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AN ORGANIC COMPOUND AS A STABILIZING AGENT FOR TWO SOIL-AGGREGATE MIXTURES

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SYNOPSIS

Laboratory investigations at Iowa State College have indicated that certain organic compounds which furnish large organic cations when dissolved in water have considerable promise as admixtures to increase the all-weather stability of soils. An investigation is described in this paper wherein one promising compound was evaluated as a stabilizing agent for two soil-aggregate mixtures having plasticity indices higher than considered desirable for highway subgrade material

The test results indicate that water solutions of the chemical admixtures had the same qualitative effect on the two soil-aggregate samples The following properties were decreased plasticity, shrinkage, maximum modified AASHO density and optimum moisture content, and unsoaked California Bearing Ratio The soaked CBR of both samples was increased and swelling was reduced

The need for more research is indicated before any definite recommendations can be made regarding the use of water-soluble organic compounds for soil stabilization purposes However, the results of this investigation show that admixtures of the compound evaluated had a beneficial effect on some engineering properties related to the all-weather stability of the soil-aggregate mixtures.

In 1845 H. S. Thompson observed that clays have the property of carrying adsorbed cations[1] which can be exchanged for other cations. During the ensuing years the ionic exchange method of altering the properties of the clay fraction of soil has been the subject of a considerable amount of research. Most investigators, however, have been principally concerned with the use of inorganic cations such as sodium (Na^+), calcium (Ca^{++}), hydrogen (H^+), and aluminum (Al^{+++}).

During the last three decades a large number of organic compounds have been developed which promote or effect lubrication, wetting, detergency, foaming, emulsification, water repellancy, and other effects associated with the term "surface activity." Many of these surface active agents have a molecular structure which is essentially oblate, that is,

[1] Positively charged ions

considerably longer than it is wide. Usually they are dipolar, one end of the oblate structure comprising a hydrocarbon radical of hydrophobic (water-hating) nature, whereas the other end is of a hydrophilic (water-loving) nature. The cation-active or cationic surface active agents are characterized by the fact that the hydrophobic group forms part of a cation when the compound is dissolved in water. A typical example of this class is octadecyl ammonium chloride which dissociates in water according to the equation

$$C_{18}H_{37}NH_3Cl \rightarrow (C_{18}H_{37}NH_3)^+ + (Cl)^-$$

Research being carried on at Iowa State College, while only in the exploratory stage, has indicated that organic cations have considerable promise as stabilizing agents for fine-grained soils. The investigation reported herein covers only one phase of this research.

Its purpose was to determine by laboratory tests the value of a promising cationic surface active agent as an admixture for two soil-aggregate mixtures having high plasticity indices to bring them within the limits recom-

was rust red in color and came from a small pit in Prince George's County, Maryland, about five and one-half miles south of the District of Columbia line just off the road to Indian Head, Maryland. Soil B had a brown-
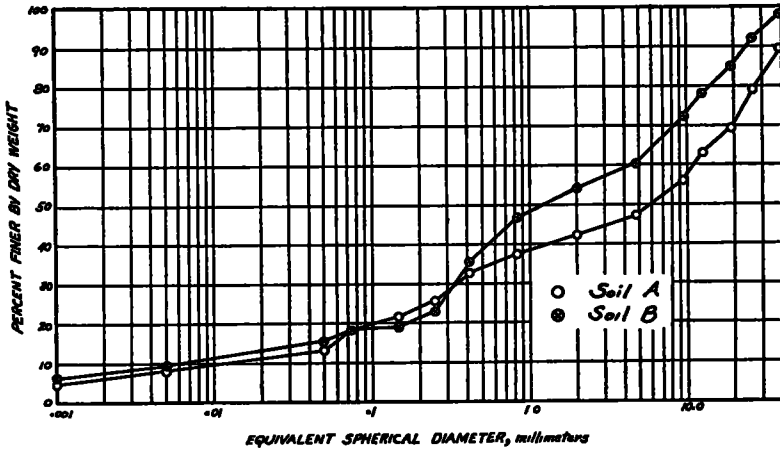

Figure 1. Grain-Size Distribution Curves for Soils A and B

TABLE 1
PROPERTIES OF SOILS A AND B

Properties	Soil A	Soil B
Liquid limit, percent dry wt soil	32 6	29 4
Plastic limit, percent dry wt soil	19 9	17 6
Plasticity index, percent dry wt soil	12 7	11 8
Shrinkage limit, percent dry wt soil	14.9	16 6
Shrinkage ratio	1.77	1 84
Hygroscopic moisture[a], percent dry wt soil	1 06	1 01
Specific gravity (minus No 40 sieve soil)	2 68	2 68
pH value	5 3	5 1
Modified AASHO dry density, pcf	139 5	141 3
Optimum moisture content, percent dry wt soil	8 8	7 0
California Bearing Ratio, percent std crushed rock		
· Unsoaked	95[b]	144[c]
Soaked	57[b]	60[c]
Revised (1945) Public Roads classification	A-2-6(0)	A-2-6(0)

[a] After having been stored in cloth bags for over one month and then exposed to air at room temperature for 10 days.
[b] At 0 1 inch penetration (1)
[c] At 0 2 inch penetration (1)

mended by the Bureau of Public Roads for highway subgrade material.

MATERIALS

The two soil-aggregate samples[2] will be referred to hereafter as soils A and B. Soil A

[2] Furnished by Mr E F Kelley, Chief of Division of Tests and Physical Research, Bureau of Public Roads
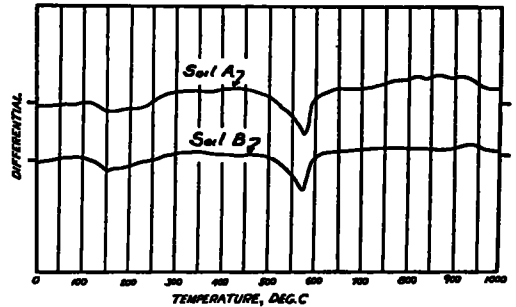

Figure 2. Differential-Thermal Analysis Curves for Colloid Portion of Soils A and B

ish color and was taken from a pit located on U. S. Coast Guard property near the Hybla Valley Experimental Area in Fairfax County, Virginia.

Figure 1 shows the grain-size distribution curves for soils A and B. Both soils met the Iowa State Highway Commission's gradation requirements for stabilized base course material. Table 1 gives additional properties of soils A and B as determined by test procedures of the American Association of State Highway Officials.[3] The plasticity index of both soils

[3] The modified AASHO density and California Bearing Ratio tests were performed in accordance with test procedures of the Corps of Engineers (1).

was considerably higher than the upper limit of 3 recommended by the Bureau of Public Roads for subgrade material.[4] It will be noted that the revised Public Roads classification was A-2-6(0) in the case of each soil.

Figure 2 shows the differential-thermal analysis curves for the colloid portions (minus 0.001 mm.) of soils A and B. Numerous reports on this method of determining the mineralogical constitution of clay samples have been made in the literature (2).[5] In comparing the curves in Figure 2 with the characteristic curves for the pure clay minerals (3, 4), it was concluded that the colloid portion of both soils contained predominantly kaolinite type clay minerals.

The cationic surface active agent selected for evaluation as an admixture was a fatty acid amine acetate made from the fatty acids derived from beef tallow. Of the six cationic compounds investigated by Davidson in 1948 (5), this material appeared to be one of the most promising for use in soil stabilization work. The chemical structure may be written as RNH₃Ac, where the R grouping represents the long carbon chain grouping found in the original fatty acid. When dissolved in water it dissociates according to the equation

$$RNH_3Ac \rightarrow (RNH_3)^+ + (Ac)^-$$

to furnish large fatty amine cations. These cations are used in industry for the purpose of causing certain types of water-loving surfaces to become water-repelling and oil-loving. The compound has been found to be very effective as a germicide, fungicide, and algacide.

The compound discussed is currently available in carload quantities on from one to three weeks' notice. According to the price list of October 21, 1949, this chemical is listed at 32 cents per pound in carload lots, f o.b. Chicago, Illinois. The manufacturer has indicated that a new plant for the manufacture of chemicals will soon be opened and that prices will be lowered considerably as soon as increased production makes such action possible. As and if demand increases, undoubtedly the output will be increased; since the compound is a by-product of the packing

industry, the potential for its manufacture is in good supply. Also others in the packing industry can make a similar chemical; and without doubt they will do so if there is a demand.

EXPERIMENTAL PROCEDURE

The investigation was carried out in three parts. The first part consisted of determining the effect of ½, 1, and 3 percent admixtures of the chemical by dry weight of the minus No. 40 sieve soil on the Atterburg plasticity and shrinkage values of soil A. The plasticity index data was then used to find the percentage of chemical needed to reduce the PI to 3. The objective of the second part of the investigation was to determine the effect of this single admixture on the modified AASHO density, optimum moisture content, and California Bearing Ratio of soil A. In the third and last part, the same series of tests were performed on soil B containing only the percentage of the chemical needed to reduce the PI of soil A to 3.

In preparing samples for the plasticity and shrinkage tests, the cationic admixtures were made to the minus No 40 sieve soil. In the case of the density and CBR tests, the minus ¾-in. sieve samples were treated with the compound by percentage of the dry weight of the minus No. 40 sieve fraction.

Before adding to the air-dry soil, each admixture was dissolved in an amount of distilled water equal in weight to the sample to be treated. The solutions were immediately added to the soil samples and the mixtures stirred thoroughly in large shallow pans with a stiff-bladed spatula. Drying was carried out at room temperature over a period of several days. When air-dry the treated samples were ground with mortar and pestle to pass through either the No. 40 or ¾-in. sieve, depending on the tests to be performed with the samples

PRESENTATION AND DISCUSSION OF RESULTS

The curve in Figure 3a indicates the manner in which the cationic admixtures increased the plastic limit of soil A. Figure 3b shows the effect of the same admixtures in decreasing the liquid limit. The numerical difference between the two limits is the plasticity index, and Figure 3c illustrates how it was decreased. The general trend of the data on the three graphs agrees with the results obtained by Davidson (5). From Figure 3c it is apparent

[4] Personal correspondence with Mr E. F. Kelley, Chief of Division of Tests and Physical Research.
[5] Italicized figures in parentheses refer to the list of references at the end of the paper

that the plasticity index reduction for soil A between 0 and 1 percent admixture was almost twice as great as between 1 and 3 percent. However, approximately 3 percent admixture was needed to reduce the PI value to 3

Figure. 3. Effect of Cationic Admixtures on Plastic Limit, Liquid Limit, and Plasticity Index of Soil A

TABLE 2
EFFECT OF CATIONIC ADMIXTURES ON PLASTICITY VALUES OF SOILS A AND B

Cationic Admixture, per cent dry wt minus No 40 sieve soil	Liquid Limit, per cent dry wt. mixture		Plastic Limit, per cent dry wt mixture		Plasticity Index, per cent dry wt mixture	
	Soil A	Soil B	Soil A	Soil B	Soil A	Soil B
0	32 6	29 4	19 9	17 6	12 7	11 8
½	29 5		20 5		9 0	
1	27 9		21.3		6 6	
3	27 5	25.7	24 6	23 1	2 9	2 6

mixture was needed to reduce the PI value to 3

Table 2 compares the effect of 3 percent cationic admixture on the plasticity values of soils A and B. It will be noted that this percentage of the chemical also reduced the PI of soil B to slightly less than 3. In terms of the

revised Public Roads classification system, treatment with 3 percent admixture reduced the plasticity of both soils sufficiently to change their classification from A-2-6(0) to A-1-b Soils classifying in this latter group are considered desirable for subgrade use (6).

The reduction of plasticity by the cationic material can perhaps be explained on the basis of the effect of large organic cations on the adsorptive capacity of the clay surface for water. When cations of the type used in this investigation are adsorbed by the clay in base exchange reaction with the basic nitrogen atom of the molecule closely held to the mineral surface and with the hydrophobic part of the molecule arrayed on the surface or directed outward from the surface, considerable areas are formed on the mineral that are not wetted by water (7). Since the plasticity index may be considered the amount of water necessary to thicken the surface films from plastic limit consistency to liquid limit consistency, it would necessarily be decreased by the exclusion of water from large areas of the surface concerned

The effect of the admixtures in decreasing the shrinkage of soil A is illustrated by the shrinkage limit and shrinkage ratio curves in Figure 4. The data indicate that admixtures up to 1 percent increased the shrinkage limit and decreased the shrinkage ratio at a much greater rate than those above 1 percent. Table 3 compares the shrinkage values of soils A and B after treatment with 3 percent chemical. Apparently 3 percent had a slightly greater effect upon soil A than upon soil B.

The decrease in shrinkage due to adsorption of large organic cations on the clay surface of the soil can probably be ascribed to disrupted water films. As water evaporates from a soil, capillary tension acts like a taut skin on the surface of the soil mass and gradually draws the particles closer together until the shrinkage limit is reached At this moisture content the resistance of the soil to further compression supposedly equals the force exerted by evaporating moisture The creation of water repellant areas on the clay surface and the destruction of the structure of the hexagonal network of water molecules on the remainder of the surface (8) would tend to weaken the force of evaporating moisture. These surface changes would result in less shrinkage of the soil.
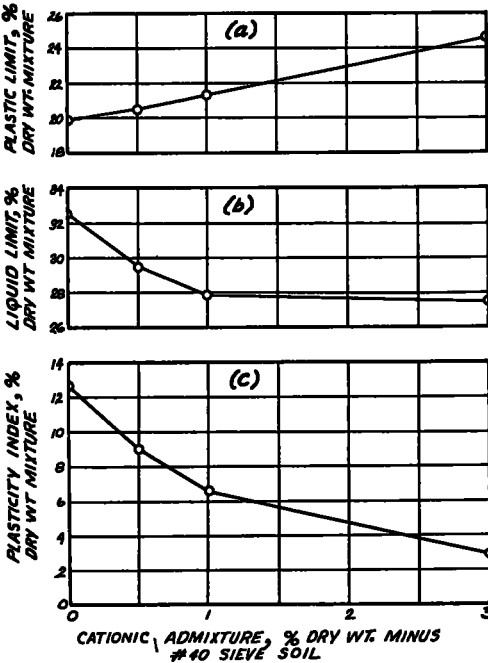
Figure 5 illustrates the effect of 3 percent admixture on the maximum dry density and optimum moisture content of soils A and B as determined by the modified AASHO method. The slightly reduced values of these properties agree with the findings of Whitesell (9). A possible explanation may be that the creation of water repellant areas on the clay surface by the adsorbed cations reduced the efficiency of the clay particles as lubricating agents.

Figures 6 and 7 show the results of California Bearing Ratio tests on natural and treated specimens of soils A and B, respectively. It will be noted that CBR values are compared at 0 1-in. penetration for soil A specimens and at 0.2-in. penetration for soil B specimens. This conforms with instructions of the Corps of Engineers which state that the CBR value at 0.2-in. penetration will be used for design purposes when it is lower than the value at 0.1-in. penetration (1).

The data of Figures 6 and 7 indicate that the unsoaked California Bearing Ratios of soils A and B were decreased by treatment with 3 percent admixture. The soaked CBR value of both soils, however, was increased by the cationic treatment. Since the soaked CBR is customarily used in pavement design, it may be concluded the 3 percent treatments had a favorable effect on the stability of soils A and B. The soaked CBR of 73 percent for treated soil A shows it to be a good to excellent base material, while a corresponding value of 91 percent for treated soil B indicates it to be excellent for use as a highway base course.

The effect of the cationic admixture in reducing the swelling characteristics of the two soils is indicated by the fact that the amount of swell for specimens soaked four days under a ten pound surcharge was reduced from 4.51 to 0 83 percent in the case of soil A and from 4.32 to 0 80 percent in the case of soil B.

The reduction of the California Bearing Ratios of the unsoaked specimens by treatment with 3 percent admixture can perhaps be explained on the basis of the work of Grim and Cuthbert (10), who found that the development of cohesion in clay bodies is contingent upon the formation of continuous films of water on the surfaces of the individual clay particles. Such films would not be continuous upon the surfaces of clay particles containing adsorbed organic cations of the

type furnished by the cationic compound The higher CBR values of the soaked specimens containing the compound are attributed to the water-proofing ability of the cations (5)

No tests were performed in this investigation to determine the permanency of the substituted organic cations. A previous laboratory experiment (5) with the fatty acid amine acetate had indicated that repeated washing
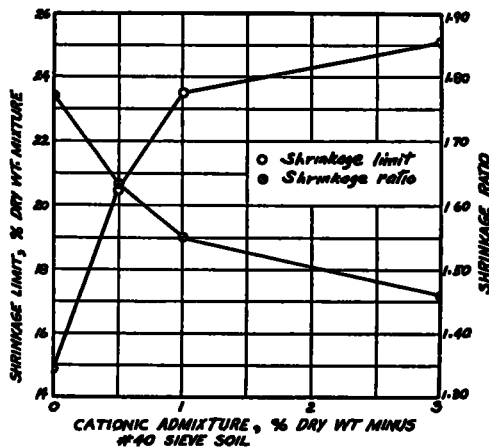

Figure 4. Effect of Cationic Admixtures on Shrinkage Limit and Shrinkage Ratio of Soil A

TABLE 3
EFFECT OF CATIONIC ADMIXTURES ON SHRINKAGE VALUES OF SOILS A AND B

Cationic Admixture, per cent dry wt minus No 40 sieve soil	Shrinkage Limit, per cent dry wt mixture		Shrinkage Ratio	
	Soil A	Soil B	Soil A	Soil B
0	14 9	16 6	1 77	1 84
½	20 5		1 63	
1	23 5		1.55	
3	25 1	24 9	1 46	1 61

of treated soil with distilled water had little, if any, effect on engineering properties

Another indication of the permanency of this type of soil treatment is furnished by the investigation of Gieseking (11), who found that large substituted ammonium cations of the NH_3R^+, $NH_2R_2^+$, and NR_4^+ types were very strongly adsorbed on the surfaces of montmorillonite type clay minerals These cations could be replaced by other organic cations of approximately the same size, but they were not exchanged by hydrogen (H^+)
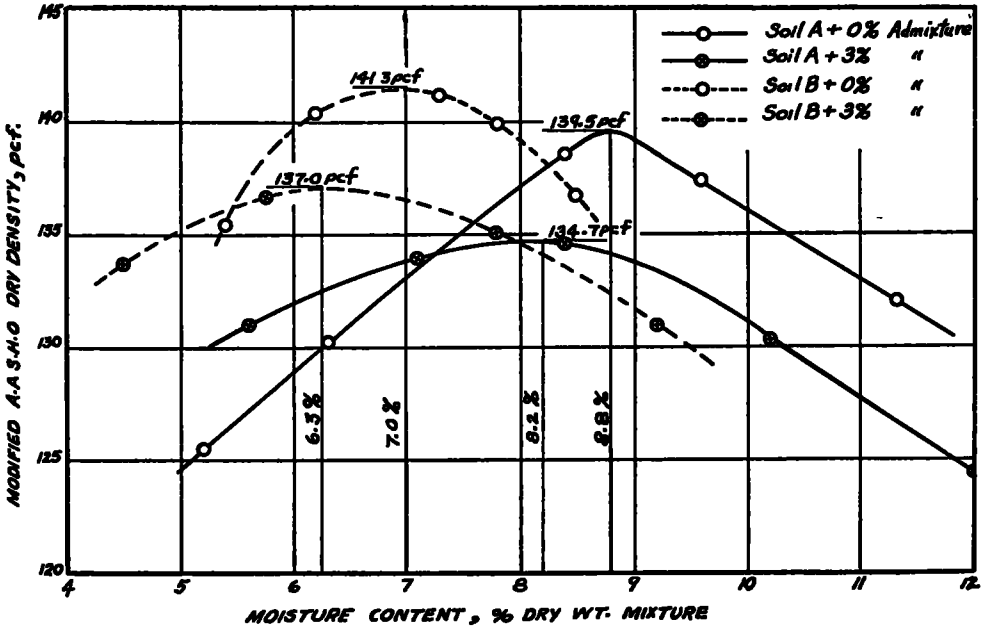
Figure 5. Modified A.A.S.H.O. Dry Density-Moisture Content Curves for Soils A and B Containing 0% and 3% Admixtures of Cationic Material
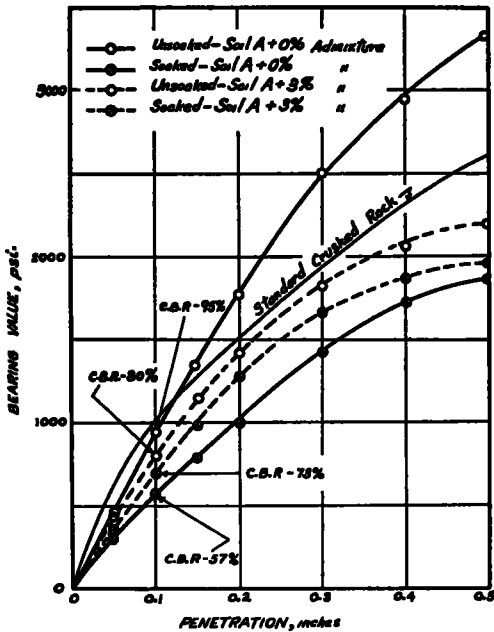

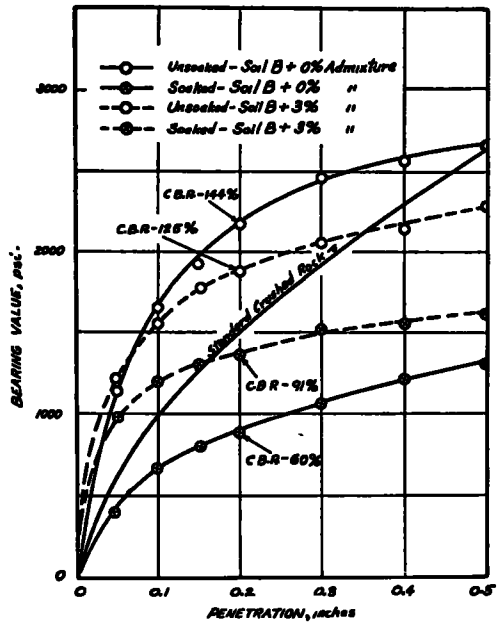Figure 6. C.B.R. Test Curves for Soil A Treated with 0% and 3% Cationic Material

Figure 7. C.B.R. Test Curves for Soil B Treated with 0% and 3% Cationic Material

which is very effective in replacing small inorganic cations.

CONCLUSIONS

It must be remembered in evaluating the results of this investigation that only one method of adding the fatty acid amine acetate to the soils was used. Accordingly, all experimental findings and conclusions drawn therefrom apply only for this mixing procedure Further study of this phase of the subject is needed.

The following are some of the more important conclusions drawn from the experimental data:

1. Cationic admixtures reduced the plasticity index of soil A by lowering its liquid limit and raising its plastic limit.

2. The admixtures reduced the shrinkage of soil A as indicated by an increase in its shrinkage limit and a decrease in its shrinkage ratio.

3. While all percentages of the chemical reduced plasticity and shrinkage, the rate of reduction decreased as the percent admixture was increased.

4. The qualitative effect of 3 percent admixture on the Atterburg plasticity and shrinkage values of soils A and B was similar.

5. Treatment of soils A and B with 3 percent admixture reduced their plasticity indices to slightly less than 3 and changed the revised Public Roads classification of both from A-2-6(0) to A-1-b.

6. The maximum dry density and optimum moisture content of both soils as determined by the modified AASHO method were slightly lowered by 3 percent admixture.

7. The unsoaked California Bearing Ratios of soils A and B were decreased by treatment with 3 percent of the chemical.

8. The soaked California Bearing Ratio of both soils was increased by the 3 percent treatment.

9. Treatment with 3 percent admixture reduced the swell of soils A and B.

Much more research is necessary before any concrete recommendations can be made regarding the use of the fatty acid amine acetate as a stabilizing agent for highway subgrade and base course materials. However, the work done so far indicates that it has considerable promise as an admixture to improve the all-weather stability of soil-aggregate mixtures such as those used in this investigation.

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