Biopolymer soil stabilization for wind erosion control

Stabilisation des sols par biopolymères pour la lutte contre l'érosion éolienne

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ABSTRACT

Laboratory experiments indicate that spray-applied biopolymer mixtures and biopolymer admixtures for compacted soil may offer cost effective means of mitigating wind-induced soil erosion. Mitigating wind-induced erosion can be a serious geotechnical consideration due to the associated soil loss and air and water quality impacts. Agricultural soil loss is a serious concern worldwide. Air quality problems due to wind-induced erosion of fine grained soil (fugitive dust) from construction sites are common in arid and semi-arid regions. Conventional techniques for wind erosion control include frequent watering of the soil, application of covering materials (e.g. geosynthetic rolled erosion control products), and application of chemical stabilizers (e.g. hydrocarbon emulsions or synthetic polymeric emulsions). All of these techniques have limitations: application of water may require continuous treatment, particularly in relatively hot and arid climates; covering with geosynthetic materials can be expensive; chemical stabilizers can be expensive and have adverse environmental impacts. Biopolymers may offer a cost-effective alternative to these conventional techniques. Laboratory testing shows that surface application of a biopolymer emulsion can significantly increase the resistance of sandy and silty soil to wind-induced detachment. Experiments also suggest that the crust formed by the application of the biopolymer emulsion may be relatively stable in the field for an extended period of time. Compaction of soil with a biopolymer admixture, though more expensive than surface application, can achieve similar results and may provide enhanced resistance to surface water-induced erosion. Furthermore, the impacts of introducing the biopolymer into the environment are expected to be relatively benign.

RÉSUMÉ

Des essais en laboratoire montrent que l'utilisation de biopolymères, soit par arrosage, soit par mélange aux sols compactés peut constituer une solution économique permettant de réduire l'érosion des sols induite par le vent. Réduire l'érosion éolienne peut être un aspect important en géotechnique, compte tenu de la perte de sol et de son impact en terme de la qualité de l'air et de l'eau. L'érosion des sols agricoles est un problème mondial. Les problèmes de qualité de l'air induits par l'érosion éolienne des fines particules des sols(nuages de poussières) dans les chantiers de construction, sont courants dans les régions arides et semi-arides. Les techniques habituelles employées pour limiter l'érosion éolienne sont l'arrosage fréquent à l'eau, l'utilisation de matériaux (géosynthétiques spéciaux contre l'érosion) et l'utilisation de stabilisants chimiques (émulsions d'hydrocarbures ou de polymères synthétiques) Cependant, toutes ces techniques présentent des inconvénients; l'arrosage quand le climat est chaud et aride doit être effectué continuellement ; l'utilisation de couvertures synthétiques peut être une technique onéreuse ; l'utilisation de produits chimiques peut être aussi une technique onéreuse et présente un impact négatif en terme environnemental. Les biopolymères, peuvent constituer alors une solution alternative économique aux techniques conventionnelles. Les essais réalisés en laboratoire ont montré que l'épandage de biopolymères en surface d'un sol sableux ou limoneux augmentait la résistance à l'arrachement des grains par l'action du vent. Ces essais montrent également que la croute formée par l'épandage des biopolymères demeurait stable durant de longues périodes. De plus, l'effet des biopolymères sur l'environnement est marginal. Le mélange en masse de biopolymères avant le compactage permet d'atteindre des performances identiques à l'épandage, mais cette technique est plus onéreuse.

Keywords : biopolymers, wind erosion, fugitive dust control, soil erosion, construction

Mot-clés: biopolymers, érosion éolienne, poussière, érosion des sols construction

1 INTRODUCTION

Wind-induced soil erosion can have serious deleterious effects on the environment and human health. Environmental impacts include soil loss from agricultural areas and reduction in visibility. Serious health problems are attributable to fine-grained airborne soil particles, especially particles with a nominal size of 10 micrometers or less (sometimes referred to as PM-10). PM-10 particles can penetrate deep into bronchial tubes, causing asthma attacks, bronchitis, and other lung diseases (Pinal County 2009). The United States (US) Environmental Protection Agency (EPA) uses airborne PM-10 concentration as an air quality indicator. EPA designates areas exceeding the US National Ambient Air Quality Standard for PM-10 as "non-attainment" zones. The EPA can mandate strict controls on PM-10 sources, including earthwork construction sites, in non-attainment zones and impose financial penalties on areas that do not achieve compliance with the air quality standard. In addition to construction activities, sources of increased airborne PM-10 (or fugitive dust) concentrations include dust storms, wildfires, and agricultural activities.

Wind-induced soil erosion problems may be particularly severe in regions where vegetation is not easily established (as establishing vegetation is a primary means of erosion control). For instance, as shown in Figure 1, air-quality problems associated with fugitive dust (PM-10) are particularly troublesome in the semi-arid southwestern US.

Phoenix, Arizona, the 5th largest city in the US by population, is located in one of the USEPA designated air quality non-attainment zones by the US EPA. Phoenix experiences strong dust storms throughout the year. Earthwork construction activities, such as the one illustrated in Figure 2, are believed to be a major contributor to the air quality problems in Phoenix.

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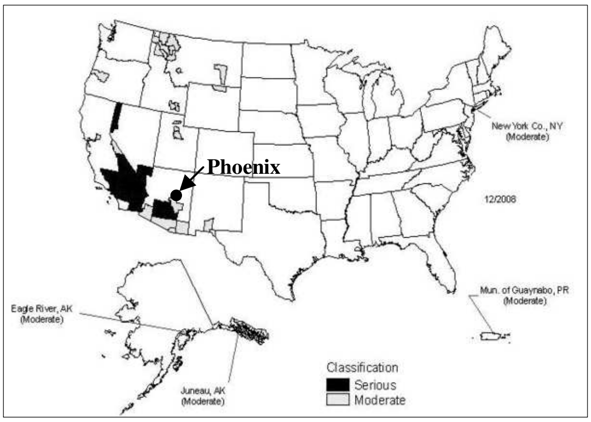

Figure 1. Counties in the US designated as air quality non-attainment zones for PM-10 (US EPA 2008a).

Figure 2. Front-end loader dumping soil into a haul truck with no dust control method implemented (Maricopa County 2009).

Conventional techniques for wind erosion (or dust) control at construction sites include frequent watering of the soil, application of cover materials (e.g. geosynthetic rolled erosion control products), and application of chemical stabilizers (e.g. hydrocarbon emulsions or cementing agents). All of these techniques have limitations: application of water may require continuous treatment, particularly in relatively hot and arid climates; covering with geosynthetic materials can be expensive; chemical stabilizers are expensive and can have adverse environmental impacts.

This paper summarizes the preliminary results from recent laboratory experiments at Arizona State University, USA, and discusses the potential use of biopolymers for soil stabilization for wind-induced erosion, both as spray-on emulsions and as admixture stabilizers.

2 BIOPOLYMERS

2.1 *Background*

Biopolymers are characterized as polymers either produced by microorganisms, plants, or animals or synthesized chemically from biological starting materials such as amino acids, sugars, oils (US COTA 1993). There are a variety of different types of biopolymers displaying different physical properties. Many industries, including oil exploration, textile, construction, cosmetics, pharmaceutics, food processing, and packaging industries make use of different types of biopolymers. Biopolymers have been used as adhesives, absorbents, lubricants, cosmetics, drug delivery vehicles, textiles, high-strength structural materials, thickeners for salad dressing, and even as computational switching devices.

Application of biopolymers in geotechnical and geoenvironmental engineering is relatively unexplored, compared to other areas. Proposed geotechnical and geoenvironmental applications have focused primarily on their use in hydraulic barriers (Martin et al. 1996, Karimi 1998, Mitchell & Santamarina, 2005). Research on the impact of biopolymers on the geotechnical properties of compacted soils was conducted by Karimi (1998), who performed hydraulic conductivity and triaxial shear strength tests on compacted specimens of Bonnie silt mixed with xanthan gum, a commercially available biopolymer. The results of the hydraulic conductivity tests indicated that the saturated hydraulic conductivity of Bonnie silt was reduced by two orders of magnitude when mixed with 0.3 percent xanthan gum by weight at a water content greater than the optimum moisture content of the silt and that this effect lasted for at least six months (Martin et al., 1996). Karimi (1998) also performed consolidated-undrained (CU) triaxial tests on compacted samples of Bonnie silt mixed with xanthan gum solution and observed an increase in the shear strength of soil samples with age (i.e., with curing time) for the compacted samples. The maximum deviatoric stresses measured by Karimi (1998) during the CU triaxial tests indicate shear strength improvement of up to 30 percent within a week for specimens prepared with a "gum 1%" solution and in about 4 weeks using a "gum 3%" solution, as shown in Fig. 3. Note that "gum 1%" solution corresponds to a xanthan gum content of 0.3 percent by weight (Karimi, 1998).

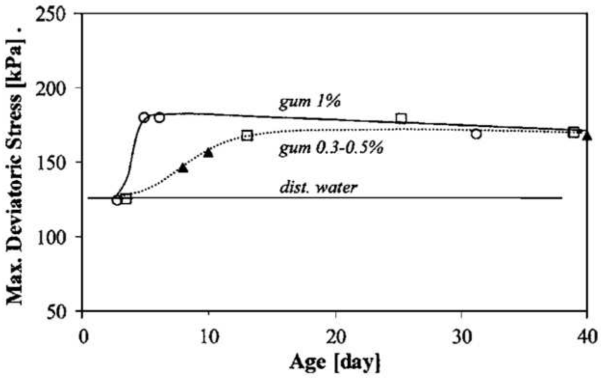

Figure 3. Change in shear strength of Bonnie silt mixed with xanthan gum with curing time (Martin et al. 1996, Karimi 1998)

The increase in shear strength with the addition of a biopolymer suggests that biopolymer admixtures may be useful for soil stabilization/erosion control. Although, biopolymers are currently used as a thickener with synthetic polymer sprays for erosion control, the use of a biopolymer itself as the stabilizing agent for erosion control has not been explored previously to the knowledge of the authors.

2.2 *Biopolymers used in ASU wind erosion experiments*

Two different commercially available biopolymers, xanthan gum and chitosan, were employed in wind-induced soil erosion control experiments recently performed at Arizona State University. Xanthan gum is a water-soluble extracellular polysaccharide produced by the bacterium *Xanthomonas campestris* during fermentation of glucose (Phillips & Williams 2000). Xanthan gum is commonly used in the food, ready-mix concrete, and drilling industries as a thickener because of its effect on the viscosity of the water even when applied at low concentrations. In addition, xanthan gum is stable over a wide range of temperature, pH, and salt concentration and displays a pseudoplastic behavior resulting in a reversible decrease in viscosity when subject to shear (Igoe 1983), which facilitates the mixing and subsequent application of this biopolymer for erosion control purposes.

Chitosan is produced from chitin in the shells of crustaceans (e.g., crabs, shrimp) after the edible parts have been removed and is one of the most common biopolymers found in the nature (US EPA 2008b). Chitosan is soluble in solutions with pH lower than 6.5 and is a positively charged bioadhesive (Kim et al. 1999, Sudhakar et al. 2006). Chitosan can selectively bind desired materials such as cholesterol, fats, metal ions, proteins, and tumor cells, resulting in a wide range of applications in pharmaceutics, agriculture, water treatment, and food industry (Li et al. 1992).

Although xanthan gum and chitosan are not the only biopolymers that have potential applications as wind-erosion reducing agents, these biopolymers were selected for trial experiments due to availability of extensive literature on their physical properties and their relatively lower cost compared to other biopolymers.

3 METHOD

The experiments discussed in this paper were designed to serve as proof of concept to evaluate the wind-erosion resistance of soils enhanced with biopolymers. Thus, a simple low-cost set-up consisting of aluminum pie plates (21.6 cm dia, 2.54 cm deep), aluminum ductwork (38 x 38 x 119 cm), and an industrial type stand fan was employed in the experiments. A non-plastic soil collected from a construction site in Phoenix was sieved through a No. 30 (0.6 mm) sieve to produce a sample representative of soils prone to wind-induced erosion in the Phoenix area. The sieved soil tested in the wind-erosion experiments can be classified as poorly graded non-plastic silty sand (SM in the Unified Soil Classification System). For each trial, an aluminum pie plate full of test soil was placed inside the aluminum conduit, 51 cm away from the end in contact with the fan and exposed to air flow for approximately 10 minutes. The aluminum conduit, shown schematically in Fig. 4, was used to direct the wind produced by the fan over the soil with minimal disturbance from the surrounding and allowed collection of the eroded soil. An anemometer placed within the conduit at the designated location of the aluminum pie plates measured the velocity of the air flow prior to the start of the experiments s approximately 26 km/hr).

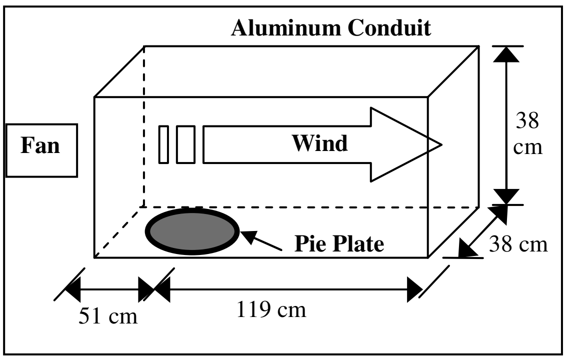

Figure 4. Schematic of wind erosion test set-up.

An initial series of tests was conducted on pie plates filled with soil treated by spraying on a biopolymer emulsion. Spray-on emulsion samples were prepared by placing the soil in the aluminum pie plate level with the rim of the plate and spraying a biopolymer emulsions evenly over the surface. Several different biopolymer concentrations and several different application rates were employed in these experiments. Control samples using untreated soil and soil treated with water without any biopolymer additive were also prepared. In the initial, the soil was placed in the pie plate dry at an approximate relative compaction of 70 percent, i.e. at approximately 70 percent of the maximum unit weight measured in the standard Proctor Compaction test. Xanthan gum emulsion was also used to prepare a compacted soil sample to assess the use of biopolymers as admixture stabilizers for wind-induced erosion. Soil mixed with the biopolymer emulsion was compacted in into the pie plate to a target relative compaction of 90 percent and at a moisture content ± 1 percent of the optimum moisture content as determined by the Standard Proctor compaction test.

The biopolymer-treated samples were left to cure under atmospheric pressure and room temperature (20^{o}C) for at least 24 hours prior to testing their wind erosion resistance. At the end of each experiment, the weight of the soil retained in aluminum pie plate was measured and "soil loss" was calculated as the amount of soil lost during the test to the initial weight of soil in the aluminum pie plate. The calculated soil loss was used as the measure of the effectiveness of the biopolymer in increasing wind-induced resistance.

In addition to the initial effectiveness of biopolymers on soil loss, the short-term durability of the biopolymer-treated soil subjected to ultraviolet radiation and to heat was also assessed. Soil samples treated with sprayed-on biopolymer were exposed to sunlight for one and two week periods and then tested for wind erosion resistance. Also, two samples treated with sprayed-on biopolymer were held in the oven for a week at 105^{o}C prior to testing for wind erosion resistance.

4 WIND EROSION EXPERIMENTS

4.1 *Preparation and application of biopolymer emulsions*

Xanthan gum emulsions were prepared at different concentrations by slowly adding the powder form of the gum into a container full with water while mixing it with a high-speed blender to prepare a homogenous emulsion. Chitosan emulsions, on the other hand, were prepared by dissolving the powder form of the biopolymer in 10 ml acetic acid and then mixing it with water plus 10 ml of ammonium hydroxide to remove the acidity of the emulsion.

For the specimens treated by spraying on the emulsion, the prepared emulsions were applied over the soil surface using plastic bottles with a trigger sprayer. For compacted samples, pre-determined amounts of biopolymer solutions and soil were mixed with dry soil to achieve the target dry density and moisture content immediately prior to compaction.

4.2 *Discussion of test results*

The results from the initial wind-erosion experiments on specimens treated with sprayed-on biopolymer emulsion are summarized in Table 1. The normalized application rate in Table 1 is the weight of biopolymer per unit surface area for sprayed-on samples and the weight of biopolymer per unit soil volume for the compacted samples. Table 1 indicates that significant reduction in soil loss was achieved by surficial application of the biopolymer emulsions, even for samples with lower normalized application rates. The soil loss was greater than 30 percent for the two trials using soil that was not treated with biopolymer or water. A reduction in soil loss of approximately three orders of magnitude was achieved by spray application of the xanthan gum biopolymer emulsions. The reduction is soil loss was approximately 2 orders of magnitude for the soil treated by spray application of the Chitosan emulsion. Application of water on the soil surface reduced the soil loss by between 1 and 2 orders of magnitude. It should be kept in mind that water typically must be applied repeatedly to the soil to maintain its effectiveness as a wind erosion (dust) control measure, particularly in arid and semi-arid climates.

Table 1. Initial wind erosion performance of biopolymer treated soil

Sample type	Biopolymer	Strength of solution (g/L)	Normalized application rate	Soil loss (%)
Dry	N/A	0	0 g/m^2	32
Dry	N/A	0	0 g/m^2	65
Wet	N/A	0	0 g/m^2	1
SPRY	XG	0.5	0.2 g/m^2	0.04
SPRY	XG	0.5	0.5 g/m^2	0.03
SPRY	XG	0.5	1.1 g/m^2	0.02
SPRY	XG	2	2.2 g/m^2	0.03
SPRY	XG	2	4.0 g/m^2	0.03
SPRY	XG	2	6.2 g/m^2	0.02
SPRY	CH	1	0.5 g/m^2	0.35
COMP	XG	0.5	138 g/m^3	0.04

SPRY: sprayed-on, COMP: compacted, XG: xanthan gum, CH: chitosan

The main mechanism by which the wind erosion resistance was enhanced by spray-application of the biopolymer emulsion appeared to be the formation of a crust on the treated specimens. The thickness of the crust varied from approximately 4 mm to 13 mm, increasing with increasing normalized application rate. Creation of three equally-spaced 3-cm wide continuous grooves that penetrated entirely through the crust on the soil surface prior to testing virtually eliminated the benefit of spray-on biopolymer application, increasing soil loss to a value comparable to that for untreated dry soil, i.e. to a soil loss of over 25 percent. The results of the test on the compacted soil sample treated with Xanthan gum are also reported in Table 1. The decrease in soil loss following compaction of the test soil to a water content within 1% of the optimum water content from the Standard Proctor compaction test but using a xanthan gum solution instead of water was similar to that of the soil treated with sprayed-on biopolymer emulsion.

The results of tests for the short term durability of the specimen treated with spray-on emulsion subject to ultraviolet radiation and to heat are reported in Table 2. Treated specimens were tested after exposure to sunlight for one and two week periods. The average air temperature over the exposure period was over 38^{o}C. As shown in Table 2, the wind erosion resistance of the specimens exposed to sunlight degraded by approximately an order of magnitude but still had an erosion resistance two orders of magnitude greater than dry specimens with no biopolymer treatment. However, treated specimens held in an oven for a week at 105^{o}C showed soil loss essentially equivalent to the dry samples with no biopolymer treatment.

Table 2. Durability of samples treated with spray-on biopolymer emulsion

Sample type	Exposure / time	Strength of solution (g/L)	Normalized application rate	Soil loss (%)
XG	UV / 1 wk	0.5	0.2 g/m^2	0.25
XG	UV / 2 wk	0.5	0.2 g/m^2	0.17
XG	105^{o}C / 1 wk	0.5	0.2 g/m^2	35
CH	105^{o}C / 1 wk	1.0	0.5 g/m^2	45

XG: xanthan gum, CH: chitosan.

5 SUMMARY AND CONCLUSION

Results indicate that biopolymers can act as a stabilizing agent against wind-induced erosion. Both spray-on application and mixing of a biopolymer emulsion with the soil prior to compaction were shown to be effective. Testing also indicates that biopolymer-stabilization against wind erosion remains effective when exposed to sunlight and summer temperatures (daily maximum temperature approximately 38^{o}C) for periods of at least two weeks. However, heating at 105^{o}C for a period of one week results in a loss of stabilization against wind erosion for a soil treated with sprayed-on biopolymer emulsion.

The initial proof-of-concept experiments described in this paper demonstrate that biopolymer application shows promise as a soil improvement measure for wind erosion control. However, additional testing is required to establish the cost-effectiveness of biopolymer stabilization. Laboratory testing should include testing for durability when exposed to surface water flow and infiltration and when subject to wetting and drying cycles and testing to establish optimal application concentrations and rates. Ultimately, test sections are required to demonstrate the effectiveness of biopolymer stabilization in the field. Once these factors have been assessed, the cost-effectiveness of biopolymers for wind erosion control can be established.

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REFERENCES

Igoe, R.S. 1983. Dictionary of Food Ingredients. Van Nostrand and Reinhold Company.

Karimi, S. 1998. A study of geotechnical applications of biopolymer treated soils with an emphasis on silt. Ph.D. Dissertation. University of Southern California. 167 p.

Kim, S., Choi, J., Balmaceda, E.A., Rha, C. 1999. Chitosan. Cell Encapsulation Technology and Therapeutics. Kühtreiber, W.M., Lanza, R.P., Chick, W.L. (Eds.). Published by Birkhäuser.

Li, Q., Dunn, E.T., Grandmaison, E.W., Goosen, M.F.A. 1992. Applications and Properties of Chitosan. Journal of Bioactive and Compatible Polymers. Vol. 7, 370-397.

Maricopa County. Dust compliance – photographs of common violations.http://www.maricopa.gov/aq/divisions/compliance/dust/resources.aspx#dust_information. Accessed on 12 January 2009.

Martin, G. R., Yen, T. F., and Karimi, S. 1996. Application of biopolymer technology in silty soil matrices to form impervious barriers. Proc., 7th Australia-New Zealand Geomechanics Conference, Adelaide, Australia.

Mitchell, J.K. and Santamarina, J.C. 2005. Biological considerations in geotechnical engineering. Journal of Geotech. and Geoenvr. Engineering. Vol. 131, No. 10, 1222-1233.

Phillips, G.O. and Williams, P.A. 2000. Handbook of Hydrocolloids. Published by CRC Press.

Pinal County. Dust storms and Monsoon season. http://pinalcountyaz.gov/Departments/AirQuality/Pages/DustStorms.aspx . Accessed on 12 January 2009.

Sudhakar, Y., Kuotsu, K., Bandopadhyay, A.K. 2006. Buccal bioadhesive drug delivery – a promising option for orally less effective drugs. Journal of Controlled Release. 114:15–40.

US Congress Office of Technology Assessment (COTA) 1993. Biopolymers: Making Materials Nature’s Way-Background Paper. OTA-BP-E-102. Washington, DC: U.S. Government Printing Office, September.

US Environmental Protection Agency (EPA). 2008a. The Green Book - Nonattainment areas for criteria pollutants. http://www.epa.gov/oar/oaqps/greenbk/. Last updated 17 December 2008.

US Environmental Protection Agency (EPA). 2008b. Chitosan; Poly-D-glucosamine (128930) fact sheet. http://www.epa.gov/pesticides/biopesticides/ingredients/factsheets/factsheet_128930.htm. Last updated 17 December 2008.