Protection of Irrigation Canals at Desert Areas from Sand Dunes Hazards using Ecotechniques

Mohamed K. Ay-Eldeen[1], Abdalazim M. Negm[2], Masaaki Suzuki[3]
[1, 2] Environmental Engineering Department, Egypt-Japan University of Science and Technology (E-JUST), Alexandria, Egypt.
[3] Chemical Engineering Department, Tokyo Institute of Technology, Tokyo, Japan.

ABSTRACT: *Wind transports billions of tons sand form sand dunes annually. Significant amount of this sand moves toward the irrigation canals and settles in. Accumulation of fine sand is causing serious hydraulics and biological problems such as rising of bed level which in turn change the hydraulic characteristics of the canal (discharge, velocity, water depth, … etc). The accumulated fine sand is a suitable media for growth of aquatic weeds and algae which reduce the canal cross sections as well as deteriorate the water quality downstream the infected area. A variety of different chemicals are available on the market for sand dune stabilization. Most of these chemicals are expensive, toxic, and contaminated. The objective of this research was to evaluate the potential use of biopolymers as a dust damping ecotechnique to protect irrigation canals in desert hot-arid areas where rainfall is very limited or no rainfall and water damping fails. The first part of the experimental program focused on the investigation of the effect of applying of biopolymer to sandy soil on the shear strength of the soil and how this is affected by time and concentration. While, in the second part, a wind box was built to investigate the effect of wind erosion on treated sand samples with different biopolymer concentrations. The results proved biopolymer can be used effectively in stabilizing sand dunes and hence has a potential use a protection ecotechnique for irrigation canals constructed in desert from the hazards of sand dunes. The study recommends a combined use of the biopolymer and the trees as well known windbreak.*

Keywords - *Soil erosion, Biopolymer, Shear strength, Sand dunes, Wind box.*

I. INTRODUCTION

Erosion is defined as the result of processes that involve wearing or grinding the earth's surface. Soil and rock debris can be eroded and carried away from their original locations by streams, ocean currents, waves, wind, groundwater, glaciers, and gravity. Each of these erosional agents may cause physical changes; and these changes depend on the magnitude of the agents and the nature of the soil and rock [1]. When the transporting agent is wind, the erosion is called wind erosion. In a different usage, when the land surface is affected by eroding agents such as rock or soil, the process is referred to as rock or soil erosion, regardless of the nature of the erosion agent[2].

Erosion occurs when the drag and lift of the eroding substance surpasses the gravitational, cohesive, and frictional forces that hold the particles together[1]. As shown in figure 1, air is slightly more effective than running water as an erosion agent for fine grained particles (i.e., particle size < 0.2 mm or fine sand). On the other hand, water is more effective than air as an erosional agent for particles larger than sand. Figure 1 shows the general relationship among velocity, particle size, erosion, transport, and deposition for wind water erosion.

Particle size plays a significant role in wind erosion. Wind usually detaches and moves smaller soil particle at lower velocities than larger particles for cohesionless sand and silt sized particles. However, very fine grained particles will be resistant to detachment due to inter particle attraction (cohesion). Once particles are detached, the moving particles abrade the soil surface and dislodge other particles, intensifying erosion. Therefore, a soil with high clay content has less wind erosion potential than a soil with low clay content. This is due to the stability of soil aggregates created by inter-particle cohesion [4].

In desert regions wind scouring causes sand to move and poses either erosional or depositional hazards on urban areas, civil structures and utilities. The mode and rate of movement of dunes depend on their type and size, the wind velocity, the sand grains property, the internal humidity of dune sand, and the relative density of the sand layers within the dune. These factors also affect the sand stabilization method and the location of any recommended stabilization remedial measure. Accumulation of fine sand is causing serious hydraulics and biological problems such as rising of bed level which in turn change the hydraulic characteristics of the canal (discharge, velocity, water depth, … etc). The accumulated fine sand is a suitable media for growth of aquatic weeds and algae which reduce the canal cross sections as well as deteriorate the water quality downstream the infected area [5].

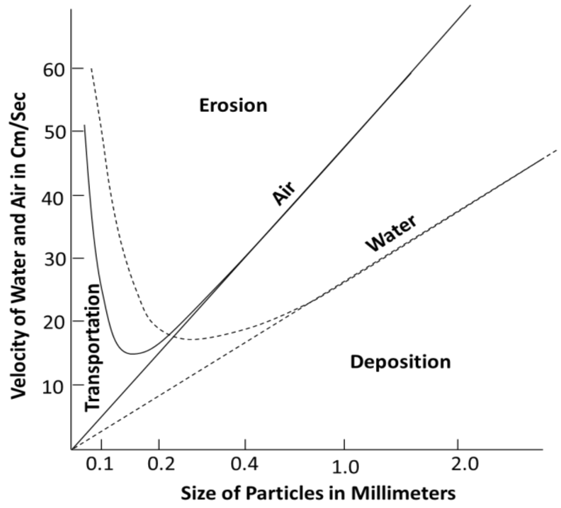

Fig. 1 Comparison of Erosion and Transport Curves for Air and Running Water Source: [3]

Stabilizing a dune to control the sand movement could be accomplished chemically, mechanically or biologically for short-term. Stabilization control measures could be temporary or permanent. A temporary sand control system is used as an initial stage during the application of a permanent one. A temporary system may include shielding the ground with stable material or erection of fences. Shielding the ground can be accomplished by stone mulching, wetting, chemical stabilizers, biological crusting or covering the ground by any other material such as plastic sheets, nets, geotextiles… etc.[4].

For long term, vegetation is the most appealing permanent solution and is accomplished through planting shelterbelts that can survive the local environmental conditions. However, its application under desert conditions is not as easy as the other temporary measures[4]. The lack of water under desert conditions hinders most of the activities to cultivate a sand dune area. On the other hand, during the vegetation process, the young seedlings are subject very often to strong winds. These winds shall transport the seeds from its place or even cover it in sand which threatens the all vegetation process. A temporary stabilization method would be required for a few years until the trees are mature enough to survive. This temporary stabilizer should be environmental friendly so as not to effect on the seedling.

Fortunately, biopolymers is environmental friendly and is a sustainable, carbon neutral and are always renewable, because they are made from natural plant materials which can be grown indefinitely. These plant materials originally come from agricultural nonfood crops. Therefore, the use of biopolymers would undoubtedly create a sustainable solution for stabilizing the sand dunes to protect the irrigation canals.

Soil Shear Strength

The shear strength of soils is an important aspect in many geotechnical engineering applications/problems such as the bearing capacity of shallow foundations and piles, the stability of the slopes of dams and embankments, and lateral earth pressure on retaining walls[5]. The safety of any geotechnical engineering structure is dependent on the shear strength of the soil beneath it[6]. Understanding shear strength can lead to the classification of the condition of a soil entity[7], and can assist engineers in drawing critical conclusions about the overall soil mechanics of a specific environment. Consequently, in this study the shear strength is considered main parameter to assess the impact of using biopolymer in controlling sand dunes erosion.

Erosion and Its Relation to Soil Shear Strength

Land erosion can be classified into two categories: sheet/rill erosion and gully erosion. These are two terms that essentially describe the same process—rill erosion being gully erosion on a small scale. Gully erosion is due to local scour and is caused by flowing water in a defined channel[8], [9]. Shear strength is of sincere importance to gully formation and ephemeral gully erosion, which is term explaining erosion that occurs on areas of such topography that runoff collects and concentrates in few well-defined channels that form in local low points and at the confluences of surface water currents before exiting[9]. The work of Hergault, et al. (2010) cites the shearing processes of a moving fluid as an important parameter involving granular flow of sediment bedload transport in a supercritical flow. In another study, hydraulic shear stress was found to control chiefly the incipient motion of particles flowing in water[10]. Using shear strength to explain erosive events is done so under the government of various critical threshold conditions.

Erosion is believed to occur once a critical shear stress exerted by the moving fluids over a bed of sediment is exceeded[11]–[13]. When this critical value is obtained, erosion will occur over a range of fluid shear stresses and sediment properties if given sufficient time[14]; and under critical conditions, a stream is said to be competent to move its sediment[15]. Critical shear stress is an important parameter governing detachment by runoff which appears in numerous erosion models[10], so this study focused on enhancement the shearing properties of the soil to reflect on an improvement in the erosion characteristics.

II. MATERIALS AND METHODS

Sand Properties

The specific gravity of the sand particles was determined by the gas jar method. The samples were tested five times and resulting an average value of 2.63. The maximum and minimum dry densities of the sand were 19.5 and 16.1 kN/m^3. This corresponds to void ratios of 0.35 and 0.63 respectively. The particle size distribution of the soil was determined using the dry sieving method and illustrated in Fig. 2. The effective diameter (D_{10}); the mean diameter (D_{50}); uniformity coefficient (C_u) and coefficient of curvature (C_c) were 0.18 mm, 0.50 mm, 3.388, and 0.99 respectively. The selected parameters were chosen to achieve a relative density of 54.3% (medium dense sand) according to the compaction of the sand with a density of 17.8 kN/m^3. Void ratio (e) and porosity (n) for the sand were calculated resulting values of 0.478 and 0.323, respectively [16].

Biopolymer Properties

The biopolymer used in the current study is a an anionic polysaccharide called Xanthan gum which produced by *Xanthomonas campestris*[17]. Xanthan gum is available in a white to cream colored free flowing powder that is derived from corn sugar by a fermentation process. It is soluble in hot and cold water and the resulting solution is high viscosity solution, even at very low concentrations, in comparison with other polysaccharide solutions.

Xanthan gum mixtures have excellent thermal stability with a uniform viscosity from freezing to near boiling temperatures. The mixtures are also soluble and stable in acidic, alkaline, and alcoholic systems.

Dry and wetting tests on xanthan gum solution indicated that no hysteresis is evident and that the solutions are highly pseudoplastic. This guarantees high degree stability during mixing and pumping because the initial viscosity is recovered immediately even after high shear rates[18].

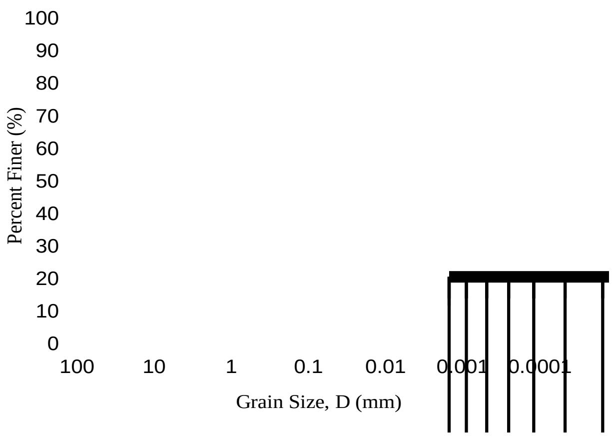

Fig. 2 Partical size distribution curve of the untreated sand used in tests [16]

Due to the already mentioned properties, xanthan gum is widely used in food and non-food industries as a thickener, viscosifier, and stabilizer for multiple suspensions, emulsions, and foams. The U.S. Food and Drug Administration (FDA) cleared xanthan gum for human consumption in 1969 and the European Union (EU) approved it for this purpose in 1980[19].

Experimental set-up

The sand was initially washed several times to get rid of debris and impurities then dried at 105°C for 24 h. The biopolymer powder was dissolved in deionized water with different concentrations. The concentration of the solutions is defined as the ratio in percentage of the dry weight of biopolymer to the total weight of the biopolymer solution. The biopolymer powder was slowly added into water, and stirred for 10 min until a homogeneous solution was obtained to prevent clumping. Xanthan gum solutions with concentrations of 0.25, 0.5, 1, and 2% were used in this study.

The sand samples were carefully mixed with different concentrations of Xanthan gum (0, 0.25, 0.5, 1, and 2%). The mixture was placed in identical containers to ensure the densities are equally distributed in all samples. The specimens were kept at a temperature of 35°C for a period of three weeks.

III. TEST PROCEDURE

Direct Shear Test

As mentioned before, the shear strength of a soil is an important parameter about its resistance to the erosion. Using a 60 x 60 mm shear box, a series of direct shear tests were performed on the untreated sand and on sand that had been treated with the four biopolymer concentrations.

The first series of shear tests were performed immediately after the mixing of the samples to evaluate the effect of uncured biopolymer solution on the sand behaviour. The tests were performed according to the ASTM D3080-04 standard.

Wind Box

Samples were tested in a chamber designed to simulate wind velocities affected on the sand dunes.

The testing chamber measured 1.2 m long, 0.4 m wide, and 0.7 m tall. Air velocities were generated by an electric fan motor and transmitted through a tube with rectangular cross section 10 cm wide and 1.50 cm tall. Air blasts were initiated 2 cm above the sample at an angle 40 degrees from horizontal and lasted for 10 minutes.

Additionally, during the air impingement test, 500 grams of the same sand was injected into the air stream. The sand injection increases surface scour and is intended to replicate actual conditions as suspended dust particles impart additional abrasion to the ground surface.

Microstructure Tests

Confocal laser scanning microscopy (CLSM) is a technique for obtaining high-resolution optical images with depth selectivity. This technique was used to capture clear images to the crosslinks inside the treated soils.

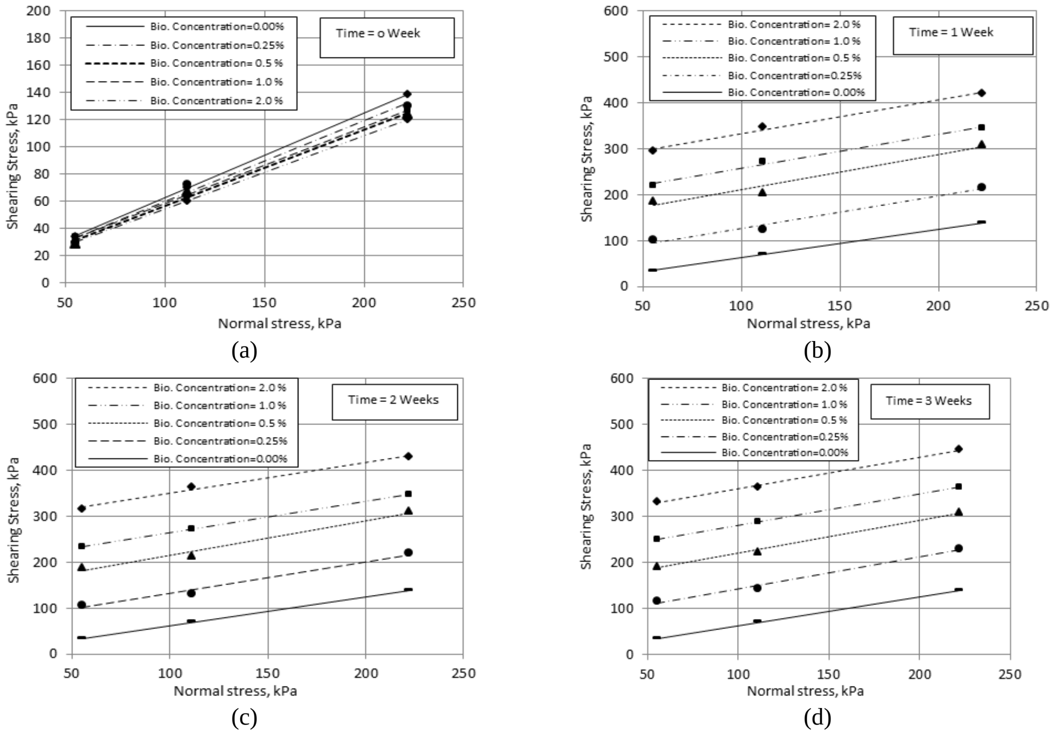

Fig. 3 Failure envelopes of untreated sand and sand treated with biopolymers
(a) After the mixing immediately; (b) After 1 week; (c) After 2 weeks; (d) After 3 weeks

The key feature of confocal microscopy is its ability to acquire in-focus images from selected depths, a process known as optical sectioning. Images are acquired point-by-point and reconstructed with a computer, allowing three-dimensional reconstructions of topologically complex objects.

IV. RESULTS AND DISCUSSION

Direct Shear Results

Figures. 3(a, b, c, and d) show the relationship between the shear strength and the applied normal stress for the treated sandy soil specimens and the untreated one. The sand stiffness after 1,2, and 3 weeks was increased by the addition of biopolymer as compared to the untreated sample and the treated ones at zero time as shown in Figs. 3. (b, c, and d). The improvement in the sand stiffness is directly proportion to biopolymer concentrations within the limit of the present experimental investigation.

The improvement in shear strength of the soil can be explained as biopolymers possess various chemical functional groups, such as hydroxyl, ester, or amines. Their long-chain structure also provides more sites at which the characteristic chemical reaction of a given functional group would occur. Chemical bonding corresponds to the adhesive forces whose function is to hold the soil particle and gel together at their surfaces.

At a microscopic scale, the effectiveness of the bonding depends mainly on the type of forces present at the interface of the particle and the gel. The forces operating at such a phase interface include ionic/electrostatic or covalent bonds (chemisorption), hydrogen bonding (strong polar attraction), and van der Waals forces (physical absorption). Short-range ionic/electrostatic and covalent bonds have the highest bond energy in terms of KJ/mol and therefore give the strongest bond. Van der Waals forces, which are the interaction between dipoles within the bulk material, develop the weakest bonds over a long range[20].

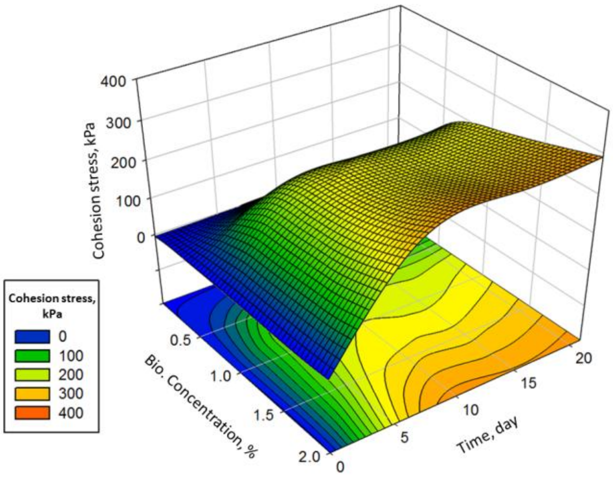

Fig. 4 Variation of cohesion stress with time for different biopolymer concentrations from direct shear test[21]

Table 1: Average mass loss for sand treated with biopolymers

Time, week	Sand Loss, gm							
	Bio. Conc. =0.25%		Bio. Conc. =0.50%		Bio. Conc. =1.00%		Bio. Conc. =2.00%	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
1	141	20.2	111	14.1	92	15.3	54	21.7
2	133	26.1	108	2.4	86	10.6	44	7.2
3	126	11.8	107	21	79	8.9	39	10.5

Figure 4 shows the effect of changing in biopolymer concentrations on the cohesion stress. The results revealed that after the first week the specimens with concentrations of 0.25% and 0.5% almost became stable and gained no more strength. However, for concentrations of 1.0 and 2.0%, the strength of the specimens increased over the time, and the percentage of such increasing is greater in case of concentration of 2.0 % compared to the 1.0%, because of the high concentration of biopolymer[21].

Wind Box Results

Erosion potential data for wind box results is given in Table 1 as the average mass loss. The mean of five samples as well as the standard deviation of the data at a 95% confidence level is provided. While the untreated dry sand has an average mass loss of 643 gm, the mass loss for the treated sand ranged from 39 gm to 141 gm.

It is obviously that the increasing in biopolymer concentration reflects positive impact on the erosion control. The average mass loss reduced from 141 gm in case of concentration 0.25% to 21.7 gm at concentration of 2.00% after the first week.

Figure 5 presents the relation between efficiency of erosion resistance and the curing time of the treated soil. It is clearly that the efficiency increased from 1200% after the first week to more than 1600% after the third week at concentration of 2.00%. The same trend also was observed for the other three concentrations.

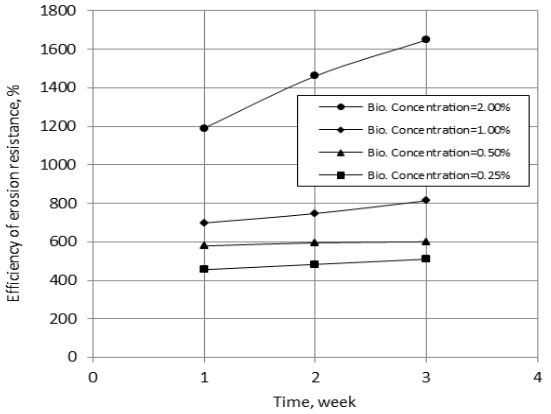

Fig. 5 Variation of efficiency of erosion resistance with time

Laser Microscope

A further analysis, from a series of laser microscope images was carried out on the same tested specimens as illustrated by typical photomicrographs presented in Figs. 6 (50 x enlargement). Figure 6 (a) presents the untreated sand specimens which clearly appear the separation of the particles. Figures 6 (b, c, and d) indicate that as the biopolymers concentrations increases, the bonding materials increases. Obviously, the images illustrate the cross-links of the biopolymers through and over the soil particles, and which increase with the concentration.

V. CONCLUSIONS

Within the experimental range of the present investigation, the following conclusions can be stated:

1- Xanthan gum has a remarkable effect on soil stiffness which begins after curing time. This effect was impacted by the concentration of the biopolymer solution.

2- The strength of the sand treated with xanthan gum increased with time. In case of concentration 0.25 % the cohesion stress increased from 55 kPa in the first week to 74 kPa in the third week and from 260 kPa to 291 kPa for the same period for concentration of 2.00%.

3- As soil erosion resistance is affected by the soil shearing resistance, any enhancement in the shearing resistance leads to an equivalent enhancement in resistance of soil erosion.

4- Biopolymer mixtures should be considered as a viable soil improvement measure for short-term wind erosion control and it can be effective as sand dunes stabilizer specially to protect the irrigation canals.

5- Although this technique is effective for short-term, it should be tested for the local soil.

6- The present investigation recommends the following:

(i) Using a combination between biopolymer and vegetation (e.g. tress) is better than using only one and seems appealing permanent solution as both of them are ecotechniques covering both short-term and long-term.

(ii) An implementation plan should be made for each dune field based on its geomorphic setting, geographic location, local climatic conditions, soil properties, and groundwater quality and depth to apply the combination of both techniques in the best effective way taking into consideration to test the biopolymer techniques on a pilot scale for verification purpose.

VI. ACKNOWLEDGEMENTS

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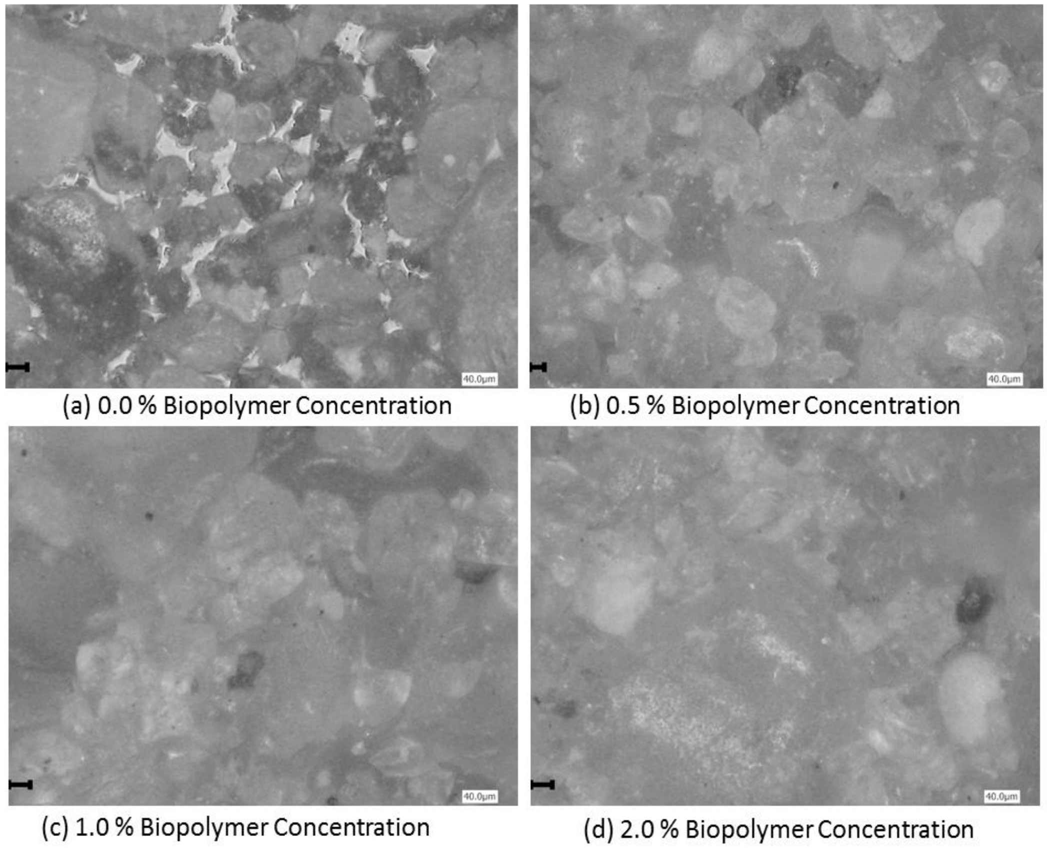

Fig. 6 Laser Microscope Photos (40 x Enlargement) of untreated and treated sand

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