




## A Study Related to Eco-Friendly Production of Lightweight Concrete by Using Expanded Polystyrene

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**Abstract:** The extensive use of conventional concrete has a negative impact on sustainable use of materials, resources, and environment. The introduction of aggregates of the recycled materials will no doubt be beneficial to certain extent. The lightweight concrete (LWC) can be an alternative material to the conventional concrete to be used in the building industry. The life span of any built environment is limited to many decades, thus the availability of aggregates of recycled materials by utilizing waste products from demolished building, together with the Expanded Polystyrene Beads (EPS) that is abundant in an oil producing country like Iraq can be constructed, six mixes of LWC-EPS (0%, 20%, 40%, 60%, 80%, and 100%) were constructed and tested in this study. The research methodology consisted of investigating the fresh features of LWC due to the impact of utilizing various EPSs percentages on LWC, while the second part concentrated on testing LWC mixtures that had been hardened for compressive strength, splitting tensile strength, dry density, water absorption, and air void content. The findings of this study revealed that while compressive and splitting tensile strengths decreased, the fresh characteristics of LWC were only marginally improved by the inclusion of EPSs. As EPS tends to form larger clumps, absorb water, and dry out the mix, the study also showed that the LWC created with these waste materials lowered the density (lightweight) of the concrete mixes. This available investigation shall be of a use by architects, building engineers, researchers, and academics

**Keywords:** Light Weight Concrete; LWC; EPS; Expanded Polystyrene; Compressive; Tensile; Water Absorption; Casting; Curing

## 1. Introduction

The extensive use of conventional concrete has a negative impact on sustainable use of materials, resources, and environment. The life span of any built environment is limited to many decades. The introduction of recycled materials will of no doubt be beneficial to a certain extent. The lightweight concrete LWC can be an alternative material to the conventional concrete to be used in the building industry. the availability of aggregates of recycled materials by utilizing waste products from demolished building, together with the Expanded Polystyrene Beads (EPS) that is abundant in an oil producing country like Iraq can be constructed. Currently, research into the effects of new admixtures on EPS-strength LWC's and performance is being investigated. research into the effects of new admixtures on EPS-strength LWC's and its performance is currently ongoing [1]. The pre-foam step determines the expanded polystyrene block's ultimate density [2], [3], the EPS chemical and mechanical properties are described below [4] The physical qualities of EPS beads have been further defined by [5].

### 1.1 Lightweight Concrete

The different types of LWC are classified in three types, no fines concrete Aerated Concrete and light Weight Concrete [6], [7], [8] [9]. [10] reported that Ideal lightweight aggregates for producing LWC

are naturally occurring aggregates such as pumice and manufactured aggregate such as expanded shale and clay. The [10] classified concrete as lightweight concrete, the unit weight of the concrete mix needs to be between 1440 – 1840 kg/m<sup>3</sup>. [11] stated that the flexibility of LWC is more than the normal weight concrete due to its lower modulus of elasticity. The flexural strength decreases with an increased amount of LWA [12]. Furthermore, increasing the strength of LWC can cause an increased risk of brittleness which can decrease ductility and workability [13]. The manufacturing of lightweight aggregate comes at a higher cost, but the savings in labor and foundation expenses are more than covered by the lighter member sections that are produced [14]. An industrial bi-product, Fly Ash can be used as lightweight aggregate which can provide environmental benefits [13]. LWC allows the reduction of the column size, footings & other load-bearing components. It also ensures space availability by reducing the component sizes in the structure. While it is more expensive, the smaller structural parts and lower concrete volume make up for some of that cost [15], [16], [17], and [14]. Structural LWC confers fire-resistance to concrete materials as the porosity of the LWA serves as a water source for internal concrete curing, thereby providing continued development of the durability and strength of the concrete [18], [19], [14] and [20]. LWC is considered a high thermal insulation material as it provides better sound and heat absorption compared to the normal-weight concrete [18], [21] and [20]. Structural LWC is well fitted for use in earthquake-prone areas as its lower internal mass ensures lesser internal force. Some of the disadvantages of using lightweight concrete are that the compressive strength can be affected with the use of lightweight aggregate (LWA). The flexural strength decreases with an increase [12]. Furthermore, increasing the strength of LWC can cause an increased risk of brittleness which can decrease ductility and workability [13]. Structural LWC is mainly used for the reduction of the dead load of concrete structures. With LWC, about 10-20% of the total cost of construction is saved compared to the use of normal weight concrete. LWC allows the reduction of the column size, footings & other load-bearing components. prosper calculated natural and optimized production rates and reservoir pressure, and water cut for the existing well based on the available data. This is the starting point for designing the future water injection operation as a technique for pressure maintenance of the reservoir.[36]

## 1.2 Research Statement

Our planet is experiencing a steady rise in the amount of solid waste generated due to lifestyle and rapid development, population growth, urbanization, and more. Metals, Wood, iron, glass, wood, glass, rubber, ceramics, plastics, and EPS are all examples of these non-biodegradable materials. Meanwhile, engineers and scientists and environmentalists are working side by side to manage sustainably the negative effects of such waste. However, some researchers researched into the use of Expanded Polystyrene Bead EPS in concrete manufacturing to make it more sustainable and eco-friendlier.

## 2. Methodology

The primary goal of this investigation is to determine the impact of EPS on lightweight concrete (EPS-LWC). So, a standard concrete mix must be used as a reference mix (R). Preliminary LWC mixes were then created and tested, to find the optimal design for a control mix. A control mix was developed, and the results of varying the Expanded Polystyrene Bead concentrations were assessed (EPS). Six mixes of LWC-EPS (0%, 20%, 40%, 60%, 80%, and 100%) were constructed and tested in this study. For both fresh and mechanical characteristics, each blend would be evaluated in line with ASTM [5] or B.S. [22] testing methods. Additionally, it was necessary to determine which tests should be included in the mix as part of this investigation. Slump flow and passing ability can be determined in centimeters by height in a conventional slump test for lightweight concrete, for example. Compression, splitting tensile, and oven-dried density were the mechanical parameters examined. Each combination would be compared to the control specimen in terms of its properties. For instance, the 28-day compressive

strengths of each mix were compared to find the strongest sample in compression. The combination that performed the best internationally was selected as a viable option for future study after it was analyzed and ranked based on specific features.

### 3. Test Procedure

Tests procedures have been conducted as follows; Firstly, mix proportion as stated in Fig. 1, casting, and curing was conducted in Concrete Laboratory, to prepare all the needed specimens (150 mm x 150 mm x 150 mm) cubes according to B.S and (150 mm diameter x 300 mm height) cylinders were prepared in accordance with the ASTM. Secondly, experimental investigations were conducted to demonstrate the effect of EPS on the fresh, hardened, and mechanical properties of lightweight concrete. The fresh state properties of all lightweight concrete mixtures were made available for analysis by conducting a slump flow making sure that they are workable, have a homogenous mixture and can be categorized as lightweight concrete. The hardened properties will be tested by conducting dry density, air voids, and water absorption tests. The mechanical properties will be tested by conducting compressive strength. The whole procedures were performed as per the workflow chart shown in Fig. 1.

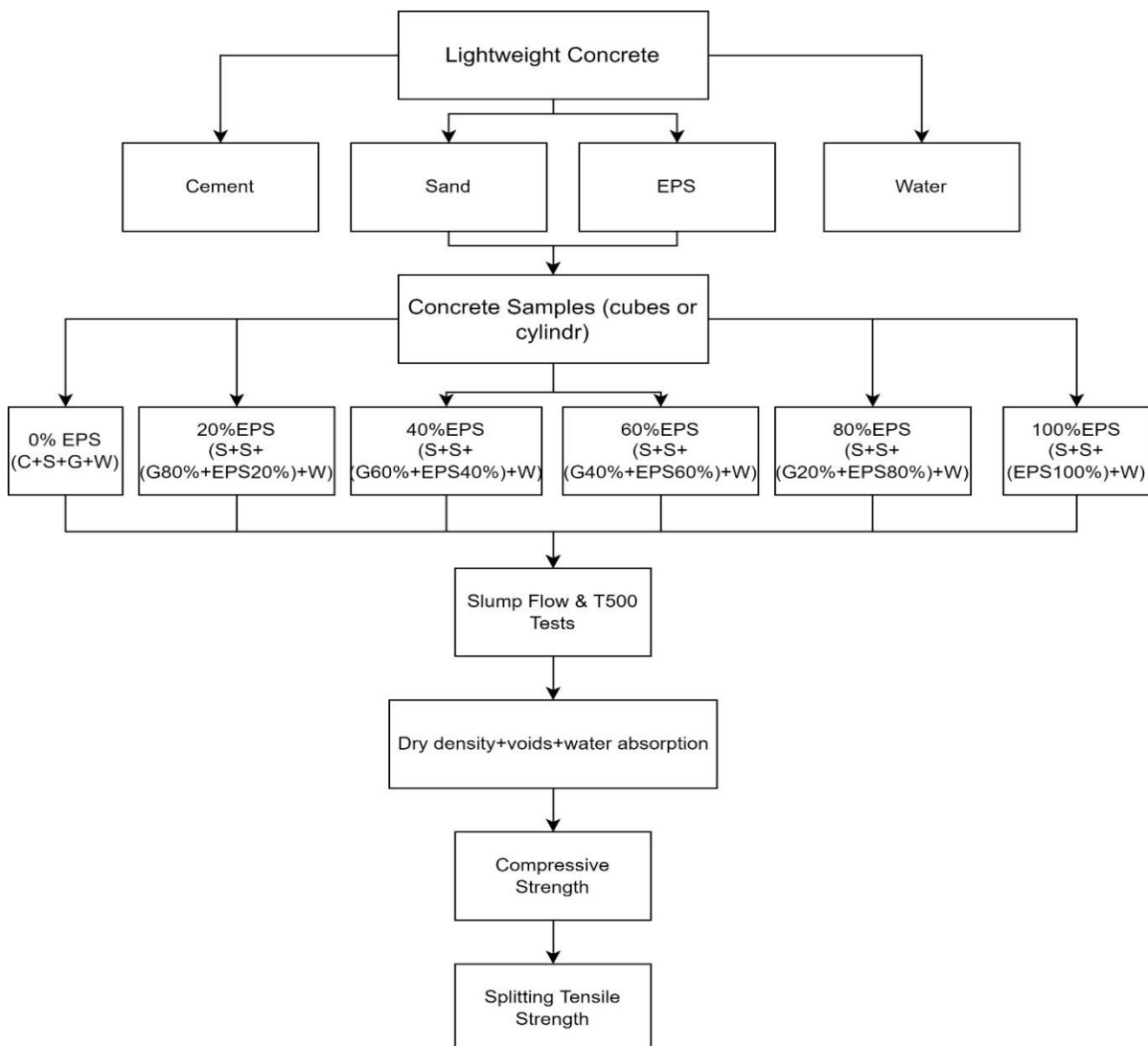


Figure 1: Experimental workflow chart of the study

### 3.1 Slump-Flow Test Procedure

Slump-flow tests were used to assess the flowability and the rate of deformability of all mixes. According to the ASTM [23] specification the slump flow (inverted slump cone) was carried out. After the concrete mixture was mixed, this test indicates how smoothly it will flow. Since there is a greater chance of lightweight aggregate segregation and mix leakage, this test is crucial to perform [24]; [7]. The test configuration for this test is shown in Figure 2.

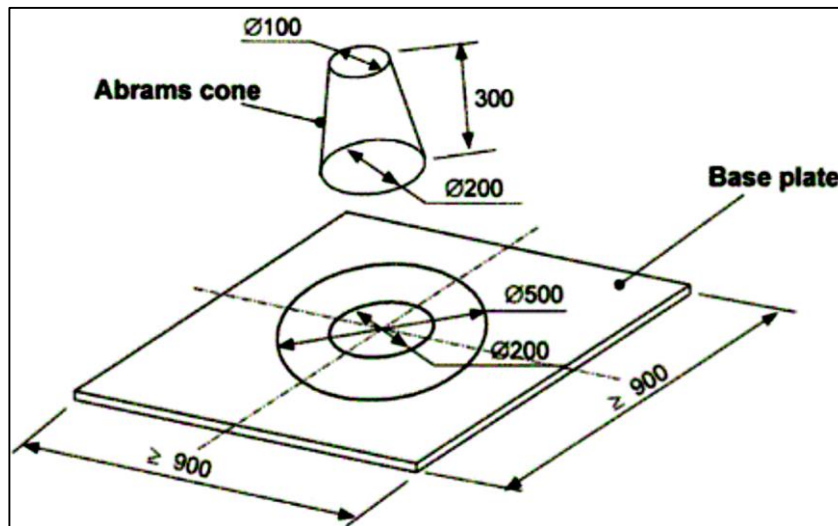


Figure 2: Slump-flow test – apparatus

### 3.2 Compressive Strength Test Procedure

One of the main tasks of this study was to distinguish how EPS affects the compressive strength of lightweight concrete. To test the compressive strength, the procedure outlined in B.S EN 12390-3 [22] was used. It is known that concrete strength improves with age. A set-up of the experiment using one of the specimens can be seen in Fig. 3. While the equation used to determine the compressive strength is shown in Eq. 1.

$$(1) \quad F_{cu} = \frac{P}{A}$$

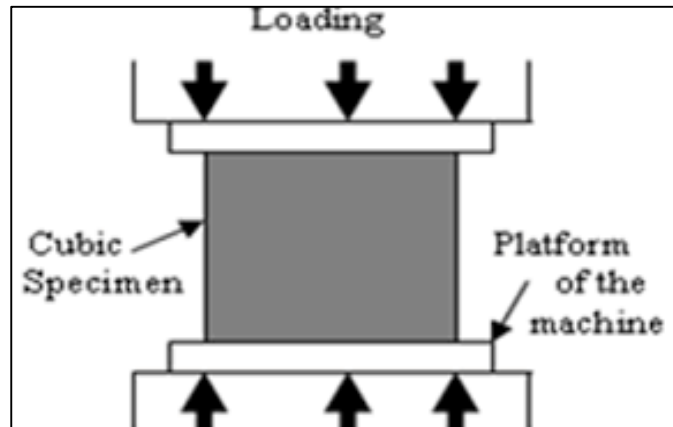


Figure 3: Compressive strength test setup

### 3.3 Splitting Tensile Strength Test Procedure

A diametric compressive force is applied throughout the whole length of the sample until failure is reached in the splitting tensile strength test (Fig. 4). As a result of the imposed load, tensile and compressive stresses are generated in the plane that contains it. Tests on the splitting strength of (150 mm x 300 mm) concrete cylinders were carried out after 28 days. The test was performed according to ASTM [25].

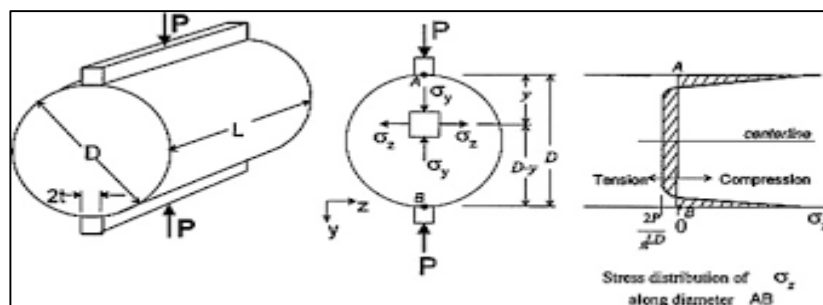


Figure 4: Splitting tensile strength test setup.

The tensile strength of concrete was calculated using the following equation.

$$(2) \quad F_{ct} = \frac{2P}{\pi LD}$$

Where  $F_{ct}$  is the splitting tensile strength in  $\text{N/mm}^2$ .  $2P$  is the maximum load in  $\text{N}$ .  $L$  and  $D$  is the length and diameter of the concrete sample, respectively in  $\text{mm}$ .

### 3.4 Dry Density Test Procedure

The density values were determined according to the requirements of ASTM [26], for lightweight with 28-day of age, using 300mm cylindrical specimens. This test was performed according to the steps below:

To determine the dry mass of the specimens, they were dried in an oven at  $80^\circ\text{C}$  for at least 24 hours and then cooled to room temperature for additional drying and mass calculation (A).

For 24 hours, the specimens were submerged in water. The wet surface of all specimens was then dried with a towel to determine the density of the specimens in a saturated state (B).

The specimens were then dried in an oven at  $80^\circ\text{C}$  for at least 24 hours before being cooled to room temperature for further dry mass determination (C).

After immersion and boiling, suspend the specimen by a wire and assess the apparent mass in water to record this apparent mass (D).

The following equation was used to compute the density of the specimens after determining their mass:

$$(3) \quad \text{Dry Density \%} = \frac{A}{B-D} \times 1000$$

### 3.5 Air Voids Test Procedure

The voids test was carried out on 300 mm cylindrical specimens, according to ASTM [26]. The average voids of each mix were the average of three cylinders by using equation (4).

$$(4) \quad \text{Voids \%} = \frac{C-A}{C-D} \times 100$$

### 3.6 Water Absorption Test Procedure

ASTM [26] standards were followed in this test. The water Absorption test was carried out on 300 mm cylindrical specimens. The average value of three specimens was adopted as a result. Water Absorption is measured by using the following equation.

$$(5) \quad \text{Water Absorption \%} = \frac{C-A}{A} \times 100$$

## 4. Experimental Work

All testing was performed in accordance with the applicable ASTM standards and B.S. Slump measurements were made according to ASTM [23]. Hardened property testing such as compression strength of cubes, splitting tensile, and oven-dry density was conducted in accordance with [25]; [26] and [22] respectively.

### 4.1 Concrete Preparing Procedure

#### 4.1.1 Mixing

The six lightweight concrete combinations listed in Table 1 were created in accordance with [27] utilizing many trial mixes of the control mix that included coarse aggregate in place of EPS content (0, 20, 40, 60, 80, and 100) percent. The goal was to replace 100% of the EPS with an ideal density of 1600 kg/m<sup>3</sup> or less. As a result, there was some variation in the ratio of fine to coarse aggregate to EPS. To compare the outcomes with those of the specimens with EPS, the control specimen (R) completed the same tests. According to Table 1, the amounts of EPS in concrete mixtures were 20, 40, 60, 80, and 100%, respectively, and were designated as (20EPS, 40EPS, 60EPS, 80EPS, and 100EPS). Prior studies that specified the minimum and maximum quantity of EPS in concrete were largely used to determine the number of EPS for each concrete [28]; [29]; [31] and [32].

Table 1: Concrete mixtures proportion ratios in (kg/m<sup>3</sup>)

Mix Code	Cement (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	Coarse Agg. (kg/m <sup>3</sup> )	Fine Agg. (kg/m <sup>3</sup> )	EPS (kg/m <sup>3</sup> )
R	450	202	855	900	0
20EPS	450	202	684	900	0.57285
40EPS	450	202	513	900	1.1457
60EPS	450	202	342	900	1.71855

80EPS	450	202	171	900	2.2914
100EPS	450	202	0	900	2.86425

#### 4.1.2 Casting

All molds were lubricated by using a brush before casting. The samples were prepared in two different shapes (cube and cylinder) to study their fresh, hardened, and mechanical properties. EPS were weighed with the aid of a sensitive balance and packed into five groups in plastic bags; cement was weighed on a digital balance before storage in dry containers for casting. Rotating the rotary mixer for three minutes before adding the EPS, the dry sand and saturated dry surface coarse aggregate were combined for two minutes just to distribute the EPS evenly throughout the mixture. Before adding water, all the other components were mixed and vigorously mixed for four minutes to create a flawless blend.

After mixing the concrete, it was poured into molds, and cubes and cylinders were compacted by hand using a steel rod. The upper side of the molds, cubes and cylinders were smoothed using a hand trowel after fifteen minutes from compaction of the last layer. Fig. 5 shows some of the casting procedures.



Figure 5: Casting process

#### 4.1.3 Curing

A drying chamber with a temperature of 25 degrees Celsius and 90 percent relative humidity was used to cure the specimens. After 24 hours, the specimens were molded and placed in the curing tank, where they remained for the next 27 days until they were ready to be used for testing. ASTM standards were used in the curing procedure of these specimens [33]. Fig. 6 shows the curing process



Figure 6: Curing process.

#### 4.2 Slump Test

The set-up for this test is shown in Figure 4-3 and a summary of the procedure of this test is as follows.

1. a reference diameter of 500 mm has been drawn out on the flat surface.
2. Then the slump cone which was placed on a flat surface in the centre of the reference diameter had been filled with the concrete mix till it reached the top of the cone.
3. After the excess concrete at the top of the cone had been removed using a bar. A fitter was measure
4. the difference between the bar and the top of the fresh concrete top.

#### 4.3 Compressive Strength Test

The compressive strength of the LWC-EPS mixes was determined in accordance with B.S [22]. At 28 days of age, all combinations were tested on 150 cm<sup>3</sup> test specimens. The loading rate of 0.5 kN/s, as illustrated in Figure 4-4, was employed in this test (UTEST) on a universal hydraulic digital compression testing equipment



Figure 7: Slump test setup and process



Figure 8: Compressive strength test setup and process

#### 4.4 Splitting Tensile Strength Test

The curing chamber was kept at ambient temperature and 95% humidity until the day of the test. One hour before the test, the concrete cylinders were taken out of the curing chamber, dried, and placed on the loading machine. At a steady rate of 0.03 MPa stress per second, the load was applied to the specimen until it is failed. The splitting tensile strength test is depicted in Figure 4-5.



Figure 9: Splitting tensile strength test setup and process

#### 4.5 Dry Density, Air voids, and Water Absorption Tests

Dry density, air voids, and water absorption were tested for all mixtures according to ASTM [26]. The specimens' dimensions for these tests were 150×150×150 mm at age of 28-day. The values of specimens were recorded for each test. After water-curing, all specimens have been dried in the oven at a temperature of 110 °C for 24 hours. After that, the specimens were left to cool in dry air at a temperature of 20-25 °C in order to be weighed later as (A). After that, all the specimens have been merged in 20-25 °C water container for 24 hours. The specimens were then dried with a towel and weighed to remove any remaining moisture (B). A heated water container was used to combine all the specimens for 5 hours, after which they were taken out to dry the surface of all specimens using towels and left to cool for 14 hours at a temperature of (20-25) degrees Celsius in order to be weighed again (C). Finally, all the specimens were immersed in water and weighed inside the water to determine the submerged weight (D). Fig. 10 shows some of the dry density test procedures.



Figure 10: Dry density test setup and process

## 5. Results and Discussion

Experimental results on fresh state, hardened and mechanical properties tests were presented and analyzed in this chapter. An analysis of the effects EPS on the properties of LWC mixtures compared to control mixtures (without EPS) was provided.

The research work addresses the sustainability challenge in construction materials by investigating the use of Expanded Polystyrene Beads (EPS) in lightweight concrete (LWC). It highlights the environmental and material-saving benefits of incorporating recycled materials from demolished buildings into concrete mixes. The major issues covered include:

The impact of various percentages of EPS: EPS percentages are (0%, 20%, 40%, 60%, 80%, and 100%) on both fresh and hardened properties of LWC.

Key performance metrics: Key performance matrices such as compressive strength, tensile strength, density, water absorption, and air void content. Have been investigated thoroughly in this work.

The covered topic is highly relevant in today's context of sustainable construction practices, with the increasing demand for reducing the environmental footprint of building materials. Lightweight concrete with recycled aggregates offers a practical solution for reducing waste and the carbon footprint of concrete production, especially in oil-producing countries with abundant EPS waste. This research is timely and addresses critical issues in sustainable construction and materials engineering.

Novelty: The paper introduces a novel mix of LWC by incorporating varying levels of EPS, especially relevant to the context of countries like Iraq with high EPS availability. While recycled aggregates have been used before, the specific focus on EPS as a waste product in oil-rich regions provides a unique perspective.

Creativity: The creative aspect lies in using demolished building waste and coupling it with EPS to develop LWC, offering a twofold environmental solution—reducing building waste and reusing EPS.

Technical Depth: The methodology seems solid, with a comprehensive set of experiments measuring important properties of LWC. However, while the technical depth is adequate, some sections could benefit from further elaboration on the scientific mechanisms driving the changes in properties (e.g., the clumping of EPS affecting the water absorption and compressive strength).

### 5.1 Results of Slump Flow Test

From previous research results [34]; [35] and [32], it was concluded by many researchers that the slump flow of the concrete mixture would increase when increasing in volume of EPS beads. Fig. 11 compares the slump flow findings of several concrete compositions. The slump flow did indeed rise between the control mix (R) and the EPS mixes. While the highest growth was visible in the slump flow for replacing coarse aggregate with EPS at 100%. The test results for all mixes from slump flow experiments are shown in Fig. 11. R is referred to the original state (controlled model)

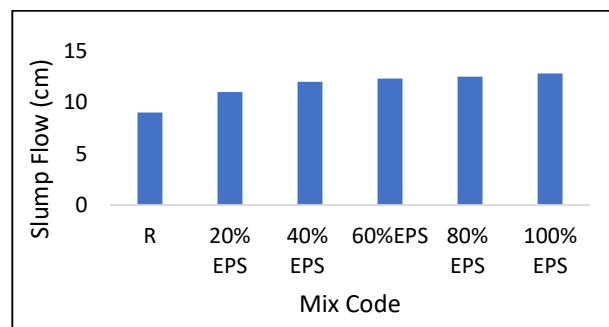


Figure 11: Slump flow test results for all mixtures

In contrast to mix (R), which included 0% EPS, the increased EPS component in the concrete mixture showed increased slump flow, as illustrated in Fig. 11, boosting workability. The non-adsorbing closed cellular EPS characteristic may be to blame for this increase.

### 5.2 Results of Dry Density Test

LWC-EPS dry density was measured in the hardened phase only. Dry density results were measured at age of 28-day and shown in Table 2 and Fig. 2.

Table 2: Dry density test results for all mixtures

Mix Code	Dry weight (A) kg	Saturated weight (B) kg	Dry weight (C) kg	Submerged weight (D) kg	Dry Density (kg/m <sup>3</sup> )
R	7.45	8.36	7.49	4.76	<b>2069</b>
20% EPS	7.12	7.31	7.19	3.79	<b>2023</b>
40% EPS	5.69	6.36	5.74	3.51	<b>1996</b>
60% EPS	5.65	5.92	5.71	3.02	<b>1948</b>
80% EPS	5.31	5.61	5.38	2.81	<b>1896</b>
100% EPS	4.84	5.51	4.9	2.74	<b>1747</b>

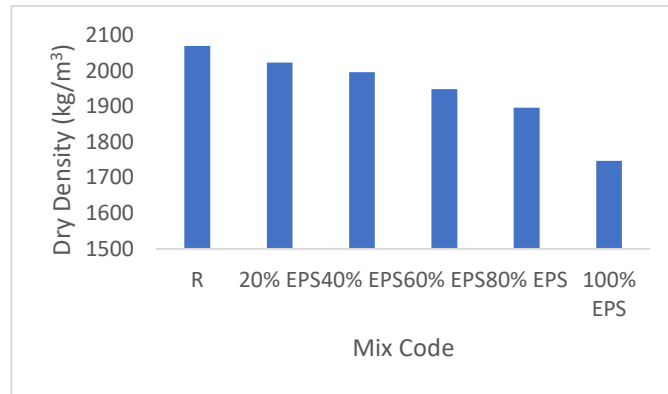


Figure 12: Dry density values for all mixture

Lightweight concrete has an oven-dry density ranging from 800 kg/m<sup>3</sup> to 2000 kg/m<sup>3</sup>, according to ASTM [26]. A semi-lightweight concrete, on the other hand, ranges in density from 1840 to 2240 kg/m<sup>3</sup>. As a result, every combination should be regarded as lightweight aggregate concrete. The dry density values for each combination in this investigation are shown in Fig. 12. The air voids that were formed once the concrete batch was mixed that's what led to the EPS specimens having lower values than the control specimen (R). The increased amount of the Expanded Polystyrene Beads could have caused the cement paste not to mix well, therefore not creating a dense concrete matrix. Thus, this could have caused larger air voids occur which reduced the density of the mixture. The same result was noticed in the work of [36]. Fig. 13 shows the differences in results with current work and Wibowo's results at the same percentages of EPS for (20, 40, 60, and 80) %. While Allahverdi's [28] study also shows a reduction in dry density values when EPS contents increased by (15, 30, and 45) % (see Fig. 13).

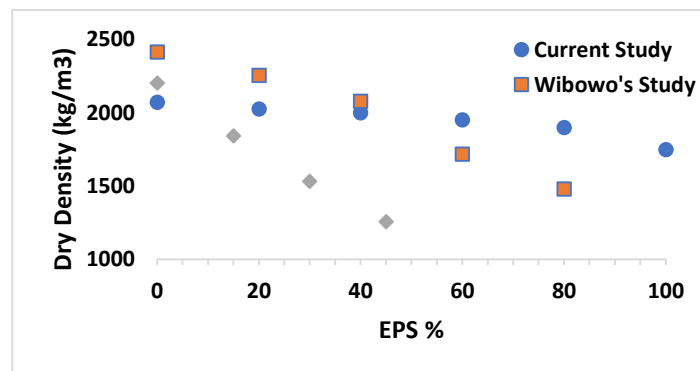


Figure 13: Differences of Dry density values for mixtures among current study, Wibowo's study, and Allahverdi's study

### 5.3 Results of Air Voids Test

The results of air voids percentage of LWC specimens incorporated with EPS are shown in Fig. 14.

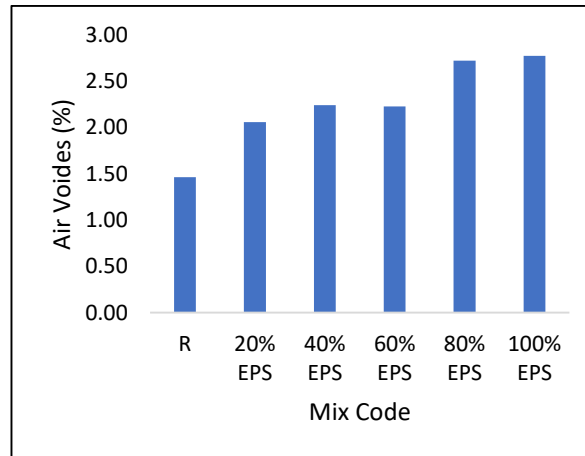


Figure 14: Air voids percentages values for all mixtures

From Fig. 14, it had been noted that the control specimen (R) had lower air voids ratio compared with EPS specimens. The air voids of lightweight concrete reduce the surface tension of water, allowing more and smaller bubbles to form and stabilize during mixing.

#### 5.4 Results of Water Absorption Test

Table 4 showed that the mixtures with the highest EPS percentages exhibit the maximum water absorption. Due to air entrapment and the production of air spaces that make it simple for water to enter the concrete matrix, the specimens with EPS demonstrated an improved ability to absorb water [32]. Fig. 15 shows the results of the water absorption test.

Table 4: Water Absorption test results for all mixtures

Mix Code	Water Absorption (%)
R	0.54
20% EPS	0.98
40% EPS	1.06
60% EPS	1.24
80% EPS	1.32
100% EPS	1.45

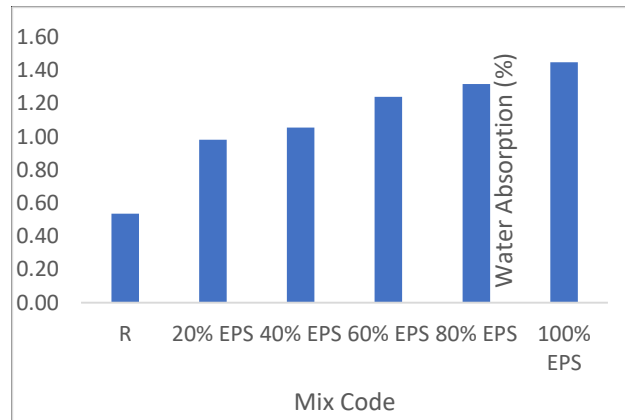


Figure 15: Water Absorption percentages values for all mixtures

Fig. 5 illustrates how water absorption is one of the factors that affect concrete's durability in relation to its porosity. The greatest EPS percentage specimens are anticipated to have more open water space, which, upon vaporization, will increase the pore content and, as a result, enhance the rate of water absorption. The current study's and [36] Wibowo's study's water absorption test findings revealed that concrete's capacity to absorb water increased with the amount of EPS present (Fig. 16) [36].

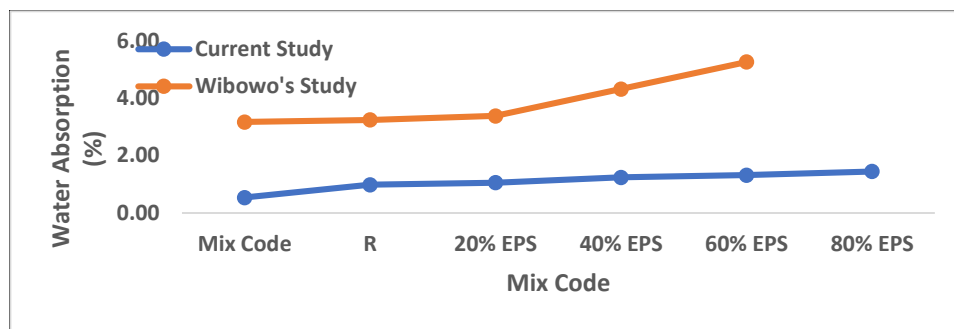


Figure 16: Differences of water absorption values for all mixtures between the current study and Wibowo's study [36]

### 5.5 Results of Compressive Strength Test

Table 5 and Figure 17 show the summary of compressive strengths for all mixtures. The table shows the compressive strengths at the 28-day age of water curing. The reported values of compressive strength are averages of three specimens prepared from each mix.

Table 5: Compressive strength test results for all mixtures

Mix Code	Compressive Strength (MPa)	Reduction (%)
R	26.81	-
20% EPS	24.22	9.66
40% EPS	16.63	37.97
60% EPS	12.49	53.41
80% EPS	12.32	54.05
100% EPS	11.87	55.73

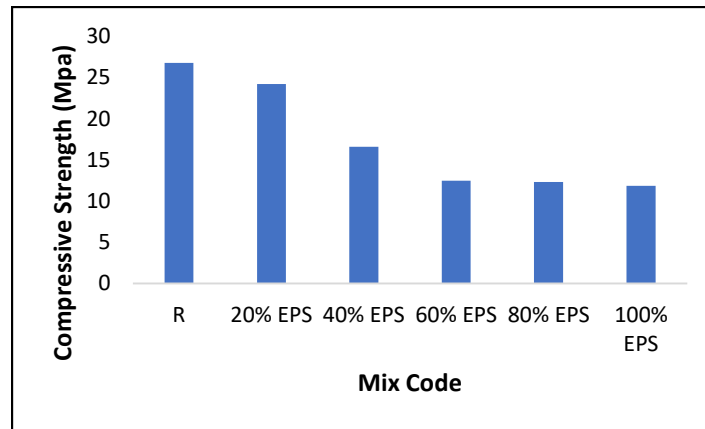


Figure 17: Compressive strength test values for all mixtures

Overall, it is evident from Fig. 17 that the addition of EPS does not improve the compressive strength of lightweight concrete, and that increasing the EPS content has the same impact on compressive strength as found in specimens containing 20%, 40%, 60%, 80%, and 100% EPS. It was found that after 40%EPS, the compressive strength reduced gradually by not more than 2%. This can be attributed to the increased percentage rate of EPS. Wibowo, 2021 showed the same trend of results for 20%EPS, 40%EPS, 60%EPS, and 80%EPS only as shown in Fig. 18. While Gunavel et al. [30] tested the lightweight concrete with (0, 10, 20, and 30) % of EPS as shown in Fig. 18.

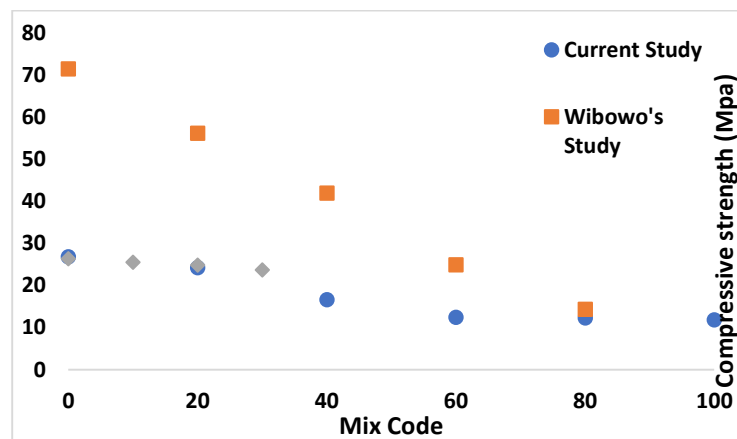


Figure 18: Differences in compressive strength values for mixtures among current study, Wibowo's study, and Gunavel's study [30]

### 5.6 Results of Splitting Tensile Strength Test

Table 6 and Fig. 19 show the summary of splitting tensile strengths for all mixtures. The table shows the splitting tensile strengths at the 28-day age of water curing. The reported values of splitting tensile strength are averages of three specimens prepared from each mix.

Table 6: Splitting tensile strength test results for all mixtures.

Mix Code	Splitting Tensile Strength (MPa)	Reduction (%)
R	5.26	-
20% EPS	2.57	51.20
40% EPS	2.48	52.89

60% EPS	2.28	56.70
80% EPS	2.16	58.99
100% EPS	1.97	62.66

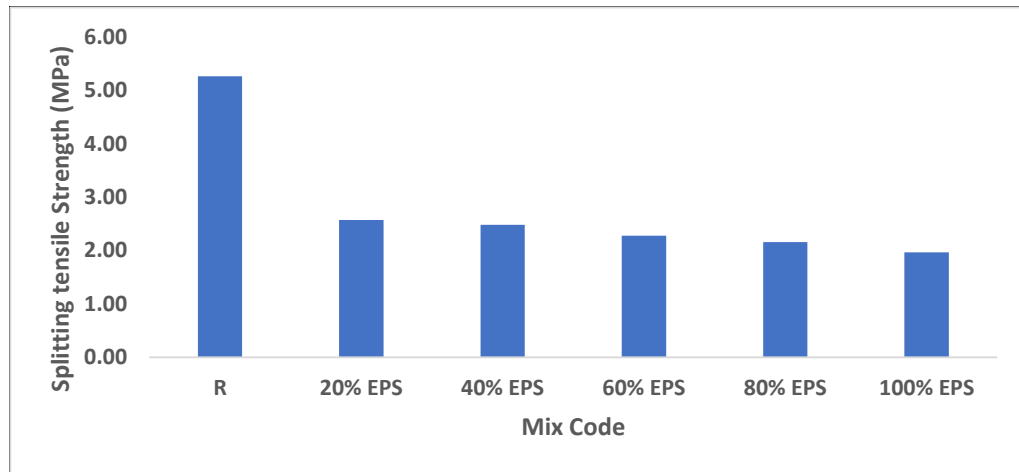


Figure 19: Splitting tensile strength test values for all mixtures.

Figure 19 shows that the splitting tensile strength of the EPS concrete declined as the EPS volume percentage increased, just as the compressive strength. With an increase in EPS volume percentage, the valid stress area decreases, resulting in a drop in tensile strength, while the packing density has no influence, previous study was in concur with these results [35].

As for Wibowo’s study, the splitting tensile strength of Wibowo’s and current studies showed that there is the same trend in results when EPS percentages increased in terms of 20% intervals. Figure 5-10 shows the results between the current study and Wibowo’s study for splitting tensile strength at 28-day. While Gunavel’s [30] study also shown in the same fig. 20 for (0, 10, 20, and 30) % of EPS. The study also shows a reduction in splitting tensile strengths for designated percentages.

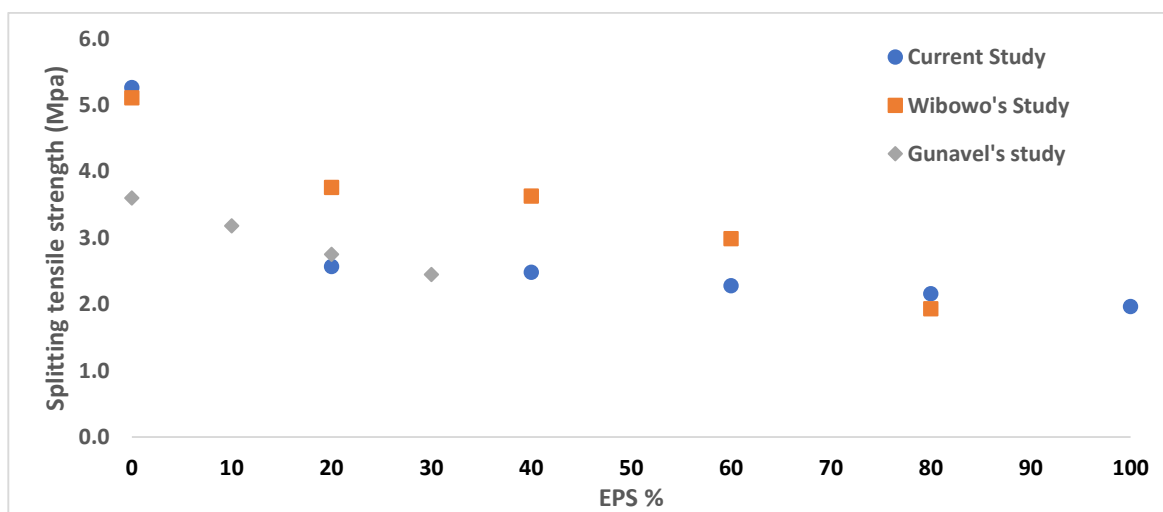


Figure 20: Differences in splitting tensile strength values for mixtures among current study, Wibowo’s study, and Gunavel’s study [30]

## 6. Conclusion

This study examined the effects of various EPS contents as a substitute for coarse aggregate on the mechanical, physical, and physical properties of lightweight concrete containing expanded polystyrene beads in the fresh state (slump flow), mechanical state (compressive and splitting tensile strengths), and hardened state (dry density, water absorption, and voids) (EPS-LWC).

In addition, to control concrete (R mix), five EPS-LWC combinations (20, 40, 60, 80, and 100 percent of EPS content) were employed in this study. As EPS tends to form larger clumps, absorb water, and make the mix dry, its inclusion reduced the density (lightweight) of the concrete mixtures. In order to counteract the loss of workability brought on by the inclusion of EPS, concrete compositions were suitably modified. The study's findings lead to the following interpretations:

1. The workability was improved with the addition of EPS. 100% EPS with a slump flow of 12.8 cm was the composition that offered the best workability.
2. With varying WPF amounts, lightweight concrete that uses EPS as a coarse aggregate showed that the density reduced; the more EPS was present in the concrete mixes, the less density was seen. However, it was found that these mixes had a higher water absorption capacity. Consequently, there are also more air voids.
3. The mechanical investigation of the EPS-LWC specimens showed that the addition of EPS did not significantly increase the compressive and splitting tensile strengths. All EPS-LWC specimens' 28-day compressive strength was found to be lower than the control specimen's (without EPS). The EPS-LWC mixture with the lowest compressive and splitting tensile strengths was 100 percent EPS, with compressive values of 11.87 MPa and splitting tensile strengths of 1.97 MPa and 62.66 percent of the control specimen, respectively.

## References

- [1] Vakhshouri, B., & Nejadi, S. (2018). Review on the mixture design and mechanical properties of the lightweight concrete containing expanded polystyrene beads. *Australian Journal of Structural Engineering*, 19(1), 1–23. <https://doi.org/10.1080/13287982.2017.1353330>
- [2] Horvath, J. S. (1994). Expanded polystyrene (EPS) geofoam: an introduction to material behavior. *Geotextiles and Geomembranes*, 13(4), 263–280. Zwiebel, N. (1973). *Expanded Polystyrene*. 211–222. [https://doi.org/10.1007/978-3-642-41714-6\\_52060](https://doi.org/10.1007/978-3-642-41714-6_52060)
- [3] AS-1366.3. (1992). *Rigid Cellular Plastics Sheets for Thermal Insulation PART 3: Rigid Cellular Polystyrene Moulded (RC/PS – M)*.
- [4] ASTM C578-19. (2019). *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*. <https://doi.org/10.1520/C0578-19>
- [5] Demirboğa, R., & Kan, A. (2013). *Design of specific gravity factor of artificial lightweight aggregate*. <https://doi.org/10.1016/j.conbuildmat.2013.08.030>
- [6] Neville, A. M. (2012). *Properties of Concrete* (5th ed.). Prentice Hall.
- [7] Newman, J., & Choo, B. S. (2003). *Advanced concrete technology 3: processes*. Elsevier.
- [8] Slaby, A. A., Aziz, K. I., & Hadeed, A. F. (2008). Mechanical Properties of Porcelinite Reinforced Concrete Beams. *Iraqi Journal of Civil Engineering*, 10, 1–24.
- [9] ACI Committee 213. (2014). *213R-14 Guide for Structural Lightweight-Aggregate Concrete*.
- [10] Doukakis, J. P. (2013). *Lightweight self consolidating fiber reinforced concrete*. Rutgers University-Graduate School-New Brunswick.
- [11] Arisoy, B., & Wu, H.-C. (2008). Material characteristics of high performance lightweight concrete reinforced with PVA. *Construction and Building Materials*, 22(4), 635–645. <https://doi.org/10.1016/j.conbuildmat.2006.11.007>

- 
- [12] Kayali, O., Haque, M. N., & Zhu, B. (2003). Some characteristics of high strength fiber reinforced lightweight aggregate concrete. *Cement and Concrete Composites*, 25(2), 207–213. [https://doi.org/10.1016/S0958-9465\(02\)00024-3](https://doi.org/10.1016/S0958-9465(02)00024-3)
- [13] Lotfy, A. (2013). *Lightweight Self-consolidating Concrete: Statistical Modelling, Mixture Design and Performance Evaluation*. Ryerson University.
- [14] Almousawi, A. N. (2011). *Flexural and Shear Performance of High Strength Lightweight Reinforced Concrete Beams*. University of Illinois at Chicago.
- [15] Gerritse, A. (1981). Design considerations for reinforced lightweight concrete. *International Journal of Cement Composites and Lightweight Concrete*, 3(1), 57–69. [https://doi.org/10.1016/0262-5075\(81\)90028-1](https://doi.org/10.1016/0262-5075(81)90028-1)
- [16] Hossain, K M A. (2004). Properties of volcanic scoria based lightweight concrete. *Magazine of Concrete Research*, 56(2), 111–120. <https://doi.org/10.1680/macr.2004.56.2.111>
- [17] Hossain, K M A, & Anwar, M. S. (2015). Influence of Foundry Sand and Natural Pozzolans on the Mechanical, Durability and Micro-structural Properties of Lightweight Concrete. *British Journal of Applied Science and Technology*, 10(4), 1–12. <https://doi.org/10.9734/BJAST/2015/14868>
- [18] Hossain, Khandaker M A, & Lachemi, M. (2007). Mixture design, strength, durability, and fire resistance of lightweight pumice concrete. *ACI Materials Journal*, 104(5), 449. <https://doi.org/10.14359/19862>
- [19] National Ready Mixed Concrete Association. (2003). *CIP 36: Structural lightweight concrete*. NRMCA, Washington, DC.
- [20] Hossain, Khandaker M Anwar. (2006). Blended cement and lightweight concrete using scoria: mix design, strength, durability and heat insulation characteristics. *International Journal of Physical Sciences*, 1(1), 5–16. <https://doi.org/10.5897/IJPS2006.004>
- [21] BSI. (2009). *BS EN 12390-3: 2009: Testing hardened concrete. Compressive strength of test specimens*. BSI London, UK.
- [22] ASTM C1611 / C1611M-18. (2018). *Standard Test Method for Slump Flow of Self-Consolidating Concrete*.
- [23] Dolch, W. L. (1996). Air-entraining admixtures. In *Concrete admixtures handbook* (pp. 518–557). Elsevier.
- [24] ASTM C496/C496M – 17. (2011). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens ASTM C-496. *ASTM International*, i, 1–5. <https://doi.org/10.1520/C0496>
- [25] ASTM C642-13. (2013). *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*.
- [26] ACI Committee 211. (2009). *211.4R-08: Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement & Other Cementitious Material*.
- [27] Allahverdi, A., Azimi, S. A., & Alibabaie, M. (2018). Development of multi-strength grade green lightweight reactive powder concrete using expanded polystyrene beads. *Construction and Building Materials*, 172, 457–467. <https://doi.org/10.1016/j.conbuildmat.2018.03.260>
- [28] Chung, S.-Y., Elrahman, M. A., & Stephan, D. (2018). Effects of expanded polystyrene (EPS) sizes and arrangements on the properties of lightweight concrete. *Materials and Structures*, 51(3), 57. <https://doi.org/10.1617/s11527-018-1164-7>
- [29] Gunavel, M., Aishwarya, S., Indhumathi, K., Jalapriya, N., & Priya, M. K. (2020). Proportioning of Lightweight Concrete by the Inclusion of Expanded Polystyrene (EPS). *International Journal of Engineering Research & Technology*, 9(2). <https://doi.org/10.17577/IJERTV9IS020253>
-

- 
- [30] Hilal, N., Hamah Sor, N., & Faraj, R. H. (2021). Development of eco-efficient lightweight self-compacting concrete with high volume of recycled EPS waste materials. *Environmental Science and Pollution Research*, 28(36), 50028–50051. <https://doi.org/10.1007/s11356-021-14213-w>
- [31] Medher, A. H., Al-Hadithi, A. I., & Hilal, N. (2021). The possibility of producing self-compacting lightweight concrete by using expanded polystyrene beads as coarse aggregate. *Arabian Journal for Science and Engineering*, 46(5), 4253–4270. <https://doi.org/10.1007/s13369-021-05710-2>
- [32] C192/C192M, A. (2019). *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*.
- [33] Lal, B. R. R., & Nawkhare, S. S. (2016). Experimental study on plastic strips and EPS beads reinforced bottom ash based material. *International Journal of Geosynthetics and Ground Engineering*, 2(3), 25. <https://doi.org/10.1007/s40891-016-0089-2>
- [34] Liu, N., & Chen, B. (2014). Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightweight concrete. *Construction and Building Materials*, 68, 227–232. <https://doi.org/10.1016/j.conbuildmat.2014.06.021>
- [35] Wibowo, A. P. (2021). THE STRENGTH AND WATER ABSORPTION OF HEATED EXPANDED POLYSTYRENE BEADS LIGHTWEIGHT-CONCRETE. *International Journal of GEOMATE*, 21(83). <https://doi.org/10.21660/2021.83.j2146>
- [36] Sadon, S. H., Hamoodi, A., & Hamoudi, M. R. (2023). Implementation of pressure maintenance for a reservoir in KH Oil Field. In *Proceedings of the 9th International Engineering Conference on Sustainable Technology and Development (IEC)*, Erbil, Iraq, 183–188. <https://doi.org/10.1109/IEC57380.2023.10438800>
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