Producing a sustainable type of concrete enhanced by industrial polystyrene

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Abstract
This research includes studying the possibility of producing a new type of no fine concrete by replacing granules of coarse aggregates with grains resulted from the fragmentation of industrial waste of polystyrene. This replacing is with different volumetric proportions of coarse aggregate, and these volumetric ratios were equal to (5%, 10%, 15% and 25%). Waste plastic fibers (WPFs) resulting from cutting of soft drinks bottles were added for strengthening this new kind of concrete. Mixing ratio was equal to (1:5) (cement: coarse aggregate) by weight. One reference mix was produced for comparative purpose. Compressive strength, flexural strength and density tests were conducted.

Compressive strength values of the new sustainable concrete were ranged from 10 MPa to 12.4 MPa at age of test equal to 28 days, while the lowest value of the density of this concrete at the same age reaches 1937 kg/m3, and highest value of modulus of rupture was equal to 2.36 MPa at 28-day age test.

1. Introduction

The first use of lightweight concrete was made two thousand years ago. There are many lightweight buildings especially in the Mediterranean region, the most important three buildings constructed in the Roman Empire are the Coliseum, the Port of Cosa, and the Pantheon Dome [1]. Recently the demand for lightweight concrete has been increasing in many of the modern building structures, because of the low density which leads to great benefit by reducing the cross sections of the elements concrete therefore leads to reducing the volume of the foundation [2].

Concrete is classified as one of the lightweight concrete type, which the fine aggregates were omitted [3]. The first use of this kind of concrete was at 1852 D.C., then used for production of warehouse and two houses in Holland [4]. Many studies were conducted to study the properties of this concrete [5-9]. Some studies dealt with the effects of adding admixtures or polymers on the mechanical property and structural performance of such kind of concrete [10-13].

The lightweight aggregates are divided into two types normal (volcanic cinders, diatomite pumice, etc.) and Industrial (clay, perlite, slate, expanded shale, sintered PFA, etc.). Polystyrene are a type of industrial very light weight (density of a reduced amount of 300 kg/m$^3$), non absorbent aggregate [14-15]. Polystyrene is a stable, little thickness foam and hydrophobic, non absorbent, closed cell nature [16-17]. It can be used as a very lightweight material for concrete development for all elements of construction, structural and non-structural, by changing the proportion ratio in concrete [18-19]. Polystyrene is commercially available all over the world, unlike lightweight industrial aggregates (slate, shale, expanded clay, sintered pfa, etc.). Many of the polystyrene construction plant life are in Europe and Russia [20].
It is well known that concrete has a brittle behavior under tensile stresses. Adding fibers to concrete leads to an increase of the ductility of this material by limiting the propagation of micro-cracks in the concrete [21]. This addition makes the concrete more homogenous and increases its strength to tensile stresses and shrinkage. So, adding fibers to concrete mixes is considered as an effective way to enhance the strength of concrete structures against the up normal forces like, earthquakes and winds [22-26]. Strengthening of concrete with waste plastic fibers (WPFs) is one method for enhancing concrete properties and a smart way to save natural resources that cannot be replenished [27]. Many researches were done in studying the possibility of developing concrete by WPFs [27-32]. Moreover, making use of WPFs as a material in elements concrete is very useful economically, and provides durability in addition to environmental aspects.

From the previous studies, it is clearly notified that no previous studies were done dealing with the effects of adding the wastes of Polyethylene Terephthalate (PET) and Expanded Polystyrene (EPS) on the properties of concrete. This study focuses on the effects of replacing aggregate with different volumetric ratios of EPS waste particles and strengthening this new material by one volumetric ratio of WPFs for producing a new sustainable concrete material [38]

2. Experimental Program

Materials

Ordinary Portland cement (OPC Type I) has been used in cast of every part of samples during the investigational work. Physical and chemical analysis and tests show that, this type of cement confirms with the Iraqi standards I.Q.S. 5/1984 [33]. Physical and chemical properties are shown in Tables (1) and (2). Gravel used in the mix preparation was of a maximum size of aggregate equal to 12.5 mm. The sieve investigation and physical properties of this aggregate proved that, this aggregate conform to the Iraqi standards I.Q.S. No.45/1984 [34] as shown in Table (3). These are available in different sizes spherically and, two different sizes were used. The first has mostly (7.2mm) size beads and the second has mostly (3.85mm) size beads, and the sieve analysis of polystyrene is given in Table (4). The waste plastic fibers (WPFs) resultant from cutting of soft drinks bottles were used for strengthening of concrete and the geometrical personality of WPFs during the investigational work are illustrate in table (5).

| Table (1): Physical Characteristics of Ordinary Portland Cement |
|---------------------------------------------------------------|
| **Physical characteristics**                                   | **Results** | **Limits of Iraqi spec No.5/1984 (33)** |
| Specific surface area, Blaine Method, (m²/kg)                  | 300         | > 230                                    |
| Setting time:                                                  |             |                                         |
| -Initial setting (hrs: min)                                    | 1:40        | ≥ 45 min                                 |
| -Final setting (hrs: min)                                      | 4:00        | ≤ 10 hrs                                 |
| Compressive strength of mortar (MPa):                          |             |                                         |
| 3-days                                                        | 21          | ≥ 15                                     |
| 7-days                                                        | 37          | ≥ 23                                     |
| Soundness % (Autoclave)                                        | 0.02        | ≤ 0.8                                    |
Three prism molds were prepared to determine the flexural strength (500×100×100) mm. Three cube molds with (100×100×100) mm were arranged to test the compressive strength. A (0.1) m³ pan mixer was used to mix all the compositions of the mixes. The inside surface of the mixer was clean and moistened before placing the materials. The materials were first mixed dry for about 15 min. to achieve homogeneous distribution of the Polystyrene and Plastic waste fibers, then water was gradually added and the combination was continued until a uniform and flowing mixture was obtained. The mixing process continued for about three minutes to get homogenous and consistent concrete. Mixture was poured into oiled molds and then, the molds were vibrated on a vibrating table for 1 min and then curved with a float to make possible compaction and reduce the amount of air bubbles. The specimens were demolded later than 24 hours and stored in water used for curing until testing.
Concrete Mixes:
Five concrete mixes were used in this work in addition to the reference mix. Table (6) shows that the proportion of the prepared concrete mixes with (1:5) (by weight) of ordinary Portland cement: coarse aggregate and the water to cement ratio of 0.45. Waste plastic fibers were used in a ratio by volume of the mix as 1, and 1.5 percent.

| Mix number | Cement: Aggregate | (Water/Cement) % | (WPFs) % | (Polystyrene/Aggregate) % |
|------------|-------------------|-----------------|----------|--------------------------|
| Ref.1      | 1:5               | 45              | -        | -                        |
| 2          | 1:5               | 45              | 1        | -                        |
| 3          | 1:5               | 45              | 1        | 5                        |
| 4          | 1:5               | 45              | 1        | 10                       |
| 5          | 1:5               | 45              | 1        | 15                       |
| 6          | 1:5               | 45              | 1        | 25                       |

Program of Tests
Compressive strength tests were accepted according on 100 mm cubes at the age of (7, 14 and 28) days by a hydraulic test mechanic (ELE) of (2000)KN capacity at a loading rate of (2.5) KN/s. Flexural strength was conducted on prisms of (100,100,500mm). The test was approved using two position load. Flexural strength was determined using (50 KN ) capacity ( ELE) machine,. The density value was found by dividing the weight by the volume for each specimen.

3. Results and discussion
Compressive strength
Results show that there is a continuous increase in the compressive strength with age up to 28 days, and this increase is due to progress in cement hydration operation with age. A comparison between the compressive strengths and mix type specimen at the period of 7, 14, and 28 days are given in Figure 1.

![Figure 1](image_url) Relationship between compressive strength with age.
From Figure 2 it can be noticed that the reduction in compressive strength of the no-fines concrete containing Polystyrene and WPFs was observed when (P/Agg) ratio was 5% and more. It indicates that the highest value of compressive strength with a reduction in the amount of Polystyrene. This is because of the fact that the lesser density concrete in general has far above the ground quantity of Polystyrene, and intrinsically has lesser strength. In the casing of upper concentration concrete mixes, which includes lesser amounts of Polystyrene, generally have high strength, but when the (P/Agg) ratio is between 15% and 25% of polyester, the compressive strength is not affected. This can be attributed in this case to the fact that the amount of Polystyrene particles occupies the existing gaps which results from the absence of fine aggregate. It can be seen that the strength is decreasing with the increase of Polystyrene amount, similar to the normal concretes. The relationship between compressive strength at 7, 14 and 28 days is given in Figure 2.

![Figure 2 Relationship between compressive strength with percentages of Polystyrene](image1)

The fines mixes with higher densities showed higher compressive strength and density value at all ages as shown in Figure 3. The association between compressive strength and density is shown in Figure 3.

![Figure 3. Relationship between compressive strength and density](image2)

From the experiment results of all specimens tested in this research, it can be clearly noticed that, the cubes which do not contain WPFs and Polystyrene have failure, are more brittle than those
containing these materials and these specimens were able to retain the load later than breakdown without full disintegration. In the case of the former, the cubes fail with the loss of a part of the cube, whereas the cubes which contain WPFs and Polystyrene were more ductile in failure and appear coherent with tiny cracks without loss of any part of the cube. That means adding of WPFs and Polystyrene leads to production of more ductile no-fines concrete with acceptable compressive strength.

**Flexural strength**

From Figure 4 it can be clearly noticed that, there was a continuous increase in the flexural strength with age for all prisms made from no-fines mixes. A comparison of the variation of flexural strength values with dissimilar percentage of Polystyrene at the period of 7, 14, and 28 days were given in Fig. 4. When comparing with reference mix all prisms produced from no-fines concrete containing WPFs and Polystyrene have modulus of rupture values less than that of reference mix prisms. The flexural strength increased with the increment in (P/Agg) ratio up to (P/Agg) 15%. As seen in Figure 5, for all mixes specimens which contain different (P/Agg) ratios, the modulus of rupture principles increases with increases to in the time of test. Because of absence of fine aggregate (sand) in this kind of concrete (No-fines concrete), a large number of big porous exist inside the structure of concrete. Adding WPFs leads to forming new porous causing decrease in flexural strength. Adding of Polystyrene grains to the no-fines mixes contains WPFs cause a decrease in the volume of porous, leading to enhancement in modulus of rupture values up to (P/Agg) equal to 15%. After that the flexural strength decrease at (P/Agg) equal to (25%), because of the big Polystyrene percentage according to coarse aggregate.

![Figure 4. Relationship between Flexural strength and age](image-url)
The connection between flexural strength and density of Polystyrene actual is shown in Figure 6. The upper density mix showed the upper flexural strength values at 28 day age. Variation of flexural strength with density show the flexural strength increases with the rise in the Polystyrene ratio and reaches a maximum 2.16 MPa at Polystyrene ratio of 15%, with low density, and reaches a minimum at 1937 Kg/m$^3$, Equivalent approximate value of the flexural strengths without Polystyrene reaches 2.38 MPa at density 2147 Kg/m$^3$.

**Figure 5.** Relationship between Flexural strength and percentages of Polystyrene %

**Figure 6.** Relationship between Flexural strength and Density

**Density**

Density is one of the most significant factors to control many physical characteristics in frivolous concrete through the density and quantity of lightweight aggregates. The preceding studies confirm that the density of lightweight concrete decrease with addition to volume of Polystyrene aggregate which causes to reduce compressive strength of the concrete [35,36,37].

The association among density and percentages of Polystyrene for all the mixes is shown in Figure 7. This figure shows that, the increase in (P/Agg) leads to drop off in density of no-fines concrete
mixes and the minimum value of density was equal to 1937 Kg/m³ for percentages of Polystyrene to coarse aggregate equal to 25%.

Figure 7. Relationship between density and percentages of Polystyrene %

4. Conclusions
- The failure of cubes which do not contain WPFs and Polystyrene is more brittle than those containing these materials and these specimens with the load later than breakdown have with no full breakdown. In case of the former, the cubes fail with the loss of a part of the cube.
- Adding Polystyrene grains to the no-fines mixes contains WPFs caused a decrease in the volume of porous, leading to enhancement in modulus of rupture values up to (P/Agg) equal to 15%.
- The increase in (P/Agg) leads to decrease in density of no-fines concrete mixes and proved that density was equal to 1937 Kg/m³ when percentages of Polystyrene to coarse aggregate equal to 25%.
- Production of new kind of sustainable no-fines concrete by taking advantages of waste materials.

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