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Physical and Mechanical Properties of Expanded Polystyrene Lightweight Aggregate Concrete

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***Abstract*— The aim for this study is to production of light weight concrete and determine the strength characteristic and studies the mechanical and physical properties. Several proportions of raw materials were used to produce this type of concrete. This study was used to produce light weight polystyrene concrete with rate of (1.5,3,5and10) % of cement weight. Compressive strength, indirect tensile strength, estimated modulus of elasticity (E) and bulk density tests were made on more than 60 specimens at age of 7 and 28 days. The results show that the addition of polystyrene (PS) with range of (1.5~10) %of cement weight is improve the bulk density strength with (14.8~48.68) %, the28-day compressive strength range is from (10.6~0.74) MPa, indirect tensile strength range is from (3.57~0.224) MPa, density range is from (2.43~1.25) ton/m^3. The scope of this study is to suitability of this type of concrete to be used in concrete masonry units of non-bearing walls.**

Keywords- Polystyrene, Lightweight concrete, Compressive strength, Indirect tensile strength, bulk density, modulus of elasticity.

I. INTRODUCTION

Due to the increasing population growth and urbanization and the accompanying increase in consumption rates which led to an increase in the generation of solid waste harmful to the environment. The most important pollutants are industrial cork residues polystyrene. Polystyrene is important in all aspects of practical life due to its many advantages, the most important of which is the ease of compressing and manufacturing it in accordance with the daily needs of man. One of the negative results of the industrial cork industry is the accumulation of large quantities of cork waste. Since cork is rapidly decomposed in nature, its residues have caused damage to the environment. This solid waste should be managed through the process of recycling and use in other ways [15]. In this research, a study was conducted to produce a new type of concrete which is used in the production of non-loaded construction cutters. Various proportions of polystyrene (industrial cork) were added as a percentage of cement. This material has been chosen because of its low density compared with the other types of aggregates used in the concrete industry and the concrete used in thermal insulation. In addition to their availability in Landfill which is one of the most important environmental waste that threaten human health and all elements of the environment. [14]

- *Research Significance:*

The fundamental objective of this study is to provide information on the fresh and hardened properties of aggregates concrete produced using Polystyrene to support the practical work in assessing the practicability of actually building with polystyrene aggregate concrete. Furthermore, this study aims to check whether the hardened properties modulus of elasticity concrete by the ACI. Method comply with the requirements specified by the ACI Committee ACI-8.5.1.[3]

II. MATERIALS

- *Cement*

Throughout the experimental work, ordinary Portland cement confirming to Libyan specification No.340/1997 was used. Its chemical and physical properties are given in Table I.

Table I. Physical properties of the used Ordinary Portland cement [NO.340:1997].

Physical Properties	Test results	Limit of specification
Standard W/C	30%	---
Setting time Initial Final	 140 min 3:40 hr	 00:45 (Min.) 10:00 (Max.)
Soundness	0.3 mm	10.0 mm (Max.)
Compressive strength (50.0mm cube), MPa 3-day 28-day	 25 MPa 46 MPa	 21.0 (MPa) 39.0 (MPa)

- *Fine Aggregate(Sand)*

Natural sand from Zliten area was used throughout this work. Table II, shows the grading of the fine aggregate (Sand) and the limits of the (BS specification No.882/1992). Sieve analysis of fine Aggregate is shown in Fig. 1.

Table II. Grain size test of fine aggregates [BS 882–1992 (F-Sand)].

Sieve Size (mm)	Passing (%)	Limit of specification	Pass? (X=Fall)
5.00	100.00	---	
2.36	100.00	80-100	
1.18	100.00	70-100	
0.600	99.66	55-100	
0.300	55.34	5-70	
0.150	6.87	---	
Fineness Modulus (%)			
1.38			

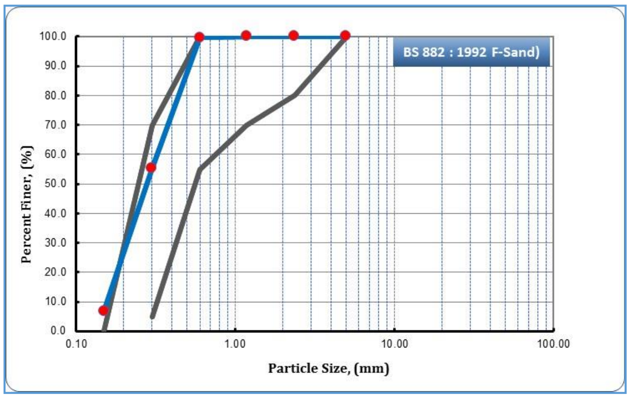

Figure 1. Grading curves of fine aggregates (Sand)

- *Coarse Aggregate:*

Crushed rock (Phonolite) with maximum size of 20 mm from Abu Arshada in Garian area was used. The coarse aggregate used conforms to the British Specification (BS: 822-1992). Table III, shows the grading of the coarse aggregate. The Fig. 2, shows the particles gradation Curve of coarse aggregate.

Table III. Grain size test of coarse aggregate [BS 882–1992].

Sieve Size (mm)	Passing (%)	Limit of specification	Pass? (X=Fall)
37.5	**100.00**	**100**	
20	**98.81**	**85-100**	
14.0	**11.69**	**0-70**	
10.0	**0.99**	**0-25**	
5.0	**0.50**	**0-5**	
2.36	**0.46**	**---**	
Fineness modulus (%)			
3.88			

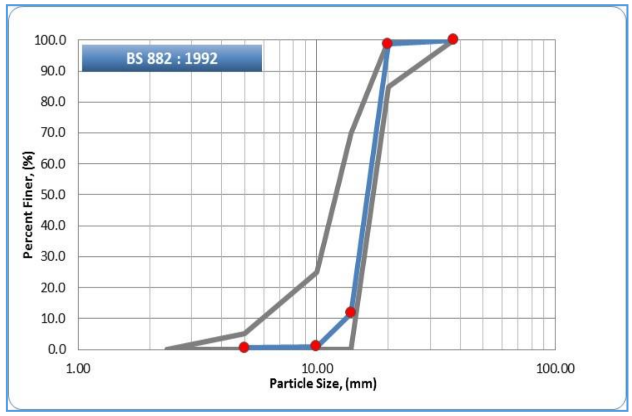

Figure 2 .Grading curves of coarse aggregate

- *Water*

Water was used throughout this research work from ground water wall the same water was used for both mixing and curing of concrete.

- *Admixtures (Polystyrene):*

The polystyrene used in this investigation was of commercial grade. It was from Al-Mnsoura company, the percentage of increase in all specimens for mixes are (0, 1.5, 3, 5, 10) % from percentage of cement. The physical properties of this polystyrene is shown in Table IV.

Table IV. Physical properties of the used polystyrene.

Physical property	Results
Diameter of granular	2 - 3 mm
Density	20 – 50 kg/m^3
Thermal conductivity, λ	0.031 – 0.047 W/m.k°
Color	White

III. CONCRETE MIX DESIGN

Concrete may be considered as being composed of four basic separate ingredients: cement, coarse aggregates, fine aggregates, and water. Another way of looking at concrete is as a graded mixture of fine and coarse aggregates held together by wetted cement. [15]

A concrete mix design can be proportioned from existing statistical data using the same materials, proportions, and concerting conditions. When there are no existing records or they are insufficient, the concrete mixture must be determined by trial mixtures. In a laboratory class situation, no body of field experience with the materials is assumed to exist [14].The method of mixture design for all concrete mixes proposed and used in this investigation is based on an absolute volume method. However, since the mix design tables are predicated on compressive strength, Equation (1) below is used to determine the approximate equivalent compressive strength (F_m) can be calculated by using the equation. [14]

$$F_m = F_{cu} + M \quad (1)$$

Where:
F_m= average design strength (MPa)
F_{cu}= minimum strength (MPa)
M= margin of safety (---)
Can be calculated (M) as follows:

$$M = K * S \quad (2)$$

Where:
M= Himsworth constant (---)
S= the standard deviation (---)

The margin of safety was considered in this study (M = +7) according to the American Institute of Concrete (ACI) in the absence of values for standard deviation (S). Where the design value of the concrete mix 25 N/mm^2 and the value of the medium resistance (Targeted) is not less than 30 N/mm^2(Shetty,M.S, 1982).

- *Concrete Mix Design by absolute Volume Method:*

This method assumes that the absolute size of the concrete is the sum of the absolute volumes of concrete constituents of cement, sand and aggregates is as follows:

$$Absolute\ Volume = 1 - \frac{W_{CA}}{1000G_{CA}} + \frac{W_{FA}}{1000G_{FA}} + \frac{C}{1000G_C} + \frac{W_W}{1000G_W} \quad (3)$$

Where:

C = content of cement (kg/m^3)

W_W= content of mixing water (kg/m^3)

W_{FA}= content of fine aggregate (kg/m^3)

W_{CA}= content of coarse aggregate (kg/m^3)

G_{CA} = specific gravity of coarse aggregate (---)

G_{CA} = specific gravity of fine aggregate (---)

G_w = specific gravity of water (---)

Tables V showed the mix proportions by weight, calculated by the equations mentioned above.

Table V. Mix proportion of concrete constituents by (Absolute volume method).

Materials	Polystyrene (%)	Cement (kg/m³)	Coarse aggregate (kg/m³)	Sand (kg/m³)	Water (kg/m³)
Mix (1) reference	—	374.5	1462.24	187.25	197.5
Mix (2)	1.5	368.9	1462.24	187.25	197.5
Mix (3)	3.0	363.27	1462.24	187.25	197.5
Mix (4)	5.0	355.78	1462.24	187.25	197.5
Mix (5)	10	337.05	1462.24	187.25	197.5

- *Fresh Concrete Tests:*

Many different test methods have been developed in attempts to characterize the properties of fresh concrete. In this study, slump tests are used to determine workability of fresh concrete. Fig. 3**,** shows the slump test of the reference mix in the quality control laboratory of the express train company.

Figure 3. The slump test according to [BS 1881 part 116].

III. HARDENED CONCRETE TEST (EXPERIMENTAL TEST)

- *Compressive strength:*

Compressive strength measures the quality and uniformity of concrete. The compressive strength is determined by using cubic specimens according to BS EN 12390-3. All the cubic specimens are tested under compression using the (ELE) testing machine, with capacity of 3000 kN and loading rate of 3 N/mm^2/min, the average compressive strength of three cubic specimens is recorded, determinant of compressive strength as shown in Fig. 4 . Compressive strength is calculated from failure load (P), the cross-sectional area of the specimen (A) and specimen by the following formula:

$$F_c` = P/A \quad (4)$$

Where:
P = the applied compressive load at failure (N)

A = the cross-sectional area of the specimen (mm^2)
F_c` = uniaxial compressive strength (N/mm^2)

Figure. 4: Compressive strength test apparatus (ELE test machine).

- *Splitting tensile strength:*

The splitting tensile strength is carried out according to (BS EN 12390-6). Cylinders of (100 × 200) are used as the same (ELE) machine was used too and the average splitting strength of three specimens was recorded. The indirect tensile strength of the specimens are determine by applying along the length of a cylindrical concrete specimen according to (BS 1881-117) at a constant rate of loading until failure occurs. Calculate the tensile splitting strength, in MPa (N/mm^2), from the equation (5). Fig.5 , shows tensile splitting strength test of cylinder specimen.

$$F_{ct}` = 2P/\pi DL \quad (5)$$

Where:

P= load at failure in N
L= the length of the line of contact in mm
D= the diameter in mm

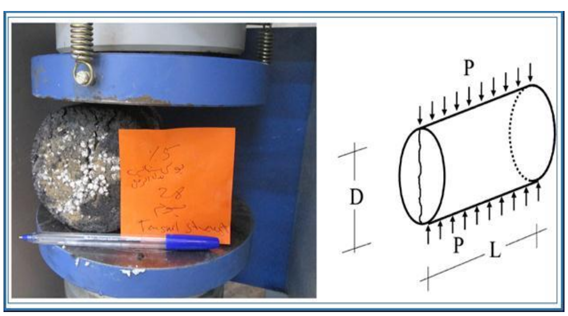

Figure 5. Machining the ELE cylinders for conducting the splitting tensile strength test.

- *Bulk density:*

The physical tests, such as density (ρ) and water absorption by weight (M_a) were performed according to BS standard (BS EN 12390-7). The density values were obtained from the ratio of the sample mass to the sample volume. Density of hardened concrete can be calculated as follows:

$$\rho = M_a/V \quad (6)$$

Where:

M_a= the mass in air in kg
V= the volume of the specimen in m^3

IV. RESULTS AND DISCUSSION

The properties of light weight polystyrene concrete mixes produced by the inclusion of polystyrene beads are shown in this section. However, from the results obtained from five mixes of lightweight concrete, as well as the reference mix.

- *Bulk Density (ρ):*

The results obtained in the bulk density test shown in Table VI varied from 2.66to 1.54ton/m^3. The density of concrete was reduced 2.66gr/cm^3 (Ref. mix). To 1.54gr/cm^3 with 10% polystyrene from percentage of cement. This is obviously related to the specific gravity of the polystyrene beads which affect the density of the concrete (Neville, A.M., 1995).[5] Fig. 6, shows the relation between density of concrete and polystyrene percentage.

Table VI. Densities of concrete.

Materials	Polystyrene (%)	Weight of specimen (kg)	Dimensions (cm)	Gross density (kg/m^3)
Mix (1) reference	—	2393.67	10*10*10	2426
Mix (2)	1.5	6687.67	15*15*15	2067
Mix (3)	3.0	6464.00	15*15*15	1955
Mix (4)	5.0	5542.00	15*15*15	1652
Mix (5)	10	3721.00	15*15*15	1245
Density of hardened concrete in accordance with BS EN 12390-7				

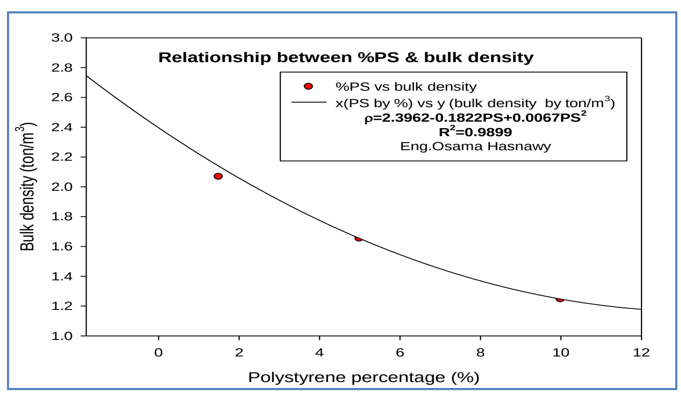

Figure. . Relationship between bulk density of concrete and Polystyrene percentage.

- *Compressive strength (σ_c):*

Usually compressive strength of hardened concrete is defined by the ultimate stress. It is one of the most important mechanical properties of hardened concrete, the results obtained in the compressive strength test at **7** and **28** days shown in Table VII. The reduction in compressive strength of lightweight concrete with the increase of polystyrene percentage. Decreased the compressive strength from 31.90MPa (Ref. Mix) to 0.743MPa at 28 days, due to the stiffness of polystyrene beads which affects the properties of concrete (Neville, A.M., 1995). Fig. 7, shows the decreased in the compressive strength with increase of polystyrene percentage.

Table VII. Results of compressive strength test for compressive strength above 25 MPa.

Materials	**Polystyrene (%)**	**Compressive Strength (MPa)**	
		7-day	**28-day**
Mix (1) reference	—	22.287	31.910
Mix (2)	1.5	11.951	10.576
Mix (3)	3.0	6.410	8.910
Mix (4)	5.0	2.633	3.591
Mix (5)	10	---	0.743
BS 1881-116 Testing concrete. Compressive strength of concrete cubes (Superseded by BS EN 12390-3)			

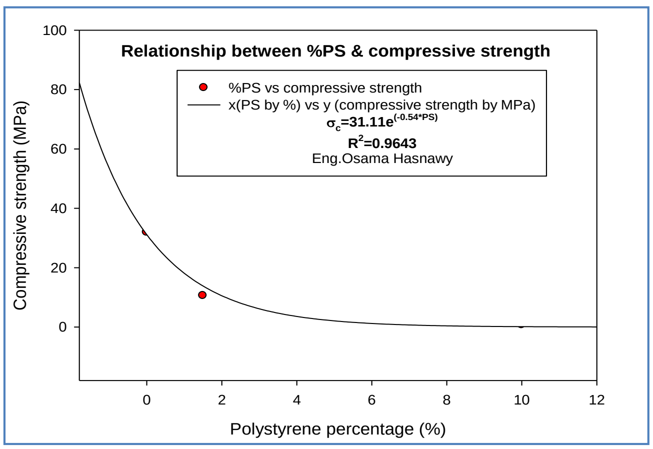

Figure. 7. Relationship between compressive strength and Polystyrene percentage.

- *Tensile splitting strength (σ_t):*

Tensile strengths of concrete are shown in Table VIII, and represented in Fig. 8. The results showed that the tensile strengths of reference concrete are better than that concrete containing polystyrene for the same causes in compressive strength. On the other hand, to obtain all mix concrete with 3.567 (Ref. Mix) to 0.224 MPa tensile strength (28-day).

Table VIII. Results of indirect tensile strengths of concrete

Materials	**Polystyrene (%)**	**Tensile splitting strength of test specimens (MPa)**	
		7-day	**28-day**
Mix (1) reference	—	1.543	3.566
Mix (2)	1.5	1.715	1.998
Mix (3)	3.0	1.022	1.140
Mix (4)	5.0	0.570	0.772
Mix (5)	10	---	0.224
BS EN 12390-6 Testing hardened concrete. Tensile splitting strength of test specimens			

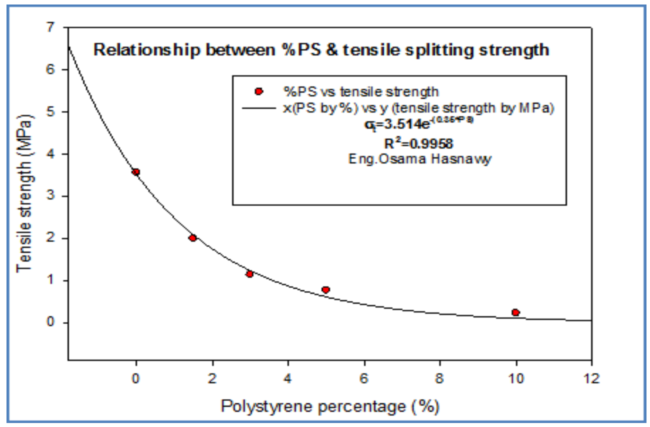

Figure. 8: Relationship between tensile strength and Polystyrene percentage.

- *Estimation of modulus of elasticity (E_c)*

The modulus of elasticity of concrete varies, unlike that of steel, with strength. The modulus of elasticity is considerably higher, and the behavior is closer to linear elastic. For lightweight concrete E-value varies with both strength and density and the following relationship can be used (ACI 209R-92)(John N., 2003).

$$E_c = 0.136 * \gamma^{1.5} * \sqrt{f}_{cu} \tag{7}$$

Where:
E_c=modulus of elasticity (kg/cm^2)
f_{cu}= compressive stress of concrete (kg/m^2)
γ = density of concrete mixes used throughout this work (kg/m^3)

The above relationships are approximate only and the (E_c) should be determined experimentally where its use is important. The relationship between modulus of elasticity and polystyrene percentage is shown in Fig.9. A significant reduction in E-value of concrete with the inclusion of polystyrene percentage is observed in Fig 9.

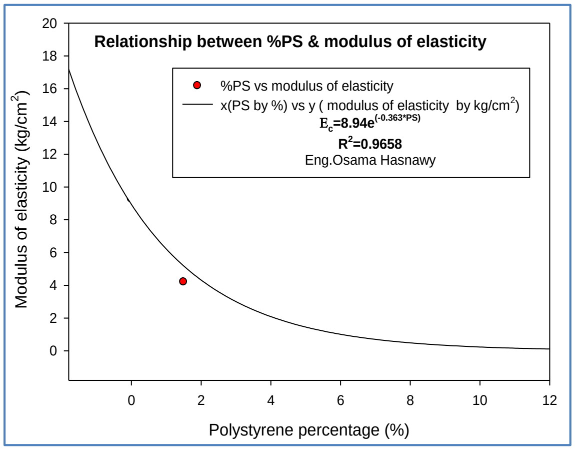

Figure 9. Relationship between modulus of elasticity and Polystyrene percentage.

V. CONCLUSIONS

With the polystyrene beads and testing program employed in this study, some important conclusions can be described in the following sections,

1. The addition of (10%) polystyrene reduced the compressive strength from 31.90 MPa to 0.74 MPa.

2. The use of 10% of polystyrene reduced the density of the concrete by about 42%.

3. The tensile strengths of concrete was decreased from 3.57MPa (Ref. Mix) to 0.22MPa, the inclusions of polystyrene decrease the tensile strengths in the similar manner to that of compressive strength.

4. The reduction in modulus of elasticity of concrete with the inclusion of polystyrene percentage, decreased the modulus of elasticity from 9.27kg/cm2to 0.52 kg/cm2.

5. The decreasing in some mechanical properties can be seen and this decreasing did not have serious effects on the design efficiency of the structure which conformed to the specifications.

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