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The Sustainable Production of Lightweight Concrete Using Polystyrene Foam

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***Abstract*—Lightweight concrete that can be casted using lightweight cement, ultra-light aggregates, hollow sealed spheres made of ceramic and glass, clay bubbles entrapping air, foam material like polystyrene and recycled materials concrete has extreme importance in the construction industry.**

The weight of the cubes has reduced approximately 22, 26, and 27% using 5, 10, and 15% adding polystyrene foam, respectively. For the 5 % added polystyrene foam, the compressive strengths of the 7, 14, and 28 days increased with 22, 7, and 6%, respectively. While for the 10 % of polystyrene enhanced the compressive strength value of the 28 days with 2.6%. Finally, the compressive strengths of the 15 % of polystyrene cubes were degraded with 29, 28, and 4 %, at 7, 14, and 28 days, respectively.

Regarding the flexural tensile strength, the more the added polystyrene foam, the lower is the related tensile. the flexural tensile strengths, at 7, 14, and 28 days, reduced with 16, 17, and 6 %, respectively adding 5 % of polystyrene foam, reduced with 26, 28, and 16 %, respectively adding 10 %, and reduced with 41, 39, and 33 %, respectively when 15 % of polystyrene foam was used.

Keywords*— *Lightweight Concrete, Polystyrene Foam, M15 Design Mix, Compressive Strength, Flexural Tensile.

I. Introduction

Light weight concrete has extreme importance in the construction industry. Most of current concrete research focuses on high-performance concrete, by which is meant a Cost-effective material that satisfies demanding performance requirements, including durability.

Several materials and additives, such as lightweight cement [1], ultra-light aggregates [2], hollow sealed spheres made of ceramic and glass [3], clay bubbles entrapping air [4], foam material like Polystyrene and recycled materials [5-6], are used to reduce the total weight of the concrete.

The main challenge with lightweight concrete is its strength because without using the classical heavy/solid aggregates, lightweight concrete cannot support the same loads as the traditional plain concrete [2].

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In this research, Polystyrene-based lightweight concrete has been casted and studied in terms of weight, compressive strength and flexural tensile. Moreover, the concrete grade M15, which can be used mainly as plain concrete for leveling course and bedding for footings were selected.

Expanded polystyrene is an industrial material that is being used in substantial quantities in packaging and insulating material. EPS, therefore the produced wastes can be recycled, to reduce its pollution footprints, by using it in lightweight concrete production [7].

A total number of 66 cubes are casted out in two phases. The both phase lasted for a period of 28 days, each, where the cubes were divided into three testing specimens cured for 7, 14, and 28 days. A total number of 12 cubes were casted with no additives, a total of 45 specimens using 5, 10, and 15 % of polystyrene foam (18 cubes, each).

II. Experiment

Here, the detailed steps of the experiment will be thoroughly explained.

A. *Design Mix*

The design of concrete mixes is concerned mainly with the determination of the proportions of the various concrete constituents, namely, cement, water, fine aggregates (FA) and coarse aggregates (CA) and admixtures, if any, which would produce concrete of specified properties both in its fresh and set states. The main indicator for fresh state is the workability of the concrete mix, while for the hardened state, the compressive strength and durability are the main indicators. The mix design is, therefore, carried out using the ACI 318-14 Building Code Requirements for Structural Concrete [8].

According to the mix design, the targeted concrete grade is M15. Such a grade is characterized with a compressive strength of 15 N/mm^2 at 28 days with a nominal maximum size of aggregate equivalent to 20 mm. Such maximum size produces 2%, in terms of concrete volume, of entrapped air.

B. *Water to Cement Ratio*

The water to cement ratio (w/c) that coincides with the targeted 28-day compressive strength of M15 grade is 0.57 with a maximum value of 0.6 for moderate exposure, according to the IS 10262-2009 [9]. The maximum water content that coincides with the maximum aggregate size, i.e., 20 mm, equals to 186 liters, which will be adjusted to the compaction factor of zone 2, turning to 191.6 $liter/m^3$.

On the one side, the minimum cement content for the M15 grade is 240 km/m^3, according to the IS 456-2000 [10]. On the other hand, the weight of Ordinary Portland Cement, whose

specific density is 3.15 tons/m^3, which coincides with the computed w/c is 336.14 kg/m^3.

C. Aggregates

The volume of CA that coincides with the M15 grade concrete is 0.62 of the total aggregates volume. Using Equation 1, the amount of the FA and CA are 673.52 and 1120 kg, respectively. The specific gravity of the FA is 2.60 tons/m^3 and 2.65 tons/m^3 for the CA.

$$V = \left[W + {}^{C}/_{G_C} + \frac{1}{1-P} \cdot \frac{V_{FA}}{G_{FA}}\right] \times \frac{1}{1000} \qquad \textbf{Equation 1}$$

where V: the volume of the mix equals 0.98, W is the water content, C is the cement content, G_i is the specific density of the component i, P is the volume of the CA with respect to the total aggregates of zone 2, and V_{FA} is the volume of the FA.

D. Mix Portions

In order to summarize the obtained volumes/weights of the concrete ingredients, i.e., w/c ratio equivalent to 0.57, Cement quantity of 337 kg, FA quantity of 674 kg, and CA quantity equivalent to 1120 kg, the mix portions can be reported as Cement:FA:CA=1:2:3.3.

E. Admixtures

Among the most prominent chemical compounds widely used in light concrete in Saudi Arabia (see Figure **1**), Polyurethane with polystyrene is the most interactive and quality ensuring compound for thermal and water insulation.

The polystyrene insulation (see Figure **2**) has been selected due to its sustainability as it is a green insulation made from recycled or all-natural products. On the one side, polystyrene insulation can withstand extreme temperatures as well as it is waterproof and noise reducer with long working life. The engineering properties of such chemical compound are reported in Table **1**.

III. Results

A total number of 63 cubes were casted for plain concrete and using 5, 10, and 15%, in terms of weight, of the polystyrene foam agent. For the purpose of this research, we will focus the light on the compressive strength, conducted according to the BS188:Part 116:1983 using Unit Test DHR 200 machine [11], after 7, 14, and 28 days.

A. Compressive Strength (7 days)

Table **2** summarizes the weight of the casted cubes as well as the achieved compressive strength after 7 days.

B. Compressive Strength (14 days)

Table **3** summarizes the weight of the casted cubes as well as the achieved compressive strength after 14 days are.

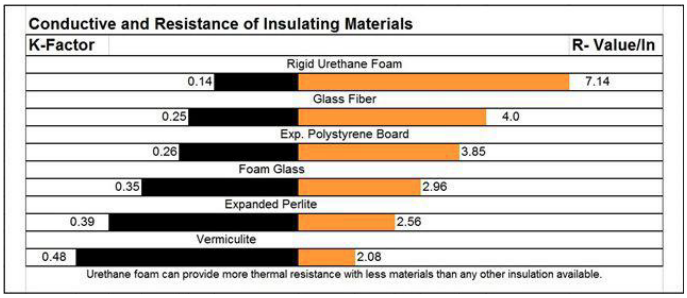

Figure 1: The chemical compounds used in light concrete.

Table 1: The engineering properties of the Polyurethane with polystyrene samples.

Property	*Value*
Hardness [Shore A]	90 ± 2
Tensile Strength [kg/cm]	200 - 300
Elongation [%]	500 - 600
Tear Strength [kg/cm]	90 - 130
Working Temprature [^{o}C]	60 - 70
Melting Point [^{o}C]	175

Table 2: The engineering properties of the casted concrete cubes of grade M15 after 7 days.

Nº	Light Weight Concrete of grade M15				
	Foam Agent [%]	Weight [kg]	Average Weight [kg]	Compressive Strength [N/mm^2]	Average Strength [N/mm^2]
A-C	0		10.50		10.00
1	5	8.10	8.21	11.0	12.20
2	5	8.22		12.6	
3	5	8.30		13.0	
4	10	7.70	7.70	14.12	14.05
5	10	7.80		13.56	
6	10	7.60		13.46	
7	15	7.80	7.63	13.63	13.21
8	15	7.70		13.14	
9	15	7.40		12.87	

C. Compressive Strength (28 days)

Table **4** summarizes the weight of the casted cubes as well as the achieved compressive strength after 28 days are summarized.

D. The Flexural Tensile

The flexural tensile strength is an indicator for the tensile strength of the tested specimens, which has been determined following the standard ACI 368 test recommendations. A total number of 12 beams were casted and cured in order to perform the flexural tensile tests, where 3 beams were casted for each case, i.e., 0, 5, 10, and 15 % added polystyrene foam.

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Figure 2: The steps of preparing the polyurethane compounds.

Table 3: The engineering properties of the casted concrete cubes of grade M15 after 14 days.

Nº	Light Weight Concrete of grade M15				
	Foam Agent [%]	Weight [kg]	Average Weight [kg]	Compressive Strength [N/mm^2]	Average Strength [N/mm^2]
D-F	0		10.40		10.80
10	5			13.0	12.76
11	5			12.0	
12	5			13.3	
13	10			10.2	9.90
14	10			9.7	
15	10			9.8	
16	15			8.12	8.66
17	15			9.65	
18	15			8.22	

Table 4: The engineering properties of the casted concrete cubes of grade M15 after 28 days.

Nº	Light Weight Concrete of grade M15				
	Foam Agent [%]	Weight [kg]	Average Weight [kg]	Compressive Strength [N/mm^2]	Average Strength [N/mm^2]
G-I	0		10.35		14.80
19	5			14.62	14.47
20	5			14.34	
21	5			14.46	
22	10			9.22	9.47
23	10			9.84	
24	10			9.35	
25	15			7.23	7.13
26	15			7.16	
27	15			7.00	

The average flexural tensile strength for the various percentile of added the polystyrene foam agent at 7, 14, and 28 days is summarized in Table **5**.

Table 5: The average flexural tensile strength of the casted concrete cubes of grade M15 at 7, 14, and 28 days.

Nº	Light Weight Concrete of grade M15			
	Foam Agent [%]	Flexural Tensile Strength [MPa]		
		7 Days	14 Days	28 Days
28-30	0	4.45	5.81	6.43
31-33	5	3.73	4.82	6.05
34-36	10	3.29	4.18	5.43
37-39	15	2.63	3.57	4.30

IV. Discussion

First of all, the weight of the casted cubes decreases with the increase of the percentage of the added polystyrene foam agent. The bulk weight (see Figure **3**) of the casted cubes has reduced approximately 21.8, 26.7, and 27.3% for the 5, 10, and 15% added-foam with respect to the original weight, i.e., 10.5 kg.

On the one hand, for plain concrete with no additives, the compressive strength has increased 19 % and 37 % after 14 and 28 days compared with that of 7 days, as shown in Figure **4**. When just 5 % of polystyrene foam was added, the compressive strengths of the 7, 14, and 28 days increased with 22, 7.2, and 5.6%, respectively.

While adding 10 % of polystyrene appears to have negatively affected the compressive strength with a percentage of 5.3 % after 7 days and 16.8 % after 14 days, it has enhanced the compressive strength value of the 28 days with 2.6%. Finally, adding 15 % of polystyrene foam has weakened the compressive strengths at the 7, 14, and 28 days with 28.7, 27.2, and 3.6 %, respectively.

Regarding the flexural tensile strength, the more the added polystyrene foam, the lower is the related tensile strength (see Figure **5**).

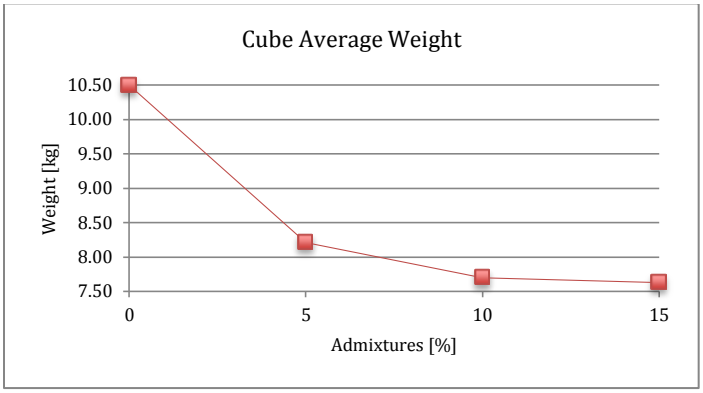


Figure 3: The average weight of the cubes in terms of the percentage of added polystyrene foam agent.

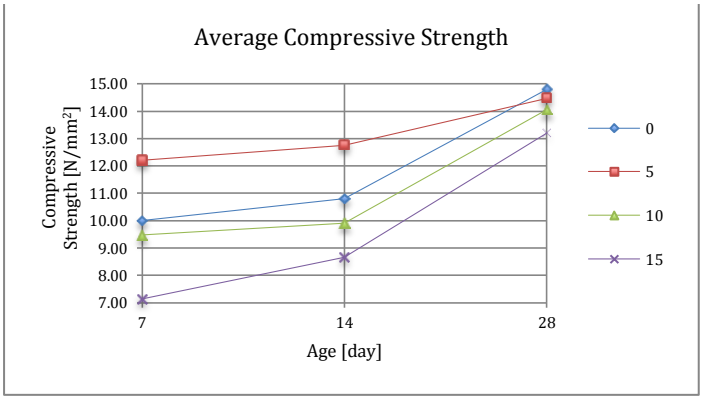
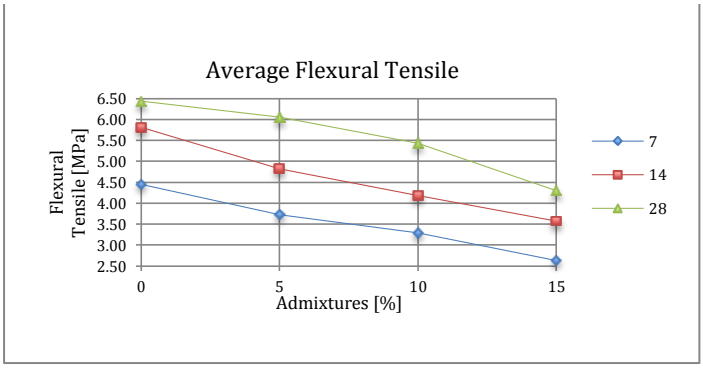


Figure 4: The average compressive strength of the casted cubes in terms of the added the polystyrene foam agent.



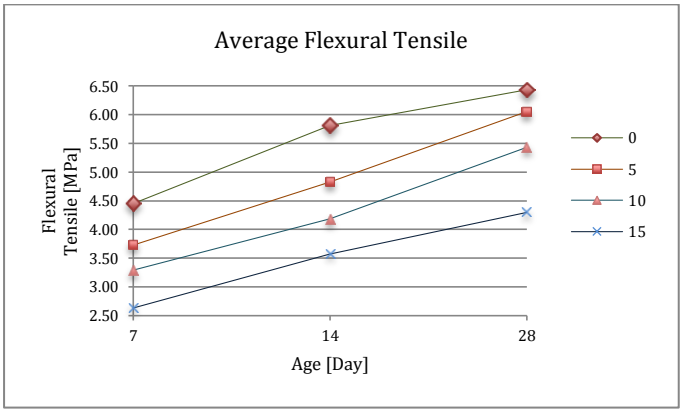


Figure 5: The average flexural tensile of the casted cubes in terms of the added the polystyrene foam agent.

Adding 5 % of polystyrene foam, reduced the flexural tensile strength at 7, 14, and 28 days with 16.2, 17.0, and 5.9 %, respectively, while adding 10 % has reduced the flexural tensile strength at 7, 14, and 28 days with 26.1, 28.1, and 15.5 %, respectively with respect to the flexural tensile strength with no admixtures added.

Finally, the addition of 15 % reduced the tensile strength at 7, 14, and 28 days with 40.8, 38.5, and 33.1 %, respectively with respect to the flexural tensile strength with no admixtures added.

I. Conclusion

Polystyrene that has thermal and water insulation capabilities, can be sustainably recycled and utilized in light concrete industry, which, in turn, is waterproof and good noise reducer that can sustain high temperatures.

On the one side, the more the added add foam agent, the lower the weight of casted concrete. While, the compressive strength of the specimens casted with 5 % polystyrene foam agent is almost identical to that of plain concrete without any additives at 28 days. On the contrary, using 10 and 15 % of polystyrene foam noticeable decreases the compressive strength with average percentages of 6.0 and 19.8 % at 28 days.

On the other side, flexural tensile strength decreases with the increase of the used percentile of polystyrene foam for all the testing epochs, i.e., 7, 14, and 28 days. The reduction percentages can be as low as 5.9 % (5 % polystyrene foam at 28 days) and as high as 40.8 % (15 % polystyrene foam at 7 days).

The one can recommend using the 5 % of polystyrene foam to produce lightweight concrete so that the one can yield all the pros, e.g., the temperature and sound insulation, bearing almost the same compressive strength.

Acknowledgment

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