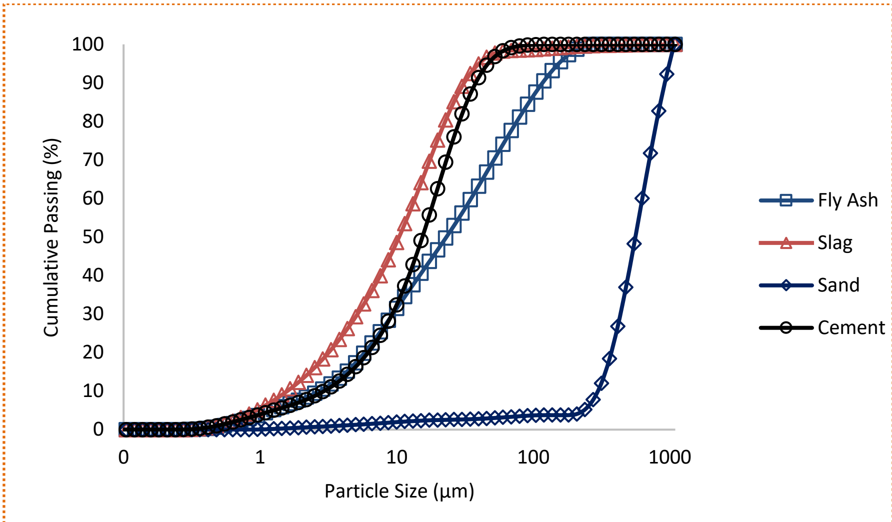

Figure 1. Particle size distribution of solid materials

2.2. Casting and Curing

The manufacture of GFRC panels was performed in collaboration with 3H Precast company. Fresh cementitious matrix was sprayed with glass fiber in the molds with dimensions of 500x1000x20 mm. The panels are demolded 24h after casting and stored in laboratory conditions at 20±2 ºC and 60±10% relative humidity for 6 days. The samples are then cut out in two different orientations as shown in Fig. 2 as a standard procedure. Before mechanical tests, the samples are immersed in water for 24h so that they have been aged for seven days at the time of the tests.

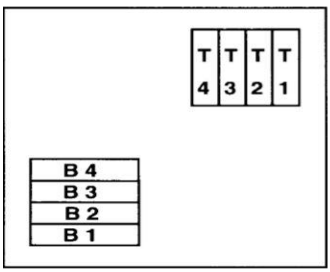

Figure 2. Position and identification of the test pieces

2.3. Testing Procedure

2.3.2. Workability

Workability of freshly mixed slurry (with no fibers) should comply with the selected processing method. Generally, high workability makes production and compaction easier. However, the strength of GFRC must not compromise or produce unacceptable bleeding to achieve high workability. Therefore use of superplasticizers appropriate for GFRC mixtures to increase workability without a reduction in strength is generally helpful. The workability is measured before addition of the glass fiber in accordance with EN 1170-1 [8]. This test demonstrate the workability and the uniformity of the freshly produced GFRC mixtures. For this purpose a cylindrical mold with 57 mm inner diameter is placed in the center of a plate. The cylindrical mold is filled with the required amount of fresh mixture and raised vertically. The span diameter is measured after the mixture has stopped spreading as seen in the Fig. 3 to determine the slump (spread) value of mixtures.

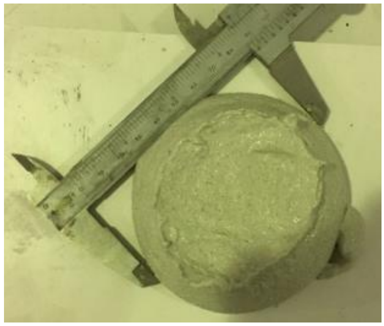

Figure 3. Slump test

2.3.3. Dimensional variations

Dimensional changes during the service of GFRC material is of primary importance. The fixing systems must be able to accommodate weight and applied loads and also all movements based on changes in humidity and temperature in service. Total dimensional changes are indicative of the combination of movements due to changes in humidity and temperature. All materials containing high amounts of ordinary Portland cement are subject to dimensional changes due to humidity changes in service environments. The dimensional changes are not only dependent on the temperature change but also because of the sunlight absorption on external GFRC surfaces. The dimensional changes are all non-linear and time-dependent. In principle, immersion in water causes expansion and drying causes shrinkage [9]. Diagrammatic representation of dimensional changes in cementitious materials is shown in Fig. 4 [10].

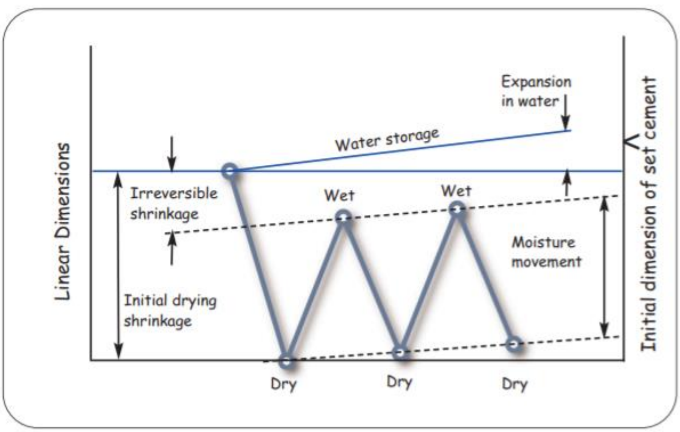

Figure 4. Diagrammatic representation of moisture movements

The dimensional variations of GFRC mixtures were determined according to EN 1170-7 [11]. The test samples after aged for 6 days are placed and kept in laboratory at a temperature of 20±3 ºC until the products have reached 10 days age. Subsequent to ageing in the laboratory, the initial length of each test piece was measured and recorded (l_0, mm). Three test samples from each GFRC mix was then placed in the ventilated drying oven adjusted to 30±3 ºC. Test pieces were removed from the oven after 21 days and stabilized in the laboratory at a temperature of 20±3 ºC for 6 h. The length of the test pieces were measured and recorded (l_2, mm) to determine the drying shrinkage. Three more test samples from each GFRC mix were placed in a tank filled with water at a temperature of 20±3. After 96h immersion in the water, test pieces were removed from the tank and wiped with a damp cloth. The final length of the test pieces were measured and recorded (l_1, mm) to determine the expansion of the mixtures.

The residual shrinkage ($\Delta l_s/l$, mm/m) and expansion values ($\Delta l_e/l$, mm/m) of GFRC mixtures were determined by Equations (1) and (2). The value of the extreme dimensional variation ($\Delta l_c/l$, mm/m) was determined by the Equation (3).

$$\frac{\Delta l_s}{l} = \frac{l_0 - l_2}{l_0} \times 10^3 \quad (1)$$

$$\frac{\Delta l_e}{l} = \frac{l_1 - l_0}{l_0} \times 10^3 \quad (2)$$

$$\frac{\Delta l_c}{l} = \frac{\Delta l_s + \Delta l_e}{l} \times 10^3 \quad (3)$$

2.3.4. Water Absorption and Dry Density

The water absorption and dry density of the samples are determined according to EN 1170-6 [12]. The test samples after aged for 6 days are placed and kept in water at 20 ±2 ºC for 24h. The samples are then removed from water, wiped with a damp cloth to remove any surface water and each test piece is weighed to determine the saturated mass (m_w). The test pieces are then placed and kept in a ventilated drying oven adjusted to 105±5 ºC for 24h to determine the dry mass (m_d). Water absorption (γ, %) and dry density ($\rho_{d,}\ kg/m^3$) was determined by using the Equations (4) and (5):

$$\gamma = \frac{m_w - m_d}{m_d} \times 100 \quad (4)$$

$$\rho_d = \frac{m_d}{V} \quad (5)$$

2.3.1. Flexural test

Flexural strength of GFRC samples was determined according to EN 1170-5 [13], at the 7[th] day by 4 point bending test. The test pieces were positioned in the testing machine, as shown in Fig. 5, on the two bottom supports with a span length (L) of 300 mm. For each mix 4 samples were tested with the mould face down on the two bottom supports and the other 4 samples with the mould face in contact with the top supports. Test was performed on a displacement controlled testing machine at a loading rate of 1 mm/min. Thickness and width of the samples were measured after the test in the failure zone to the nearest 0.1 mm and the modulus of rupture (σ_{MOR}. MPa) is determined by the Equation (6):

$$\sigma_{MOR} = \frac{F_{MOR} \times L}{b \times d^2} \quad (6)$$

In this equation F_{MOR}, L, b and d represents the maximum load, span length, width and thickness of test samples, respectively.

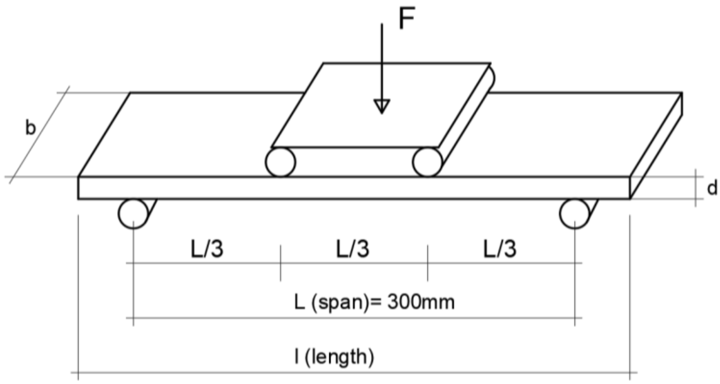

Figure 5. Schematic representation of flexural test

3. RESULTS AND DISCUSSION

This study aims to research the effect of fly ash and blast furnace slag replacement with cement on the workability, water absorption, density and early age flexural strength of GFRC. Fig. 6 presents the slump test results. Slump values varied between 73 and 107mm and substitution of cement with fly ash resulted in an enhanced workability due to the spherical shape of the fly ash particles. On the other hand slag addition did not have any significant effect on the workability.

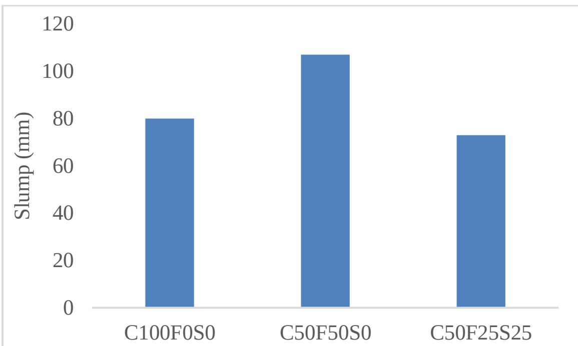

Figure 6. Slump test results

The extreme dimensional variations of the mixtures are presented in Fig. 7. The use of fly ash reduced the total dimensional variation by about 25% compared to the reference mixtures (C100F0S0G3 and C100F0S0G4). It is known that the shrinkage and expansion of cementitious matrix is governed by the amount of cement in the mixture. Therefore, any attempts to reduce the amount of cement provides reduction in shrinkage and expansion. The addition of slag, on the other hand, increased the dimensional variation, never the less the results obtained were still lower than the reference mixes. The increase in glass fiber content was found to slightly increase the dimensional variations of the mixtures.

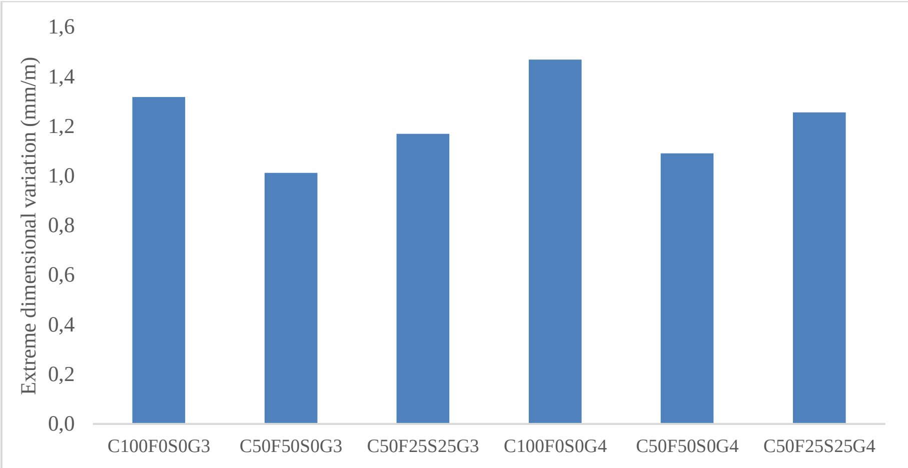

Figure 7. Total dimensional variations due to shrinkage and expansion

Water absorption test results of the mixes are presented in Fig. 8. The use of pozzolanic materials and the increase in fiber content had no significant effect on the water absorption of the mixes, the values varied between 10.8% and 11.5% as seen in Fig.8. Previous studies show that the replacement of cement with fly ash by up to 20% in GFRC reduces water absorption. The reason for the decrease in water absorption is attributed to the pozzolanic reaction that lead to a reduction in pore structure in cement paste [14]. However the slow reaction of pozzolanic materials, especially fly ash compared to the slag, retards this contribution. Therefore the effect of pozzolanic materials on the water absorption should be expected at later ages. Another impact of pozzolanic materials on cementitious matrix is their pore filling capability (contribution of non-reacted particles) especially at earlier ages which also is expected to reduce the water absorption. The median particle size of the binding materials shows that fly ash is coarser and slag is finer than the cement used in this study. Therefore the contribution of non-reacted fly ash particles on the early age water absorption might be hindered due to their coarser particle size compared to the cement. However, fly ash and blast furnace slag as a pozzolanic material has a significant effect on reducing the dry density of mixtures as shown in Table 3. Although densities of reference GFRC mixes were about 2000 kg/m^3, lower densities were obtained by replacing cement with fly ash and slag.

Table 3. Dry density of the mixtures

	Sample ID					
	C100F0S0G3	C50F50S0G3	C50F25S25G3	C100F0S0G4	C50F50S0G4	C50F25S25G4
Dry Density (kg/m^3)	1999	1928	1932	2000	1910	1923

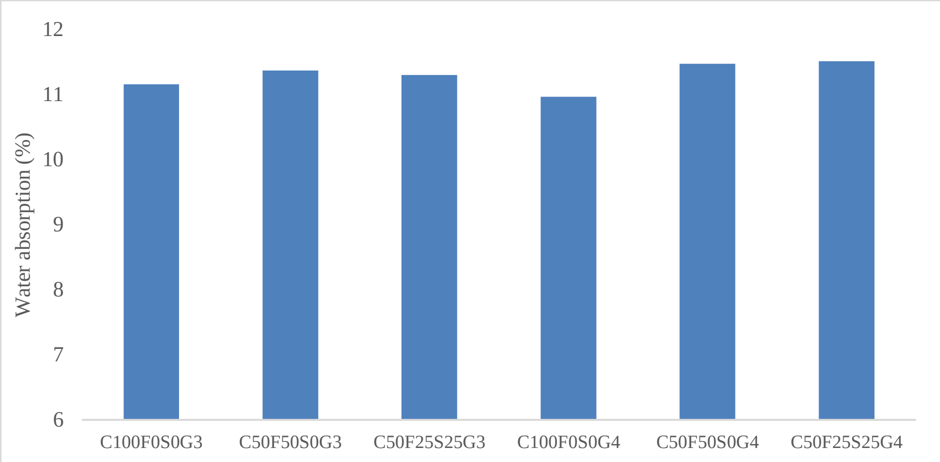

Figure 8. Water absorption results of GFRC samples

The flexural strength (σ_{MOR}) of the mixes was evaluated by comparison with the reference mixes C100F0SOG3 and C100F0SOG4, in which the cement was used as the sole binder and the fiber content varied as 3 and 4%. The average load-deflection curves of the mixes are shown in Fig. 9-10 and the average of flexure strength of the mixes are presented in Fig. 11. Test results showed that the flexural strength of the reference mixes are higher than the mixes containing pozzolanic materials. As seen in Fig. 11, the use of high content fly ash and blast furnace slag reduces the early age strength. The increase in the glass fiber content from 3 to 4% did not alter the flexural strength of the reference mix but improved the flexural strength of mixes containing fly ash and slag. The increase in flexural strength was noted as about 20% when higher amount of glass fiber was used in C50F50S0G4 and C50F25S25G4 mixes.

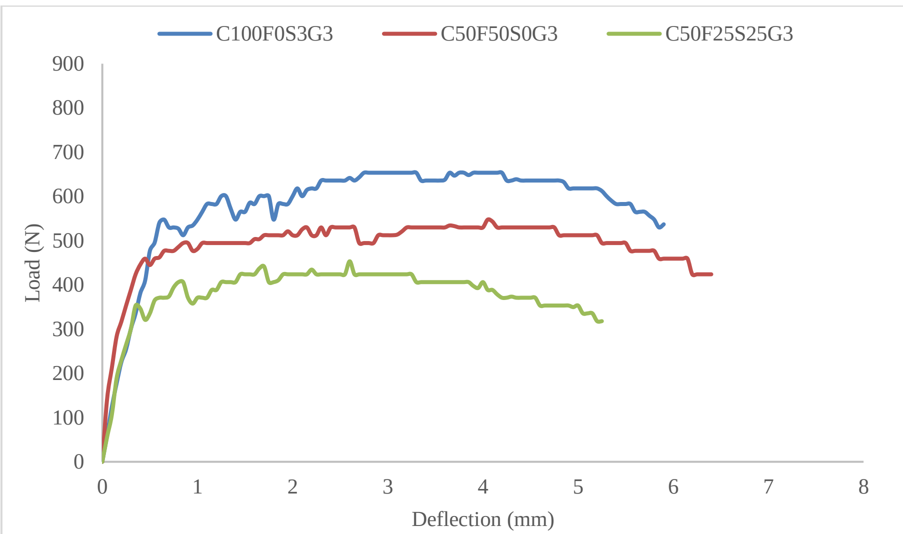

Figure 9. Load-Deflection Curves mixes with 3% glass fiber

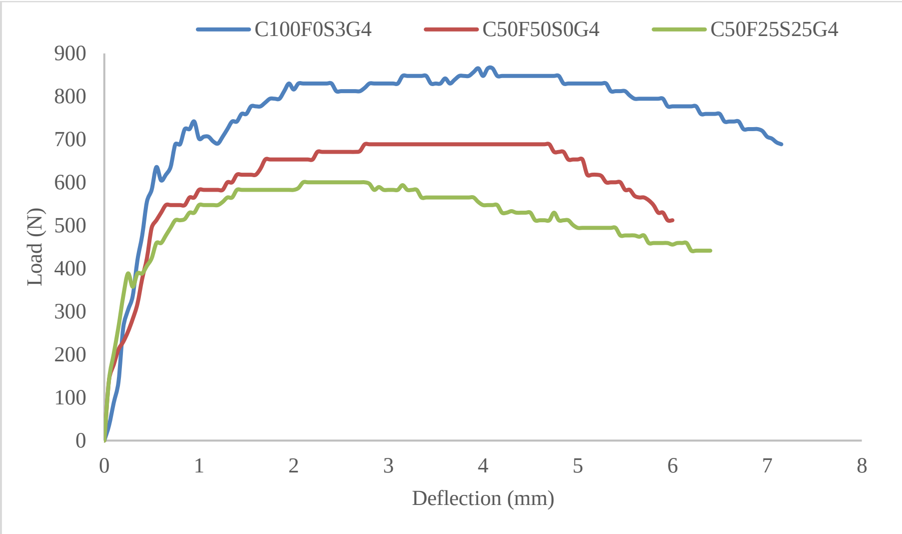

Figure 10. Load-Deflection Curves mixes with 4% glass fiber

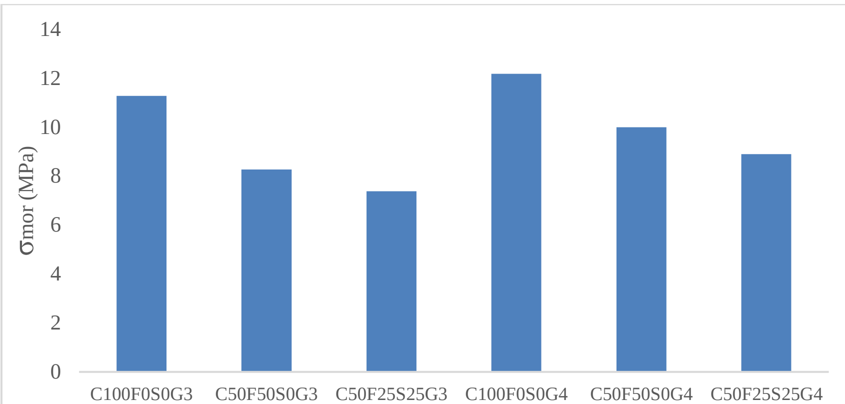

Figure 11. Flexural strength of GFRC mixes at 7 days

Microstructure of fly ash incorporated GFRC sample is shown in Fig. 12. The figure shows that the fibers are aligned in one direction and are stick together without any dispersion in the matrix and that they are well surrounded with the cementititous matrix.

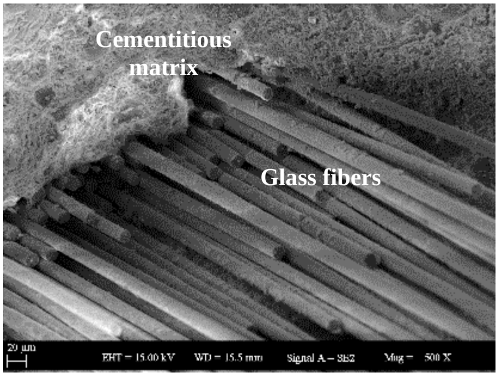

Figure 12. SEM micrograph of GFRC sample

4. CONCLUSIONS

This research investigated the effect of high content fly ash and blast furnace slag replacement with cement on the flexural strength and water absorption of GFRC. Based on the test results the following conclusions may be drawn:

1. Substitution of cement with fly ash resulted in an enhanced workability, however slag addition did not have any significant effect on the workability.
2. Replacement of cement by high amount of fly ash and blast furnace slag reduced the flexural strength at 7 days. The increase in fiber content enhanced the flexural strength, the effect was more pronounced in mixes containing pozzolanic materials.
3. The use of pozzolanic materials and the increase in fiber content had no significant effect on the water absorption of the mixes. However, use of fly ash has a considerable effect on reducing dry density and total dimensional variation and improving the workability.
4. Further research should be performed to determine the effect of pozzolanic additions on physical and mechanical properties of GFRC at later ages.

Acknowledgements

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