

1964

Soil Stabilization with Polystyrene

Gilbert L. Roderick
Iowa State University

Turgut Demirel
Iowa State University

Copyright © Copyright 1964 by the Iowa Academy of Science, Inc.
Follow this and additional works at: <https://scholarworks.uni.edu/pias>

Recommended Citation

Roderick, Gilbert L. and Demirel, Turgut (1964) "Soil Stabilization with Polystyrene," *Proceedings of the Iowa Academy of Science*: Vol. 71: No. 1, Article 54.
Available at: <https://scholarworks.uni.edu/pias/vol71/iss1/54>

This Research is brought to you for free and open access by UNI ScholarWorks. It has been accepted for inclusion in Proceedings of the Iowa Academy of Science by an authorized editor of UNI ScholarWorks. For more information, please contact scholarworks@uni.edu.

Soil Stabilization with Polystyrene¹

GILBERT L. RODERICK AND TURGUT DEMIREL²

Abstract. This paper presents results of an investigation of the effect of polystyrene on the engineering properties of three soils. Use of a polystyrene-benzene solution as an admixture resulted in increased strength values. Satisfactory resistance to expansion and frost action was obtained with sandy and silty soils; unsatisfactory results were obtained with a clayey soil. Polystyrene stabilization is most effective with sandy soils; effectiveness decreases with increasing clay content. At present the method does not compare favorably with the economics of other available methods of stabilization.

Much of the recent research on soil stabilization has been with synthetic resins which cement or bond the soil particles together. One such synthetic resin is polystyrene, one of the most widely produced of the synthetic, aromatic, organic chemicals on the market. It is a completely non-toxic, inert, tough and extremely amorphous substance.

Mainfort (1, 2, 3) investigated many synthetic resins for soil stabilization, including several commercial styrene resins. He reported that most of these styrene resins were slightly effective, but they proved to be unsuitable under severe laboratory tests.

LABORATORY INVESTIGATION

Soils and Admixtures

Three soils were used: a friable Wisconsin Age loess, a plastic Wisconsin Age loess and a dune sand (Table 1). The polystyrene used was a commercial product which expands to a white opaque foam when heated. This foam was more easily dissolved than was unexpanded polystyrene. Reagent grade benzene was used. Distilled water was used in all tests.

Preliminary Work

A preliminary investigation of the effectiveness of various polystyrene solvent systems was conducted with miniature test specimens (4). On the basis of this screening study, a 40 percent polystyrene-60 percent benzene solution was chosen for use in the main investigation.

¹ The subject matter of this report was obtained as a part of Project 505-S of the Iowa Engineering Experiment Station, and Project HR-97 of the Iowa Highway Research Board with funds supplied by the Iowa State Highway Commission.

² Research Associate and Assistant Professor, respectively, Iowa Engineering Experiment Station, Iowa State University, Ames, Iowa.

Table 1. Description and Properties of Soils.

Sample	Friable loess (Lab No. 20-2)	Plastic loess (Lab No. AR-7)	Dune sand (Lab No. S-6-2)
Textural composition, %			
Gravel (>2.0mm)	0	0	0
Sand (2.0-0.074mm)	0.4	0.2	94
Silt (0.074-0.005mm)	80.0	60.8	4
Clay (<0.005mm)	19.6	39.0	2
Clay (<0.002mm)	16.0	33.0	..
Predominant clay mineral	Montmorillonite	Montmorillonite	Montmorillonite
Physical properties			
Liquid limit, %	30.8	52.1	..
Plastic limit, %	24.6	20.0	..
Plasticity index	6.2	32.1	Non-plastic
Shrinkage limit %	22.3
Chemical properties			
Cat. ex. cap., m.e./ _{100g}	13.4	23.5	..
Carbonates, %	10.2	1.5	Non-calcareous
pH	8.7	5.6	..
Organic matter, %	0.2	0.2	..
Classification			
Textural	Silty loam	Silty clay	Fine sand
Engineering (AASHO)	A-4(8)	A-7-6(18)	A-3(0)

Method of Investigation

Specimen preparation. The required amount of 40 percent polystyrene—60 percent benzene solution was thoroughly mixed with the soil. Distilled water was added to give the desired volatile content and mixing continued. Immediately after mixing, three 2" high by 2" diameter specimens were molded with a drop-hammer apparatus. The specimens were weighed and measured, and moisture samples were taken.

Curing. The specimens were cured by air drying at room temperature and humidity for seven days. They were then weighed and measured again to determine volatile loss and shrinkage.

Testing. At the end of the curing period the specimens were immersed in distilled water for 24 hours. They were measured, weighed again, and tested for unconfined compressive strength (immersed strength).

DISCUSSION OF RESULTS

Effects on Immersed Strengths and Dry Densities

Mix designs investigated contained the following percentages of polystyrene (based on the oven dry weight of soil) for the various soils:

- Friable loess—5, 7 and 9 percent
- Plastic loess —5, 7, and 8 percent
- Dune sand —2, 3 and 4 percent

Greater amounts with the two later soils resulted in mixtures which could not be molded satisfactorily because they stuck to the molding apparatus.

For each soil-admixture combination several sets of specimens, at various volatile contents, were prepared. The volatile content within a set was maintained at ± 1.0 percent; the dry densities were maintained within ± 2 pcf (5). The immersed strengths obtained for individual specimens of a set were maintained within 10 percent of the average value for the set, as required by ASTM Designation C109-54T (6).

Plots of immersed strengths vs volatile contents are presented in Figure 1 for the various soils and mix designs investigated.

Figure 1a shows that increasing the polystyrene content of the friable loess resulted in substantial gains in immersed strength, approximately 300 psi for the maximum strength for each 2 percent increase in polystyrene. Optimum molding volatile content for maximum strengths were 12.6, 16.2 and 15.1 percent, respectively, for polystyrene contents of 5, 7 and 9 percent.

Figure 1b shows that the strength increase with increasing polystyrene content was not as great with plastic loess. An increase of about 200 psi for the maximum strength occurred when the polystyrene was increased from 5 to 7 percent. At higher contents no strength increase was obtained. With the higher polystyrene contents and higher volatile percentages satisfactory specimens could not be obtained. Optimum molding volatile contents for maximum strengths were 17.3 and 17.4 percent, respectively, for polystyrene contents of 5 and 7 percent.

Figure 1c shows that the maximum immersed strengths were obtained with the dune sand at the lowest volatile contents, when the soil was mixed with the polystyrene-benzene solution alone. When water was added the strengths obtained decreased, the rate of decrease being greater at higher polystyrene contents. In each case, a minimum strength was reached at a molding volatile content between 8 and 9 percent.

Plots of dry density vs molding volatile content for the various soils and mix designs are presented in Figure 2.

Figure 2a shows that for the friable loess the optimum molding volatile contents for maximum densities did not correspond with those for maximum strengths. Also, the maximum dry densities were nearly the same for all polystyrene contents investigated. Figure 2b shows a similar pattern for the plastic loess. However, the increase in maximum density with increasing polystyrene content was greater.

Figure 2c, for the dune sand, exhibits a volatile content-density relationship similar to that obtained with volatile content vs immersed strength. The highest dry density values were obtained at the lowest volatile content, i.e., when no water was added to

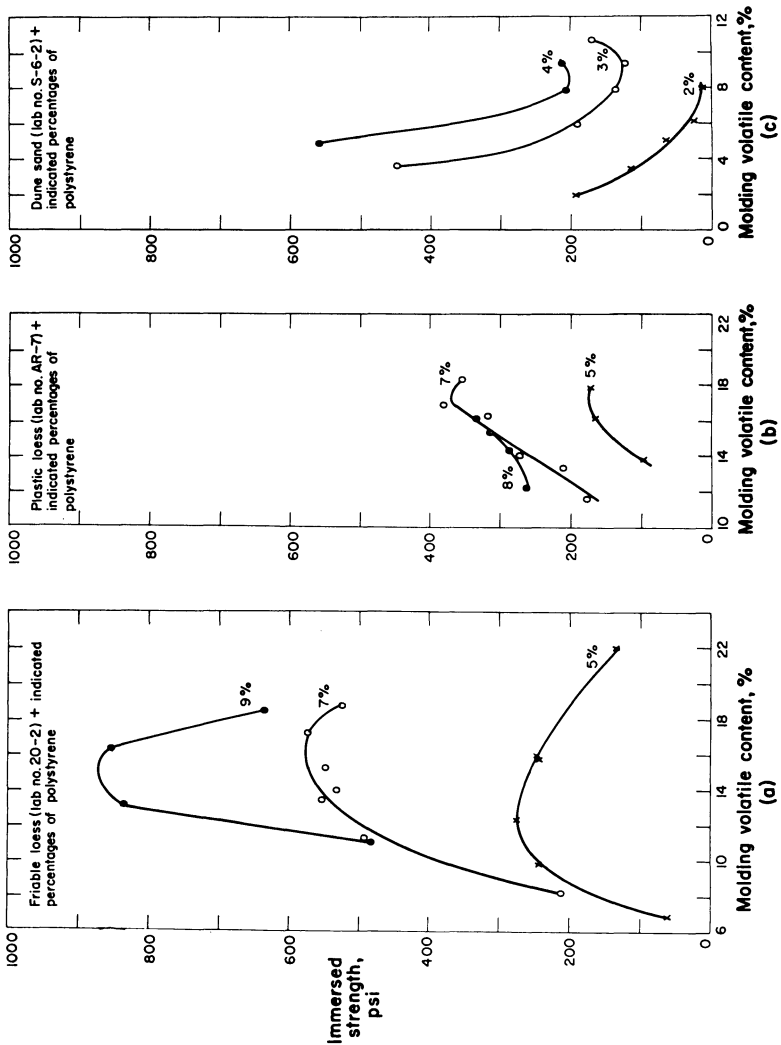


Figure 1. Effect of polystyrene on molding volatile content-immersed strength relationships. (a) friable loess (b) plastic loess (c) dune sand

the soil-polystyrene mixture. The curves also show an increase in density at higher volatile contents.

The difference in the volatile content vs strength and density relationships obtained for the loess and sand soils may have an explanation.

When the polystyrene solution alone is mixed with the sand, it coats individual grains. When the volatiles evaporate, solid polystyrene left between the grains adheres to them and binds them together. Water is a non-solvent for polystyrene. It has

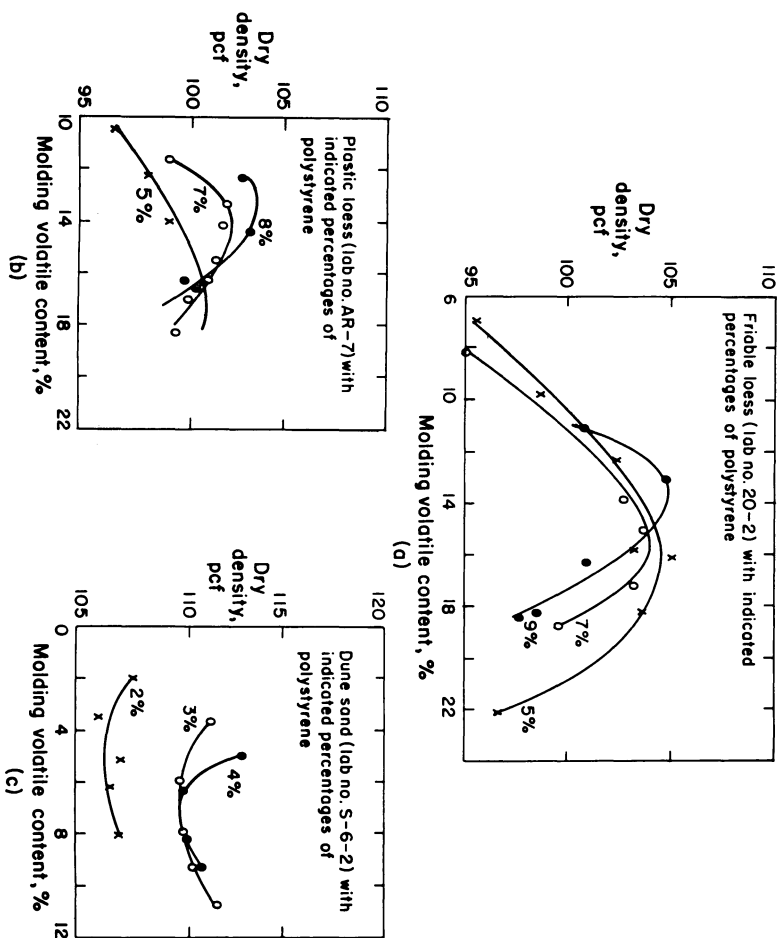


Figure 2. Effect of polystyrene on molding volatile content-dry density relationships. (a) friable loess (b) plastic loess (c) dune sand

been shown that the additions of increasing amounts of a non-solvent to a polystyrene solution will result in precipitation of some of the polystyrene (7). This premature precipitation may be a cause of decreased strengths obtained when water is mixed with a sand-polystyrene solution system. However, most of the strength loss is probably due to the hydrophilic nature of quartz grains which causes each grain to be surrounded by a film of water. This film prevents contact between the sand grains and polystyrene solution which is present as globules between water coated grains. During curing, the benzene evaporates more rapidly than the water. Thus, much of the polystyrene solidifies before the water film about the sand grains has evaporated; the water film prevents adherence of the polystyrene to sand grains

prior to solidification. The resultant system is one of solid polystyrene particles and sand grains, most of which are not very effectively bound together. At higher water contents more thorough mixing and dispersion of the polystyrene solution may be obtained, resulting in increased strengths.

For the loess soils the volatile content vs strength and density relationships follow the more usual pattern of increasing strength or density with increasing volatile content until a maximum is reached, and then values decrease with further increase of volatiles. With these soils the addition of water is necessary to obtain a workable mixture and to attain a thorough distribution of the polystyrene. Also, finely divided solids may act as dispersing agents (8, 9); so the clay sized particles may aid in dispersing the polystyrene globules in the aqueous medium and thereby effect a more even distribution. Upon curing, a system of solid polystyrene adhering to and binding together soil grains or agglomerates is attained. With higher volatile contents less effective compaction is attained, and the strength values decrease.

Effect on Expansion

In addition to strength, the amount of shrinkage upon drying and expansion upon wetting are important criteria in the evaluation of soils for engineering purposes. Excessive shrinking or swelling may cause cracking, settling, or heaving of the soil structure and thus damage structures or road components resting on the soil.

For bituminous stabilized soils used as base courses for roads, a recommended requirement with respect to expansion is that the volumetric swell is not greater than 5 percent of the volume of the test specimen before adsorption (10). This value is significant in respect to distortion of the pavement. Assuming expansion to be the same in horizontal and vertical directions, the allowable linear expansion would be about 1.6 percent.

From the measurements of the test specimens prior to and after immersion in distilled water, the linear expansions on immersion were calculated. At the optimum volatile contents for strength the calculated values for linear expansion of the various soils were as follows:

Friable loess—0.9, 1.3 and 1.4 percent for 5, 7 and 9 percent polystyrene, respectively.
Plastic loess—3.2 and 2.7 percent for 5 and 7 percent polystyrene, respectively.
Dune sand—0.3, 0.3 and -0.2 percent for 2, 3 and 4 percent polystyrene, respectively.

On the basis of allowable linear expansion of 1.6 percent, therefore, the friable loess and dune sand would be suitable for

road base courses when stabilized with the amounts of polystyrene investigated. The stabilized plastic loess would not be suitable.

Frost Susceptibility

The Iowa Freeze-Thaw Test (11) was conducted with both unstabilized and stabilized specimens of each of the three soils. The stabilized specimens contained 7, 7, and 3 percent polystyrene, respectively, for the friable loess, plastic loess and dune sand. The effect of alternate freezing and thawing was based on the deformation of the sample and the loss of strength. The results are tabulated in Table 2.

Table 2. Effect of 10 Cycles of Freezing and Thawing and of 11 Days of Immersion on Stabilized and Unstabilized Soil Specimens.

	Friable loess		Plastic loess		Dune sand	
Polystyrene content, %	0	7	0	7	0	3
Linear expansion after 10 cycles freeze-thaw, %	37.5	1.86	25.0	5.09	9.4	0.15
Linear expansion after 11 days immersion, %	...	1.78	...	5.73	...	0.17
Unconfined compressive strength after 10 cycles freeze-thaw (P _f), psi	...	456.0	...	110.7	...	333.3
Unconfined compressive strength after 11 days immersion (P _c), psi	...	442.0	...	113.0	...	299.3
Index of Resistance to freezing (R _f), %	...	103.2	...	98.0	...	111.4

The unstabilized test specimens were all completely destroyed by the freeze-thaw test. The index of resistance of freezing, R_f, for the stabilized specimens were computed from: $R_f = \frac{P_f}{P_c} \times 100$ where P_f is the unconfined compressive strength after 10 cycles of freeze-thaw and P_c is that after 11 days immersion in water. The values of R_f show that the freeze-thaw and immersion tests were of nearly equal severity for the loess soils, the immersion test was the more severe for the dune sand. The strengths obtained after the freeze-thaw were about 79, 31 and 74 percent of those obtained after one day of immersion for the friable loess, plastic loess and dune sand, respectively.

CONCLUSIONS

1. Polystyrene stabilization is most effective with sandy soils. Silty soils can be stabilized, but the effectiveness decreases with increasing clay content. Sandy soils require as little as 2 percent polystyrene; silty soils require more than 4 percent.
2. Best results are obtained with sandy soils when no water is

added to the soil-polystyrene solution system. Silty and clayey soils require added water to obtain the best strength values.

3. Soils similar to the plastic loess can not be made suitable for base course material with this method of stabilization because of excessive expansion on adsorption of water and because of expansion and strength loss on alternate freeze-thaw cycles. Soils similar to the friable loess and dune sand can be made suitable for base courses. Stabilized sandy soils may be suitable for surfaces, since there is little water adsorption, little shrinking or swelling and relatively small strength loss after immersion in water or after freeze-thaw cycles. However, its resistance to abrasion has not been investigated.

4. The present cost of polystyrene makes it compare unfavorably with other available methods of stabilization.

Literature Cited

1. Mainfort, R. C. 1955. Highway Research Bulletin 108: 112-120.
2. Mainfort, R. C. 1951. U. S. Civil Aeronautics Administration Technical Development Report No. 136.
3. Sherwood, P. T. 1961. Roads and Road Construction. 39: 102-111.
4. Roderick, G. L. Demirel, T. and Davidson, D. T. 1962. Iowa Academy of Science, Proceedings. 69: 370-378.
5. American Society for Testing Materials. 1958. ASTM Standards. Part 3, Designation D560-57.
6. American Society for Testing Materials. 1955. ASTM Standards. Part 3, Designation C 109-54T.
7. Boyer, R. F. and Sinha, R. 1952. In Boundy, R. H. and Boyer, R. F. eds. Styrene its polymers, copolymers and derivatives. Rainhold Publishing Corp. New York, N. Y. pp. 356-357.
8. Abraham, Herbert. 1962. Asphalts and allied substances. D. Van Nostrand Company, Inc. Princeton, N. J. 6th ed. Vol. 3, p. 39.
9. McBain, James M. 1950. Colloid science. D. C. Heath and Company. Boston, Mass. p. 22.
10. Holmes, A. and Klinger, E. W. 1958. ASTM Standards, Part 4, pp. 490-495.
11. George, Kalankamary P. 1961. Development of a freeze-thaw test for evaluating stabilized soil. M.S. thesis. Library, Iowa State University of Science and Technology, Ames, Iowa.