



USE OF GREEN SOIL STABILIZATION FOR PROTECTION OF ROADSIDES AGAINST WIND EROSION

Dunja Perić¹, Arash Olia²

¹ Department of Civil Engineering, Kansas State University, USA

² Kiewit Corporation, USA

Abstract

This study experimentally evaluated a sustainable and environmentally friendly protection of roadsides from wind erosion. The approach relies on use of lignin, a bio-polymer that is a by-product of paper mill and bio-fuel industries. Lignin is the main component of the plant cell wall that enhances its rigidity while its hydrophobic properties promote transport through vascular plant bundles. Plant skeleton is formed by lignin, cellulose and hemicellulose. Lignin is naturally generated through photosynthesis resulting in 50 billion tons per year, and lignin isolated from lignocellulosic biomass is the second most abundant natural polymer next to cellulose. Lignosulfonates are produced from lignin by sulfite pulping process of the wood. They are renewable, inherently bio-degradable and non-toxic, thus offering a sustainable alternative to use of synthetic polymers for protection of near-surface soil from wind erosion. In this study the effectiveness of lignosulfonates in protecting the near-surface soil from wind erosion was evaluated by conducting laboratory scale erosion tests in a wind tunnel. The selected silty soil was oven dried, placed loosely in a tray, and sprayed with different concentrations of lignosulfonate water solutions at different spraying rates. The trays were placed in the wind tunnel in an inclined position, and exposed to a wind duration of 15 min. The wind speeds varied between 38 and 54 km/h. Spraying the soil with lignosulfonate solutions either completely suppressed the soil erosion or significantly decreased it compared to 78 to 91% erosion of unprotected soil. Therefore, the lignosulfonate offers environmentally friendly, effective and sustainable protection of roadsides from wind erosion during the critical construction phase prior to emergence of protective vegetation.

Keywords: green soil stabilization, lignin, near-surface soil, sustainability, wind erosion

1 Introduction

Soil erosion refers to dislodging of soil particles by water and wind. In 2002, 126.82 million tons of soil was eroded on cropland in Kansas [1]. In addition to cropland, erosion occurs on unpaved roads and on roadsides during road construction. Moreover, wind erosion is detrimental to ground and air transportation due to possible impairment of visibility. For example, a series of collisions involving 164 vehicles occurred on Interstate 5 in San Joaquin Valley, in California, in 1991, during a dust storm that reduced the visibility to nearly zero [2]. Acceleration of uncontrolled erosion with time necessitates development and application of erosion mitigation techniques. In the past rapid revegetation including quick growing grasses, manual placement of harvested straw, placement of erosion control blankets and use of compost on embankments [3] was used to control the erosion.

Although vegetative stabilization is efficient in preventing wind erosion while improving wildlife habitats and aesthetics, clearing of vegetation prior to construction makes the exposed soil more vulnerable to erosion during the construction. New vegetation is established only after the completion of the construction.

This study adopted a sustainable and environmentally friendly approach for control of wind erosion that relies on the use of lignin, a bio-polymer, which is a by-product of paper mill and bio-fuel industries. Lignin is a natural phenolic polymer with complex composition and structure and high molecular weight. It forms a plant skeleton together with cellulose and hemicellulose and it enhances the rigidity of the cell wall while its hydrophobic properties promote transport through the vascular plant bundles [4]. It is a renewable material as it possesses the ability to regenerate in natural conditions through the photosynthesis, thus resulting in approximately 50 billion tons per year [5]. Lignosulfonates are produced from lignin by sulfite pulping process of the wood and they are non-toxic, thus offering environmentally friendly and sustainable alternative to synthetic polymers. This makes them ideally suited for protection of soil against wind erosion.

The potential of lignosulfonate as a dust palliative was demonstrated in [6] and [7] while the silty sand stabilized by lignin offered superior resistance to water erosion as compared to Portland cement treated soil [8].

The principal goal of this study was to assess effectiveness of sodium/calcium lignosulfonate in protecting roadsides from wind erosion during the critical construction phase that occurs prior to emergence of new vegetation. To reach this goal the experimental study was devised and experiments were conducted on protected and unprotected soil. Details of the experimental program are provided in the next section.

2 Experimental program

Experimental program comprised basic soil classification tests, laboratory hand penetrometer tests and wind erosion tests on a sloped soil. Basic soil classification tests included sieve analysis, hydrometer test and determination of Atterberg limits. The experimental program for laboratory hand penetrometer tests is shown in Table 1. Each test was repeated two times, resulting in a total of three tests for a given testing configuration. The strength of unprotected soil was measured prior to the spraying it with lignin solution.

Table 1 Experimental Program for laboratory hand penetrometer tests

Lignin solution concentration [%]	Spraying rate [l/m ²]			
	0.66	1.32	2.00	3.53
0	3	3	3	3
1	3	3	3	3
2	3	3	3	3
4	0	3	0	3

Experimental program for wind erosion tests on the sloped soil, which were conducted in a wind tunnel, is shown in Table 2. Each test was conducted at three different wind speeds, resulting in a total of 24 tests.

Table 2 Experimental program for wind erosion tests on sloped soil

Lignin solution concentration [%]	Spraying rate [l/m ²]				
	0	0.66	1.00	1.32	3.53
0	3	-	-	-	-
1	-	3	3	3	3
2	-	3	3	3	0

3 Results

3.1 Basic soil classification Tests

In accordance with Unified Soil Classification System (USCS) the selected fine-grained soil classified as a silt of low plasticity (ML) with corresponding liquid limit of 32 and plastic limit of 24. This study also determined Atterberg limits of the soil and lignin mixes using Borregaard LignoTech Norlig G [9] or lignin. Norlig G is a neutral pH, purified calcium/sodium lignosulfonate solution in water that contains 58% of solids. In this study Norlig G was further diluted by adding water as needed. Lignin extracted from wood chips is subsequently sulfonated using hydrogen sulfite, introducing sulfonic and acid groups onto the lignin structure and resulting in a water-soluble polymer [10]. Norlig G has a high molecular weight, making it highly viscous and resistant to flow. Lignin gravimetric content (χ_l) is defined by Eq. (1):

$$\chi_l = \frac{M_l}{M_s} \quad (1)$$

where M_l is mass of lignin solids and M_s is mass of soil solids. For soil-lignin mixes modified moisture (w) content was measured to determine the corresponding modified Atterberg limits. It is defined by

$$w_l = \frac{M_w}{M_l + M_s} = \frac{w}{(1 + \chi_l)} \quad (2)$$

where M_w is mass of water and w is standard gravimetric moisture content. Liquid and plastic limits based on both, the standard and modified water contents decrease with increasing lignin content. Nevertheless, plastic limit exhibits larger rate of decrease, resulting in increased plasticity index as compared to pure soil. Consequently, the classification of soil-lignin mixes containing 2%, 4% and 6% of lignin by mass changes from ML to clay of low plasticity (CL).

3.2 Laboratory hand penetrometer tests

This study sprayed lignin solutions onto the surface of soil prior to hand penetrometer tests. To simulate field conditions, the soil for these tests was oven dried, grinded, and placed loosely in 5.08 cm deep trays. Hand penetrometer (Gilson Soil Pocket Penetrometer HM-500) was used to measure the unconfined compression strength (UCS) of the soil. Measurements were taken during the 24 hour period following immediately after spraying by pushing a penetration piston measuring 0.635 cm diameter into the soil to a groove machined on the piston at 0.635 cm. Penetration resistance from the calibrated spring was registered on an integrated scale, engraved on the penetrometer barrel. Scale units were shown, and a sliding indicator ring retained the reading until reset.

An optional adapter foot attachment with increased piston area was available for very soft soils. Three measurements were averaged to obtain the final reading and minimize reading errors. Development of UCS vs. time depicted in Fig. 1 shows that the maximum strength in this case was achieved in the time period up to four hours after spraying. Strength of soils sprayed at lower spraying rates subsequently decreased to an early post-peak value and remained approximately constant up to 24 hours after spraying. The strength of the soil sprayed at 3.52 l/m² showed a small additional decrease beyond the early post-peak strength. The larger the spraying rate, the larger the strength at any time. It is believed that development of maximum strength can be attributed to an integral action of lignin induced cohesion and suction. With further drying suction becomes negligible, thus leaving the lignin induced cohesion as the principal mechanism responsible for the strength gain.

Fig. 2 shows a plot of UCS versus spraying rate. Peak and early post peak strengths increased exponentially with increasing spraying rate, with peak strength showing larger rate of increase. Although Fig. 2 includes different lignin concentrations they clearly have minor effect on UCS compared to the effect of spraying rate.

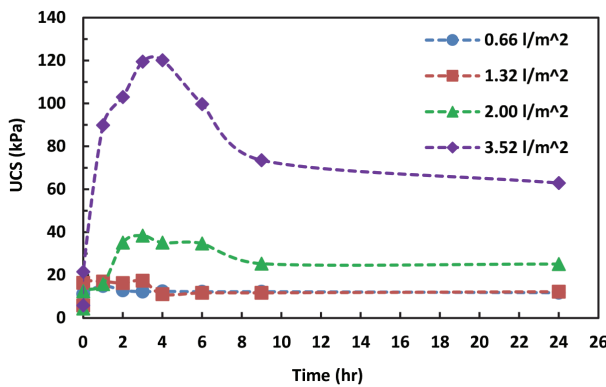


Figure 1 Results of laboratory hand penetrometer tests vs. time at $x_1 = 2\%$

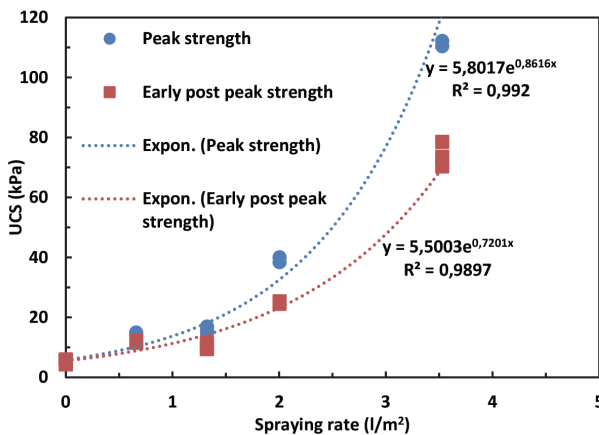


Figure 2 Hand penetrometer based UCS vs. lignin solution spraying rate

3.3 Wind erosion tests

Samples for wind erosion tests were prepared following the preparation procedure used for laboratory hand penetrometer tests. In this case the soil was deposited in 121.9 cm long, 20.3 cm wide and 2.54 cm deep container. The container was inclined at 18.4° towards the horizontal direction and placed inside the wind tunnel constructed from PVC frame and transparent polyvinyl fabric. Wind was generated by placing a blower in front of the wind tunnel. Three anemometers were placed near the container for measurement of the wind speed. Duration of all tests was 15 minutes. The container with the sprayed or unprotected soil, as the case may be, was weighted immediately prior to each test and upon the completion of the test, thus providing the weight of eroded material.

Fig. 3 shows percentage of the eroded soil mass vs. spraying rate for wind speeds of 42.8 kph and 49.9 kph. Experimental data include different lignin solution concentrations. Quadratic functions were fitted to the experimental data, indicating a quadratic decay of eroded soil mass vs. increasing spraying rate. Equations of the quadratic functions along with the corresponding values of the coefficients of determination are provided in Fig. 3.

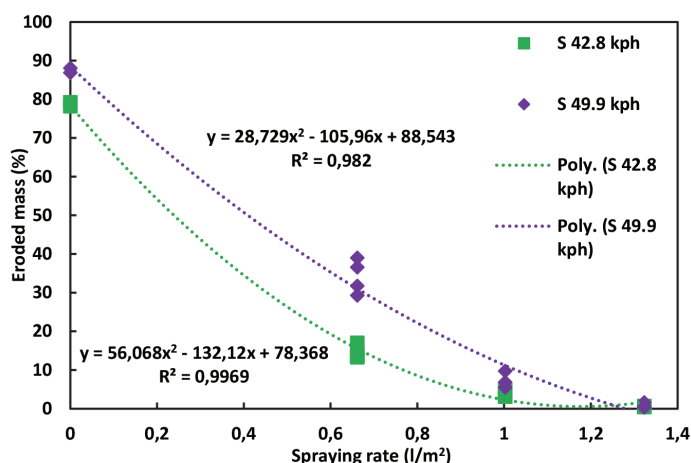


Figure 3 Mass of eroded dry soil vs. wind speed for different spraying rates and lignin solution concentrations applied to sloped soil

As expected, mass of eroded material increases with increasing wind speed while lignin solution concentration has a very minor effect on erosion. Based on the experimentally established relationships between UCS and spraying rate (Fig. 2), and eroded mass and spraying rate (Fig. 3) the relationship between eroded mass and UCS can be derived for wind speeds of 42.8 kph and 49.9 kph. It is given by

$$E = a_1 (\ln q_u)^2 + a_2 \ln q_u + a_3 \quad (3)$$

where q_u is unconfined compression strength obtained from hand penetrometer. Eq. (3) is depicted in Fig. 4 for two different wind speeds. Parameters a_1 , a_2 and a_3 are equal to 50.068, -132.12 and 78.368 for wind speed of 42.8 kph, and 28.729, -105.96 and 88.543 for wind speed of 49.9 kph.

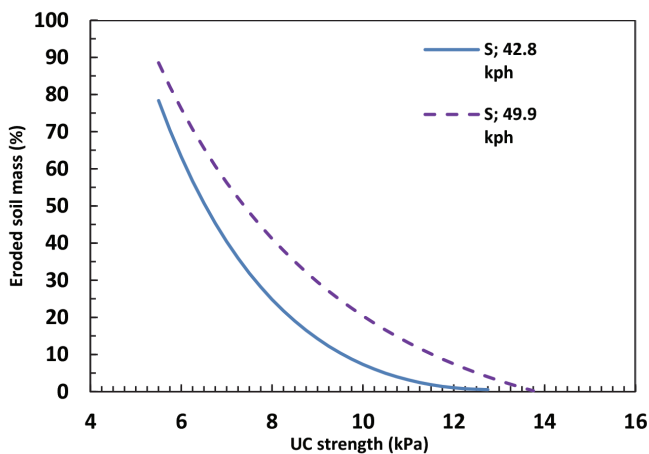


Figure 4 Eroded mas (%) vs. UC strength (kPa) for wind erosion tests on sloped soil

5 Conclusion

Experimental program was conducted in the laboratory to assess the effectiveness of lignin in preventing the wind erosion on the roadsides during the critical construction period prior to emergence of vegetative cover. In addition to sieve analysis, hydrometer and determination of Atterberg limits, laboratory hand held penetrometer tests and wind erosion tests were conducted. The results indicate that spraying rate of lignin solution has a major effect on both, UCS and percentage of eroded soil while lignin solution concentration has very marginal effect on UCS and erosion. In this study spraying rates equal and larger than 1.32 l/m^2 at lignin solution concentrations 1% and 2% completely prevented erosion for the duration of the test. The bonds that lignin forms with particles are responsible for both, increase in UCS and decrease of erosion, thus enabling establishment of a relationship between UCS and erosion that can be used for a quick estimate of the treated soil protection against erosion.

Acknowledgment

Both authors gratefully acknowledge funding provided by Kansas Department of Transportation through the KTRAN program.

References

- [1] The state of erosion on U.S. farms, Successful Farming, www.agriculture.com/crops/conservation/the-state-of-erosion-on-us-farms, 02.02.2024.
- [2] Pauley, P.M., Baker, N.L., Barker, E.H.: An observational study of the “Interstate 5” dust storm case, *Bulletin of the American Meteorological Society*, 77 (1996) 4, pp. 693–720
- [3] Barkley, T.: Erosion control with recycled materials, *Public Roads*, 67 (2004) 5, <https://highways.dot.gov/public-roads/marchapril-2004/erosion-control-recycled-materials>
- [4] Schuetz, M., Benske, A., Smith, R.A., Watanabe, Y., Tobimatsu, Y., Ralph, J., Demura, T., Ellis, B., Samuels, A.L.: Laccases direct lignification in the discrete secondary cell wall domains of protoxylem, *Plant Physiology*, 166 (2014), pp. 798–807
- [5] Shen, D., Jin, W., Hu, J., Xiao, R., Luo, K.: An overview of fast pyrolysis of the main constituents of lignocellulosic biomass to valued-added chemicals: Structures, pathways and interactions, *Renew-*

able and Sustainable Energy Reviews, 51 (2015), pp. 761–774

- [6] Surdahl, R., Woll, J., Everett, R., Andersen R.: Road stabilizer product performance: Buenos Aires National Wildlife Refuge (Report No. FHWA-CFL/TD-05-011), Federal Highway Administration, 2005.
- [7] Woll, J.H., Surdahl, R.W., Everett, R., Andersen, R.: Road stabilizer product performance: Seedskade National Wildlife Refuge (Report No. FHWA-CFL/TD-08-005), Federal Highway Administration, 2008.
- [8] Indraratna, R., Muttuvel, T., Khabbaz, H.: Modelling the erosion rate of chemically stabilized soil incorporating tensile-force deformation characteristics, Canadian Geotechnical Journal, 46 (2009) 1, pp. 57–68, 2009.
- [9] Borregaard: Norlig G product description sheet, LignoTech, 2008.
- [10] Your guide to lignin and lignosulfonates, <https://www.borregaard.com/product-areas/lignin/your-guide-to-lignin-and-lignosulfonates>, 28.2.2024.

