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Chemical Stabilization of Expansive Shale Using Natural Bagasse Fibers: A Case Study from Qena Area, Egypt

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THE geotechnical performance of natural sugarcane bagasse fibers mixtures was investigated during chemical stabilization process of Dakhla expansive shale. Compositionally, Dakhla Formation, exposed at El-Mahrowsa, Qena, consists mainly of smectite, kaolinite, quartz, calcite, and anhydrite. These mineral associations are reflected by 36.83 wt.% SiO_2, 16.76 wt.% Al_2O_3, 28.59 wt.% CaO, and 6.99 wt.% SO_3. Geotechnically, the natural compacted shale without bagasse fibers addition exhibited 88 Kpa compressive strength, 35 Kpa tensile strength, and 450 m/s ultrasonic velocity. The free swelling percent of natural expansive shale is 73 %. During the chemical stabilization process, mixtures of natural bagasse fibers (1%) were thoroughly homogenized and compacted with expansive shale. These mixtures were cured at 7, 28, and 90 days under room temperature and 100 % humidity. The geotechnical performance of these mixtures was evaluated using measurement of unconfined compressive strength, tensile strength, longitudinal ultrasonic velocity, and free swelling percent. The overall results indicate that the application of natural bagasse fibers (1%) is useful to improve the geotechnical behaviour of the expansive shale at 7 days curing time (e.g. compressive strength increased from 88 to 310 Kpa, tensile strength increased from 35 to 130 Kpa, and ultrasonic velocity increased from 450 to 541 m/s). Unfortunately, the geotechnical properties of the treated expansive shale using natural bagasse fibers including unconfined compressive strength, tension strength, and ultrasonic velocity do not improve with increasing curing time from 7 to 90 days. Free swelling percent reduces very slightly with increasing curing time from 7 to 90 days.

Keywords: Expansive Shale, Chemical Stabilization, Natural Bagasse Fibres.

1. Introduction

The term expandable shale refers to fine-grained sedimentary rocks consisting mainly of smectite mineral group, montmorillonite as such example, which is known for its swelling and shrinkage behavior under varied moisture conditions (Sabtan 2005). The occurrence of this shale type as a principle component of the foundation soil must be seriously considered as alarm for many problems that are expected to occur in construction projects, for example, damage to basements, lifting and/or settlement of buildings, and cracks in road pavements (e.g. Maduka et al. 2016; Hakro et al. 2022). Accordingly, several stabilization studies (e.g. Dayioglu et al. 2017; Ismaiel et al. 2017;; Hakro et al. 2022) were conducted on this shale type using different additives (e.g. fly ash, lime, bagasse fibers ash, cement kiln dust, marble dust, saw dust, and rice husk ash) in an attempt to reduce its swelling pressure and enhance the strength behavior. Through this context, the current study contributes to the stabilization of expansive shale, El-Mahrowsa Dakhla shale as a case in point, using natural sugarcane bagasse fibers. Although the stabilization process of expansive shale was studied using bagasse fibers (e.g. Dang and Khabbaz 2018) and mixture of lime and bagasse fiber (e.g. Dang et al. 2016), the current study sheds more light on the effect of the natural bagasse fibers on the geotechnical performance of stabilized shale.

2. Materials and Methods

2.1 Sample collection and preparation

five shale samples (each sample weights 30 Kg) were collected from the Maastrichtian-Paleocene Dakhla Formation that is located at El-Mahrowsa village, Qena governorate, Egypt, between 26 º1′ 3.7″ N and 32º 43′ 18.8″ E (Fig. 1). The studied section is a part

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of the Upper Cretaceous-Lower Tertiary succession in Egypt. It is exposed as 10 m thick gray to greenish laminated shale, with marl interbred and gypsum veinlets. Occasionally, yellowish spots and patches are observed on shale samples due to the iron oxidation contained in the crystal structure of clay minerals (Fig. 2). The collected shale samples were dried and crushed using jaw crusher up to -2mm in diameter.

Regarding bagasse fibers, it was obtained from Deshna sugar factory located at Qena governorate, Egypt.

2.2 Shales and fibers characterization

The mineralogical and chemical composition of El-Mahrowsa expansive shale was investigated using X-ray diffractometer “XRD” and X-ray fluorescence “XRF”, respectively. Also, shale microstructure was studied using 1cm x 1cm cubic sample prepared and coated with thin gold film for scanning electron microscope “SEM”. Geotechnically, free swelling, ultrasonic velocity, tensile strength, and unconfined compressive strength were investigated.

2.3 Procedures of shale stabilization

For stabilization, successive steps of shale mixing with natural fibers mixtures, compaction using proctor hammer, and curing for 7, 28, and 90 days were followed. About 1 % fibers of the total dry soil weight was used for the mixing process under room temperature and 100 % humidity. At each curing interval, the stabilization efficiency was monitored by measuring the unconfined compressive strength, tensile strength, Vp velocity, and free swelling. All tests were carried out according to American Association of State Highway and Transportation Officials (AASHTO) except Vp velocity after Yesiler et al., 2001. Moreover, the microstructure of stabilized samples was studied.

3. Results

3.1 Mineralogy, geochemistry, and microstructure of natural shale

Interpretation of XRD data using X′Pert High Score Plus (Fig. 3) reveals the occurrence of smectite and kaolinite as the main clay minerals; on the other hand, the non-clay fraction is represented by quartz, calcite, and anhydrite. All of these mineral components are chemically reflected by 36.64 wt.% SiO_2, 15.41 wt.% Al_2O_3, 20.3 wt.% CaO, and 6.99 wt.% SO_3 (Table 1). Moreover, the studied shale is characterized by flaky microstructure within which the honeycomb- and rosette-like morphologies of smectite and kaolinite, respectively (Fig. 4).

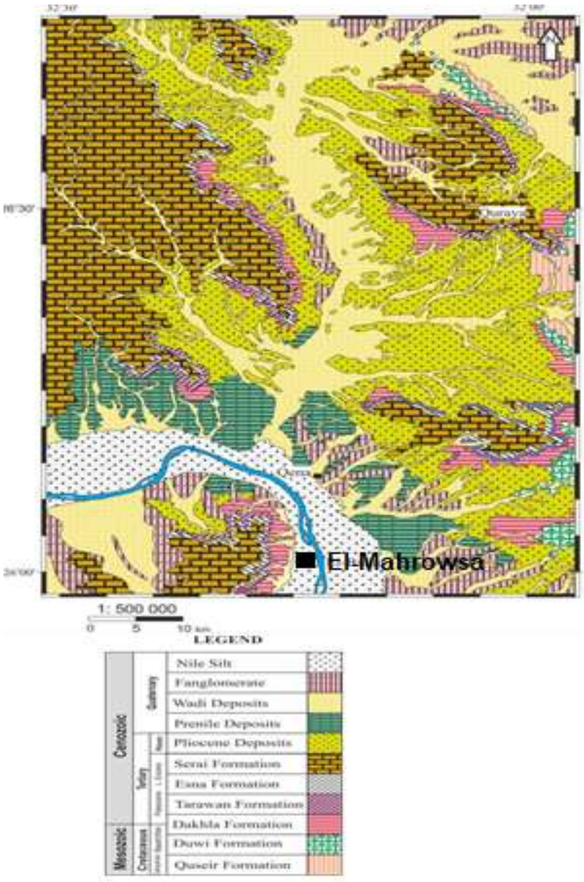
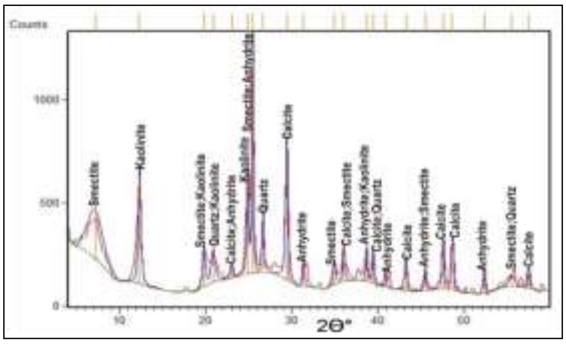


Fig.1. Geological map showing the different rock units exposed at the studied section (El-Mahrowsa village) (after Ismaiel et al., 2017).

Fig. 2. Photograph of the studied section (El-Mahrowsa village) (after Ismaiel and Abdellateef, 2018).



3.2 Geotechnical properties of natural shale

El-Mahrowsa expansive shale samples exhibits free swelling behavior measured at 73 %, with 24 % clay and 71 % silt. Also, it follows AASHTO classification as A-7-5 class and characterized by 47.3 % liquid limit, 29.6 % plastic limit, 17.7 % plasticity index,

Fig. 3. XRD pattern of El-Mahrowsa expansive shale.

2.01 g/cm3 maximum dry density, and 17.9 % optimum moisture content. Vp velocity is measured at 450 m/s and tensile strength is determined at lower value of 35 Kpa. Moreover, the studied shale revealed 88Kpa compressive strength, making it medium in consistency according to Das 1994 (Table 2).

Table 1. Distribution of major oxides (wt.%) of El-Mahrowsa expansive shale samples (as average).

Oxides	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3	Cl	L.O.I
Contents	36.6	1.33	15.41	7.73	20.3	1.08	0.23	0.78	0.67	6.99	0.30	8.0

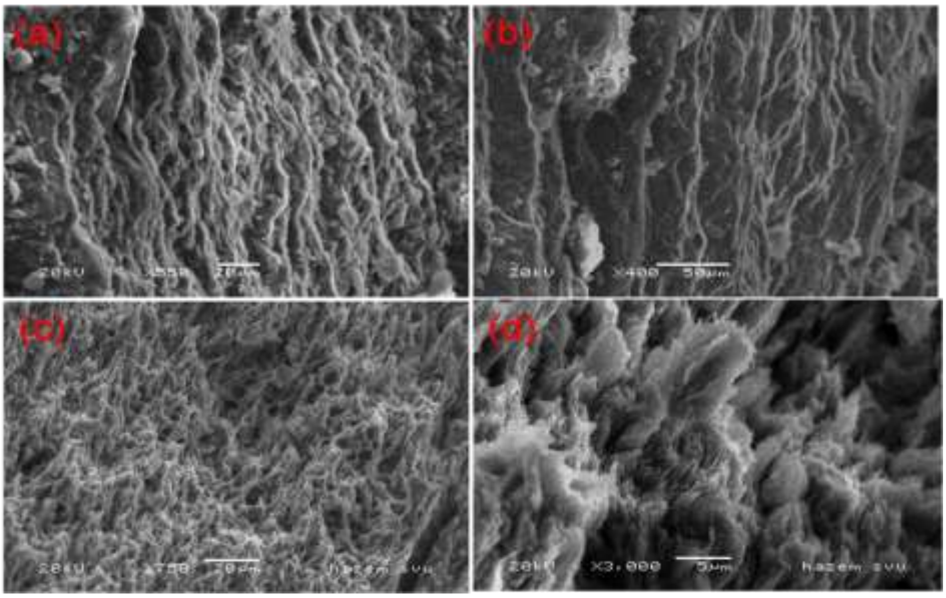


Fig. 4. SEM photomicrographs of El-Mahrowsa shale showing the flaky clay structure (a & b), honeycomb-like structure of smectite (c), and rosette-like structure of kaolinite (d).

Table 2. Geotechnical properties of El-Mahrowsa expansive shale

LL	PL	PI	Clay	Silt	Qu	TS	MD	MC	Vp
47.3 %	29.6%	17.7%	24%	71%	88 Kpa	35 Kpa	2.01 g/cm^3	17.9%	450 m/s

LL, Liquid limit; PL, Plastic limit; PI, Plasticity index; Qu, Unconfined compressive strength; TS, Tensile strength; MD, Maximum dry density; MC, Optimum moisture content; and Vp, Ultrasonic P-wave velocity.

3.3. Natural bagasse fibers

Figure (5) illustrated the cellular fibers structure and the smooth surface of the natural bagasse fibers using in the stabilization process.

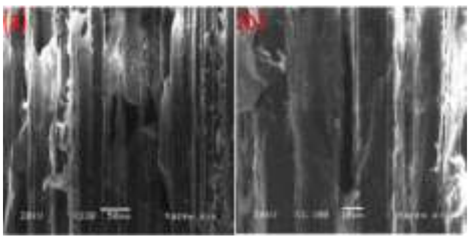


Fig. 5. SEM photomicrographs of the cellular fiber structure (a & b).

3.4. Chemical stabilization of expansive shale

Chemical stabilization of expansive shale using bagasse fibers mixtures was evaluated through specific tests, including compressive strength, tensile strength, ultrasonic velocity “Vp”, and free swelling. As shown in Figs. (6 , 7 & 8), unconfined compressive strength values increase at 7 days curing time from 88 to 310 Kpa and tension increased also from 35 to 130 Kpa. Ultrasonic velocity also increased from 450 to 541 m/s at 7 days curing time. Unfortunately, the geotechnical properties of the treated expansive shale using natural bagasse fibers including unconfined compressive strength, tension strength, and ultrasonic velocity do not improve with increasing curing time from 7 to 90 days. Regarding free swelling, it is very slightly decreased with increasing curing time from 7 to 90 days (Fig. 9).

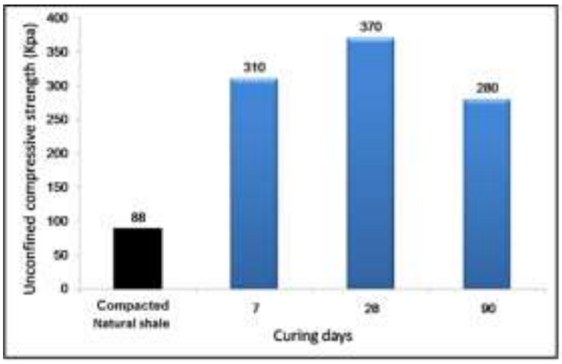


Fig. 6. Binary plot of the unconfined compressive strength "Kpa" vs. curing days for fibers stabilized mixtures.

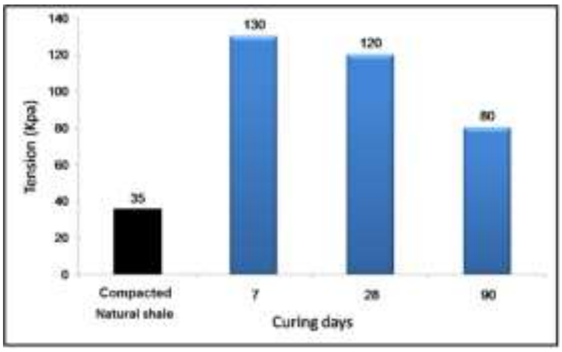


Fig. 7. Binary plot of the tension strength "Kpa" vs. curing days for fibers stabilized samples.

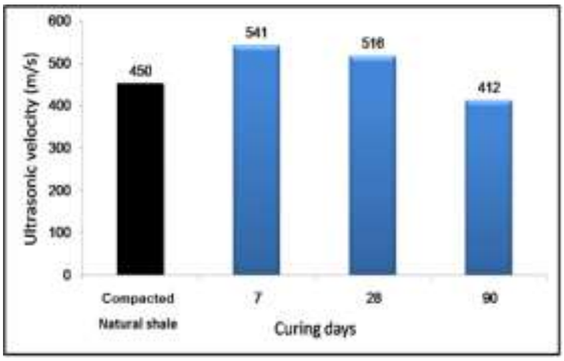


Fig. 8. Binary plot of Ultrasonic velocity "m/s" vs. curing days for fibers stabilized mixtures.

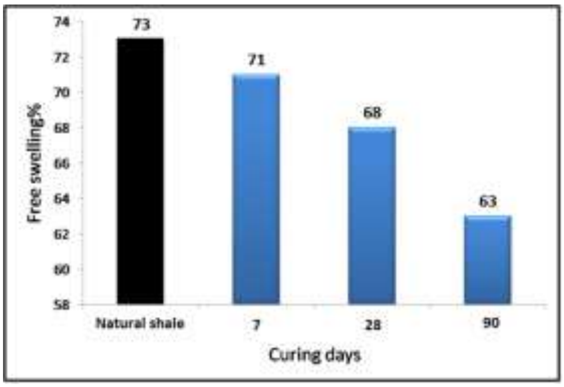


Fig. 9. Binary plot of free swelling percent vs. curing days for fibers stabilized mixtures.

4. Discussion

Unconfined compressive strength (qu); the occurrence of natural fibers in the expansive shale mixtures generally enhanced the unconfined compressive strength of the stabilized samples compared to the natural compacted shale sample "88 Kpa" (Fig. 6). For instance, natural fiber-based stabilization promotes the strength development up to 310 and 370 Kpa at 7 days and 28 days curing time, respectively. Afterwards, the strength values started to decrease and measured at 280 Kpa at 90 days curing time. In this case, the strength decline can be attributed to the noticeable occurrence of microbial patches, white and dark in color, during all curing days (Fig. 10 & 11). This microbial growth and its metabolic products (e.g. organic and mineral acids and sulfur compounds) are well-known for its adverse effect on the strength development (Bertron, 2014; Yakovleva et al., 2018). Further, the preliminary inspection of the compacted samples revealed the following: the microbial growth rate in case of treated fiber was slower at 7 days curing time than at 90 days curing time. The microbial colonization is expected to be accelerated with increase curing time from 7 to 90 days. Regarding soil quality and consistency, Das (1994) made a general classification scheme of soil depending on the obtained compression strength. Through this context, soil consistency can be recognized as very soft "0-23.94 Kpa", soft "23.94-47.89 Kpa", medium "47.89-95.78 Kpa", stiff "95.78-191.57 Kpa", and very stiff "191.57-383 Kpa". Accordingly, the studied shale samples stabilized using natural fibers are characterized by very stiff consistency compared to the natural sample classified (88 Kpa) as medium consistencies, This reveals the role of fibers in filling the spaces between shale particles and form an interlocking between the shale particles which due to hence increasing the compressive strength.

Tensional strength (Ts); the fiber stabilized mixtures at 7 days curing time exhibited higher tensile behavior (130 Kpa) than the natural compacted shale (35 Kpa) (Fig. 7). These values are considered to be the maximum tensile strength measured for the fiber-stabilized shale. The increase of tension may be due to the interlocking bonds between fibers and shale particles. Further curing come with tension failure that reached the minimum values (80 Kpa) at 90 days curing time. This result may be due to the increase of microbial growth with increasing curing time from 7 to 90 days. Which may be lubricates and weak the interlocking between fibers and shale particles.

Ultrasonic velocity (Vp); The studied expansive shale is characterized by Vp measured at 450 m/s. After fibers addition, Vp values increased, at 7 days curing time, up to 541 m/s (Fig. 8), indicating more compaction and reduction of the time interval consumed during the transportation of P-waves through shale samples. The ultrasonic velocity values were reduced at 28 and 90 days curing time, that may be due to, the increase of microbial colonization growth with increase the curing time. In other words, the microbial growth results in varied metabolic products and colonies, which in turn induce the formation of numerous voids through the infected samples. Consequently, the traveled P-waves will take more time interval through stabilized shale samples. This microbial growth destructs the interlocking structure of the fiber shale stabilized mixtures.

Free swelling percent; free swelling is generally measured for natural expansive shale and fiber stabilized shale samples. The free swelling is slightly decreased with increasing the curing intervals from 7 to 90 days curing time (Figs. 9). The reduction of free swelling in case of natural fiber mixtures can be ascribed to the microbial activities. For more clarifications, the microbial colonization in contact with clay particles greatly effects on the crystalline structure of clay minerals due to the partial consumption of the interlayer cations (e.g. NH_4^+, Mg^{2+}, Ca^{2+}….etc), resulting in a partial collapse of clay structure and of its expandability (e.g. Cuadros, 2017).

Microstructural changes; figure (10) illustrated the interlocking structure between the fibers and shale particles, which may be the response to increase the qu, Vp, and Ts of the fiber-shale mixtures at 7 days curing time. This figure showed also microbial growth on both the fibers and the shale particles surfaces. Figure (11) showed that the increase of microbial growth and colonization on both the fibers and the shale particles surfaces.

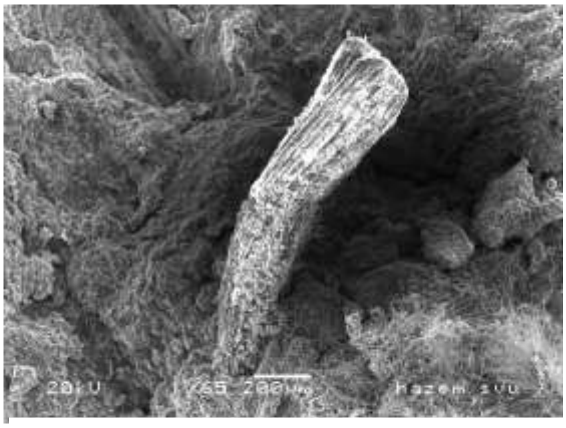


Fig. 10. Interlocking sturcture and microbial growth of fiber stabilized mixture at 7 days curing time.

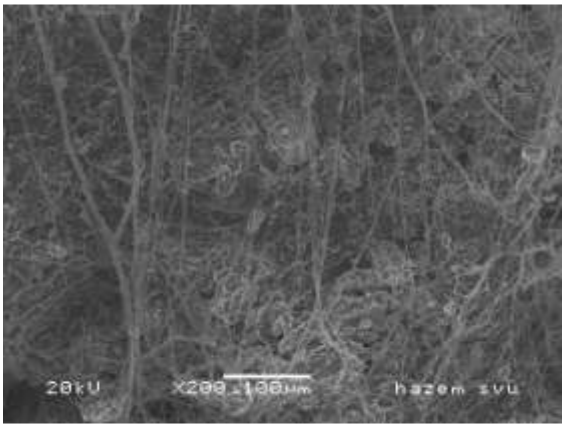


Fig. 11. Increase microbial growth of fiber stabilized mixture at 90 days curing time.

5. Conclusions and recommendations

5.1. Conclusions

Five shale samples (each sample weights 30 Kg) were collected from the Maastrichtian-Paleocene Dakhla Formation that is located at El-Mahrowsa village, Qena governorate, Egypt. For stabilization, successive steps of shale mixing with natural fibers mixtures, compaction using proctor hammer, and curing for 7, 28, and 90 days were followed. About 1 % fibers of the total dry soil weight was used for the mixing process under room temperature and 100 % humidity. At each curing interval, the stabilization efficiency was monitored by measuring the unconfined compressive strength, tensile strength, ultrasonic velocity, and free swelling. Moreover, the microstructure of fiber stabilized samples was studied. Interpretation of XRD data reveals the occurrence of smectite and kaolinite as the main clay minerals; on the other hand, the non-clay fraction is represented by quartz, calcite, and anhydrite. All of these mineral components are chemically reflected by 36.64 wt.% SiO_2, 15.41 wt.% Al_2O_3, 20.3 wt.% CaO, and 6.99 wt.% SO_3. During the chemical stabilization process, mixtures of natural bagasse fibers (1 %) were thoroughly homogenized and compacted with expansive shale. These mixtures were cured at 7, 28, and 90 days under room temperature and 100 % humidity. The overall results indicate that the application of natural bagasse fibers (1 %) is useful to improve the geotechnical behaviour of the expansive shale at 7 days curing time (e.g. compressive strength increased from 88 to 310 Kpa, tensile strength increased from 35 to 130 Kpa, and ultrasonic velocity increased from 450 to 541 m/s). Unfortunately, the geotechnical properties of the treated expansive shale using natural bagasse fibers including unconfined compressive strength, tension strength, and ultrasonic velocity do not improve with increasing curing time from 7 to 90 days, this result may be due to the increase of microbial growth with increasing curing time from 7 to 90 days. Which may be lubricates and weak the interlocking between fibers and shale particles. This microbial growth destructs the interlocking structure of the fibers shale stabilized mixtures. Free swelling percent reduces very slightly with increasing curing time from 7 to 90 days.

5.2. Recommendations

1- To increase the improvement of the geotechnical behavior of the studied expansive shale, treatment of natural bagasse fiber is recommended to reduce or prevent the microbial effect.

2- To increase the hydration reaction and form strong bind materials between the bagasse fibers and the shale particles, hydrated lime addition is recommended.

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التثبيت الكيميائي للطفلة الإنتفاشية باستخدام ألياف مصاصة قصب السكر الطبيعية: دراسة حالة من منطقة قنا، مصر

هشام إسماعيل، وهبة عثمان، ورافت العطار

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تم فحص الأداء الجيوتقني لخلطات ألياف قصب السكر الطبيعي مع الطفلة الانتفاشية لمكون الداخلة أثناء عملية التثبيت الكيميائي. من الناحية التركيبية، تتكون طفلة مكون الداخلة الانتفاشية، المكشوفة في المحروسة، قنا، بشكل أساسي من معادن السمكتايت، والكاولين، والكوارتز، والكالسيت، والأنهيدريت. تنعكس هذه المكونات المعدنية بنسبة ٣٦,٨٣٪ بالوزن SiO_2 و١٦,٧٦٪ بالوزن Al_2O_3 و٢٨,٥٩٪ بالوزن CaO و٦,٩٩٪ بالوزن SO_3. من الناحية الجيوتقنية، أظهرت الطفلة الانتفاشية الطبيعية بدون إضافة ألياف مصاصة قصب السكر قوة ضغط ٨٨ كيلو باسكال، وقوة شد ٣٥ كيلو باسكال، وسرعة فوق صوتية ٤٥٠ م/ ث. نسبة الانتفاش الحر للطفلة الطبيعية الانتفاشية هي ٧٣٪. أثناء عملية التثبيت الكيميائي، تم تجهيز خلطات من الالياف الطبيعية لمصاصة قصب السكر (١٪) مع الطفلة الانتفاشية ودمكها. تمت تخزين هذه الخلطات فترات زمنية ٧ و٢٨ و٩٠ يومًا تحت درجة حرارة الغرفة و١٠٠٪ رطوبة. تم تقييم الأداء الجيوتقني لهذه الخلطات المعالجة باستخدام قياس قوة الانضغاط غير المحصورة وقوة الشد والسرعة الطولية للموجات فوق الصوتية ونسبة الانتفاخ الحر. تشير النتائج النهائية إلى أن استخدام ألياف مصاصة قصب السكر الطبيعية (١٪) مفيد لتحسين السلوك الجيوتقني للطفلة الانتفاشية عند ٧ أيام تخزين (على سبيل المثال، زادت قوة الانضغاط من ٨٨ إلى ٣١٠ كيلو باسكال، وزادت قوة الشد من ٣٥ إلى ١٣٠ كيلو باسكال، وزادت سرعة الموجات فوق الصوتية من ٤٥٠ إلى ٥٤١ م/ ث). لسوء الحظ، لا تتحسن الخصائص الجيوتقنية للطفلة الانتفاشية المعالجة باستخدام ألياف مصاصة قصب السكر الطبيعية بما في ذلك قوة الانضغاط غير المحصورة وقوة الشد والسرعة فوق الصوتية مع زيادة زمن التخزين من ٧ إلى ٩٠ يومًا. كما لوحظ انخفاض نسبة الانتفاش الحر بشكل طفيف للغاية مع زيادة وقت المعالجة من ٧ إلى ٩٠ يومًا.