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Strength Characteristic of Lightweight Modular Block (LMB) Element using Stabilized Dredged Soil-EPS

Nurul Marfuah [1], Tri Harianto [1*], A. B. Muhiddin [1], Rita Irmawaty [1]

[1] Department of Civil Engineering, Hasanuddin University, Gowa 92171, Indonesia.

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Abstract

For several decades, lightweight material applications have been extensively studied. Modifying various types of soil with EPS beads or lightweight geomaterials is an alternative construction material on site that can reduce excessive problems such as large deformation and lateral pressure. This study aims to examine the strength characteristics of lightweight geomaterials, namely lightweight modular block/LMB. LMB is composed of EPS beads, dredged soil, and cement. The cement amounts are 3%, 5%, 7%, and 9%, with EPS variations of 0.5% and 0.75% to the mixture weight. Laboratory tests were conducted to investigate the strength with unconfined compression and undrained direct shear tests. Before testing, the specimens were made using the one-layer static compaction method and were cured for 7, 14, and 28 days. This paper also presents explanations related to the specimens making and treatment by providing preliminary test results to compare the effectiveness of the three-layer and one-layer methods. Moreover, the curing treatments to avoid cracking were explained explicitly. The result shows linearity between both increasing the amount of cement and adding more curing time to the increase of the strength parameter. In contrast, adding more EPS decreased the strength, but adding cement helped increase the strength parameter with a remarkable value at C7% and C9%. Increasing the amount of EPS also reduced the density of the mixture by 18%–29%.

Keywords: Lightweight Geomaterial; LMB; EPS beads; Dredged-soil; Static Compaction; Strength Parameter.

1. Introduction

Recently, the growth of construction projects such as road infrastructure, bridges, buildings, landfill covers, dams, retaining walls, and many more has increased rapidly. Consequently, some land with problematic soil is often used as an alternative location for construction. There are various ways to improve the soil's geotechnical properties, either through soil reinforcement or soil improvement. Soil reinforcements that are commonly used are: using a timber-based raft pile [1], geosynthetics [2-4], and using fiber as an additional in the soil mixtures [5, 6].

The determination of the improvement method is very dependent on the needs. Lack of adequate construction materials sometimes triggered and affected the use of alternative materials. Some areas might have many materials that some might not. Therefore, various studies using many materials, such as sand, silt, or clay, are found. The use of these materials sometimes requires stabilization when having poor properties. The soil improvement techniques can be mechanical or chemical stabilization. Many kinds of materials are already practical as stabilizing agents in soil mixtures, such as cement [7], lime [8], zeolite [4], and bacteria [9].

Usually, soil improvement is also made by replacing the problematic soil with another material. Material that is quite popular as a replacement material is strong, lightweight material such as EPS geofoam and lightweight geomaterial. These lightweight materials are popular for overcoming settlement problems.

* Corresponding author: triharianto@unhas.ac.id

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2. Literature Review

The well-known lightweight EPS geofoam was first introduced around the 1960s. EPS Geofoam is available in a large factory-manufactured block with specific dimensions, and it became extensively used around the 1990's decade in solving extra settlement problems over soft ground [10, 11]. EPS possesses a high percentage of air content [12], which is approximately 98%, making it have a very low density compared to the other construction materials. While it has a very low density, it has high strength and superb impact resistance, which makes it suitable in geotechnical engineering applications such as: thermal insulation, compressible inclusion, vibration damper, lightweight fill behind a retaining wall, tunnel, below slabs or beams at foundations, and above pipelines [13].

However, the wide range of applications of EPS geofoam has been limited due to some disadvantages, such as: it cannot readily be used to fill in irregularly shaped places, has poor buoyancy resistance, and has a dissolvability problem when exposed to liquid fuels. Moreover, it is also relatively high at cost [12, 14, 15]. In contrast, a lightweight geomaterial may offer solutions to eliminate excess settlements while avoiding the above issues. Lightweight geomaterial is a lightweight material made by mixing soil with EPS, which is commonly added with cement as a stabilizing agent to bind the soil-EPS mixture.

Lightweight geomaterials were first introduced in Japan in 1980. It has been introduced under various names depending on the researcher, including lightweight treated soil, EPS beads mixed with lightweight geomaterial, soil-EPS mixes, Expanded Polystyrene Composite Soil (EPSCS), and so forth [16]. It has been used in many construction projects, such as buildings, roadway embankments, retaining wall backfill, bridge abutments, and many more.

EPS wastes occupy a large amount of landfill area in many countries. Despite that, incineration is also not a viable option as it causes toxins problems. Since the European Union has restricted the disposal of EPS into landfills and has made it a recycling target [17], many researchers have been attracted to modifying soil with EPS to make a lightweight geomaterial. It can be seen from the many studies about the investigations of soil-EPS characteristics and properties that have been and are still being conducted over the last few years. Some of the researchers, but not limited to, that have already studied the characteristics of lightweight geomaterials are described as follows:

Liu et al. [16, 18] studied the influence of various factors on Expanded Polystyrene Composite Soil/ EPSCS using soft silty clay EPS with cement stabilization. The tests were conducted with cement amounts of 10%, 15%, 20%, and 25% of the soil weight, with EPS amounts of 2%, 3%, 4%, 5% and 6%, with a density of 0.19 kN/m^3. The study found that EPS beads inclusion leads to the reduction of the unconfined compression strength and undrained shear strength of the mixtures. It is further noted that the cement effect has a paramount influence on the strength of the mixture, potentially more than the EPS bead inclusion effect. The most considerable strength was obtained in 10% and 15% cement. Miao et al. (2013) [19] carried out some laboratory experiments, including standard proctor, CBR, unconfined compression, CU, and UU triaxial tests on the EPSCS, which consists of the sand-EPS mix, portland cement, and water. It was concluded that the embankment constructed from lightweight material provides a lower settlement rather than the embankment made up of lime-stabilized soil, disregarding other ground improvement substances.

Abdelrahman et al. (2013) [15] investigated a new replacement material made of sand mixed with EPS for an expansive soil layer. A circular footing rested on top of the replacement layer. The tests were done with 3 different densities of EPS beads (0.1, 0.16, and 0.20 kN/m^3). The result indicated that the inception of this replacement layer significantly reduced the volumetric changes of the expansive soil and the settlement of circular footing, with a trend: increasing the bead density and bead content led to a significant decrease in swelling and settlement.

Chenari et al. (2018) [20] proposed lightweight fill materials that consist of sand-EPS with cement and fly ash stabilization. Additional fly ash is intended to increase the silica amount in the mixtures to optimize the pozzolanic reaction. The tests were done in 3 different EPS bead amounts (0.25%, 0.35%, and 0.45%) with a density of 0.08 kN/m^3. Cement and fly ash amounts were 4%, 6%, 8% and 0%, 6%, and 12%, respectively. The mechanical properties of these lightweight materials were evaluated with laboratory tests, including the modified standard proctor test, the unconfined compression (UCS) test, the California Bearing Ratio (CBR) test, and a large-scale direct shear test. It was summarized that increasing cement and fly ash content led to the increment of the UCS, CBR Value, and cohesion while increasing EPS beads content had the opposite trend. Nonetheless, the failure strain of samples increased, suggesting a more ductile behavior. The most remarkable enhancement was observed in the mechanical properties of the samples with cement and fly ash contents of 8% and 12%, respectively.

Rauf et al. (2019) [21] conducted interesting research on a lightweight geomaterial that was composed of clay-EPS. Waste materials were used as the binder agent, a byproduct of the Buton Asphalt extraction process called Waste of Buton Asphalt (WBA). The mechanical properties, such as the Unconfined Compression Test and California Bearing Ratio of the clay-EPS beads with WBA mixtures were investigated. The EPS amounts are 0.15% and 0.3%, with a density of 0.17 kN/m^3. The specimens were tested on 3%, 5%, 7%, and 9% WBA. Several things can be deduced, including the following: According to the results of the two tests that were conducted on the mechanical properties, WBA was effective in increasing both the UCS and CBR value of the mixtures, with UCS ranging from 0.7 to 1.87 MPa and the CBR value were 14 to 71%, which depends on the constituents. The increase in the amount of WBA is also unique since it has a trend curve of 7% as the peak amount. It was also suggested that 0.3% was the maximum amount to avoid segregation.

3. State of the Art

There has been enormous research conducted on the characteristics of the soil-EPS mixture. However, there has been no explicit explanation related to the compaction method and the treatment after the compaction. Since the method is unclear, it causes difficulties in its repetition by other researchers or in its application in the field. The compressibility of EPS is quite devious. Thus, the researchers should explain the making process in detail. Except that the liquid form of the soil-EPS mixture does not require any compaction [16]. In this present study, the compaction method, treatment right after compaction, until the curing method necessitated to minimize any crack that might occur due to the swelling of EPS when the applied force is removed will be explained. This method is developed specifically for use in the production of lightweight geomaterials in the form of blocks, also known as lightweight modular blocks (LMB) throughout this paper. The strength characteristics of the LMB elements test, such as unconfined compression and shear strength, are presented.

In the literature review, previous studies have been explained with various types of materials and also types of stabilization agents. LMB is composed of dredged soil as the primary material, cement as the stabilization agent, and EPS beads. LMB is designed to be an environment-friendly, lightweight geomaterial that utilizes recycled dredged soil, specifically from the Bili-Bili Dam disposal area. The potency of dredged soil deposits from sedimentation is abundant. It is still increasing during the operation period of the Bili-Bili Dam. Based on measurements using the echo-sounding method at the Bili-Bili dam, sedimentation in the body of dam accumulations up to 2008 has reached 60.959 million m^3 and increased to 110.371 million m^3 in 2019 [22]. These matters make dam sedimentation one of the materials that look promising to be used.

4. Materials and Method

4.1. Materials

There were two kinds of mixtures that will be explained in this paper:

1. Dredged soil-cement mixture, consisting of dredged soil (DS) and cement (C);
2. Lightweight Modular Block (LMB) which is composed of 3 types of materials including, dredged-soil (DS), Expanded Polystyrene (EPS) in beads form, and cement (C) as a binder material.

Dredged-Soil (DS)

Dredging using a dredging machine is an annual activity that must be carried out to maintain the dam's sedimentation conditions and not exceed the storage capacity. The dredged sediment is directed to an area known as the disposal area. The disposal area is located on the Bili-Bili Dam, Gowa Regency, South Sulawesi, Indonesia (Figure 1). Exactly located on 5 17'05" S and 119 35'06" E. Dredged soil is used as the main component of the lightweight modular block. The details of the soil preparation procedure are provided in Figure 2. From the disposal area (Figure 2-b.), material was taken in sludge form (Figure 2-c) and then aerated until it reached the air-dried condition (Figure 2-d.). Furthermore, the air-dried soil is crushed and sieved until it passes the #4 sieve, as shown in Figure 2-e. The dredged soil is placed in a container to keep the moisture constant. Before use, samples were taken at several points to determine the initial water content.

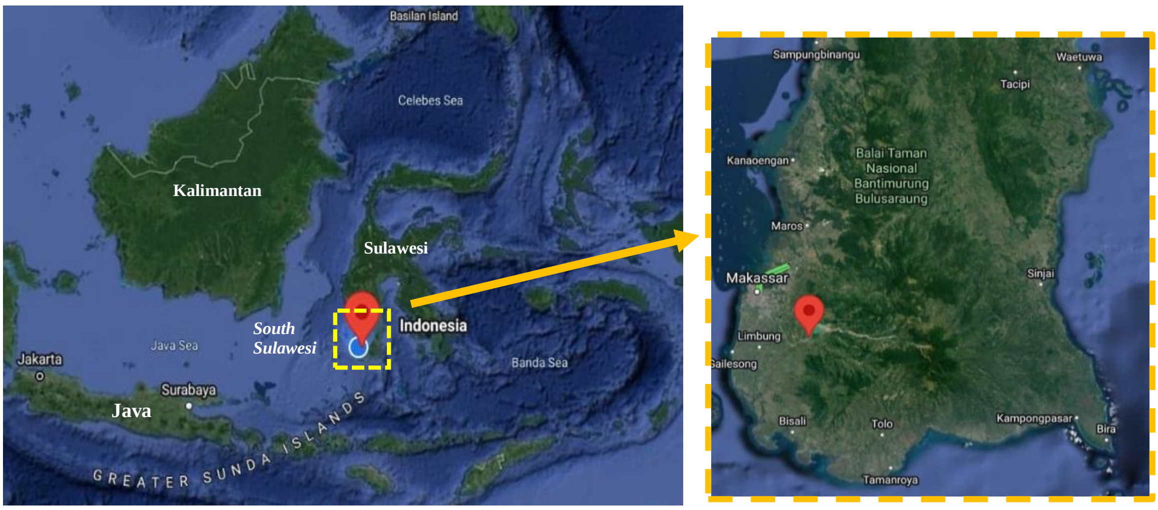


Figure 1. Bili-Bili Dam on Satellite Map

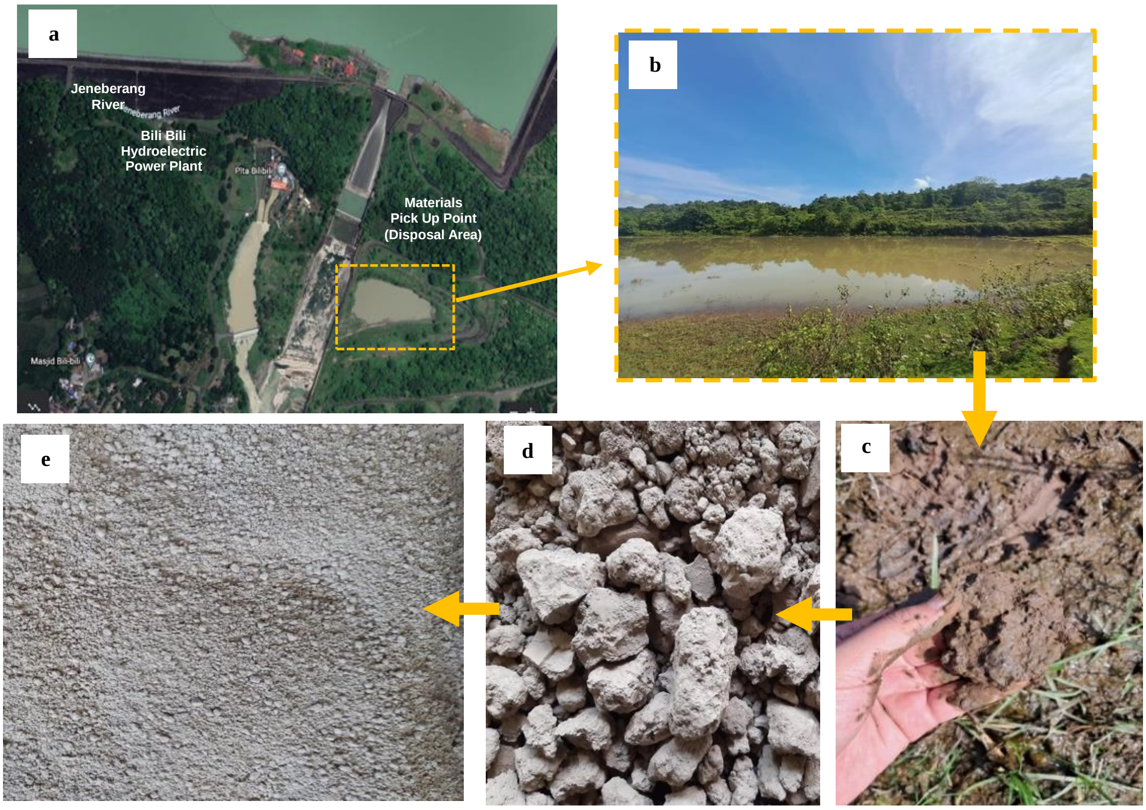


Figure 2. a) disposal area on the map; b) disposal area location; dredged soil in c) sludge form; d) boulder form; e) pass #4 sieve

In Figure 3, the grain size distribution of the soil is given. The distributions are: 90.5 % finer, 9.1% sand, and the remaining portion is gravel. Based on the Unified Soil Classification System (USCS), this dredged soil is classified as inorganic silt with low plasticity (ML), with an MDD of 14,455 kN/m^3 and an OMC of 27,20%. Furthermore, a summary of the physical and mechanical properties of the dredged soil is attached in Table 1.

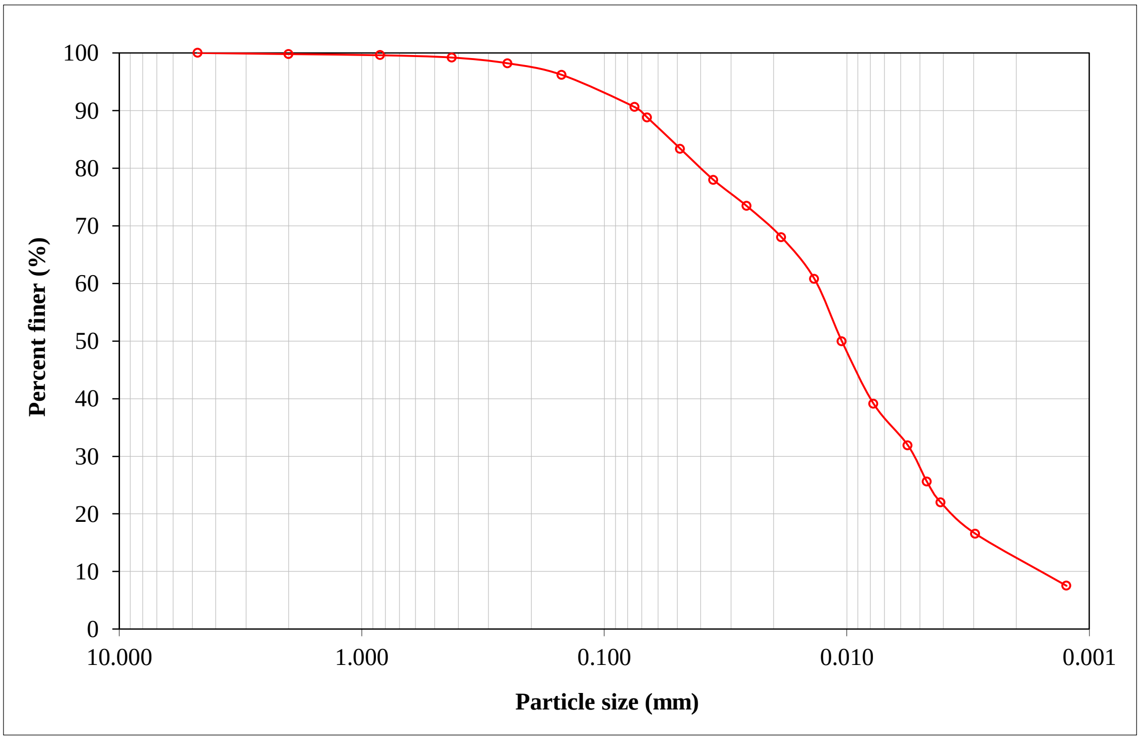


Figure 3. Dredged-soil distribution curve

Table 1. Properties of Dredged Soil

Properties	Value
Specific Gravity, Gs	2.664
Initial Water Content, (%)	11.26
Consistency Limit	
Plasticity Index, PI (%)	6.50
Liquid Limit, LL (%)	38.00
Plastic Limit, PL (%)	31.50
Shrinkage Limit, SL (%)	27.16
Grain Size Analysis	
Sand (%)	9.20
Silt (%)	83.10
Clay (%)	7.50
USCS Classification	ML
Standard Proctor Test	
MDD (kN/m^3)	14.455
w opt (%)	27.20
UCS (kN/m^2)	192,8
Direct Shear	
c (kN/m^2)	24.96
ϕ (°)	18

Expanded Polystyrene (EPS)

The EPS are in beads rounded particles with a bulk density only ± 2% of soil density. The diameter of EPS on the market generally varies between 1.2 mm – 9.5 mm. Nonetheless, the diameter of EPS varies at intervals of 2 mm – 4 mm with an average density of 0.33 kN/m^3. These measurements were obtained using a Vernier Caliper.

Cement (C)

Cement was used as a binder material of dredged soil-EPS. The cement types are factory cement made by PT. Semen Tonasa and is equated for all the specimens to avoid diversity.

4.2. Experimental Program

The details of the research program can be seen in the flowchart in Figure 4. Prior to making the element test specimens, it is necessary to conduct a compaction test to determine the MDD and OMC of the dredged soil-cement mixtures using the standard proctor method. After that, for LMB specimens, the EPS amount was determined by substituting 20% and 30% of the mould volume with EPS volume, which is equal to 0.5% and 0.75% of the weight of the mixture, respectively. According to it, the weight of the LMB mixtures will be known, while the moisture content of LMB follows the OMC of dredged soil-cement mixtures. It is due to the very low water absorbency of the EPS beads [16]. It is also stated that there is no remarkable impact of adding EPS on the OMC [20].

Before conducting the element test, preliminary research was carried out to determine the method of sample treatment. The sample was created using the method of static compaction. In addition, the three-layer method and the one-layer all at once method were compared in terms of their respective efficiencies. The method used for the element test was determined based on the results of the preliminary test.

The element tests consisted of two strength tests: an unconfined compression test using cylindrical soil specimens with dimensions of 5.7 cm in diameter and 11.4 cm in height, and an undrained direct shear test to determine shear strength with dimensions of 6 cm in diameter and 2 cm in height. Each sample was evaluated at three different curing periods: 7, 14, and 28 days. The specimen testing method was conducted in accordance with ASTM standards.

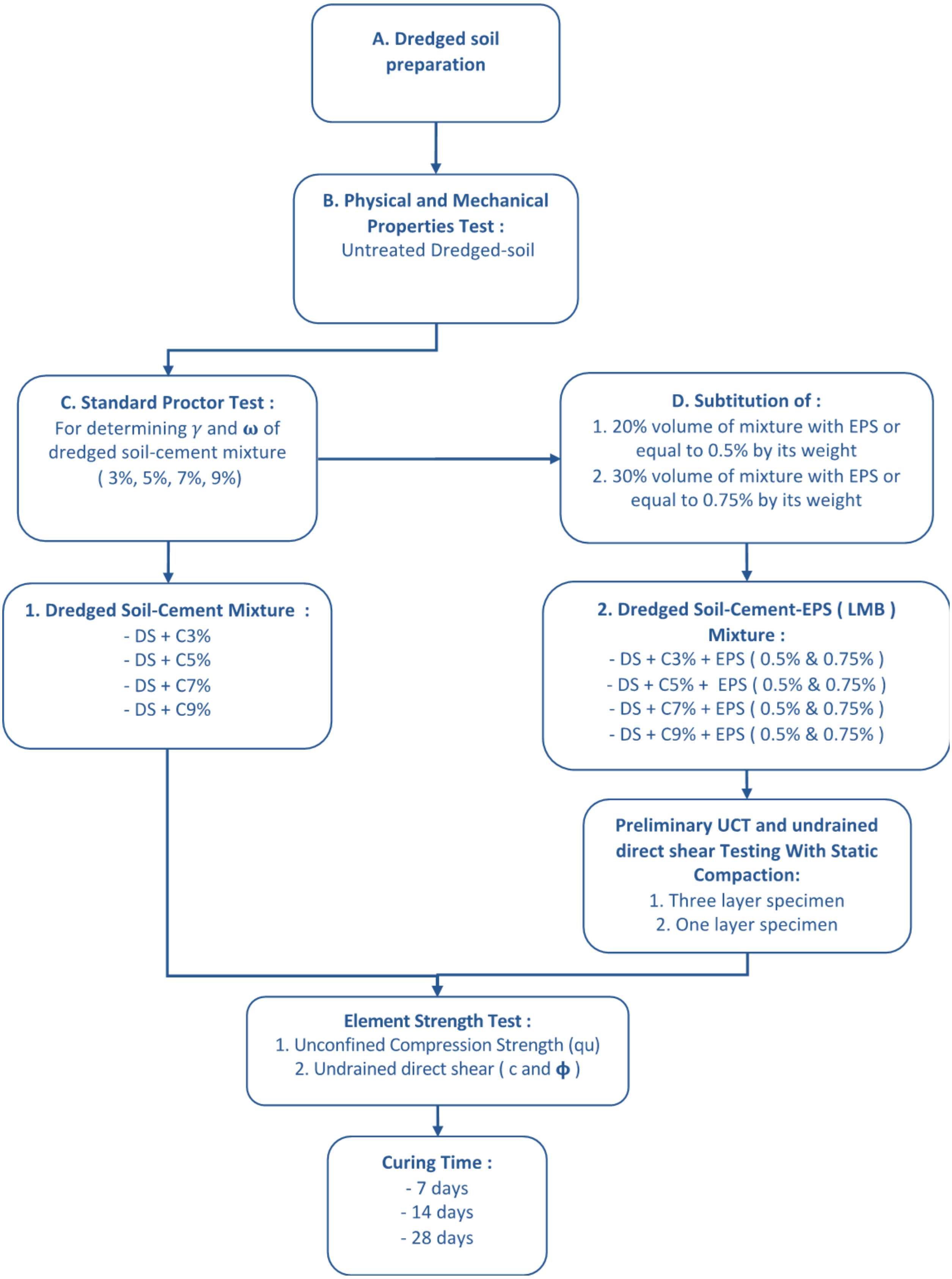


Figure 4. Experimental program

Standard Proctor Test of Dredged Soil-Cement Mixture

The MDD and OMC values obtained from the standard proctor test for the dredged soil-cement mixture are shown in Figure 5. The addition of cement from 3% to 9% increases MDD, whereas the OMC has the opposite trend. A higher percentage of cement consumes more water for the cement hydration process with the same amount of water added. It causes the final moisture content to decrease.

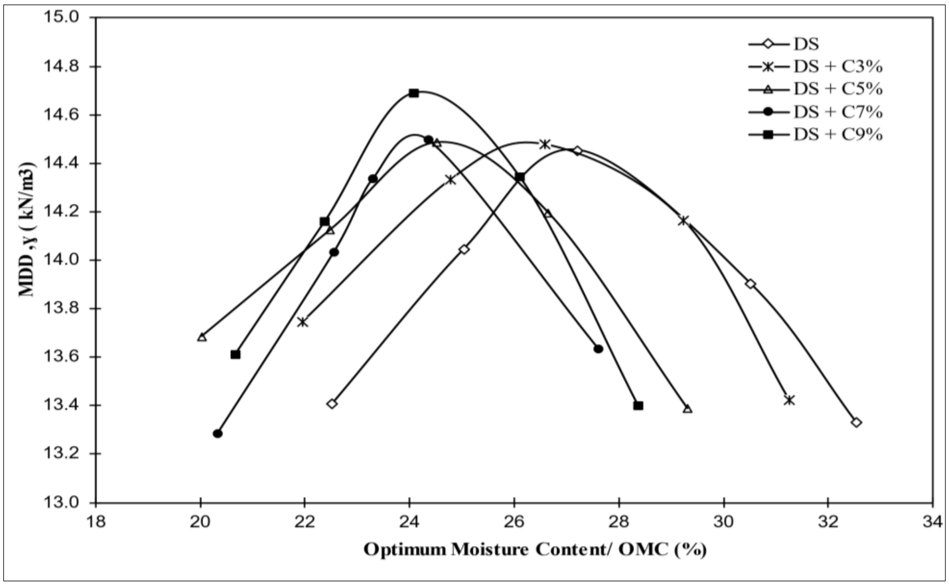


Figure 5. Correlation of MDD and OMC

Static Compaction Method on Lightweight Modular Block Making

Soil compaction is a method for mechanically increasing the unit weight of soil by reducing the air volume inside the void. The moisture content-dry unit weight relationship of the soil obtained from the laboratory test, forms the basis for specifications and field compaction control. In Geotechnical testing laboratories, the standard ASTM D698-91(2012) and modified ASTM D1557-91(2012) Proctor or dynamic compaction tests are most commonly used to determine the compaction characteristics for proper control over the field compaction.

However, it is undeniable that standard proctor test methods are ineffective on some materials, such as, soil mixture with EPS in this case. The compaction efforts on the standard proctor to compact soil mixtures containing EPS are not efficient. Therefore, an alternative and more efficient method should be considered. Chenari et al. [20] used a modified standard proctor in his research. The research was performed with the bulk density maintained constant (γ=1.5 g/cm^3). It was stated that, when the bulk density is constant, higher compaction efforts are required to achieve the same bulk density when the EPS amount rises since EPS are voluminous constituents. It is reached by applying more compaction efforts and blows to contain a constant overall mixture weight in the test mould.

Another compaction method, static compaction, was developed [23-25]. During the process, the soil is compacted by applying forces within a gradual movement of the piston. Adoption of this method in this present study was inspired by pressing-blocks production with the machine-pressed method which essentially is a static compaction method. Since the output will be making a lightweight geomaterial in block form, all the element test specimens were made using this method. Some studies reported that the static compaction method is more effective than dynamic compaction in achieving higher density due to higher energy losses during the impact of falling weight on the dynamic compaction. Another study also reported that the density curves of static compaction are almost similar to the proctor curves with a tendency of higher value [23-25].

In the specimens making, LMB is compacted by a static compaction method known as "Variable Peak Stress - Constant Stroke Compaction." Reddy explained in his paper that the force at the end of compaction could vary, but the variable control is the final thickness of the soil layer [23]. The final thickness of the mixtures was set following the height of the mould block. This method is adopted for specimens making only. No compaction test was conducted to identify the γdry design and OMC for LMB. The density is obtained after specimens making by the following Equation 1.

$$\gamma_{\text{dry}}\ \text{LMB} = \frac{\gamma\ wet\ LMB}{1+w} \tag{1}$$

5. Result and Discussion

5.1. The swelling potential of EPS on LMB

The compressibility of EPS makes the making process more difficult than conventional soil samples. Therefore, static compaction is easier and more effective to apply. In the static compaction process, a force is given by the piston controlled by a hydraulic pump. The control of compaction is when the final thickness of the sample has been reached. After reaching the final thickness, the applied force was removed, and the mould was released. This phenomenon is shown in Figure 6-a.

(a) (b) (c)

Figure 6. Sample condition after a). Releasing the piston and mould right after compaction b). Releasing the piston right after compaction - were cured within the mould for 4 hours, c). Releasing piston 15 minutes after compaction – cured for 4 hours within the mould.

Figure 6-a, depicts a specimen that has undergone cracking in the entire sample. The cylindrical sample's height and diameter changed significantly due to this treatment. The presence of crack lines at some points where EPS were distributed indicates that the cracks were caused by the EPS beads swelling due to the load discharges. The dredged soil-cement mixtures were not sufficiently bound to endure the EPS swelling. The dredged soil-cement portion, which has been fully shaped and being chemically reacted due to the cement hydration process, experienced cracks due to the swelling of the EPS particles. From this phenomenon can be inferred that the treatment after compacting is important. This stage is crucial. Therefore, another method should be tried.

Another trial was conducted using a different method, in which the applied force was released immediately after the sample had been compacted but being cured in the mould for 4 hours. The vertical dimension of the sample was still changing after the piston was lifted. Meanwhile, the lateral dimension changes will be observed after 4 hours. Previous research stated that 4 hours are the final setting time for cement paste [26]. Thus, it was assumed, to reduce sample swelling in the lateral direction, the sample needed to be cured in a cylinder mould for 4 hours. Figure 6-b shows the result after 4 hours. Cracks appear only in the area of 1.5-2 cm from the sample surfaces and the diameter had no remarkable changes. The curing process in the mould caused the EPS space to swell limited. The surface crack pattern occurred as a result of quick load discharges, so the part of the specimen that received the least load rebounded.

By examining the disadvantages of the two previous methods, for the next specimen, a method was developed. After compaction was completed, the piston was held for 15 minutes and it was also being cured for 4 hours within the UCS mould. Figure 6-c illustrates the results. There were no changes in the vertical dimensions. However, to anticipate minor swelling, a rectangle plate that is larger than the UCS mould was seated on top of the mold. A bigger plate than the cylinder mould was used so the weight from the plate does not provide additional load which can make the sample experience settlements. After 4 hours, there have been no changes in height or diameter were measured and the crack did not occur either. The final sample dimensions are presented in Table 2.

Table 2. Dimension UCS specimen

Sample Code	Diameter (cm)	Height (cm)
6A	$d_1 = 5.92$	$h_1 = 11.94$
	$d_2 = 5.90$	$h_2 = 11.95$
	$d_3 = 5.84$	$h_3 = 12.01$
6B	$d_1 = 5.71$	$h_1 = 11.64$
	$d_2 = 5.72$	$h_2 = 11.65$
	$d_3 = 5.71$	$h_3 = 11.65$
6C	$d_1 = 5.71$	$h_1 = 11.41$
	$d_2 = 5.71$	$h_2 = 11.41$
	$d_3 = 5.72$	$h_3 = 11.40$

Note: Measurement of d_1 – d_3 sequentially from the surface, middle, bottom and h_1–h_3 from left to the right part of the sample.

Mould dimensions are d = 5.71 cm, h = 11.4 cm.

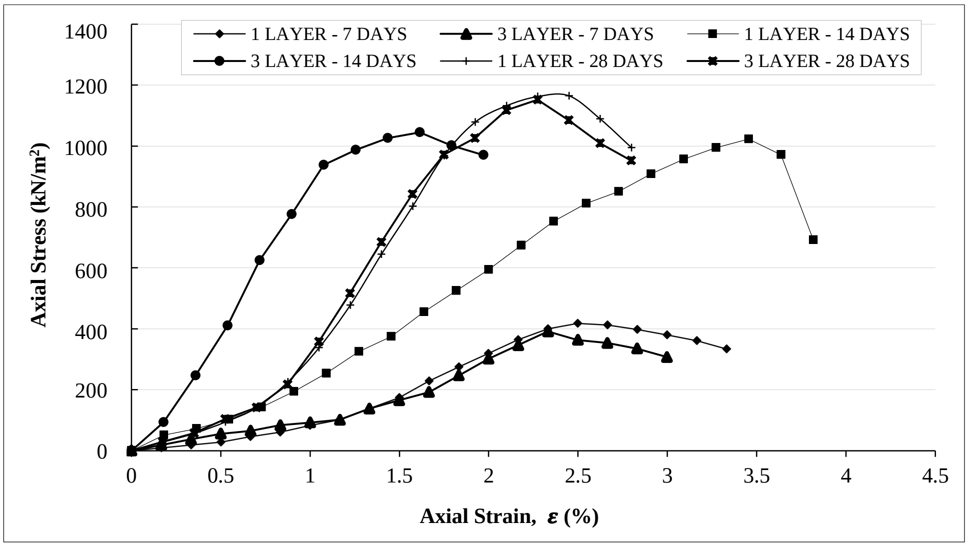
5.2. Strength Comparison between Three-Layer and One-Layer Specimens

The most common method for compacting specimens is three-layer compaction based on the standard proctor test. Thus, some investigations were carried out to compare one-layer, all-at-once compacted specimens with three-layer specimens. It was carried out to validate the effectiveness of each method in the LMB compaction process. The effectiveness parameters were the compressive and shear strength performance of specimens. The tests were conducted using a representative of 0.5% EPS with the addition of 9% cement.

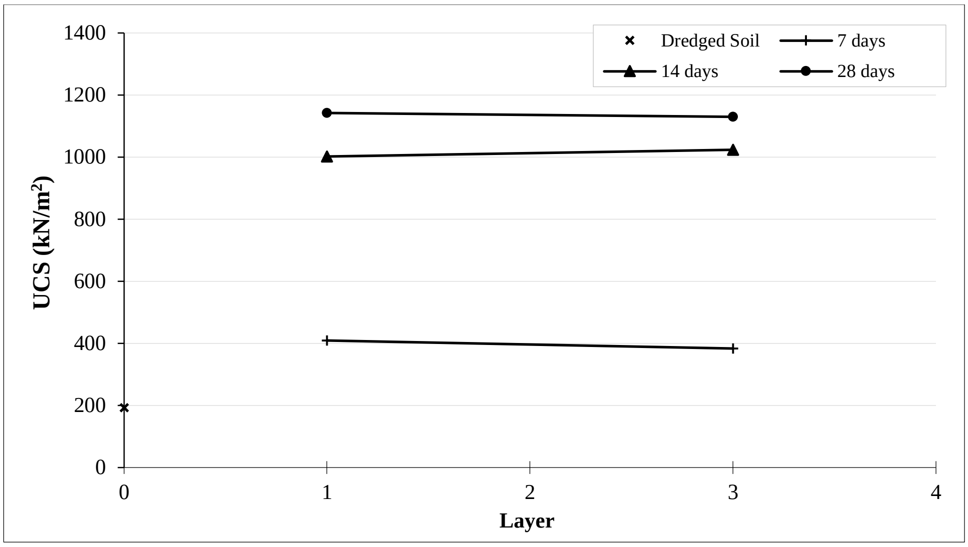
The EPS swelling phenomenon that has been stated in point 5.1 is inevitable. The sample needs to be remained loaded for 15 minutes after completion of compaction and curing for 4 hours in the cylinder mold. In contrast, leaving 15 minutes for each layer in three-layer compaction would make the compaction process too long and cause the mixture to begin to set before the compaction process is finished, as the cement paste is entering its initial setting time phase. Thus, for three-layer specimens, the piston must be lifted immediately after the compaction of each layer.

In Figures 7 and 8, the pictures and stress-strain charts of one-layer and three-layer compacted specimens are attached. The tests were carried out in 7, 14, and 28 days. The UCS value in both methods was relatively the same. There is no significant difference in the UCS value, although a fine crack between the layers occurred in the three-layer specimen. However, the shear strength value shows a significant difference, which is presented in Figure 9. A one-layer compacted sample has a higher cohesion value than a three-layer. Fine cracks between layers occurred since the piston must be lifted every layer to put in the second and third portions of the mixture. The EPS were subjected to the loading-unloading phase repeatedly. The existence of a small crack between the layers causes the layers to not properly merge with each other. It makes the sample more susceptible when receiving shear force.

Figure 7. The specimens of 1 layer and three layers compacted

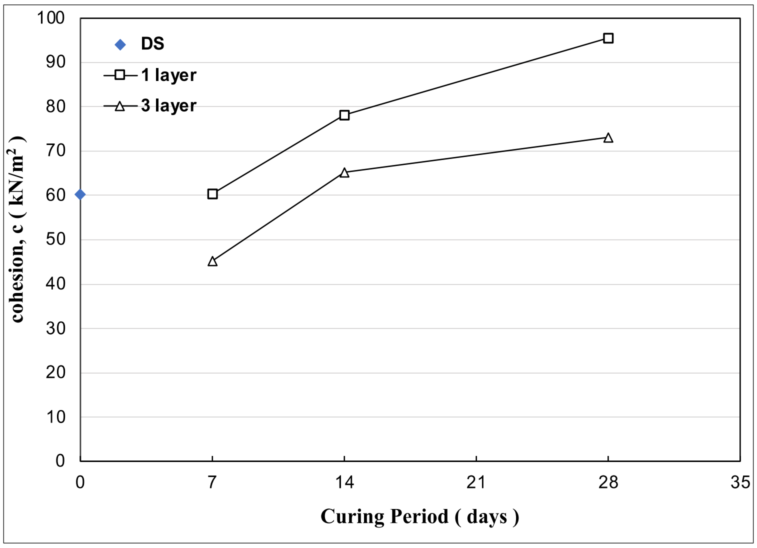


(a)

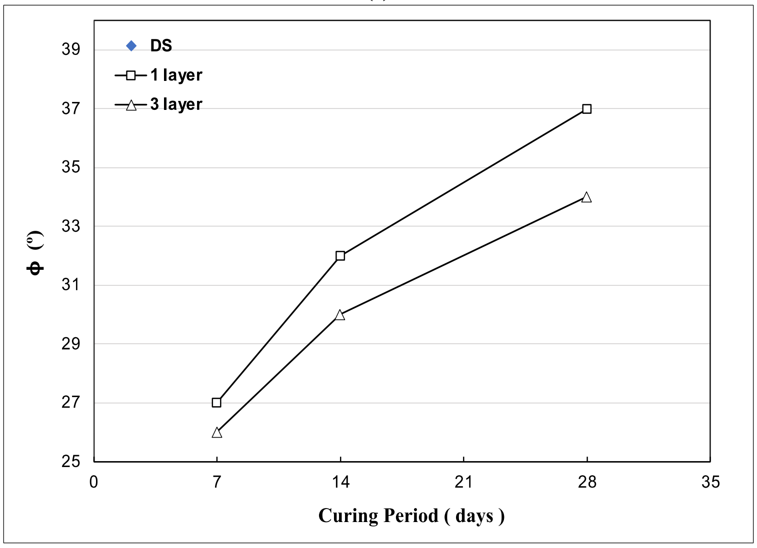


(b)

Figure 8. a) Axial Stress-Strain Relationship; b) UCS Value of 1 layer vs. three layers



(a)



(b)

Figure 9. 1 layer vs. three-layer a) cohesion value; b) friction angle

By considering the previous result, the strength element test was conducted using the static compaction method with one layer all at once.

5.3. Effect of Cement Content

Figures 10 and 11 show the results of unconfined compression and undrained direct shear tests. The trend data show a linear relationship between increasing the amount of cement to the UCS value, cohesion, and internal friction, respectively. UCS values ranged from 1000.2 to 3187 kN/m^2, cohesion from 61.35 to 196.75 kN/m^2, and friction angle from 21^0 to 46^0. Strength increased gradually along with the increase in cement content. While the correlation between adding more curing time and given strength was also linear, the maximum strength occurred at 28 days. According to the findings, cement performed well as a stabilizing agent in this typical dredged soil. Significant increases were presented from C3% to C9%.

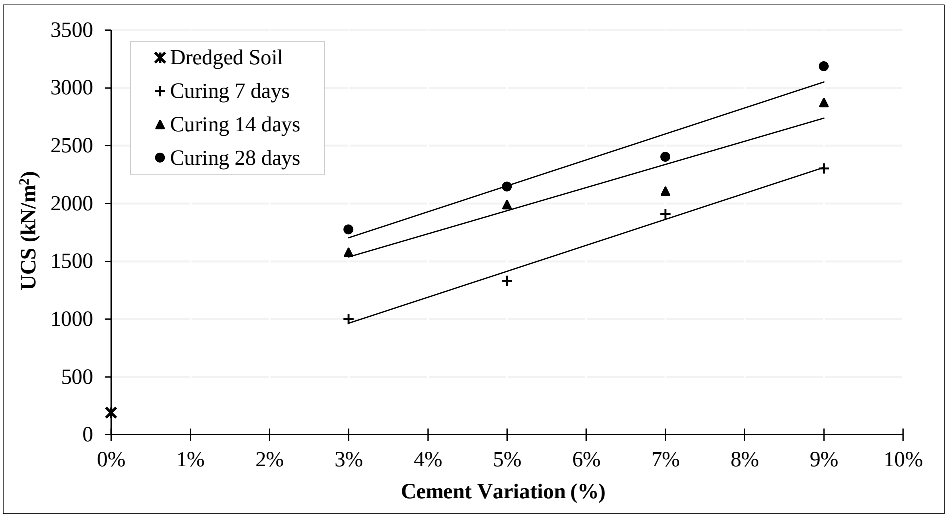


Figure 10. UCS Value of DS + C

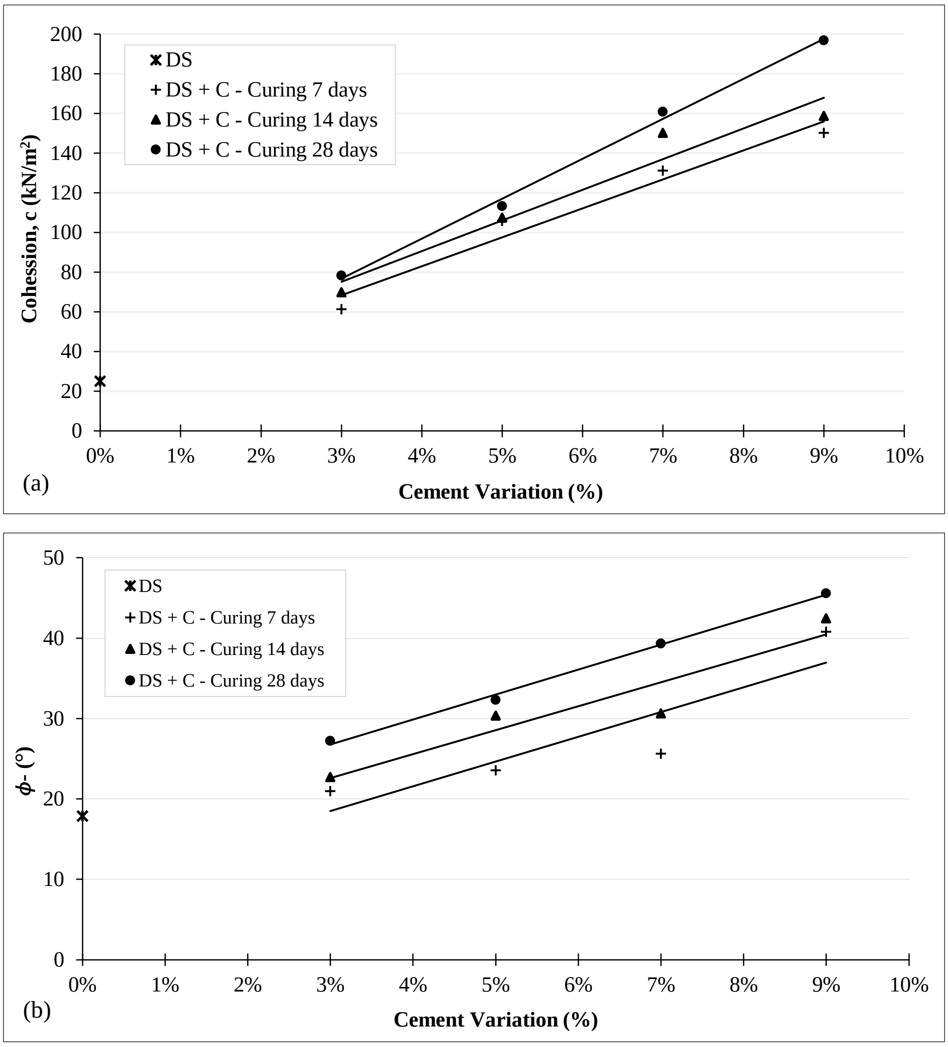


Figure 11. a) Cohession "*c*", and b) ϕ Value

5.4. Effect of EPS Beads Content

According to the result in Figure 12, it shows that with the addition of EPS beads, the density of the LMB mixture is much lower than that of the dredged soil and dredged soil-cement mixture. The same trend was also presented in most previous research [12–14, 18–21, 27]. Adding more EPS beads to the mixture, reducing the density of the material. Figure 12 shows that increasing the amount of EPS beads from 0.5 to 0.75% reduced the density by around 18% to 29%, depending on the amount of EPS beads.

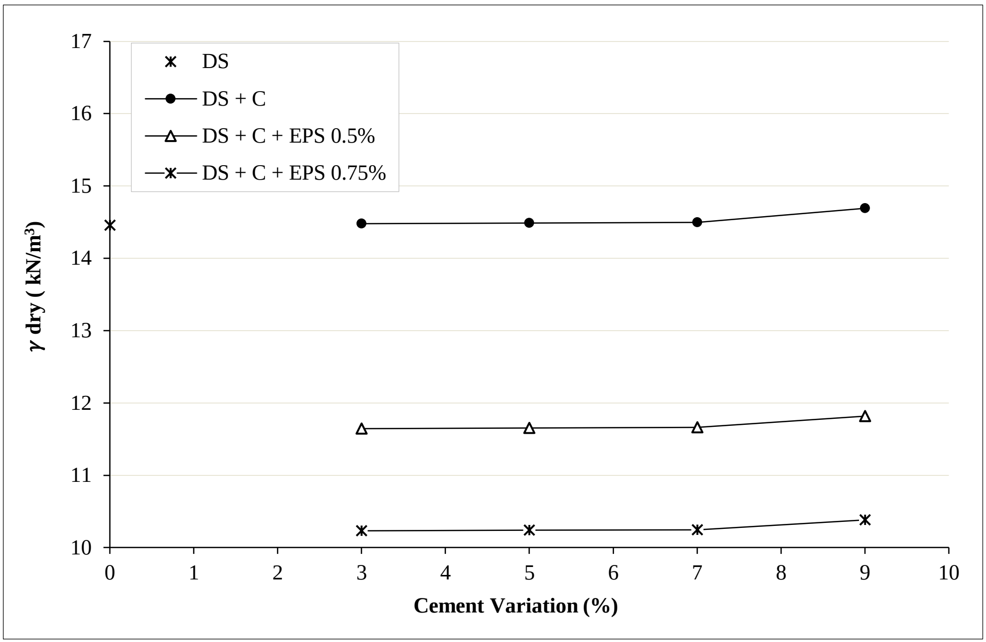


Figure 12. The dry density of the mixtures

However, as shown in Figures 13 and 14, the strength decreased as the number of beads increased, but the addition of cement helped increase the strength parameter. This can be influenced by the separation of soil particles and binders caused by the presence of EPS, which prevents the soil-cement from bonding to each other. Because EPS does not absorb water, there are no chemical reactions occur between EPS and the other materials in the mixture. Thus, the strength of LMB was entirely laid on the dredged soil-cement portion, and as the amount of EPS increased, the dredged soil-cement portion in the mixture decreased, causing the strength to decrease as well.

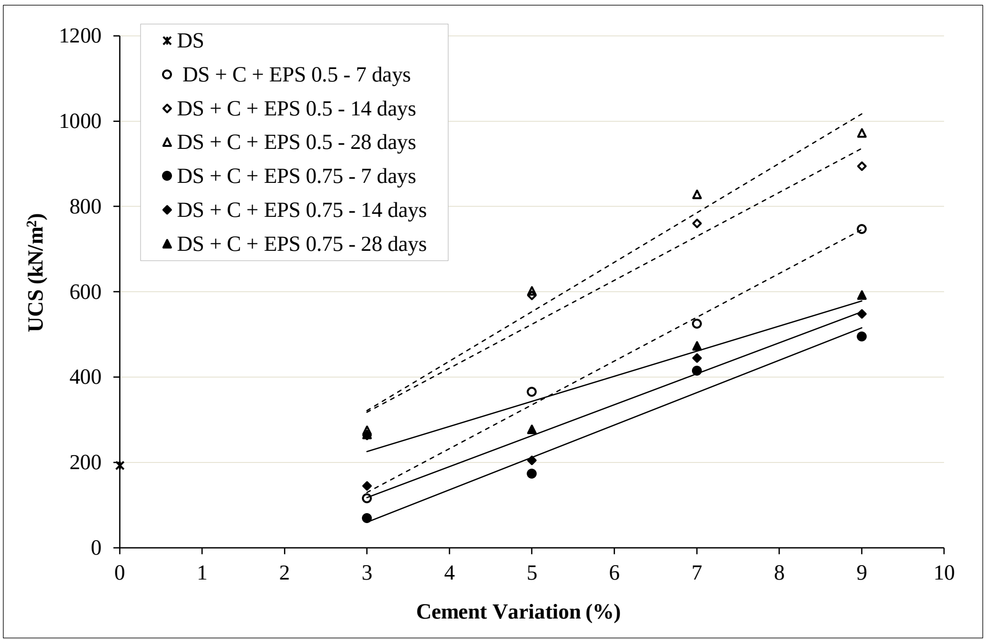


Figure 13. UCS Value of DS + C + EPS

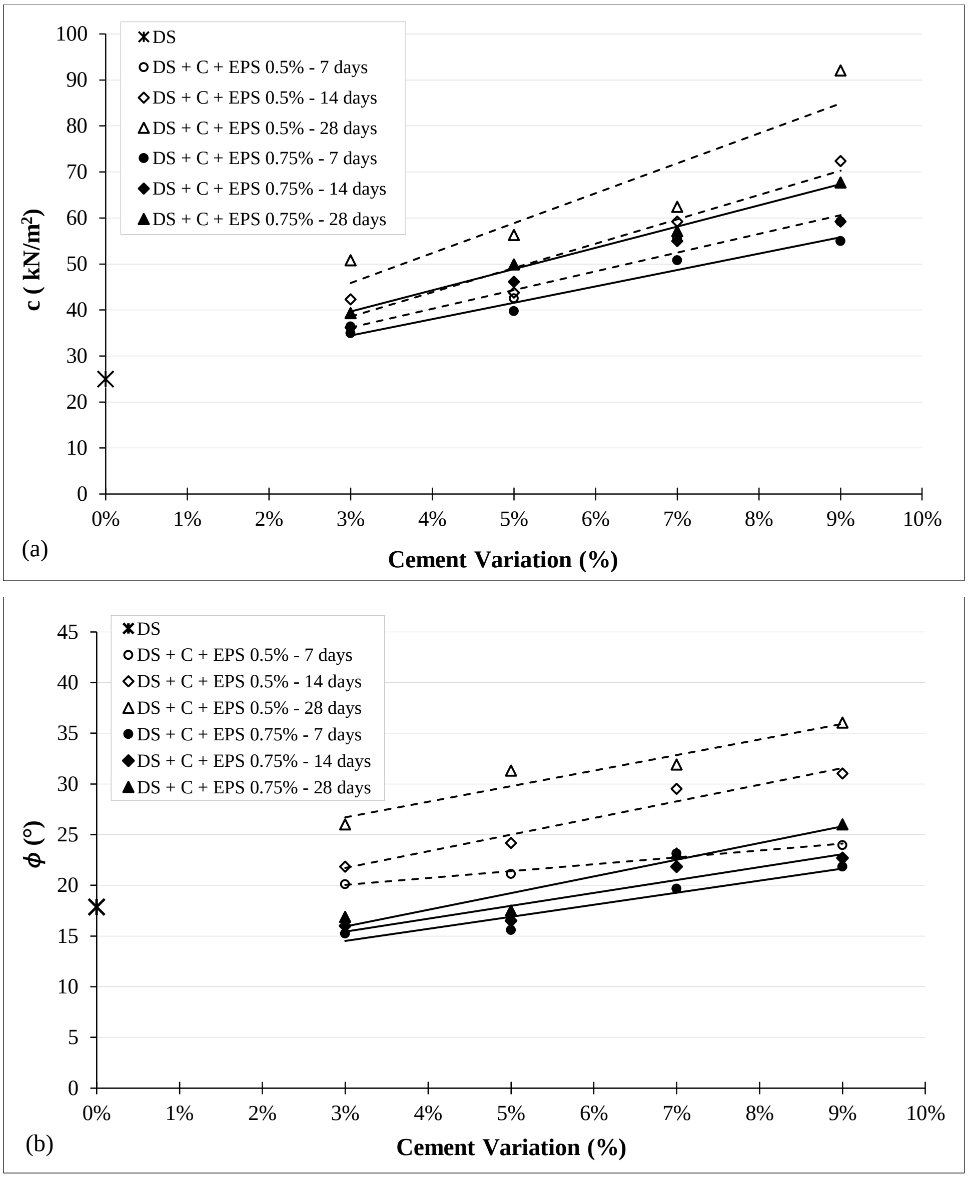


Figure 14. Summary of a) cohesion b) ϕ of DS+C+EPS

The UCS value ranged from 68.98 – 972.16 kN/m^2, cohesion was from 34.91 – 92.03 kN/m^2, and the friction angle was 15^0 – 36^0. However, not all the cement amount increased the strength. Instead of increasing, some of the cement addition showed a decrease in the UCS value and internal friction compared to the value of dredged soil. Most of them are in addition to C3% and C5%. The significant enhancement of the strength properties occurred at C7% and C9%. Therefore, it is the suggested amount to be used.

6. Conclusions

The results of a study on the potential use of dredged soil–EPS stabilized with cement have been presented. The strength properties of these lightweight materials were evaluated with laboratory tests, including the unconfined compression test and the undrained direct shear test. To summarize the main findings of the study, some points can be concluded as follows:

- Prior to making the element test specimens, standard proctor tests were conducted to determine the MDD and OMC of the dredged soil-cement mixtures. Thereafter, for LMB specimens, the EPS amount was determined by substituting 20% and 30% of the mould volume with EPS volume, which is equal to 0.5% and 0.75% to the weight of the mixture, respectively.
- The static compaction method was used for the element test specimens made in this study.
- The EPS swelling phenomenon is an unavoidable characteristic. The phase after compacting is a crucial stage that can cause cracks in the sample. Therefore, some treatments need to be applied. After conducting three types of tests, it can be inferred that the treatment of releasing the piston 15 minutes after compaction and curing for 4

hours within the mold with a seated rectangular plate on the top of the mold showed the best performance. After applying these treatments, there were no changes in both the vertical and lateral dimensions that were measured.

- The one-layer compacting method was compared to the three-layer compacting method. It is shown that there were no significant differences occurred in the UCS value, even though a fine crack was detected between layers on the three-layer specimens. On the opposite, the shear strength parameters (c and ϕ) decreased due to its crack.
- The trend data show a linear relationship between increasing the amount of cement and the increment of the strength parameter. Strength increased gradually along with the increase in cement content. While the correlation between adding more curing time and given strength was also linear, with the maximum strength occurring at 28 days.
- Adding more EPS beads to the mixture reduced the density of the material. Increasing the amount of EPS beads from 0.5% to 0.75% reduced the density by 18% - 29%, while the strength parameter decreased, but the addition of cement helped to increase the strength parameter.
- The strength properties were significantly enhanced at C7% and C9%. Therefore, it is the suggested amount to be used. In comparison, C3% and C5% are not recommended since most of the strength parameters were decreasing.

7. Declarations

7.1. Author Contributions

Conceptualization, N.M.; methodology, N.M.; validation, T.H., A.B.M., and R.I.; formal analysis, N.M.; investigation, N.M.; resources, N.M.; data curation, N.M. and T.H.; writing—original draft preparation, N.M.; writing—review and editing, N.M.; visualization, N.M.; supervision, T.H., A.B.M., and R.I.; project administration, N.M. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available in the article.

7.3. Funding and Acknowledgements

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7.4. Conflicts of Interest

The authors declare no conflict of interest.

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