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# Effect of Glass Fibers on Tensile Strength of High Performance Lightweight Foamed Concrete (HPLWFC)

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**Abstract: High performance lightweight foamed concrete has the same mechanical properties of normal weight concrete (conventional concrete). The main applications are void filling, bridge abutments, bridge decks, marine structures, frame buildings, roads, sewer systems, roofing, walls, and floors. However, concrete is extensive brittleness and considered weak material in tension. Glass fibers are used as additive to the lightweight foamed concrete to increase the energy absorption capacity. The work was prepared to investigate the effect of glass fibers on tensile properties of lightweight foamed concrete with different volume fraction of glass fibers (0.06, 0.2, 0.4 and 0.6%) by the testing fresh density, dry density, flowability, compressive strength, direct tensile strength and splitting tensile strength. The results showed that a reduction in flowability was obtained with increased glass fibers content. Besides, the fresh and dry densities increased with the addition of glass fibers. Also, significant enhancements in compressive strength, direct tensile strength and splitting tensile strength were got by glass fibers inclusion. Thus, the increase of compressive strength, direct tensile strength and splitting tensile strength were up to the 56.6%, 50% and 46%, respectively, due to 0.6% glass fibers.**

**Keywords: Lightweight Concrete; Lightweight Foamed Concrete (LWFC); Glass Fibers (GF).**

## 1. Introduction

Aerated concrete is known as lightweight foamed concrete (LWFC). LWFC is lighter than normal weight concrete by mixing foams into cement slurry, LWFC has been a very recognized material with its noticeable characteristics particularly in thermal insulation with a low thermal conductivity between 0.10 W/mK to 0.66 W/mK [1,2]. Density of foam concrete about ( 400 to 1600 kg/$m^3$) depending on proportion of foam agent and water, foam concrete can be using for structural application, partition, insulation and filling grades [2]. The structural lightweight concrete having bulk density lower than 1950 Kg/$m^3$and compressive strength more than 17 MPa. The structural lightweight concrete is 25% lighter than normal-weight concrete with a compressive strength up to 60 MPa [3]. The main reason of using lightweight concrete for structural purposes is to reduce the self-weight of concrete structures. Reducing the dead load of the structure is very important in earthquake regions, for tall buildings, and special concrete structures [4].

The Concrete is substantial brittleness, and 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. Concrete with fibers have wide range of usage due to their obvious advantages over ordinary concrete. The function of the use fibers in concrete to enhance the mechanical properties of 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. The concrete with fiber as additive are used widely in highways, tunnel linings, concrete pipes, reinforced concrete frames, reinforced concrete beam members, shell roof systems, skyscrapers and pre-stressed concrete, light shell constructions, domes and folded plates in recent years [5-9]. (Ghorpade, 2010) [10] investigated the effect of glass fiber on high performance concrete with silica fume as admixture. The length of fiber is 12mm and the specific gravity of the fiber is 2.68. Glass fibers by 0, 0.5, 1.0, and 1.5 % to produce high performance concrete. The maximum percentage increase in compressive strength is observed at 1% fiber and 10% silica fume. The flexural strength is increased up to 1% of fiber volume then the strength is decreased. It is also observed that the use of glass fiber up to 1.0% percentage increases the splitting tensile strength. (Murthy et al., 2012) [11] studied the performance of glass fiber reinforced concrete. The results shows the increase in compressive strength is nominal while the flexural strength increased significantly as expected with the increase in percentage of glass fiber. Also, significant reduction in the slump value of the glass fiber reinforced concrete was observed with increase in glass fiber content. (Chandramouli et al., 2010) [12] founded the addition of glass fibers to concrete enhance the mechanical properties of the concrete. Significance improved in the compressive strength, flexural strength and splitting tensile strength due addition 0.03% glass fibers.

## 2. Aim and Objectives of the Study

The aim of this study is to investigate the effect of glass fibers on fresh and hardened properties of high performance lightweight foamed concrete. The effects of glass fibers on flowability, fresh and hardened densities, compressive and tensile strengths on high performance lightweight foamed concrete (direct tensile strength and "indirect" splitting tensile strength) with various volume fraction of glass fibers (GF). However, this paper shows the performance of lightweight foamed concrete reinforced with different percentages of glass fibers and the tensile behavior of such concrete is highlighted.

## 3. Materials and Mix Proportions

### 3.1 Materials

**Cement:** The cement used in mortar mixtures was Ordinary Portland cement (OPC) type I from Badoosh manufacture in Nineveh Governorate of Iraq was used in this study, the physical characteristics according to IQS : 5/1984 [13] are shown in Table 1, the chemical compositions of cement according to ASTM C 150 [14] are shown in Table 2.
**Sand:** 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 [15] are given in Table 3.
**Water:** Potable water was used in this study.
**Foam Agent:** Foam agent was used to obtain lightweight foamed 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 manufacturer.
**Glass Fibers (GF):** The glass fibers were used in the lightweight foamed concrete. Straight shape fibers are 12 mm length. The properties of the glass fibers are listed in Table 4.

Table 1: Physical characteristics of ordinary Portland cement

| **Tests** | **Results** | **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 | Min. 230 $m^2/kg$ |
| Compressive strength of 50 mm cubic mortar specimen (MPa)<br>3 days<br>7 days | <br><br>23<br>30 | <br><br>Min. 15 MPa<br>Min. 23 MPa |

Table 2: 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 | $\leq 6\%$ |
| $SO_3$ | 2.6 | $\leq 2.3\%$ |
| Loss of ignition | 1.59 | $\leq 3\%$ |
| Insoluble residue | 0.24 | $\leq 0.75\%$ |
| 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 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.50 (0.3) | 24.65 | 5-30 |
| No.100 (0.15) | 7.26 | 0-10 |

Table 4: Characteristics of glass fibers

| Fiber properties | Quantity |
|---|---|
| Aspect ratio | 857 |
| 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 |
| Shape | Straight |

### 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 to obtain structural lightweight foamed concrete, this proportion was found by many trial mixes to obtain structural lightweight foamed concrete as shown in Table 5. The foam agent used was 1 kg/m$^3$ in all mixes. 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 manufacturer. This is calculated as a part of the total water of the mix. Mortar and foam should be blended to make homogeneous mix. Glass fibers are incorporated in different proportions of volume fraction as shown in Table 6. The mix should have a uniform dispersion of the fibers in order to prevent segregation or balling of the fibers during mixing [9].

Table 5: Mix proportions

| Mix no | Mix Proportion | w/c | Cement (kg/m$^3$) | Sand (kg/m$^3$) | Water (kg/m$^3$) | Foam agent (kg/m$^3$) | Voids (%) |
|---|---|---|---|---|---|---|---|
| M0 | (1:2.25) (cement : sand) | 0.49 | 465 | 1046 | 228 | 1 | 23 |

Table 6: Volume fraction of glass fibers

| Mix no. | T0 | T1 | T2 | T3 | T4 |
|---|---|---|---|---|---|
| Glass fibers (%)* | 0.0 | 0.06 | 0.2 | 0.4 | 0.6 |

*Percentages of glass fibers taken by total volume of concrete.

## 4. Experimental Works: Casting, Curing, and Testing of Concrete Specimens

After completion of mixing materials, fresh concrete properties were tested, flowability and fresh density. Three cubes were cast (100×100×100 mm) for each mix to determine the compressive strength and tested at 28 days according to BS 1881: part 116 [16]. The three Briquet specimens were cast for direct tensile strength and tested at 28 days according to ASTM C 190 [17] as shown in Figure 1. Three cylinders were cast (100 mm in diameter and 200 mm in height) to determine the splitting tensile strength (indirect tensile strength) and tested at age 28 days according to ASTM C 496 [18] as shown in Figure 2. 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). Each mix proportion was measured in term of flow (flowability) according to ASTM C 1437 [19]. The fresh density was measured by using container of known weight and volume according to ASTM C 138 [20]. 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

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of 23 ºC ± 2 ºC according to ASTM C 192 [21]. The dry density and voids were determined using 100 mm cubes according to ASTM C 642 [22].

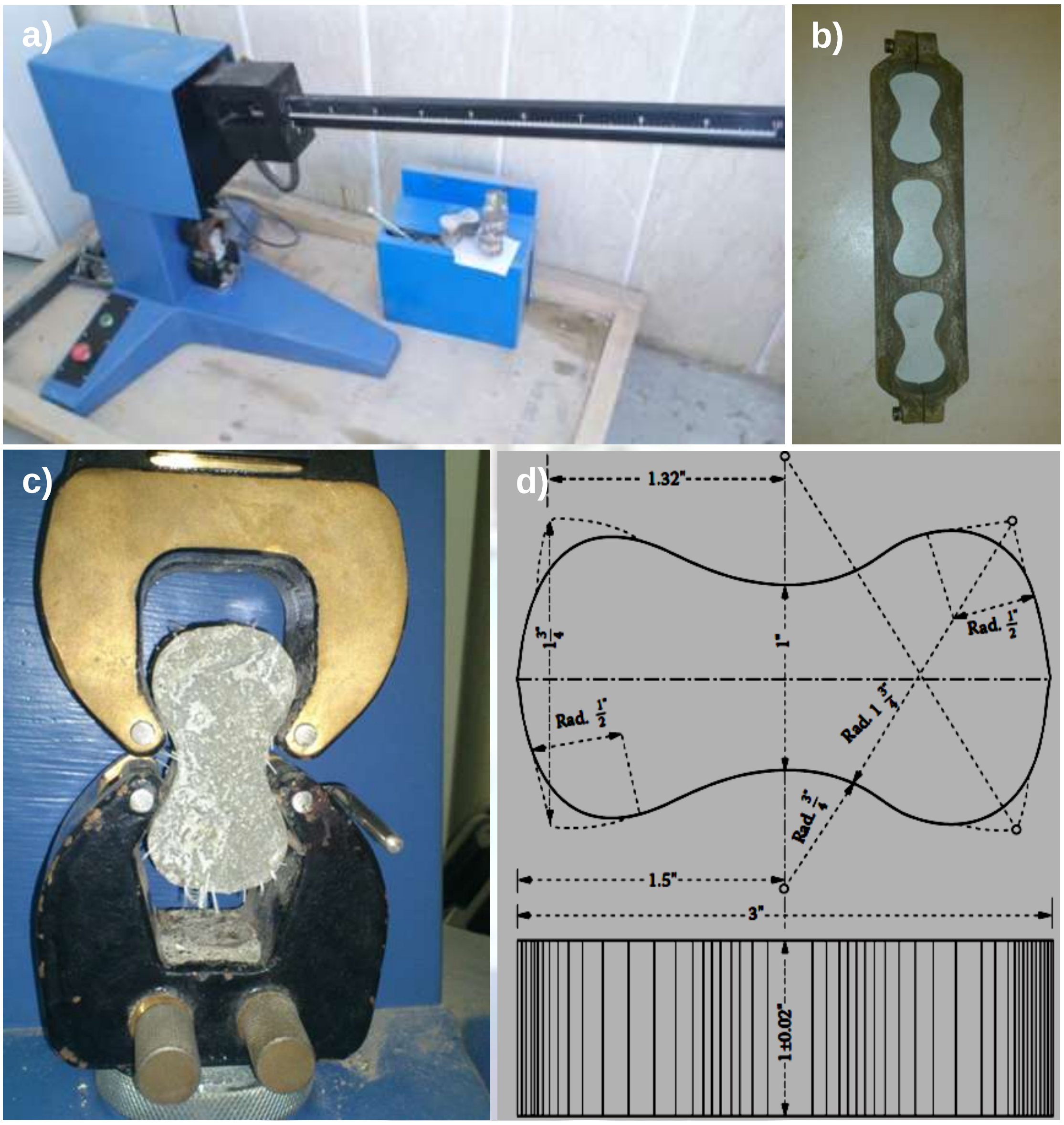


Figure 1: a) Direct tensile strength machine. b) Briquet of direct tensile strength. c) Specimen inside the direct tensile strength test machine after 28 days. d) Standard dimensions of Briquet according to ASTM C 190.

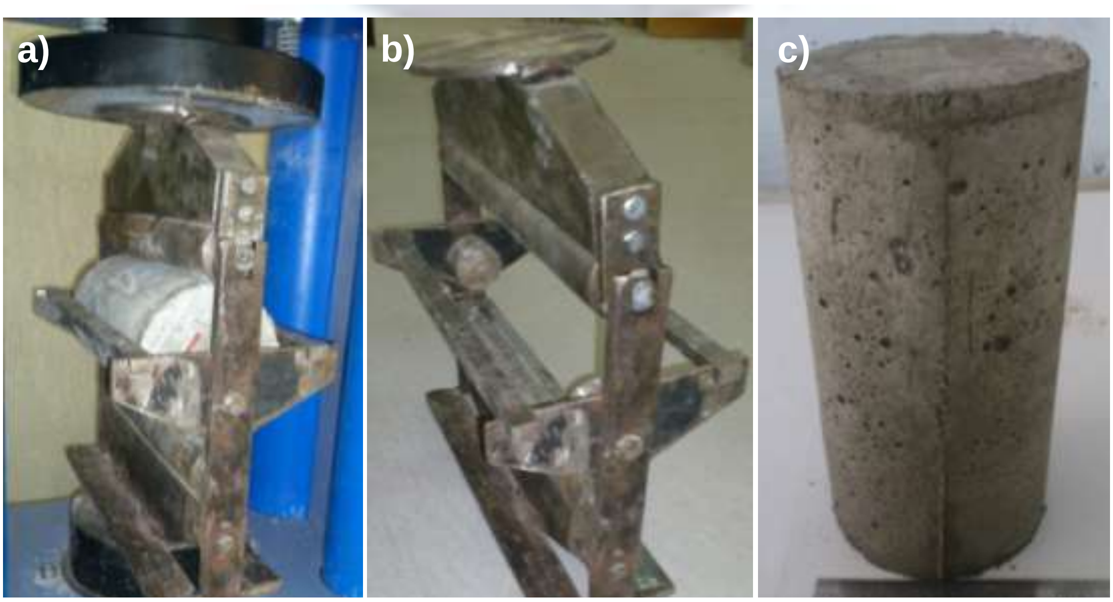


Figure 2: a) Specimen positioned in a testing machine for determination of splitting tensile strength. b) Assembly of test for splitting tensile strength. c) Cylinder foam concrete specimen 100 mm in diameter and 200 mm in length.

### 5. Results and discussions

#### 5.2 Fresh and dry density

The fresh density of lightweight foamed concrete increased with the addition of glass fibers. The fresh density for reference mix (T0) was 1755 kg/m$^3$ and increased up to 1860 kg/m$^3$ with addition 0.6% glass fibers as shown in Table 7. Continuously, The dry density increased with glass fibers content. The dry density of reference mix (T0) was 1670 kg/m$^3$, and the dry density for mixes with addition 0.06%, 0.2%, 0.4% and 0.6% glass fibers were 1680, 1710, 1755 and 1800 kg/m$^3$. Figure 3 shows the relationship between glass fibers percentages and dry density. However, the dry density of lightweight foamed concrete is increased with the addition of glass fibers.

#### 5.2 Flowability

The flowability (workability) was measured according to ASTM C 1437, the flow for lightweight foamed concrete reinforced with glass fibers varied among mixes depending on volume fraction of glass fiber, the flow of the various mixes are given in Table 7. The flow varied between (130-100%), the flow was about 130% for reference mix (T0), and flow reduced with the increase of glass fibers. Thus, the use of 0.6% of glass fibers gave least reduction in the flow to 100%, this reduction in flow attributed to the hindrance offered to the aggregates by the fibers to freely slip past the adjoining aggregates due to their geometry [11]. Figure 4 shows the effect of glass fibers percentages on the flowability of lightweight foamed concrete, this relationship illustrates that the flowability (workability) reduces with the increase of fibers [23].

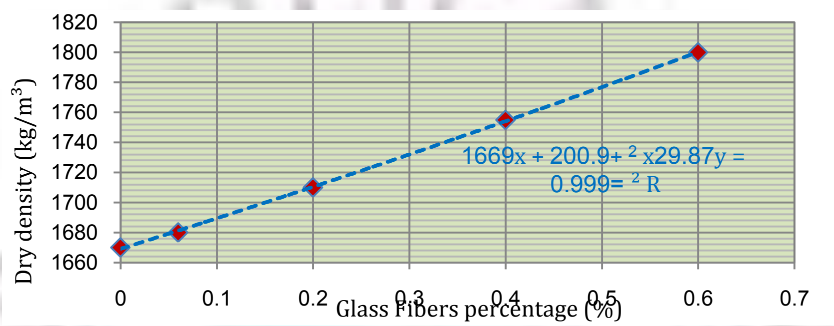


Figure 3: Effect of glass fibers percentage on the dry density of lightweight foamed concrete

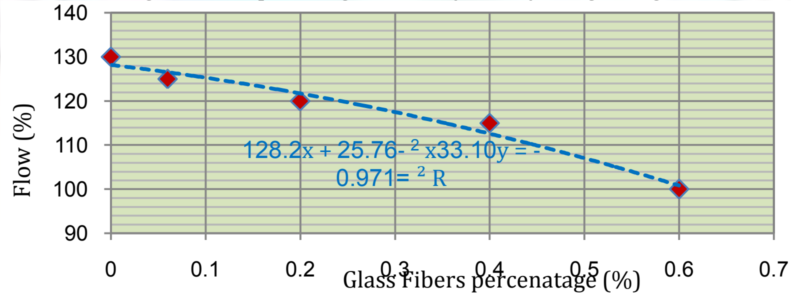


Figure 4: Effect of glass fibers percentage on flowability of lightweight foamed concrete

#### 5.3 Compressive Strength

The results of compressive strength at 28 days are shown in Table 7. The compressive strength of lightweight 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 as seen in Table 7. It can be observed that the compressive strength increased by about 8%, 28.4%, 42.6% and 56.6% with addition 0.06%, 0.2%, 0.4% and 0.6% glass fibers respectively, compared with reference mix (T0). Figure 5 shows the relationship between the percentage of glass fibers and compressive strength of lightweight foamed concrete.

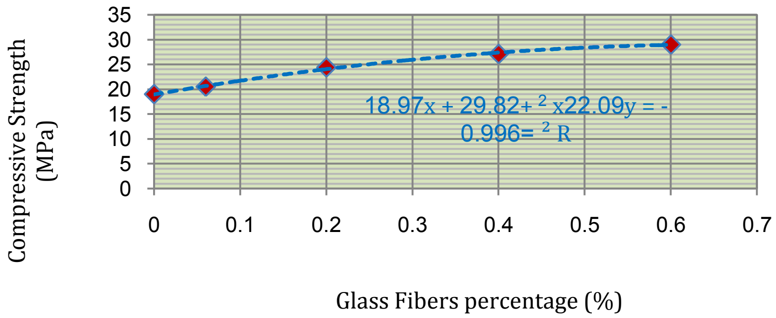


Figure 5: Effect of glass fibers percentage on compressive strength of lightweight foamed concrete

### 5.4 Direct Tensile Strength

Table 7 gives the test results of direct tensile strength at 28 days. The average direct tensile strength without glass fibers mix (T0) is 1.5 MPa. However, the addition of glass fibers will enhance the tensile strength of lightweight foamed concrete with glass fibers percentage increase. It can be observed that the increase in direct tensile strength of the lightweight foamed concrete at 28 days was up to 50% with 0.6% glass fibers (T4), compared with the reference mix (T0). Besides, the direct tensile strength increased by about 6.6%, 22.6% and 40% with the addition of 0.06%, 0.2% and 0.4% glass fibers, respectively. Figure 6 shows the effect of glass fibers percentages on direct tensile strength of lightweight foamed concrete. The shape of specimens failure in the direct tensile test are shown in Figure 7.

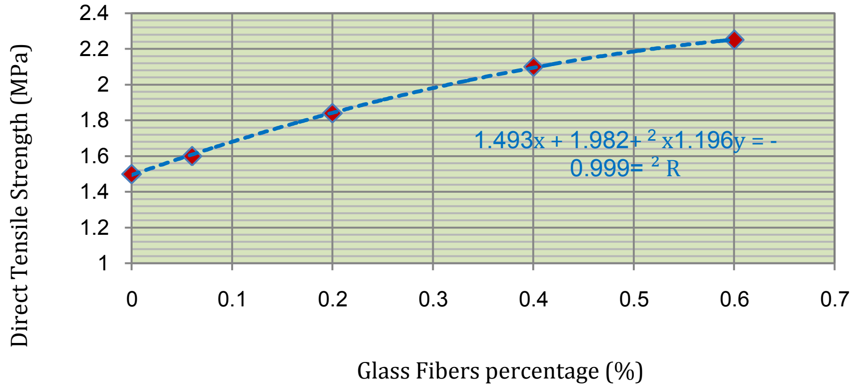


Figure 6: Effect of glass fibers percentage on the direct tensile strength of lightweight foamed concrete.


Figure 7: Shape of specimens failure after direct tensile test.

### 5.5 Splitting Tensile Strength (Indirect Tensile Strength)

Lightweight foamed concrete reinforced with glass fibers, the splitting tensile strength increased with the percentage increase of glass fibers. These results are comparable with other researches [10,24]. The highest splitting tensile value obtained by the maximum volume fraction of glass fibers (0.6%) added to the lightweight foamed concrete. The increase of splitting tensile strength of the LWFC reinforced with glass fibers at 28 days was up to 46% for lightweight foamed concrete with 0.6% glass fibers (T4) compared with the reference mix (T0). The incorporation of 0.2% and 0.4% glass fibers increases the splitting tensile strength by about 15.7% and 31.5%, respectively, compared with reference mix (T0) as shown in Table 7. Figure 8 shows the relationship between glass fibers percentages with splitting tensile strength of lightweight foamed concrete.

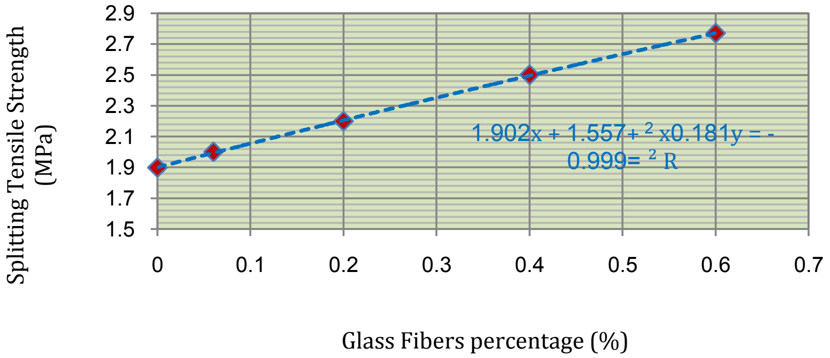

Figure 8: Effect of glass fibers percentage on the splitting tensile strength of lightweight foamed concrete

Table 7: Fresh and Hardened properties of HPLWFC

| Mix no. | Fresh density (kg/m$^3$) | Dry density (kg/m$^3$) | Flow (%) | Compressive strength (MPa) | Direct tensile strength (MPa) | Splitting tensile strength (MPa) |
|---|---|---|---|---|---|---|
| T0 | 1755 | 1670 | 130 | 19.0 | 1.50 | 1.90 |
| T1 | 1765 | 1680 | 125 | 20.5 | 1.60 | 2.00 |
| T2 | 1790 | 1710 | 120 | 24.4 | 1.84 | 2.20 |
| T3 | 1825 | 1755 | 115 | 27.1 | 2.10 | 2.50 |
| T4 | 1860 | 1800 | 100 | 29.0 | 2.25 | 2.77 |

## 6. Conclusion

The experimental work on the lightweight foamed concrete reinforced with various volume fractions of glass fibers shows the following conclusions:

- The flowability of the lightweight foamed concrete reinforced with glass fibers decreased significantly with increase in the percentage of fibers. The fresh and dry density of lightweight foamed concrete increased with the addition of glass fibers.
- The addition of glass fibers into the lightweight foamed concrete mixture greatly improves the tensile strength. The compressive strength, direct tensile strength and splitting tensile strength increased up to 56.6%, 50% and 46% respectively with 0.6% of glass fibers. Thus, such percentage of glass fiber would highly enhance the properties of lightweight foamed concrete.
- The use of glass fibers may result in compatible increase in compressive and tensile strengths.

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