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AN EXPERIMENTAL INVESTIGATION OF THE OPTIMUM REPLACEMENT RATIO OF COARSE GRAVEL WITH EXPANDED POLYSTYRENE BEADS IN CONCRETE

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Previous researches have shown that partial replacement of aggregates with Expanded Polystyrene (EPS) in concrete mixes reduces both the density and compressive strength of concrete, but enhances its durability. As there is no effort was made to determine the optimum EPS/gravel replacement ratio in a concrete mixture, this study triedl to determine this ratio. An experimental investigation is performed by using six different concrete mixes produced by partially replacing gravel with an equivalent volume of EPS beads. The adopted volumetric replacement ratios of coarse aggregate by EPS were (11%, 22%, 33%, 44%, and 55%). The results indicated that A drop in the density of both the fresh and hardened concrete was found to be in the range (of 0% to 35%) compared to the corresponding density value of the base mix (without EPS). Concrete compressive strength was also found to drop in the range (0% to 91%) compared with the corresponding value of the base mix. Within the limit of this work, it was found that the 22% replacement volumetric ratio of coarse aggregate with EPS is the optimum ratio based on a ratio of the drop in density to the drop in compressive strength. Generally, it was concluded that the optimum volumetric replacement ratio lies between 15% to 30%, according to the comparison with other prior studies.

Keywords: expanded polystyrene (EPS), lightweight concrete, optimum replacement ratio, compressive strength

1 INTRODUCTION

Polystyrene is a polymer with a long hydrocarbon chain. It is produced by polymerization from styrene [1]. If polystyrene is steam heated it will expand and when this expanded polystyrene is used as a partial replacement with aggregates it results in lightweight concrete of low strength and good energy absorption [2]. Polystyrene aggregate concrete has good thermal insulation properties making it suitable to be used as lightweight construction material in precast roofing as well as wall panels fill blocks, fill material in sandwich panel beams, and slabs [3]. Additionally, it can be utilized as a sub-base material for paving roads [4]. Expanded polystyrene (EPS) beads have been used in numerous past research to create lightweight concrete. The findings of an experimental examination on the use of chemically treated EPS in concrete mixtures were published by Ravindrarajah and Tuck [5]. Empirical equations were created to connect strength to pulse velocity and predict the modulus of elasticity from strength after considering strength, stiffness, and drying shrinkage.

Sadrmomtazi, A.; et al [6] presented a series of tests on concrete mixes containing EPS with silica fume and rice husk ash as supplementary cementitious materials reinforced with different volume fractions of polystyrene fibers. The effects of using such mixtures showed improvement in some mechanical properties of EPS concretes by using polypropylene fibers in the matrix, mainly in energy absorption capability.

Mohammed, and Aayeel [7] presented an experimental investigation of the mechanical properties of lightweight concrete containing EPS beads of volume ratios ranging between (5% to 30%). They found that increase in EPS beads content in concrete mixes reduces compressive and tensile strengths with improving the workability of the mix and providing the solution to EPS disposals.

Shi W, et al. [8] combined matrix concrete, expanded polystyrene spheres, polymer emulsion, and thickener to generate EPS concrete. This concrete showed good vibration energy absorption properties based on testing results on EPS volume ratios of 0 percent, 20 percent, 30 percent, and 40 percent generated by replacing matrix or coarse aggregate. The study's findings were applied in long-term cyclic dynamic load engineering using EPS concrete. By determining the compressive strengths of pastes, mortars, and concretes containing 5% and 10% raw (EPS) or dandified (EPS), respectively (EPS).

The effects of EPS on cement and concrete were studied by Z. Zhang et al. [9]. They also looked into the characteristics of the zone at the interfacial transition between paste and aggregate. In mortar and concrete, the water-to-binder ratios (W/B) were restricted to 0.29 and 0.24, respectively. The degree of crystalline orientation, crystalline size, and calcium hydroxide content at the interface were all decreased by adding (EPS). The main causes of the varied roles of (EPS) in paste, mortar, and concrete are the varying dispersion and the enhancement of the interfacial transition zone.

Expanded polystyrene (EPS) was investigated by S. Mahmoud et al. [10] in their investigation of the use of EPS as a partial replacement of coarse particles in concrete. They also assessed the effects of EPS granulation on the durability and mechanical qualities of concrete. Results showed that both slurry EPS and granules were stronger and had higher surface electrical resistivity than the control sample while having lower permeability.

Abd-ElAziz et al. [11] studied lightweight concrete incorporating EPS beads ranging between (0% to 50%). The results indicated that EPS beads generally decrease the mechanical properties but increase the workability of the concrete mix.

Ismail, et al. [1] performed experimental results on hardened concrete bricks of size 215x102x65mm containing EPS beads as partial replacement of sand in the mixes. The results showed that the bricks' compressive strength was reduced at a rate proportional to the EPS content.

M P Jayanth and S M Sowmya [12], conducted Various tests on fresh and hardened concrete that included Expanded Polystyrene (EPS) to know the physical and mechanical properties of this concrete at age of 7,14, and 28 days. The outcome indicates that increasing the quantity of EPS beads will be decreasing the strength of concrete with a reduction in density.

The experimental study's findings on different workability and durability tests, including compressive, split tensile, and flexural strength tests, on concrete incorporating polystyrene as a replacement for coarse aggregate were presented by Ganie and Prakash [13]. The outcomes demonstrated that the characteristics of hardened concrete are influenced by the quantity of polystyrene beads added to concrete. When compared to concrete without EPS, the compressive strength of concrete with EPS was found to be 91%, 77%, 71%, 63%, and 57% strong at 28 days.

H. Patidar, et al. [14] study on the properties of hardened concrete. Also, the compressive strength, Split tensile strength and Flexural Strength for M30 & M40 with 5%, 10%, 15%, 20%, 25%, & 30% replacement of coarse aggregate. The workability of the mix is very high at a low water/cement ratio.

According to CARVALHO and MOTTA [15], expanded polystyrene (EPS) is utilized in lightweight concrete to enhance its properties for structural wall applications. To examine the effectiveness of concrete with the addition of EPS in pearls and recycling Although the compressive strength of the EPS-concrete was lower than that of the reference concrete, it had better capillarity and thermal property absorption. Given the similar results obtained, it is inferred that it is possible to substitute recycled EPS for the EPS contained in pearls.

The compressive strength and tensile strength of lightweight concrete containing Expanded Polystyrene (EPS) beads were studied by Jahan and Sangitha [16]. Its characteristics are contrasted with those of regular concrete, which is concrete without EPS beads. As a partial substitute for coarse aggregates, EPS beads are employed. The findings indicated that the qualities of hardened concrete are affected by the amount of polystyrene beads added to concrete. Compressive strengths of concrete incorporating standard ,10%, 15%, 25%, and 35% EPS were determined to be 91%, 77%, 71%, 63%, 57%, and 45%, respectively.

M. Gunavel as well as associates [17] In order to determine the ideal dosage of expanded polystyrene beads. The findings show that a volume of fine aggregate can replace an expanded polystyrene bead replacement up to a maximum of 10%. It can be used in constructions made of plain concrete in places where M25 concrete is preferred.

Expanded polystyrene (EPS) particles were used in Rao and Mohan's [18] investigation into the compressive and tensile strengths of lightweight concrete. Coarse aggregates are partially replaced by the EPS beads. The findings showed that the characteristics of hardened concrete are influenced by the amount of polystyrene beads in the concrete.

By replacing some of the concrete with available waste materials, Verma and Jain's main objective was to introduce waste materials into the concrete industry [19]. In this study, M50 and M60 grades are used, and tests are run for different percentages of polystyrene with coarse aggregate, including 2.5 %, %, 7.5%, 10%, 12.5 %, 15 %, 17.5 %, %, 22.5 %, and 25 %. It was observed that an increase in EPS beads in concrete mixes decreases the concrete's compressive strength, tensile strength, and flexural strength while an increase in polystyrene beads increases workability.

2 AIM AND SCOPE OF WORK

To produce lightweight concrete, part of the coarse aggregate is replaced by polystyrene beads in the concrete mixture, although such replacement is accompanied by a drop in the compressive strength of the resulting concrete. This work aims to determine the optimum ratio that gives the maximum value of concrete compressive strength along with the lower value of concrete density. To reach this goal several trial mixes containing different polystyrene/aggregate volumetric replacement ratios were attempted. The next sections deal with all details of the experimental work including materials, preparation, casting, curing, and testing of the concrete specimens.

3 EXPERIMENTAL WORK

3.1 MATERIAL

The following material were applied in concrete mixtures to form the concrete specimens:

Expanded polystyrene beads (EPS): Lightweight Foam expanded polystyrene beads are used for the packing of goods and foods for protection and insulation processes in the form of white small spheres of diameters approximately (1 to 1.2) mm used with bulk density (17 kg/m3) as shown in Figure 1 below.

Fig.1. Used Expanded Polystyrene Beads (EPS)

Cement: Ordinary Portland cement (type I) conforming to the I.Q.S No.5/1984 [20] was used in this study with the testing results listed in Table 1.

Table 1. Results of the Tested Cement

Physical Properties	Test Results	Limits of Iraqi specification No.5/1984
Specific surface area (Blain method) (m2/kg)	320	230(min)
Setting time		
Initial setting time	1:50	0:45 hr (min)
Final setting	3:40	10:00 hr (max)
Compressive strength (MPa)		
Three days	21.7	15(min)
Seven days	23.8	23(min)
Specific gravity	3.15	--

Fine aggregate: It was natural sand from the Al-Ekaidher area utilized conforming to I.Q.S No.45/1984 [21]. Grading of this sand is given in Table 2, with specific gravity equal to (2.75), Fineness modulus (3.1), water absorption (1.9%), and bulk density (1605 kg/m3).

Table 2. Grading Test of the Used Sand

Sieve size (mm)	Cumulative Passing %	Limits of Iraqi specification No.5/1984 for zone 2
10	100	100
4.75	93.21	90- 100
2.36	82.74	75- 100
1.18	79.85	55- 90
0.60	57.37	35- 59
0.30	26.11	8- 30
0.15	4.23	0- 10

Coarse aggregate: Crushed river gravel with a maximum particle size of 10 mm was employed. Table 3 shows the gravel's grading, which includes its specific gravity of 2.69, water absorption of 0.8%, fineness modulus of 3.6, and bulk density of 1520 kg/m3.

Table 3. Grading of the used gravel

Sieve size (mm)	Cumulative passing %	Limits of Iraqi Specification N0. 45/1984 [21]
14	100	100
10	93	85-100
5	17	0-25

Sieve size (mm)	Cumulative passing %	Limits of Iraqi Specification NO. 45/1984 [21]
2.36	0	0-5

Superplasticizer: High range water reducing admixture of the trade name Flowcrete SP 90S was used and added to the mix with a dosage of 2% by weight of cement. The technical properties of this superplasticizer as supplied by the manufacturer are listed in Table 4.

Table 4. Properties of Flowcrete SP 90S @ 25ºC

Color	Brown liquid
Freezing point	-2ºC
Specific gravity	1.175 ± 0.01
Chloride content BS5075	Nil
Air entrainment	Typically, less than 2% additional air is entrained above the control mix at a normal dosage

Water: For both cast and curing of samples, a water supply was utilized in High Strength Concrete (HSC) mixtures.

3.2 CONCRETE MIXTURES

Initially, a concrete mix free of polystyrene beads was designed following the conventional absolute volume concrete mix design equation. According to this mix design, the cement content was (326) kg/m3, the cement /sand/gravel ratio (c/s/g) was taken as 1: 2: 4 by weight, and the water/cement ratio was adopted to be (0.45). A plasticizer (Flocrete / SP90S) with a dose equal to 2% of cement weight is then added to the mix to get flowable concrete. This mix was selected to be the base mix and designated as (T0). Five more concrete mixtures were studied namely (T1, T2, T3, T4, and T5) with different volumetric replacing ratios of polystyrene beads by the gravel. The replacement ratios by volume of EPS/ gravel in these five mixtures were (11%, 22%, 33%, 44%, and 55%) for (T1, T2, T3, T4, and T5) respectively. This was compensated by the use EPS beads to cement ratios of (0.5%, 1%, 1.5%, 2%, and 2.5%) respectively. Table 5 and Table 6 inform all about these six mixtures with details.

Table 5. Constituents of Concrete Mixtures Used in the Experimental Work

Mix symbol	% Polystyrene beads to cement weight	Cement	Sand	Gravel	Water	Plasticizer	Polystyrene
T0	0	326	652	1304	146.7	6.52	0
T1	0.5	326	652	1158.3	146.7	6.52	1.63
T2	1.0	326	652	1012.5	146.7	6.52	3.26
T3	1.5	326	652	866.8	146.7	6.52	4.89
T4	2.0	326	652	721	146.7	6.52	6.52
T5	2.5	326	652	575.3	146.7	6.52	8.15

Note; polystyrene beads bulk density = 17 kg/m3, gravel bulk density = 1520 kg/m3

Table 6. Weights of concrete mixes constituents

Mix symbol	Polystyrene (Kg)/m3	The volume of polystyrene beads (m3/m3)	Weight of gravel in the base mix (kg/m3)	The volume of gravel in the base mix (m3/m3)	%(EPS/gravel) volumetric replacement ratio
T0	0	0	1304	0	0
T1	1.63	0.0959	1304	0.8579	11.18
T2	3.26	0.1917	1304	0.8579	22.34
T3	4.89	0.2876	1304	0.8579	33.52
T4	6.52	0.3835	1304	0.8579	44.7
T5	8.15	0.4794	1304	0.8579	55.89

3.3 PREPARATION, CASTING, CURING, AND TESTING

First natural aggregates (sand and gravel) were washed with raw water and air-dried, then all materials were weighted according to the proportions stated in Table 6. First, a small amount of cement and water was added to the polystyrene beads and mixed thoroughly in a separate pan to prepare a slurry paste and avoid the floatation of polystyrene beads due to their low density. A mechanical blender was used in the mixing of the concrete materials, so the mixing process can be done consecutively as the procedure described next:

1 - Natural sand and gravel were mixed in the blender for 3 minutes.

2 - Cement was added and kept mixing for 2 minutes.

2 - Mixture of water and the superplasticizer was added gradually to the dry mix, along with the addition of the previously prepared slurry paste (cement, water, and polystyrene beads), and

3 - Adding polystyrene beads with approximately 20 % every 2 minutes of blending, until the entire mix became homogenous and uniform.

Then standard slump test was carried out under ASTM C143 [22], and the mixture was poured into three prepared150x150x150 mm standard cubes. The cubes were cast in three layers with hand compaction according to BS EN 12390-3 [23], then each cube surface was leveled, finished carefully, and covered with a humid cloth. After 24 hours these cubes were opened, weighed, and placed in a controlled heat water bath for 28 days. The main steps of the experimental work were documented by pictures that were shown in Figure (2). 28 days later, the cubes were removed from the water bath and allowed to air dry for two hours. Before testing the concrete specimens, they should be weighed to see how well they held their shape.

Fig. 2. Main Stages of Experimental Work

4 EXPERIMENTAL RESULTS

The results obtained from concrete cubes tests for the six types of mixtures are presented in Table 7. It is obvious that increasing the %EPS replacement, increases slump, while the fresh and hardened densities and compressive strength decrease with different ratios. The percentage ratios of losses in properties with increasing EPS were calculated by obtaining the variation between the result value of the considered mixture, and the M0 mixture value divided by the M0 value for each property under consideration, as listed in Table 7.

Table 7. Experimental test results

Mix symbol	% Polystyrene beads to cement weight	Slump* mm	D_f * kg/m3	D_h * kg/m3	Fc * Mpa
T_0	0	50	2488.2	2524.3	24.2
$T_{0.5}$	0. 5	70	2338.6	2363.2	19.8
T_1	1. 0	75	2009.5	2018.9	17.8
$T_{1.5}$	1. 5	82	1970.3	1987.1	6.4
T_2	2	90	1684.8	1703.8	3.2
$T_{2.5}$	2.5	100	1629.3	1640.3	2.2

**Average of three tests.*

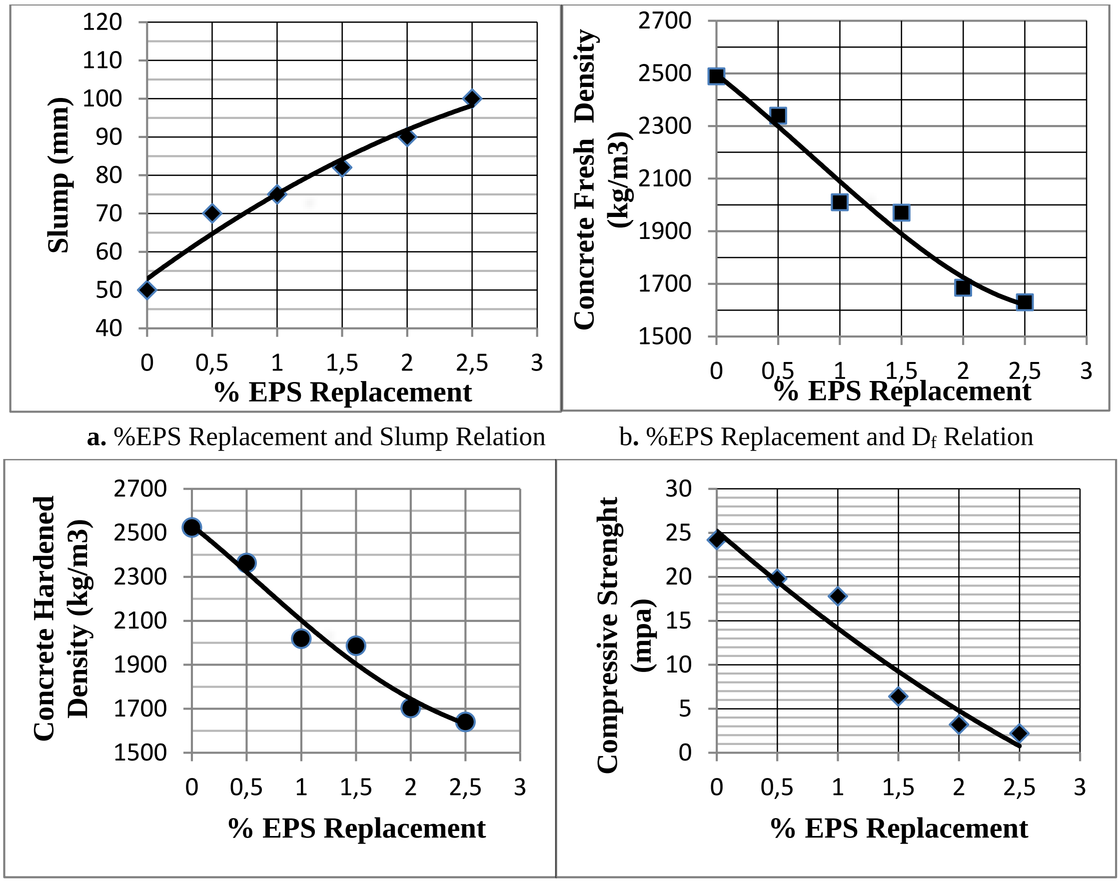
Table 8. The percentages of loss in Properties with Increasing % EPS

Mix symbol	% Polystyrene beads to cement weight	% dD_f	% dD_h	% d_{Fc}
T_0	0	0	0	0
$T_{0.5}$	0.5	6.01	6.38	18.2
T_1	1.0	19.23	20	26.4
$T_{1.5}$	1.5	20.81	21.3	73.5
T_2	2	32.3	32.5	86.7
$T_{2.5}$	2.5	34.52	35	90.9

5 COMPARISON OF RESULTS AND DISCUSSION

Figure.3. demonstrates the increase in a slump with increasing % EPS replacement, that is because of the spherical lightweight smooth surface of EPS particles [24].

Figures 3. b, and c illustrate the decrease in fresh and hardened density as increasing % EPS replacement in the mixture respectively from about 2500 to 1600 kg/m3 with approximately percentage decrease from 6% to 35% for replacement ratio equal 11 to 55% respectively. Figure 3.d shows that increasing % EPS leads to a drop in the compressive strength of the concrete. This expected behavior because of the weak link between polystyrene beads and cement, as a result of the smooth surface of the beads.



a. %EPS Replacement and Slump Relation   b. %EPS Replacement and D_f Relation

c. % EPS Replacement and D_h Relation.   **d.** %EPS Replacement and F_c Relation

Fig. 3. Relationships of % EPS replacement with hardened and fresh densities and compressive strength

The percentage of dropping ratio was from 18 to 91 % for replacement ratio of 11 to 55% respectively. The details of these drops were gathered in Table. 9. The benefit ratio (r) is the ratio resulting from dividing the percentage drops in concrete density by the percentage drop in compressive strength obtained from the present research and from [5], [6], [11], and [12] experimental results were recorded in Tables (10, 11, 12,13 and 14). The comparison between these ratios was drawn in Figure .4 for the five types of research mentioned above. The optimum EPS/aggregate volumetric replacement ratio is considered as that which gives the highest value of the benefit ratio (r) within less drop in concrete compressive strength. As it is clear from the figure that the replacement ratio equal to 22% can be considered the optimum one for the present work.

Table 9. Results Analysis of the Experimental Tests Conducted by the Present Study

EPS/aggregate Ratio (volumetric)	Hard Concrete Density			Compressive Strength (f '$_c$)			Benefit ratio (r)
	Value (kg/m3)	% of the base mix	% drop	Value (MPa)	% of the base mix	% drop	
0	2524.3	100	-	24.2	100	-	-
11%	2363.2	93.6	6.4	19.8	81.8	18.2	0.35
22%	2018.9	80.0	20.0	17.8	73.6	26.4	0.76
33%	1987.1	78.7	21.3	6.4	26.4	73.6	0.29
44%	1703.8	67.5	32.5	3.2	13.2	86.8	0.37
55%	1640.3	65.0	35.0	2.2	9.01	90.9	0.38

Table 10. Results and Analysis of the Experimental Tests Conducted by Ravindrarajah and Tuck [5]

EPS/aggregate Ratio (volumetric)	Hard concrete Density			Compressive Strength (f 'c)			Benefit ratio (r)
	Value (kg/m3)	% of the base mix	% drop	Value (MPa)	% of the base mix	% drop	
0	2455	100	-	79	100	-	-
10%	2330	94.9	5.1	56	70.9	29.1	0.18
20%	2210	90.0	10.0	39	49.4	50.6	0.20
30%	2080	84.7	15.3	28	35.4	64.6	0.24

Table 11. Results and Analysis of the Experimental Tests Conducted by Sadrmomtazi, A. et al [6]

EPS/aggregate Ratio (volumetric)	Hard concrete Density			Compressive Strength (f 'c)			Benefit ratio (r)
	Value (kg/m3)	% of the base mix	% drop	Value (MPa)	% of the base mix	% drop	
0	2300	100	-	42	100	-	-
15%	2000	87.0	13.0	33	78.6	21.4	0.61
25%	1750	76.1	23.9	17.5	41.7	58.3	0.41
40%	1350	58.7	41.3	11	26.2	73.8	0.56
55%	1000	43.5	56.5	7.5	17.9	82.1	0.69

Table 12. Results and Analysis of the Experimental Tests Conducted by Abd-ElAziz, et al [11]

EPS/aggregate Ratio (volumetric)	Hard concrete Density			Compressive Strength (f 'c)			Benefit ratio (r)
	Value (kg/m3)	% of the base mix	% drop	Value (MPa)	% of the base mix	% drop	
0	2449	100	-	33.4	100	-	-
15%	2148	87.7	12.3	23.3	69.8	30.2	0.41
25%	1965	80.2	19.8	13.7	41.0	59.0	0.33
50%	1486	60.7	39.3	6.5	19.5	80.5	0.49

Table 13. Results and Analysis of the Experimental Tests Conducted by Jayanth and Sowmya [12]

EPS/aggregate Ratio (volumetric)	Hard concrete Density			Compressive Strength (f 'c)			Benefit Ratio (r)
	Value (kg/m3)	% of the base mix	% drop	Value (MPa)	% of the base mix	% drop	
0	2410	100	-	36	100	-	-
10%	2261	93.8	6.2	31	86.1	13.9	0.45
28%	1950	80.9	19.1	29	80.6	19.4	0.98
34%	1801	74.7	25.3	15	41.7	58.3	0.43
49.8%	1500	62.2	37.8	9	25.0	75.0	0.5
77%	990	41.1	58.9	4	11.1	88.9	0.66

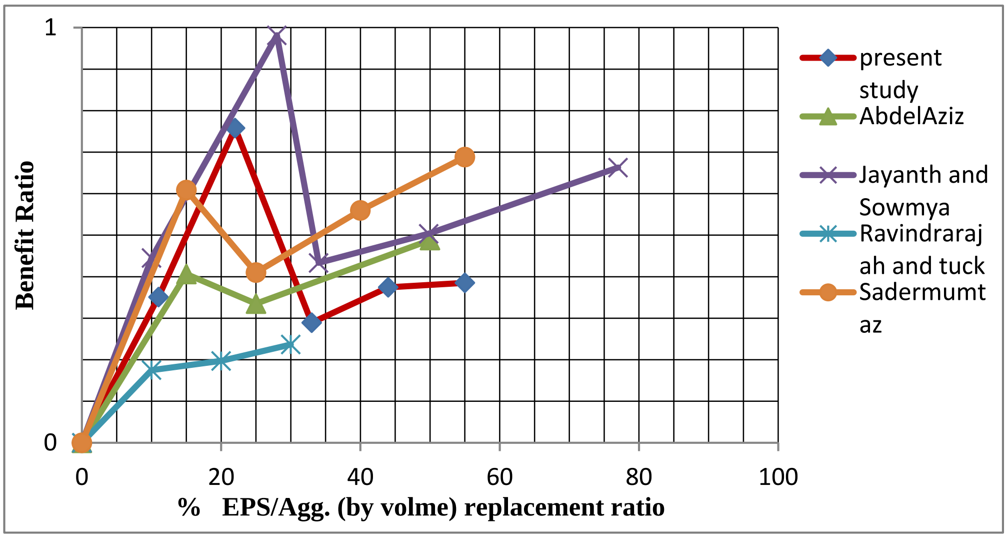


Fig. 4. Comparison Between Benefit Ratios Among Previous Research

As it is preferable to use structural members with self-weight as less as possible along with considerable compressive strength, it was adopted the benefit ratio as a criterion that has been relied upon. The comparison in Figure 4 May indicates that the optimum replacement ratio ranges between 15% and 30% since the compressive strength dropped between 19.4 and 30.2 for all studies except for [5] which reaches 50.6%. But this research [5] did not try a high replacement ratio and limited the experimental work to a maximum replacement ratio of 30%.

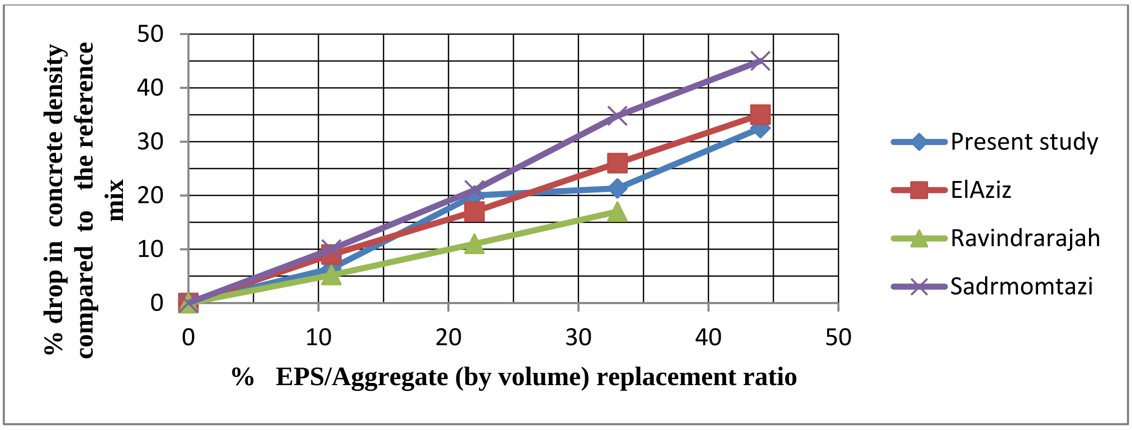


Fig. 7. Comparison between % (drops in concrete density)

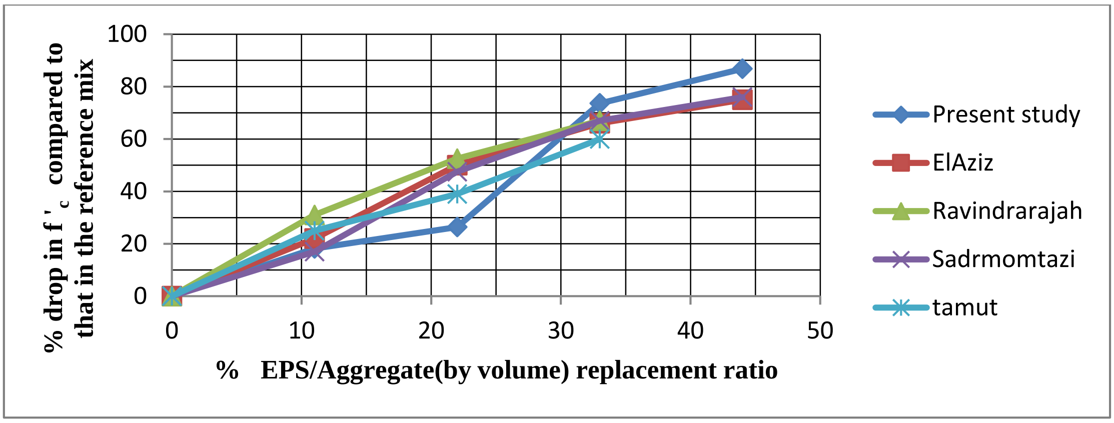


Fig. 8. Comparison between % (drops in compressive strength FC)

6 CONCLUSIONS

The previous researchers discovered that utilizing EPS as a partial substitute for coarse aggregate in concrete mixtures dramatically decreased the unit weight of a particular concrete mix. Additionally, a lower EPS/aggregate ratio greatly reduces the concrete's compressive strength. The major conclusions from this experimental work and the earlier research are as follows:

- The optimum replacement ratio of EPS/aggregate equal to (22%) was found from the experimental work of this study depending on the highest value of the benefit ratio with a minimum decrease in compressive strength.
- As the research on this subject is still limited and not sufficient to determine the accurate optimum value it is recommended to perform more studies dealing with different replacement ratios.
- The proposed mix of concrete will be used as lightweight concrete by the use of EPS as a partial replacement of coarse aggregate in concrete as stated below:

a) As a heat-insulating, leveling concrete layer for roofs instead of earth fill, Styrofoam, and precast tiles because of their lighter weight, and in external and interior non-structural walls such as voided precast panels. This kind of concrete will be inexpensive and practical, particularly in hot nations that have spent much money to improve the interior thermal insulation of buildings. It may also serve as an excellent option for EPS waste disposal.

b) A substitute to multilayer compacted soil filling of ground floor system which could be more economical and workable.

c) This concrete form may be utilized to make hollow precast concrete blocks for heat and sound insulation and prefabricated lightweight concrete tiles for roofing.

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