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MECHANICAL PROPERTIES OF RECYCLED EPS CONCRETE

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Abstract

Investigation the mechanical properties of recycled expanded polystyrene (EPS) concrete is aim of this study. Seven recycled EPS concrete percentages are manufactured experimentally by replacing 0%, 15%, 20%, 25%, 35%, 45% and 60% of the coarse aggregate volume with recycled EPS, whereas the cement is replaced with 10% silica fume (SF). The mechanical tests conducted such as compressive strength, tensile strength, density and modulus of rupture. The results show that the decrease values of the compressive strength, splitting tensile strength and modulus of rupture of recycled EPS concretes with increase recycled EPS ratio about 50%, 41% and 60%, respectively (60% substituting of recycled EPS) compared to normal concrete. They also reveal that recycled EPS concrete density decrease about 30 % of normal concrete. The recycled EPS is useful in concrete and meets requirements.

Keywords: Recycled EPS; RC beam; Flexural strength; EPS concrete; Static load.

INTRODUCTION

Natural materials containing coarse aggregate, fine aggregate and cement are common materials considered the concrete through an average density of 2300 kg/m^3. Concrete is compression strong but tension weak. Concrete has several benefits, including high elasticity, bending resistance, and low creep, shrinkage and permeability [1].

Many researchers have conducted studies regarding the mechanical properties of concrete. A number of variables, such as concrete compressive strength and tensile strength and density [2]. EPS is a very lightweight material with high compression and water resistance and excellent cushioning properties [3-6]. Styrobar is an EPS producer, and its waste is common.

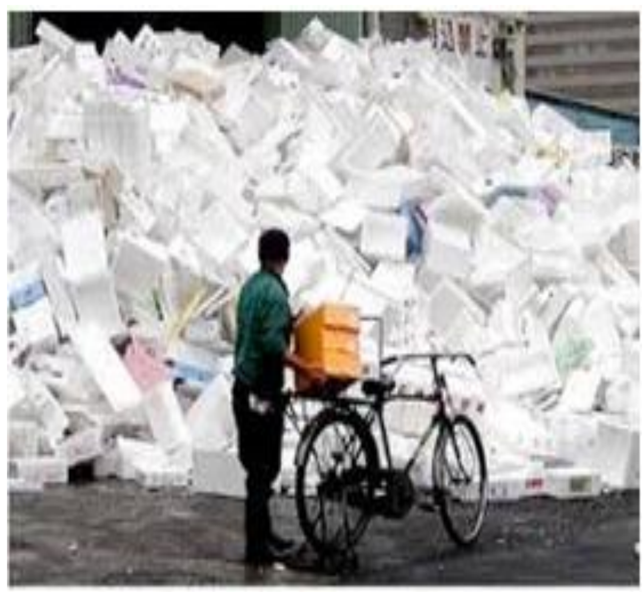


Figure 1: Styrobar negative effects on environment [7]

A recycling way out is desired to reduce the undesirable effects of this waster on the environment, as shown in Figure (1) [7].

First used of EPS as an artificial aggregate in concrete. Concern established in utilizing EPS concrete for numerous applications, for example in wall panels and blocks [8-10]. Recycled EPS has a closed-cell structure, little absorb water, and exhibitions effective sound and thermal insulation features in addition to impact resistance [11].

The experimental investigation is involved as a partial volume replacement of coarse aggregate without variation in EPS [12]. Recycled Styrobar EPS is a non-ecofriendly unwanted material from packaging manufacturing and industrial progressions. It generates a preservation problem [13], and moreover causes environmental issues because of retention in great quantities, and the material's long life and its chemically inactive nature. This problem can be solved by using waste Styrobar EPS in concrete manufacture. Finding ways to use it in construction will help to address the environmental issue.

The objective of this study is to investigate the mechanical properties of recycled Styrobar EPS concrete. The concrete samples used comprise different ratios of recycled Styrobar EPS pieces as a partial replacement of coarse aggregate, at volumes of 0%, 15%, 20%, 25%, 35%, 45%, and 60%. The mechanical properties like; density, compressive strength, tensile strength and rupture modulus of the recycled EPS concrete with new particle sizes and shapes are investigated.

Experimental Work and Materials

The cement was used an ordinary Portland (Type I). The chemical and physical tests of cement carried out according to the ASTM C150 / C150M-19a [14], as displayed in Tables (1) and (2).

Table 1: Chemical Properties of Cement (Type I)

Oxides Composition	Content (%)	ASTM C150
CaO	32	-
Al_2O_3	3.5	8% Max
SiO_2	18	21% Max
Fe_2O_3	4	5% Max
MgO	3	5 % Max
SO_3	2	2.5 %Max
Loss on Ignition(L.O.I)	1	4 %Max
Insoluble Material	0.75	1.5 %Max
Lime Saturation Factor (L.S.F)	0.85	(0.66-1.02)
C_3S	8.28	-
C_2S	3.5	< 5 %
C_3A	11.16	-
C_4AF	75.4	-

Table 2: Physical Properties of Cement (Type I)

Physical Properties	Test Results	ASTM C150
Specific surface area (m^2/kg)	289 m^2/kg	(230 m^2/kg) lower limit
Setting time Initial setting: Final setting:	 3 hrs. 15 8 hrs. 35	 ≥ 45 min ≤ 10 hrs.
Compressive strength (MPa) at 3-day at 7-day	 18.32 MPa 30.22 MPa	 ≥ 15 MPa ≥ 23 MPa

A river fine aggregate (sand) was used. The results of the sieve analysis and chemical and physical properties tests, obtained according to specifications ASTM C778-17 [15], are shown in Tables (3) and (4).

Table 3: Results of fine aggregate grading test

Sieve size (mm)	Cumulative Passing (%)	Limit of Passing of ASTM C778-17
4.75	98	95-100
2.36	83	80-100
1.18	58	50-85
600	52	25-60
300	17	5-30
150	5	0-10

Table 4: Chemical and physical properties of fine aggregates

Properties	Test Results	Limits of specification
Specific Gravity	2.58	-
Moisture content	5.8 %	-
Absorption %	1.1 %	-
Dry Loose Unit Weight, kg/m^3	1520	-
Sulfate Content (as SO_3), %	0.08%	0.5 (max. value)
Material Finer than Sieve 0.075 mm	3.2%	5 (max. value)

Natural coarse aggregate (gravel) was used, with the maximum size measured as 12.5 mm. Tables (5–7) present the test results of the coarse aggregate properties according to ASTM C33 / C33M-18 [16] requirements.

Table 5: Results of grading of normal coarse aggregate

Sieve size	Cumulative Passing (%)	ASTM C33 / C33M-18
20 mm	100	100
14 mm	95	90 – 100
10 mm	55	50 – 85
5 mm	2	0 – 15
2.36 mm	0	0 – 5

Table 6: Physical properties of normal coarse aggregates

Properties	Test Results	Limits of specification
Specific gravity	2.67	-
Moisture content	2.2%	-
Absorption (%)	0.8%	-
Dry loose unit weight kg/m^3	1700	-
Sulfate content (SO_3) (%)	0.055	0.1(max. value)

Table 7: Chemical properties of normal coarse aggregates

Properties	Test Results	Limits of specification
Sulfate content as SO3 %	0.09	-
Materials finer than 75µm%	0.08	≤0.1
Salts	0.3	-

Recycled (waste) EPS aggregate is white in color, and can be in the practice of chips or cubes. Herein, it was used to decrease the weight of the concrete, with different ratings of EPS concrete manufactured [4, 17-19]. Portions of recycled Styrobar were cut into semi-regular pieces in graduated sizes using a knife, to achieve alike coarse aggregate particles in volume, as presented in Figure (2). The sieve analysis of recycled Styrobar (EPS) displays that it matches with coarse aggregate grading. Figure (3) presents the sieve analysis for the recycled Styrobar. After the cutting, the gradient and the density of the recycled EPS aggregate were tested in accordance with ASTM C33 / C33M-18 [16]. As shown in Table (8), the density measured as 14 kg/m^3.

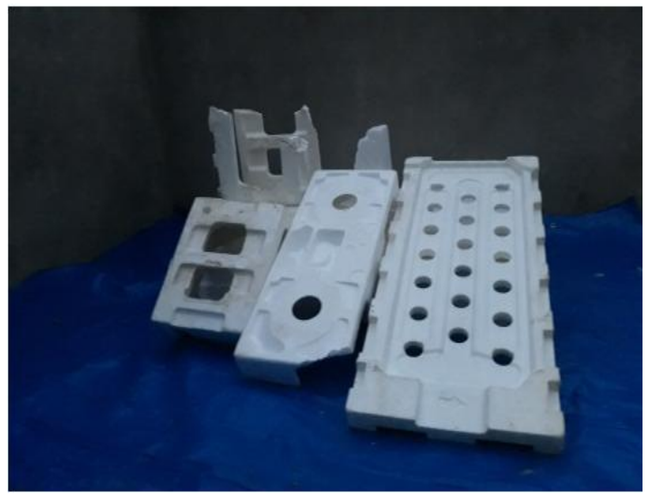


Figure 2: Recycled Styrobar (EPS) used in concrete mixtures

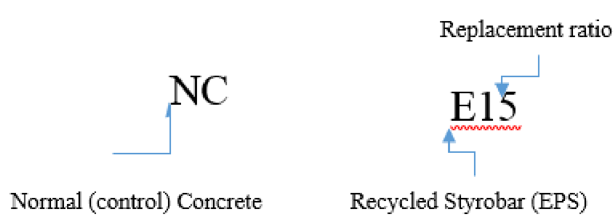
Figure 3: Sieve analysis of recycled Styrobar (EPS) particles

Table 8: Results of recycled EPS aggregate grading test

Sieve size	Cumulative Passing (%)	ASTM C33 / C33M-18
20 mm	100	100
14 mm	92	90 – 100
10 mm	62	50 – 85
5 mm	4	0 – 15
2.36 mm	1	0 – 5

Silica fume (SF) used as substitute for accompanying cementitious material. The SF was added into the mix (substituting 10% of cement weight) to increase the bonding between the recycled EPS and the cement paste, which increased the concrete strength [4-6].

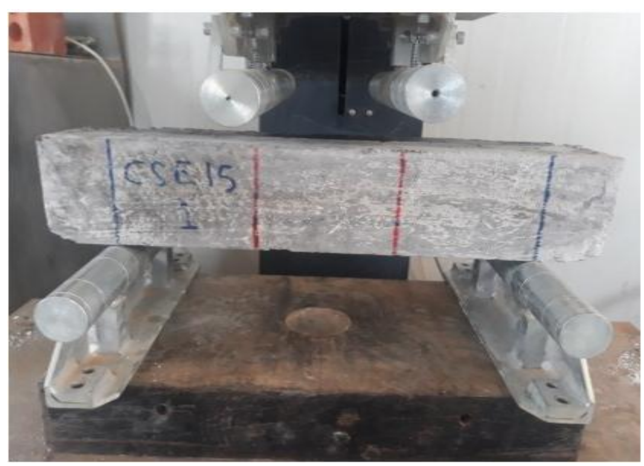
The mixture details quantities used herein are revealed in Table (9), and Figure (4) shows the designation symbols. The mixtures contain replacing 0%, 15%, 20%, 25%, 35%, 45% and 60% of the coarse aggregate volume with recycled Styrobar EPS, and partial replacement of the cement weight with 10% SF. The normal concrete was prepared in the similar concrete mix design method (1: 1.39: 1.96) recommended by ACI code requirements (ACI 211) [20]. The concrete mix density had 2321 kg/m^3, a W/C ratio of 0.39, and target strength of 35 MPa at 28 days of curing with a 9.8 kg/m^3 superplasticizer.



The coarse and fine aggregates were weighed first. The mixing was achieved in an electric mixer with a capacity of 0.05 m^3. Normal concrete was mixed by addition gravel and sand in the mixer. The water added equivalent to about one-third of the volume whereas the mixer was running and the mixing continued for one minute. Then the cement was added, and water was poured gradually into the mixer after three minutes of mixing. The process was stopped at a point when a uniform mixture had been gained, and then the slump and fresh densities were measured.

For the recycled EPS concrete mixes, a particular series was applied in the mixing of materials. Firstly, about 40% of water with SP was dispensed inside the mixer, then dry recycled EPS particles were added, and mixing continued for around two minutes to guarantee a full wetting with water and super-plasticizer. Following, the solid materials were poured into the mixer and the lasting 60% of the water was added gradually whereas the mixing was in movement to get a uniform mixture and even spreading of recycled EPS particles. The mixing sustained for three to five minutes, and then the fresh densities and slump were measured.

Standard test specimens were designated for testing the numerous parameters. A slump test was conducted for all types of mixes in agreement with ASTM C143 / C143M-15a [21]. According to ASTM C39/C39M-18 [22], six cylinders with a 150 mm diameter and a 300 mm height used to discover the compressive strength at 28 days of curing. The cylinder dimension was 150 mm diameter x 300 mm height to measure splitting tensile strength (ASTM C496 / C496M-17) [23], as well as to determine the density of the concrete (ASTM C29 / C29M-17a) [24]. Prism specimens of dimensions 100×100×500 mm were cast to determine the modulus of rupture. The test was carried out in agreement with ASTM C78-02 [25], as shown in Figure (5).



-a- sample under test

-b- sample failure

Figure 5: Modulus of rupture test for recycled EPS concrete specimens

Results and Discussion

Table (10) shows the results of the compressive strength tests for all types of concrete mixtures. In this study, a normal concrete mix was used as a reference intended for comparison. A key variable was used for the other mixtures, which of the recycled EPS content as a replacement of the normal coarse aggregates. In addition, in these mixtures, SF and super-plasticizer were used to regain some of the lost compressive strength and workability, reducing the loss resulting from the use of recycled EPS. The compressive strength reduced as the level of recycled EPS content in the mixtures increased (E15, E20, E25, E35, E45, and E60), as illustrated in Table (10). This decrease is due to the nature of the recycled EPS that was used as a substitute for natural coarse aggregates, as it is fragile.

Table 9: Quantities of materials in mix proportions

Mix design	Cement (kg/m^3)	SF (kg/m^3)	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Wasted EPS (kg/m^3)	% Replaced EPS
NC	500	0	680	960	191	0	0
E15	450	50	680	816	157	0.932	15
E20	450	50	680	768	154	1.242	20
E25	450	50	680	720	151	1.553	25
E35	450	50	680	624	147	2.174	35
E45	450	50	680	528	143	3.726	45
E60	450	50	680	384	140	4.968	60

Table 10: Concrete properties and strengths of the mixes.

Concrete type	Slump (mm)	Density (kg/m^3)	Tensile stress (MPa)	Compressive strength (MPa)	Modulus of rupture (MPa)
NC	60	2382	3.9	34.2	7.5
E15	75	2120	3.2	32.6	5.6
E20	83	2032	3.0	30.9	5.4
E25	92	2008	2.6	25.1	4.8
E35	101	1920	2. 5	22.6	4.1
E45	108	1820	2.4	20.2	3.7
E60	123	1665	2.3	17.1	3.0

When compared to normal coarse aggregates, there is a significant difference in compressive strength. At the same time, the specific weight and density of expanded polystyrene is much lower than the levels observed in normal coarse aggregate.

Further, recycled EPS concrete mixes contain a greater percentage of voids and pores compared to normal concrete, which is another reason for the decrease in compressive strength. These findings are similar to those of some previous studies [4-5 and 17]. Finally, based on the ACI code, which advises a minimum compressive strength of 17 MPa, all these types of concrete can be used for structural purposes (ACI 318M-14)[26]. This behavior also occurred in the tensile strength of concrete. The density as reduced to reach the lightweight limits, due to the little weight of the recycled EPS particles more than natural aggregate. Furthermore, the modulus of rupture was decreased up to 60%, at the E60 concrete.

Conclusions

The current experimental work has presented a study of the mechanical properties of concrete comprising recycled EPS. This reflects a new pattern of trials of using recycled garbage and debris as replacement materials for the natural coarse aggregates of the concrete. The following conclusions have been found:

1. Increasing ratio of recycled EPS replacement causes an increase in the slump results. This occurred because of the super-plasticizer effect, especially with mix time addition seven to eight minutes.

2. Up to a 30 %, concrete density reduction of the control mixture density can be accomplished by deducting considered quantities of coarse aggregate and substituting it with the lighter recycled EPS.

3. Recycled EPS content in the concrete mix as a partial replacement of coarse aggregate decreases the density and the compressive strength after 28 days by 30% and 50%, respectively, compared with the control specimens.

4. The most significant factor contributing to the reasonably high fresh density is the influence of SF in increasing compressive strength and density. The compressible formal of recycled EPS through casting needs an increase in solid material amounts to compensate for the decreasing in concrete volume. The interaction between the mix materials during mixing.

5. Recycled EPS content has a noticeable influence on the splitting tensile strength of concrete, displaying a decrease of up to 41%, while the modulus of rupture is reduced up to 60% at the highest ratio of replacement with recycled EPS.

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