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Curing time impact on flexural properties of alkali activated clayey soil with and without Polypropylene fiber reinforcement

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Abstract

Soil remediation is one of well-known methods used in construction engineering to treat problematic soil. Alkali activator such as Potassium hydroxide has been known for its activation of amorphous aluminum silicate occurring in fly ash. This when added to soft soil results in cemented material with strength properties resembles that of cement. However, the failure mode observed is very brittle making the application of such technique very limited to specific engineering applications. To extend the use of alkali activation method in the field of construction engineering soil reinforcement using polypropylene fibers has been recentlyadapted. One of engineering properties in assessing resistance against horizontal displacement is flexural strength towards bending. In this regard alkali activated soft soil with Potassium hydroxide and

تم استلام الورقة بتاريخ: 2024/4/5م   وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

reinforced with polypropylene fibers was subjected to two different curing regimes namely 28 and 90 days. The flexural tests revealed greater impact on flexural properties for both alkali and alkali reinforced specimen due to prolonged curing regime of 90 days when comparing with that of specimen cured for 28 days.

Keywords: Soil stabilization; Polypropylene fibers; Alkali activation; flexural strength; Curing regime.

تأثير زمن المعالجة على خواص الانحناء للتربة الطينية المنشطة القلوية مع وبدون تقوية ألياف البولي بروبيلين

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الملخص

تعتبر معالجة التربة احدي انجع الطرق لتحسين خواصها الهندسية، حيث يستخدم المحفز القلوي هيدروكسيد البوتاسيوم للتفاعل مع الومنيوم سيليكات الموجودة في رماد الفحم المتطاير لجعلها مادة ذات صلابة عالية والتي تعطي خليطا صلبا عند إضافتها للتربة. من جهة اخري تتخذ العينة المعالجة نموذجاً انهيارياً هشا عند بلوغ اجهاد الخضوع مما يجعل استخدام هذا النوع من التربة المعالجة مقيدا جدا. لذا كان من الضروري اجراء بعض التحسينات على العينة لغرض توسيع نطاق المجالات الهندسية التي يمكن استخدامها فيها. من هنا كان من الضروري إضافة ألياف البوروبروبلين للخليط المتكون من التربة وهيدروكسيد البوتاسيوم والرماد المتطاير لغرض تحسين نموذج الانهيار ضد الانحناء اثناء الازاحة الافقية لدي الخليط وتحويله من هش الي لدن. وللوقوف على تأثير

تم استلام الورقة بتاريخ: 2024/4/5م وتم نشرها على الموقع بتاريخ: 30/ 2024/4م

زمن المعالجة للخليط المدعم بألياف البووبروبلين والخليط المتكون فقط من هيدروكسيد البوتاسيوم والرماد المتطاير على قدرة العينة على مقاومة الانحناء اثناء الازاحة الافقية تم اجراء اختبارات الانحناء على العينات المذكورة بعد 28 و90 يوما على التوالي. بعد تحليل النتائج المستقاة من التجارب يمكن تأكيد التأثير الايجابي للزمن على اجهاد الانحناء لكل من العينة المدعمة بألياف البوروبروبلين والعينة المعالجة بهيدروكسيد البوتاسيوم والرماد المتطاير. بمعني ان العينات التي تعرضت لمعالجة لمدة 90 يوما اظهرت قيما اعلي لإجهادات الانحناء أكثر من تلك التي تعرضت فقط ل28 يوما من المعالجة.

1. Introduction

Not much recently fly ash has been a favorable substitution for cement in soil improvement. An increasing number of research works have concluded the possibility of fly ash-based binder for soil improvement. Two major parameters including stiffness and durability of soft soil have been amended due to alkaline activation of fly ash. (Cristelo et al., 2011; Parhi, 2014; Rios et al., 2016; Pourakbar et al.,2016).

However, a major shortcoming including brittleness has been recorded when reaching failure. This finding matches very much with cement and lime failure mode. (Alsafi 2017).The brittleness of soilmakesasoilcolumn crack and fail under tension when subjected to lateral earth pressures or exposed to seismic loads (Correia et al.,2015). In addition, polypropylene fibers have been known for their significant role in the mobilization of strength when added to soil as reinforcement. Their function is that of restricting of cracks when approaching failure. (Consoli et al., 2009 ; Elkhebu Ahmed et al 2019). Finally, the aim of the persuaded study is to address the effect of curing regime on flexural properties of alkali activated and reinforced soil specimen.

Polypropylene fibers: The first trial to synthesize high molecular crystalline PP fibers to be than further developed and widely utilized was undertaken by Natta et al., 1954. In addition, possessing of a very low specific gravity, high thermal properties, stiffness and low cost involved in its manufacturing make PP fibers good candidate to be involved in various applications such as a composite material in the vehicle industry, films, furniture. Furthermore, hydrophobicity and resistivity against alkalinity make PP fibers supreme over other synthetic fibers when dealing with soft soil alkaline activation. Additionally, its high tensile strength of 400 N/mm^2 allows the interaction between soil particles and PP fibers, thus transferring the shear strength into tensile strength, which results in a more ductile behavior of reinforced specimen when reaching failure.

2. Testing Program

2.1 Material:

The soil was provided by kaolin Company in Puchong/ Kuala Lumpur, Malaysia. It is a red brown colour indicating a platyun modified structure. In addition the measured soil compressive strength was extremely frail namely 190 kPa, while it indicated a high Plasticity index of 30. Therefore, it is considered high plasticity clay as per ASTM D2487 (ASTM 2010). Based on theses specification the soil geotechnical does not fit to make up soil layers for construction purposes. The physical properties of the clayey soil are presented in table 1 and its chemical composition and that of fly ash as provided by Energy Dispersive X-ray Fluorescence (EDXRF) analyses conducted at laboratories of University Putra Malaysia, are listed in table2.

Fly ash class F was collected at the electric power station (Kapar) Selangor. As can be recorded from the chemical analyses in

Table 2, it possess a high alumina and silica, which are expected to enrich the alkaline activation reactions.

Table 1 Physical characteristics of host soil

Basic soil property	Standard	Value
Specific gravity (GS)	BS 1377-2	2.58
Liquid limit (LL) (%)	BS 1377-2	73%
Plasticity index (PI) (%)	BS 1377-2	30
OMC (%)	BS 1377-4	30
MDD (Mg/m^3)	BS 1377-4	1.3
UCS (kPa)	BS 1377-7	190

Table 2 Chemical analysis of soil and fly ash

Constituent	Natural soil (%)	Fly ash (F) (%)
Silica (SiO_2)	38.622	42.873
Alumina (Al_2O_3)	28.311	16.057
Iron oxide (Fe_2O_3)	26.854	20.559
Calcium oxide (CaO)	-	8.888
Potash (K_2O)	3.522	3.951
Titanium Dioxide (TiO_2)	1.972	2.949
Sulfite (SO_3)	0.406	0.751

In a study conducted by Crsitello 2011 a 40% fly ash (by dry weight of soil+ fly ash mixtures) was reported to achieve effective compressive strength values. In order to allow for alkaline activations, KOH pellets were provided by R&M Chemical. In order to prepare a solution with predesigned molarity of 12M, 672 g of KOH pellets were dissolved in one litter of distilled water. The solution was kept for a day to cool before using as suggested by

Elkhebu Ahmed, et al 2019. Furthermore, in order to reinforce the alkali activated soil, polypropylene multifilament fibers, which have been provided by Timuran Engineering SdnBhd Malaysia, were first mixed with KOH solution than added to the soil to prevent balling of mixture. Their specifications are listed in table3.

Table 3 Specifications of PP multifilament fiber (Timuran Engineering SdnBhd Malaysia)

Properties	Value
Length	12 mm
Mass (Denier)	15 denier
Specific gravity	0.9 g/cm^3
Aspect ratio	Nil
E-Modulus	3500 N/mm^2
Tensile strength	400 N/mm^2
Tensile at break	35 N per 1000 denier
Elongation at break	15%
Chemical composition	C-33%, H- 67%
Melting point	160 - 170°C
Acid & alkaline resistivity	High

2.2 Method and Methodology

Afixed fly ash content to a solid ratio of 40% was introduced to the clayey soil as reported by Ahmed Elkhebu (2019) to provide greatest strength evolution rate. Curing regimes of 28 and 90 days were adapted to allow for alkali reactions and PP fiber mobilization to take place. Furthermore, polypropylene fibers 0.75% was considered in the present investigation to allow for proper mixing and compaction as confirmed by Ahmed Elkhebu. (2019). Firstly, the fly ash was added to the oven dried soil and mixed thoroughly to ensure even distribution. In order to prevent balling and grant for proper poly propylene fiber distribution, the latter were submerged in KOH solution and introduced to the mix as reported by Ran jbar etal. (2016). Note that an isothermal reaction takes place between KOH pellets and distilled water. Therefore, the latter should be prepared a day prior to testing procedures. Table 4 displays sample type, curing regime, flexural strength tests.

Table4 Group series, Samples, Curing regime and Type of testing

Group series	Test number	Samples	UCS test, curing (days)+ Number oftested specimen
S	S	Natural Soil	(3)
SF	SF40	12MKOH + 40% Fly ash+ 60% Soil	28, 90 (6)
SFR	SFR0.75	12MKOH + 39.7% FA, 59.55% S, 0.75%PP	28, 90 (6)

2.3 Flexural Strength

The specimens S, SF40, SFR0.75 cured for 28 and 90 days were exhibiting flexural stresses to evaluate the binding resistance using a three-point bending tests respectively. These tests were conducted in accordance with the ASTM D 1635 (ASTM 2012). The specimens are consistently compacted in a cylindrical steel mold (50mm diameter and100 mm high) in three equal layers, using a manually operated 45 mm diameter steel rod to apply a static load induced by 27 drops. Subsequently, the specimens were closely wrapped in polythene covers and aluminum sheets to prevent moisture loss. Curing regimes of 28 and 90 days at room temperature were adapted for the present study. The monotonic speed under which the testing was carried out was 0.1mm/min and a supports pan of 60 mm was used to hold the specimen. The flexural strength was calculated based on the following equation:

$$f = \frac{PL}{\pi r^3} \tag{1}$$

Where P = maximal applied load; r = radius of the specimen; and L = support span. The samples were broken with Instron 3369 universal testing machine, fitted with a 50kN load cell, after 28 and 90days respectively.

3. Results

Flexural Strength, the results include flexural stresses of 5 specimens as depicted in figure 1. This was in a line with the predesigned study objectives.

As depicted in figure.1 the flexural load versus deflection curves of the SF40 and SFR0.75 mixtures cured for 28 days recorded a peak force of 1272 N corresponding to bending stress of 1555 kPa and a peak force of 1447 N corresponding to bending stress of 1770 kPa respectively. On the other hand, the host soil indicated a frail resistance to bending at only 52 N corresponding to bending stress of 62 kPa. However, the failure mode of SF40 specimen was brittle when overloaded. In addition, the high achieved flexural resistance was accounted for the alkaline activation reactions. Though, the enhancement in bending resistance is less than that observed by SFR0.75 specimen, which exhibited a deflection softening behavior due to fibers mobilizing their tensile strengths. In other words, the specimen manages to restrict crack propagation and recover in strength after failure. These observations are in a line with the results reported by Jams awang et al. (2014). Moreover, a great deal of alkaline activation impact on flexural bending resistance was observed for SF40 and SFR0.75 cured for

وتم نشرها على الموقع بتاريخ: 30/ 4/2024م تم استلام الورقة بتاريخ: 5/4/2024م

90 days. The effect of geopolymerization was more evident than soil reinforcement indicating a peak force of 2579 N corresponding to bending stress of 3153 kPa and a peak force of 2575 N corresponding to bending stress of 3149 kPA for SF40, SFR0.75 respectively. Nevertheless, SFR0.75 unlike SF40 underwent crack restriction and strength recovery after reaching failure. This was in agreement with studies conducted by Jams awang et al. (2014)& Elkhebu Ahmed et, al. (2019).

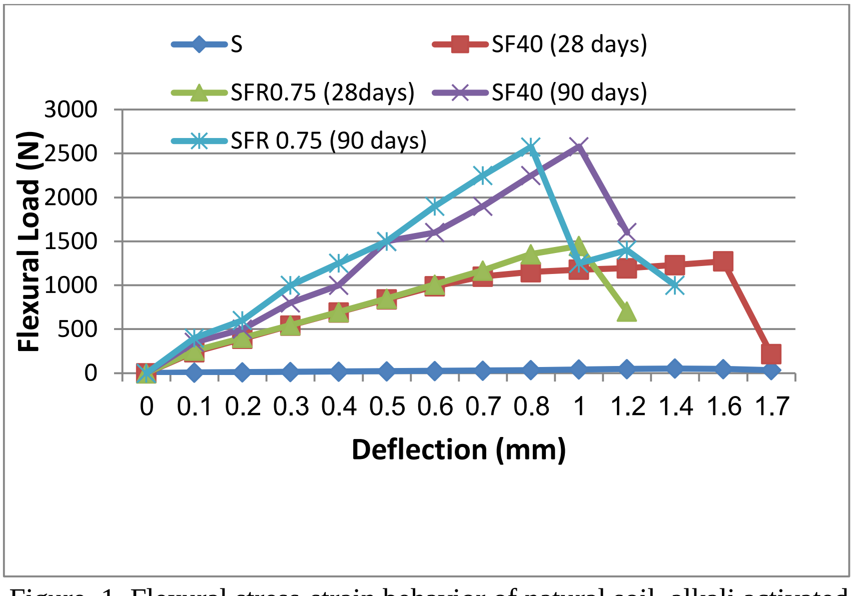

Figure. 1. Flexural stress-strain behavior of natural soil, alkali activated-alkali activated reinforced samples after 28,90 days curing regime

4. Discussion

As can be seen from the results the effect of both alkaline activation and soil reinforcement was clearly revealed after 28 days curing. The reason behind could lie in the coupled effect of low dissolution rate of silica bonds and fiber capability to transfer the shear strength between the soil particles to a tensile strength allowing for even higher residual strength.Furthermore, SFR0.75

indicated higher deflection rate after strength recovery of about 1.2%. In contrast, SF40 dropped promptly when reaching failure. On the other hand, the effect of fiber on bending resistance after 90 days curing was negligible. This is due to the fact the shrinkage porosity could have negatively impacted on strength development of the matrix. Nevertheless, the deflection rate reached by the later was almost 1.2%, while SF40 cured for 90 days dropped shortly after reaching the ultimate stress.

5. Conclusion

From the results of this study, the following can be concluded:

- The addition of PP fibers brought about an increment in bending resistance when compared with SF40 and S for the 28 days curing regime. In addition, when the alkali activated and reinforced soil mixture reached failure, localized cracks developed and a drop in the flexural strength was exhibited. However, PP fibers prevented the movement of the cemented particles by bridging the latter. Therefore, the cracks were either restrained or transferred to another plan.
- For the 90 days curing regime both of SF40 and SFR0.75 recorded almost equal values ofBending resistance namely 3153 kPa and 3149 kPa respectively with the later indicating higher residual stress at higher deflection rate.
- The effectiveness of prolonged curing regime of 90 days for alkali activated and alkali activated reinforced specimen was incredibly high. Nevertheless, this is not practical for engineering application.
- A novel technique should be elaborated on how to speed up the geopolymer reactions, thus allowing for field construction to be carried out in squeezed time table.

تم استلام الورقة بتاريخ: 2024/4/5م
وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

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تم استلام الورقة بتاريخ: 2024/4/5م وتم نشرها على الموقع بتاريخ: 30/ 2024/4م

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