The Effect of Adding Expanded Polystyrene Beads (EPS) on the Hardened Properties of Concrete

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Abstract-This study investigated the possibility of producing lightweight concrete using Expanded Polystyrene Beads (EPS), using one reference and five light concrete mixes by replacing coarse aggregates with EPS grains in five volumetric ratios: 20, 40, 60, 80, and 100%. The properties of hardened concrete of all mixed specimens, such as compressive strength, flexural strength, and density, were evaluated. The results showed that the addition of EPS caused an apparent reduction in the mechanical properties of concrete. The compressive strength at 28 days of curing ranged from 13.6 to 1.96MPa, while the rupture modulus ranged from 2.26 to 0MPa. Adding EPS grains as coarse aggregates led to a decrease in the concrete's weight. Replacing the coarse aggregates with EPS grains resulted in lightweight concrete with a density of 1086.5kg/m^3.

Keywords-lightweight concrete (LWC); coarse aggregates; Expanded Polystyrene Beads (EPS); properties of hardened concrete

I. INTRODUCTION

Concrete is an artificial material used to construct various civil engineering structures [1]. Concrete is the most commonly used substance in construction and can be used as stand alone mass concrete, reinforced concrete, or prestressed concrete when combined with steel [2]. For every ton of cement produced, one ton of carbon dioxide (CO_2) is emitted into the atmosphere. Cement manufacturing is responsible for 5% of anthropogenic CO_2 emissions [3]. Cement production produces a significant amount of CO_2 and requires a large amount of energy during the manufacturing process. Given that Pakistan is already facing an energy crisis, the high energy consumption in cement production puts additional pressure on its energy sector. As a result, the price of cement is rising daily. Furthermore, waste disposal and the restoration of concrete components after demolition have negative environmental consequences. As a result, the use of this waste reduces cement manufacturing and energy consumption while also helping protect the environment [4]. One of the drawbacks of traditional concrete is its high self-weight. The density of regular concrete ranges between 2200 and 2600kg/m^3 making it an uneconomical structural material. Several attempts have been made in the past to reduce the self-weight of concrete to increase its efficiency. Lightweight Concrete (LWC) is a type of concrete with a density ranging from 300 to 1850kg/m^3 [5].

Since LWC was first used approximately two thousand years ago, several lighter structures were built, particularly in the Mediterranean region. The three most important structures built during the Roman Empire are the Colosseum, the Port of Cosa, and the Pantheon Dome [6]. The use of LWC in buildings, structural and non-structural, as construction material must have specific characteristics that meet the requirements of strength and performance for the application. Before using any material in construction, there is a need to study its mechanical properties to determine its suitability [7]. Due to its low density, which offers tremendous benefits by reducing the cross sections of the components, there is an increase in the demand for LWCs in many modern architectural constructions [7]. There are two categories of lightweight aggregates: natural, such as diatomite, volcanic cinders, etc., and industrial such as expanded shale, clay, and slate. Polystyrene is an industrial material with a density less than 300kg/m^3 and no absorption properties [8-9]. Polystyrene has a closed cell structure, is stable, has low density, and is not absorbent or hydrophobic [10-11]. Concrete can be used for all parts of a building (structural and non-structural) as a very lightweight material by altering the percentage ratio of its aggregates [12-13].

Unlike lightweight industrial aggregates, polystyrene is commercially available everywhere. Most polystyrene manufacturing facilities are located in Europe and Russia [14]. The effects of adding EPS to cement mortar and concrete have not been extensively studied. This addition leads to a decrease in the density and mechanical properties of both cement mortar and concrete [15-16]. Ultra-high-performance concrete and EPS beads composite sandwich plates were investigated in [17], examining the use of these sandwich plates in high-rise structures. Because of their low density and high compressibility, EPS beads are frequently used as filling materials in earthquake buffers [18-20]. This study aimed to investigate the production of LWC using EPS as coarse aggregate, carrying out several tests to examine the effect of adding EPS as coarse aggregate with different volume percentages on the properties of the new LWC.

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II. EXPERIMENTAL SETUP

A. Cement

All specimens were cast using Ordinary Portland Cement (OPC) Type I throughout the experiment. This kind of cement complies with the Iraqi specification 5/2019 [19]. Table I shows its physical attributes and chemical composition.

B. Fine Aggregates

Sand from the Al-Ekhadir area (Karbala city) was used as fine aggregates, as shown in Figure 1. This sand is classified as zone 2 and meets the physical and chemical requirements of the Iraqi standard 45/1984 [20], as shown in Table II.

Fig. 1. Fine aggregates (left) and coarse aggregates (right).

C. Coarse Aggregates

Natural gravel from the Al-Nibaee region with a nominal aggregate size of 5-10mm, shown in Figure 1, was used as coarse aggregates in all mixes. Table III shows that the physical and chemical parameters of the coarse aggregates comply to the Iraqi standard 45/1984 [20].

D. Water

Potable (tap) water, obtained from the laboratory, was used for mixing and curing. This water meets the requirements of the Iraqi standard 1703 [21].

E. Expanded Polystyrene Beads (EPS)

This study used spherical-shaped EPS beads with a maximum nominal size of 10mm to replace coarse aggregates. Table IV depicts the gradient and physical properties of EPS beads, shown in Figure 2.

Fig. 2. Expanded Polystyrene Beads (EPS).

F. Superplasticizer (SP)

A superplasticizer called Sika ViscoCrete 5930, which complies with the ASTM C494 type G [22] criteria, was used in the adjusted mixes, and Table V shows its features.

TABLE I. PHYSICAL AND CHEMICAL COMPOSITION OF CEMENT

Physical properties		**Test result**	**Limits of IQS 5/2019 [19]**
Setting time: -Initial setting (min) -Final setting (hrs.)		 106 4.83	 45 min 00 hrs. max
Comp. Str. (MPa): 2-days 28-days		 11.25 33.31	 Min. 10 Min. 32.5
Chemical properties			
Oxide composition		**Result**	**Limits of IQS 5/2019 [19]**
(SiO_2)		21.62	No limited
(Al_2O_3)		5.94	No limited
(Fe_2O_3)		3.32	No limited
(CaO)		61.55	No limited
L.S.F. %		0.86	No limited
(MgO)		2.85	Max. 5
Sulfate (SO_3 %) max	C_3A<5%	Not applicable	2.5
	C_3A >5%	2.25	2.8
(L.O.I.)		1.07	Max. 4
(I.R.)		0.88	Max. 5
(C_3S)		35.11	No limited
(C_2S)		35.07	No limited
(C_3A)		10.13	No limited
(C_4AF)		10.09	No limited

TABLE II. FINE AGGREGATES SIEVE ANALYSIS

Sieve Size (mm)	**Passing %**	**Limits of [20] (Zone 2)**
10	100	100
4.75	92	90-100
2.63	85	75-100
1.18	56	55-90
0.6	42	35-59
0.3	13	8-30
0.15	5	0-10
Physical and chemical properties		
Physical characteristics	**Test results**	**Limits of Iraqi standards**
Specific gravity	2.5	-----
(SO_3 %)	0.4%	0.5% (max)
Absorption (%)	0.7%	-----

TABLE III. COARSE AGGREGATE'S PROPERTIES

Sieve Size (mm)	**Test Results**	**Limits of [20]**
14	100	90-100
10	75.1	50-85
5	1.2	0-10
2.36	--	No limited
SO_3% content	0.092	Max. 0.1%

TABLE IV. SIEVE ANALYSIS AND PROPERTIES OF EPS

Sieve Size	**Passing %**	**ASTM C330**
12.5mm	100	100
9.5mm	91	80-100
4.75mm	6.5	5-40
2.36mm	1.5	0-20
Specific gravity	--	--
Water absorption	0	--
Maximum particle size (mm)	10	--

TABLE V. PROPERTIES OF SUPERPLASTICIZER [23]

Density	1.08 kg/l
pH	8.0 ±1.0
Chloride content	NIL (EN934-2)

III. MOLDS, MIXING, AND CASTING

Three 100×100×400mm prism samples were produced for each group of 7, 14, and 28 days of curing to test the flexural strength and three 100×100×100mm cube samples with ages 7, 14, and 28 days were constructed to test compressive strength. Before placing the materials, the internal surface of the mixer was cleaned and wet. To ensure even dispersion of the polystyrene, the raw materials were first thoroughly combined and dried for about 3 minutes. Afterward, water was gradually added while mixing to produce a smooth and flowing liquid. The mixing process was extended for 3 minutes to create a uniform and consistent concrete. This process was performed in the concrete laboratory of Baghdad University's College of Engineering. All concretes were blended using a planetary mixer, shown in Fig. 4. The mixture was poured into oiled molds, which were then vibrated on a vibrating table for 1 minute to improve compaction and reduce air bubbles. The samples were demolded after 24 hours and placed in water for curing before testing.

Fig. 3. Mixing of concrete.

IV. CONCRETE MIX

This study used 1 reference and 5 different concrete mixes to create the samples. Concrete was produced with a water/cement ratio of 0.45 and a coarse aggregate ratio of 1:1.6:3.12, by weight, of OPC. Table VI shows the details of the samples.

TABLE VI. MIX OF 1m^3 OF CONCRETE

Mix Code	R	E20%	E40%	E60%	E80%	E100%
Cement (kg/m^3)	401	401	401	401	401	401
SP (kg/m^3)	1.2	1.2	1.2	1.2	1.2	1.2
Fine aggregates (kg/m^3)	643	643	643	643	643	643
Coarse aggregates (kg/m^3)	1254	1002	753	501	250	0
EPS (kg/m^3)	0	2	4	6	8	10
Water (kg/m^3)	180	180	180	180	180	180

V. TEST RESULTS AND DISCUSSION

A. *Density*

The quantity and density of lightweight aggregates are two of the most crucial elements in regulating a variety of physical properties in LWC. Due to the low density of polystyrene, the density of LWC falls as polystyrene volume increases [24-25]. Table VII shows the densities of the samples and Figure 4 shows their density variation with age.

TABLE VII. DENSITY TEST RESULTS

Mix Code	7 days	14 days	28 days
R	2550	2573	2589
E20%	2266	2283	2295
E40%	1944	1975	1984.5
E60%	1615	1627	1635
E80%	1356.5	1400	1422.5
E100%	1035	1055.5	1086.5

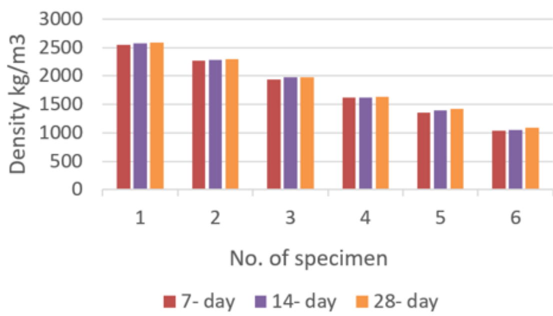

Fig. 4. Variation of density with age

B. *Compressive Strength*

According to Figure 5, the compressive strength gets stronger with curing time. This rise is the result of the cement hydration process becoming more advanced with time. Figure 6 and Table VIII both provide a comparison of the compressive strengths of several specimens at 7, 14, and 28 days of age.

TABLE VIII. COMPRESSIVE STRENGTH TEST RESULTS

Mix Code	7 days	14 days	28 days
R	25.7	33.11	42.4
E20%	9.67	10.12	13.6
E40%	6.04	9.29	10.88
E60%	3.47	3.62	4.08
E80%	3.42	3.62	3.86
E100%	1.36	1.81	1.96

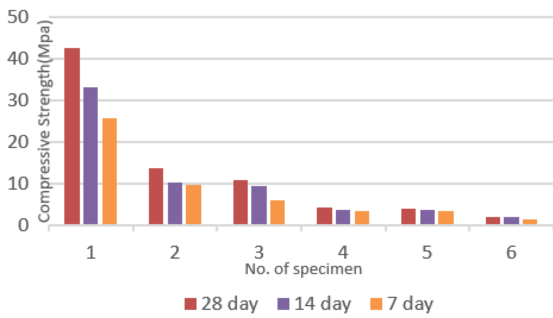

Fig. 5. Variations of compressive strength with age per sample.

Figure 6 shows that the concrete containing EPS had a decrease in compressive strength when the *P/Agg* ratio reached 20% or higher. As EPS increased, the compressive strength decreased. In the case of higher-density concrete mixes, those that contained less polystyrene typically had higher strengths, but compressive strength decreased when the polyester content was greater than 80% of the aggregate. This is because the polystyrene fills in the gaps left by the absence of coarse aggregates. In addition, the compressive strength of polystyrene is lower than that of coarse aggregates. Similar to the conventional concrete, it is evident that strength declines as polystyrene content increases. Figure 6 shows the variation in compressive strength per sample and Figure 7 shows the compressive strength test procedure.

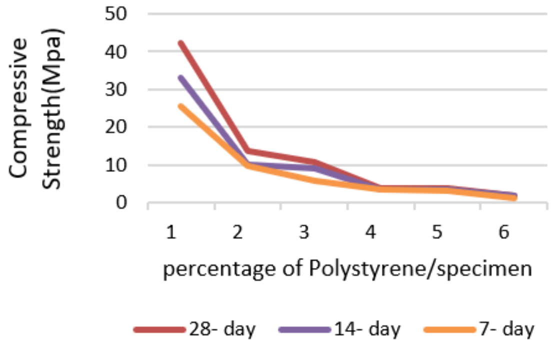

Fig. 6. Variation of compressive strength with polystyrene content %.

Fig. 7. Compressive strength test.

C. *Flexural Strength*

Figure 8 shows that all prisms made of concrete mixtures exhibited a steady increase in flexural strength over time. Figure 8 and Table IX show a comparison of the variance in flexural strength values with different polystyrene content percentages at 7, 14, and 28 days of age.

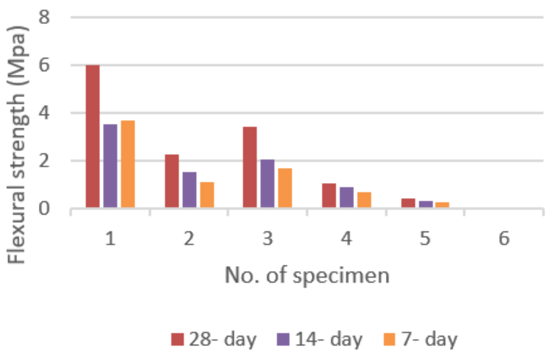

Fig. 8. Variation of flexural strength with age.

TABLE IX. RESULTS OF FLEXURAL STRENGTH TESTS

Mix Code	7 days	14 days	28 days
R	3.72	3.85	6.01
E20%	1.13	1.52	2.26
E40%	1.71	2.09	3.43
E60%	0.73	0.93	1.09
E80%	0.28	0.36	0.42
E100%	0	0	0

Figure 9 shows the change in flexural strength after 7, 14, and 28 days, and Figure 10 shows the flexural strength test procedure. Figure 9 shows that the flexural strength of concrete containing polystyrene decreased when the P/Agg ratio was 20% or higher. This could be because lower-density concrete has lower flexural strength as it contains higher amounts of polystyrene. Figure 9 illustrates how higher-density concrete mixes with lower amounts of polystyrene typically had a higher flexural strength. However, flexural strength decreased when polyester content was greater than 80% of the aggregates. This is because polystyrene fills in the gaps left by the absence of coarse aggregates and has lower flexural strength than coarse aggregates.

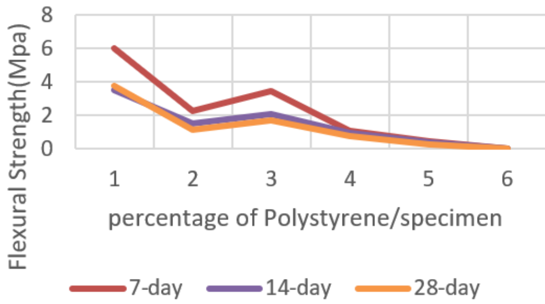

Fig. 9. Variation of flexural strength with polystyrene content %.

Fig. 10. Flexural strength test.

VI. CONCLUSION

This study investigated the compressive and flexural strengths of concrete with various proportions of EPS beads replacing coarse aggregates. The results showed that:

- As the polystyrene/aggregate ratio increases, lightweight concrete's compressive strength decreases.

- As the polystyrene/aggregate ratio increases, the density of the lightweight concrete mixes decreases. The lowest density value was 1086.5 kg/m^3 for the total replacement of coarse aggregate with polystyrene (100%).
- As the polystyrene/aggregate ratio increases, the flexural strength of the lightweight concrete mixes decreases. The lowest value of flexural strength was 0Mpa for total replacement of coarse aggregates with polystyrene (100%).

Finally, recycling waste materials can help create new and environmentally friendly lightweight concrete for specific purposes.

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