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Investigation of the geotechnical properties of lightweight fill ground containing EPS-waste tire

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Abstract

Nowadays, in addition to several classic mechanical improvement methods, lightweight fill materials are used to reduce earthquake and vibration loads acting on the ground, as well as to minimize soil settlements. In recent years, the use of lightweight fill systems in geotechnical engineering has grown more common. In retaining structures, lightweight fill materials are also used to reduce the forces that impact the structure. Likewise, it makes it likable to utilize lightweight fill materials in order to lessen the loads on city center subsurface structures. In this study, the geotechnical properties of the lightweight fill materials which included EPS (Expanded Polystyrene Foam), waste tire, sand and cement materials as lightweight fill material were investigated. The L_{25} design model relevant to the Taguchi method was applied in the experimental study. The cement/mixture (EPS + waste tire + sand) weight ratios in designs include 8/1, 10/1, 12/1, 14/1, and 16/1. cement/water ratio was kept constant, EPS and waste tire in the mixture were used at rates ranging from 10% to 50% by weight. Unconfined compression, California bearing ratio (CBR), and freeze-thaw cycle tests were performed on the produced specimens, and the 'optimal mixing ratio for lightweight filler was investigated. As a result of the experiments, it was observed that the strength increased as cement ratios in the mixtures increased, whereas the strength reduced when the EPS ratio increased. Taking into consideration the ratios used in the study. Waste tires were found to have no impact on the designs' strength.

1. Introduction

The increased human population and the requirement for infrastructure and superstructure necessitated the usage of weak and problematic soils Even though, methods for improving soil are getting a lot better. One of these improvements is the use of lightweight fill material, which has a lower design load than ordinary filling materials Furthermore, in coming up with solutions to stability and settlement issues that arise while filling soft soils, it is used also to reduce soil pressures on retaining walls, buried pipelines, and other structures by filling formation on slopes with significant slip potential. Its usage is expanding in order to lighten the weights on the structures and reduce cost of infrastructure [1-5]. A well-compacted fill indicates that the allowed bearing capacity, which is a common criterion in determining a soil's capacity to carry a load, is between 0.3 MPa and 1 MPa [6].

As a lightweight fill material, materials that are slightly lighter than the soil are used, such as rubber trees, sawdust, pumice stone, foam concrete fly ash, silica fume, thermal power plant ash, volcanic ash-cement-foam combination, waste tire pieces, EPS, and glass foam. Cement is best as binding material.

The importance of polymer recycling has grown significantly in recent years. Expanded polystyrene is a significant component of plastic waste. Due to its low density (15–50 kg/m^3), recycling EPS involves technological challenges [7]. Because most recycling facilities lack the necessary equipment, EPS must be transported to a unique site where it may be concentrated in order to be recycled. Lightweight, buoyant, thermally insulating, dimensionally stable, chemically resistant, electrically conductive, hygienic appearance, cheap cost, etc., are some of the characteristics of EPS. It is utilized in numerous applications as a result of its characteristics. Nowadays, more than 3 million tons of EPS are used globally, an increase of about 6% annual [8, 9]. After being used, EPS usually ends up in landfills or is burned. Since its volume is large, the disturbance value in the environment is high. Also, there are considerable transportation costs involved with carrying low bulk density waste EPS [10]. In response to the high expense of disposal and rising public aversion to waste, a variety of EPS recycling strategies have been designed. Recycling can be profitable if waste EPS can be recycled into other polymers using cost-effective processes.

EPS beads are the end result of the pre-inflating process of the EPS raw material. EPS beads have been employed in a variety of applications recently by being mixed with the ground as a lightweight fill material [11-14]. Light-weight fill materials used by [11-13] were combined with cement and EPS beads to recover the mud that hydraulic excavation had removed from the bottom. In order to avoid the need for extra storage spaces for excavation waste and to recycle the waste into the industry, this new filling material is important. According to Miao et al. [14], a lightweight filler material composed of a blend of sand, EPS beads, and cement was utilized in the constructing of the bridge approach ramp resting on soft clay soil.

Haşal [15] created a lightweight filler material for use in ground constructions by combining cement, Orhaneli fly ash, and an air-entraining component. The compressed fly ash samples were cured for 1, 7, 15 and 28 days in the humidity chamber in order to determine their pozzolanic properties. The investigations have resulted in the development of fly ash-cement-foam combinations that are strong enough to be used as lightweight filler in soil constructions while also being stable. Ahmedov [16] performed experiments using EPS beads, cement, and sand by creating samples of 25%, 50%, 75%, and 100% EPS beads and a 12/1 weight ratio of cement to the mixture. Najmaddin [17] performed CBR studies using 0%, 5%, 10%, 15%, and 20% waste styrofoam to the mixture by weight, as well as compaction experiments using stream sand and modified waste styrofoam. Atabek [18], Proctor and CBR tests were carried out by using cement with volume sand/tire ratios of 90/10, 80/20, 70/30, 60/40, 50/50 in the mixtures. Pierce and Blackwell [19], Utilizing waste tires, cement, plasticizer at a weight ratio of 0.5%, and F-class fly ash as lightweight fill material. In the studies, he investigated whether waste tire material could be used in place of sand and found that it would work up to 38% by weight. In Liu et al. [20], samples were made at various water/cement ratios as well as rates of 2%, 3%, 4%, 5%, and 6% by weight of polystyrene beads/sand, 10%, 15%, 20%, and 25% by weight of cement/sand. The results of the unconfined compressive strength test showed that the strength criteria for filler materials were satisfied at 100-510 kPa [20]. In this study, lightweight filler materials such as EPS beads, waste tires, sand, and cement as binder were used to investigate the properties of lightweight fill material. EPS beads are mixed with conventional earth fill material and cement to form lightweight fill material [20]. The addition of cement as a binder to the lightweight filling material made using EPS beads improves the strength of the lightweight fill system [20]. Edinçliler and Özer [21] investigated the effect of EPS bead density on the mechanical properties of lightweight filling materials consisting of a mixture of EPS beads and sand. These investigations have clearly demonstrated that the adding of EPS beads decreases the strength of the mixture as well as the unit volume weight. The percentage of EPS bead in the composite lightweight fill system by weight is critical here, and this design parameter should be determined particularly for the project [21].

2. Material and Method

2.1. Expanded Polystyrene (EPS)

The EPS beads used in the study were obtained from Akpor Yalıtım A. in Gebze/Kocaeli. It is manufactured in various densities based on the usage of EPS beads. The surface of beads is rounded. It has diameters ranging from 2 to 5 mm and a density of 0.016 gr/cm^3. Sieve analysis tests were performed in accordance with the TSE 1900-1 standard, and it was determined that the EPS beads ranged between 2-4.75 mm [22]. Table 1 lists the physical properties of ESP particles.

Table 1. Physical properties of EPS particles

Particle density (ρ_s) (g/cm^3)	0.016
Effective diameter (mm) (D_{10})	2.25
Uniformity coefficient (C_U)	1.47
Curvature coefficient (C_C)	0.98

2.2. The waste tires

Granular waste tire was obtained from the Barutçular recycling facility in Konya Province's Selçuklu District, and the waste tires physical properties were assessed using TS 1900-1 specifications [22]. Table 2 lists the physical properties of granular waste tire.

Table 2. Physical properties of granular waste tire

Specific density (ρ_s) (g/cm^3)	1.00
Effective diameter (D_{10}) (mm)	0.42
D_{30} (mm)	1.25
D_{50} (mm)	2.1
D_{60} (mm)	2.65
Uniformity coefficient (C_U)	6.31
Curvature coefficient (C_C)	1.40

2.3. Soil properties

In this study, the physical properties of the soil obtained from Konya Province, Selçuklu District, Eğribayat sand quarry were determined. According to ASTM D6913-04, 2009 and ASTM D854-10, 2010. In addition, the soil class was determined according to TS 1500, 2000 [23-25]. Table 3 shows the physical properties of sand.

Table 3. Physical properties of the sand

USCS classification	SW
Specific density (ρ_s) (g/cm^3)	2.64
Effective diameter (mm) (D_{10})	0.18
Uniformity coefficient (C_u)	11.67
Curvature coefficient (C_c)	1.11
Optimum moisture content (%w)	6.40
Dry unit weight in compacted state $\rho_{k,max}$ (gr/cm^3)	1.18
Dry unit weight in loose State $\rho_{k,min}$ (gr/cm^3)	1.46
Minimum voids ratio e_{min} (%)	20
Maximum voids ratio e_{max} (%)	79

2.4. Cement

The cement used in the experiments is an early strength cement that satisfies TS EN 196 and TS EN 197-1 standards [26, 27]. Portland cement has fine-grained silt characteristics with an average diameter of 0.01 mm. Table 4 shows the specific density and chemical composition of cement.

Table 4. Chemical components and properties of CEM I 42.5R cement

Contents (%)	CEM I 42.5 R
CaO	62.10
SiO_2	20.10
Al_2O_3	4.92
Fe_2O_3	3.17
MgO	1.81
Na_2O	0.32
K_2O	1.07
SO_3	4.71
Cr_2O_3	0.05
TiO_2	0.42
Ignition loss	2.69
Specific mass (g/cm^3)	3.08
Specific surface Fineness (cm^2/g)	3312

2.5. Experiment design

The Taguchi method investigates the impacts of parameters on results by conducting a limited number of experiments with the most appropriate orthogonal index chosen by using factors that are effective on the result and can be controlled for an experimental study. Using this method, the cost of the experiment may be kept to a minimum while maximum and lowest values can be approximated from the results of unconducted experiments. In the Taguchi method, specially developed orthogonal index tables are used for designs.

The geotechnical properties of the lightweight fill, which includes EPS (Expanded Polystyrene Foam), waste tires, sand, and cement components, were examined in this study. Using the L_{25} design table with the Taguchi method-specific 5 parameters and 5 levels, experimental studies were carried out. The weight cement/mixture (EPS + waste tire + sand) ratios for the designs shown in Table 5 are 8/1, 10/1, 12/1, 14/1, and 16/1. The amount of waste tire and EPS in the combination ranged from 10% to 50% by weight while the cement/mixture ratio was kept constant.

Table 5. Mixtures ratios

Mixture No	Cement/ Mixture (EPS+ Tire+ Sand)	EPS (%)/(Mixture)	Tire (%)/(Mixture)
1	8/1	10	10
2	8/1	20	20
3	8/1	30	30
4	8/1	40	40
5	8/1	50	50
6	10/1	10	20
7	10/1	20	30
8	10/1	30	40
9	10/1	40	50
10	10/1	50	10
11	12/1	10	30
12	12/1	20	40
13	12/1	30	50
14	12/1	40	10
15	12/1	50	20
16	14/1	10	40
17	14/1	20	50
18	14/1	30	10
19	14/1	40	20
20	14/1	50	30
21	16/1	10	50
22	16/1	20	10
23	16/1	30	20
24	16/1	40	30
25	16/1	50	40

2.6. Sample preparation and experiments

While samples of lightweight fill were being prepared for each design in Table 5, To ensure that the mixes were homogeneous, cement, waste tire, and sand were blended dry in the first stage. The required water was then added to each mixture and well mixed to achieve homogeneity. EPS were added and mixed again (homogeneously) according to the technical specifications of the EPS beads obtained in the laboratory, and the specimens were compacted in three layers in volume-controlled PVC molds of 5 cm diameter and 10 cm height (Figure 1).

Figure 1. Sample preparation process

Airtight packaging was used for test samples compacted in PVC molds. 7 and 28-day-old spheroids were left at room temperature in a plastic rectangular storage container. 90 unconfined pressure test specimens were prepared for the samples that were extracted from the PVC molds at the end of the curing periods, three for each design, with curing times of 7 and 28 days (Figure 2).

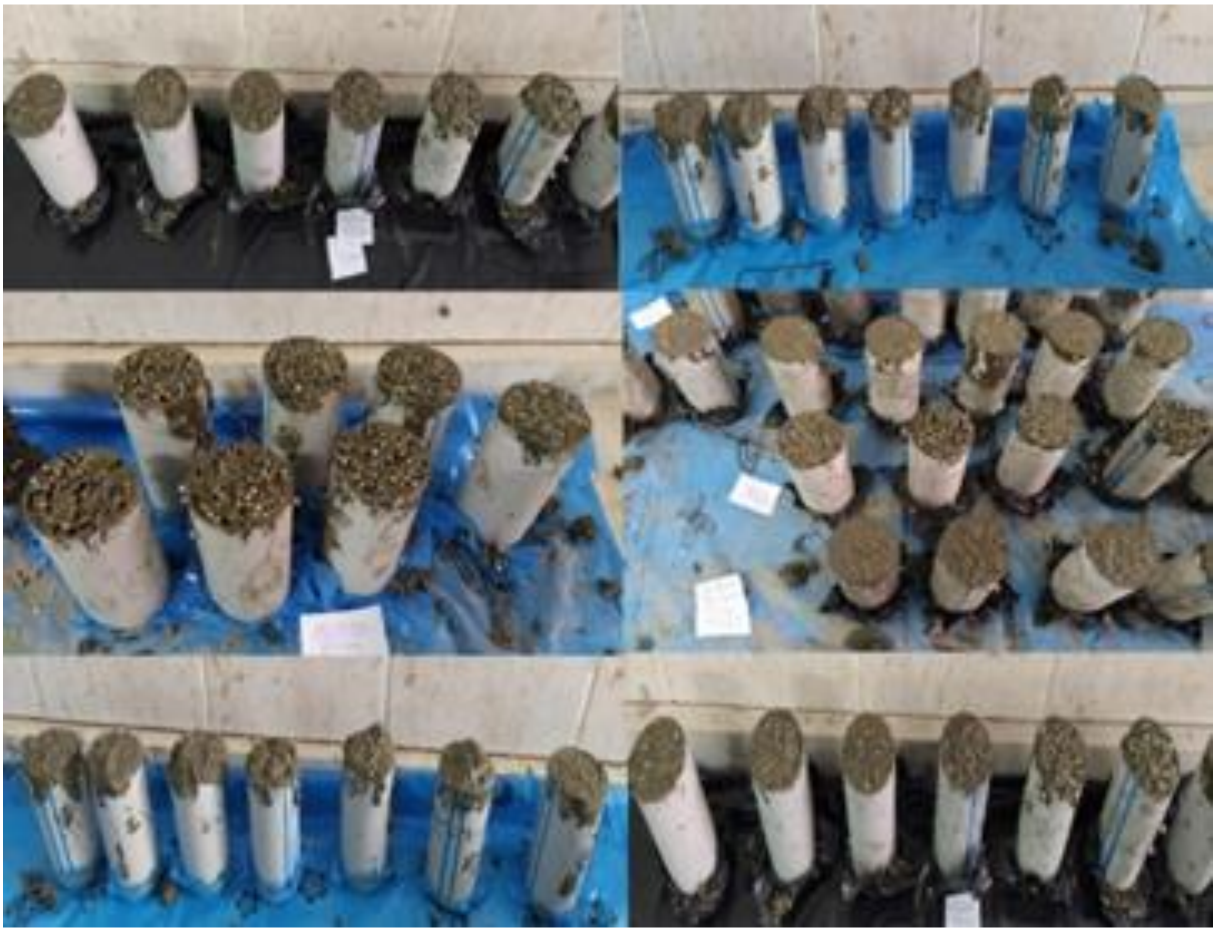

Figure 2. Prepared test samples

According to ASTM D2166 standard, the unconfined compressive strenght test was conducted [28]. The samples (D=50mm; L=100mm) were taken out of their molds and placed into the testing dvice. 0.5 mm/min was selected as the loading speed tests were carried out after the samples had been cured for 7 and 28 days, respectively. The computer was used to keep a record of the load and penetration changes during the experiment.

It was deemed sufficient for the 7-day strength to be more than 0.3 MPa and the 28-day strength to be less than 1.0 MPa since back-cutting is a possibility after the use of lightweight fill materials. CBR and freeze-thaw tests were conducted for the designs (numbered 3-9-10-15-20), whose strengths ranged from 0.3 MPa to 1.0 MPa as a result of the unconfined compressive test. A deep freezer was used to determine the freeze-thaw behavior of the samples. Between -18 and -21 ℃, the freezing procedure was used. The thawing procedure was completed at working room temperature of +21 ℃. There have been 12 freeze-thaw cycles, with 12 hours of waiting between each temperature. After the detached parts of the samples were removed after the freeze-thaw test, unconfined compressive test and CBR tests were performed on the samples before and after freezing-thawing to determine the freeze-thaw behavior. CBR tests were conducted in accordance with TS 1900-2 [29]. Prepared in molds with a diameter of 150 mm. They were held for cure times of 7 and 28 days. A CBR test equipment with an adjustable piston speed between 0.5 and 5 mm/min was used for the experiments, which were conducted using a digital data acquisition and control unit.

3. Results and Discussion

3.1. Unconfined compressive strength results

The test program's design densities and the density of the prepared samples after 7 and 28 days were determined by considering the densities and percentages of the materials that were used to create the samples for 25 different mixses (Table 6). The density variation in the samples varies depending on the ratios of the materials used. With increasing EPS ratios, densities decrease. It can be observed from the graph in Figure 3 that the density increases as the cement/mixture ratio does so while holding the same EPS ratios. It was found that the density in every design experiment was less than the soil's fill density.

Table 6. Densities of samples and densities in mixtures

Mix No	Cement/ Mixture	EPS (%)/Mixture	Tire (%)/Mixture	Design density (g/cm^3)	7-day average density (g/cm^3)	28-day average density (g/cm^3)
1	8/1	10	10	0.982	1.053	1.132
2	8/1	20	20	0.666	0.723	0.770
3	8/1	30	30	0.504	0.528	0.660
4	8/1	40	40	0.406	0.407	0.424
5	8/1	50	50	0.339	0.353	0.360
6	10/1	10	20	1.071	1.125	1.217
7	10/1	20	30	0.754	0.842	0.857
8	10/1	30	40	0.582	0.620	0.692
9	10/1	40	50	0.474	0.517	0.563
10	10/1	50	10	0.403	0.389	0.415
11	12/1	10	30	1.141	1.183	1.263
12	12/1	20	40	0.829	0.923	0.931
13	12/1	30	50	0.651	0.750	0.789
14	12/1	40	10	0.540	0.591	0.663
15	12/1	50	20	0.459	0.445	0.528
16	14/1	10	40	1.198	1.297	1.343
17	14/1	20	50	0.893	0.968	0.971
18	14/1	30	10	0.719	0.785	0.740
19	14/1	40	20	0.597	0.696	0.718
20	14/1	50	30	0.510	0.569	0.592
21	16/1	10	50	1.246	1.333	1.352
22	16/1	20	10	0.960	1.075	1.034
23	16/1	30	20	0.774	0.880	0.879
24	16/1	40	30	0.648	0.744	0.786
25	16/1	50	40	0.557	0.643	0.655

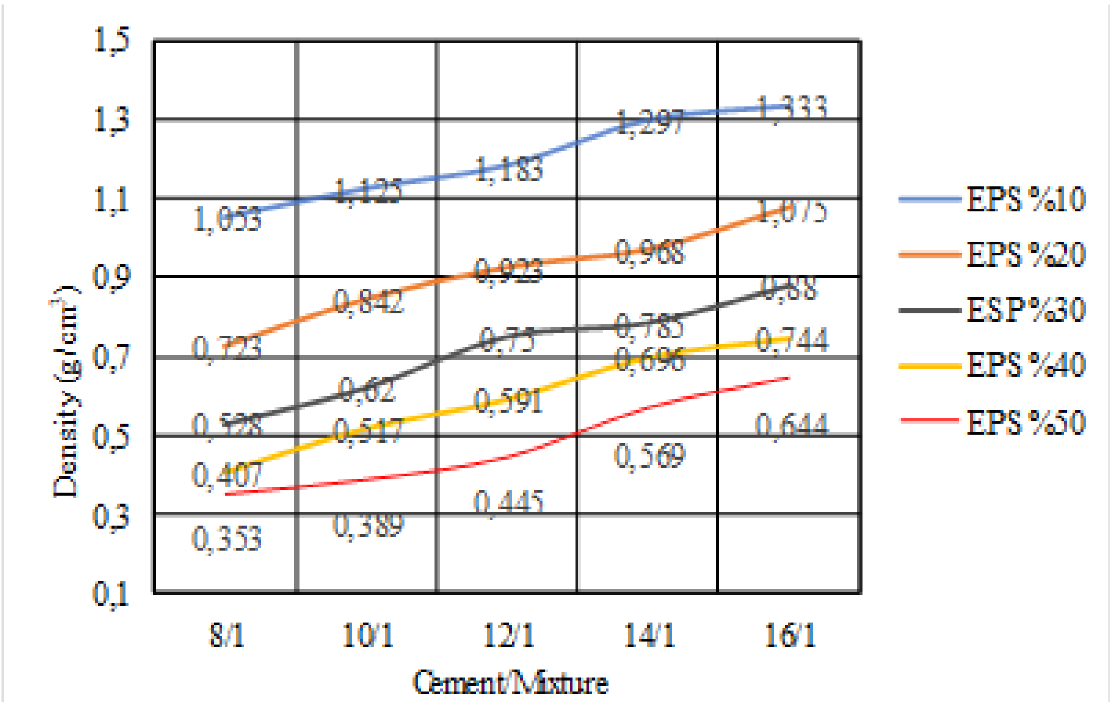

Figure 3. Samples changing densities graph

According to the cement/mixture weight ratios of 8/1, 10/1, 12/1, 14/1, and 16/1 determined for each design, unconfined compressive strengths of 7 and 28 days were obtained, as shown in Figures 4a-4b. It was observed that the strengths changed in accordance with the amount of EPS (%) in the mixture. Figures 5 and Figure 6 show how this change has occurred. When the mixture's EPS ratio is 10%, it has been shown that each design's strengths are higher, however at a 50% EPS ratio, the strengths are lower. In this circumstance, it was found that the samples' strengths increased as the cement ratio in the designs increased, and that the samples' strengths significantly decreased as the amount of EPS (%) increased. As well, it can be shown that Mixture No. 16's 14/1 cement/mixture ratio has the highest value of all the EPS ratios in the material for the 28-day unconfined compressive strength test. The unconfined compressive strength test results are given in Table 7.

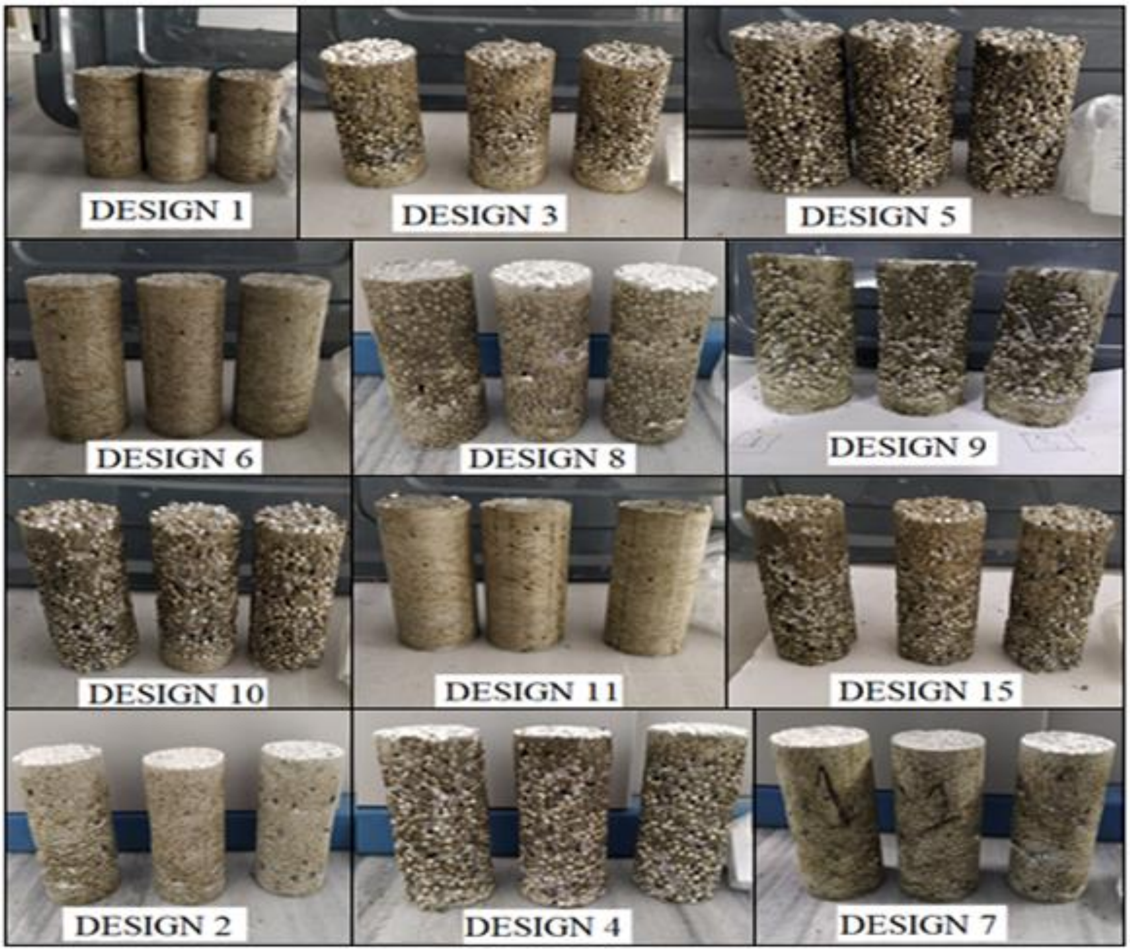

Figure 4a. The prepared specimens

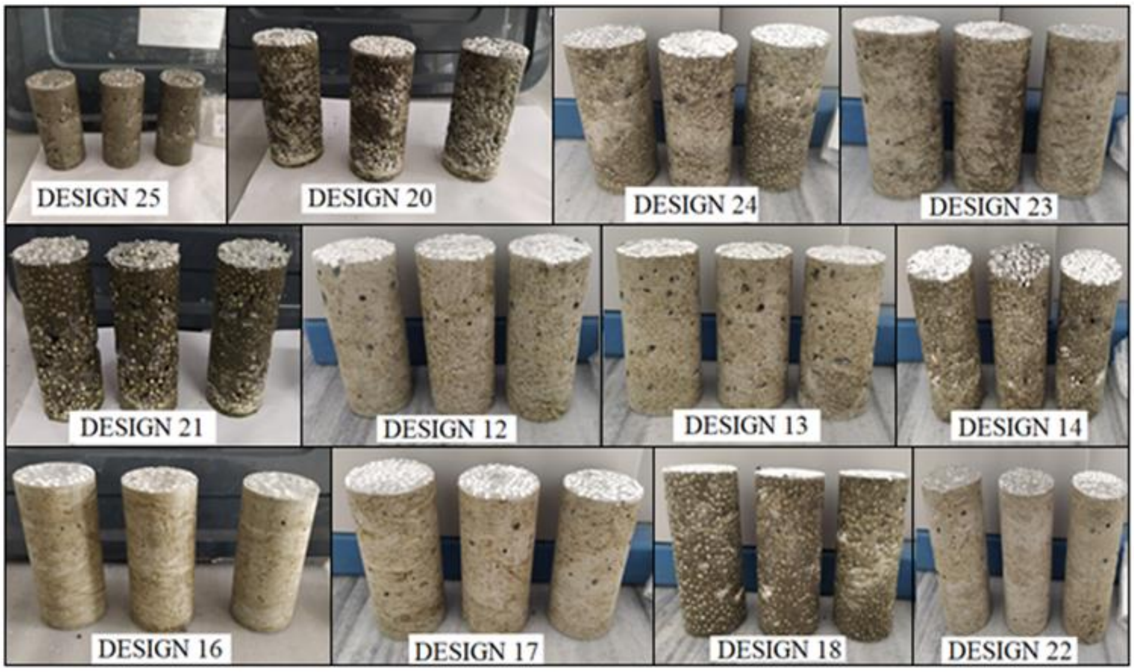

Figure 4b. The prepared specimens

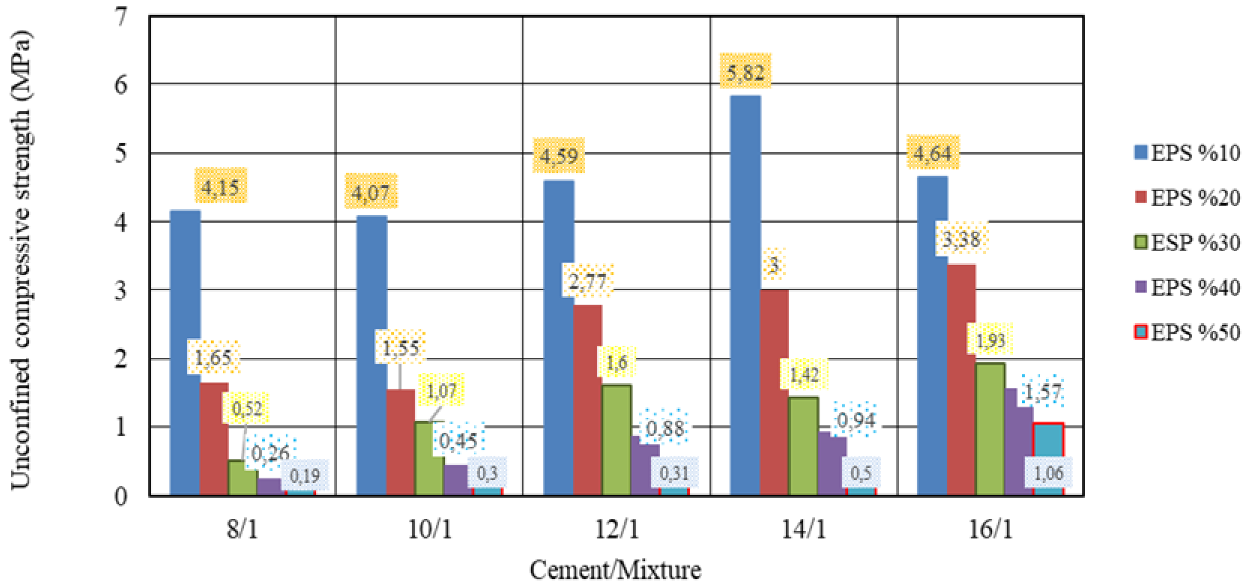

Figure 5. The 7-day unconfined compressive strength variation depending on the mixtures EPS ratio

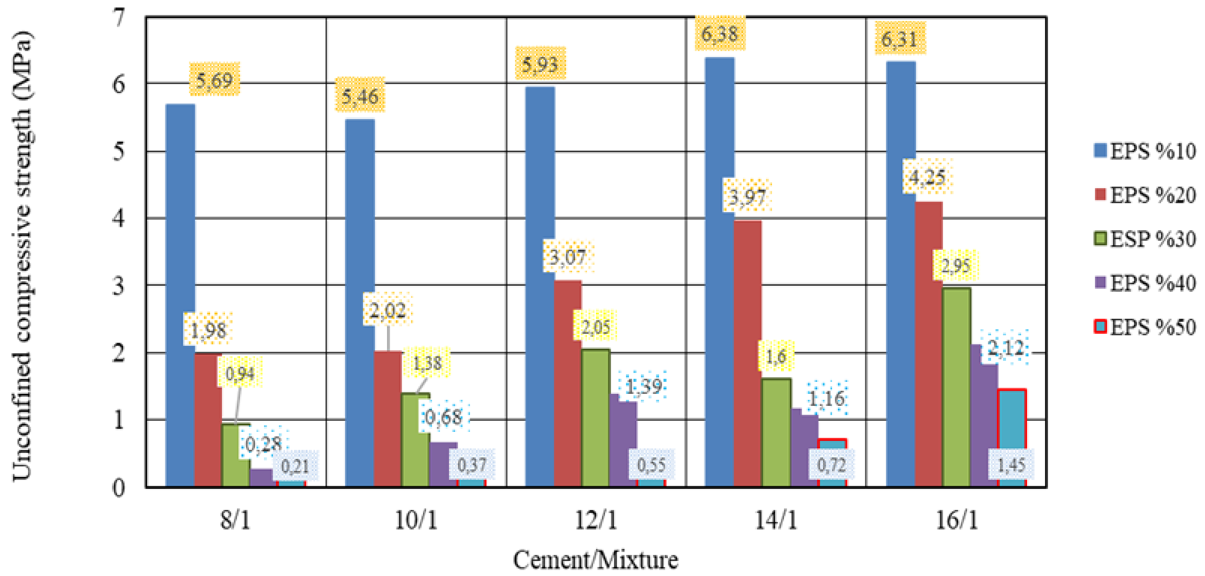

Figure 6. The 28-day unconfined compressive strength variation depending on the mixtures EPS ratio

A common criterion for identifying a soil's capacity for bearing load is the idea that a soil with a strength of between 0.3 and 0.7 MPa is equivalent to a well-compacted fill [6]. ACI, 2000, For light fillings, it is defined as materials with a compressive strength not exceeding 8.3 MPa within the scope of the ACI 116R report [30]. The unconfined compressive strength in the majority of today's lightweight fill applications is no higher than 2.1 MPa. The lightweight fill material must satisfy the low strength requirement in order to be appropriate for possible excavation in the future. Due to the possibility of re-excavating the lightweight fill material, the unconfined compressive strength values are planned to be at least 0.3 MPa for 7-day samples and 1.0 MPa for 28-day samples. The mixes nos. 3, 9, 10, 15, and 20 are demonstrated to be within the required strength limits of 0.3 MPa–1.0 MPa when Table 6 is examined.

3.2. Unconfined compressive strength results for mixtures 3, 9, 10, 15, and 20

Samples were made again for the mixtures (3, 9, 10, 15, and 20) that can be used as a lightweight fill material, and unconfined compressive strength tests were conducted. When the test results were compared to the results of the first mixture samples, it was found that they were extremely close. The 7- and 28-day densities were calculated by measuring the weights and dimensions of the samples before testing (Table 8). Table 9 shows the average strength values of test results.

Table 7. Samples 7- and 28-day compressive strengths

Mix No	Cement/ Mixture	EPS (%)/Mixture	Tire (%)/Mixture	7 day average strength (MPa)	28 day average strength (MPa)
1	8/1	10	10	4.15	5.69
2	8/1	20	20	1.65	1.98
3	8/1	30	30	0.52	0.94
4	8/1	40	40	0.26	0.28
5	8/1	50	50	0.19	0.21
6	10/1	10	20	4.07	5.46
7	10/1	20	30	1.55	2.02
8	10/1	30	40	1.07	1.38
9	10/1	40	50	0.45	0.68
10	10/1	50	10	0.30	0.37
11	12/1	10	30	4.59	5.93
12	12/1	20	40	2.77	3.07
13	12/1	30	50	1.60	2.05
14	12/1	40	10	0.88	1.39
15	12/1	50	20	0.31	0.55
16	14/1	10	40	5.82	6.38
17	14/1	20	50	3.00	3.97
18	14/1	30	10	1.42	1.60
19	14/1	40	20	0.94	1.16
20	14/1	50	30	0.50	0.72
21	16/1	10	50	4.64	6.31
22	16/1	20	10	3.38	4.25
23	16/1	30	20	1.93	2.95
24	16/1	40	30	1.57	2.12
25	16/1	50	40	1.06	1.45

Table 8. The mixture densities at 7 and 28 days

Mix. No	Mixture density (g/cm^3)	1-7	2-7	3-7	7-day average density (g/cm^3)	1-28	2-28	3-28	28-day average density (g/cm^3)
3	0.504	0.605	0.616	0.581	0.601	0.696	0.655	0.781	0.711
9	0.474	0.567	0.562	0.525	0.551	0.612	0.574	0.583	0,590
10	0.403	0.418	0.460	0.431	0.436	0.548	0.488	0.580	0.539
15	0.459	0.445	0.415	0.422	0.427	0.536	0.504	0.516	0.519
20	0.510	0.619	0.666	0.696	0.660	0.593	0.557	0.614	0.588

Table 9. The results of 7 and 28 day unconfined compressive strength test

Mix. no	7. day strength	7. day average strength	28. day strength	28. day average strength.
3-1	0.6		0.98	
3-2	0.62	0.59	0.92	0.95
3-3	0.54		1.07	
9-1	0.53		0.79	
9-2	0.48	0.49	0.73	0.76
9-3	0.46		0.75	
10-1	0.32		0.47	
10-2	0.35	0.34	0.43	0.47
10-3	0.34		0.5	
15-1	0.31		0.63	
15-2	028	0.30	0.54	0.59
15-3	0.3		0.6	
20-1	0.54		0.69	
20-2	0.58	0.57	0.61	0.71
20-3	0.59		0.83	

3.3. Freeze-thawing cycle and CBR tests

Since the unconfined compressive strength test results of mixes nos. 3, 9, 10, 15, and 20 range between 0.3 and 1.0 MPa, they have been determined to be adequate for lightweight filling, which may be used as lightweight fill material. CBR and freeze-thaw cycle tests were carried out by selecting the mixture samples 3-5-9-10-15. Unconfined compressive strength tests were carried out after freeze-thaw cycle tests.

Table 10 shows the experiment's results. According to Mix no. 3, the average strength was 0.95 MPa after a 28-day curing time and 0.80 MPa after a freeze-thaw cycle. The average strength of mix no. 20 was found to be 0.72 MPa duration of the 28-day curing period, and it was found to be 0.71 MPa after a freeze-thaw cycle test in the same mixture. Because there are less EPS beads used as insulation material in the third mix, there is a difference in strength. Since the EPS ratio is more than 30% in mixture numbers 9, 10, 15 and 20, it has been observed that the strength values are close to each other. As a result of the freeze-thawing cycle, the test results showed a general decrease in specimens' strength. It has been understood that the strength difference is high in mixes with low EPS ratio. The results of the tests revealed that the samples were less affected by freezing and thawing since EPS is a good insulator.

Table 10. Strengths of specimens after 7 and 28 days of freeze-thaw cycles test

Mix. No	7. day strength	7. day average strength	28. day strength	28. day average strength
3-1	0.49		0.76	
3-2	0.51	0.50	0.83	0.80
3-3	0.50		0.95	
9-1	0.43		0.76	
9-2	0.42	0.43	0.68	0.74
9-3	0.44		0.78	
10-1	0.29		0.37	
10-2	0.31	0.30	0.38	0.37
10-3	0.29		0.36	
15-1	0.28		0.54	
15-2	0.30	0.30	0.62	0.56
15-3	0.31		0.51	
20-1	0.48		0.74	
20-2	0.49	0.48	0.70	0.71
20-3	0.48		0.68	

After curing the specimens for 7 and 28 days, CBR values were obtained. According to the test results, all mixtures' CBR values at 2.5 mm penetration were lower than those at 5 mm penetration. CBR value at 5mm penetration was used while defining the test results. Figure 7 provides visuals of the specimens used in the CBR test. The CBR values in Table 12 are classified based on the test results shown in Table 11 [31]. Mix Nos. 3 and 20 can be used as a foundation or sub-base layer since they meet the criteria for the "good" class, with CBR values of 31.74 and 24.44, respectively. Designs Nos. 9, 10, and 15 satisfy the requirements of the "Fair" class and have CBR values of 7–20. It has been determined that Mixes 9, 10, and 15 may be used as the sub-base layer.

Table 11. The mixtures 7- and 28-day CBR results

Mix. No	7 days average CBR		28 days average CBR	
	2.5 mm	5 mm	2.5 mm	5 mm
3	17.45	20.42	21.53	31.74
9	7.03	11.27	10.93	19.72
10	5.57	8.56	7.52	11.02
15	6.47	10.65	10.01	18.07
20	14.47	19.01	18.35	24.44

Table 12. Classification of CBR values [31]

CBR Value (%)	General Evaluation	Objective	Unified Classification System
0-3	Very Poor	Subgrade	OH, CH, MH, OL
3-7	Poor	Subgrade	OH, CH, MH, OL
7-20	Fair	Subbase	OL, CL, ML, SC, SM, SP
20-50	Good	Base or Subbase	GM, GC, SW, SM, SP, GP
>50	Excellent	Base	GW, GM

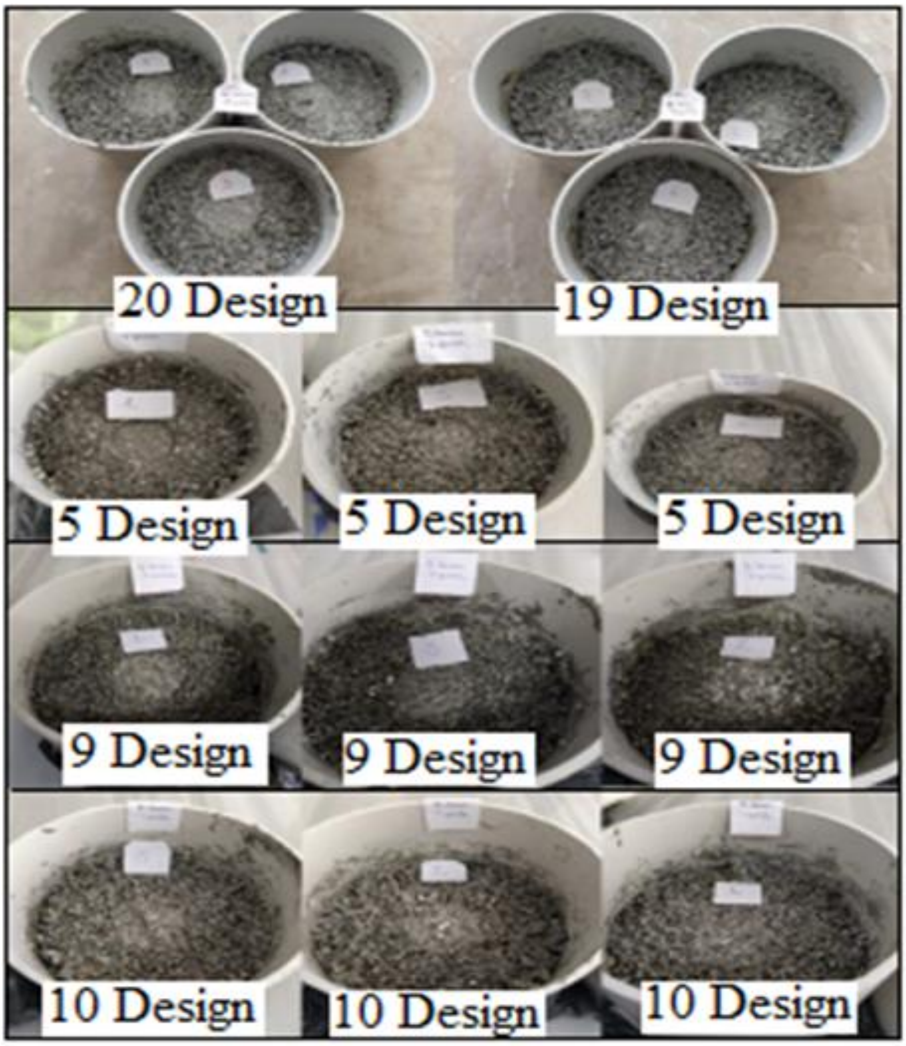

Figure 7. Specimens after the CBR test

4. Conclusion and Recommendations

Appropriate mixing ratios for lightweight filler material were examined using various ratios of EPS beads, waste tires, cement, and sand. The experiment findings are presented as:

- The density of EPS beads is 0.016 g/cm^3, whereas the density of waste tires is 1.0 g/cm^3. These materials are less heavy than soil.
- In lightweight fill mixes, weight cement/mix ratios of 8/1, 10/1, 12/1, 14/1, and 16/1 were used. 25 mixtures were prepared with EPS and waste tires, having weights ranging from 10-20-30-40-50-50%. The one-week strength of the designed lightweight soil fill should be greater than 0.7 MPa, however the 28-day strength value should not exceed 1.0 MPa, considering a possible excavation on the lightweight fill in the future.
- Designs 3, 9, 10, and 15 were found to have strengths ranging between 0.3 and 1.0 MPa. As can be seen in Table 6, the 7- and 28-day densities of these designs are significantly lower than those of fill materials.
- The amount of EPS and cement used in unconfined compressive testing affect the test results. The strengths were found to decrease as the EPS amount increased, but also to increase when the cement amount increased. The 7- and 28-day strength values of mixture No. 10 were 0.30 MPa and 0.37 MPa, respectively. The 3rd design 7 and 28-day strength results with 30% EPS and 30% waste tire materials provided the highest strength with 0.52 MPa and 0.94 MPa values, respectively.
- The results of the CBR tests conducted using mixtures nos. 3, 9, 10, and 15 are shown in Table 7. The mixture no. 10 had the lowest 7 and 28-day CBR values, with 5mm penetration readings of 8.56 and 11.02, respectively. The mixture No. 3 in it had the highest values of 20.42 and 31.74 for 5 mm penetration, respectively, in the 7- and 28-day CBR results. Taking into consideration the 28-day 5mm penetration values, designs 9, 10, and 15 from the "medium" class of the CBR assessment may be applied for sub-base, while design No. 3 from the "good" class of the CBR assessment can be used as the foundation or sub-base layer.

- When the samples' unconfined compressive strengths were examined as a result of the freeze-thaw tests, it was determined that there was minimal difference in the strengths.

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Author contributions

Atila Demiröz: Conceptualization, Methodology, Visualization, Investigation, Writing-Reviewing and Editing
Özcan Diker: Data curation, Writing-Original draft preparation, Validation.

Conflicts of interest

The authors declare no conflicts of interest.

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