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# Effect of curing time on strength development of alkali-activated clayey soil reinforced with Polypropylene fibers

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## الملخص

في بعض التطبيقات الهندسية لا يمكن لصلابة التربة وحدها أن تكون معيارا موثوقا به عند التعامل مع التحميل الديناميكي . بمعنى آخر، يجب تحسين مرونة التربة المكونة للأساسات من أجل منع الضرر المفاجئ بسبب هشاشتها . العديد من البحاث اهتموا بدراسة تدعيم التربة بواسطة الياف البوليبروبلين. من ناحية أخرى هناك طريقة جديدة تستخدم لتحسين الصلابة لدي التربة الناعمة تسمى بطريقة التفاعل القلوي لمادة الفحم المتطاير والتي فيها يضاف محلول هيدروكسيد البوتاسيوم لإنتاج ماد شبيهة بالإسمنت من ناحية الصلابة. علاوة على ذلك توجد تجارب حديثة جدا دمجت الطريقتين سالفتي الذكر لتحسين الصلابة والمرونة لدى التربة الطينية في آن واحد. في هذا البحث تم إجراء اختبار مقاومة الانضغاط لعينات محسنة قلويا 40SF واخري محسنة قلويا ومدعمة بألياف البوليبروبلين 0.75SFR بعد أن تعرضت للمعالجة الكيميائية في أكياس حافظة للرطوبة لمدة 28 و 90 يوما. أفضت النتائج المستخلصة من البحث بأن العينات المحسنة قلويا قد اكتسبت صلابة عالية جدا مقارنة بإجهاد التحميل للتربة الأصلية S والذي يقدر ب 190 kPa, متمثلة في 3680 kPa و 18500 kPa لمدة 28 و 90 يوما على التوالي مع تعرض العينات للكسر الفوري عند بلوغ اجهاد التحميل. مع إضافة ألياف البوليبروبلين التدعيمية للعينات المعالجة كيميائيا لمدة 28 و 90 يوما تغير

 

وضع الانهيار عند إجهاد التحميل من وضع هش جدا إلى وضع أكثر مرونة بسبب إجهاد الشد المنتقل من ألياف التدعيم إلى التربة.

## Abstract

In some engineering applications soil stiffness only could not be a reliable parameter in accordance with specific standardizations especially, when dealing with dynamic loading. In other words, foundation soil should be altered regarding its ductility in order to prevent sudden damage due to brittleness. Plenty of researchers have studied the effect of multifilament polypropylene fibers on soil reinforcement. Besides, the alkaline activation method has been adapted to alter the strength properties of soft soil. Furthermore, in a cutting edge method, alkaline activation of soft soil, using fly ash and Potassium hydroxide, coupled with soil reinforcement was adapted to change the post-peak behavior of soft soil. The goal of this novel technique is to increase the ultimate strength and to enhance the failure mode. In this research work alkali activated kaolin soil and alkali-activated reinforced kaolin soil were cured for 28 and 90 days respectively. Compressive stress tests were conducted on both mixtures, namely, SF40 ( Soil +40% fly ash) and SFR0.75 ( Soil+ 39.7% fly ash + 0.75% PP fibers) samples. Results drawn from the tests revealed a drastic increase in Compressive strength for SF40 samples cured for 28 and 90 days, namely, 3680 kPa and 18500 kPa, respectively. Whereas, the strength recorded by the control sample was only 190 kPa. Though a sharp drop was seen when approaching failure. The addition of reinforcing Polypropylene fibers brought about a drastic enhancement in failure mode for both of curing regimes.

**Keywords:** Soil stabilization; Polypropylene fibers; Alkali activation; Compressive strength; Curing regime

## Introduction

The use of fly ash-based geopolymers in the field of soft soil engineering has made significant strides in the last ten years. The viability of using a fly ash-based binder for soil remediation has been demonstrated in numerous investigations. This research has demonstrated that using fly ash binders increases the treated soils' stiffness and durability [1-7].

Despite increasing the stiffness of the treated soil, alkaline-activated soils have a very brittle failure mechanism. This is consistent with the outcomes seen in soils treated with cement and lime, where the cementitious agent is present in the form of ASH( Aluminum Silicate hydrate) or CSH ( Calcium Silicate hydrate), respectively, leading to high strength values [8-11]. Due to the soil's brittleness, a soil column that is exposed to seismic loads or lateral earth pressures will crack and collapse under tension [12-13].

In addition, numerous studies have looked into how polypropylene fibers affect the mobilization of tensile strength between soil particles that have been cemented. These investigations have found that polypropylene fibers are effective in preventing crack spread in concrete and cemented soils, resulting in higher residual strengths [13-15]. Additionally, Elkhebu Ahmed et, al [16-17] has developed a novel method to modify the ductility characteristics of soft soil. In this case, soft soil and polypropylene fibers were combined while being subjected to an alkaline activator. Compressive strength tests were performed after the samples had been cured for 28 days. The conclusions reached indicated a better ductile failure mode. The current study explore the effect of prolonged curing time on strength development of treated soil. The curing period was suggested to be 90 days to allow for the effect of geoplimezation and polypropylene fiber mobilization on ductility and strength evolvement.

## Experimental Program

## Material

Malaysia's Kaolin Company in Puchong/Kuala Lumpur provided the soil that was used in the current investigation. As seen in Fig. 1, its reddish-brown color indicates an undamaged platy structure. It is important to note that the host soil does not lend itself to being used to create soil layers for building since it has a low strength and a high plasticity index, making it a high-plasticity clay according to ASTM D2487 [18]. Table 1 lists the clayey soil's physical characteristics. Table 2 lists the fly ash's chemical composition as determined by Energy Dispersive X-ray Fluorescence (EDXRF). The electric power station (Kapar) Selangor supplied fly ash class F (Fig. 2). This precursor has a high alumina and silica content, which is expected to enhance the alkaline activation processes, as can be observed from the chemical analyses in Table 2.

**Fig. 1.** Host clayey soil

**Fig. 2.** Fly ash

**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 (SiO2) | 38.622 | 42.873 |
| Alumina (Al2O3) | 28.311 | 16.057 |
| Iron oxide (Fe2O3) | 26.854 | 20.559 |
| Calcium oxide (CaO) | - | 8.888 |
| Potash (K2O) | 3.522 | 3.951 |
| Titanium Dioxide (TiO2) | 1.972 | 2.949 |
| Sulfite (SO3) | 0.406 | 0.751 |

In a recent experiment, Ahmed Elkhebu et, al [16-17] showed that effective compressive strength values were achieved using 40% fly ash (by dry weight of soil+fly ash combinations). KOH (Potassium hydroxide) pellets as illustrated in fig.3 were supplied by R&M Chemical. According to Alsafi et, al

[19], the KOH (Potassium hydroxide) pellets were dissolved in distilled water a day before testing to create a solution with a predetermined concentration of 12 Mol. Timuran Engineering Sdn Bhd Malaysia provided polypropylene multifilament fibers (Fig. 4) for the purpose of reinforcing. Their tensile strength, resistance to alkaline environments, and other details are listed in Table 3. They are excellent candidates for soil enhancement because of these qualities.

**Fig. 3.** KOH pellets

**Fig. 4**. Multifilament polypropylene fibers

 

**Table 3** Specifications of PP multifilament fibers

| 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 |

Provided by Timuran Engineering Sdn Bhd

Malaysia

## 1.1 Mixing method

According to Ahmed Elkhebu et, al [16-17], the clayey soil was mixed with fly ash at a rate of 40% in order to achieve the fastest strength evolution rate. To allow for alkali reactions and PP fiber mobilization, 28 and 90-day curing periods were adapted. According to Ahmed Elkhebu et, al [16-17], polypropylene fibers of 0.75 percent were also taken into account in this study to enable optimal mixing and compaction. In order to guarantee a uniform distribution, the fly ash was first put into the oven-dried soil and carefully mixed. According to Ranjbar et al. [20], PP fibers were dipped in KOH solution and added to the mixture to prevent mixing up and ensure adequate dispersion. One should be aware that the interaction between KOH pellets and pure water leads to heat development. KOH solution should therefore be ready a day before testing operations. Sample type, curing schedule, and compressive strength testing are displayed in Table 4.

**Table 4** Group series, Samples, Curing regime and Type of testing

| **Group series** | **Test number** | **Samples** | **UCS test, curing (days)+ Number of tested 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) |

## Unconfined Compressive Strength

As previously indicated, to achieve the intended OMC and MDD, according to Abdullah, Shain and Sarker [6], the cool KOH solution was added to the soil fly ash mix at a preset optimal moisture level similar to that of a 40% fly ash soil mixture. In the current studies, 26% of the combination (soil plus 40% fly ash) is OMC. In other words, 260 mL KOH was applied to 1 kg of the soil fly ash mix, and further water was added to attain the predetermined OMC by matching the KOH content. In the second series of tests, polypropylene fibers were added to fly ash soil mixes at a solid content of 0.75% by first being immersed in a KOH solution. The specimens are then uniformly compressed in three equal layers in a cylindrical steel mold (50 mm in diameter and 100 mm in height) using a manually driven 45 mm steel rod to apply static stress brought on by 27 drops. The specimens were then tightly wrapped in aluminum sheets and polythene covers to stop moisture loss. The current investigation modified the 28- and 90-day room temperature curing regimens used by Alsafi et al. [19] Pourakbar [21] and. It should be mentioned that while polypropylene fibers are regarded as hydrophobic and do not exhibit any attraction for water, their influence on the compaction parameters is minimal. According to Malekzadeh and Bilsel [22] and Senol [23], their impact is limited to a negligible MDD reduction rate. For all soil fly ash, polypropylene fiber combinations, a similar OMC to that of soil fly ash mixtures is therefore implemented. A day before testing, all of the treated soil samples were immersed in water to counteract the beneficial effects of suction.

According to the established standard [24], the unconfined compressive strength (UCS) measurement was done. For the sake of repetition, three specimens were used for the UCS measurements, and the findings were only acceptable if the difference from the average was less than 5%. These tests were conducted on an Instron 3382 universal testing machine that was equipped with a 100 kN load cell. Each test yielded the whole stress-strain curve and was conducted under monotonic displacement control at a rate of 1 mm/min. All specimens were kept after shearing for subsequent mineralogical investigation.

## Results and Discussion

The connection between stress and strain for combinations of S, SF40, and SFR 0.75 is presented in Fig. 5. As can be shown, compared to the UCS of 190 kPa reported by host soil after 28 days, both alkali-activated and reinforced alkali-activated soil showed a significant improvement in compressive strength. For SF40 and SFR0.75, respectively, the compressive strength values were measured at 3680 kPa and 6450 kPa. This result is consistent with the findings of Cristelo et al. [1] and Tang et al. [25], who reported that a ratio of 40% fly ash to soil and fly ash contributed to the best compressive strength and that polypropylene fibers increased the strength increment rate of the cemented soil matrix, respectively. Although the incorporation of fibers increased residual strengths observed with fiber content as much as 0.75%, indicating a more progressive decline after failure, the failure mode recorded by SF40% was exceedingly brittle. Furthermore, the alkali-activated soil samples cured for 90 days exhibited a major increase in compressive strength marking a value of about 18500 kPa. However, the failure mode experienced was brittle at a strain rate of only 1.1%. This was in agreement with the results confirmed by Kamaruddin, et al. [26], after 90 days curing regime, observed a strength value of 10900 kPa for reinforced soil treated with an alkaline activator. On the other hand with the inclusion of fiber content of 0.75% the failure mode was improved recording a strain rate of 2.2%, Though a reduction in strength, due to shrinkage porosity, was observed namely 13500 kPa. Nevertheless, this was two times greater than that value recorded for SFR0.75 cured for 28 days.

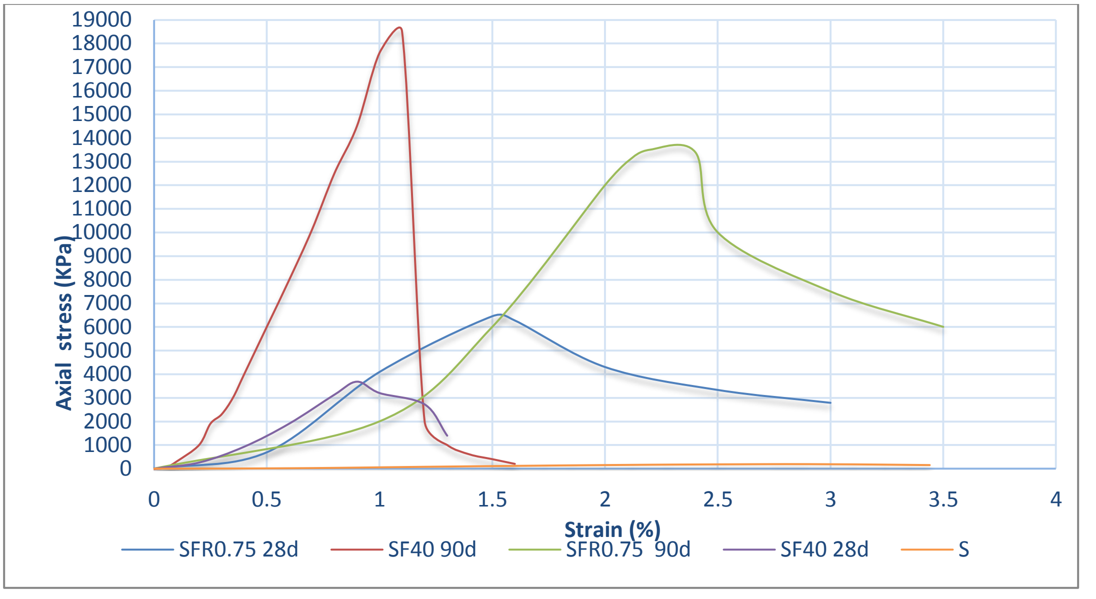


Fig. 5. Stress-strain behavior of natural soil, alkali activated-and

alkali activated reinforced soil samples after 28, 90 days curing regime

Alkali-activated fly ash was added to the naturally clayey soil, and a notable improvement was noticed. This explains why vitreous alumina on the surface of the fly ash particle immediately dissolves and absorbs the potassium hydroxide solution. In addition, a strong rise of 18500 kPa was seen after 90 days, which is five times more than that value recorded by the treated sample cured for 28 days. This was attributable to the existence of Si species in the internal entity of fly ash and its accompanying poor dissolving rate. Si bonds, therefore, control the increase in strength. These results support the judgment made by Abdullah et al. [27]. For SF40 samples that had been cured for 28, and 90 days, respectively, a corresponding strain of less than 1% and 1.1% indicated that strength was approaching failure. Therefore, polypropylene fibers were added to the pretreated alkali-activated soil to enable increased residual strength and better post-peak tendency.

The findings for the 28-day-cured reinforced sample showed a notable PP fiber impact on the mechanical characteristics of the pretreated alkali-activated soil. In other words, a considerable rise in the post-peak strength was seen for the treated sample cured for 28 days as a result of the interfacial link created between the latter and the soil gel matrix. Indicating that the polypropylene fibers were successful in transferring the shear strength between the soil particles to a tensile strength, which allowed for even higher residual strength at strain rates greater than 1.5%, the matrix becomes stronger as it approaches failure. These data concurred with Tang et al. [25] conclusion that fiber inclusion and the compressive strength of cemented soil exhibited a proportionate relationship. Although a reinforced sample that had been cured for 90 days showed a considerably greater propensity toward ductility of 2.3%, a notable drop in strength was detected, primarily because of shrinking porosity between the fiber and the treated soil alkali matrix. These findings are fairly consistent with those made public by Ranjbar et al. [20].

## Conclusion

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

- A great deal of fly ash impact on the compressive strength of SF40 was observed. The samples cured for 28 days displayed a value of 3680 kPa. In addition, after a prolonged curing regime of 90 days, a compressive strength of 18500 kPa was recorded. This was due to the low dissolution rate of silicate bonds that have built a cemented cluster with host soil and Potassium hydroxide.
- The impact of prolonged curing regime of 90 days was obvious bringing about a 500% strength enhancement rate when comparing to that of 28 days cured sample. However, with either a lower or higher strain rate, both of alkali-activated soil mixtures indicated a sharp drop when reaching failure.
- Throughout the 28-day curing regimens, a sharp increase in the strength evolution of SFR0.75 samples was seen, with a strength increment rate of 1.8 times that of the pretreatment specimen. The interaction between cemented clusters and PP fibers brought about an increase in compressive strength. As a result, the peak value of the pretreatment specimen was

 

nearly doubled. In a controversial finding, compressive strength was decreased for SFR0.75 after a 90-day treatment. Due to prolonged curing, it was expected that the porosity between the cemented clusters and polypropylene fibers would diminish.

- The effectiveness of a prolonged curing regime of 90 days was incredibly high. Nevertheless, this is not practical for engineering applications.
- A novel technique should be elaborated on how to speed up the geopolymer reactions, thus allowing for field construction to be carried out in a short-defined plan.

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