Concrete with Recycled EPS Granules

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Abstract **- This study objective is to investigate the mechanical properties of concrete incorporating recycled expanded polystyrene (EPS) granules. To improve the environment, recycled EPS try to use in concrete. The experimental test uses recycled EPS concrete and exchanges 0%, 10%, 15%, 20%, 35%, 45%, and 55% of the coarse aggregate with recycled EPS granules. While, Silica fume (SF) partially replaced 10% of the cement's weight. The mechanical tests achieved such as compressive strength, tensile strength and density. The results display that the reduction values of the compressive strength, tensile strength and density of recycled EPS concretes with increase recycled EPS particles ratio about 53%, 36% and 27%, respectively, related to normal concrete. The recycled EPS used in EPS concrete with ratios of 10%, 15%, 20%, 35% and 45% resist the applied loads acceptably and are consequently better than a ratio of 55%. The recycled EPS is suitable in concrete and meets requirements.**

keywords **- Recycled EPS, EPS concrete, compressive strength, tensile strength, density.**

I. INTRODUCTION

Solid waste managing has developed into a difficult problem handled by big cities around the world. Mostly in developing countries, the solid waste quantity takes increased because of fast people growth, manufacturing improvement, and economic development. Styrobar is the made expanded polystyrene (EPS); traditional waste involves of cheap and extensive material that wants a recycling solution to reduce its harmful influence on the environment. Manufacturing packaging is the main source of Styrobar waste. The use of EPS beads as aggregates in the concrete manufacture has become familiar [1-4].

Styrobar waste can be used as one of the opportunities in the field of concrete manufacturing. There is a little of studies that effort on using recycled Styrobar EPS in concrete.

EPS concrete is arranged from a mixture of cement, natural aggregates, and EPS aggregate beads. Cook [5] performed a study to consider EPS as an aggregate for concrete [2, 4, 6, 7]. EPS is a lightweight material that effects segregation through the concrete mixing. Furthermore, EPS is hydrophobic, and its surface desires to be chemically treated [1, 8-10].

A brief summary of the literature review shows that important work has been accomplished to investigate the mechanical properties of concrete comprising recycled EPS. As stated in previous studies, it was shown that the EPS concrete is considerably changed when a natural aggregate is substituted with a recycled aggregate. Nevertheless, EPS can change the behaviour of the concrete properties. Consequently, in this study, the influence of using recycled EPS on the concrete properties was considered when concentrating on the recycled EPS content.

II. MATERIALS

2.1 Cement

Cement was used (Type I) Ordinary Portland. Tables 1 and 2 display the chemical and physical results test of the cement that were agreed to the ASTM C150/C150M-19a [11].

Table 1 Chemical Properties of Cement (Type I)

Oxides Composition	Content (%)	ASTM C150
CaO	88	-
$Al2O_3$	4.98	8% Max
SiO_2	20.95	21% Max
Fe_2O_3	3.015	5% Max
MgO	2.19	5 % Max
SO_3	2.1	2.5 %Max
Loss on Ignition(L.O.I)	2.28	4 %Max
Insoluble Material	0.35	1.5 %Max
Lime Saturation Factor (L.S.F)	0.92	(0.66-1.02)
C_3S	51.54	-
C_2S	21.08	< 5 %
C_3A	6.8	-
C_4AF	9.071	-

Table 2 Physical Properties of Cement (Type I)

Physical Properties	Test Results	ASTM C150
Specific surface area (Blaine method) (m_2/kg)	320 m²/kg	(230 m_2/kg) lower limit
Setting time (vacate apparatus) Initial setting:	2 hrs. 30 min	≥ 45 min

Final setting:	4 hrs. 20 min	≤ 10 hrs.
Compressive strength (MPa) at 3-day at 7-day	 16.7 MPa 24.7 MPa	 ≥ 15 MPa ≥ 23 MPa

2.2 Fine aggregate

A river aggregate (sand) was used. The sieve analysis test results achieved and agreed to ASTM C778-17 specifications [12], as presented in Table 3.

Table 3 Results of fine aggregate grading test

Sieve size (mm)	Cumulative Passing (%)	Limit of Passing of ASTM C778-17
4.75	100	95-100
2.36	85	80-100
1.18	67	50-85
600	52	25-60
300	25	5-30
150	7	0-10

2.3 Coarse aggregate

A natural coarse aggregate (gravel) was used, with a maximum size of 12.5 mm. Tables 4 and 5 presented the test results of the coarse aggregate properties that agreed to ASTM C33/C33M-18 [13].

Table 4 Results of grading of normal coarse aggregate

Sieve size (mm)	Cumulative Passing (%)	ASTM C33 / C33M-18
20	100	100
14	99	90 – 100
10	59	50 – 85
5	0.5	0 – 15
2.36	0	0 – 5

Table 5 Physical properties of normal coarse aggregates

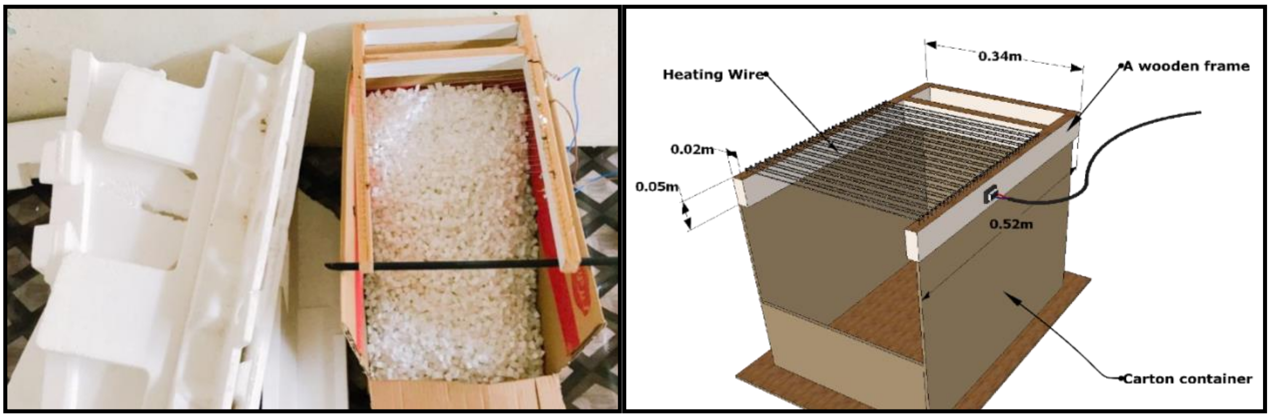
Properties	Test Results	Limits
Specific gravity	2.67	-
Moisture content	2.2%	-
Absorption (%)	0.8%	-
Dry loose unit weight kg/m^3	1700	-
Sulfate content (SO_3) (%)	0.035	0.1(max. value)

2.4 Recycled EPS aggregate

Herein, the recycled EPS used. It was waste utilized for packaging industrial goods. Pieces of different shapes and sizes of recycled EPS material were collected and cut almost the same size as the natural coarse aggregates. In this study, an electric machine was designed to cut the recycled EPS into granules. The apparatus consists of an electric heating wire set up on a wooden frame, with measured distances representing the natural coarse aggregate sizes (<12.5 mm and >5 mm), as presented in Fig. 1. After the cutting (as displayed in Fig. 2), the gradient and density of recycled EPS aggregate were tested and agreed to ASTM C33/C33M-18 [13]. Table 6 displayed the test results of the recycled EPS grading. Recycled EPS density was 14 kg/m^3.

Table 6 Results of recycled EPS aggregate grading test

Sieve size (mm)	Cumulative Passing (%)	ASTM C33 / C33M-18
20	100	100
14	95	90 – 100
10	75	50 – 85
5	8	0 – 15
2.36	0	0 – 5



a) Electric machine design b) Electric machine image

Figure 1 Details of electric machine

Figure 2 Recycled EPS aggregate used in concrete mixtures

III. CONCRETE MIXTURES

The normal concrete (NC) was arranged using the concrete mix design technique (1: 1.44: 2.01) that adopted by ACI code [14], (slump value of 75–100 mm),(maximum size aggregate of 12.5 mm).The concrete target strength was 35 MPa at 28 days.

Make of the mixtures of replacing 0% (NC), 10% (E10), 15% (E15), 20% (E20), 35% (E35), 45% (E45), and 55% (E55) of the coarse aggregate volume with the recycled (waste) EPS aggregate. A partial replacement of the cement weight with 10% silica fume (SF). Furthermore, superplasticizer (SP) was used throughout the work of recycled EPS concrete mixtures.

To improve the mechanical properties of recycled EPS concrete SF and SP were used, as recommended by studies [8, 15, 16]. SF was used by substituting 10% of the cement weight, and SP was added to 2% of the cement weight. The amount of SP led to a reduction of the mixing water up to 20%. Table 7 describes the details and weights of the concrete mixtures.

Table 7 Details and weights of recycled EPS mixtures and normal concrete mix

Concrete type	Replaced % of recycled EPS	Cement (kg/m^3)	SF (kg/m^3)	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	Recycled EPS aggregate (kg/m^3)	Water (kg/m^3)
NC	0	485	0	700	975	0.00	180
E10	10	436.5	48.5	700	877.46	0.8029	170.3
E15	15	436.5	48.5	700	828.71	1.2044	170.3
E20	20	436.5	48.5	700	779.96	1.6058	170.3
E35	35	436.5	48.5	700	633.72	2.8102	170.3
E45	45	436.5	48.5	700	536.22	3.6131	170.3
E55	55	436.5	48.5	700	438.73	4.4160	170.3

There were two types of mixtures during mixing procedure. The first was the normal mixture. The mixing procedure started by adding the coarse aggregate, fine aggregates, and cement together, then mixing them for two minutes with an electric mixer. At that time, the water was added. Mixed was for 4–5 minutes up to the mixture was consistent. The second type of mixing comprised mixing cement, sand, coarse aggregate, and water with recycled EPS aggregate, SF, and SP. The mixing procedure began by putting SP to 40% of mix water with the recycled EPS aggregate, then mixing for two minutes to moisturize completely the Styrobar pieces. The other dry materials were added sequentially. Finally, the residual water was added. The mixing procedure continued for 7–8 minutes up to the mixture was a consistent material.

Several parameters were determined with standard test specimens. The slump test is a display of its workability and smoothness through manufacture. The slump test was performed for all kinds of mixtures agreeing to ASTM C143/C143M-15a [17]. Agreeing to ASTM C39/C39M-18 [18], six cylinders (150-mm diameter and 300-mm height) were used to measure the compressive strength (after 28 days of curing). Also, the cylinder used to determine splitting tensile strength (ASTM C496 / C496M-17) [19] and measure density of concrete (ASTM C29 / C29M-17a) [20] (had a 150-mm diameter and was 300 mm height).

IV. Results and Discussion

Table 8 demonstrations the results of the compressive strength tests of all kinds of concrete mixtures. Herin, a normal concrete mix was used as reference that was implemented agreeing to ACI code. While, the other mixtures used a main variable that is the recycled EPS content used to substitute the normal coarse aggregates. Furthermore, in these mixtures, silica fume and superplasticiser were used to apart from the reduction compressive strength and workability. That resulted from the use of recycled materials. The compressive strength was found to decrease as the volume of recycled EPS in the mixtures increased (E10, E15, E20, E35, E45, and E55), as clarified in Table 8. This reduction occurred due to the brittleness of the recycled EPS. That was used as a replacing for natural coarse aggregates. Nevertheless, when compared to normal coarse aggregates, there is a large difference in compressive strength. Simultaneously, the specific weight and density of recycled EPS was much lesser than in the normal coarse aggregate. Furthermore, the recycled EPS concrete mixes comprised a bigger percentage of voids and pores related to the normal concrete. This is additional purpose for the reduction in compressive strength, this take place as in references [8, 9, 15].

Finally, based on the ACI code, all these types of concrete be able to use for structural purposes, except the E55 concrete. For which the minimum compressive strength is 17 MPa, as stated in ACI code [21].

Table 8 Concrete properties and strengths of the mixes.

Concrete type	Slump (mm)	Density (kg/m^3)	Tensile stress (MPa)	Tensile stress coefficient of variation	Compressive strength (MPa)	Compressive strength coefficient of variation
NC	80	2398	3.75	0.00	35.40	0.00
E10	115	2217	3.46	0.92	30.80	0.87
E15	115	2180	3.18	0.85	27.00	0.76
E20	120	2045	2.92	0.78	25.30	0.71
E35	135	1950	2.88	0.77	24.50	0.69
E45	135	1820	2.71	0.72	21.00	0.59
E55	140	1760	2.41	0.64	16.75	0.47

V. Conclusions

According to the experimental results of this study, the following conclusions have been drawn:

1. Cutting EPS waste by means of an electric heating wire set up on a wooden frame with particular dimensions creates it easy to get the size of the recycled EPS granules. Particles were the same size as the natural coarse aggregate used in the concrete mix. This procedure helped the testing of the grades of recycled EPS groups.
2. A 27% reduction in concrete density was recorded with the highest ratio of recycled EPS aggregate (E55), compared to the normal concrete. EPS must be very lightweight compared to natural aggregates.
3. When the percent of recycled EPS aggregate in the concrete increased. There was a reduction in the compressive strength up to 53% after 28 days (E55), compared to normal concrete.
4. The tensile strength is a clear drop with an increase the recycled EPS content up to 36% reduction in concrete mix (E55), compared to the normal mix.

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