STUDY ON MECHANICAL PROPERTIES OF STRUCTURAL LIGHTWEIGHT FOAMED CONCRETE WITH GLASS FIBERS

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ABSTRACT

Foam concretes (FCs) have a stronger matrix structure than lightweight concretes. The porosity of foam and lightweight concretes reduces as the density of the material increases. In addition, the porosity of lightweight concrete is highly affected by the aggregates' pore features, and that of FC is totally affected by the pore structure of the matrix. Lightweight foamed concrete exhibits many advantages and excellent features comprising a more efficient strength-to-weight ratio in structural elements, high strength, reduced dead load, decrease foundation loads, energy saving, waste consumption, temperature conservation, and noise insulation. This work was prepared to investigate the effect of glass fibers on the mechanical properties of structural lightweight foamed concrete (SLFC), Foam agent (organic material) was used to produce SLFC using different mix proportions to obtain structural compressive strength and high workability with the slightest fresh density Five mixes of SLFC with Superplasticizer is experimentally studied, also five mixes without Superplasticizer were tested. The compressive strength, flexural strength, ultrasonic pulse velocity (UPV), workability (flowability), and density were measured. The superplasticizer used in some mixes was 1% by weight of cement. Glass fibers were added in different volume fractions for SLFC and SLFC with superplasticizer. The volume fractions of the glass fibers used are 0.06, 0.2, 0.4, and 0.6 % of the total volume. The results of SLFC mixes showed that the increase of glass fiber content can reduce foam concrete with enhanced mechanical properties. For all percentages of glass fibers in the mixes it increases in compressive strength and flexural strength. But the increase in compressive strength was 51% for 0.6% glass fibers. Also, the flexural strength increased by 19.2% for 0.6% glass fibers. The compressive and flexural strength increased with the increase of glass fibers with an acceptable range of workability.

KEYWORDS: Structural lightweight foamed concrete (SLFC); Lightweight concrete; foamed concrete; Glass fibers; Mechanical properties.

1. INTRODUCTION

Lightweight concrete is widely used for modern construction as it is mortar less and can be produced with different densities. Lightweight concrete is also known as aerated, cellular lightweight concrete, or foam concrete. Lightweight concretes have an oven-dry density varying from 300 kg/m^3 to 2000 kg/m^3, with compressive strength for a cube that may reach more than 60 MPa. Recently, with the rapid development in construction, lightweight concrete has been used for structural purposes 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. Structural lightweight concrete have bulk density lower than 1950 kg/m^3 with compressive strength of more than 17 MPa, such concrete can be produced with 25% lighter than normal-weight concrete with a compressive strength up to 60 MPa. 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 varies from 300 to 1600 kg/m^3. Aerated concrete is known as foamed concrete. Foamed concrete is classified into two types according to the method producing. i. pre-foaming method includes 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 produce voids inside the concrete. The density of foam concrete depends on the proportion of foam agents and water. The compressive strength of foam concrete is just about 1 to 60 Mpa compared to normal concrete which achieved 100Mpa in compressive strength. Foam concrete can be used for structural application, partition, insulation, and filling grades. Concrete is a considerably brittle material, 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 Therefore, to improve the mechanical properties of concrete, fibers can be used. 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 ductile glass Fibers are 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. Glass fibers improve the strength of the material by increasing the force required for deformation and enhance the toughness by increasing the energy required for crack propagation. The glass fibers when added to the mix would enhance the mechanical properties, flexural strength, compressive strength, tensile strength and young modulus of the materials. However, the use of glass fibers decreases the workability of fresh concrete and this effect is more prominent for fibers with higher aspect ratios.

Therefore, this work was conducted to produce structural lightweight foam concrete with structural compressive strength, high workability (flowability), and an acceptable range of density. Adding glass fibers to structural lightweight foam concrete with different ratios to study the effect of glass fibers on compressive strength, flexural strength, ultrasonic pulse velocity, workability and density.

2. MATERIALS AND MIX PROPORTIONS

2.1. Materials

2.1.1.Cement: ordinary Portland cement type I was used in this study. The physical characteristics are shown in Table 1.

2.1.2. Fine aggregates (Sand): sand used in this study was natural sand. The specific gravity of sand 2.63 and fineness modulus is 2.69. The grading limits according to ASTM C33 [12] are given in Table 2.

2.1.3. **Water:** Potable water was used in this study.

2.1.4. Foam agent: Foam agent named (NEOPOR) (leycoChem LEYDE GmbH Germany) was used to obtain structural lightweight foam concrete. It is an organic material, which has no chemical reaction but serves solely as wrapping material for the air to be induced in the concrete shown in figure 3. The foaming agent has to be diluted in 40 parts of water before using it according to the manufacturer.

2.1.5. Glass fibers: were used in the lightweight foam concrete, the properties of the glass fibers are listed in Table 3 and Figure 4. Different volume fractions of glass fibers are used as given in Table 4.

FIG. 1 Portland Pozzolana Cement

FIG. 2 Fine aggregate (M sand)

TABLE 1. Physical characteristics of ordinary Portland cement.

Test	Result	IS: 455/1989
Initial setting time (minute)	210	Min. 45 minute
Final setting time (minute)	330	Max. 600 minute
Fineness (Blain m^2/kg)	263	Min. 230 (m^2/kg)

TABLE 2. 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	0-1

FIG. 3 CLC Foaming agent

FIG. 4 Glass fiber

TABLE 3. Properties of glass fibers.

Fiber properties	Quantity
Fiber length	1.2 cm.
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 4. The volume fraction of glass fibers and Superplasticizers in lightweight concrete mixes.

Mix no.	N0	N1	N2	N3	N4	N5	N6	N7	N8	N9
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

2.2 Mix Proportions

The mix proportion used in this study was 1:2.25 cement and sand respectively with water cement ratio w/c=0.4 for mixes with superplasticizer and w/c =0.49 for mixes without 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 to obtain lightweight foamed concrete. 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 the manufacturer. This is calculated as a part of the total water of the mix shown in Table 5. When the foam is added to the mortar, the foam should be blended to make a homogeneous mixture. Glass fibers are incorporated in different proportions of volume fraction as shown in Table 5. Gradually the glass fibers are added to the mix (foamed concrete). 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. An increase of aspect ratio, volume percentage of fiber, and size and quantity of coarse aggregate will intensify the balling tendencies and decrease the workability. The superplasticizer used in the mix is 1% of the weight of cement as shown in Table 5. Each mix proportion was measured in terms of flow according to ASTM C 1437 and ASTM C 230.

FIG. 5 Foam generation **FIG. 6 Foam density**

TABLE 5 Mix proportions

Series	Mix No.	Glass fibers (kg/m^3)	w/c	Cement (kg/m^3)	Sand (kg/m^3)	Water (lit)	Foam agent (kg/m^3)	Theoretical density (kg/m^3)	Flow (%)
Series I	N0	0	0.49	481.2	1082.7	235.8	1	1799.6	130
	N1	1.6	0.49	484.8	1090.8	237.5	1	1813.1	125
	N2	5.4	0.49	488.4	1098.9	239.3	1	1826.6	120
	N3	11	0.49	490.2	1103	240.2	1	1833.4	113
	N4	16	0.49	493.2	1109.7	241.6	1	1844.5	95
Series II	N5	0	0.4	510.6	1148.9	204.2	1	1863.7	118
	N6	1.6	0.4	517.6	1164.7	207	1	1889.3	114
	N7	5.4	0.4	521.4	1173.2	208.5	1	1903.1	107
	N8	11	0.4	522.7	1176.1	209	1	1907.8	92
	N9	16	0.4	523.3	1177.5	209.3	1	1910.1	84

FIG. 7 casting of specimens

3. EXPERIMENTAL WORK

Test specimens of 50×50×50 mm^3 cubes were used for testing the compressive strength of lightweight concrete according to ASTM C 109 as shown in Figure 8. a. The average of three cubes was used to determine the compressive strength for each age (7 and 28 days) of the test. The prisms of 40×40×160 mm^3 were used to determine the flexural strength according to ASTM C 348 as shown in Figure 8. b. The average of three prisms was used to determine the flexural strength. In the laboratory the foam is produced by using a mixer, which forms the foam according to the pre-foaming method, adding the preformed foam to a base mix (cement, sand, and water). The structural lightweight foamed concrete mixture was divided into two series: Series I, which used glass fibers only, and series II, which used fibers of glass and superplasticizer as shown in Table 5. The fresh density was measured by using a 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 23 ºC ± 2 ºC according to ASTM C 192. Each mix was tested in the compressive strength and flexural strength at ages (7 and 28 days) according to ASTM C109 and ASTM 348 respectively.

a)

b)

FIG. 8: a) Compressive strength test machine. b) Flexural strength test machine and specimen inside the testing machine

4. RESULTS AND DISCUSSION

The workability (flow) was measured according to ASTM C 1437[14], The flow for foamed concrete reinforced with glass fibers varied among mixes depending on the volume fraction of glass fiber, the flow of mixes is given in Table 5. The flow varied between (130-84%), the flow was about 130% for mix N0 (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%. The flow for mixes containing superplasticizers decreases due to the reduction in water-cement ratio (w/c=0.4) and also the use of glass fibers. The flow was 118% for mix N5, and also with the fiber increase the workability (flow) would decrease. For mix N9, with glass fibers at 0.6%, the flow is 84% and thus the percentage of reduction in the flow is about 28.81% compared with the reference mix (N5).

Before the compression test, ultrasonic pulse velocity was measured. The results of each test have been assessed and summarized in this report in Table 6. The variance between expected and experimental strength for Ultrasonic Pulse Velocity testing was found by this research; the higher the pulse velocity, the lower the predicted strength, and the lower the periods pass by pulse velocity, the higher the predicted strength.

TABLE 6 Ultrasonic Pulse Velocity Test Results

Series	Mix No.	Pulse Velocity (km/sec)		Concrete Quality
		7 Days	28 Days	
Series I	N0	3.29	3.37	Medium
	N1	3.33	3.41	Medium
	N2	3.49	3.53	Good
	N3	3.58	3.65	Good
	N4	3.62	3.7	Good
Series II	N5	3.38	3.49	Medium
	N6	3.48	3.51	Good
	N7	3.52	3.67	Good
	N8	3.69	3.78	Good
	N9	3.74	3.84	Good

The results of compressive strength at the age of 7 and 28 days are in Table 6. The compressive strength of structural lightweight foamed concrete incorporated with different percentages of glass fibers as 0.06, 0.2, 0.4, and 0.6 % volume fraction. Compressive strength increases with the percentage increase of glass fibers as seen in agree with. 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 is studied here.

TABLE 7 Compressive Strength Test Results

Series	Mix No.	Glass fibers (kg/m^3)	w/c	Theoretical density (kg/m^3)	Flow (%)	Compressive Strength (N/mm^2)	
						7 Days	28 Days
Series I	N0	0	0.49	1799.6	130	5.79	10.51
	N1	1.6	0.49	1813.1	125	6.38	12.06
	N2	5.4	0.49	1826.6	120	7.89	14.2
	N3	11	0.49	1833.4	113	8.14	15.26
	N4	16	0.49	1844.5	95	7.45	14.18
Series II	N5	0	0.4	1863.7	118	5.86	10.71
	N6	1.6	0.4	1889.3	114	7.26	13.51
	N7	5.4	0.4	1903.1	107	8.49	15.56
	N8	11	0.4	1907.8	92	8.57	15.86
	N9	16	0.4	1910.1	84	8.12	15.2

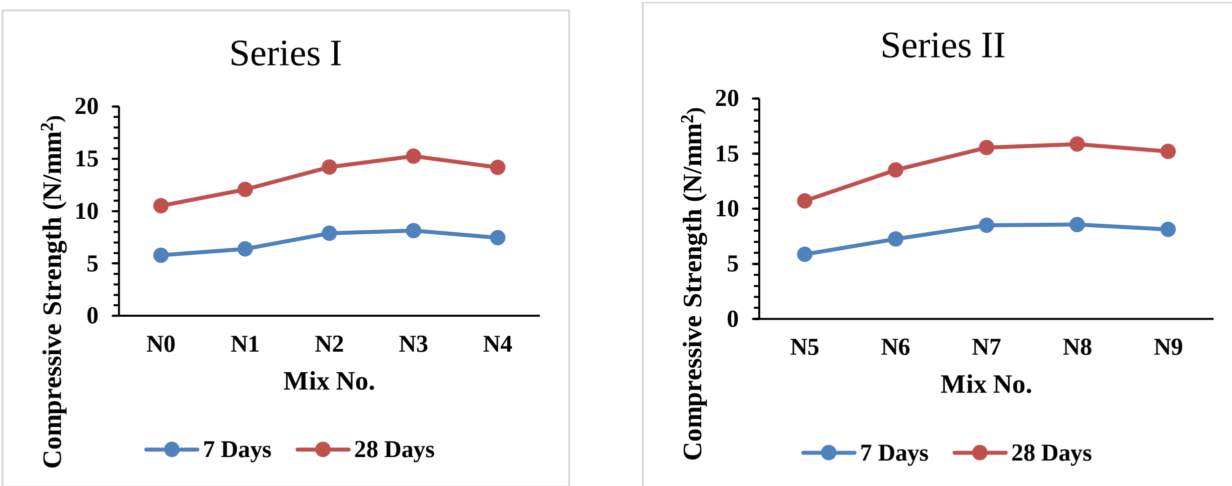


Chart 1: Compressive strength test results

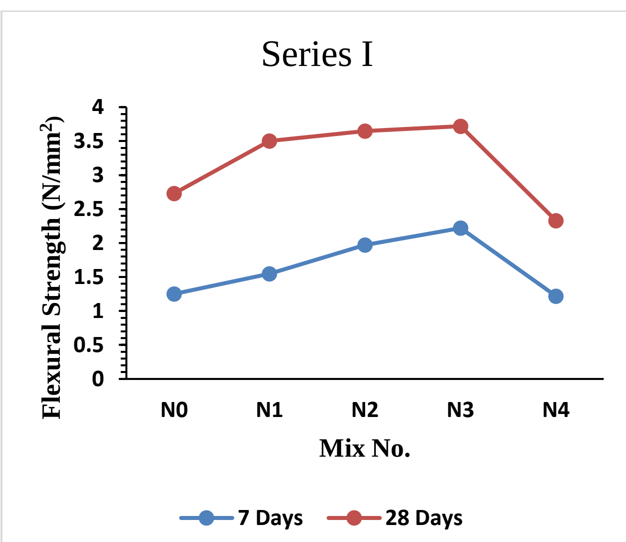
For the series I mix, it can be seen that the compressive strength increased by 14.28% with the addition of 0.06% of glass fibers compared with reference mix N0. Also, it can be noticed that the compressive strength is increased by 35.2% with the addition of 0.2% of glass fibers. Whereas, with the incorporation of 0.4% glass fibers the compressive strength increased by about 45.2% compared with mix N0, and the compressive strength increased by about 34.9% with the addition of 0.6% glass fiber when compared with N0.

For the series II mix, the compressive strength increased with the glass fibers increase. The compressive strength increased by about 26.2% with the addition of 0.06% glass fibers compared with reference mix N5. The addition of 0.2% of glass fibers would increase the compressive strength by about 45.3%. However, the incorporation of 0.4% of glass fibers increases the compressive strength by about 48.1%. Furthermore, the compressive strength increases by about 41.9% with the addition of 0.6% glass fibers from the reference mix N5 as can be noticed in. The results of compressive strength of series II mixes containing superplasticizer show that compressive strength at an early age (7 days) exhibits better performance compared with mixes without superplasticizer (series I). Chart 1 shows the gain in compressive strength of foam concrete for mixes with and without superplasticizer (series II and series I)

The results of flexural strength at the age of 7 and 28 days are provided in Table 7. The flexural strength of structural lightweight foamed concrete incorporated with different percentages of glass fibers as 0.06, 0.2, 0.4, and 0.6 % volume fraction. flexural strength increases with the percentage increase of glass fibers as seen in agree with. The relationship between the flexural strength and percentage of glass fibers for two group mixes: series I and series II (without and with superplasticizer), respectively is studied.

TABLE 8 Flexural Strength Test Results

Series	Mix No.	Glass fibers (kg/m^3)	w/c	Theoretical density (kg/m^3)	Flow (%)	Flexural Strength (N/mm^2)	
						7 Days	28 Days
Series I	N0	0	0.49	1799.6	130	1.25	2.73
	N1	1.6	0.49	1813.1	125	1.55	3.5
	N2	5.4	0.49	1826.6	120	1.97	3.65
	N3	11	0.49	1833.4	113	2.22	3.72
	N4	16	0.49	1844.5	95	1.22	2.33
Series II	N5	0	0.4	1863.7	118	1.65	2.92
	N6	1.6	0.4	1889.3	114	1.82	3.6
	N7	5.4	0.4	1903.1	107	2.13	3.71
	N8	11	0.4	1907.8	92	2.72	3.98
	N9	16	0.4	1910.1	84	2.08	2.46



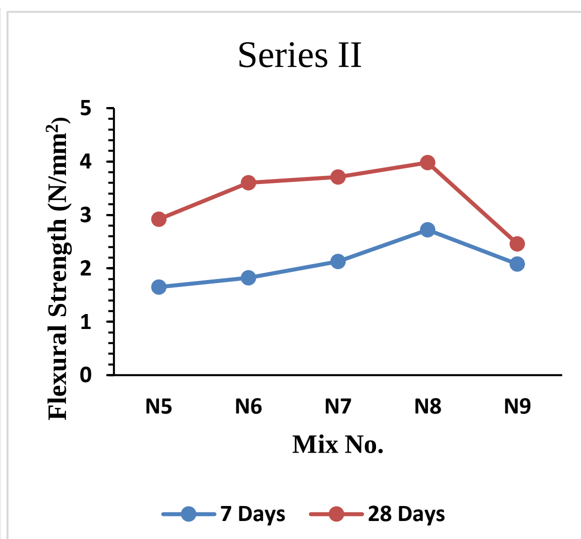


Chart 2: Flexural strength test results

For the series I mix, it can be seen that the flexural strength increased by 28.28% with the addition of 0.06% glass fibers compared with reference mix N0. Also, it can be noticed that the flexural strength is increased by 33.7% with the addition of 0.2% of glass fibers. Whereas, with the incorporation of 0.4% glass fibers the flexural strength increased by about 36.26% compared with mix N0, and the flexural strength decreased by about 14% with the addition of 0.6% of glass fiber.

For series II mixes, the flexural strength increased with the glass fibers increase, and the flexural strength increased by about 23.3% with the addition of 0.06% of glass fibers compared with reference mix N5. The addition of 0.2% of glass fibers would increase the flexural strength by about 27.05%. However, the incorporation of 0.4% of glass fibers increases the compressive strength by about 36.3%. Furthermore, the flexural strength decreases by about 15% with the addition of 0.6% glass fibers as can be noticed in. The results of flexural strength of series II mixes containing superplasticizer show that flexural strength at an early age (7 days) exhibits better performance compared with mixes without superplasticizer (series I). Chart 1 shows the gain in compressive strength of foam concrete for mixes with and without superplasticizer (series II and series I)

From the Chart 1 and Chart II, it is very clear that both compressive and flexural strength were improved with the addition of glass fibers. But it is also noticeable that the increase in strength (compressive and flexural) is only up to 0.4% of the addition of glass fibers. Further increase in the percentage of glass fibers considerably reduces the strength. Hence it is very clear that the optimum percentage of glass fiber as an additive is 0.4%.

5. CONCLUSIONS

In this paper Structural lightweight foamed concrete is produced by using a foaming agent, with an average density of 1750-1850 kg/m^3. Glass fibers and superplasticizers are used in mixes. Glass fibers are used as reinforcement for foamed concrete to enhance the mechanical properties of such concrete. From the results, the following conclusions were drawn

- The workability of structural lightweight foamed concrete decreases with the increase of glass fiber percentages. The lowest 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. The increase of the percentage of glass fiber by more than 0.6% will significantly reduce the workability.
- The microstructure of structural lightweight foamed concrete shows that the percentages of glass fibers are more effective on internal voids of structural lightweight foamed

concrete. The density increases with glass fibers percentage increase leading to a reduction in internal voids within structural lightweight foamed concrete.

- The UPV reading was 3.37 to 3.7 km/sec for mixes without superplasticizer and 3.49 to 3.84 km/sec with superplasticizer, which means the UPV reading will increase with the increase of density. Besides UPV reading would increase with the compressive strength of structural lightweight foamed concrete increase.
- The compressive strength of structural lightweight foamed concrete increases with the increase of glass fiber percentages in the mixes. For mixes without superplasticizer, the best glass fiber percentages used are 0.2 and 0.4%, and for mixes with superplasticizer, the best percentage is 0.4%. For all percentages of glass fibers in the mixes it can be observed increase in compressive strength would obtain with the volume fraction of glass fibers. For mixes without superplasticizer, the compressive strength increases up to 45.2% with the addition of 0.4% glass fibers, and for mixes with superplasticizer, the flexural strength increases by 48.1% with the addition of 0.4% of glass fibers.
- The flexural strength increases with the increase of glass fiber percentages in the mixes. For mixes without superplasticizer, the flexural strength increases up to 36.26% with the addition of 0.4% glass fibers, and for mixes with superplasticizer, the flexural strength increases by 27.05% with the addition of 0.4% of glass fibers.

REFERENCES

[1]Kamarulzaman, N. B., 2010, 'An investigation on effect of quarry dust as sand replacement on compressive and flexural strength of foam concrete', bachelor of civil engineering thesis, universiti Malaysia Pahang.

[2]Owens, P., Newman, J. and Choo B. S., 2003, Advanced Concrete Technology Processe, Elsevier Ltd.

[3]Libre, N. A., Shekarchi, M., Mahoutian, M., and Soroushian, P., 2011, ‘Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice’, Construction and Building Materials, vol. 25, pp. 2458–2464.

[4]Li, Z., 2010, Advanced Concrete Technology, John Wiley & Sons, Canada, pp. 317.

[5]Fouad, H. F., Lamond, J. F. and Pielert J. H., 2006, Significance of Tests and Properties of Concrete and Concrete-Making Materials, stp 169d, ASTM International.

[6]Ramamurthy, K., Kunhanandan Nambiar, E. K. and Indu Siva Ranjani, G., 2009, ' A classification of studies on properties of foam concrete', cement and concrete composites, vol. 31, pp. 388-396.

[7]Zahari, N. M., Rahman, I. A., and Ahmad Zaidi, A. M., 2009, 'Foamed Concrete: Potential Application in Thermal Insulation', Malaysian Technical Universities Conference on Engineering and Technology, pp. 47-52.

[8]Dawood, E. T., and Ramli, M., 2011, 'High strength characteristics of cement mortar reinforced with hybrid fibres', Construction and Building Materials, vol. 25, pp. 2240– 2247.

[9]Abdullah, M. M., and Jallo, E. K., 2012, 'Mechanical properties of glass fiber reinforced concrete', Al-Rafidain Engineering, vol. 20, no. 5, pp. 128-135.

[10]Chandramouli, K., Srinivasa R. P., Pannirselvam N., Seshadri, S.T.,andSravana, P., 2010, 'Strength properties of glass fibre concrete', Journal of Engineering and Applied Sciences, vol. 5, no. 4, pp. 1-6.

[11]IQS No: 5, 1984"Characteristics of OPC" Central Agency for standardization and quality control, Iraq.

[12]ASTM C 33-02a, 2002, standard specification for concrete aggregates, annual book of ASTM, standards, vol. 04.02