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ORIGINAL STUDY

Sandy Soil Stabilization Using Paper Waste Ash as a Supplementary Cement Material

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Abstract

Soil stabilization is one of the processes that have used widely to enhance pavement structure. Using natural and man-made resources as efficiently as possible while inflicting little environmental harm is known as sustainable roadway building. Reducing energy consumption during construction and making optimal use of materials to reduce waste are two approaches to make roads more sustainable. This project work is concern in chemical soil stabilization with a waste or by-product material. The experiential work included improve sandy soil by using Paper Waste Ash (PWA) and ordinary Portland cement (OPC). Laboratory tests included sieve analysis, standard proctor compaction test, California Bearing Ratio Test, Atterberg Limits and Compressive Strength test to determine soil properties. The results showed that mixing of PWA and cement can improve compressive strength of subgrade, reduce pavement layers' thicknesses and then reduce the total cost of construction. It concluded that using PWA reduce the impact on natural materials, landfill and preserve the environment by rotate rubbish and used it instead of cement or other additives in stabilization of unbound pavement layers.

Keywords: California Bearing Ratio (CBR), Stabilizer, Soil stabilization, PWA, Unconfined compressive strength

1. Introduction

The process of changing a soil's characteristics to make it more engineering-friendly than its unsterilized equivalent is known as chemical soil stabilization. Mechanical characteristics, particularly compressive and shear strength, permeability, volume stability, and durability, are the main areas of concern for chemically stabilized soils. Portland cement and lime are the most often used compounds for chemical soil stabilization, with a lengthy history and a wealth of research supporting their usage. The search for improved engineering performance, the requirements of different unique soil conditions and projects, cost considerations, and environmental concerns all drive the development of novel soil stabilizers [1]. Each additive behaves differently from the others due to its specific application and limits; Portland cement, lime, lime-pozzolana, and sodium silicate are a few examples [2]. [3]discovered that treating soil with a mixture of lime and sodium silicate improves its geotechnical qualities. Fly ash is typically regarded as pozzolana, which is not cementitious in and of itself. Because of the hydration and long-term pozzolanic reaction, it can mix with Ca-rich materials like cement, lime, etc. to create cementitious ones, such as calcium silicate hydrate (CSH), calcium aluminate hydrate (CAH), calcite ($CaCO_3$), etc. among soil particles [4]., certain fly ash exhibits cementitious qualities and falls within the Class-C fly ash category. In addition to significantly raising the unconfined compressive strength and CBR values, fly ash stabilization may provide a

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substitute for subgrade improvement in highway building., geopolymers based on fly ash and ground granulated blast furnace slag (GGBFS) are utilized to stabilize soil. The findings demonstrated that fly ash and GGBFS are effective soil stabilization methods [5]. In this study, in order to stabilize a sandy soil, we look at the possible application of waste paper ash (PWA) as an addition. However, the main hypothesis of this research work is the ability of PWA to be a supplementary cement materials, in other words, replace of OPC by significant percentages.

2. Materials

2.1. Soil

The subgrade soil utilized in this study was taken from a Karbala Street and serves as a representation of the road's subgrade. The soil type was sandy soil; the analysis was carried out to limitation the gradient and classification of the soil.

2.2. Cement

According to the Iraqi Specification, Ordinary Portland cement or sulphate-resistant cement, as determined by the engineer's representative based on laboratory test findings, must be used for stabilization. The Portland cement must meet the specifications of [6] Portland cement (ordinary and rapid hardening) [7], or to [8] Type V for High Sulphate Resistant Portland Cement. The Portland cement that used in this study was produced by Karbala Plant, and where all its properties satisfied to the requirement as can be seen in Table 1.

Table 1. Testing of cement used in the study.

Testing	Result	specification
Initial setting time (min)	128	No less than 45 min
Final setting time (min)	330	No more than 600 min
Compressive strength (age 3 day)	22.2	No less than 15 (N/mm2)
Compressive strength (age 7 day)	30.0	No less than 23(N/mm2)
(Sio2) %	22.9	–
(Cao) %	63	–
(Al2O3) %	4.0	–
(Fe2o3) %	5.2	–
(Mgo) %	1.8	No more than 5 %
(So3) %	2.0	No more than 2.5 %
(%) Fe2o3/Al2o3	0.91	–
(Free lime) %	0.912	–
Loss at fire	3.8	No more than 4 %
Factor of saturation	0.9	1.02–0.66
Material unable for soluble	0.9	No more than 1.5 %
(C3S) %	49.0	–
(C2S) %	27.35	–
(C3A) %	3	No more than 3.5 %
(C4AF) %	14.6	–

2.3. Paper waste ash (PWA)

The fly ash that is produced after burning paper waste at temperatures between 700 and 900 °C include reactive silica and alumina (in the form of metakaolin) together with lime (CaO), which chemically contribute to the constituents of Portland cement. There is formerly paper waste ash that may be used as an ingredient in:

- The cement kiln feed, which contributes calcium, silica, and alumina.
- The production of cement blends [9,10].

The PWA used in the study was a burnt paper burning in air at approximately 400 °C to reduce its size, and then burn it with an electric oven at a temperature of 750 °C to obtain fly ash which contain reactive silica and alumina.

3. Experimental works

3.1. Sieve analysis test

Sieve analysis is the process of finding granular gradient of soil and comparing it with standard specifications for classification. At first we did the quartering of soil according to [11] and then electrical vibration was used as shown in Fig. 1 to analysis particles size. The class of soil was determined by using Table 2 which represents the gradation according to AASHTO soil classification method [12].

3.2. Laboratory compaction characteristics

In this lab test, soil with a known moisture content is typically compacted into a cylindrical mold with define dimensions. Each of the three equal layers, as shown in Fig. 2, will receive a total of (25 blows) from a conventional weighted hammer at a specific height. The dry densities are then calculated for each water content after this procedure is repeated for different moisture values.

The compaction curve is then created by graphing the dry density and moisture content graphically in order to determine the maximum dry density and ideal moisture content. Table 3 below shown the compaction characteristics of soil (known that the natural soil gradation is presented in Table 4).

Fig. 1. Quartering and electrical sieving.

Table 2. AASHTO classification of highway subgrade material.

General classification	Granular materials (35 % or less passing #200)							Silt–clay Materials (more than 35 % passing #200)			
Group classification	A − 1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis											
#10	0–50										
#40	0–30	0–50	51–100								
#200	0–15	0–25	0–10	0–35	0–35	0–35	0–35	36–100	36–100	36–100	36–100
Characteristics of fraction passing #40:											
Liquid limit				0–40	41+	0–40	41+	0–40	41+	0–40	41+
Plasticity index	0–6		N.P	0–10	0–10	11+	11+	0–10	0–10	11+	11+
Group index	0		0	0		0–4		0–8	0–12	0–16	0–20
Usual types of significant constituent materials	Stone fragments Gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good					Fair to poor					

Fig. 2. Compaction process of soil.

3.3. Effectiveness of paper waste ash burn in 750 °C

After done the burn process of the paper to produce the paper waste ash, we should certain the effectiveness of the paper sludge ash, and know whether the burn of paper at 750°C in more effective to produce the pozolanc materials or not, by cast it down in the cubic with cement in two

Table 3. Compaction characteristics of soil.

Description	Sample
Mold weight	4196 gm
Volume	994.58 cm3
Height	11.53 cm
Diameter	10.48 cm
Weight of hammer	44.5 N
Height of hammer drop	45.72 cm
Number of blows per layer	25
Test on soil fraction passing sieve	# 4
Water content %	4 %–8 %–12 %

Table 4. Result of sieve analysis.

Sieve No.	Retaining weight on sieve	% of passing	ASTM Designation
4	38	98.19	[13]
8	80	94.37	
16	341	78.1	
30	756.5	41.97	
50	657	10.60	
100	208	0.7	
200	10.5	0.2	
Pan	3.5	0.00	

cases, when we get it direct from the burn paper in air at 400 °C and the second is when burn it in the oven in 750°C and know its strength, then compare the result to find the need to burn it in oven in 750°C or not, Fig. 3 below shown the process of test.

3.4. California bearing ratio test (CBR %)

The CBR (California Bearing Ratio) of pavement subgrade, subbase, and base course materials can be determined using this test method using laboratory-compacted specimens, as shown in Fig. 4. The primary purpose of the test method is to assess the strength of cohesive materials with maximum particle sizes of less than 3⁄4 in. (19 mm), though it is not restricted to that.

3.5. Atterberg limits

Using the apparatus seen in Fig. 5, this test is carried out to determine the fine-grained soil's plastic and liquid limits. The liquid limit (LL) is the percentage of water that, when subjected to 25 blows from a standard cup dropped 10 mm in a standard liquid limit apparatus running at two blows per second, will cause two parts of soil cut by a standard-sized groove to flow together at the base of the groove for a distance of 13 mm (1/2 in.). The

Fig. 3. Cubes of burnt PWA and cement.

Fig. 4. Procedure of CBR % test.

percentage of water in a soil that prevents it from disintegrating when rolled into threads with a diameter of 3.2 mm (1/8 in.) is known as the plastic limit (PL).

3.6. Unconfined compressive strength

The amount of stress required to cause an arbitrary quantity of material distortion. In a compression test using the apparatus seen in Fig. 6, the highest load is divided by the specimen's initial cross-sectional area to determine the compressive strength. Ordinary Portland cement (OPC) was used in this test totally with PWA; OPC was partially or completely replaced with PWA.

Fig. 5. Apparatus of (L.L&P.L).

4. Results

4.1. Sieve analysis test

From these results and by comparing with AASHTO specification Table 2 we can classify the soil as type (A3).

4.2. Compaction test

This test used to obtain the maximum dry density (MDD) and optimum moisture content (OMC) as can be seen in Table 5 for soil with or without any additives that obtained from standard proctor compaction, Cement addition to the soil was selected to be 9 % of weight of soil according to ACI recommendation as can be seen in Table 6 as a middle percentage of (7–11 %).

Then, we replaced different percentage of cement by Paper Waste Ash to find the OMC of the soil with binder from curve in Fig. 7 we find the other percentages of replacement. The results of these testing are shown in Table 7 Increasing the cement content improves the workability of the soil by the generated paste, which means the amount of water required to achieve optimum density decreases. As a result, the optimum water content (OMC) decreases with higher cement percentages.

Fig. 6. Unconfined Compressive strength test.

Table 5. MDD & OMC for percents of soil & binder.

Percent of soil & binder	MDD, gm/cm3 (ASTMD698 2021)	OMC, % [14]
Soil+0 % cement +0 % PWA	1.795	7 %
Soil+100 % cement +0 % PWA	–	9.2
Soil+75 % cement +25 % PWA	–	10.2

4.3. Effectiveness of paper waste ash burnt at different temperature

We did this test to know the hydraulic effectiveness of PWA with burn in air (approximately 400 °C) or which burn in closed furnace at 700 °C. Two concrete mixes (1 cement: 10 % PWA: 3 sand) comprising the two PWA types were used to cast (5*5 cm cube) then test them by compressive strength test to choose the most effective mix. Result showed that the 700 °C burning temperature transfer the waste paper to more effective ash, as can be seen from Table 8. It is worth mentioning that at 700 °C, the organic content in the paper ash decomposes more completely into inorganic compounds like active silica or pozzolanic materials. These compounds react more effectively with cement components (e.g., calcium hydroxide), enhancing strength.

4.4. The optimum percentage of cement and PWA

By replacing different percentage of (cement by PWA) and test the compressive strength we notice that increasing in compressive strength values because Increasing cement content boosts the

Table 6. Typical cement requirements.

AASHTO soil classification	ASTM soil classification	Typical range of cement requirement,[a] percent by weight	Typical cement content for moisture-density test (ASTM D 558),percent by weight	Typical cement contents for durability tests (ASTM D 559 and D 506), percent by weight
A-1-a	GW, GP, GM, SW, SP, SM	3–5	5	3–5–7
A-1-b	GM, GP, SM, SP	5–8	6	4–6–8
A-2	GM, GC, SM, SC	5–9	7	5–7–9
A-3	SP	7–11	9	7–9–11
A-4	CL,ML	7–12	10	8–10–12
A-5	ML, MH, CH	8–13	10	8–10–12
A-6	CL, CH	9–15	12	10–12–14
A-7	MH, CH	10–16	13	11–13–15

[a] Does not include organic or poorly reacting, soils. Also, additional cement may be required for severe exposure conditions such as slope-protect&.

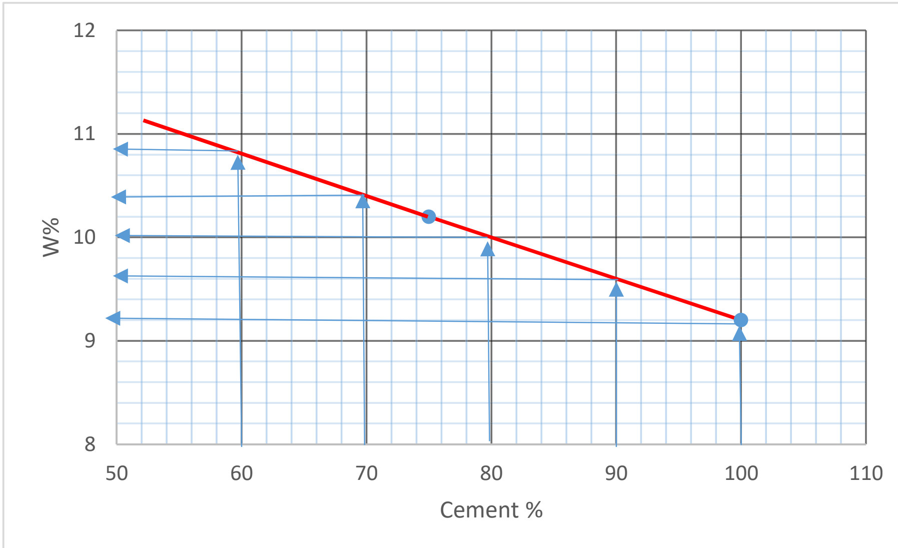

Fig. 7. Relationship between the amount of cement and moisture content.

Table 7. OMC % & cement %.

% of cement	OMC %
100	9.2
90	9.6
80	10
70	10.5
60	10.9

Table 8. Compressive strength between burn in 400 °C and burn in 700°C.

Strength of burn in 400° C	Average Strength	Strength of burn in 700 °C	Average strength
6.7 MPa	6.65 MPa	10.23 MPa	9.84 MPa
7.03 MPa		8.6 MPa	
6.22 MPa		10.71 Pa	

production of hydration products, reduces porosity, and improves cohesion and density, resulting in higher compressive strength. We choice the most effective percents, The result shown in Table 9 and Fig. 8 below.

Table 9. Results of compressive strength test.

% Cement	% PWA	Average compressive strength of 3 samples
100	0	12.3
95	5	11.24
90	10	9.85
85	15	10.57
80	20	10.75
75	25	8.95
50	50	7.53
25	75	–

4.5. California Bearing Ratio test (CBR %)

CBR test was conducted to obtain the mechanical properties of natural soil. The middle gradation of each class was used to identify the CBR, Table 10 shows that the results of CBR of natural soil and with addition of 9 % cement.

4.6. Atterberg Limits

These properties were obtained to identify the percentage of liquid & plastic limits according to [16]. In this study the soil was Sand and it does not has plasticity (Non Plastic) as shown in Table 11 below.

4.7. Unconfined compressive strength test

Compressive strength test was conducted to obtain the mechanical properties of cylindrical mold. The natural gradation of each percent was used to identify compressive strength in age (7-days) and (28-day) as shown in Figs. 9 and 10 respectively,We used several percentages of cement and PWA with soil and test to calculate its compressive strength, The increase in compressive strength at 28 days compared to 7 days is due to the completion of the hydration process which results in the formation of more solid compounds like calcium silicate hydrate Over time, the bond between particles strengthens, reducing porosity and enhancing the microstructure of the concrete. This leads to increased density and strength.

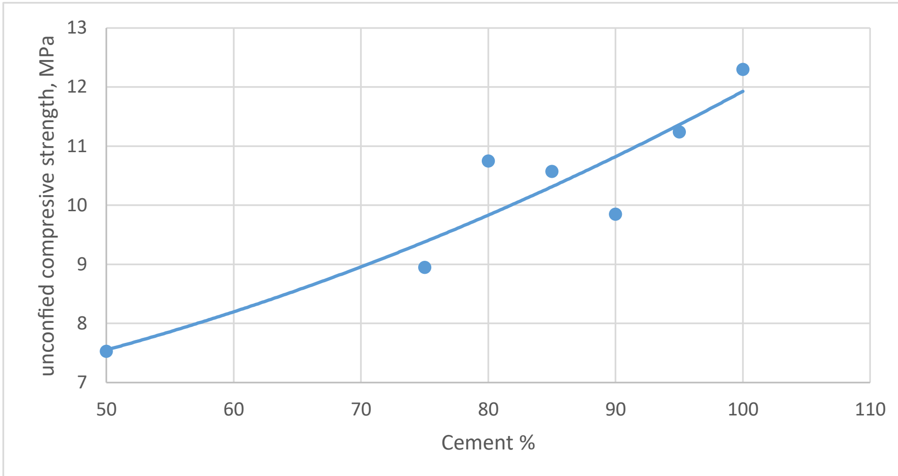

Fig. 8. Curve of results of unconfined compressive test.

Table (10). CBR results.

Property	ASTM designation	Results
CBR of soil, %	[15]	10 %
CBR of (soil+9 % cement), %	[15]	–

Table (11). L.L & P.L results.

Property	ASTM designation	Results
Liquid limit, %	[17]	N. P
Plastic limit, %		N. P
Plasticity index, %		–

4.8. Calculation the thickness of pavement

The AASHTO method for design of highway pavements [12] was based in this study work for design flexible pavement. Specific parameters were selected to represent a traditional local arterial pavement. There parameters are the carry significant Level of traffic is (6,100,000 18-kip **ESAL**), the Reliability (95 %), the overall standard deviation, so (0.45), the resilient modulus, Mr of subgrade soil (3000PSI), and present serviceability index **(PSI)** initial and terminal are (4.2) and (2.5).

Other design parameters that related to the sub-base characteristics were determined depends on its mechanical properties. However, CBR is used to represent the characteristics of unbound subgrade layers, and compressive strength of age (7 day) is used to represent cement modified subgrade. Fig. 12 was used to determine the mechanical properties of the subgrade modified layer. Simultaneously, Standard AASHTO design chart of flexible highway

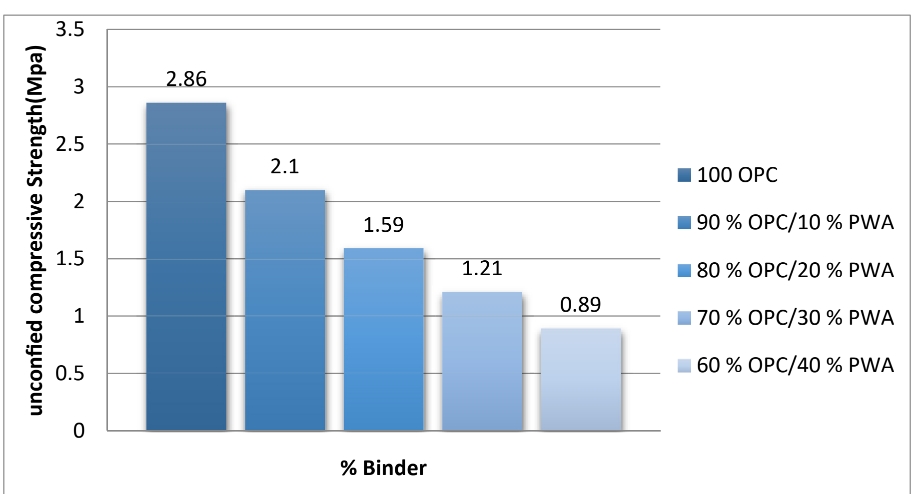

Fig. 9. Unconfined compressive strength after (7) days.

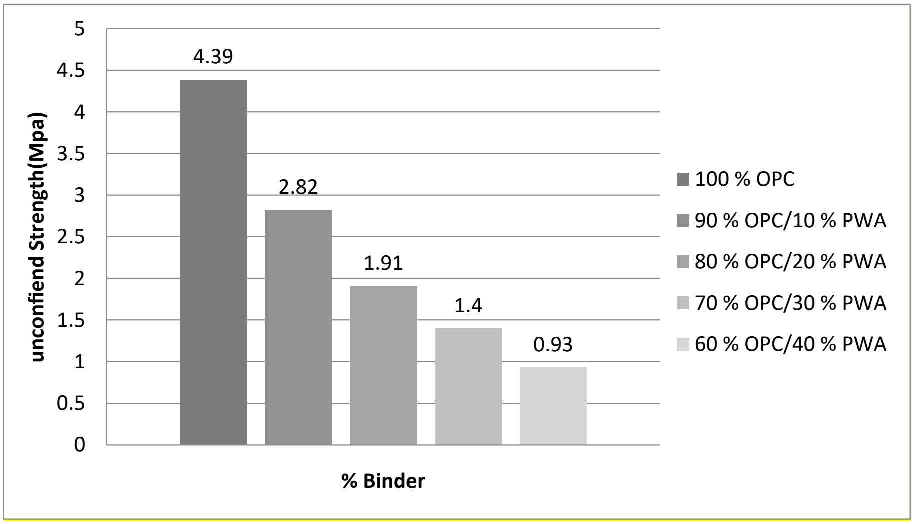

Fig. 10. Unconfined compressive strength after (28) days.

pavements was used to determine the structural number of each layer depends on input parameters directly.

Results shown a significant improve in mechanical characteristics due to adding of hydraulic materials; namely OPC, and PWA. These improvements reflected on pavement layer thicknesses. According to the AASHTO pavement design method and the parameters specified and obtained the structural numbers of proposed pavement are shown in Fig. 11.

5. Discussion

Many researchers have used chemical additives successfully to stabilize soil. This study approved the same with OPC (ordinary Portland cement) and for the first time in Iraq PWA (Paper Waste Ash). However, replace the OPC with PWA partially have shown an acceptable improvement in soil stabilized subgrade. This due to the hydration process of pozzolanic materials (such as active silica and alumina) produced when paper is burned at a high temperature (such as 700 °C) which react with calcium hydroxide to form additional compounds that enhance compressive strength. Additionally, the burned paper ash may react with carbon dioxide in the air, forming calcium carbonate, which improves certain mechanical properties of the mix. The ash also acts as a fine filler, improving the mix's density and reducing its porosity. Which were strengthening the materials structure, consequently, improve the mechanical properties of stabilized subbase.

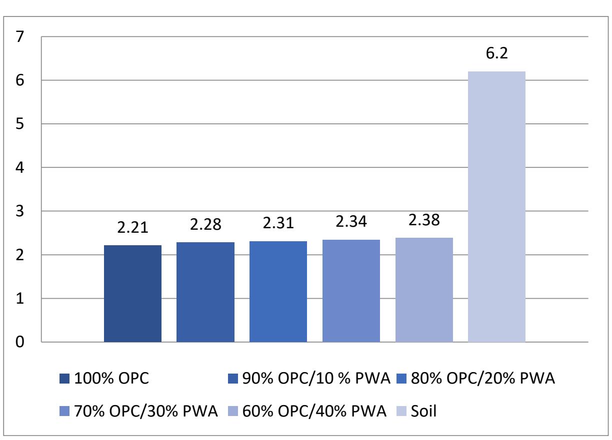

Fig. 11. Ratio between SN and Percentage of additives.

6. Conclusion

According to the conducted study works, the following points can be concluded:

1 Soil stabilization improve soil engineering properties, consequently, improve pavement layer characteristic.
2 Addition of PWA and cement collectively can reduce total cost of a specified traditional main Highway pavement.
3 Waste material i.e. PWA, have been approved as a vital material in enhancing the pavement layer mechanical properties instead of send these materials to landfill, which is proved as sustainable option.

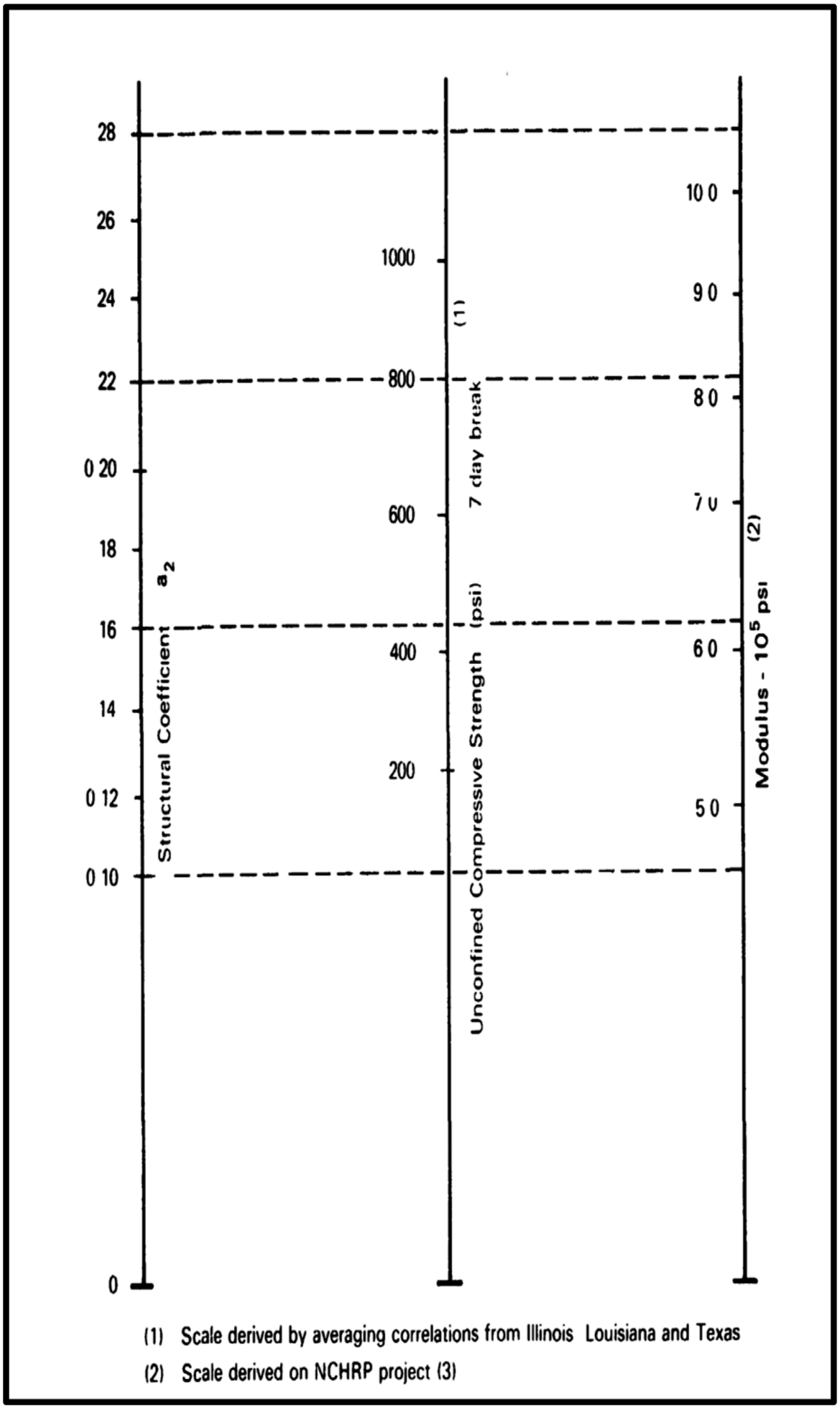

Fig. 12. Variation in a for cement –Treated Bases with Base strength parameter [12].

Data availability statement

All data are presented through tables and figures of this research work. However, tabulated data is available on request.

Conflict of interest

None declared.

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