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Ethyl Cellulose: A Novel Hydrophilic Biopolymer for Soil Strengthening

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ABSTRACT

The current research presents a pilot study of a new application for a hydrophilic biopolymer to stabilize loose sand backfills under dry and wet conditions. Ethyl cellulose (EC) biopolymer is mixed with clean sand in concentration of 1%-2%, by weight. The unconfined compressive strength of the EC-treated sand ranged from 1.16 to 2.38 MPa. Compared to sand treated with similar concentration of Xanthan and Guar biopolymers, the compressive strength is higher, and the collapse potential is much lower. The EC-treated sand is insoluble in water and the strength is unaffected by soaking in water.

Keywords: *Concrete, Foundation, Structure, Analysis, Buckling, Material.*

INTRODUCTION

Soil improvement is defined as changing or controlling the geotechnical properties of problematic soils to be more competent for foundation support, earthwork and underground construction. These properties include increasing strength, density, stability, and resistance to seismic loads, or reducing compressibility, expansiveness, collapsibility and hydraulic conductivity. Historically in Egypt, soil improvement under the foundations of massive temples and structures on soft alluvial soils in the Nile valley dates to 3000 BC [1]. The foundations of the Great Hypostyle Hall located in Karnak Temple is one example, where a 1.5-m trench was dug down from ground surface, and then partly backfilled with clean, dry sand. Courses of blocks were then laid, providing a uniform levelled surface for the wall and columns.

Various soil improvement techniques and methods have been successfully applied in the past and are being continuously modified and updated. These methods are either mechanical or chemical improvements [2]. Compaction, consolidation and reinforcement are examples of mechanical improvement. Chemical treatment is applied by introducing cementitious binders such as cement, lime, sodium silicate and bituminous materials [3]. Most of these materials are environmentally unfriendly, as they may increase pollution or contamination. Chang [3] stated that cement is the most favorable material that is used in multitude of geotechnical engineering applications including grouting, soil stabilization, deep cement mixing and soil nailing. He added that the overdependence on, and overuse of cement have caused many environmental concerns. Cement alone is responsible for (5%-7%) of the annual global CO_2 production, where the total amount of CO_2 emitted per ton of cement produced is 0.95 tons [4, 5]. Egypt's cement industry produces around 58 million metric tons of cement per year, and the yearly domestic consumption of cement in Egypt is estimated to reach 86 million tons in 2022 [6].

Geotechnical engineering researchers and professionals have been recently seeking more use of green and environmentally friendly materials in various applications. One such alterative, is

the use of biopolymers. Biopolymers are bio-degradable organic polymers produced from animal products or agricultural plants. Biopolymers may be classified into four main types:
1) sugar-based (e.g. lactose extracted from potatoes and sugar beet), 2) starch-based (e.g. found in wheat and corn), 3) biopolymers based on synthetic materials (e.g. aliphatic aromatic copolymers obtained from petroleum), and 4) Cellulose-based (obtained from corn, wheat and wood).

Biopolymers are now being increasingly produced in large quantities for use in a variety of applications; mainly, in food production, cosmetics, medical treatment, pharmaceuticals and agriculture. During the last two decades, many researchers embarked on studying the use of biopolymers in soil improvement to overcome difficulties and impracticality of other biological methods, such as microbial injection and byproduct precipitation [3]. Several methods can be used to treat the soil and improve its properties using biopolymers, such as mixing, injection, spraying, and grouting [3]. Many biopolymers, such as Xanthan gum, Guar gum, Agar gum, Gellan gum, Beta-glucan, modified starches, and Chitosan, have been reported in published laboratory studies and have demonstrated their effectiveness in improving the mechanical properties of several soil types [7, 8, 9]. Most of these biopolymers are either soluble in water or their permanence and strength upon water inundation have not been studied thoroughly. Many of the researches discuss comparisons between various biopolymers to differentiate between them. Xanthan gum (X), is one of the most famous biopolymers used in soil improvement due to its availability, in addition to its low price compared to the prices of other biopolymers [10]. However, all available published researches presented the dry strength of the X-treated soils and did not consider or provide information on the permanence upon inundation in water [2, 11, 12]. For example, Chang et al. [11] performed unconfined compression tests on dry specimens of Xanthan and Gellan treated soil sand concluded that the stability under cyclic wetting and drying should be verified in further studies. Chang et al. [13] concluded that the strength of biopolymer-treated soils is significantly reduced to 1/10th that of the dry strength when fully saturated under water. Qureshi et al. [14] performed standard slake durability tests on dry specimens of sand treated with Xanthan gum percentages varying from 1% to 5%. Each cycle of this standard test is performed by rotating 10 pieces of the treated specimens, each weighing 40-50 gm, in a drum rotated at 20 rpm for 10 minutes half submerged in water. Slake durability index is reported after each cycle as the percentage of initial dried weight to the dried weight at the end of each slaking cycle. Their results indicated low to very low durability of the Xanthan-treated sand.

MATERIALS AND EXPERIMENTAL PROGRAM

Ethyl Cellulose

Cellulose is the most common organic compound and biopolymer on Earth. About 33 percent of all plant matter is cellulose. Cellulose is a polysaccharide mainly composed of repeated units of glucose monomer. Cellulose and its derivatives are widely used as additive to foods and in various biomedical, pharmaceutical and biotechnological applications [15, 16, 17]. There are many types of cellulose derivatives; such as ethyl cellulose, hydroxyethyl cellulose, hydroxypropyl cellulose, methylcellulose, carboxymethyl cellulose and sodium carboxymethyl cellulose [17].

Ethyl Cellulose (EC), a derivative of cellulose, is one of the most widely used water-insoluble biopolymers. It is used as a food additive, emulsifier and in pharmaceutical film coating [17]. It can be prepared from cotton and wood pulp by treatment with alkali and ethylation of the alkali cellulose with ethyl chloride. Ethyl cellulose is characterized by its ability to dissolve in a variety of organic solvents and organic-solvent mixtures. The ethyl cellulose used in this study has an ethoxyl content of (48% - 49.5%), and is produced by LOBA CHEMIE PVT. LTD®, CAS number 9004-57-3.

Xanthan Gum

Xanthan gum is an extracellular hetero-polysaccharide produced by pure fermentation of glucose or sucrose by the bacterium Xanthomonas campestris. Lauren [18] explained the structure of xanthan gum as it consists of repeating penta-saccharide monomers with varying amounts of acetyl and pyruvate substituents. Xanthan gum biopolymer is used in many commercial applications as a viscosity thickener of aqueous solutions in food, medicines, drilling muds and other industrial applications. According to Davidson [19], The negative charge of Xanthan gum is provided by the carboxylic acid groups attached to the backbone. The gum is also applied as an additive in concrete to increase viscosity and prevent washouts. Xanthan gum used in this study is produced by Neimenggu Fufeng Biotechnologies Co Ltd®.

Guar Gum

Guar gum (G) is another biopolymer which is extracted from the seeds of the leguminous shrub Cyamopsis Tetragonaloba. It is a polysaccharide commonly used in many industrial applications due to its excellent hydrogen bonding quality such as oil recovery, food and personal care [10, 20]. Guar is characterized by its high viscosity even at low concentrations. The viscosity of Guar Gum solution is influenced by the temperature and pH of salts and other solids, but a constant high viscosity can be held throughout a broad range of pH owing to its non-ionic nature. The use of guar has become very widespread due to its stabilizing, thickening, emulsifying and film forming properties [18]. Guar gum used in this study is produced by AGRO GUMS®.

Siliceous Sand

Siliceous sand was sampled from a borrow pit in Zagazig City, Sharkia Governorate, Egypt. The in-situ soil is classified as a poorly graded sand (SP), with fines content less than 0.5%. Table 1 presents the physical properties of the sand used. According to the results of the modified compaction test (ASTM-698-78) the optimum moisture content of the sand is 6.24%, corresponding to a maximum dry unit weight of 17.3 kN/m^3.

Table 1: Index properties of Zagazig sand

D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c	Fines (%)	Specific Gravity	e_{min}	e_{max}
0.17	0.27	0.48	2.77	0.89	0.5	2.65	0.445	0.572

Specimen Preparation

Ethyl cellulose powder is first dissolved in ethanol, which is a simple alcohol, using a magnetic stirrer at room temperature. The ethanol-to-soil ratio (w_e/w_s in mass units) is selected to be 8%, which is slightly higher than the optimum moisture content of the sand (6.25%) obtained from the modified Proctor test. The ethyl cellulose solution is then mixed with the dry sand at percentages of 1% and 2%, by weight of powder to sand and the mixture is compacted into the cylindrical test mold.

In preparing sand specimens treated with Xanthan and Guar gums, the same wet mixing method is used, but at high temperatures. To prepare 5%, 5.7%, and 10% gum solutions, distilled water is heated to 60 °C and the xanthan or guar powder is added gently, to avoid agglomeration, and mixed while gradually increasing the temperature to 80 °C. Mixing of the biopolymer solutions is performed using a hot plate equipped with a magnetic stirrer for 20 minutes until homogeneity. The biopolymer solution is then mixed with the sand, which was also heated to above 75°C. The sand is mixed with different biopolymer solution to achieve the ratios of 1% and 2% by weight of the sand to the dry biopolymer. (i.e., w_b/w_s= 1%, and 2%).

Reference specimens are also prepared by mixing the same sand with ordinary Portland cement in the ratios of 4% and 10%, by weight, of cement to sand. The mixing method of cemented treated sand is like that described in [21].

For unconfined compression tests, all sand-treated specimens are poured and compacted in three identical layers, into cylindrical molds measuring 50-mm in diameter and 100-mm in length. For one dimensional collapse testing, specimens are compacted in 75-mm diameter molds at a height of 20-mm. All biopolymer treated specimens are air dried at room temperature at 30 °C and with 75% humidity, while cement treated specimens are covered with wet canvas.

RESULTS AND DISCUSSION

Unconfined Compression

The unconfined compression test is performed using a standard screw-type loading frame conforming to the ASTM requirements; strain rate controlled at 1% per minute. For each case, three samples are loaded until failure and the average compressive strength is recorded. Fig. 1 shows the stress-strain curves of sand treated with 1% and 2% ethyl cellulose (EC) after 7 and 28 days of curing. From the figure, we notice that for EC 1% the unconfined strength increases from 0.8 MPa at 7 days to 1.2 MPa after 28 days of curing, which corresponds to a 50% increase. For EC 2% the unconfined strength increases from 1.8 MPa at 7 days to 2.4 MPa after 28 days of curing, which corresponds to a 33% increase. Despite the noticeable increase in strength with curing time, the initial Young's modulus of the treated sand remained unchanged.

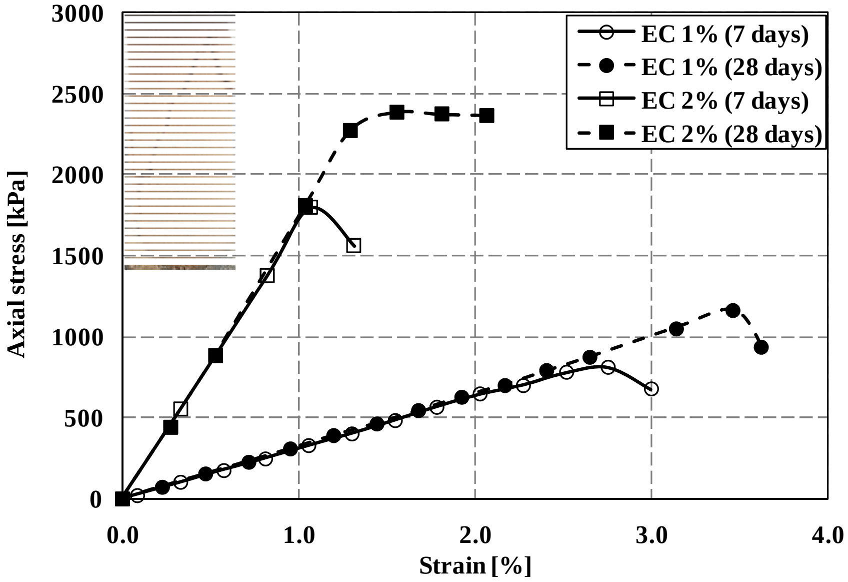

Fig. 1: Stress–strain curves of ethyl cellulose treated sand after 7 and 28 days of curing.

Fig. 2 shows stress-strain curves of Xanthan gum (X1% & X2%) treated sand after 7 and 28 days of curing. The curves show that after 28 days of curing, the compressive strength increases by only 6.25% when the Xanthan percentage is increased from 1% to 2%. Increasing the Xanthan content to more than 2% results in increasing the viscosity of the Xanthan solution, making it more difficult to mix homogenously with the sand. These results are in good agreement with [22], where they concluded that using Xanthan contents higher than 1.5% leads to lower workability as the viscosity of the xanthan-water solution increases significantly. Limiting Xanthan gum content to 1% is provides enough compressive strength at a lower cost. Fig. 2 also shows that, unlike the case of EC-treated sand, the X1%-treated sand after 28 days of curing becomes stiffer and more brittle than that after 7 days. The strength gain during the curing period from 7 to 28 days ranges between 45.5% and 54.5% for the X1% and X2% treated sand, respectively.

Fig. 3 shows stress-strain curves of sand treated Guar gum (G1% & G2%) after 7 and 28 days of curing. The curves show that after 28 days of curing, the compressive strength increases by 15.4% when the Guar percentage is increased from 1% to 2%. For the Guar-treated sand (G1% and G2%), the strength gain during the curing period from 7 to 28 days is four folds.

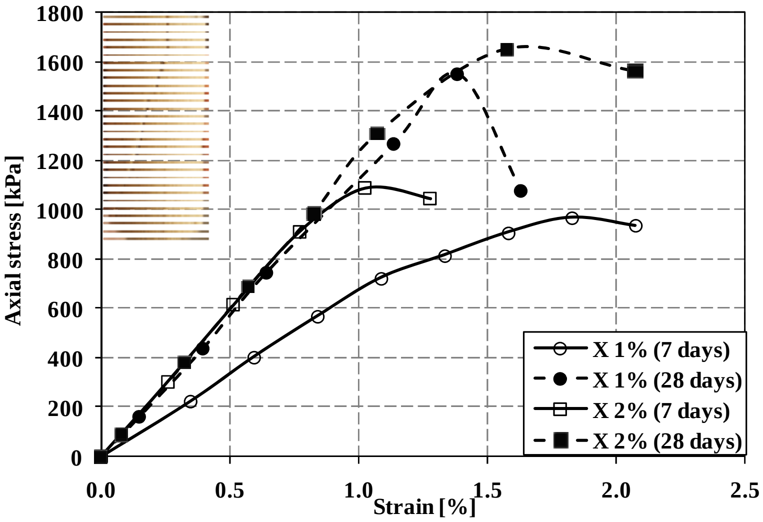

Fig. 2: Stress–strain curves of Xanthan treated sand after 7 and 28 days of curing.

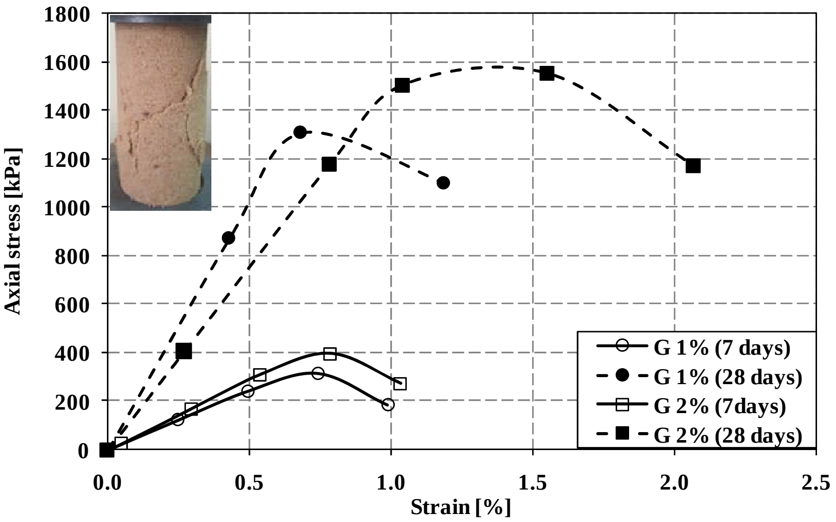

Fig. 3: Stress–strain curves of Guar treated sand after 7 and 28 days of curing.

Fig. 4 presents a comparison between compressive strength values of the various contents of Xanthan (1%, and 2%), Guar (1%, and 2%), Ethyl Cellulose (1%, and 2%), and cement (4%, and 10%). The sand specimens treated with 1% of any of the three environmentally friendly biopolymers, the compressive strengths range between 2 to 2.5 times that treated with 4% cement. Increasing the Xanthan and Guar biopolymers content to 2% results in a slight increase in the compressive strength. However, increasing the Ethyl Cellulose content from 1 to 2% increases the compressive strength by two folds. The average compressive strength of the EC 2% is 2.4 MPa which is comparable to sand treated with 10% cement.

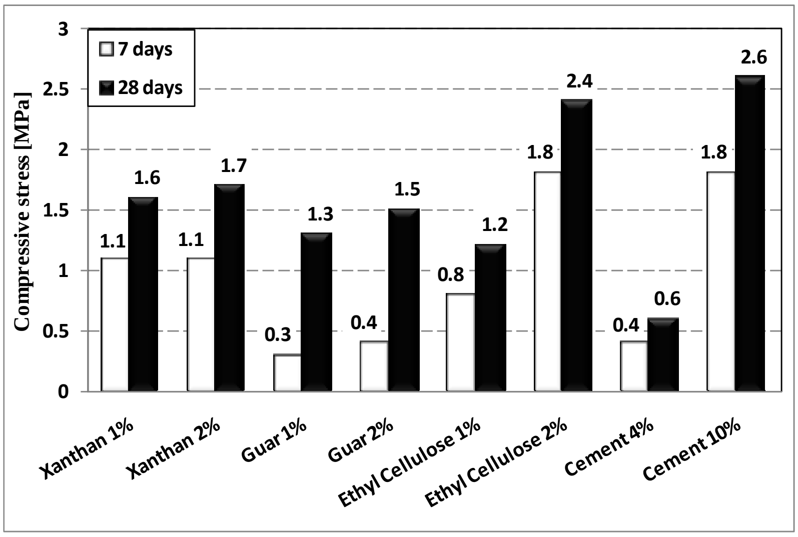

Fig. 4: Comparison of the average compressive strengths of all treated samples.

Ultrasonic Pulse Velocity

Portable ultrasonic nondestructive digital indicating tester (PUNDIT) is performed on all cylindrical samples before compression testing. The test is performed according to the ASTM C 597-02, where the speed of propagation of ultrasonic compression waves is monitored. Fig. 5 Presents the results of the static modulus (initial tangent modulus of the unconfined compression test, E_i) and the dynamic modulus (E_d) measured in the PUNDIT test, for biopolymer-treated sand after 28 days of curing.

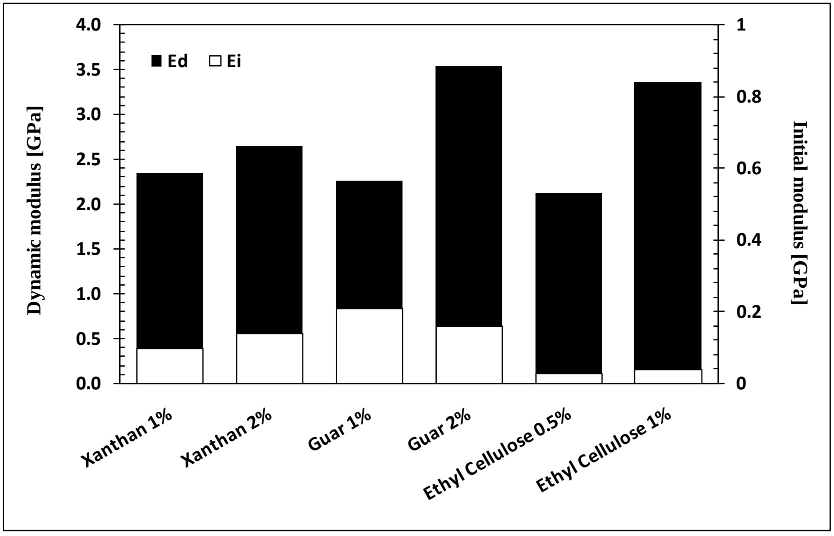

Fig. 5: Initial static (E_i) and dynamic (E_d) moduli of all treated Samples after 28 days of Curing.

Collapse Potential

Collapse potential tests are performed on sand-treated specimens to estimate the magnitude of one-dimensional collapse upon water inundation. The tests are performed in a standard oedometer apparatus, according to ASTM D5333. The treated specimen is cast directly into a standard consolidation ring, and a predetermined vertical stress of 200 kPa is applied incrementally. The specimen is then inundating with distilled water to induce potential collapse.

The collapse index I_e, percent—relative magnitude of collapse determined at 200 kPa is calculated using the equation,

$$I_e = \frac{d_f - d_i}{h_0}(100) \quad (1)$$

where:
d_f = final dial reading at 200 kPa after wetting, mm.,
d_i = initial dial reading at 200 kPa before wetting, mm.,
h_0 = initial specimen height, mm.

Fig. 6 presents the compression curves of the collapse potential tests performed on the three sand treated specimens, while Fig. 7 depicts the comparison of the results of the collapse potential index. According to Table 2 (ASTM D5333), the collapse of the xanthan and guar treated sand is classified as moderate, while it is classified as slight for the ethyl cellulose case.

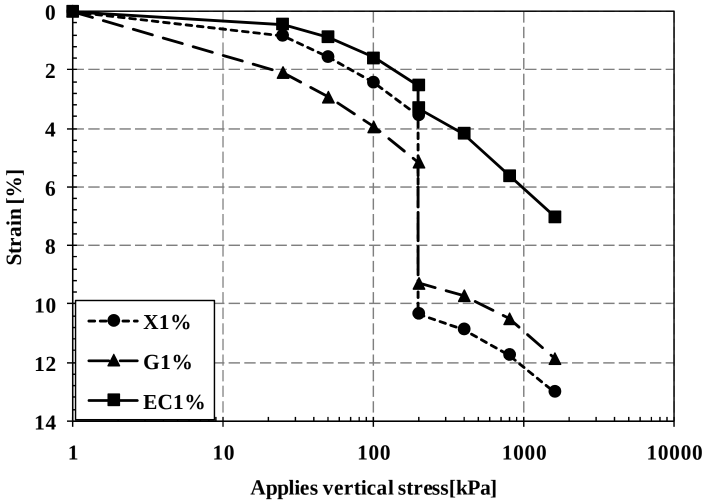

Fig. 6: Compression Curves of the Collapse Potential Tests.

Water Inundation Permanence

Disk samples of sand treated disk-samples were with were immersed in glass beakers filled with potable water for a period of three days, to assess the permanence of sand treated with different biopolymers. Fig. 8 shows that Guar treated sample G2% has completely decomposed after one hour of immersion, followed by the Xanthan treated sample X2% which remained coherent for several hours and then completely decomposed after two days. In contrast, the ethyl cellulose treated sample EC2% remained coherent and unaffected for the whole period of three days.

Table 2: Classification of Collapse Index (ASTM D5333).

Degree of Specimen Collapse	Collapse Index I_e, %
None	0
Slight	0.1 to 2.0
Moderate	2.1 to 6.0
Moderately severe	6.1 to 10.0
Severe	>10

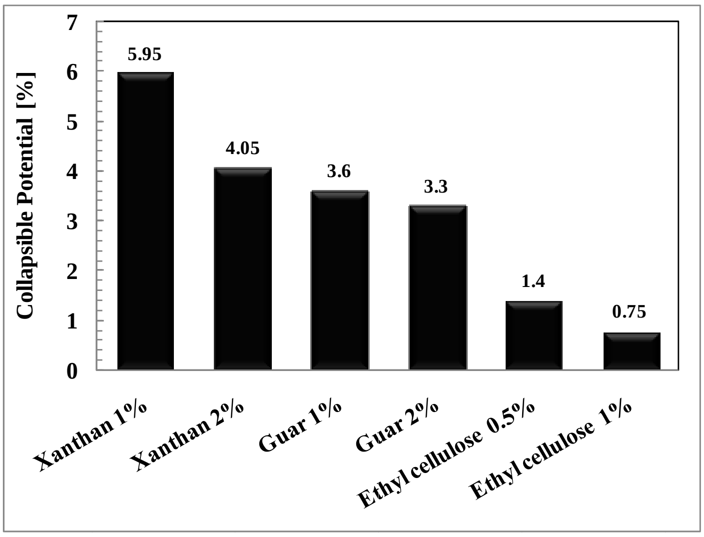

Fig. 7: Comparison of the Collapse Indices of sand-treated specimens

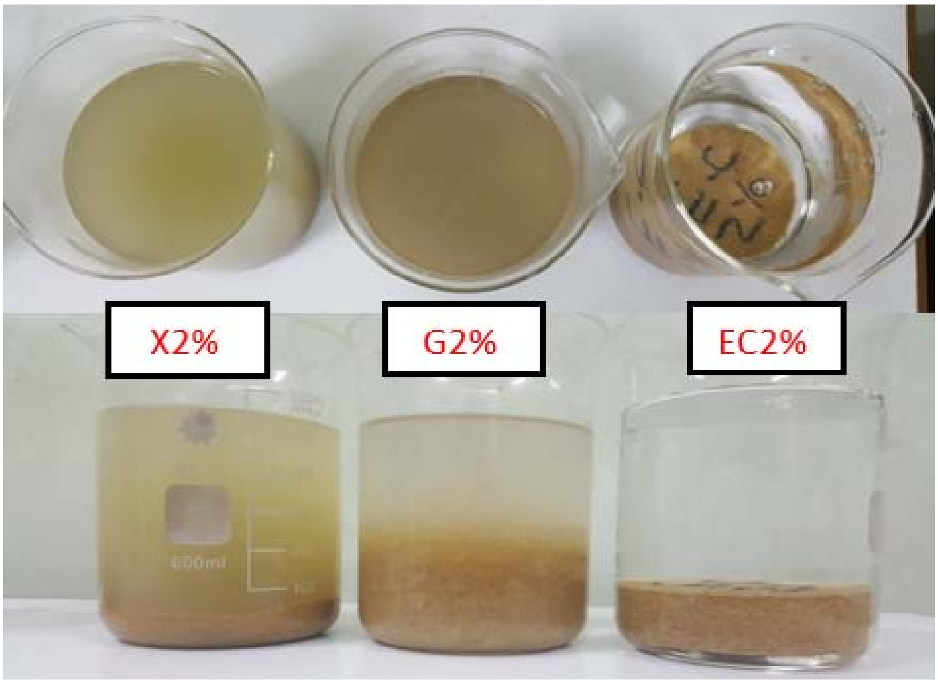

Fig. 8: Water inundation permanence test of biopolymer-treated sand samples

CONCLUSIONS

The main aim of the current research is to explore the feasibility of using ethyl cellulose; a hydrophilic biopolymer, as new alternative soil environmentally friendly stabilizer. The specific conclusions are as follows:

1. Ethyl Cellulose is a very promising new alternative as an environmentally friendly biopolymer for use in soil stabilization applications. The main advantages of EC are that the solution is prepared under room temperature and is characterized by its very low viscosity that could be easily mixed or grouted into fine soils.

2. The use of 1% Ethyl Cellulose, by weight of the sand, results in a compressive strength of 1.2 MPa, which is twice the strength of the same sand treated with 4% Portland cement.
3. The use of 2% Ethyl Cellulose, by weight of the sand, results in a compressive strength of 2.4 MPa, which is comparable to the strength of the same sand treated with 10% Portland cement.
4. The collapse potential of sand treated with 1% of EC is classified as slight, confirming superiority over Xanthan and Guar treated sand, therefore providing enhanced performance in geotechnical applications under water.
5. When Xanthan and Guar treated samples are immersed for a long time in the water, they completely decompose, in contrast, the hydrophilic EC treated sand does not dissolve and remains coherent.

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REFERENCES

[1] B. Carpani, A Survey of Ancient Geotechnical Engineering Techniques in Subfoundation Preparation. SAHC2014–9th International Conference on Structural Analysis of Historical Constructions, F. Peña & M. Chávez (eds.) Mexico City, Mexico, 14–17 October 2014.

[2] N. Latifi, S. Horpibulsuk, C.L. Meehan, E.T. Mohamad, Improvement of Problematic Soils with Biopolymer—An Environmentally Friendly Soil Stabilizer. Materials in Civil Engineering, 29 (2) (2017).https://doi.org/10.1061/(ASCE)MT.1943-5533.0001706.

[3] I. Chang, J. Im and G.C. Cho, Introduction of Microbial Biopolymers in Soil Treatment for Future Environmentally-Friendlyand Sustainable Geotechnical Engineering. Sustainability 8 (3) (2016) 251.https://doi.org/10.3390/su8030251.

[4] M. Stajanča, A. Eštoková, Environmental Impacts of Cement Production, Ph.D. Thesis, University of Košice, Civil Engineering Faculty, Institute of Architectural Engineering, 2012.

[5] A. Larson. Sustainability, Innovation, and Entrepreneurship, University of Virginia: Charlottesville, VA,USA, 2011.

[6] Statista– The portal for statistics Statista. https://www.statista.com/statistics/507174/egypt-production-of-cement/2018(accessed 7 October 2018).

[7] I. Chang and G.C. Cho, Geotechnical Behavior of A Beta-1,3/1,6-Glucan Biopolymer-Treated Residual Soil. Geomechanics and Engineering, 7 (6), (2014) 633–647. https://doi.org/10.12989/gae.2014.7.6.633.

[8] I. Chang, J. Im, S.W. Lee and G.C. Cho, Strength Durability of Gellan Gum Biopolymer-Treated Korean Sand with Cyclic Wetting and Drying. Construction and Building Materials. 143 (2017) 210–221. http://dx.doi.org/10.1016/j.conbuildmat.2017.02.061.

[9] N. Hataf, P. Ghadir, N. Ranjbar, Investigation of Soil Stabilization Using Chitosan Biopolymer, J. Cleaner Production. 170 (2018) 1493-1500. https://doi.org/10.1016/j.jclepro.2017.09.256.

[10] M. Ayeldeen, A. Negm, M. El Sawwaf, M. Kitazume M, Enhancing Mechanical Behaviors of Collapsible Soil Using Two Biopolymers, Rock Mechanics and Geotechnical Engineering 9 (2017) 329-339. http://dx.doi.org/10.1016/j.jrmge.2016.11.007.

[11] I. Chang, M. Jeon, G.C. Cho, 2015. Application of Microbial Biopolymers as an Alternative Construction Binder for Earth Buildings in Underdeveloped Countries, Polymer Science. 9, e326745.http://dx.doi.org/10.1155/2015/326745.

[12] H.R. Khatami, B.C. O'Kelly, Improving Mechanical Properties of Sand Using Biopolymers, Geotechnical and Geoenvironmental Engineering. 139 (2013) 1402–1406. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000861.

[13] I. Chang, J. Im, S.W. Lee, G.C. Cho, Strength Durability of Gellan Gum Biopolymer-Treated Korean Sand with Cyclic Wetting and Drying, Construction and Building Materials. 143 (2017) 210–221. http://dx.doi.org/10.1016/j.conbuildmat.2017.02.061.

[14] M.U. Qureshi, K. Al.Sadrani, I. Chang, Strength and Durability Characteristics of Bio-Improved Sand of AlSharqia Desert, Oman. The 2016 World Congress on Advances in Civil, Environmental and Materials research (ACEM 16), Jeju Island, Korea, August 28-September 1, 2016.

[15] T. Miyamoto, S. Takahashi, H. Ito, H. Inagaki, Tissue Biocompatibility of Cellulose and its Derivatives, Biomedical Materials Research, 23 (1989) 125-133. https://doi.org/10.1002/jbm.820230110.

[16] R.F. Urrusuno, J.M. Gines, E. Morillo, Development of Controlled Release Formulations of Alachlor in Ethylcellulose, Microencapsulation. 17 (3) (2000) 331-342.https://doi.org/10.1080/026520400288300.

[17] A. Sannino, C. Demitriand, M. Madaghiele, Biodegradable Cellulose-Based Hydrogels: Design and Applications, Materials. 2 (2009) 353-373. https://doi.org/10.3390/ma2020353.

[18] L. Lauren, Physical and Microbial Responses of Dredged Sediment to Two-Soil-Stabilizing Amendments, Xanthan Gum and Guar Gum, for Use in Coastal Wetland Restoration, MS Thesis, Louisiana State University, 2010.

[19] R.L. Davidson, Handbook of water-soluble gums and resins, New York, London: McGraw-Hill, 1980.

[20] D. Risica, M. Dentini, V. Crescenzi, Guar Gum Methyl Ethers. Part I. Synthesis and Macromolecular Characterization, Polymer. 46 (2005) 12247–12255. https://doi.org/10.1016/j.polymer.2005.10.083.

[21] I Shooshpasha, R.A. Shirvani, Effect of Cement Stabilization on Geotechnical Properties of Sandy Soils, Geomechanics and Engineering. 8 (1) (2005) 17-31. https://doi.org/10.12989/gae.2015.8.1.017.

[22] I. Chang, J. Im, A.K. Prasidhi and G.C. Cho. Effects of Xanthan Gum Biopolymer on Soil Strengthening, Construction and Building Materials. 74 (2015) 65–72. http://dx.doi.org/10.1016/j.conbuildmat.2014.10.026.