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PARTIAL REPLACEMENT EFFECT OF FIREWOOD ASH (FWA) ON THE GEOTECHNICAL PROPERTIES OF CLAY STABILIZED WITH CEMENT

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Abstract

With the intention of providing a balance between the disposal of wastes generated from incineration processes and mitigate the emissions from industrial activities, the reuse of incineration waste as alternatives to conventional binders would offer a sustainable solution to reduce their environmental impact. This study aims to experimentally investigate the effect of firewood, ash (FWA) and ordinary Portland cement on some of the geotechnical properties of low plastic clayey soil (CL). The experimental program was introduced by partial replacement of ordinary Portland cement with firewood ash (FWA) up to 10 % with an increment of 2 %. A series of unconfined compressive test (UCT) and Atterberg limits test were performed. The results indicate that plasticity characteristics are affected by the addition of both cement and (FWA). Also, the results showed that the unconfined compressive strength increases for all replacement levels in comparison with the plain clay sample. The term deformability index (DI) also discussed with respect to different replacement level. The 70.61 % pozzolanic activity index indicates that (FWA) is a good pozzolan in accordance with ASTM C 618 specification. Finally, three modes of failure were detected which varying in accordance with the proportion of replacement.

Keywords:

Clay stabilization;
Portland cement;
Pozzolan;
Unconfined compressive strength;
Atterberg limits.

1 Introduction

Clayey soils in their natural existence are problematic and weak if they adopted for subgrades of high way construction or any foundation subjected to heavy loads that exceed its bearing capacity. Stabilization techniques are one of the effective approaches which toughen the cohesive soils and increase their potential to carry extra loads. Several additives were used as stabilizing agents, those stabilizer additives consist of various cementitious binders [1 - 3]. Portland cement has been utilized as stabilizing agent to improve the physical and mechanical characteristics of soils such as, enhancing volume stability, providing extra cohesion and improving wet soil strength. In the mid of 1960 precisely in Sweden and Japan, Portland cement blended with marine soft clay to achieve higher strength characteristics [4].Till now, Portland cement is considered as the most widely used as a stabilizing agent in the manner of soil stabilization. It is worthy to be noted that the stabilizer percentage depends upon the type of soil and require level of strengthening. Based on past studies [5 - 7], the increment of cement content in the soil stabilization has a significant effect on the unconfined compression test (UCT) of soil-cement composite. In general, with cement increment, unreinforced soils exhibits a brittle behavior under axial loads, unlike fiber reinforced cemented soils which exhibit a ductile behavior at failure due to fiber inclusion [8]. Also, at high w/c ratio the cemented soils can exhibit a ductile behavior. Pakbaz and Alipour [9] stated that at the same cement content of 10 %, the soil behaves more brittle at 30 % water content, while with 70 % of water content, the ductile behavior of soil specimen´s under axial loads is clearly observed.

The effect of Portland cement addition on values of the unconfined compressive strength was investigated by Suksun Horpibulsuk & Runglawan Rachan [7]. They observed three zones of strength development, first zone with cement content less than 11 % which denoted as the (active zone) which

shows a significant increase in the values of (UCT). The second zone which denoted as (inert zone) with cement content between 11 - 30 % shows the same development in strength with cement increment. The third zone with cement content higher than 30 % which denoted as (deterioration zone) shows a decreasing trend of (UCT) as cement increases. The reduction on strength is attributed to insufficient amount of water which ensue complete hydration for cement particles.

The addition of binders such as cement and lime has a significant influence on the plasticity characteristics of clayey soils. Based on previous studies conducted on clayey soils treated with different ratios of cement, it was found that the liquid limit slightly decreases with increasing the cement content [1 - 3], [10, 11] except one researcher which highlighted that the liquid limit increased with increasing the cement ratio [9]. Unlike lime addition which showed a significant decrease in liquid limit and less decrease with the combination of supplementary materials such as coal waste and coal waste ash [12].

By increasing the concern about the environmental impact caused by production of the cementitious materials, there was an urgent need to mitigate the consumption of these materials in the construction process. In fact, cement manufacturing is not only an energy consuming process, but its increases the environmental pollution by CO_2 emissions. The production of 600 kg of cement releases 400 kg of carbon oxide [13]. Every ton of ordinary Portland cement generates one ton of CO_2 during its production. Moreover, its production is charged with 7 % of CO_2 existing in the atmosphere [8, 14]. Indeed, these tons of carbon dioxide obstacles the sustainability progress and threatens the future generations.

In the recent years, the boom of the concept of partial replacement of Portland cement by waste materials assured an access to an effective sustainable strategy. Moreover, the incorporating of pozzolans with ordinary Portland cement provides financial and environmental benefits by reducing the consumption of Portland cement and re-using of huge amount of waste materials. Furthermore, involving supplementary waste materials in the matrix of concrete or soils could enhance their mechanical properties. Therefore, many by-products and waste materials were used in from of powders or pozzolans to be partially replaced by Portland cement [15,16] In accordance with ASTM C 618 specification, finely divided materials exhibits cementitious or pozzolanic action if silicon dioxide plus iron oxide plus aluminum oxide exceeds 70 % of total chemical composition. Four major mechanisms were noticed during the stabilization process, these are cation exchange, flocculation and agglomeration, cementitious hydration and pozzolanic reaction. In fact, pozzolanic reaction takes months or years to be achieved, and high pH environment during the stabilization process is an important factor to maintain strength and durability of the system [15].

In the context of replacing conventional stabilizers such as cement and lime with alternatives by-product materials, ashes gained great attention by many researchers. Rich husk ash, saw dust ash, sugarcane bagasse ash and Kosovo fly ash were partially replaced by cement and the researchers highlighted that up to a certain level, these ashes shows significant pozzolanic bond [14, 17, 18].

Among ashes derived from renewable source, sawdust ash (SDA) has been used as a supplementary cementing material in concrete. A. A. Raheem [17] examined the use of saw dust ash as partial replacement for ordinary Portland cement in concrete, the result showed that for all replacement levels, the compressive strength decreases while with curing time, the results shows a slight increment in strength with curing time. U. Elinwa & P. Ejeh [19] investigated the effect of sawdust waste incineration fly ash (SWIFA) on the strength properties of cement mortar, the results showed a systematic reduction in strength with respect to additive increment. The effect of SDA on the compressive strength of self-compacted concrete has been also investigated by U. Elinwa & P. Ejeh [20], the results showed that the maximum performance has been observed with the addition of SDA up 10 %. Further addition of SDA showed a systematic reduction in the compressive strength.

In general, little attention was given by researches to utilize ashes derived from bio-mass fuels such as firewood ash in geotechnical applications. Firewood ash (FWA) is the leftover of wood combustion utilized as energy producer for domestic and industrial purposes. Based on statistical data achieved by United Nations Development Programme (UNDP) showed that domestic activities are responsible for 30 - 90 % of total energy consumption while only 25 - 30 % of energy consumed by industrial needs [21]. Furthermore, over 50 % of global cooking energy obtained from fuel wood and 90 % of north-eastern Himalayan's population consuming firewood as a major source of energy [22]. Also, the small scale boilers units and thermal power generator plant are one of the common methods using the wood wastes as chief sources of energy [13]. Accordingly, an abundant waste generated from waste wood consumption is a reality that cannot be ignored. One way to mitigate the impact of

these wastes on the environment is to reuse them in the construction activities such as soil stabilization. The main objective of this study was to experimentally investigate the firewood ash (FWA) to be partially replaced by cement stabilized clayey soil and explore the effect of their integration on the strength and plastic characteristics of low plastic clayey.

2 Materials and mix design

The materials used in this research to prepare the modified soil specimens were low plastic clay (CL), ordinary Portland cement and firewood ash (FWA). The technical properties of these materials are presented in the following subsections.

2.1 Material properties

2.1.1 Clayey soil (CL)

In this study, clayey soil was collected from a borrow site 12.5 m below the ground surface level in Amara city in the south of Iraq. For the row soil sample, the Atterberg limits test was conducted using ASTM D4318 test and the results showed that the liquid limit was 43 % and the plastic limit was 22 % .Based on the analysis of particle Size distribution in accordance with unified soil classification system (USCS), soil can be classified as low plastic clay (CL). Fig. 2 shows the curve of size distribution analysis which shows that 82.86 % passed 75 μm sieve. Moreover, the natural water content W_n of the soil was 30.3 % and the specific gravity was 2.74.

2.1.2 Firewood ash (FWA)

Throughout this study, Firewood ash (FWA) with pozzolanic activity index of 70.61 % was collected from different places were fuel wood using as energy producer. This type of waste contains both coarse and fine particles [13] as seen in the Fig. 1a. In order to get homogenous powder, the collected material sieved by #75 μm standard as seen in the Fig. 1b. The particles passing 75 μm sieve were used as a supplementary material to be partially replaced by cement. Fig. 2 shows the size distribution curve which shows clearly that the (FWA) is finer than 0.075 mm. The chemical composition shown in Table.1 showed that the (FWA) is mainly composed of silica, iron and alumina with small percentage of magnesium, and calcium. The chemical composition of (FWA) directly depends on the incineration temperature of wood and the origin of wood. Moreover, the low amount of CaO indicates that the incineration temperature of firewood was below 500 ^{o}C [13]. Since the pozzolanic activity index is exceeds the minimum range of ASTM C 618 specification, so that it can be considered as good pozzolan.

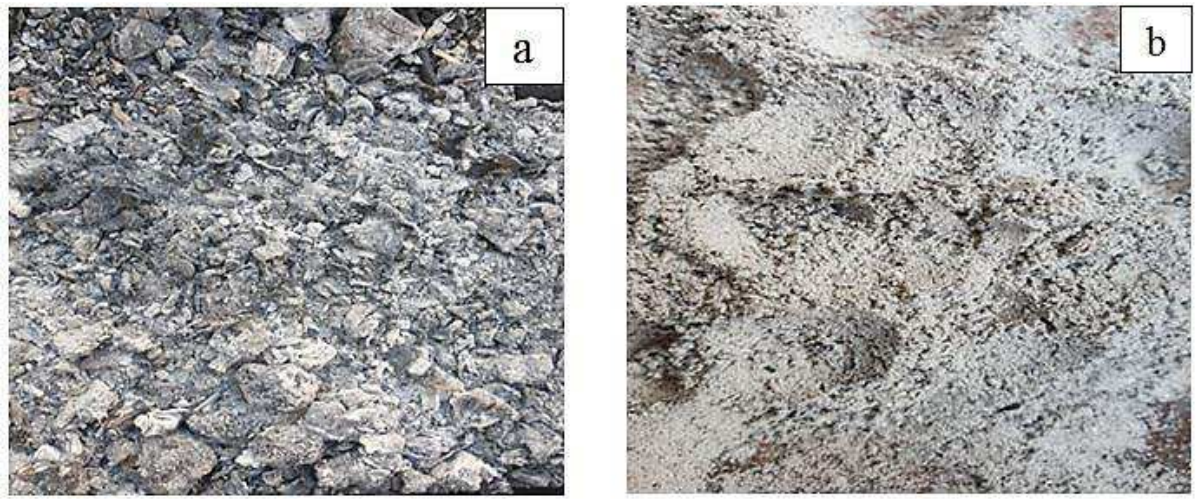


Fig. 1: a - Pictorial view of fire wood waste; b - Pulverized fire wood waste passing 75 sieve.

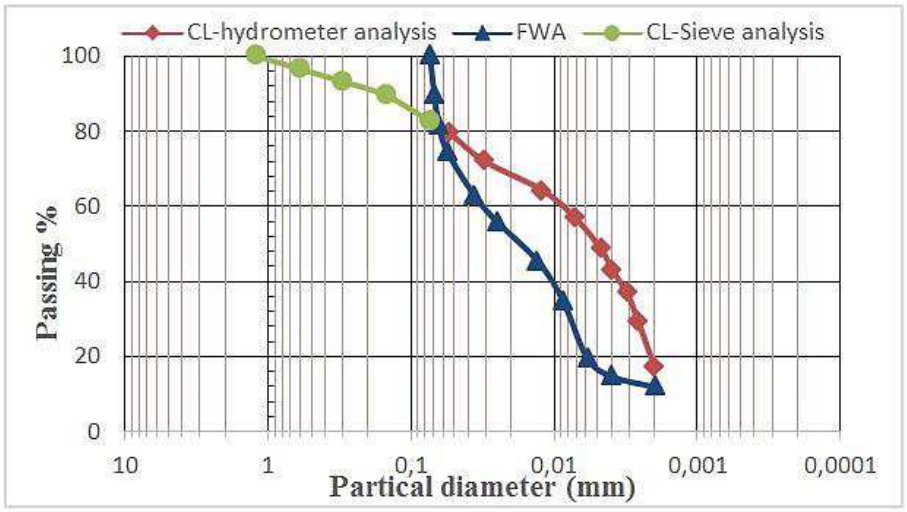


Fig. 2: Size distribution of (FWA) and (CL) soil in accordance with (ASTM D422).

2.1.3 Ordinary Portland cement

Portland cement used in this study as conventional stabilizer. Table 1 shows its chemical composition which mainly composes of silica and calcium with small amounts of alumina and iron.

Table 1: Chemical constitution of firewood ash and ordinary Portland cement.

Oxides	FWA	Cement
SiO_2	59.35	33.21
CaO	0.61	31.07
Al_2O_3	7.48	2.89
MgO	0.856	5.18
Fe_2O_3	3.78	5.18
SO_3	-	1.05

2.2 Mix design

The adopted mix design used to prepare modified soil samples are introduced in Table 2. Eight mixtures were designed to study the feasibility of partial replacement of cement by (FWA). It is important to be noted that the requirement of cement in the stabilization process depends on the gradation of soil. Accordingly, for well graded soils, 5 % or less of cement by weight is considered as sufficient for stabilization and for low plastic to moderate plastic soils, up to 10 % is required [22]. In the current study, the binder content was taken up to 10 % of the weight of dry mass of the clayey soil. The replacement levels of cement with Firewood ash (FWA) were considered as 0 %, 2 %, 4 %, 5 %, 6 %, 8 % and 10 %. The water added to the samples was quantified according to the formula given below:

$$W_t = W/B\% + W_{opt}\%, \quad (1)$$

where W_t is the total weight of water added to the sample, W/B% is the water to binder ratio which taken as 0.5 and W_{opt}% is the optimum water content obtained from the compaction test which equal to 18.1 % by weight of dry soil. The mix designations with their proportions are shown in Table 2. Mixes were described by three capital alphabets, and each alphabet was subsequent by a numeric value in subordinate. The numeric value in subordinate specifies the percentage of clay, cement, and firewood ash. For example, description $S_{90}C_4FWA_6$ refer to a mixture containing 90 % of clay, 4 % of cement and 6 % of firewood ash. And S, C, and FWA represented the clay, cement, and firewood ash.

Table 2: Mix designations and their proportions.

Mixtures description	Clayey soil	Binders (%)		Total
		Cement	FWA	
$S_{100}C_0FWA_0$	100	0	0	100
$S_{90}C_2FWA_8$	90	2	8	100
$S_{90}C_4FWA_6$	90	4	6	100
$S_{90}C_6FWA_4$	90	6	4	100
$S_{90}C_5FWA_5$	90	5	5	100
$S_{90}C_8FWA_2$	90	8	2	100
$S_{90}C_{10}FWA_0$	90	10	0	100
$S_{90}C_0FWA_{10}$	90	0	10	100

3 Laboratory experiments and casting procedure

To examine some of Geotechnical properties of S-C-FWA composite, unconfined compression test and Atterberg limits with respect to different mixes were achieved.

3.1. Atterberg limits

A group of tests were accomplished to investigate the effect of cement and its combination with firewood Ash (FWA) on the plastic properties of low plastic clayey soil. The adopted procedure of sample preparation was similar to that recommended by by Mesri and Cepeda Diaz [24] and adopted by Tugba Eskisar [11]. Accordingly, soil sample pulverized throw out 75 μm sieve then mixed with binder for one hour to be prepared for testing.

3.2. Strength test

For cemented soils, the triaxle shear test is not suitable due to confining stresses (σ_3) which can weaken the bond between soil-cement particles [8]. Therefore, it is more reliable to adopting the unconfined compressive test (UCT) to discover the strength characteristics of soil-cement matrix. For samples perpetration, similar procedure accomplished by Pongsivasathit & Horpibulsuk [2] was adopted. For this purpose, cylindrical specimens of 10 cm height x 5 cm diameter were compacted manually in three layers under the energy of Proctor test by using a small 2 kg rammer and every layer surface was scarified to ensure better interlocking between them and prevent horizontal cracks, the specimens were kept inside the molds for 24 hours, then stored in a closed nylon bags with zero-water curing condition. The samples were tested in accordance with ASTM D-1633 after 28 days of certain curing conditions.

4 Results and discussion

4.1 Atterberg limits

The results obtained from the Atterberg limits tests are shown in Figs. 3 and 4. As shown in Fig. 3, a systematic reduction in liquid limits with respect to designed mixtures. However, the addition of FWA only shows higher values of reduction in liquid limits. Unlike other mixes contains cement/FWA combination, which showed less reduction in liquid limit values. The results of plastic limit, showed a slight reduction with respect to different replacement level. Finally, the values of the plasticity index which considered as an indicator to soil workability, the results showed a slight increase in soil plastic properties up to 40 % replacement of FWA by cement, while more than 60 % replacement of FWA by cement shows a better soil workability due to the reduction in the values of plasticity index. Generally, those results were found to be satisfied with the results obtained by Eskisar & Modarres [11, 12]. In fact, the rate of ion exchanges reaction modifies the plastic behavior of treated soil. The reaction leads to replacement of the single valence ions by divalent ions of calcium, which reduces the water absorption of the soil particles [25].

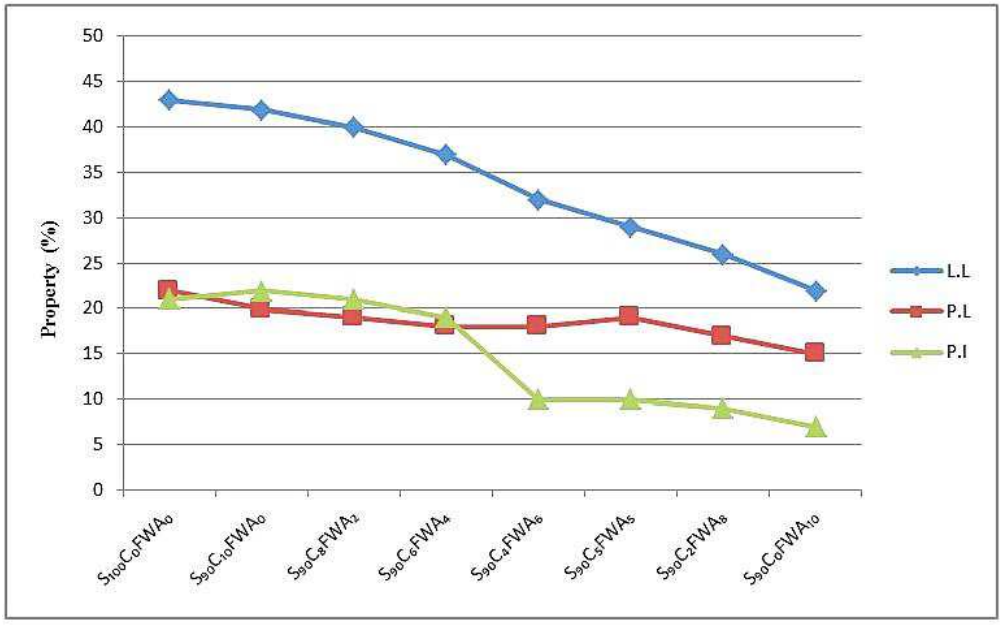


Fig. 3: Atterberg limits trends with respect to supplementary additives.

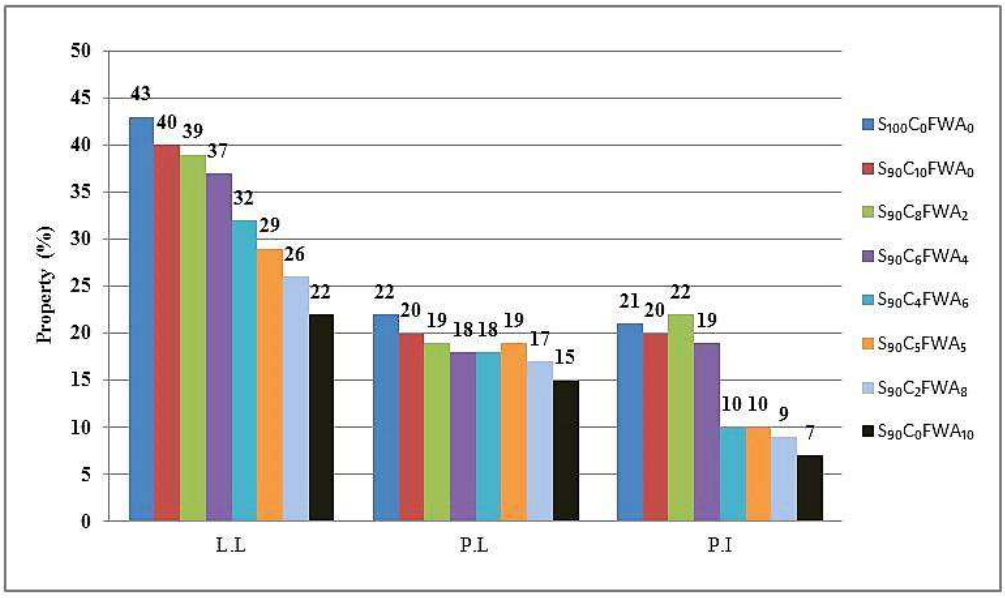


Fig. 4: The values of Atterberg limits tests with respect to the adopted mix design.

4.2 Strength and deformation properties

Fig. 5 illustrates the stress-strain behaviour of cemented soil specimens prepared with different levels of replacement of cement by firewood ash, specifically, 0, 2, 4, 5, 6, 8, and 10 %. Fig. 5 showed that with 10 % of cement addition to the clay, the axial stress increases outstandingly from 232.6 kPa to 1312.9 kPa. The calcium silicate hydrate (C-S-H) generated by the chemical reaction between cement and soil particles is responsible for the improvement of soil strength. It can be deduced from Fig. 5 that the axial stress of clay specimen increases from 232.6 kPa to 339.9 kPa with addition of 10 % FWA. This strength development could be attributed to the physical effect of ultra-fine particles of FWA, which fill the voids between soil particles and enhance the soils microstructure [26]. For soil mixes contain both cement and firewood, ash, a systematic reduction in strength is detected in comparison with clay samples treated with 10 % of cement. The explanation for this reduction can be given after understanding the pozzolanic reaction of FWA. As seen the Fig. 6 the reaction of FWA started after 28 days of cement hydration. The hydration of cement releases $Ca(OH)_2$. FWA consumes the $Ca(OH)_2$ to form C-S-H gel. Accordingly, a sufficient time is required to complete the pozzolanic reaction [19, 26, 27]. The strain of clay at failure stress is 4.66 %, which decreases to 2.12 % with the

addition of 10 % cement. The addition of cement only increases the rate of post-peak strength loss, which reduces the soil ductility. Although, the specimen $S_{90}C_0FWA_{10}$ shows less strength improvement compared with specimen $S_{90}C_{10}FWA_0$, its axial strain at failure stress is 2.69 %, which reveal less brittle attitude compared with $S_{90}C_{10}FWA_0$. The rate of post-peak strength loss slightly decreases with the combination of FWA with cement. This decrease shows an indicator to a slight ductility improvement. In general, the unconfined compressive strength of clay-firewood and clay-cement-firewood ash mixtures increases significantly in comparison with untreated clay.

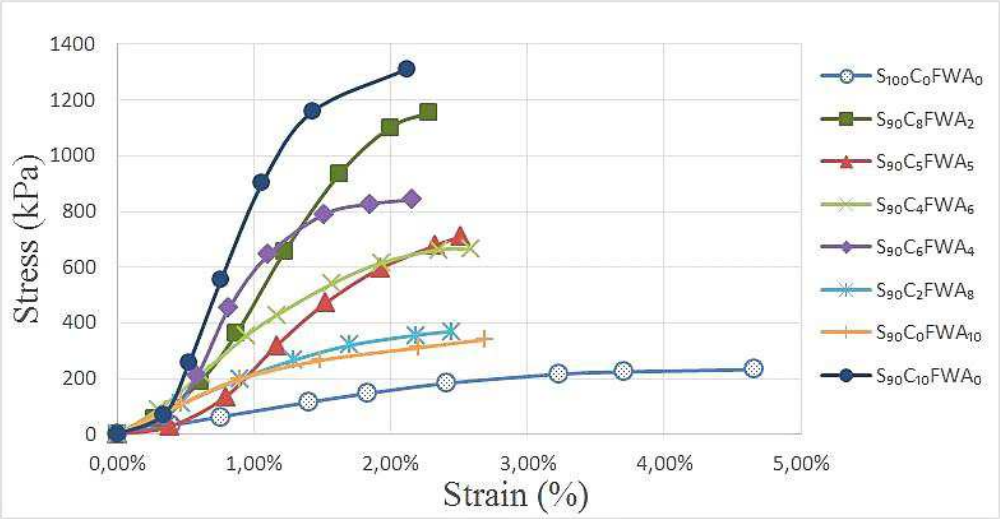


Fig. 5: Stress-strain behaviour of modified soil mixtures.

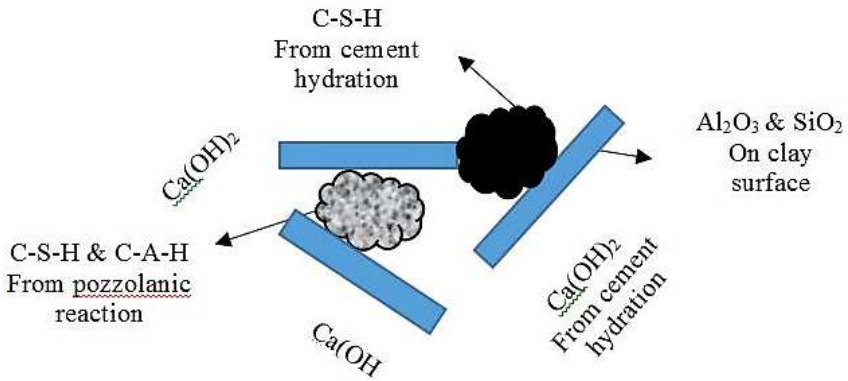


Fig. 6: Pozzolanic reaction and cement hydration [27].

In fact, there is a difficulty in defining the residual state for brittle cement-treated soils subjected to axial load. In this case, the deformability index is a useful parameter to describe the deformation behaviour of modified clay samples [28]. In this study, the term deformability index DI is presented as follows:

$$DI = \frac{\Delta t}{\Delta p}. \quad (2)$$

In Eq. (2), Δt is the is the axial strain at peak strength of modified soil samples and Δp is the axial strain at peak strength in parent or untreated soil specimens. Accordingly, it is the ratio of axial strain at top strength of treated to untreated soil specimens. As stated by one researcher [11], the applications of this index are limited for modified soils with the same water content, so that in this study, water to binder ratio was adopted as 50 % of the weight of binder. Table 3 summarizes the values of DI with respect to different replacement levels of Portland cement by (FWA).

Table 3: Results of unconfined compressive tests and deformability index values.

Mixtures description	Peak strength q_u (kPa)	Axial strain at peak strength (%)	Deformability index, *DI*
$S_{100}C_0FWA_0$	232.6	4.66 %	1
$S_{90}C_0FWA_{10}$	339.9	2.69 %	0.58
$S_{90}C_2FWA_8$	369.5	2.45 %	0.53
$S_{90}C_4FWA_6$	665.3	2.59 %	0.56
$S_{90}C_5FWA_5$	709.9	2.51 %	0.54
$S_{90}C_6FWA_4$	841.9	2.15 %	0.46
$S_{90}C_8FWA_2$	1154.1	2.27 %	0.49
$S_{90}C_{10}FWA_0$	1312.9	2.12 %	0.45

The deformability index decreases from 1 to 0.45 with the addition of 10 % of cement. With the combination of firewood ash by partial replacement by cement, the deformability index values increases from 0.45 to 0.58. This increment reveals that the addition of firewood ash slightly improves the soil ductility.

Fig. 7 illustrates the relationship between strength developments to deformation characteristics of different mix design. The figure showed that the strength development is inversely proportional to the values of the deformability index.

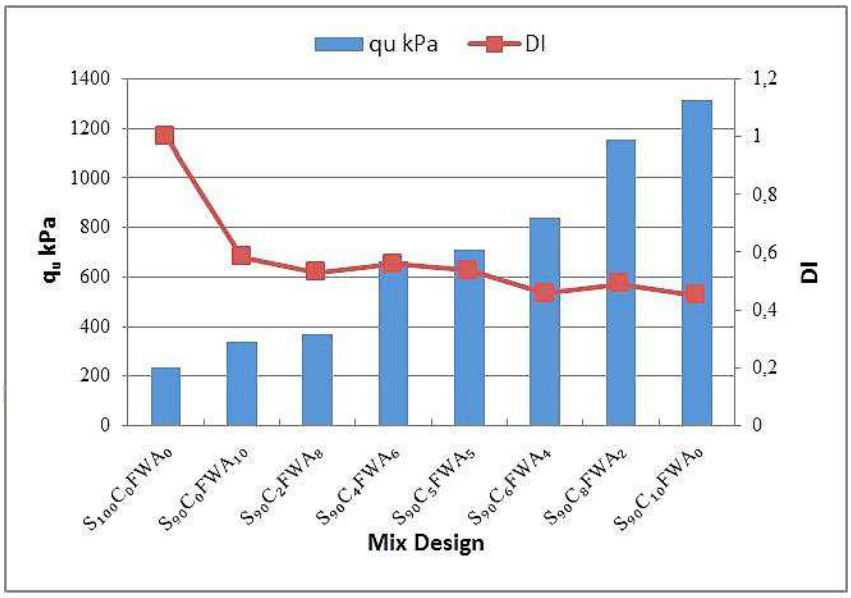


Fig. 7: The relationship between q_u and DI based on different mix design.

4.3 Failure modes

Fig. 8 clearly unveils the failure fashion of modified soil specimens under unconfined compressive load. For plain soil specimens $S_{100}C_0FWA_0$ as seen in the Fig. 6a, the multiple crack failure with bulging at the middle of the specimens was developed. Similarly, for the soil specimen contains 10 % firewood ash, the multiple crack failure with bulging at the end of the specimen has been observes. This failure pattern found to be satisfied with the results obtained by Wu 2014 [29]. Fig 8c shows an inclined shear failure plane along the body of the specimen. The inclined shear failure observed for $S_{90}C_2FWA_8$ mix design. The change of failure patterns from the multiple crack failure with bulging to inclined shear failure could be attributed to 2 % cement inclusion. By decreasing the replacement level of firewood ash by cement to 6 % and further, the vertical to dual vertical crack failure are observed. This failure is combined by axial strain reduction and sudden collapse. The change in failure patterns from the inclined to vertical crack failure could be attributed to progressive increment of cement verses firewood ash reduction.

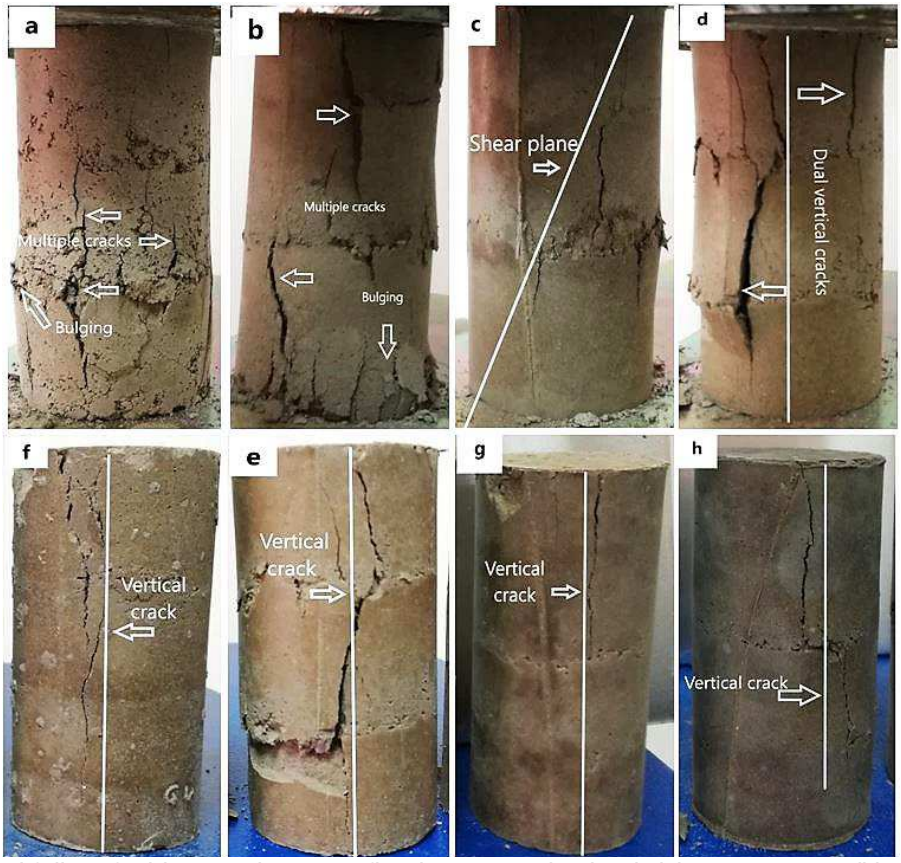


Fig. 8: Typical failure fashions under unconfined compressive load: (a) $S_{100}C_0FWA_0$ (b) $S_{90}C_0FWA_{10}$ (c) $S_{90}C_2FWA_8$ (d) $S_{90}C_4FWA_6$ (e) $S_{90}C_5FWA_5$ (f) $S_{90}C_6FWA_4$ (g) $S_{90}C_8FWA_2$ (h) $S_{90}C_{10}FWA_0$.

5 Conclusion

The conclusion of this paper can be summarized as follows:

1. The partial replacement of (FWA) by cement introduces a sustainable approach of reusing an abundant waste material, which contributes to reduce the dependence on conventional binders.
2. The replacement of (FWA) by cement with 60 % and further, enhanced soil workability by decreasing the values of plasticity index.
3. The unconfined compressive strength increases with the addition of 10 % FWA while maximum performance achieved with the addition of 10 % of cement.
4. The unconfined compressive strength for all replacement levels increase when compared with the plain clay samples.
5. The reaction of cement is much faster than the reaction of firewood, ash, so that, the unconfined compressive strength systematically decreases with the partial replacement of FWA by cement when compared with the addition of cement only.
6. 28 day of curing condition is considered as insufficient time to reach the maximum pozzolanic reaction.
7. The addition of cement only, decreases the deformability index values to minimum unlike the existence of firewood, ash which increases the DI values.
8. Three modes of failure were noticed, the first mode shows a multiple cracks failure with bulging for plain soil sample and samples contains 10 % of FWA , the second mode have found for clay containing 8 % FWA and 2 % cement which, shows an inclined shear failure. The third failure mode have notice for 4 % and further of replacement of FWA by cement which, shows vertical to dual vertical cracks.

References

[1] HORPIBULSUK, S. - PHOJAN, W. - SUDDEEPONG, A. - CHINKULKIJNIWAT, A. - LIU, M. D.: Applied Clay Science Strength development in blended cement admixed saline clay. Appl. Clay Sci., Vol. 55, 2012, pp. 44–52.

[2] PONGSIVASATHIT, S. - HORPIBULSUK, S. - PIYAPHIPAT, S.: Case Studies in Construction Materials Assessment of mechanical properties of cement stabilized soils. Case Stud. Constr. Mater., Vol. 11, 2019, p. e00301.
[3] CHEW, S. H. - KAMRUZZAMAN, A. H. M. - LEE, F. H.: Physicochemical and Engineering Behavior of Cement Treated Clays. Vol. 130, No. 7, 2004, pp. 696–706.
[4] YI, Y. - GU, L. - LIU, S.: Applied Clay Science Microstructural and mechanical properties of marine soft clay stabilized by lime-activated ground granulated blastfurnace slag. Appl. Clay Sci., Vol. 103, 2015, pp. 71–76.
[5] MILLER, G. A. - AZAD, S.: Influence of soil type on stabilization with cement kiln dust. 2000, pp. 89–97.
[6] PAPER, O.: Strength Properties of Sandy Soil – Cement Admixtures. 2009, pp. 681–686.
[7] HORPIBULSUK, S. - RACHAN, R. - CHINKULKIJNIWAT, A. - RAKSACHON, Y.: Analysis of strength development in cement-stabilized silty clay from microstructural considerations. Constr. Build. Mater, Vol. 24, No. 10, 2011, pp. 2011–2021.
[8] PARK, S.: Unconfined compressive strength and ductility of fiber-reinforced cemented sand. Constr. Build. Mater, Vol. 25, No. 2, 2011, pp. 1134–1138.
[9] PAKBAZ, M. S. - ALIPOUR, R.: Applied Clay Science Influence of cement addition on the geotechnical properties of an Iranian clay. Appl. Clay Sci., Vol. 67–68, 2012, pp. 1–4.
[10] SARIOSSEIRI, F. - MUHUNTHAN, B.: Effect of cement treatment on geotechnical properties of some Washington State soils. Eng. Geol., Vol. 104, No. 1–2, 2009, pp. 119–125.
[11] ESKISAR, T.: Influence of Cement Treatment on Unconfined Compressive Strength and Compressibility of Lean Clay with Medium Plasticity. 2015, pp. 763–772.
[12] MODARRES, A. - MOHAMMADI, Y.: Applied Clay Science Clay stabilization using coal waste and lime — Technical and environmental impacts. Appl. Clay Sci., 2015.
[13] CHOWDHURY, S. - MISHRA, M. - SUGANYA, O.: The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete : An overview. Ain Shams Eng. J., Vol. 6, No. 2, 2015, pp. 429–437.
[14] LUGA, E. - PAJA, A.: An Investigation On The Partial Replacement Of Portland Cement An Investigation On The Partial Replacement Of Portland Cement With Kosovo Fly Ash In Cement. November, 2017.
[15] BEHNOOD, A.: Transportation Geotechnics Soil and clay stabilization with calcium- and non-calcium-based additives : A state-of-the-art review of challenges, approaches and techniques. Transp. Geotech, Vol. 17, May, 2018, pp. 14–32.
[16] LUGA, E. - PAJA, A. - ATIS, C. D.: An Investigation on the Partial Replacement of Portland Cement with Kosovo Fly Ash in Cement. Vol. 3, No. 3, 2017, pp. 125–141.
[17] RAHEEM, A. A.: Saw Dust Ash as Partial Replacement for Cement in Concrete. December, 2012, 2016.
[18] PATEL, M.: Review on Partial Replacement of Cement in Concrete. December, 2015.
[19] ELINWA, A. U. - EJEH, S. P.: Effects of the Incorporation of Sawdust Waste Incineration Fly Ash in Cement Pastes and Mortars. Vol. 1881, May, 2004, pp. 1–7.
[20] ELINWA, A. U. - EJEH, S. P. - MAMUDA, A. M.: Assessing of the fresh concrete properties of self-compacting concrete containing sawdust ash. Vol. 22, 2008, pp. 1178–1182.
[21] LEACH, G. A.: Residential energy in the third world. 1988, pp. 47–65.
[22] BHATT, B. P. - SACHAN, M. S.: Firewood consumption pattern of different tribal communities in Northeast India. Vol. 32, 2004, pp. 1–6.
[23] MURTHY, V. N. S.: Geotechnical Engineering-Principles and practices of soil mechanics and foundation engineering.
[24] MESRI, G. C. D.: Permeability of shales. Proceedings of 8th Panamerican Conference on Soil Mechanics and Foundation Engineering, 1987, pp. 89–100.
[25] KHEMISSA, M. - MAHAMEDI, A.: Applied Clay Science Cement and lime mixture stabilization of expansive overconsolidated clay. Appl. Clay Sci., 2014.
[26] LI, Z. - DING, Z.: Property improvement of Portland cement by incorporating with metakaolin and slag. Vol. 33, 2003, pp. 579–584.
[27] PRUSINSKI, J. R. - LAND, S.: Effectiveness of Portland Cement and Lime in Stabilizing Clay Soils. pp. 215–227.
[28] BEIGE, B.: A new approach to stone deformation : stone deformability index. Vol. 165, 2012.
[29] WU, Y. K. - LI, Y. B. - NIU, B.: Investigation of mechanical properties of randomly distributed sisal fibre reinforced soil. Vol. 18, 2014, pp. 953–959.