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UTILIZING CEMENT AND FLY ASH FOR ENHANCEMENT IN SOFT IRAQI SOILS

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ABSTRACT: Problematic soil, especially soft clay, is widespread in the central and southern parts of Iraq, which is described via its low bearing capacity and settlement problems that occur either during or after construction because of low shear strength, high compressibility, and low permeability of this soil. This study aims to investigate the appropriateness of certain local materials to be utilized as stabilizers, like fly ash and cement, which are obtainable in Iraq at a lower cost. This work was carried out on a soil specimen brought from the Gramet Ali location (538 km) south of Baghdad in Al-Basra city. This study consists of three stabilization strategies using cement, fly ash, and their combination, aiming to systematically enhance shear strength and physical properties through rigorous testing protocols (Specific gravity, Consistency limits, Compaction and Unconfined shear strength with curing time (immediately after preparation sample, 7 days & 28 days) that were carried out, it was determined how the soil's dry weight responded to the supplement of various amounts of fly ash and cement (3%, 5%, and 7% for each additive, respectively). Finding out how the soil reacted to adding varying amounts of each additive allowed us to calculate these percentages. The investigation revealed that incorporating fly ash and cement material into the clay soil resulted in a notable enhancement of the clay soil's shear strength and physical properties.

Keywords: Shear strength, Fly ash, Cement, Atterberg limit, Unconfined compression

1. INTRODUCTION

Soft clay soils, which occupy extensive regions across southern and central Iraq, present important geotechnical defies owing to their high compressibility, low shear strength, and vulnerability to water-induced instability. These constraints often lead to excessive settlement and bearing capacity failures in infrastructure projects. The rising demand for cost-effective and sustainable ground improvement solutions has prompted increased utilization of industrial by-products, notably fly ash in conjunction with Portland cement, to address these soil deficiencies [1,2], other researchers have conducted numerous studies to enhance the properties of soil used in foundation projects and utilize waste materials for better results. [1]. The majority have conducted detailed studies on the effectiveness of these stabilizing additives individually [2]. Recent global research highlights the efficacy of cement and fly ash combinations in enhancing geotechnical soil properties for strengthening soil [3, 6–15]. In one of the earliest experiments, field-scale study reported that combined treatments significantly improved Unconfined Compressive Strength (UCS) and reduced permeability compared to untreated clay soils [3]. Another 2022 review underscored the role of Class C fly ash in long-term pozzolanic activity, leading to greater strength gain and moisture control [4]. Indraratna et al. [6] demonstrated that it can be incorporated into concrete in specific ratios that promote the strength of soil. Another experiment demonstrated that 10% of the fly ash used in this experiment with cement would have the same strength as the cement alone after a longer period in the curing process achieved the maximum amount of unconfined pressure that can be applied (UCS) of 628.82 kPa with a 35% dosage of fly ash in 28 days; they noted a decrease in strength if (1%) or (2%) of cement was supplemented to the similar quantity of fly ash (35%). Cristelo et al. [3] combined fly ash that was activated with alkali and cement in a separate application to produce a comparable degree of UCS in soil specimens beyond (28 days) of cure. But alkali-activated fly ash achieved very high strengths compared to cement alternatives in long-term cures. Rai et al [14] researched the clay soil stabilization employing cement and fly ash whereby they attained an effective strength of (127.75 kPa) about (48%) improvement from the virgin soil; this was achieved by using 0.08-part cement and 0.2-part fly ash in the mentioned research carried out in year 2023, coal ash bottom + fly ash combination along with ordinary Portland cement were used for soil stabilization. It has been reported that the addition of (13% coal ash + 2% cement) gives stabilized soil strength of (536 kPa) at (180 days) [7]. The method has also been employed by [11] to consider the potential for soft clay to be enhanced by low-calcium fly ash (weight per unit, shear-force, compaction, and plasticity of the soil are all affected). An X-ray diffractometer was also employed to observe if the mineral composition of soft clay soil would change due to the low-calcium fly ash addition. Ordinary concrete cement was employed for promoting the fly ash. The total percentage of fly ash and cement in the mix was 10% to assess the effectiveness of variation. The test results showed that, in addition to this, the cement could be employed for enhancing the fly ash activation. And, the maximum value of dry volume was only marginally influenced by the process of activation from (1.747 g/cm^3) to (1.738 g/cm^3), with a matching decrease in the optimal content of water from (17.45%) to (15.5%). Also, the cohesion factor of soil was altered from (188 kN/m^2) to (206 kN/m^2), while the inner friction angle increased from around (56.7°) to (59.1°). Additionally, the pozzolanic and hydration reactions of fly ash and cement, correspondingly, improve the clay soil shear strength [15]. The fly ash usage reduces the overburden and lateral pressures since its dry density is lower than that of the other stabilizing agents. This, therefore, makes it very relevant in the structural loads reduction during the construction projects, like backfilling for the retaining walls, embankments of the highway, and pavements. Furthermore, experimental work on fine-grained soils stabilized with 3% cement and 5–25% fly ash demonstrated substantial improvements in California Bearing Ratio (CBR) and shear strength after (28 days) [5].

However, there remains a distinct knowledge gap regarding the synergistic effects of varying fly ash and cement ratios when applied specifically to native Iraqi soils under local climatic and subsoil conditions. Existing studies have largely focused on temperate climates or isolated additive usage, often without comprehensive optimization of dosages [2, 6].

2. RESEARCH SIGNIFICANCE

The study was conducted to see the influence of fly ash (Class C) on the improvement of soft soils. To quicken strength build-up and consolidation, a large amount of ordinary Portland cement was used in this work as a secondary additive. Its quantity has been defined in this paper as the ratio of its weight to the dry weight of natural clay, expressed in percentage terms (3, 5, and 7 %). The tests carried out in this study are: (Specific gravity, Consistency limits, Compaction test, and Unconfined Compression tests through 0, 7, and 28 days.). And, the all tests were performed in three phase, fly ash only in the first phase, adding cement only in the second phase, and adding fly ash-cement in the third phase.

3. MATERIALS

3.1 Used Soil

The soil sample used in this study was brought from the Gramet Ali site (538 km) south of Baghdad in Al-Basra city, as manifested in Fig.1. Table 1 depicts the clay's chemical and physical properties. And, the utilized clay's grain size distribution revealed (2%) sand, (33%) silt, and (65%) clay, as displayed inFig. 1. The Unified Soil Classification System (USCS) classifies the soil as CL.

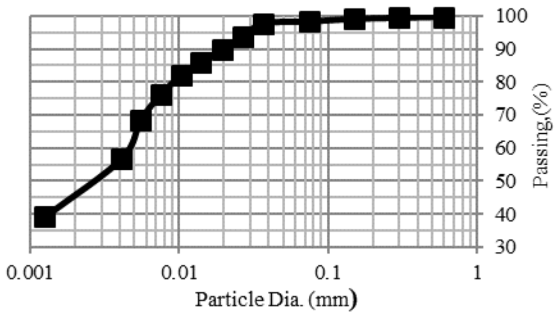

Fig. 1: The distribution of the grain size of used clay

Table 1. The chemical and physical properties of the used clay.

Index Property	Test Standard	Index Value Soil
Liquid Limit, (L.L%)	ASTM D 4318 [16]	48
Plastic Limit, (P.L%)		18
Plasticity Index (P.I %)		29
Shrinkage Limit (S.L%)	ASTEM D 427-04 [17]	20
Specific gravity (Gs)	ASTM D 854 [18]	2.69
Soil Classification (USCS)	ASTEM D 2487 [19]	CL
Max. Dry),Densit (kN/m3)	ASTM D2166 [20]	16.9
Optimum Moisture Content, (O.M.C)		17
Modified Max. Dry Density (MDD), (kN/m3)	ASTM D1557 [21]	17.9
Modified Optimum Moisture Content, (O.M.C)		14.5
Calcium oxide CaO %	Das [4]	21.12
Organic Matter (O.M) (%	[22], [23]	0.01<
SO3 content (%)	BS1377:1990	0.38
Total dissolved salts TDS (%)	Part 9, MD 8264-9 Earth Manual	1.73
Total solved salts TSS (%)		6.89
PH value		8.69

3.2 Fly Ash

This study used fly ash of the Class C variety, produced at the Al-Doura thermal power station by burning coal Fig. 2. Table 2 provides an in-depth description of the chemical characteristics of the fly ash used in the study. Fly ash chemical analysis and properties differ considerably depending on the nature of the coal burned) lignite, anthracite, and bituminous) and the power plant features. Fly ash can be regarded as non-plastic fine silt by the USCS. It creates glassy particles with a spherical shape and is finer than

Portland cement. Also, the particles of fly ash comprise generally (Al_2O_3), (Fe_2O_3), and (SiO_2) [9, 10].

Fig. 2: Used Fly Ash

Table 2. The used fly ash chemical properties

Parameter	Value	Parameter	Value
Type	Class C or High	SO_3	7.81
Loss upon ignition	Lime Fly A Fly ash sh	K_2O	0.91
Fineness > 0.045 mm	2.2	Na_2O	0.57
Free lime (Cao free)	6.3	Na_2O equiv.	1.18
Sulfate (SO_3)	33	Reactive Silicous	28.8
SiO_2 (S)	14.60	Reactive CaO	25.6
Fe_2O_3 (F)	4.3	Pozzolanic Activity (TS EN 450, 1998)	72
S+A+F	51.2		78
CaO	35.14	(%) 7D	78
MgO	1.16	(%) 28D	

3.3 Cement

Cement is the top material in the present construction field. This material is used in nearly all constructions today and has a strength and durability under water that is a supremely higher degree than any other material. The primary components of cement are clay and limestone. It is sulfate-resistant Portland cement (Type V) produced via Al Jessir Factory located in Iraq. Its chemical and physical characteristics are shown in Table 3.

Table 3. The used cement physical and chemical properties

Index property	Index value
Physical properties	
Specific gravity (G.S)	3.15
The compressive strength after (3 days), MPa	17
The compressive strength after (7 days), MPa	26
The initial setting time, min	93
The final setting time, hour	4.28
Chemical properties	
SiO_2 %	19.79
CaO %	63.8
MgO %	3.19
SO_3 %	2.15
C_3A %	3.27
L.O.I %	0.89

4. PREPARATION OF THE SOIL MIXTURE

To sample a sample, after the soil has been brought to the laboratory, it is maintained in an oven at $105C^0$ for approximately 24 hours to remove all of the moisture content. Before being incorporated into the mixes and then ground down by a Los Angeles device, the clayey soil and supplements were first dried. The incorporation of different concentrations of fly ash and cement was (3%, 5%, and 7% for each component, respectively). Each step of the process of manual mixture was considered with caution for producing uniform combinations (3%, 5%, and 7% of the total weight of soil), respectively. The outcomes of these analyses are described as follows:

4.1 Specific gravity

The specific gravity (Gs) of the soil was tested according to ASTM D 854.

4.2 Atterbeg's limits

- Liquid Limit Test: This test was conducted on samples that passed the screen (No. 40) 0.425mm, using Casagrande's equipment, the liquid limit equipment as prescribed in ASTM D 4318, with soil types that contain (0, 3, 5, 7 %) of supplemental ingredients.
- Plastic Limit Test: This test was performed on samples that passed the 0.425 mm (No. 40) screen, using the techniques listed in the ASTM D 4318 standard with clayey soil types, (0, 3, 5, and 7%) of which are additives.

4.3 Compaction

The soil participated in a typical Proctor test that conforms to the ASTM D 1557 protocol. The diameters of object were 102 mm and 116 mm, both of which are documented in reference [12]. Fly ash and cement-fly ash in the studied soils increased the moisture content of the ideal density and decreased the final dry mass. The moisture content of soil that is stabilized often has a flat profile. The common flattening of the compaction curves enables the desired density to be achieved across a larger range of moisture levels. Changes to the shape or attributes of the highest point of the compaction graph can greatly reduce the time, labor, and energy needed [5].

4.4 Unconfined Compression Strength

The investigation entailed examining the unconfined compression strength of specimens with different ratios of fly ash, cement and fly ash + cement. The compaction states were significantly duplicated, and the curing process was conducted at room temperature for periods (Immediately, 7 days and 28 days). The loading conditions and sample dimensions complied with the British Standard BS1377 Part 7. The plastic tubes were used to create the additives column that was manufactured. Tubes were cleaned, labeled, and weighed before the manufacture of the mix. Likewise, a thin layer of grease was applied to the within surface of the pipes. 3%, 5%, and 7% of the clay's weight were added, and it was well mixed by hand while it was drying. The clay (fly ash and cement) mixture was carefully loaded into the tubes in three layers, each 40mm high. To attain the maximum dry density, the mixture was subjected to 15 blows with a hammer weighing 700 grams. After adding wax to both ends of the tube, they were immersed in water for seven and twenty-eight days.

5. PRESENTATION AND DISCUSSION

5.1 Impact of Additives upon the Specific Gravity

Specific gravity of the soils produced, corresponds with the various percentages of (cement, fly ash, and cement + fly ash) in Fig. 3, Fig. 4 and Fig. 5, respectively. From the figures, the specific gravity starts increasing with the addition of cement because the specific gravity of cement (3.15) is much higher than that of the soil (2.69). In other words, the specific gravity decreases with the fly ash addition because the solid fly ash reduces in mix with soil: fly ash fills up voids between soil particles but adds weight to a packed state; hence, this packed state indicates that there should be less weight when not in an arranged manner. In the other case, for soft soil, a composite is added, cement + fly ash, the specific gravity increases in small amounts because the weight of solids increases in the form of the soil additives mix. This increase occurs due to the molecular rearrangement of the matrix of soil because of the higher composite density than that of the soft clay. Similar results were obtained by Shareef [24].

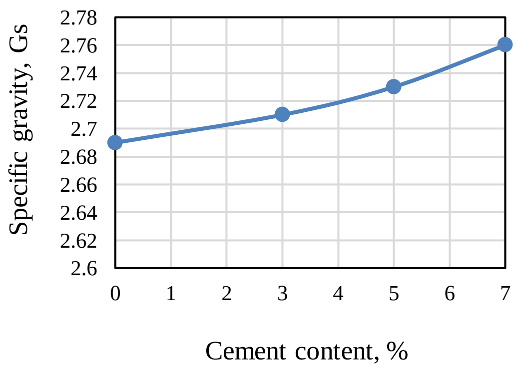

Fig. 3: Specific gravity versus cement content, %

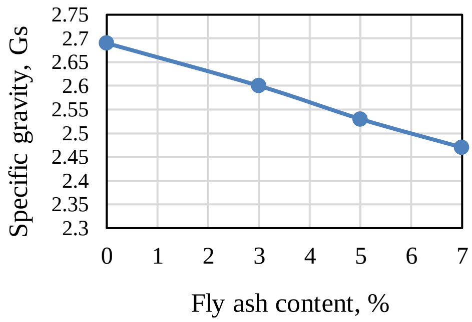

Fig. 4: Specific gravity versus fly ash content, %

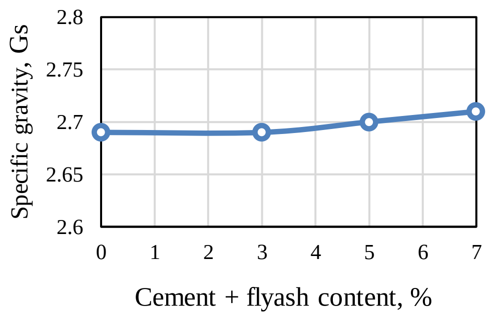

Fig. 5: Specific gravity versus cement + fly ash content, %

5.2 Impact of Additives upon the Consistency Limits

Figure 6, Fig. 7, and Fig. 8 manifest the consistency limits for both natural and treated soils at varying concentrations of cement, fly ash, and cement + fly ash, respectively. These figures also indicate the additives impact upon the plasticity index. For cement-treated soil, it is seen that the liquid limit reduced and plastic limit increased with the addition of cement; however, plasticity index was found to decrease with an increase in the amount of cement. 7% cement caused a reduction in the liquid limit from 48 to 43.8; the plastic limit rose from 19 to 24.4. Thus, the plasticity index fell from 29% to 19%. For example, the addition of fly ash at most up to 7% of total volume causes the liquid limit to fall from 48% to 42%, and the plastic limit falls from 19% to 14%. The plasticity ratio also decreased by about 29% to about 27.5%. A combination of cement + fly ash in maximum concentration of 7% caused the liquid limit of all from (48) to (45) plastic limit falling from (19) to (28), resulting in a plasticity index decrease of 17. The plasticity index decrease is ascribed to the soil nature conversion from a granular to a crumbly state, attributed to its composition, sandy clay soil. Many scientists have attributed the decrease in the liquid limit of treated soils to their type, Jawad et al., 2014 [8]. Also, the soil's decreased liquid limit is associated with the estrangement evolution between clay and water; this is brought about by compound hydration. However, in all these settlements, the ultimate effects are a decrease in the degree of plasticity, whereby the soil is transformed into a more practical substance, and also moisture effect on it is decreased. The major factor for the increase in plastic content of the soil-composite mixtures is the water absorbed by cement and fly ash; therefore, it becomes necessary to add more water to the soil until it can be molded into a ball of (3 mm) diameter by hand kneading, up to the point just before cracking begins—that is considered an indication when P.L. is reached. Conversion of soil structure flocculates and coagulates soil particles, leading firstly to large aggregates or grains formed subsequently, followed by an increase in plastic limit value.

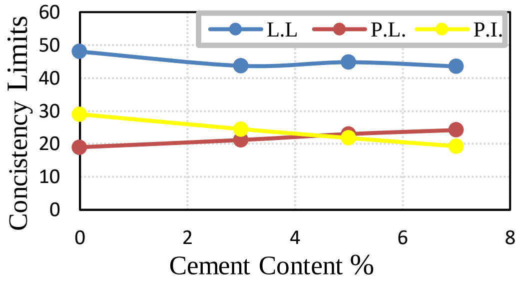

Fig. 6: Consistency limits versus cement content, %

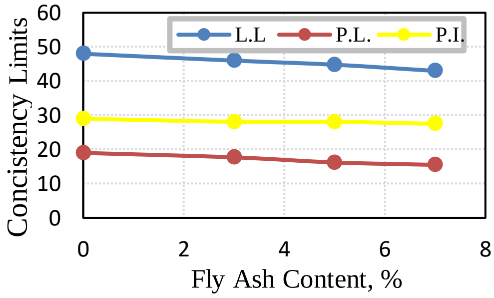

Fig. 7: Consistency limits versus fly ash content, %

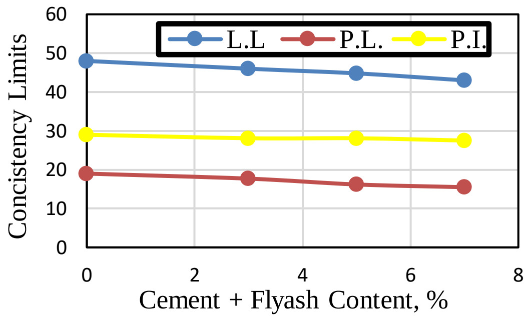

Fig. 8: Consistency limits versus cement + fly Ash content, %

5.3 Impact of Additives upon the Compaction Test

In this series, 10 tests were conducted to assess the effects of untreated soil and soil that was treated with different percentages of (cement, fly ash, cement + fly ash) on the capacity to compact. Different amounts of these substances were incorporated into the soil to recognize their effects on the property of compacting. Figure 9 illustrates the association between water content and dry unit weight (ɣd) of different amounts of cement. The inclusion of cement enhances both the cohesiveness and density of the soil. Cement has a positive effect on the soil structure by strengthening the arrangement of particles, hence improving the mechanical characteristics. The rise in density signifies enhanced mechanical robustness of the soil, rendering it stiffer and more resilient. Figure 10 depicts the variation of water content versus dry unit weight (ɣd) for different proportions of fly ash. The fly ash trials demonstrate a marginal reduction in the necessary moisture content (w.c %) and dry density (Ɣ dry). This implies that the ash enhances soil compaction and minimizes the required moisture content for achieving this compaction. Adding 3% ash and 5% ash leads to a greater reduction in required moisture, accompanied by an additional increase in dry density. This indicates a notable enhancement in soil density and decreased moisture needed. In addition, the inclusion of 7% ash demonstrates a consistent reduction in the necessary moisture content as the dry density increases. This suggests that higher ash levels contribute to increased density and decreased moisture requirements. Figure 11 elucidates the relation between the content of water and the dry unit weight (ɣd) for different proportions of fly ash mixed with cement. Incorporating fly ash and cement into clayey soil enhanced its density and mechanical characteristics, resulting in heightened overall strength and reduced moisture content requirements. The chemical reactions interaction and the cement influence upon the soil structure contribute to the improvement of cohesion.

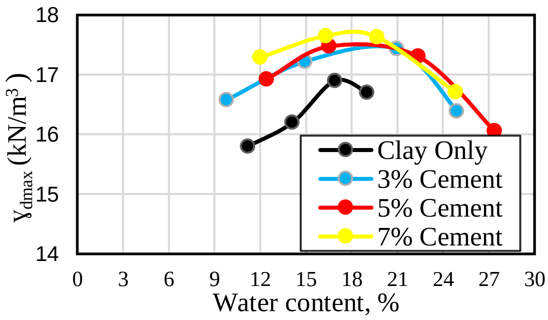

Fig. 9: Dry unit weight - moisture content for different cement contents, %

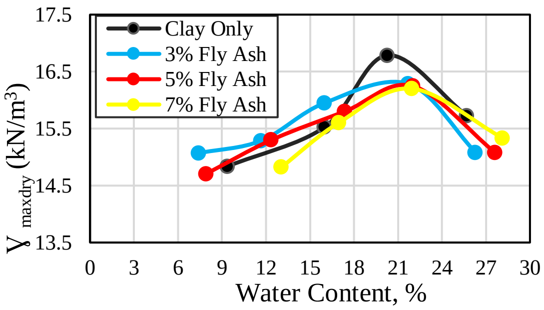

Fig. 10: Dry unit weight - moisture content for different fly ash contents, %

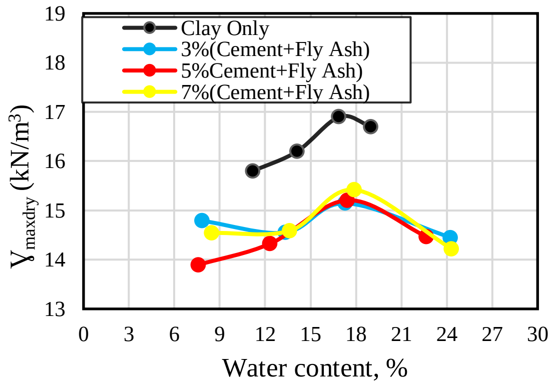

Fig. 11: Dry unit weight - moisture content for different mixtures of cement + fly ash content, %

5.4 Impact of Additives upon the Unconfined Compression Test

UCS tests were carried out upon various soil specimens with (3%, 5%, and 7%) of cement, fly ash, and cement incorporated with fly ash content, and examined at different periods (immediately, 7 days and 28 days), as revealed in the Figs. (12-21). Figures (14-16) evince that the unconfined compressive strength of soil rises with the cement content rise. There's an increasing strength development about the period owing to the cement's hydration and pozzolanic reaction between the chemical stabilizer and the soil particles of soil in addition to the intricate reactions producing the particle cementation of soil. The sudden increase in strength is attributed to the flocculation-agglomeration reaction, leading to improved workability. Meanwhile, the sustained strength enhancement is attributed to the pozzolanic responses, as previously noted [25]. It is noticed that UCS increased from 36 kPa to 123 kPa with 7% cement content at 0.5 hour after preparation sample increased to 798 kPa after 7 days and to 1016 kPa after 28 days of curing. Figures (17 - 19) portray that increasing fly ash's content raises the unconfined compressive strength. From testing the specimens at curing period 0.5 hour of preparation directly, 7days and 28 days, it can be observed that UCS at 7% fly ash content increases from 36 kPa to 60.6 kPa, to 68 kPa and 102 kPa respectively. Figures (22 - 23) illustrate the increment of with the increase of cement as well as fly ash content owing to the pozzolanic reactivity that occurred between the minerals of soil and the fly ash's calcium aluminates that leads to creating the cementations properties, which don't dissolve into water and work as buffer and binder. This outcome is in agreement with the obtained outcome via [26].

It can be seen that UCS increases from 36 kPa to 116 kPa after 0.5 hour of preparation samples directly, to 246 kPa after curing for 7 days and to 492 kPa after curing for 28 days.

Figures (23 - 25) reveal the relationship between the undrained shear strength cu and different additives content The strength increases with the content increment of cement due to the cement hydration, which works as a connection among the particles of soil for increasing the resistance, but the persistence of additives in the soil is over the periods (0.5 hour, 7, and 28 days).

It was noted that the unconfined compressive strength rises significantly with the cement and fly ash additive remaining in the soil, and this percentage increases with the increase in the retention period.

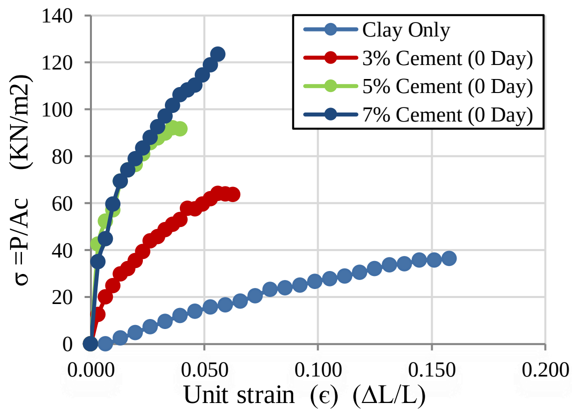

Fig. 12: The stress-strain relationship for stabilizing the soil with different percentages of cement immediately

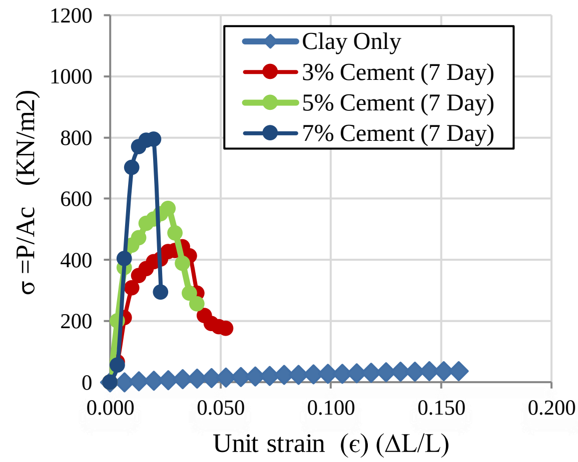

Fig. 13: The stress-strain relationship for stabilizing the soil with different percentages of cement after 7 days

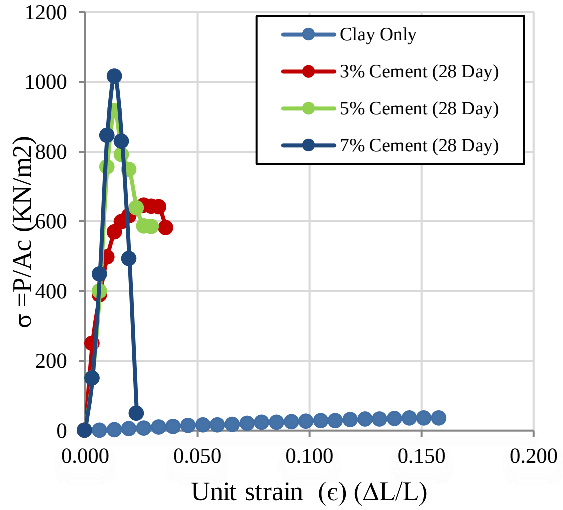

Fig. 14: The stress-strain relationship for stabilizing the soil with different percentages of cement after 28 days

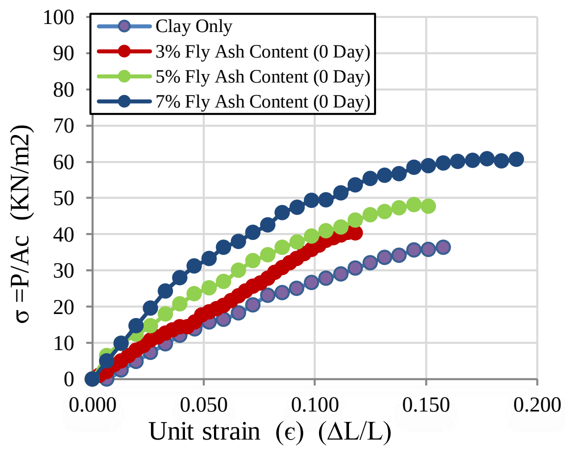

Fig. 15: The stress-strain relationship for stabilizing the soil with different percentages of fly ash immediately

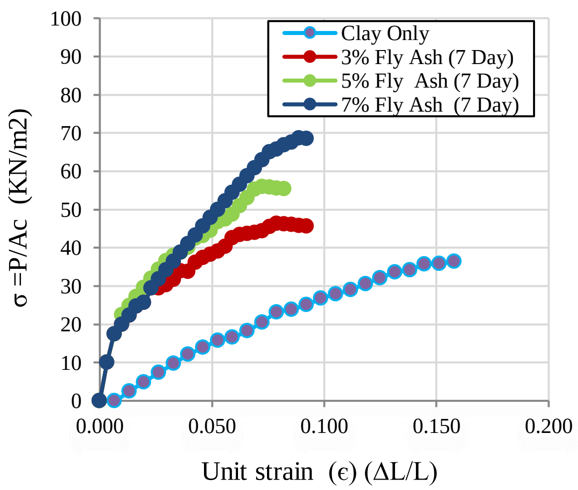

Fig. 16: The stress-strain relationship for stabilizing the soil with different percentages of fly ash after 7 days

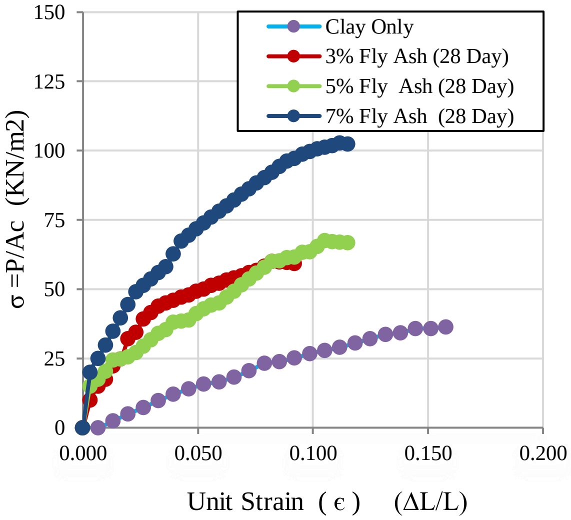

Fig. 17: The stress-strain relationship for stabilizing the soil with different percentages of fly ash after 28 days

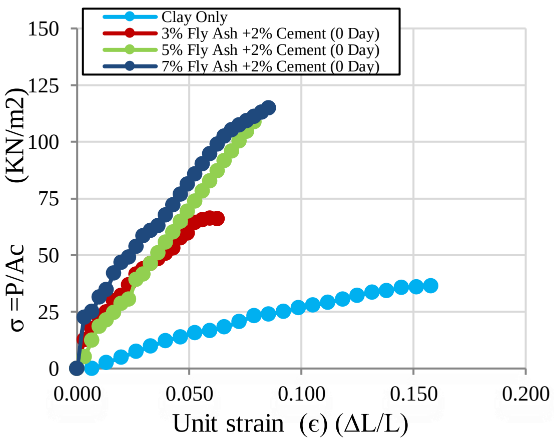

Fig. 18: The stress-strain relationship for stabilizing the soil with different percentages of cement and fly ash immediately

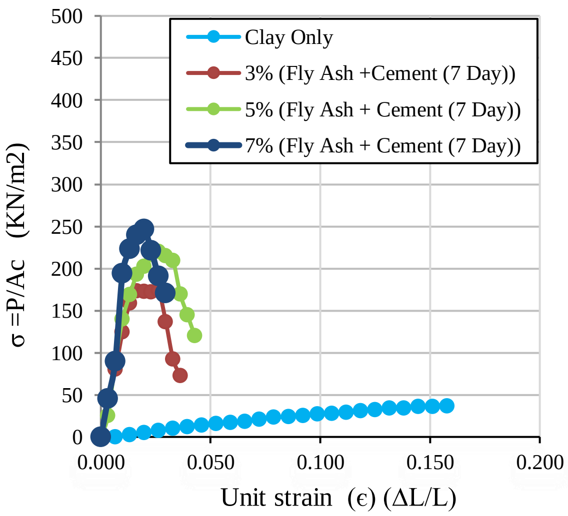

Fig. 19: The stress-strain relationship for stabilizing the soil with different percentages of cement % fly ash after 7 days

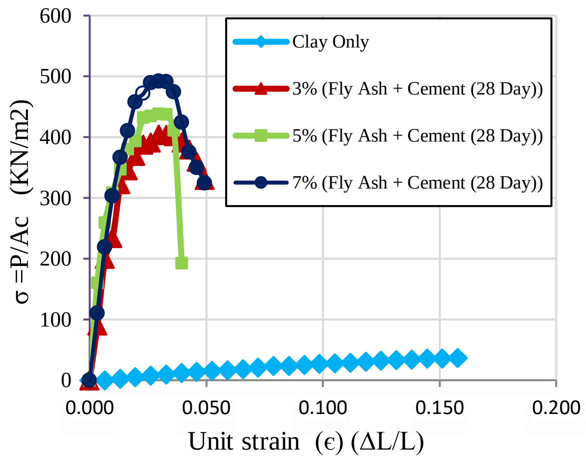

Fig. 20: The stress-strain relationship for stabilizing the soil with different percentages of cement and fly ash after 28 days

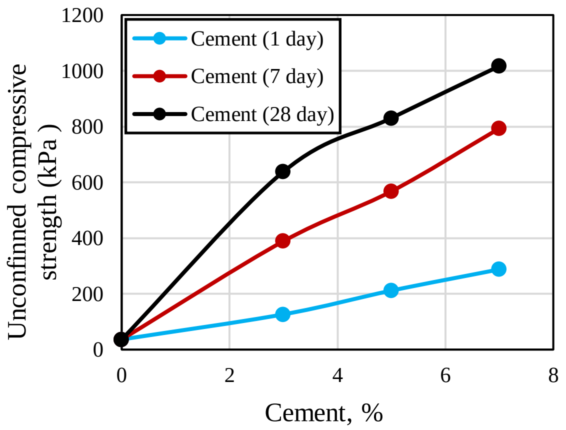

Fig. 21: The relation between the unconfined compressive strength with different percentages at the other times

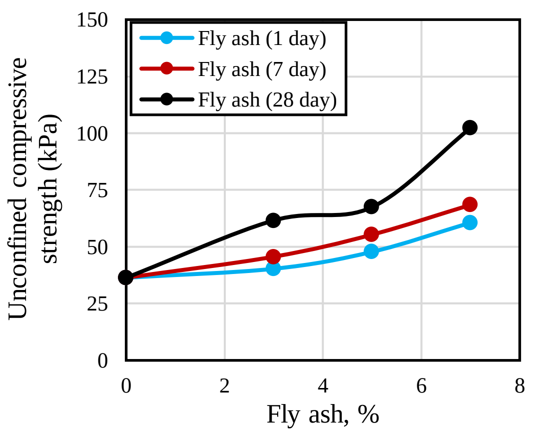

Fig. 22: The relation between the unconfined compressive strength with different fly ash percentages at the other times

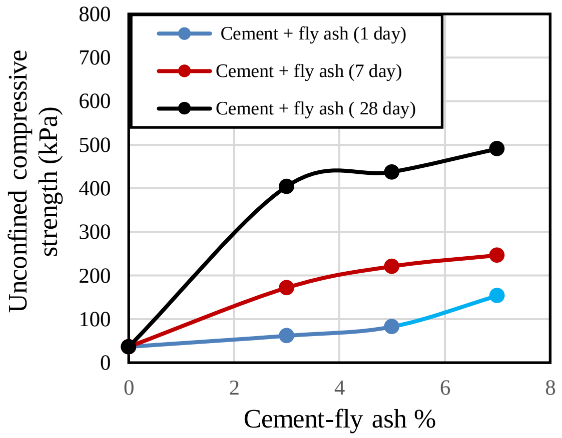

Fig.23 Relation between the unconfined compressive strength with different cement % at other times

6. CONCLUSIONS

The study of the effects of using volatile ash and cement was compared once with each material separately and again with each other for specific proportions. This work investigated the effects of utilizing fly ash to enhance soil characteristics. An increase in the concentration of cement-fly ash from 0 to 7 percent resulted in a notable enhancement of around 24% in the soil's unconfined compressive strength. This is consistent with earlier research showing that adding fly ash improves soil qualities, specifically compressive strength. Furthermore, the study demonstrates that the maximum dry density of the soil increases when additives are added at either 5% or 7%. This indicates the beneficial impact of fly ash on the physical characteristics of the soil. Overall, fly ash can be utilized to improve soil properties, and the study above indicates that this effect is favorable and can bolster the mechanical attributes of the soil. It should be emphasized that the most effective fly ash and cement dosage can differ based on the particular soil conditions, project specifications, and engineering design. Performing laboratory experiments and conducting field trials is essential to ascertain the optimal ratios for attaining the desired soil enhancement and meeting the project's criteria.

7. REFRENCES

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