High performance lightweight concrete reinforced with glass fibers

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Abstract

This paper demonstrates the effect of glass fibers on mechanical properties of high performance lightweight concrete which are: compressive strength, flexural strength, workability (flow), and density. Foam agent was used to produce lightweight concrete using different mix proportion to obtain good workability and compressive strength with least fresh density. Superplasticizer used in some mixes about 1% by weight of cement. Glass fibers were added in different volume fraction 0.06, 0.2, 0.4, and 0.6 %for foam concrete and foam concrete with superplasticizer. The results of foamed concrete mixes indicate that the increase of glass fibers content can produce high performance lightweight concrete and improve the mechanical properties of such concrete. The compressive and flexural strength increased with the increase of glass fibers with acceptable range of workability, addition 0.6% of glass fibers increase 33.7% and 16.1% of compressive and flexural strength respectively but the flow reduced about 38% compare without glass fibers.

Keywords : Lightweight concrete; Foam concrete; Glass fibers; Mechanical properties.

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1. Introduction

Recently, with the rapid development in the construction, the lightweight concrete has been used for structural purpose and many applications for modern construction. The advantages of lightweight concrete are high strength/weight ratio, good tensile strain capacity, low coefficient of thermal expansion due to the voids, thermal insulation, increased fire resistance over ordinary concrete, improved durability properties, smaller cross-sections in load-bearing elements and reduction in the size of foundations. The applications of lightweight concrete are tall buildings, long span structure, the requirements for high performance are higher strength and higher toughness (Chen and Liu, 2005; Tanyildizi, 2008; Kurugol et al.,2008; Libre et al., 2011). Structural lightweight concrete have bulk density lower than 1950 kg/m^3 with having compressive strength more than 17 MPa, can be produced structural lightweight concrete 25% lighter than normal-weight concrete with a compressive strength up to 60 MPa (Guo et al., 2000).Aerated concrete is produced by introducing or generating bubbles voids within the concrete (cement matrix),the voids or cell structure having a homogeneous distribution in cement matrix when formed of voids inside the fresh cement mixture, density range from 300 to 1600 kg/m^3 (Fouad, 2006 ; Neville, 2000). Aerated concrete is known as foamed concrete , foamed concrete is classified in two types according to method producing i. pre-foaming method include preformed foamed (foam agent with water) and mixed with cement slurry (cement paste or mortar), ii. mixing foaming method is mixed of foam agent with cement slurry , foam will produced voids inside the concrete (Ramamurthy et al. , 2009 ; Byun et al., 1998; Short & Kinniburgh, 1978).Density of foam concrete about (400 to 1600 kg/m^3) depending on proportion of foam agent and water, foam concrete can be used for structural application, partition, insulation and filling grades (Ramamurthy et al., 2009).

Concrete considerable brittleness, which results in poor fracture toughness, poor resistance to crack propagation, and low impact strength. This inherent brittleness has limited their application in fields requiring high impact, vibration and fracture strengths, for this can be use fibers to improve the mechanical properties of lightweight concrete. Fibers are used to modify the tensile and flexural strengths, toughness, impact resistance, fracture energy, arrest crack formation and propagation, and thus improve strength and ductility (Dawood and Ramli, 2011; Ahmad et al., 2010; Wafa, 1990).

Glass Fibers is one type of fiber reinforced concrete, the main applications used in exterior building facade panels and as architectural precast concrete. The fibers glass is less dense than steel thus is very good in making fair face in front of any building (Abdullah and Jallo, 2012).Glass fibers are produced in a process in which molten glass is drawn in the form of filaments, through the bottom of a heated platinum tank or bushing (Shakor and Pimplikar, 2011). Glass fibers improve the strength of the material by increasing the force required for deformation and improve the toughness by increasing the energy required for crack propagation (Chandramouli et al., 2010). The glass fibers when added to the mix will increased and more effect on the mechanical properties, flexural strength, compressive strength, tensile strength and young modulus of the materials (Abdullah and Jallo, 2012). The diameter ranges of glass fibers from 0.005 to 0.015mm (may be bonded together to form elements with diameters of 0.13 to 1.3mm).The disadvantage of glass fibers decreases the workability of fresh concrete and this effect is more prominent for fibers with higher aspect ratios(Chandramouli et al., 2010).

2. Aim and objectives of the study

It can be noticed from the previous literatures that most papers deals with normal concrete reinforced with glass fibers. However, this study was conducted to investigate the properties of high performance lightweight concrete reinforced with different percentages of glass fibers. The mechanical properties of such concrete were determined.

3. Materials and mix proportions

3.1 Materials

Ordinary Portland cement type I from Badoosh manufacture of Iraq was used in this study, the chemical compositions of cement according to ASTM C 150 are shown in Table 1, and the physical characteristics according to IQS : 5/1984 are shown in Table 2. The natural river sand used as a fine aggregate with a specific gravity of 2.63 and fineness modulus is 2.69. The grading limits according to ASTM C 33 are given in Table 3.

Foam agent was used to obtain high performance lightweight concrete. The type of foam agent (NEOPOR) (leycoChem LEYDE GmbH Germany) is an organic material, which has no chemical reaction but serves solely as wrapping material for the air to be induced in the concrete. The foaming agent has to be diluted in 40 parts of water before using it according to ASTM C 796.

Glass fibers were used in the lightweight foam concrete, the properties of the glass fibers are listed in Table 4 and Figure 1.Different volume fractions of glass fibers are used as given in Table 5. A High Range Water Reducing based on naphthalene sulphonate (RHEOBUILD® 181 K) (BASF the chemical company) was used in this study, the technical data and features of High Range Water Reducing based on naphthalene sulphonate shown in Table 6.

Table 1.Chemical properties of ordinary Portland cement.

Constituent	Component of OPC (%)	Limits of ASTM C 150
SiO_2	21.31	…
Al_2O_3	5.89	…
Fe_2O_3	2.67	…
CaO	62.2	…
MgO	3.62	≤ 6%
SO_3	2.6	≤ 2.3%
Loss of ignition	1.59	≤ 3%
Insoluble residue	0.24	≤ 0.75%
Free CaO	1.74	…
L.S.F.	0.8818	…
C_3S	33.37	…
C_2S	35.92	…
C_3A	11.09	…
C_4AF	8.12	…

Table 2.Physical characteristics of ordinary Portland cement.

Test	result	IQS : 5/1984
Initial setting time (minute)	210	Min. 45 minute
Final setting time (minute)	330	Max. 600 minute
Fineness (Blain m^2/kg)	263	230

Table 3.Grading of fine aggregates.

Sieve No. (mm)	Passing (%)	Limits of ASTM C 33
No.4 (4.75)	100	95-100
No.8 (2.36)	80.96	80-100
No.16 (1.18)	66.33	50-85
No.30 (0.6)	51.5	25-60
No.60 (0.3)	24.65	5-30
No.100 (0.15)	7.26	0-10

Table 4.Characteristics of glass fibers used.

Fiber properties	Quantity
Fiber length	12 mm.
Aspect ratio	24
Specific gravity	2.68 g/cm^3
Modulus of elasticity	72 GPa
Tensile Strength	1,700 MPa
Chemical Resistance	Very high
Electrical Conductivity	Very low
Softening point	860 °C
Material	Alkali Resistant Glass

Table 5.Volumetric fractions of glass fibers and superplasticizer in lightweight concrete mixes.

Mix no.	F0	F1	F2	F3	F4	F5	F6	F7	F8	F9
Glass fiber ratio (%)	0.0	0.06	0.2	0.4	0.6	0.0	0.06	0.2	0.4	0.6
Superplasticizer (%)	0.0	0.0	0.0	0.0	0.0	1	1	1	1	1

Table 6.Technical date and Features for High Range Water Reducing based on naphthalene sulphonate.

Technical data	
Structure of the materials	Napthalene Sulphonate Based
Color	Brown
Density	1.153-1.213 kg/liter
Chloride content %(EN 480-10)	< 0.1
Alkaline content %(EN 480-12)	< 10
Features and benefits	

- Decreases the amount of water at least 12% by weight compared to concrete without admixture.
- Enables lower water/cement ratio or high workability in the same water/cement ratio and easy pumpability compared to concrete without admixture.
- Increases early and final strengths compared to concrete without admixture.
- Improves formwork and surface finishes compared to concrete without admixture.
- Improved concrete's other mechanical properties like impermeability, durability, contraction, and creeping.
- Enables setting with lesser vibration even in densely reinforced concrete structures.

Figure 1: Micro glass fibers.

3.2 Mix proportions

The mix proportion used in this study was 1:2.25 cement and sand respectively with water cement ratio w/c=0.49 for mixes without Superplasticizer and w/c = 0.4 for mixes with superplasticizer. The foam agent used was 1 kg/m^3.The procedure of mixing is achieved by blending the cement with sand according to the mix proportion and then the water was added to prepare the mortar. After that, the foam was added to the mortar. It should be mentioned that the preparation of the foam is done using the foam agent which is diluted in 40 parts of water according to ASTM C 796. This is calculated as a part of the total water of the mix shown in Table 7. Mortar and foam should be blended to make homogeneous mixture .Glass fibers are incorporated in different proportions of volume fraction as shown in Table 5. The mix should have a uniform dispersion of the fibers in order to prevent segregation or balling of the fibers during mixing. Most balling occurs during the fiber addition process. Increase of aspect ratio, and volume percentage of fiber, will intensify the balling tendencies and decrease the workability(Wafa, 1990). Superplasticizer used in the mix as 1% from weight of cement as shown in Table 5. Each mix proportion was measured in term of flow according to ASTM C 1437 and ASTM C 230.

Table 7. Mix proportions

Series	Mix No.	Mix proportion	W/C	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Foam agent (kg/m^3)	Theoretical density (kg/m^3)	Flow (%)
Series I	F0	(1 : 2.25) (cement : sand)	0.49	481.2	1082.7	235.8	1	1799.6	130
	F1		0.49	484.8	1090.8	237.5	1	1813.1	125
	F2		0.49	488.4	1098.9	239.3	1	1826.6	120
	F3		0.49	490.2	1103.0	240.2	1	1833.4	113
	F4		0.49	493.2	1109.7	241.6	1	1844.5	95
Series II	F5		0.4	510.6	1148.9	204.2	1	1863.7	118
	F6		0.4	517.6	1164.7	207.0	1	1889.3	114
	F7		0.4	521.4	1173.2	208.5	1	1903.1	107
	F8		0.4	522.7	1176.1	209.0	1	1907.8	92
	F9		0.4	523.3	1177.5	209.3	1	1910.1	84

4. Casting, Curing, and Testing of Concrete Specimens

Test specimens of 50×50×50 mm cubes were used for testing the compressive strength of lightweight concrete according to ASTM C 109 as seen in Figure 2. The average of three cubes was used to determine the compressive strength for each age of test. The prisms of 40×40×160 mm were used to determine the flexural strength according to ASTM C 348 as shown in Figure 3. The average of three prisms was used to determine the flexural strength. In the laboratory the foam produced by using a mixer, which forming the foam according to the pre-foaming method, adding the preformed foam to a base mix (cement, sand, and water). The foamed concrete mixes was divided into two series: series I, used fibers glass only, and series II, used fibers glass and superplasticizer as shown in Table 7. The fresh density was measured by using container of known weight and volume. The specimens were stripped approximately 24 h after casting and placed in water using a water tank as a normal water curing method with a controlled temperature of 27 ºC ± 2 ºC. Each mix to test the compressive strength and flexural strength at various ages (7 and28 days) according to ASTM C109 and ASTM 348 respectively. The oven dry density and voids were determined using 100 mm cubes according to ASTM C 642 for each mix.

Figure 2: a) Compressive strength test machine. b) Specimen inside the testing machine.

Figure 3: Flexural strength test machine and specimen inside the testing machine.

5. Results and discussion

5.1. Workability

The workability (flow) was measured according to ASTM C 230, the flow for foam concrete reinforced with glass fibers varied among mixes depending on volume fraction of glass fiber, the flow of the various mixes and are given in Table 7. The flow varied between (130-84%), the flow was about 130% for mix F0 (series I), and flow reduced with the increase of glass fibers. Thus, the use of 0.6% of glass fibers reduced the flow to 95%.Figure 4 shows the effect of glass fibers on flow, this relationship illustrates that the workability (flow) reduces with the increase of fibers (Neville and Brooks, 2010).

The flow for mixes containing superplasticizer decreases due to the reduction in water-cement ratio (w/c=0.4) and also presence of glass fibers as can be seen in Table 7. The flow was 118% for mix F5, and also with the fiber increase the workability (flow) would decrease. For mix F9, with glass fibers 0.6%,the flow is 84% and thus the percentage of reduction in the flow is about 28.81% compared with reference mix. Figure 4 shows the effect of glass fibers on the flow of mixes containing superplasticizer (series II).

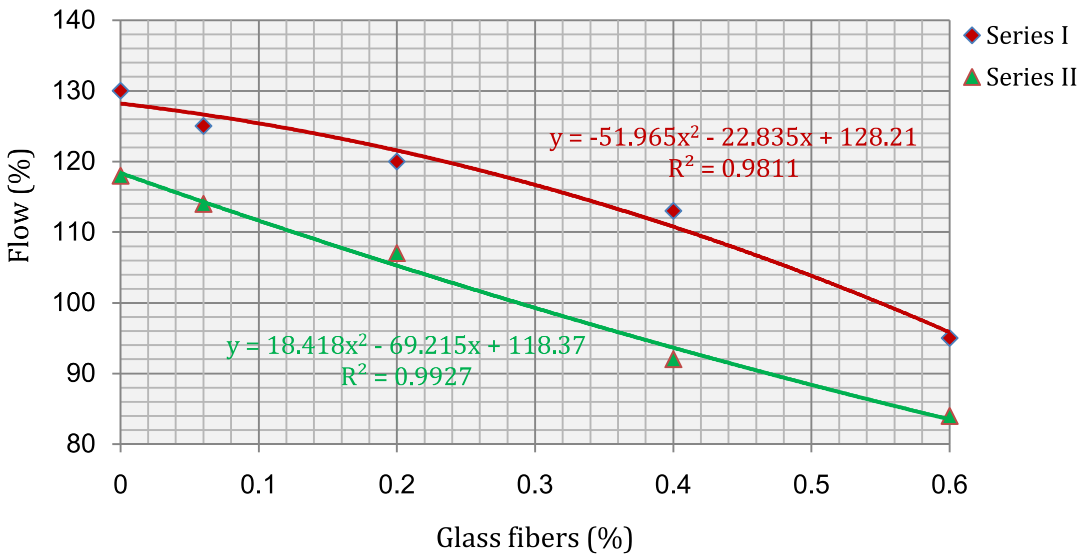

Figure 4: Effect of glass fiber (%) on the flow of the mixes.

5.2. Compressive strength

The results of compressive strength at the age of 7 and 28 days are shown in Table 8. The compressive strength of foamed concrete incorporated with different percentage of glass fibers as 0.06, 0.2, 0.4, 0.6% volume fraction. Compressive strength increases with the percentage increase of glass fibers (Deshmukh et al., 2012). Figure 5 shows the relationship between the compressive strength and percentage of glass fibers for two group mixes: series I and series II (without and with superplasticizer), respectively.

For series I mixes, it can be seen that the compressive strength increased by 14.28% with the addition of 0.06%of glass fibers compared with reference mix (F0). Also, it can be noticed that the compressive strength is increased by 26.05% with the addition of 0.2% of glass fibers. Whereas, the incorporation of 0.4% glass fibers the compressive strength increased by about 32.03% compared with mix F0, and the compressive strength increased by about 33.75% with the addition of 0.6% of glass fibers.

For series II mixes, also the compressive strength increased with the glass fibers increase, the compressive strength increased by about 20.75% with the addition of 0.06% of glass fibers. The addition of 0.2% of glass fibers would increase the compressive strength by about 30.31%. However, the incorporation of 0.4% of glass fibers increases the compressive strength by about 33.24%. Furthermore, the compressive strength increases by about 37.76% with the addition of 0.6% glass fibers as can be noticed in figure 5.

The results of compressive strength of series II mixes containing superplasticizer show that the gain of the compressive strength at early age (7 days) exhibit better performance compared with mixes without superplasticizer (series I) (Neville and Brooks, 2010). Figure 6 shows the gain in compressive strength of foam concrete for mixes with and without superplasticizer (series II and series I).

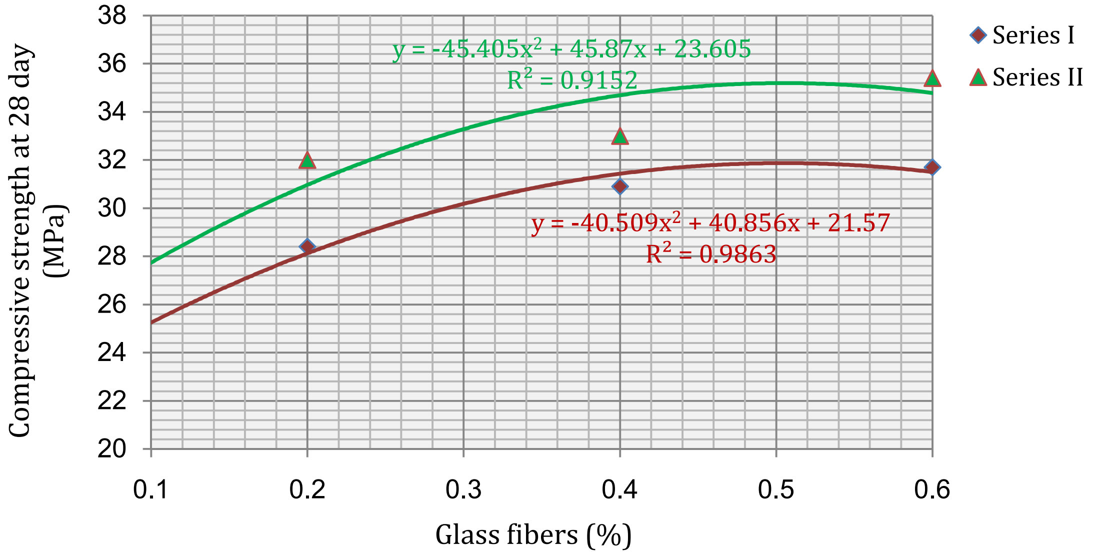

Figure 5: Relationship between the compressive strength at 28 day and percentage of glass fibers.

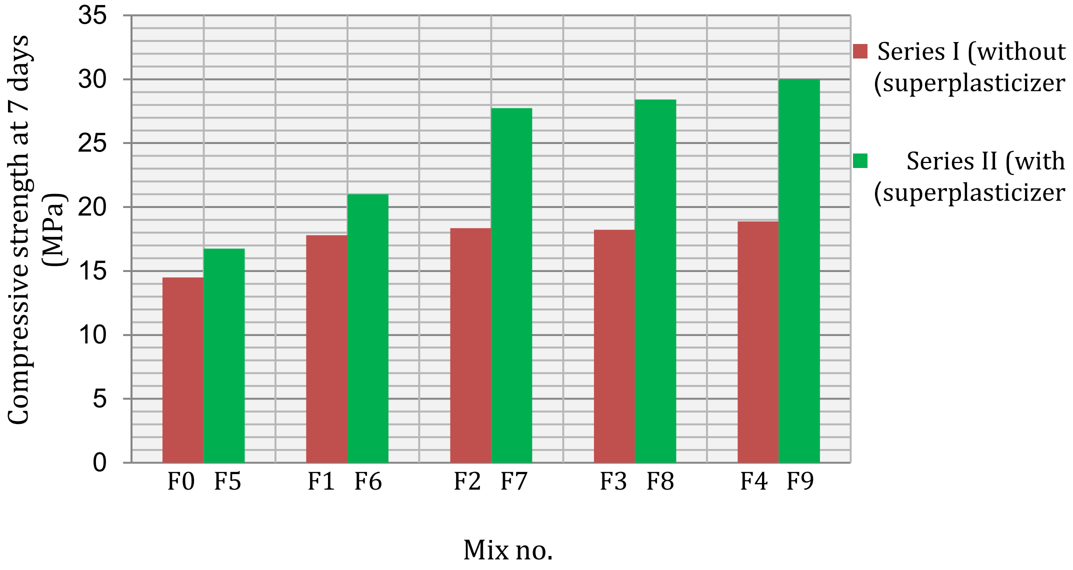

Figure 6: The influence of the addition of superplasticizer on the early strength of foam concrete.

Table 8.
Hardened foam concrete properties.

Series	Mix No.	Fresh density (kg/m^3)	Dry density (kg/m^3)	Compressive strength (MPa)		Flexural strength (MPa)	Voids (%)
				7 days	28 day	28 day	
Series I	F0	1760.00	1718.00	14.50	21.00	7.48	20.0
	F1	1784.00	1759.40	17.8	24.50	7.87	19.4
	F2	1810.00	1787.50	18.34	28.40	8.06	18.8
	F3	1850.00	1824.00	18.23	30.50	8.44	18.5
	F4	1881.00	1868.00	18.88	31.70	8.92	18.0
Series II	F5	1775.00	1731.00	16.75	22.03	6.90	19.7
	F6	1819.00	1795.00	21.00	27.80	7.48	18.6
	F7	1845.00	1822.00	27.73	32.64	7.68	18.0
	F8	1870.00	1849.00	28.42	32.00	7.86	17.8
	F9	1886.00	1861.00	30.00	35.40	8.16	17.7

5.3. Flexural strength

Table 8 gives the test results of flexural strength at 28 days. For series I mixes, the average flexural strength without glass fibers mix F0 is 7.48 MPa. However, the addition of glass fibers would enhance the flexural strength of foamed concrete with glass fibers percentage increase. It can be observed that the flexural strength increased by about5% with the addition of 0.06% glass fibers compared with mix F0. The use of 0.2% of glass fibers would increase the flexural strength by about 7.19%. Besides, the flexural strength increased by about 11.37% with the addition of 0.4% glass fibers. Whereas, the use of 0.6% glass fibers increases the flexural strength of foamed concrete by about 16.14%. Figure 7 shows the relationship between flexural strength and glass fibers percentage. It can be noticed that flexural strength of foamed concrete increases with the glass fibers increase.

For series II mixes the average flexural strength without glass fibers mix (F5) is 6.9 MPa. It can be observed that the flexural strength increased by about 7.75% with the addition of 0.06% glass fibers as can be noticed in Table 8. The flexural strength increases with the addition of 0.2% of glass fibers and the percentage of increase is 10.15%. The flexural strength increases by about 12.2% with the addition of 0.4% of glass fibers, and the incorporation of 0.6% glass fibers increases the flexural strength by about 15.44% as seen in Figure 7. The failure of specimen for flexural strength test is shown in Figure 8.

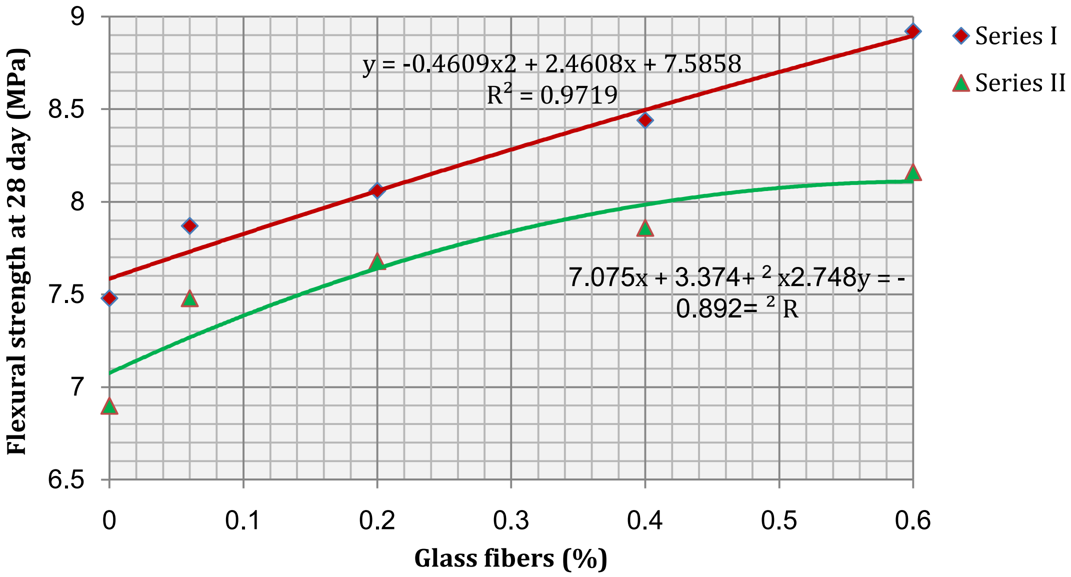

Figure 7: Relationship between flexural strength and glass fiber percentage.

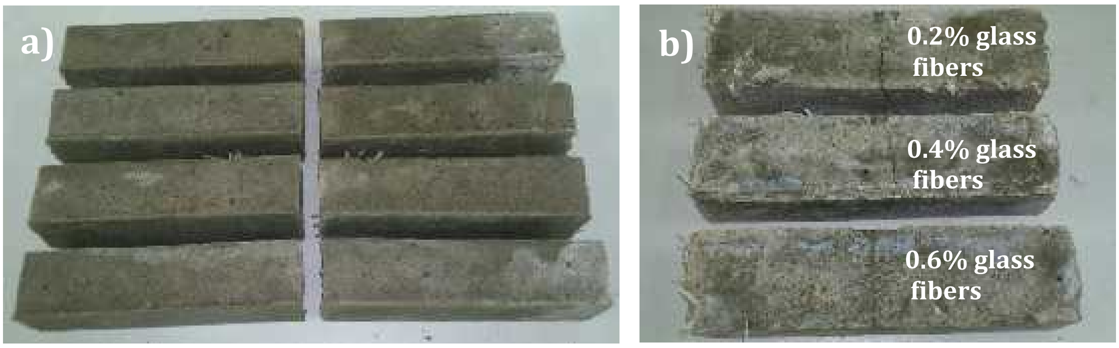

Figure 8: a) The prism specimens before flexural strength testing. b) The behavior of prism specimens failure after testing.

6. Conclusion

Foam agent was used to produce high performance lightweight concrete and lightweight concrete reinforced with glass fibers, consider the mechanical properties of high performance foamed concrete, with addition of glass fibers and superplasticizer. The results of foam concrete exhibit good compressive strength, flexural strength, and workability. Some conclusions can be drawn as follows:

1- The workability of high performance foam concrete reduces with the increase of glass fibers percentages. The least value of flow is 84% with the use of 0.6%of glass fibers. This reduction in workability may be influenced by the high percentage of glass fibers, but this reduction in workability should be compared with the compressive strength increases.
2- The compressive strength of high performance foamed concrete increased with the increase of glass fibers percentages in the mixes but when the addition of glass fibers more than 0.6% will decrease the workability. For mixes without superplasticizer the best glass fibers percentages used are 0.2 and 0.4% , and for mixes with superplasticizer the best percentage is 0.6%.
3- The flexural strength increases with the increase of glass fibers percentages in the mixes. For mixes without superplasticizer the flexural strength increases up to 16.14 % with the addition of 0.6% glass fibers, and for mixes with superplasticizer the flexural strength increases by 15.44% with the addition of 0.6% of glass fibers.

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الخرسانة الخفيفة الوزن العالية الاداء المسلحة بالألياف الزجاجية

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المستخلص

هذا البحث يتناول استخدام الالياف الزجاجية وتاثيرها على الخصائص الميكانيكية للخرسانة الخفيفة الوزن عالية الاداء. تم دراسة الخصائص الميكانيكية وهي مقاومة الانضغاط ومقاومة الانحناء وقابلية التشغيل (الانسيابية) والكثافة. الخرسانة الرغوية استخدمت لانتاج خرسانة خفيفة الوزن بنسب مختلفة للحصول على مقاومة انضغاط وقابلية تشغيل مناسبة مع تقليل الكثافة. الملدن المتفوق استخدم بنسبة 1% من وزن السمنت. الالياف الزجاجية استخدمت كنسب حجمية وكانت كالاتي : 0.06 0.2 0.4 و 0.6% . النتائج اوضحت بان الخرسانة الرغوية تحسنت بشكل واضح باستخدام الالياف الزجاجية وخاصة مقاومة الانضغاط ومقاومة الانحناء ,حيث ان اضافة 0.6% من الالياف الزجاجية سوف يحسن من مقاومة الانضغاط بنسبة زيادة 33.7% وكذلك تحسن في مقاومة الانحناء بنسبة زيادة 16.1% مقارنة مع الخرسانة التي لاتحتوي على الالياف الزجاجية ولكن من جهة اخرى سوف تقل قابلية التشغيل بنسبة 38%.

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