Concrete Properties using Treated Recycled EPS

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Abstract. The study explores the mechanical properties of treated recycled extended polystyrene (TEPS) concrete, treated by two methods, one by heating, and the other by immersed recycled EPS in cement neat. By substituting 0 %, 15 %, 25 %, and 35 % of the coarse aggregate volume with treated recycled EPS, (for both method). Treated recycled TEPS concrete ratios are experimentally prepared, while the cement is substituted thru 10 % silica fume (SF). Tests were carried out, like compressive strength, splitting tensile strength, modulus of rupture, and density. The outcomes display the decreasing of the compressive strength, tensile strength and modulus of rupture of TEPS concretes with rise TEPS percentage around 26 %, 17 % and 32 %, respectively (35% TEPS) related to standard concrete. They also show that TEPS concrete density decrease about 30 % of normal concrete. The TEPS is suitable in concrete and meets provisions.

1. Introduction
Concrete materials comprising cement, fine aggregate, and coarse aggregate are popular materials, which, with an average density of 2300 kg /m³, are considered concrete. Compression is concrete, efficient yet fragile in strain. Concrete has many advantages, comprising great elasticity, struggle to bending, and little creep, retraction, and permeability [1].

Several experts on the mechanical properties of concrete have carried out studies. A variety of influences, like the compressive strength of concrete and the tensile strength and density [2]. TEPS seems to be a very lightweight with excessive pressure resistance and water and excellent properties for cushioning [3-6]. EPS is commonly waste. To reduce the undesirable effects of this waste on the environment, a recycling approach is required, as shown in figure (1) [7].

The first use of EPS in concrete was as an artificial aggregate. Concern regarding the use of EPS concrete for various applications, such as wall panels and blocks [8-10]. In addition to impact resistance [11]; a confined structure, small water absorption and efficient sound as well as thermal isolation characteristics are shown in recycled EPS.

Replacement of coarse aggregate as a part volume without the EPS variation [12]; an experimental investigation is involved. Recycled EPS is an unwanted non-eco-friendly material from the processing of packaging and industrial advances. It poses a storage problem [13-14]. Moreover, causes environmental problems due to large amounts of retention and the long life of the substance and its chemically inactive existence. Using waste, EPS in the manufacture of concrete will solve this problem. It will help to solve the environmental crisis by seeking ways to use it in building.

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The study objective is to explore the mechanical properties of concrete containing treated recycled EPS. The concrete mixes utilized consist of varying ratios of TEPS portions as a part substitution of coarse aggregate, at quantities of (0%, 15%, 25%, and 35%). The mechanical properties like; density, compressive strength, modulus of rupture, and tensile strength of the TEPS concrete with new piece sizes and forms are studied.

2. Experimental Work and Materials

Type I of an ordinary Portland cement is utilized. Chemical and physical examination of cement in compliance with ASTM C150 / C150M-19a [15]; as shown in tables (1) and (2).

| Specifications                              | Results | ASTM C150 |
|---------------------------------------------|---------|------------|
| CaO                                         | 53.65   | -          |
| Al2O3                                       | 4.90    | ≤ 8%       |
| SiO2                                        | 15.2    | ≤ 21%      |
| Fe2O3                                       | 3.0     | ≤ 5%       |
| MgO                                         | 3.5     | ≤ 5%       |
| C4                                          | 1.5     | ≤ 2.5 %    |
| SO3                                         | 3.2     | ≤ 4%       |
| Loss on Ignition(L. O.I)                    | 0.5     | ≤ 1.5 %    |
| Unsolvalelly                                | 0.7     | (0.66-1.02) |
| L.S.F                                       | 6.3     | -          |
| C3S                                         | 3.2     | < 5 %      |
| C2S                                         | 9.2     | -          |
| C3A                                         | 50.2    | -          |
| C4AF                                        | 53.65   | -          |

Table 1. Cement Chemical Characteristics.

A fine river aggregate (sand) was used. Sieve grading results and the chemical and physical properties experiments performed by the requirements of ASTM C778-17 [16]; are shown in tables (3) and (4).
A normal coarse aggregate (gravel) is utilized, measuring a dimension of 12.5 mm. The experiment outcomes of the gravel features agreeing with ASTM C33 / C33M-18 [17]; specifications are presented in tables (5-7).
Reused TEPS; It's generated in the shape of cuts. In this analysis, cutting of recycled EPS by hand to parts in incremental dimensions to achieve a similar CA element in volume occupation and cement mortar restriction [18-20]. Then cured by two methods, first by warming: Put EPS cubes in an oven at 130 °C for 15 minutes [21]. Secondly by submerging EPS in cement neat (2 hours) earlier by means of in the concrete mixture, as presented in figure (2).

Recycled TEPS's sieve analysis reveals that it coincides with coarse aggregate grading. Following ASTM C33 / C33M-18 [17]; the sieving and unit weight of the TEPS aggregate were determined after cutting. As shown in table (8), a density of 14 kg/m³ was measured.

| Size of sieve | Passing Cumulative (%) | Requirements |
|---------------|-------------------------|--------------|
| 20 mm         | 100                     | 100          |
| 14 mm         | 95                      | 90 – 100     |
| 10 mm         | 60                      | 50 – 85      |
| 5 mm          | 4                       | 0 – 15       |
| 2.36 mm       | 2                       | 0 – 5        |

Figure 2. a) EPS treated by heated
For the corresponding cement, SF is utilized as a substitution. SF increases the linking between the cement paste and TEPS, that lead enlarged the strength of concrete [4-6]. SF was applied to the mix (substituting 10% of the weight of cement).

The amounts of mixture data used herein are shown in the table (9). The mixes contain replacing 0%, 15%, 25%, and 35% of the volume of the CA thru reused TEPS (two methods of treatment). By means of the similar concrete mixture design approach (1: 1.41: 1.98) suggested by the ACI code necessities [22]; the normal concrete was prepared. The unit weight of the concrete mix was 2321 kg/m$^3$, (W/C=0.39), and ($f'_c = 35$ MPa), using a superplasticizer 4.9 kg/m$^3$.

| Mix designation | Cement (kg) | SF (kg) | Sand (kg) | Coarse Aggregate (kg) | Water (kg) | Treated EPS (kg) | % Replaced TEPS |
|------------------|-------------|---------|-----------|------------------------|------------|------------------|----------------|
| NC               | 490         | 0       | 680       | 960                    | 191        | 0                | 0              |
| TH15             | 441         | 49      | 680       | 816                    | 153        | 18.228           | 0              |
| TH25             | 441         | 49      | 680       | 720                    | 153        | 30.38            | 0              |
| TH35             | 441         | 49      | 680       | 624                    | 153        | 42.532           | 0              |
| TC15             | 441         | 49      | 680       | 816                    | 153        | 0                | 0.932          |
| TC25             | 441         | 49      | 680       | 720                    | 153        | 0                | 1.553          |
| TC35             | 441         | 49      | 680       | 624                    | 153        | 0                | 2.174          |

SP : 4.9 kg/m$^3$

They measured the gravel and sand first. The blending was carried out in a mixer (0.05 m$^3$ volume). In the mixer, ordinary concrete was mixed by putting fine and coarse aggregate. Whereas the blender was working and the mixing nonstop for one minute, the water contributed about one-third of the amount. Then the cement was applied and, after three minutes of mixing, water was discharged steadily keen on the mixer. At a point where a uniform mixture had been collected, the process was stopped. After that the fresh unit weight and were assessed.
In the mixing of materials, a special sequence was used for TEPS concrete mixes. First, inside the mixer, about 40% of the water with SP was dispensed. After that, TEPS pieces were extra and then mixing nonstop around two minutes to confirm complete water and superplasticizer wetting. Then, the other materials are putting into the mixer and gradually applied the remaining water. While, the mixing was in motion to achieve, a consistent mixture and smooth disperse TEPS pieces. Three to five minutes of mixing continued, and then the fresh densities and slump were assessed.

For testing the various parameters, standard test specimens were named. Under ASTM C143 / C143M-15a [23]; a slump test was conducted for all forms of mixes. Agreeing to ASTM C39/C39M-18 [24]; at 28 days of curing, six cylinders with a diameter of 150 mm and a height of 300 mm were used to classify the compressive strength. Acceptable to calculate the splitting tensile strength (ASTM C496 / C496M-17) [25]; and to assess the concrete density (ASTM C29 / C29M-17a) [26]; as shown in figure (3), the cylinder size was 150 mm diameter x 300 mm height. To calculate the rupture module, prism specimens of sizes 100 to 100 to 500 mm were cast. The test was performed in compliance with ASTM C78-02 [27].

3. Results and Discussion
The results of all forms of concrete mixes are shown in table (10). A normal concrete mixture was utilized in this analysis such as a guide intended for comparison. For the other mixtures, a main variable was used, which substituted the usual coarse aggregates with a recycled TEPS material. Moreover, silica fume was utilized to recover the compressive strength. In addition, super-plasticizer was used to improve the workability of TEPS concrete.

The compressive strength decreased when the ratio of TEPS in the mixes enlarged (TH15, TH25, TH35, TC15, TC25 and TH35). The reducing is because of the features of TEPS compared with natural gravel, as it is brittle.
Voids and pores of TEPS mix associated to ordinary concrete that is extra cause lead the reduction in concrete compressive strength. Experimental results are similar to the results getting in some studies [4-5, 18]. ACI code was adopted 17 MPa compressive strength. So, the all types of TEPS concrete could be used for structural considerations [28]. This performance also happened in the tensile strength of concrete. The density as reduced to reach the lightweight limits, due to the little weight of the recycled TEPS particles more than natural aggregate. Moreover, the modulus of rupture was decreased about 32%, at the TH35 concrete.

Table 10. Concrete mixes results.

| Concrete Mix designation | Slump (mm) | Fresh density (kg/m³) | Hardened density (kg/m³) | Tensile stress (MPa) | Compressive strength (MPa) | Modulus of rupture (MPa) |
|--------------------------|------------|------------------------|--------------------------|----------------------|---------------------------|-------------------------|
| NC                       | 40         | 2430                   | 2382                     | 3.89                 | 39.33                     | 10.3                    |
| TH15                     | 55         | 2234                   | 2120                     | 3.79                 | 38.757                    | 9.9                     |
| TH25                     | 76         | 2150                   | 2032                     | 3.65                 | 33.24                     | 8.8                     |
| TH35                     | 94         | 2075                   | 2008                     | 3.39                 | 30.11                     | 7.0                     |
| TC15                     | 62         | 2200                   | 1920                     | 3.68                 | 38.23                     | 10.0                    |
| TC25                     | 85         | 2112                   | 1820                     | 3.43                 | 31.85                     | 9.4                     |
| TC35                     | 100        | 2033                   | 1665                     | 3.22                 | 29.15                     | 9.3                     |

4. Conclusions

A test of the concrete mechanical properties containing treated recycled EPS was provided for the present experimental work. This represents a recent trend of experiments utilizing waste and rubbish as substitute materials for the concrete's existing gravel. The following findings were discovered:

1. Growing in the ratio of TEPS substitution results in an increase in the results of the slump. This occurred because of the super-plasticizer effect, seven to eight minutes, especially with mix time addition.

2. Up to a 30 %, concrete density decrease of the normal mixture density can be achieved by decrease by considered quantities of coarse aggregate and replacing it with the lighter recycled TEPS.

3. As a partial substitute for gravel, the recycled TEPS content in the concrete mix reductions the unit weight (density) and compressive strength (28 days) about 30 % and 26%, respectively, relative to the normal concrete.

4. SF effects on growing compressive strength and density is the most essential contribution to the reasonably great density. The recycled TEPS compressible formal by casting causes a rise in material quantities to pay for the decrease in concrete volume. Interaction between the materials in the mix during the mixed methods.

5. Recycled TEPS material has a significant influence on the splitting tensile strength of concrete, presenting a reduction of about 17 %, whereas at the maximum substitution ratio with recycled TEPS, the modulus of rupture is decreased by up to 32%.

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