weight; soil engineers have set the arbitrary, although convenient, definition of dry weight as that obtained at 105 C.

Drying to 105 C. removes some of the adsorbed water which is part of the effective soil grain. This effect is of more importance in soils whose grains are colloidal or expanding in behavior. Due to the removal of part of the soil particle, one tends to obtain natural water contents, Atterberg Limit values, void ratios and specific gravities that are too high.

The above error in absolute value of soil properties does not appear to be as important as the scatter one may obtain by not carefully maintaining the arbitrary standard drying procedure.

A STUDY OF BITUMINOUS-SOIL STABILIZATION BY METHODS OF PHYSICAL CHEMISTRY[1]

A. C. ANDREWS, *Kansas State College* AND G. G. NOBLE, *State Highway Commission of Kansas*

SYNOPSIS

This report describes laboratory studies of several phases of bituminous-soil stabilization

The work described was carried out with two general aims in mind:

Phase 1 To develop laboratory tests that would permit evaluation of some of the physical, physical chemical and surface properties of the materials being studied

Phase 2. To make studies that would lead to the development of methods and (or) treatments which would allow bituminous stabilization of a wider range of soils than is practical at the present time

The two general phases of the work were carried out simultaneously so that information obtained as the work progressed could be utilized in later experiments

The first phase of the work was carried out by using techniques standard to physical chemistry but foreign to the field of bituminous-soil stabilization These techniques were used for the measurement of physio-chemical and surface properties of soils and asphalts The ability of soils and asphalt to imbibe and retain moisture was also examined

The second phase consisted of studying the effect of approximately 85 different substances added to soil-water-asphalt systems The effect of the additives was evaluated by obtaining the compressive strength of small briquettes before and after immersion in water.

The results are not conclusive; however valuable data were collected and are presented here to serve as a guide for future investigations

A study of the literature pertaining to soil stabilization in general reveals that the past ten years has been a period of rapid advancement in this field. This is also true in the more specialized field of bituminous stabilization.

Mills (*1*)[2] gives charts and tables showing the mileage of different types of stabilized roads constructed in the United States in the period 1925 to 1939 by State and Federal agencies. It is interesting to note the years in which the first 100 miles of road stabilized with various stabilizing agents were completed They are: 1931 for cutback asphalt, 1933 for chemical stabilization, 1935 for tar, and 1937 for portland cement and for asphalt emulsion. As a comparison, there were about 600 miles of soil-aggregate stabilization in 1929 and 4000 miles in 1936.

The bibliographies attached to articles on soil stabilization published in the last ten years are very revealing. They show that there has been a definite movement from "rule of thumb" methods to methods attempting to use all available knowledge in the fields of

[1] A report of a project sponsored by Skelly Oil Company, Kansas City, Mo and performed cooperatively by the Engineering Experiment Station of Kansas State College and the State Highway Commission of Kansas.

[2] Italicized figures in parentheses refer to the list of references at the end of this paper.

physics, chemistry, physical chemistry and soil mechanics. There have been many notable contributions to the knowledge of basic factors and their utilization in the construction of stabilized soil roadways and airport surfaces.

The use of asphaltic materials in soil stabilization work has been prominent in both research and construction work during this period of development. This is logical because asphalt has long been used as a binder and water-proofing agent in highway construction.

Benson and Becker (*2*) identify two procedures for bituminous soil stabilization The first is based on the establishment of a definite soil-water-bitumen system This method utilizes an intermediate moisture content known as the "fluff point" and produces a system consisting of soil-water aggregations which are in turn coated with films of bitumen. The writers point out the following advantages of this procedure over those based on the theory of intimate mix

1. Relatively small bitumen contents required.

2 A minimum of mixer work and time required.

3. Economy because of the intermediate moisture content required.

4 The more complete utilization of soils "in situ" due to the greater range of soils which may be successfully treated

The second method discussed by Benson and Becker is that utilizing supplementary admixtures. Their findings on the use of heavy metallic salts lead to the conclusion that such salts affect soils only slightly at the concentrations used (three percent and less) and that use of such salts is economically prohibitive They continue by saying that the use of portland cement and lime in connection with bituminous stabilization has beneficial effects and is economically feasible.

Endersby (*3*) concludes that it is possible to improve soil stabilization with liquid oils several fold over normal previous practice by attention to the following items:

1. Proper relation between oil and water content.

2. The significance of phase mixing.

3. Proper curing.

4 Improvement of and (or) proper selection of stabilizer

5 Proper selection of stabilizer content.

Winterkorn and Eckert (*4*) make the statement that the success of bituminous-soil stabilization is a function of the general character of the soil and its exchange cations, and of the character of the bituminous material employed. In their very interesting article they discuss the classification of bituminous material by a series of tests as well as the evaluation of the effect of various exchange ions on a series of soils mixed with different bitumens.

Preece (*5*) while not primarily concerned with bituminous stabilization of soils, gives a very interesting discussion of atomic and molecular structures as applied to soils. He continues with a description of the lattice structure of the various clay minerals, ionic exchange, preferential adsorption and surface energies His discussion of these subjects as well as of electrokinetics is very interesting and pertinent to any study of soil stabilization.

While the papers mentioned, together with many more, show that much progress has been made, it is obvious that soil stabilization is far from an exact science. That much more work is needed and is being carried out is illustrated by the assignments made to committees under the Department of Soils Investigation of the Highway Research Board in 1947 (*6*). A partial list follows:

1. Construction of experimental roads containing both calcium chloride treated and untreated sections.

2. Studies of the use of small amounts of portland cement to modify subgrade soils and to increase the stability of soil road materials.

3. Study of the use of bituminous materials in relatively small amounts to modify or waterproof either subgrade soils or soil roads.

4. Study of the effect of resin admixtures as reducers of frost damage in subgrade soils and soil roads.

5. The compilation, correlation and report of the effect of all chemical admixtures not covered by other committees

6. Stabilization of fine grained foundation soils by means of electrical current.

The Kansas Highway Commission has been active in research work pertaining to soil stabilization and has constructed a very considerable mileage of highway embodying the various theories of stabilization. There are large areas in the State, however, where suitable granular materials are not available for stabilization purposes. To a large extent these areas coincide with areas of comparatively light traffic and rainfall. It was with the needs

of this area particularly in mind that the work herein described was started.

This research was conducted jointly by the Engineering Experiment Station of Kansas State College and the Kansas Highway Commission with the Skelly Oil Company of Kansas City, Missouri acting as sponsor. All the work except the extensive investigation of the effect of aniline hydrochloride was performed in 1944 and 1945.

The research was divided into two general phases:

1. An attempt to find methods that would permit evaluation of soil and (or) asphalts as to their suitability for bituminous stabilization.

2. Development of methods and (or) treatments that would make bituminous stabilization practical with soils now considered unsuitable for bituminous stabilization. In general, it was thought that this end could be attained by better dispersion of asphalt through the soils. With better dispersion, increased percentages of asphalt might be used with resultant improvement in waterproofness and consequent retention of stability when wet.

MATERIALS USED

The physical properties of the six Kansas soils used in this research are shown in Figure 1. They were selected to give a wide variation in physical properties and yet be more or less representative of Kansas soils. The samples were secured by Kansas Highway Commission personnel by the methods used in regular sampling operations.

Soils AA 3326-1 and AA 5187-1 are heavy clays from Shawnee County. The two samples were secured at locations approximately eight miles apart. They are both found in the B horizon of the Summit Series and are residual soils resulting from the decomposition of shale.

Soils AA 3131-1C1 and AA 3131-1C2 are found in Jewell County where they occur in the Colby Series. Soil 1C1 is from a loessial C horizon approximately three feet thick while sample 1C2 is from a buried B horizon from an earlier deposit. Soil 1C2 occurs directly below 1C1 in a stratum approximately three and one half feet thick.

Soil AA 3133-3C was secured in Thomas County, approximately 150 miles west of the samples described above. It is also a loessial soil occurring in the C horizon of the Colby Series.

The remaining soil used (AA 3149-51) is from Edwards County. It is typical of sandy soils occurring along the Arkansas River. This soil is from the Pratt Series and is a mixture of the loessial and alluvial soils common in this area.

Soil AA 3326-1 was used for most of the investigations of chemical admixtures. Three other soils were used in the work with aniline hydrochloride.

Three MC-2 cutback asphalts, made by two refiners, were used in this investigation. All were refined from Mid-continent crudes by Kansas refiners and met requirements of the Kansas Highway Specifications. Test results are shown in Table 1.

The first two cutbacks were used for all the work except the extensive work on the effect of aniline hydrochloride when ED 352 was used. On all the investigational work with the different admixes the first MC-2 (Lab. No. 47901) was used.

TABLE 1
PROPERTIES OF MC-2 CUTBACKS USED IN STABILIZATION RESEARCH

Lab no	47901	AU-X	ED-352
Sp gr 60 F 60 F	0 9548	1 0313	0 9567
Viscosity (Saybolt furol) 140 F, sec, flash point (tag open cup) deg. F	187	140 170	178 180
Flash point (Cleveland open cup) deg F	190+		
Distillation			
Initial boiling point deg F	415	450	440
Total to 437 F (percent)	1 1		
Total to 500 F (percent)	38 5	21	39 5
Total to 600 F (percent)	83 5	72	84 5
Total to 680 F (percent)	100	100	100
Volume of residue (percent)	77 3	83 5	79
Characteristics of Residue from Distillation			
Penetration 77 F, 100 g, 5 sec	152	161	268
Soluble in CCl_4 (percent)	99 75	99 74	99 78
Ductility at 77 F, cms	124	100+	
Ductility at 60 F, cms			130
Oliensis spot test	Neg	Pos	Neg

PHASE 1—EVALUATION OF MATERIALS FOR BITUMINOUS STABILIZATION

One phase of the study was an attempt to evaluate various properties of the materials used through the methods of physical chemistry.

The approaches used in this phase were as follows:

1 A study of the capacity of asphalt to imbibe and retain moisture under various conditions

2. A study of the practicability of the use of contact angle measurements to determine

the suitability of various materials and to measure the effect of pretreatment

3. Surface pressure determinations to evaluate the effect of various media on the spreading ability of asphalt.

4 Investigation of the use of the principles of electrophoresis to determine the suitability of various asphalts and soils and to measure the effect of pretreatment

Hydration and Dehydration Studies—At the start of the investigation, it seemed pertinent to study the ability of asphaltic oils to imbibe and retain moisture. Accordingly, nine series of two samples each were started. Small beakers containing MC-2 (Lab. No. 47901)

TABLE 2
RESULTS OF EXPOSING MC-2 (LAB NO. 47901) TO VARIOUS AGENTS IN SEALED SYSTEMS

Exposed to	Temp	Time	Change in Weight Percent Original
	deg. C.	*days*	
Air	4	270	−1 0
H_2O	4	270	+0 7
Air	26	270	−2 6
H_2O	26	270	+1 0
$CaCl_2$	26	270	−3 2
H_2SO_4	26	270	−4 9
P_2O_5	26	270	−3 0
Air	37	270	−6 5
Air	37	229	−5 8
H_2O	37	270	−3 4[a]
H_2O	37	229	+5 4

[a] Both samples showed sudden, unexplainable loss of weight after about 40 days

were placed on supports in two-liter wide-mouthed jars equipped with plastic caps A second substance (water or a dehydrating agent) was placed on the bottom of the jar below the beaker.

The sealed jars were kept in constant temperature rooms. At intervals the beakers were removed from the jars, carefully weighed and the percentage change in weight determined.

The details of these series are shown in Table 2. The exposure to air was carried on in a manner identical to the others except that no second substance was placed in the jar.

After about forty days, the MC-2 exposed to water and to air in the 37 C. room showed a sudden unexplainable loss in weight. Eight more jars were prepared as checks. Four of these contained MC-2 and water arranged in the same manner as the original and four contained MC-2 only.

The second run exposed to water at 37 C. lost a small amount of weight during the third week of exposure but recovered and showed a gain for the rest of the period The second run of samples exposed to air at 37 C. showed a uniform loss for the entire period.

The data given in Table 2 leads to the following conclusions, most of which are in accord with common knowledge and practice. These results seem to be borne out by the work of Anderson and Wright (*12*), and by Beckman, Badger, Gullekson, and Stevenson (*13*). The latter found a small but definite diffusion constant for water through asphalt.

1. Loss of the lighter portions of cutbacks when they are exposed to air varies directly with temperature.

2. Exposure to a moist atmosphere reduces the loss or more than compensates for loss of volatiles by addition of moisture.

3. Exposure to a very dry atmosphere as in the presence of dehydrating agents increases the amount of loss from cutback asphalt.

TABLE 3
RESULTS OF EXPOSING OVEN DRY CLAY (AA 3326-1) TO "WET" MC-2 AND TO AIR IN SEALED SYSTEMS

Exposed to	Temp.	Time	Change in Weight Percent Original
	deg C	*days*	
"Wet" MC-2	37	259	+4 8
Air	37	259	+4 1

In connection with this study, oven dry clay (AA 3326-1) was exposed to "wet" MC-2 and to air at 37 C. by the same method shown above The "wet" MC-2 was prepared by placing distilled water and the cutback in the same container for 48 hr. at 37 C then draining off the water.

The results of this study are shown in Table 3. It will be noted that the clay exposed to the treated MC-2 gained slightly more weight than that exposed to air It is doubtful if there is enough difference between the gain in weight of the clay under the two sets of conditions to be significant

Contact Angle Studies—The coating of the surface of soil particles with asphaltic material is the major consideration in bituminous-soil stabilization. This is true whether an attempt is made to coat individual particles or aggregations. For a material like asphalt to spread and coat soil surfaces, the adhesion of soil for asphalt must be sufficient to overcome all other forces in the system For optimum conditions, the asphalt should be spread in a thin uniform film on all exposed surfaces

For asphalt to spread, it must advance along the soil surface. The degree of spreading or wetting is indicated by a determination of the contact angle between the solid and liquid phase.

From the above, it appeared logical that the magnitude of the contact angle between a given soil surface and asphalt could be used as a measure of the suitability of the materials for bituminous stabilization. It also appeared probable that measurement of contact angles could be used to evaluate the effect of pretreatment of the soil and (or) asphalt.

The contact angle is the angle measured from the surface of the solid through the liquid to the tangent to the drop's surface at the point of contact of the two phases As

TABLE 4

CONTACT ANGLES FORMED BETWEEN DROPS OF MC-2 (LAB NO 47901) AND VARIOUS SURFACES

No of Determinations	Contact Surface	Moist	Ave Contact Angle	Range of Angles
		%	*deg*	*deg*
6	Soil AA 3326-1	0	102 0	74 5–132 7
3	"	5	82 1	69 2–106 2
6	"	10	43 1	30 5– 50 4
42	"	15	30 9	19 3– 66 9
35	Soil AA 3326-1+ 5% ethyl silicate	15	27 1	20 6– 38 9
18	Soil AA 3326-1+ 3 5% oleic acid	15	29 3	20 2– 38 7
15	Soil AA 3326-1+ 3 5% oleic acid + 5% ethyl silicate	15	28 0	21 1– 33 8
19	Activated alumina	0	139 7	110 3–167 3
30	Glass plate	0	29 0	18 1– 40 3
12	Polished steel	0	40 1	32 0– 53 7

the wetting becomes more complete, this angle approaches zero. The more incomplete the wetting, the nearer this angle is to 180 deg.

In the contact angle studies, small drops of asphalt were placed on the end of carefully prepared soil briquettes and an actual size photograph taken The developed plate was placed in a slide projector and the necessary measurements made on the projected image.

The briquettes were formed in a 1-in diameter cylindrical mold using steel pistons with carefully polished ends. The briquettes were molded under a load of 2500 lb. held for 2 min

The drops of asphalt were placed by means of a small hypodermic syringe fitted with a 24 gauge needle from which the point had been ground. It was found that very uniform, small drops could be placed after considerable practice.

In making the photographic exposures, the light source was placed behind the briquettes, so that the image on the plate was a silhouette showing the line of the surface and the shape of the drop

Using the developed plate as a slide, the image was projected on a piece of rough textured drawing paper This paper was mounted on a sketch board that could be adjusted to orient the image with the guides. The necessary lines were drawn on the paper which was then removed for measurements and calculations.

The kind of calculations necessary to obtain the numerical value of a contact angle is dependent upon whether the angle is acute or obtuse For acute angles, the calculations used were described by Mack (*7*). The measurements and calculations for acute angles were relatively simple.

The calculations used to determine the magnitude of an obtuse contact angle are described by Mack and Lee (*8*). Supplemental material from Dorsey (*9*) and Sugden (*10*) was also used These calculations, while more involved than those for acute angles, could readily be used in routine laboratory work

A summary of the data obtained in the contact angle studies is shown in Table 4. It will be noted that there is a rather wide variation in the values obtained on a given surface. This is due in part to the non-uniform character of the surfaces In the case of acute angles, more consistent results might have been obtained by measuring the radius and volume of the drop as suggested by Mack (*7*) rather than the radius and height.

A number of trends are evident in the data in Table 4. The decrease in contact angle with an increase in moisture content is very evident. This fact is compatible with field experience which has indicated that moist soil is easier to coat than dry soil.

The addition of Ethyl Silicate to the soil-water mixture apparently decreased the contact angle between asphalt and soil slightly. This would indicate that treatment with Ethyl Silicate might decrease the work necessary to coat soil with asphalt

It should be pointed out that ease of coating is but one factor that need be considered in evaluating the effect of admixes in the soil-water-asphalt system. As will be shown later, the addition of Ethyl Silicate has more effect on the physical properties of a soil and the stability of compression specimens after im-

mersion than is indicated by its effect on the contact angle.

Since the effect of the admixes on the contact angle was not large, it was decided to check the contact angle between the MC-2 and other substances to make doubly sure the method being used was capable of measuring widely different values. The values obtained on activated alumina, glass and polished steel indicate that a wide range of contact angles can be measured by the system employed.

It will be noted that the contact angle between MC-2 and soil did not approach zero or 180 deg closely. The positive finite values obtained show that asphalt is not completely non-wetting, but spreads on soil with difficulty.

It appears possible that contact angle determination is one of several approaches that might be used to study the suitability of materials for bituminous stabilization in a qualitative manner at least Additional investigation and work on techniques and methods probably would develop a method that would have value of a much more definite, quantitative nature.

Details of the methods and calculations used in the contact angle studies are shown in the appendix.

Surface Pressure Studies—As mentioned in the section on contact angles, spreading of asphalt is a major consideration in bituminous-soil-stabilization.

In order to study the spreading of asphalt by a method entirely different from that used in the contact angle studies, it was decided to use the surface pressure balance method. This method utilizes measurement of film pressure to determine the film forming characteristics of oils or investigate the area of monomolecular films floating upon an immiscible liquid.

The surface pressure balance used in this work was the "Hydrophyll Balance" as sold by the Central Scientific Company. It consists essentially of a long, shallow trough which holds the substrate liquid. It is equipped with an adjustable barrier across one end and a movable float near the other end. The float is attached to a torsion wire fitted with a vernier at one end.

In use, a known amount of the material being studied is placed on the surface of the substrate liquid between the barrier and the float. If the material added is polar to the substrate liquid, it will spontaneously spread over the entire surface. The final film thickness of this spread layer in perfect spreading is monomolecular. The movable barrier is advanced by increments to force the film into a smaller area. For each movement of the barrier, the movable float is returned to its original position and the force in dynes required to move it determined by the vernier.

Knowing the molecular weight of the substance being studied, it is possible to compute the area occupied by each molecule in the film. The vernier readings, when converted to dynes per centimeter of float length, are plotted against the area of each molecule in the surface under compression. The curve that is obtained starts at low pressures and large areas and remains fairly constant for these successive large areas. Then it begins to rise very rapidly as small decreases in area cause rapid changes in pressure. Suddenly the curves become nearly horizontal again, while the pressure remains constant with decreasing area The curves so obtained are in the shape of an elongated reversed S. The portion of the rapidly rising curve is extrapolated to zero pressure; and the extrapolated area so obtained is the cross sectional area of the molecules on the surface. Such values check satisfactorily with similar data from independent sources

The three different portions of the reversed S curve are accounted for in the following manner. The first flat portion obtained at low pressures and large areas corresponds to the process of pushing the film's molecules closer together from a very sparse population to a more dense one. When the curve begins to rise, the surface molecules are beginning to touch each other, and as pressure is applied these molecules pack into a closely meshed arrangement and become ever closer together. The second break in the curve is due to the inability of the molecules to further adjust themselves to packing Suddenly they begin to fly out of a monolayer and become deposited upon others, producing polymolecular layers of irregular thickness.

In these calculations, a value of 2000 was used as the molecular weight of asphalt. This value seems to be suggested as about an average according to Traxler (*11*).

The asphalt was applied to the substrate liquid in two ways. Usually it was applied in a benzene solution, but direct application

was found to work equally well. The weighing of the asphalt and its controlled dropping on the surface was done by use of a small hypodermic syringe with a short blunt needle. The substrate liquids were prepared in large quantities and then used in the trough as needed.

The results of this investigation are shown in Table 5. The two asphalts were spread on the substrates indicated in the third column. The molecular areas determined are in the fourth column. It is seen that on water the extrapolated area for one MC-2 cutback (47901) is eight square A°, while the value for the other (Au-X) is about three and one half square A° These areas are much too small to be correlated with any dimensions

TABLE 5
RESULTS OF SURFACE PRESSURE BALANCE EXPERIMENTS ASPHALTS ON WATER AND WATER SOLUTIONS

Number of Determinations	Substance Spread	Substrate	Area[a] per Molecule
			sq. A°
6	MC-2 47901	0 13N HCl	15
3	" "	0 13N HCl	16 (curves irregular)
1	" "	0 325N HCl	10.5 (poor curve)
5	" "	Water	8
5	MC-2 AU-X	Water	3.5
6	MC-2 47901	1% NaCl	7
3	" "	1% NaCl	7
3	MC-2 AU-X	1% $CaCl_2$	3 5
3	" 47901	1% $AlCl_3$	12 (curves irregular)
3	" AU-X	1% $AlCl_3$	5

[a] Values are extrapolated from force-area curves to zero pressure. 1 A° = 10^{-8} centimeter.

of molecules of the type known to be present in asphalt. The explanation of the small area obtained must lie in the fact that these asphalts do not spread on water as monomolecular layers. They probably spread, incompletely and imperfectly, many molecules deep in certain areas and leave other areas nearly bare.

The extrapolated areas on acid substrates were about twice the value on pure water. These areas of 16 square A° approach areas of the paraffin hydrocarbons However, the film is imperfect and probably to some extent polymolecular. The values seem conclusively to point to much better spreading on acid media than on neutral water.

Salts dissolved in the substrate produced very little, if any, effect. The results obtained while using aluminum chloride were erratic and discordant. The best spreading seemed to be obtained on dilute acid (0.13 N HCl) with stronger acid medi showing less effect.

At best, asphalt spreads poorly on aqueous substrates. It spreads very slowly as compared to substances like stearic acid. Usually, the spreading can be followed visually and the film is noticeably sluggish in its movement. The film on the substrate is nonuniform, being composed of areas that are dark, some that are irridescent, and others that appear to be uncoated.

Apparently all fractions of asphalt do not spread with equal ease, some showing very little tendency to spread at all.

Electrophoresis Studies—In order to obtain a better understanding of the factors involved in spreading of asphalt and in coating soil with asphalt films, it was decided to investigate the particle charge on soil and asphalt. It was felt that a study of the effect of admixtures could be carried out by the same methods.

Use of electrophoretic methods was the obvious approach to a problem of this nature. In electrophoresis, which is similar to electrolysis, colloidal particles are subjected to the field of a direct current (*12*). The particles then move in a direction that carries them toward the electrode of opposite sign. Knowing the sign of the electrodes, the sign of the particle charge is easily determined.

A U-tube about ¾ in. in diameter with 4-in. arms was filled with a suspension containing the material to be studied and a platinum electrode immersed in each arm. The electrodes were then connected to a carefully controlled source of direct current. A potential of from 28 to 29.5 volts was found to be most satisfactory.

At first no attempt was made to form an initial boundary. Under this method, the material collected in the arm of the U-tube containing the electrode of sign opposite to the charge on the particles As migration due to electrophoresis continued, definite boundaries became noticeable as concentration layers formed around or below the electrode.

Later, the results were obtained in less time by forming initial boundaries. To form these boundaries, the pure solvent was introduced into the bottom of the U-tube. The suspension of the material to be studied was

introduced carefully into the bottom of the U-tube by means of a hypodermic syringe equipped with a seven-inch needle. The pure solvent and the liquid used to suspend the material being studied were identical. When the direct current was applied to the liquid, the boundaries between the suspension and pure solution moved toward the electrode tion. However, settlement of the soil particles was so rapid that it completely overcame the effect of the electric current. After considerable experimentation, it was found that a soil suspension of ample stability could be prepared by use of sodium hydroxide and oleic acid. The soil was agitated with N/50 sodium hydroxide and allowed to settle. Then

TABLE 6
RESULTS OF ELECTROPHORESIS STUDIES

No. of Trials	Material Suspended	Solvent	Additive	Remarks	Particle Charge
1	MC-2-47901	H_2O	Oleic acid—trace	Emulsion set overnight before placing in U-tube	Neg.
1	" "	"	Oleic acid emul	Emulsion set overnight before placing in U-tube	
1	MC-2 AU-X	"	" " "	Emulsion set overnight before placing in U-tube	
3	Soil AA 3326-1	"	Na_2SiO_3	Supernatant fluid from std soil hydrometer sol After standing 2 hours	Neg.
2	" "	"	—	Soil shaken with 0 4% NaOH. Washed with ethanol and water	Neg
3	" "	N/50 NaOH	Oleic acid 5 drops		Neg.
2	" "	N/500 NaOH	" " " "		Neg.
6	" "	N/50 NaOH	Oleic acid	2 to 22 drops of oleic acid used in different runs	Neg
1	" "	" "	Oleic acid 5 drops	Soil containing 15% moisture dehydrated by excess $SiCl_4$	Neg
	" "	" "	" " " "	Identical to above except for strong agitation before test	Pos.
1	" "	N/500 NaOH	" " " "	Soil containing 15% moisture dehydrated by excess $SiCl_4$	Neg.
1	" "	N/50 NaOH	" " " "	Dry soil pretreated with 5% ethyl silicate	Neg
1	" "	M/50 NaOH	" " " "	Identical to above except for strong agitation before test	Neg
1	" "	" "	" " " "	Wet soil pretreated with 5% ethyl silicate	Neg.
1	" "	" "	" " " "	Identical to above except for strong agitation before test	Neg.
1	" "	" "	" " " "	Wet soil dehydrated with $SiCl_4$ & treated with 5% ethyl silicate	Neg.
1	" "	" "	" " " "	Identical to one before except for strong agitation before test	Pos
2	" "	" "	" " " "	11% MC-2(47901) incorporated in soil before suspending	Neg
2	Soil AA 3131-101	" "	" " " "		Neg.
1	" " " "	N/500 NaOH	" " " "		Neg.
1	Soil AA 3131-102	N/500 NaOH	" " " "		Neg
2	" " " "	N/50 NaOH	" " " "		Neg.
1	" AA 3132-2C	" "	" " " "		Neg
1	" AA 3133-3C	" "	" " " "	Results inconclusive	Pos ?
2	" " " "	" "	" " " "		Neg.
1	" " " "	N/500 NaOH	" " " "	Results inconclusive	Pos ?
1	" " " "	" "	" " " "		Neg.
1	" " " "	" "	" " " "	Results indefinite	?
1	" AA 3149-1	N/50 NaOH	" " " "		Neg
1	Oleic acid	N/50 NaOH	None		Neg
1	" "	Distilled H_2O	"		Neg.

having a sign opposite to the charge on the particles in suspension. The mobility was followed by photographing the U-tube assembly at various intervals of time to record the position of the boundaries.

The most difficult obstacle to overcome in this work was the tendency of soil suspensions to settle and of emulsions made with asphalt to "break". At first, it was attempted to suspend soil in distilled water by violent agitation. However, settlement of the soil particles was so rapid that it completely overcame the effect of the electric current. After considerable experimentation, it was found that a soil suspension of ample stability could be prepared by use of sodium hydroxide and oleic acid. The soil was agitated with N/50 sodium hydroxide and allowed to settle. Then a small amount of oleic acid was added and the suspension agitated again. The coarse particles settled out rapidly, but the supernatant liquid retained the finer soil particles in suspension. The use of sodium hydroxide solutions of different concentrations and of different amounts of oleic acid affected the stability of the suspensions but had no apparent effect on the direction of boundary movement during electrophoresis.

Fairly stable emulsions of the cut-back asphalts being used were prepared by use of oleic acid. A small amount of oleic acid was emulsified in water and then the cutback added to this emulsion. The emulsions were made by repeatedly forcing the mixture through a small laboratory homogenizer.

The results of the electrophoretic tests are shown in Table 6. It will be noted that the majority of the results show the suspended particles to be carrying a negative charge.

It is of interest to note that of the two MC-2 cutbacks used, one had a positive and the other a negative Oliensen spot. The cracked and uncracked asphalts both had negative particle charges.

Soil AA 3131-3C apparently does not carry a very definite charge Of the six tests run using this soil, three clearly indicated the particles to carry a negative charge, two gave results that were doubtful but indicated a positive charge and the sixth gave indefinite results.

The only other tests that indicated the particles had a positive charge were on suspensions of soil AA 3326-1 treated with silicon tetrachloride ($SiCl_4$) that was shaken for 45 minutes immediately before the test. This change of charge may have been due to a combination of the treatment with silicon tetrachloride and the agitation. Identical suspensions on which the agitation was stopped two hours before testing showed negative particle charges. Suspensions of the same soil containing no silicon tetrachloride showed negative particle charges even when agitated immediately before testing.

Silicon tetrachloride and Ethyl Silicate were chosen for soil treatment because they have a very marked effect on the grain size and plasticity characteristics of soil AA 3326-1. This will be discussed in a later section. In spite of the radical effect of these two substances on the physical properties of the soil, they did not change the particle charge of the material in suspension.

The fact that the soils and asphalts tested have like (negative) particle charges explains, in part at least, the results obtained in the contact angle studies In the discussion of the results of contact angle measurements it was pointed out that asphalt spreads on soil with difficulty.

It is felt that further work on the determination of particle charges on soils and asphalts would be well worth while in more detailed studies of bituminous-soil stabilization. If methods or materials can be found that will economically change the particle charge of one material it probably would make the covering of soil particles with asphalt much easier and more permanent.

PHASE 2—INVESTIGATION OF ADMIXTURES AND TREATMENTS

The second phase of this project was concerned with the development of methods or treatments that would make bituminous stabilization more practical and extend the range of soils that can be treated successfully with bituminous materials.

The major portion of the work in this second phase consisted of the study of the effect of various additives on soil-water-asphalt systems. However, some work was done to determine the effect of various substances on the physical properties of the soil AA 3326-1 which was a heavy clay with a plastic index of 38. Some work was also performed to study the effect of silicon tetrachloride on asphalt.

Effect of Silicon Tetrachloride on Asphalt—Asphalt, when mixed with silicon tetrachloride, reacted to form a rubbery mass having quite spongy properties. If this asphalt was refluxed with silicon tetrachloride, either hot or cold, it passed through this rubbery stage and became hard and brittle. The peculiar products thus formed when used as admixture agents showed no value. These products were soluble in carbon bisulfide but not appreciably soluble in Skellysolve.

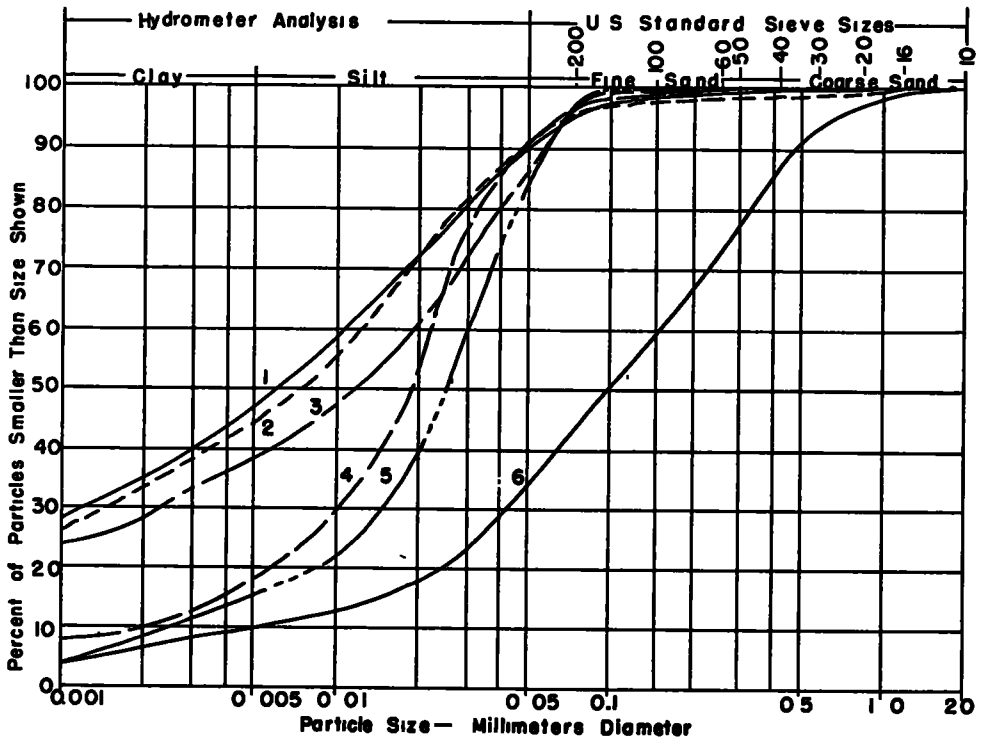
Effect of Chemical Treatment of Soil AA 3326-1 on Soil Texture and Plasticity—The results of chemical treatment on the physical properties of soil AA 3326-1 are shown on Figure 2 This soil was chosen for this phase of the investigation because its high plastic index and clay content made it the most undesirable of the ones being used for highway purposes.

Curve No. 1 on Figure 2 shows the untreated soil It is identical to curve No 2 on Figure 1 and is repeated so the effect of chemical treatment may be more plainly seen.

Curve and line No 2 in the tabulation, Figure 2, show the effect of adding 15 percent

of water to the dry soil and then treating the moist soil with an amount of silicon tetrachloride ($SiCl_4$) equal to 72 percent of the dry soil by weight. This amount of silicon tetrachloride is slightly in excess of that required to react with the water present The silicon tetrachloride reacts with the water to form silicon dioxide and hydrochloric acid then adding five percent of Ethyl Silicate is shown by curve and line No. 4.

The material treated with silicon tetrachloride flocculated so that it was impossible to run a hydrometer analysis. Consequently, the portion of curves Nos. 2 and 4 shown is for sieve analysis only. A comparison of the curves and physical properties shown for Nos.



Curve No	County	Soil No	LL	PL	PI	Sp Gr	Class
1	Shawnee	AA 5187-1	59	23	36	2.60	C
2	Shawnee	AA 3326-1	58	20	38	2.58	C
3	Jewell	AA 3131-1C-2	39	19	20	2.49	C
4	Jewell	AA 3131-1C-1	36	22	14	2.58	Sil
5	Thomas	AA 3133-3C	32	21	11	2.59	Sil
6	Edwards	AA 3149-51	22	13	9	2.60	Sl

Figure 1. Physical Properties of Kansas Soils Used in Stabilization Research

The reaction is violent and produces enough heat to vaporize and drive off hydrochloric acid formed. The silicon dioxide formed is deposited on the soil particles, cementing them together and giving the mass a sandy texture. When sufficient silicon tetrachloride is used to react with all moisture present, the treated soil is completely dry.

The effect of treating the soil as above and 1, 2 and 4 gives a clear picture of the effect of treatment with silicon tetrachloride with or without the addition of Ethyl Silicate.

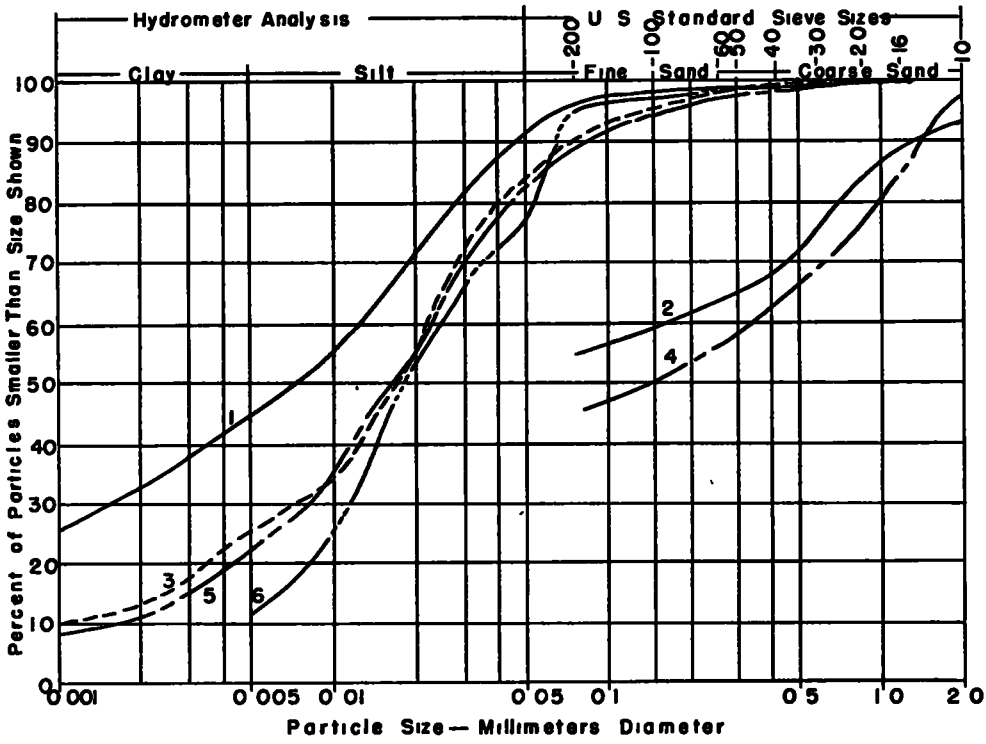
Curves and lines numbered 3 and 5 show the effect of adding Ethyl Silicate to the soil. In case No. 3, the Ethyl Silicate was added to the dry soil while in No. 5 it was added to soil containing 15 percent moisture. While the textural properties were not so radically

changed as with silicon tetrachloride, the plasticity characteristics were greatly altered. The amount of moisture in the soil at the time the Ethyl Silicate is added does not appear to be an important factor in the treatment.

In order to assure complete dispersion of the Ethyl Silicate, it was mixed with twice its weight of Skellysolve B and the mixture added to the soil. After mixing, the Skellysolve was allowed to evaporate. Skellysolve B is a light petroleum solvent manufactured for use as an extraction solvent.

The effect of adding aniline hydrochloride to the soil is shown by curve and line No. 6. Aniline hydrochloride equal to 5 percent of the dry soil by weight was dissolved in three times its weight of water and the combination added to the dry soil. The effect of aniline hydrochloride on the plasticity and textural grading of the soil is considerably more marked than that of Ethyl Silicate.

While aniline hydrochloride reduced the plastic index of the soil more than silicon tetrachloride and almost as much as silicon tetrachloride and Ethyl Silicate combined, its effect on the grain size was not as great. The soil treated with silicon tetrachloride was granular and harsh appearing while that treated with aniline hydrochloride was smooth and fine grained in appearance.



Curve No	Treatment	LL	PL	PI	Sp. Gr	Class.
1	Untreated (AA 3326-1).	58	20	38	2.58	C
2	15% moisture dehydrated by 72% $SiCl_4$	26	17	9	2.32	
3	5% ethyl silicate added to dry soil	43	23	20	2.54	SiCl
4	15% moist. dehydrated by 72% $SiCl_4$. 5% ethyl silicate added	27	23	4	2.37	
5	5% ethylsilicate added to wet soil	42	25	17	2.58	SiCl
6	5% aniline hydrochloride added in 15% water	38	32	6	2.48	Sil

Figure 2. Effect of Chemical Treatment on Physical Properties of Soil AA 3326-1

The effect of these chemicals on soil-water-asphalt systems as determined by compression tests will be discussed in the next section.

Compression Tests to Evaluate the Effect of Chemical Admixtures—The evaluation of the effect of approximately 85 admixtures on soil-water-asphalt systems was the largest single undertaking of the project. In this work, approximately 400 lots of 1-in. diameter by 1-in long briquettes were made and broken. A lot consisted of either four or six identical briquettes molded from material mixed at one time.

The choice of a method to evaluate the effect of chemical admixtures on soil-water-asphalt systems was made after considerable study. The use of a simple compression test on small briquettes was chosen as being the most expedient.

The materials for each lot of briquettes were mixed by hand using a mortar and pestle. Enough soil was used to make the desired number (four or six) of briquettes containing 25 g. of dry soil each. Some variation was used in the order of addition of ingredients, but with a majority of the additives the substance being studied was added to and thoroughly mixed with the dry soil. The desired amount of water was then incorporated. Finally the MC-2 was added and mixing continued until a mixture of uniform consistency was obtained

The mixture was then divided into portions of a suitable size (containing approximately 25 g. of dry soil) and molded. Molding was performed in a 1-in. diameter cylindrical mold fitted with double pistons so that load was applied to both ends of the specimen. A total load of 2500 lb (3183 psi.) held for 2 min. was used for molding.

After removal from the mold, each briquette was weighed and measured so that the density could be determined. Measurements were made by means of an Ames dial equipped with a bearing plate and mounted in a jig that allowed direct measurement of diameter and length. The density in pounds per cubic foot of the dry soil and admix in each briquette was determined. It was felt that the density of the dry soil plus admix would be better for comparative purposes than the usual density of the dry soil only.

After the measurements were taken, the briquettes were placed in a stoppered Erlenmeyer flask and allowed to cure 24 hr. at room temperature. After curing, they were removed and half of the lot broken in compression. The other half of the lot was immersed in distilled water for 24 hr., then broken in compression. The compression strength of each briquette was computed.

The breaking load of the briquettes was determined by means of a converted small double beam platform scale. The load was applied by means of a mechanical screw mounted in a yoke above the platform. During the load application the beam was kept balanced by discharging shot into a container suspended on the end of the beam. After failure of the briquette, the shot in the container was weighed to determine total load.

In addition to the compressive strength of the briquettes, an index called the saturation factor was determined. The saturation factor is the ratio of the average strength of the immersed briquettes to the average strength of the unimmersed briquettes in one lot. The saturation factor shows the effect of saturation on briquettes made from a given mixture, but does not evaluate the strength of either the immersed or unimmersed briquettes. Taken alone, the saturation factor is not a satisfactory index to the desirability of a given admixture. It is of value, however when used in connection with the compressive strength of the briquettes

Most of the briquettes were made from soil AA 3326-1 which is the heavy clay used in the investigation of chemical treatments described in the preceding section. However, five other soils were used in exploratory work and for detailed study of the effect of a few substances.

The percentage of water and MC-2 used with each soil was held constant in most of the investigations of the effect of various admixtures. The amount of moisture was chosen from the results of tests to determine the fluff point as described by Benson and Becker (*2*). The amount of MC-2 to be used was chosen from the results of compaction tests using different percentages of the asphalt. The amount of MC-2 and moisture was varied in some instances, but the majority of the briquettes made used the quantities shown in the following tabulation.

Soil	Water *Percent*	MC-2 *Percent*
AA 3149-51	10	7 & 11
AA 3133-3C	9	9
AA 3131-1C1	8	11
AA 3131-1C2	12	11
AA 5187-1	20	11
AA 3326-1	15	11

Note· The percentages shown are based on dry weight of soil

Four of the chemical admixtures studied were used with more than one soil. For convenience, the effect of these substances will be discussed first. A tabulation of all the briquettes made is shown in the appendix and may be consulted for more detailed information.

Ethyl Silicate—Ethyl Silicate, which is a tetra-ethyl-ortho-silicate, was chosen because of its molecular structure. It was felt that it would anchor to the siliceous soil particles and also have large groups soluble enough to dissolve in the asphalt and act as a tie-in between soil and asphalt.

Ethyl Silicate was used with a sandy loam (AA 3149–51), a silty loam (AA 3131-1C1) and a clay (AA 3326-1) Its effect on the molding characteristics of the mixtures was remarkable. The briquettes made using Ethyl Silicate had a brown color and a smooth, glazed surface.

The effect of 5 percent of Ethyl Silicate on the compressive strength of the three soils is shown in Table 7. The strength of the same soil-water-asphalt mixture without Ethyl Silicate is shown for comparative purposes.

It will be noted that Ethyl Silicate is much more effective against the weakening effect of water when it is added to the dry soil than when it is added to the wet soil.

TABLE 7
SUMMARY OF COMPRESSIVE STRENGTHS OF BRIQUETTES TO SHOW EFFECT OF ADMIXTURES OF DIFFERENT SOILS

Soil		H_2O	Admixture Used			MC-2	Compressive Strength		Saturation Factor
Lab No	Class		Kind	Amount	How Added		Unimmersed	Immersed	
		%		%		%	psi	psi	
AA 3149-51	Sandy loam	10				11	31	22	0 71
"	" "	10	Ethyl silicate	5	To dry soil	11	120	100	0 83
"	" "	10	" "	5	To wet soil	11	174	43	0 25
AA 3131-1C1	Silty loam	8				11	132	16	0 12
"	" "	8	Ethyl silicate	5	To dry soil	11	174	146	0 84
"	" "	8	" "	5	To wet soil	11	40	28	0 70
"	" "	8	Hydrated lime	1	In water	11	123	15	0 12
"	" "	8	Aluminum sulfate	0 5	In water	11	137	19	0 14
AA 3326-1	Clay	15				11	43	17	0 40
"	"	15	Ethyl silicate	5	To dry soil	11	83	60	0 72
"	"	15	" "	5	To wet soil	11	13	11	0 85
"	"	15	Aniline hydrochloride	5	To dry soil	11	64	53	0 83
"	"	15	Hydrated lime	1	In water	11	50	12	0 24
"	"	15	Aluminum sulfate	0 5	In water	11	38	14	0 37
AA 3133-3C	Silty loam	9				9	182	41	0 23
"	" "	9	Aniline hydrochloride	5	To dry soil	9	66	52	0 79
AA 3131-1C2	Clay	12				11	90	12	0 13
"	"	12	Aniline hydrochloride	5	To dry soil	11	44	42	0 96
AA 5187-1	Clay	20				11	37	8	0 22
"	"	20	Aniline hydrochloride	5	To dry soil	11	34	24	0 70

To check the effect of the amount of moisture in the soil before the addition of the Ethyl Silicate, a series of briquettes were made with soil AA 3326-1, five percent of Ethyl Silicate and eleven percent of MC-2 In the series, part of the moisture was added before the Ethyl Silicate. After the Ethyl Silicate was incorporated, enough water was added to bring the total moisture content to 15 percent. The initial moisture was varied from 2 to 14 percent in 2 percent increments. The compressive strength of the immersed briquettes varied inversely with the amount of initial moisture. When 2 percent of initial moisture was used, the immersed briquettes

had an average compressive strength of 70 psi. When 14 percent of initial moisture was used, the comparative strength was 30 psi.

Aniline Hydrochloride—A rather extensive investigation of the effect of aniline hydrochloride was undertaken because it was found in some exploratory work that its use increased the ability of briquettes made of soil AA 3326-1 to withstand the effect of water. It was used with silty loam (AA 3133-3C) and three clays (AA 3131-1C2, AA 3326-1 and AA 5187-1).

TABLE 8

TABULATION OF ADMIXTURES WHICH GAVE IMMERSED COMPRESSIVE STRENGTH OF MORE THAN 35 PSI TO BRIQUETTES MADE OF SOIL AA 3326-1

(15 percent water and 11 percent MC-2 used in all specimens)

Admixture, Kind	Amount	Compr Str		Saturation Factor
		Unimmersed	Immersed	
	%	psi	psi	
—		43	17	0 40
Chlorinated starch	5			
Ethylene diamine	5	54	56	1 04
Silicon tetrachloride	Excess	220	54	0 25
" "	35 4	110	41	0 37
" "	5 0			
Ethyl silicate	1 7	124	41	0 33
p-Phenylene-diamine-hydrochloride	4	83	62	0 75
p-Aminobenzoic acid	5	59	37	0 63
p-Aminophenol	5	74	39	0 53
o-Aminophenol		63	40	0 63
p-Dimethylaminobenzaldehyde	5	62	37	0 60
Sulfamic acid	5	70	44	0 63
o-Phenylenediamine	5	72	44	0 61
p-Phenylenediamine	5	43	41	0 95
p-Nitroaniline	5	72	40	0 56
Phenylhydrazine hydrochloride	5	50	37	0 74
p-Dimethylaminophenol Oxalate	5	78	61	0 78
Uric acid	5	89	48	0 54
Isatin	5	73	37	0 51

The effect of 5 percent of aniline hydrochloride on the compressive strength of the four soils is shown in Table 7. It will be noted that the strength of the immersed briquettes was increased by the use of aniline hydrochloride in each case.

Five percent of aniline hydrochloride gave values of the saturation factor at or near the maximum obtained with each soil. In some cases, however, smaller amounts of aniline hydrochloride gave higher strength on the immersed briquettes.

In the case of soil AA 5187-1, immersed strengths of briquettes containing 6 percent aniline hydrochloride and no asphalt were higher than corresponding strengths on briquettes containing 6 percent aniline hydrochloride and 11 percent asphalt. All other percentages of aniline hydrochloride with this soil gave better immersed strengths when asphalt was used.

Hydrated Lime—The effect of hydrated lime on soil-water-asphalt systems was investigated to a limited extent using a silty loam (AA 3131-1C1) and a clay (AA 3326-1). The results of this investigation are also shown in Table 7. While the use of 1 percent of hydrated lime had no apparent effect on the mixture, work by other investigators indicates that the use of 3 to 5 percent might have been effective.

Aluminum Sulfate—A small amount (0.5 percent) of aluminum sulfate was used in briquettes made of the same soils used in the work on hydrated lime As seen in the results shown in Table 7, the use of small quantities of this material had no apparent effect on the strength of briquettes either before or after soaking.

All the chemical admixtures not shown in Table 7 were used with soil AA 3326-1 only.

It was shown in Table 7 that the use of soil AA 3326-1 mixed with 15 percent water and 11 percent MC-2 resulted in briquettes having an average immersed compressive strength of 17 psi. A majority of the admixtures used with soil AA 3326-1 gave immersed strengths at least as good as the untreated soil-water-asphalt briquettes.

An immersed compressive strength of more than 35 psi. was chosen as a criterion for separating the more effective chemical admixtures. This figure would indicate that the admix used had more than doubled the strength of the saturated briquettes.

Table 8 is a tabulation showing all admixtures which gave immersed strengths meeting the above criterion. All lots of briquettes shown in Table 8 were made with soil AA 3326-1 using 15 percent water and 11 percent MC-2.

Table 8 reveals that a majority of the substances which at least doubled the strength of immersed briquettes when added to soil-water-asphalt mixtures were amines. This general class of substances is derived from ammonia by replacement of hydrogen by one or more hydrocarbon radicals

The good results obtained with the amines in the preliminary work discussed in this paper indicate that they are well worthy of more extensive and detailed study.

It will be noted in the tables in the appendix that briquettes containing only soil and water were made from each soil. These briquettes had high compressive strengths when unimmersed but were totally without strength after saturation.

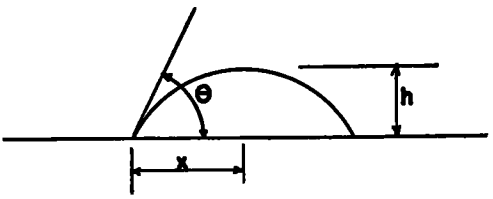


Figure A. Sketch Showing Acute Contact Angle and Dimensions Necessary for Determination

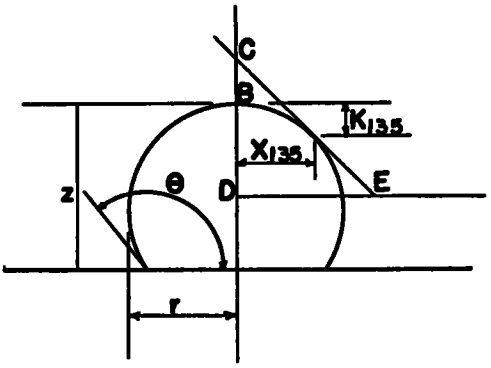


Figure B. Sketch Showing Obtuse Contact Angle and Dimensions Necessary for Determination

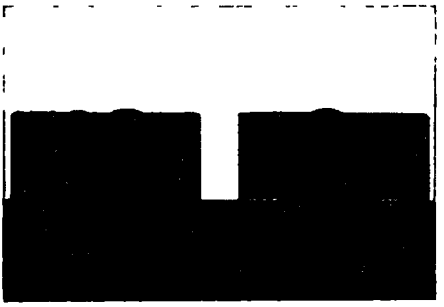


Figure C. Drops of MC-2 on Soil AA 3326-1 Containing 15 Percent Moisture

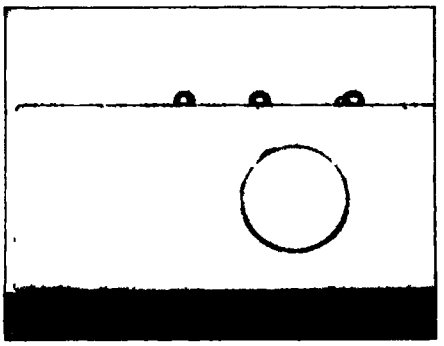


Figure D. Drops of Water on a Paraffined Glass Surface

SUMMARY AND CONCLUSIONS

The results obtained from the work described in this paper may be summarized as follows:

Phase 1—Methods of Study

Four methods were used to investigate improvements made in the wetting ability of asphaltic products and to study the behavior of these materials under various conditions.

1. Investigation of the contact angles between soil surfaces and drops of asphalt indicated that asphalt is not completely nonwetting in regard to soil but that it spreads on soil with difficulty. Measurement of contact angles is believed to be of value in bituminous-soil stabilization at least in a qualitative sense.

2. Surface pressure studies, while not leading to consistent measurements of molecular cross-sectional areas, indicated that asphalt spreads more readily on acid media.

3 Electrophoretic measurements showed that the soils and asphalts studied have the same electric particle charge This would indicate a possible repulsion between the two materials. While attempts to change the sign of the particle charge were not successful, it is felt that further work toward this end is very desirable

4. Hydration and dehydration studies showed that the loss of volatiles from cutback asphaltic materials is strongly influenced by variations of temperature and humidity.

Phase 2—Soil Treatments

It is believed that the future of bituminous-soil stabilization depends upon the development of economical admixtures for soil-water-asphalt systems, and it is felt that the work performed here shows the most likely field and some of the additives which apparently are ineffective.

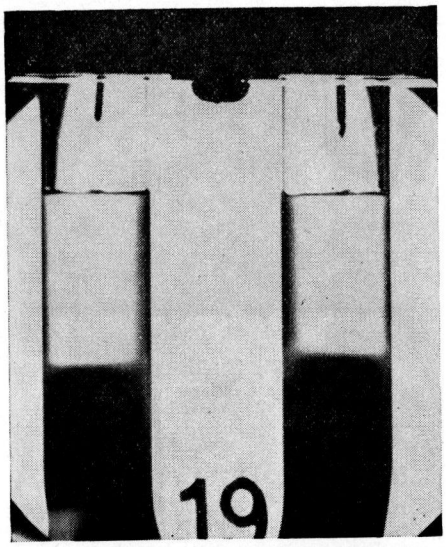


Figure E. View of U Tube Showing Boundaries Between Soil Suspension and Buffer Solution Before Start of Electrophoresis

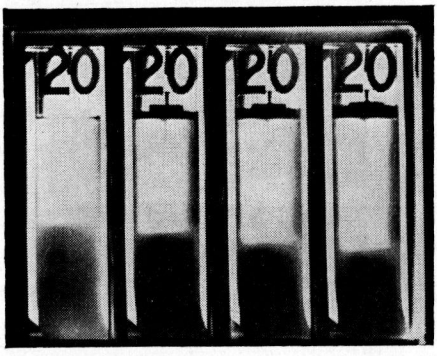


Figure F. Sequence of Views of Negative Leg of U Tube Showing Boundary Moving Away from Electrode

1. The amines seem to be rather effective, as a group, in increasing the water resisting properties of soil-water-asphalt systems. One of these, aniline hydrochloride, altered the physical properties of a heavy clay very radically. Ethyl Silicate also changed the physical properties of the soil. However in the stability tests, it was found that Ethyl Silicate was not so successful when added to wet soil. Silicon tetrachloride was very effective in altering the physical properties of a heavy

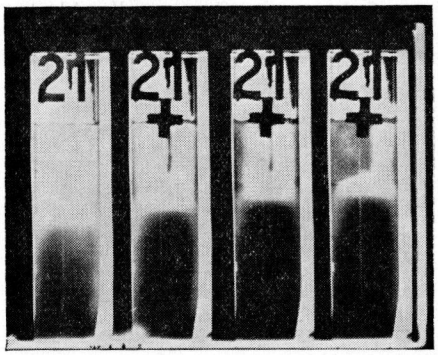


Figure G. Sequence of Views of Positive Leg of U Tube Showing Boundary Moving Toward Electrode

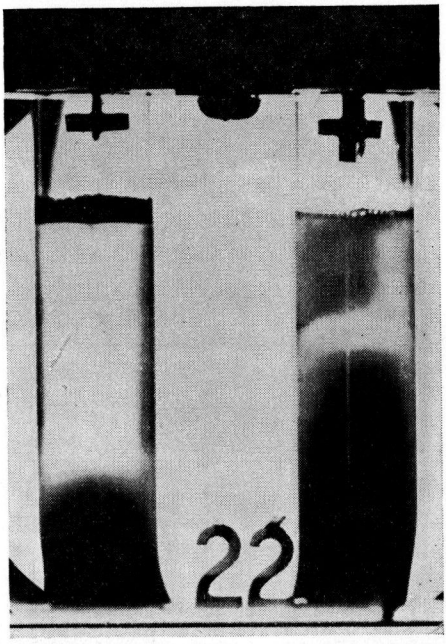


Figure H. U Tube Forty-eight Minutes After Start of Current, Showing Movement Toward Positive Electrode

TABLE A

Admixture			H_2O	NC-2	Density	Compressive Strength		Saturation Factor
Kind	%	How Added				Unimmersed	Immersed	
			%	%	*pcf.*	*psi.*	*psi*	
			10			161	0	0
			10	11		30 6	22 0	0 72
			0	11	115	49.0	9 0	0 18
			2	11	117	58 9	13 5	0 23
			4	11	112	45 6	22 2	0 49
			0	7	109	51 2	7 4	0 14
			2	7	118	63 5	22 6	0 36
			4	7	110	106	38 4	0 36
			6	7	110	115	58 7	0 51
			8	7	117	Not broken		
			10	7	114	Not broken		
Ethyl silicate	5 0	To dry soil	10	11		120	100	0 84
" "	5 0	To wet soil	10	11		174	42 9	0 25

TABLE B

Admixture			H_2O	NC-2	Density	Compressive Strength		Saturation Factor
Kind	%	How Added				Unimmersed	Immersed	
			%	%	*pcf*	*psi*	*psi*	
			9		119	528	0	0
Aniline hydrochloride	1 5	To dry soil	9		121	487	0	0
" "	2 5	" " "	9		121	572	0	0
" "	4 0	" " "	9		124	429	0	0
" "	5 0	" " "	9		121	347	0	0
" "	6 0	" " "	9		121	263	0	0
" "	10 0	" " "	9		118	112	0	0
			9	9	110	182	40 5	0 22
Aniline hydrochloride	1 5	To dry soil	9	9	108	88 4	28 5	0 32
" "	2 5	" " "	9	9	107	124	50 8	0 41
" "	4 0	" " "	9	9	109	76 5	43 2	0 56
" "	5 0	" " "	9	9	104	66 0	52 2	0 79
" "	6 0	" " "	9	9	109	60 8	35 5	0 58
" "	10 0	" " "	9	9	104	36 0	0	0

TABLE C

Admixture			H_2O	MC-2	Density	Compressive Strength		Saturation Factor	Remarks
Kind	%	How Added				Unimmersed	Immersed		
			%	%	*pcf*	*psi*	*psi.*		
			8			421+	0	0	
			8			429+	0	0	
Aluminum sulfate	0 5	In water	8			429+	0	0	
			8	11		132	12 4	0 09	
			8	11		115	14.4	0 13	H_2O added 24 hrs before MC-2
			8	11		139	18.9	0 14	
			8	11		124	15 3	0 12	H_2O added 24 hrs before MC-2
			8	11		117	18.0	0 15	
			0	11	102	181	0	0	
			2	11	104	196	0	0	
			4	11	105	180	0	0	
			6	11	106	202	11 0	0 05	
			8	11	104	160	16 9	0 11	
			10	11	104	169	28 3	0.17	
Aluminum sulfate	0.5	In water	8	11		141	18.5	0.13	
" "	0.5	" "	8	11		133	20.1	0.15	H_2O added 24 hrs before MC-2
Hydrated lime	1 0	" "	8	11		129	14 5	0 11	
" "	1.0	" "	8	11		116	14.5	0 13	H_2O added 24 hrs before MC-2
Ethyl silicate	5 0	To dry soil	8	11		174	146	0 84	
" "	5 0	To wet soil	8	11		40 2	28 4	0 71	

clay but was not as effective as the amines in increasing the water resisting properties of the soil-water-asphalt briquettes.

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TABLE D

Admixture			H_2O	MC-2	Density	Compressive Strength		Saturation Factor
Kind	%	How Added				Unimmersed	Immersed	
			%	%	*pcf*	*psi*	*psi*	
			12		123	723	0	0
Aniline hydrochloride	1 5	To dry soil	12		121	728	0	0
" "	2 5	" " "	12		120	515	0	0
" "	4 0	" " "	12		123	268	0	0
" "	5 0	" " "	12		120	419	0	0
" "	6 0	" " "	12		118	454	0	0
" "	10 0	" " "	12		117	192	0	0
			12	11	100	90 3	12 1	0 13
Aniline hydrochloride	1 5	To dry soil	12	11	103	86 9	20 1	0 23
" "	2 5	To dry soil	12	11	100	76 2	44 3	0 58
" "	4 0	" " "	12	11	100	74 8	50 6	0 68
" "	0 0	" " "	12	11	99	43 7	42 4	0 97
" "	6 0	" " "	12	11	100	60 0	42 0	0 70
" "	10 0	" " "	12	11	99	66 9	36 0	0 54

TABLE E

Admixture			H_2O	MC-2	Density	Compressive Strength		Saturation Factor	Remarks
Kind	%	How Added				Unimmersed	Immersed		
			%	%	*pcf*	*psi*	*psi*		
			20		109	285	0	0	
Aniline hydrochloride	1 5	To dry soil	20		109	406	0	0	
" "	2 5	" " "	20		105	262	8 0	0 03	
" "	4 0	" " "	20		117	307	17 7	0 06	
" "	5 0	" " "	20		104	232	17 5	0 08	
" "	6 0	" " "	20		109	244	39 1	0 16	
" "	10 0	" " "	20		102	127	19 0	0 15	
			20	11	87	16 0	4 5	0 28	Asphalt added to soil before water
			20	11	91	36 9	8 1	0 22	
Aniline hydrochloride	1 5	To dry soil	20	11	92	48 2	15 2	0 32	
" "	2 5	" " "	20	11	89	72 8	24 2	0 33	
" "	2 5	" " "	20	11	89	58 0	28 2	0 49	Oven dry aniline hydrochloride used
" "	4 0	" " "	20	11	92	55 3	28 8	0 52	
" "	5 0	" " "	20	11	86	33 9	24 1	0 71	
" "	6 0	" " "	20	11	92	48 1	32 2	0 67	
" "	10 0	" " "	20	11	86	38 8	27 7	0 71	

APPENDIX

Contact Angle Determination

The determination of acute contact angles was based on a figure similar to Figure A The base line on which the circular arc rests represents the top of the briquette and the circular line represents the silhouette of the asphalt drop The dimensions x and h are determined

TABLE F

Admixture			H_2O	MC-2	Density	Compressive Strength		Saturation Factor	Remarks
Kind	%	How Added				Unimmersed	Immersed		
			%	%	*pcf*	*psi*	*psi*		
			20			168	6 8	0 04	
			15			405+	0	0	
			15			404+	0	0	
			0			185	0	0	
			15		121	527	0	0	
Kojic acid	0 2	In water	20			167	12 4	0 07	
Aluminum sulfate	0 5	" "	15			418+	0	0	
Ethyl silicate	5 0	To dry soil	0			198	0	0	
" " "	5 0	" " "	15			209	39 4	0 19	
Aniline hydrochloride	1 5	" " "	15		118	526	0	0	
" "	2 5	" " "	15		118	373	0	0	
" "	4 0	" " "	15		117	366	0	0	
" "	5 0	" " "	15		117	303	26 2	0 09	
" "	6 0	" " "	15		106	232	0	0	
" "	10 0	" " "	15		111	225	18 8	0 08	
			0	7 53		398	0	0	
			0	7 53		358	0	0	
			0	11		193	0	0	
			0	11		186	0	0	
			0	15 05		99 5	0	0	
			0	15 05		75 7	0	0	
			3	11	107	162	0	0	
			6	11	105	95 5	0	0	
			9	11	103	83 2	0	0	
			10	7 53		169	2 2	0 01	
			10	15 05		19 5	4 5	0 23	
			12	11	101	37 4	6 4	0 17	
			15	11		53 4	14 5	0 27	
			15	11		37 9	8 3	0 22	Water added 24 hrs. before MC-2
			15	11		36 0	5 9	0 16	
			15	11		28 7	5 4	0 19	Water added 24 hrs before MC-2
			15	11		29 7	14 3	0 49	
			15	11		38 7	16 3	0 42	
			15	11		35 8	9 0	0 25	Cured 48 hrs at 37 C before molding
			15	11		41 8	9 8	0 23	Cured 48 hrs at 37 C after molding
			15	11		49 7	21 6	0 43	
			15	11		43 7	11 2	0 26	Cured 48 hrs at 53 C before molding
			15	11		36 9	9 8	0.27	Cured 48 hrs at 53 C after molding
			15	11	97	26 1	6 7	0 26	
			15	11	95	35 3	6 8	0 19	
			15	11	95	50 3	11 0	0 22	
			15	11	96	49 3	23 0	0 47	
			15	11	98	48 3	31 8	0 66	
			15	11	97	46 0	26 0	0.57	
			15	11	95	56 9	32 7	0.57	
			15	11	97	49 6	23 9	0 48	
			15	11	96	37 1	14 8	0 40	
			15	11	96	40 5	15 9	0 39	
			15	11	96	51 3	25 8	0 50	
			15	11	96	44 1	17 2	0 39	
			15	11	96	48 7	24 2	0 50	
			15	11	95	35 1	15 6	0 45	
			15	11	97	42 8	17 4	0 41	
			15	11	95	49 6	20 2	0 41	
			15	11	100	125	20 9	0 17	
			15	11	97	48 1	25 3	0 53	
			15	11	97	42 7	22 8	0 53	
			15	11	98	47 9	14 7	0 31	MC-2 ED-352
			20	7 53		55 9	14 2	0 25	
			20	15 05		10 6	3 7	0 35	
Kojic acid	0 2	In water	20	7 53		70 9	19 3	0 27	
" "	0 2	" "	10	7 53		218	2 0	0 01	
" "	0 2	" "	20	15 05		12 8	4 4	0 34	
" "	0 2	" "	10	15 05		22 5	4 9	0 22	
" "	0 2	" "	20	7 53		348+	0	0	Oven dried before MC-2 added
" "	0 2	" "	10	7 53		363	0	0	" "
" "	0 2	" "	20	15 05		70 2	0	0	" "
" "	0 2	" "	10	15 05		76 8	0	0	" "
Aluminum sulfate	0 5	" "	15	11		45 3	18 3	0 40	
" "	0 5	" "	15	11		31 0	10 1	0 33	Water added 24 hrs before MC-2

TABLE F—*Continued*

Admixture			H_2O	MC-2	Density	Compressive Strength		Saturation Factor	Remarks
Kind	%	How Added				Unimmersed	Immersed		
			%	%	pcf	psi	psi		
Hydrated lime	1 0	In water	15	11		52 0	10 6	0 20	
" "	1 0	" "	15	11		48 9	13 0	0 27	Water added 24 hours before MC-2
Ethyl silicate	5 0	In MC-2	0	11		123	0	0	
" "	5 0	" "	15	11		11 0	12 5	1 14	
" "	5 0	" "	15	11		25 3	17 9	0 71	Cured 48 hrs at 37 C before molding
" "	5 0	" "	15	11		13 7	12 8	0 93	" "
" "	5 0	" "	15	11		14 6	11 3	0 77	
" "	5 0	" "	15	11		24 7	22 1	0 89	Cured 48 hrs at 53 C before molding
" "	5 0	" "	15	11		26 2	24 0	0 92	" "
" "	5 0	To dry soil	0	11		112	0	0	
" "	5 0	" " "	0	11	109	123	6 5	0 05	
" "	5 0	" " "	0	11		188	0	0	
" "	5 0	" " "	3	11	109	136	0	0	
" "	5.0	" " "	6	11	108	121	24 3	0 20	
" "	5 0	" " "	9	11	106	120	53 8	0 45	
" "	5 0	" " "	12	11	102	103	83 6	0 81	
" "	5.0	" " "	15	11	98	110	95.9	0 87	
" "	5 0	" " "	15	11		110	62 1	0 56	
" "	5 0	" " "	15	11		130	58 9	0 45	
" "	5.0	" " "	15	11	96	87 7	78 5	0 90	
" "	5 0	" " "	15	11	94	87 0	88 0	1 02	
" "	5.0	" " "	15	11	96	106	79.4	0 75	
" "	5.0	" " "	15	11	94	80 7	86 9	1 08	
" "	5 0	" " "	15	11		111	54 5	0 49	
" "	5 0	" " "	15	11		62 2	52 4	0 84	
" "	5.0	" " "	15	11		45 7	37 5	0 82	
" "	5 0	" " "	15	11		46 2	28 3	0 61	
" "	5 0	" " "	15	11		43 8	30 9	0.71	
" "	2 0	" " "	15	11	95	70 1	34 0	0 49	
" "	2 0	" " "	15	11	96	85 2	30 0	0 35	
" "	3 0	" " "	15	11	95	83 1	46 8	0.56	
" "	4 0	" " "	15	11	96	95 5	64 3	0 67	
" "	6 0	" " "	15	11	94	86 0	74 6	0 87	
" "	6.0	" " "	15	11	94	91.7	79 0	0 86	
" "	8 0	" " "	15	11	94	81 3	78 0	0 96	
" "	8 0	" " "	15	11	93	52 3	57 1	1 09	
" "	8 0	" " "	15	11	93	67 8	78 5	1.16	
" "	10 0	" " "	15	11	94	61.7	78 5	1.27	
" "	12 0	" " "	15	11	92	33.3	47 3	1 42	
" "	14 0	" " "	15	11	90	21.6	25 4	1 18	
" "	16 0	" " "	15	11	91	22 8	27 5	1 21	
" "	5.0	To wet soil	3	11	110	80 9	11 4	0 14	
" "	5 0	" " "	6	11	108	59 9	21 5	0 36	
" "	5 0	" " "	9	11	105	20 9	18.7	0 89	
" "	5 0	" " "	12	11	101	16 1	15 1	0 94	
" "	5.0	" " "	15	11	99	11.3	12 4	1 10	
" "	5.0	" " "	15	11		13 4	8 0	0.60	
" "	5 0	" " "	15	11		10 5	7 8	0 74	Cured 18 hrs. before MC-2 added
" "	5.0	" " "	15	11		14 4	5 0	0 35	Cured 48 hrs. before MC-2 added
" "	5 0	" " "	15	11	86	15.6	23 3	1 49	
" "	5 0	To soil at 2% moist	15	11	94	55 8	69 5	1 25	
" "	5 0	To soil at 4% moist	15	11	94	38 7	48.0	1 24	
" "	5 0	To soil at 6% moist	15	11	95	26 0	37 8	1 45	
" "	5 0	To soil at 8% moist	15	11	94	22 8	33 4	1 46	
" "	5 0	To soil at 10% moist	15	11	92	12 3	29.5	2 40	Results doubtful
" "	5 0	To soil at 12% moist	15	11	94	21 7	31.7	1 46	
" "	5 0	To soil at 14% moist	15	11	94	18 1	26 1	1 44	
" "	2.0	To wet soil	15	11	95	32 5	16 4	0 50	
" "	4 0	" " "	15	11	95	19 8	12 2	0 62	
" "	6 0	" " "	15	11	94	14 7	11 2	0 76	
" "	8 0	" " "	15	11	94	9 0	8 2	0 91	
Aniline hydrochloride	5 0	To dry soil	0	11		242	0	0	
" "	1 5	" " "	15	11	98	76.5	33 8	0 44	MC-2 ED 352
" "	2.5	" " "	15	11	97	86 8	52 9	0 61	MC-2 ED 352
" "	4.0	" " "	15	11	98	77.4	59 9	0 77	MC-2 ED 352
" "	5 0	" " "	15	11	98	79.5	56 7	0 71	MC-2 ED 352

TABLE F—*Continued*

Admixture			H_2O	MC-2	Density	Compressive Strength		Saturation Factor	Remarks
Kind	%	How Added				Unimmersed	Immersed		
			%	%	*pcf*	*psi.*	*psi*		
Aniline Hydrochloride	5 0	To dry soil	15	11	95	49 2	48 9	0 99	
" "	5 0	In water	15	11		85 0	70 7	0 83	
" "	6 0	To dry soil	15	11	94	54 3	46 7	0 86	MC-2 ED 352
" "	10 0	" " "	15	11	94	54 2	42 5	0 78	MC-2 ED 352
" "	15 0	" " "	15	11	90	37 6	23 9	0 64	
Lignin	2 5	" " "	15	11	97	67 0	10 4	0 16	
"	5 0	" " "	15	11	95	92 5	10 8	0 12	
"	10 0	" " "	15	11	97	166	7 8	0 05	
Urea	2 5	In water	15	11	96	39 3	11 2	0 28	
"	5 0	" "	15	11	97	27 9	6 4	0 23	
"	10 0	" "	15	11	96	21 5	5 7	0 27	
Chlorinated starch	2 0	To dry soil	15	11	97	35 7	14 2	0 40	
" "	5 0	" " "	15	11	101	66 7	18 4	0 28	
" "	5 0	" " "							
Ethylene diamine	5 0	In water	15	11	98	54 0	56 3	1 04	
See remarks			10	12		45 3	16 5	0 36	MC-2 refluxed with ethyl silicate & surplus evaporated
Thymol	2 0	To dry soil	15	11	99	51 7	13 8	0 27	
"	4 0	" " "	15	11	97	49 8	9 5	0 19	
By product of T-SD-5	5 0	" " "	15	11	96	41 2	7 5	0 18	
Chlorinated lime	1 0	" " "	15	11	95	46 4	9 9	0 21	
" "	3 0	" " "	15	11	96	73 6	25.3	0 34	
" "	5 0	" " "	15	11	98	60 8	18 8	0 31	
MC-2 refluxed with $SiCl_4$	6 9	To wet soil	15	12		66 5	11 5	0 17	
See remarks			15	11		139	58 0	0 42	MC-2 refluxed with $SiCl_4$ & surplus evaporated
Silicon tetrachloride	Exc.	" " "	15	11		220	53 6	0 24	$SiCl_4$ & MC-2 combined before adding to soil
" "	"	To dry soil	0	11		294	0	0	$SiCl_4$ & MC-2 combined before adding to soil Surplus $SiCl_4$ evaporated
" "	35 4	To wet soil	15	11		110	40 9	0 37	
" "	73	To soil at 15% moist	2.5	11		104	37 4	0 36	Orig moist hydrolyzed by $SiCl_4$
" "	70 8	" "	5	11		58 0	42 5	0 73	" "
" "	73	" "	7.5	11		59 0	30 5	0 52	" "
" "	70 8	" "	10	11		36 0	22 6	0 63	" "
" "	70 8	" "	15	11		42 0	22 2	0 53	" "
" "	5 0	Mixed-to soil at 15% moist	*	11		124	40 7	0 33	Amount of moisture after treatment not known*
Ethyl silicate	1 7								
Silicon tetrachloride	Exc	To soil at 15% moist	0	11		111	50 2	0 45	Orig moist hydrolyzed by $SiCl_4$
Ethyl silicate	1 7	After $SiCl_4$							
Silicon tetrachloride	Exc	To soil at 15% moist	5	11		101	59 8	0 59	" "
Ethyl silicate	1 7	After $SiCl_4$							
Silicon tetrachloride	72 0	To soil at 15% moist	0	15		93 1	38 3	0 41	" "
Ethyl silicate	5 0	After $SiCl_4$							
Silicon tetrachloride	72 0	To soil at 15% moist	2 5	11		62 7	21 8	0 35	" "
Ethyl silicate	5 0	After $SiCl_4$							
Silicon tetrachloride	72 0	To soil at 15% moist	8	11		49 5	16 1	0 33	" "
Ethyl silicate	5 0	After $SiCl_4$							
Silicon tetrachloride	72 0	To soil at 15% moist	10	11		48 2	19 6	0 41	" "
Ethyl silicate	5 0	After $SiCl_4$							
Silicon tetrachloride	72 0	To soil at 15% moist	15	11		46 4	14 6	0 31	" "
Ethyl silicate	5 0	After $SiCl_4$							
Silicon tetrachloride	72 0	To soil at 15% moist	0	11		186	100 3	0 54	" "
Aniline hydrochloride	5 0	After $SiCl_4$							
Silicon tetrachloride	72 0	To soil at 15% moist	15	11		32 7	20 6	0 63	" "
Aniline hydrochloride	5 0	In water							
Silicon tetrachloride	35 4	Mixed—to soil at 15% moist	*	11		115	25 1	0 22	Amount of moisture after treatment not known
Oleic acid	5 0								
Silicon tetrachloride	20 0	Mixed—to soil at 15% moist	*	11		39 0	15 2	0 39	Amount of moisture after treatment not known
Oleic acid	5 0								

TABLE F—*Continued*

Admixture			H_2O	MC-2	Density	Compressive Strength		Saturation Factor	Remarks
Kind	%	How Added				Unimmersed	Immersed		
			%	%	*pcf*	*psi*	*psi*		
Silicon tetrachloride	Exc	Mixed-to soil							Orig moist hydrolyzed by $SiCl_4$
Palmitic acid	5.0	at 15% moist	0	11		71 7	23 0	0 32	
Oleic acid	5 0	To wet soil	15	11		16 0	0	0	
Silicone stopcock grease	*5 0	" " "	15	11		22 7	14 2	0 63	High vacuum type*
" "	*5 0	" " "	15	11		24 5	11 1	0 45	Ordinary type*
p-Phenylene-diamine	5 0	To dry soil	15	11		78 1	53 8	0 69	
Aniline oil	5 0	To wet soil	15	11		37 2	0	0	
Sulfanilamide	5 0	To dry soil	15	11		45 8	15 0	0 33	
p-Phenylene diamine hydrochloride	4 0	In water	15	11		82 7	62 3	0 75	
Roccall	5 0	To dry soil	10	11		74 1	42 3	0 57	
"	22 0	" " "	0	11		57 8	45 8	0 79	
0 3246 N hydrochloric acid	15	" " "	*	11		40 5	24 5	0 60	Soil wet with HCl*
0 322 N Potassium hydroxide	15	" " "	*	11		56 0	18 0	0 32	Soil wet with KOH*
Ortho-nitro-biphenyl	5 0	To wet soil	15	11		23 4	10 1	0 43	
dl-Alanine	5 0	To dry soil	15	11	94	26 7	0	0	
"	15 0	" " "	15	11	92	92 3	7 7	0 83	
p-Aminobenzoic acid	5 0	" " "	15	11	91	59 3	36 6	0 62	
" "	15 0	" " "	15	11	92	86 4	28 8	0 33	
p-Aminophenol	5 0	" " "	15	11	94	74 1	39 3	0 53	
"	15 0	" " "	15	11	92	91 0	36 7	0 40	
1-Amino-2-naphthol-4-sulfonic acid	5	" " "	15	11	98	74 4	32 7	0 44	
" "	15	" " "	15	11	96	114	33 7	0 30	
p-Bromoacetanilide	5	" " "	15	11	97	66 2	31 4	0 47	
"	15	" " "	15	11	95	65 8	30 0	0 46	
p-Bromophenocyl bromide	5	" " "	15	11	97	59 7	32 9	0 55	
" "	15	" " "	15	11	97	73 3	36 7	0 50	
Benzamide	5 0	" " "	15	11	94	51 7	25 2	0 49	
"	15 0	" " "	15	11	91	72 6	25 9	0 36	
p-Dimethylaminobenzaldehyde	5 0	" " "	15	11	93	61 6	36 9	0 60	
" "	15 0	" " "	15	11	90	67 9	24 6	0 36	
p-Dimethylaminoazo benzene	5 0	" " "	15	11	93	59 1	20 2	0 34	
" "	15 0	" " "	15	11	89	107	44 2	0 41	
Diphenylcarbamine chloride	5 0	" " "	15	11	95	69 6	32 9	0 47	
" "	15 0	" " "	15	11	91	72 6	30 5	0 42	
Diphenylamine	5 0	" " "	15	11	92	38 6	22 1	0 57	
"	15 0	" " "	15	11	90	74 0	27 6	0 37	
Diazo aminobenzene	5 0	" " "	15	11	94	60 6	30 5	0 50	
" "	15 0	" " "	15	11	90	103	37 5	0 36	
Hydroxilamine hydrochloride	5 0	" " "	15	11	92	53 3	21 0	0 39	
" "	15 0	" " "	15	11	90	17 9	<3	<0 17	
Sulfamic acid	5 0	" " "	15	11	97	70 1	43 8	0 62	
" "	15 0	" " "	15	11	98	77 3	39 1	0 51	
o-Phenylenediamine	5 0	" " "	15	10	94	72 3	43 8	0 61	
"	15 0	" " "	15	11	89	70 7	45 5	0 64	
Metanilic acid	5 0	" " "	15	11	96	37 4	14 4	0 39	
" "	15.0	" " "	15	11	95	52 5	10 9	0 21	
m-Nitroaniline	5 0	" " "	15	11	95	62 0	34 8	0 56	
"	15 0	" " "	15	11	92	86 9	39 9	0 46	
Ammonium benzoate	5 0	" " "	15	11	95	58 3	24 3	0 42	
" "	15 0	" " "	15	11	92	66 3	12 9	0 19	
Acetanilide	5 0	" " "	15	11	95	50 2	26 8	0 53	
"	15 0	" " "	15	11	90	79 5	24 5	0 31	
Anthranilic acid	5 0	" " "	15	11	93	66 1	33 9	0 51	
" "	15 0	" " "	15	11	92	67 7	30 3	0 45	
o-Amino phenol	5 0	" " "	15	11	95	62 7	39 7	0 63	
" "	15 0	" " "	15	11	90	54 1	17 3	0 32	
p-Nitroaniline	5 0	" " "	15	11	96	71 5	39 7	0 56	
"	15 0	" " "	15	11	92	72 6	34 3	0 47	
b-Naphthylamine	5 0	" " "	15	11	94	69 8	34 4	0 49	
"	15 0	" " "	15	11	90	71 1	34 8	0 49	
Triethanolamine	5 0	" " "	15	11	93	60 2	32 4	0 54	
"	15 0	" " "	15	11	90	19 4	<5 5	<0 28	
s-Diphenylthio urea	5 0	" " "	15	11	94	51 0	24 6	0 48	
" "	15 0	" " "	15	11	91	68 5	26 0	0 38	
Phenylhydrazine hydrochloride	5 0	" " "	15	11	93	50 2	37 1	0 74	
" "	15 0	" " "	15	11	89	61 2	32 9	0 54	

TABLE F—*Concluded*

Admixture			H_2O	MC-2	Density	Compressive Strength		Saturation Factor	Remarks
Kind	%	How Added				Unimmersed	Immersed		
			%	%	*pcf*	*psi*	*psi*		
p-Aminoazobenzene	5 0	" " "	15	11	93	51 2	27 0	0 53	
"	15 0	" " "	15	11	89	77.9	23 9	0 31	
Methyl orange	5.0	" " "	15	11	95	53 2	0	0	
" "	15 0	" " "	15	11	92	74 1	0	0	
1-Amino-8-Naphthol-3,6-disulfonic acid	5.0	" " "	15	11	96	27 2	10 6	0 39	
" "	15 0	" " "	15	11	95	52 0	12 8	0 25	
4-Chloro-2-amino-phenol	5.0	" " "	15	11	95	57 2	27 1	0 47	
" "	15 0	" " "	15	11	93	96 0	28 0	0 29	
2,4-Dinitroaniline	5 0	" " "	15	11	96	66 8	34 2	0 51	
"	15.0	" " "	15	11	93	55 5	32 5	0 59	
p-Dimethylamino phenol oxalate	5 0	" " "	15	11	94	78.3	61 2	0 78	
" "	15 0	" " "	15	11	90	27 0	16 7	0 62	
Diphenylethylene-diamine	5.0	" " "	15	11	94	55 2	31 8	0 58	
" "	15 0	" " "	15	11	91	20 3	14 4	0.71	
Diglycol stearate	5.0	" " "	15	11	91	18.7	10 6	0 57	
" "	15 0	" " "	15	11	87	25.1	17 3	0 69	
Hexamethylene-tetramine	5 0	" " "	15	11	94	32 9	7 5	0 23	
" "	15 0	" " "	15	11	91	25 2	0	0	
α-Naphthylamine	5 0	" " "	15	11	92	36 2	16 6	0 46	
"	15 0	" " "	15	11	88	52 1	16.3	0 31	
Phthalimide	5.0	" " "	15	11	95	62.5	27.5	0.44	
"	15 0	" " "	15	11	92	55 7	27.7	0.50	
p-Phenylenediamine	5 0	" " "	15	11	94	43 0	40 8	0.95	
"	15.0	" " "	15	11	89	0	0	0	
p-Toluidine	5.0	" " "	15	11	94	48.7	19.9	0.41	
"	15 0	" " "	15	11	88	61.8	15.6	0 25	
Acid pyrogallic	5 0	" " "	15	11	93	14.7	9 2	0.63	
" "	15 0	" " "	15	11	93	29.9	9.0	0.30	
Benzidine	5 0	" " "	15	11	93	68 0	28.5	0 42	
"	15.0	" " "	15	11	90	137	46 3	0 34	
Di-ethylene glycol mono ethyl ether	5 0	" " "	15	11	93	29.9	12.4	0.41	
" "	15.0	" " "	15	11	87	16.0	0	0	
Adipic acid	5 0	" " "	15	11	94	40.2	12.7	0.32	
" "	15.0	" " "	15	11	89	36.7	10.4	0 28	
Benzil	5 0	" " "	15	11	93	41 8	20 2	0 48	
"	15.0	" " "	15	11	91	54.4	18.0	0.33	
Hydroquinone	5 0	" " "	15	11	95	36 7	12 6	0 34	
"	15.0	" " "	15	11	92	44.9	14.1	0 31	
Rosin	5.0	" " "	15	11	95	40 3	23.7	0.59	
"	15.0	" " "	15	11	91	64 3	31.7	0 49	
Resorcinol	5 0	" " "	15	11	92	33 4	12 0	0 36	
"	15 0	" " "	15	11	91	16.6	0	0	
Trioxymethylene	5 0	" " "	15	11	95	54.8	18.0	0.33	
"	15 0	" " "	15	11	93	78 9	23.0	0.29	
Acid tannic	5 0	" " "	15	11	97	37.7	21.7	0.58	
" "	15 0	" " "	15	11	93	62 6	27.7	0 44	
Triphenyl carbinol	5 0	" " "	15	11	97	48 3	15 8	0.32	
" "	15.0	" " "	15	11	89	57.7	23.6	0 41	
Xylose	5.0	" " "	15	11	95	26.1	10 1	0 39	
"	15.0	" " "	15	11	93	19 2	8.0	0 42	
Uric acid	5 0	" " "	15	11	96	88 5	47 8	0 54	
" "	15.0	" " "	15	11	94	90 7	50 8	0 56	
Saponin	5.0	" " "	15	11	96	46 9	13 3	0.28	
"	15 0	" " "	15	11	91	21 8	0	0	
Permutit	5 0	" " "	15	11	97	77 2	32 6	0 42	
"	15 0	" " "	15	11	94	89 6	6 2	0.07	
Sulfanilic acid	5 0	" " "	15	11	95	39 9	13 1	0 33	
" "	15.0	" " "	15	11	93	55 4	9.3	0 17	
Gallic acid	5 0	" " "	15	11	96	41 2	18 8	0 46	
" "	15 0	" " "	15	11	94	60 8	24 9	0 41	
Lauric acid	5 0	" " "	15	11	94	26 4	8 5	0 32	
" "	15 0	" " "	15	11	88	31 3	11 3	0 36	
Lactose	5 0	" " "	15	11	95	27 0	7 6	0 28	
"	15 0	" " "	15	11	93	42 0	9 1	0 22	
Isatin	5 0	" " "	15	11	96	72 5	36 6	0 51	
"	15 0	" " "	15	11	92	78 0	35 8	0 46	
Dextrine	5 0	" " "	15	11	95	43 5	17 1	0 39	
"	15 0	" " "	15	11	92	42 0	12 2	0 29	
Casein	5 0	" " "	15	11	94	55 0	23 6	0 43	
"	15 0	" " "	15	11	89	46 6	0	0	
Benzoic acid	5 0	" " "	15	11	95	44 5	16 5	0 37	
" "	15 0	" " "	15	11	90	50 2	19.9	0 40	
Sulfur sublimed	5 0	" " "	15	11	98	62 2	24 0	0 39	
" "	15 0	" " "	15	11	95	55 3	25 3	0 46	

from the projected image The contact angle, θ is given by the formula.

$$\theta = 2 \tan^{-1}\frac{h}{x}$$

When the contact angle is obtuse, the projected image from which the dimensions are determined is similar to that shown in Figure B. Here again, the base line on which the partial circle rests represents the top of the briquette and the circular arc represents the silhouette of the asphalt drop E is any point on the tangent drawn at 45 deg to the base line The dimensions r, z, DE and DB are determined directly from the projected image.

The value of θ, the contact angle, is determined by use of formulae from Dorsey (*9*) and Mack and Lee (*8*) as well as tables from Sugden (*10*) and Mack and Lee.

Figure C is a reproduction of a typical plate from which acute contact angles were determined. The drops are of MC-2 and the briquettes are of soil AA 3326-1 containing 15 percent moisture The average contact angle is 29 6 deg.

Figure D is a reproduction of a typical plate from which obtuse contact angles were determined. The drops were of distilled water. The surface is the edge of a glass microscope slide that had been coated with paraffin The average contact angle is 109 6 deg.

Electrophoresis Studies

Figures E, F, G and H show the movement of the boundaries between a suspension of soil AA 3326-1 and the buffer solution due to electrophoretic action. Figure E shows both legs of the U tube before the current was turned on The electrodes may be seen above the top of the solution. In Figure F are four views of the left (negative) leg The left view is identical to the left leg in Figure E. The second view from the left shows the position of the boundary 18 min after the electrodes were lowered into place and the current started The third view was taken 7 min. after the second and the right hand one 9 min. after the third. It will be noted that the boundary moves downward away from the negative electrode

Figure G shows four views of the right leg containing the positive electrode The left view was taken before the current was started and the other three were taken at approximately the same time intervals as the ones in Figure F. It will be noted that the boundary moves toward the positive electrode

Figure H shows both legs of the U tube 48 min after the current was started It will be noted that the boundaries have moved away from the negative and toward the positive electrode This movement indicates that the soil particles are carrying a negative electrical charge

Compressive Tests on Briquettes

Tables A through F give the details of all the 1-in diameter briquettes made and broken during the investigation of the effect of admixtures on the compressive strength of soil-water-asphalt systems.

Each table contains the data obtained with one soil as follows

Table No	Soil	MC-2
A	AA 3149-51	47901
B	AA 3133-3C	ED-352
C	AA 3131-1C1	47901
D.	AA 3131-1C2	ED-352
E .	AA 5187-1	ED-352
F. .	AA 3326-1	47901[a]

[a] Exceptions marked.

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SOME CAPILLARY PHENOMENA IN SANDY MATERIALS

D P KRYNINE, *University of California*

SYNOPSIS

The study of the physical principles on which the accumulation of moisture under pavements is based is an engineering problem of major importance This paper should be considered as an attempt to disclose some of these principles from a few laboratory tests on sandy materials (Ottawa sand and two California sands) Emphasis is laid on the items not sufficiently clarified in the highway and runway literature such as. (a) horizontal capillarity, as in the case of movement of moisture from the edges of a pavement toward its center, and (b) the boundary effect when the moving moisture reaches an outflow face or some obstacle handicapping its further movement. Some consideration is also given to the phenomenon of condensation of water vapor

Variation in moisture content of the base and subgrade of a pavement is a subject matter worthy of detailed study. Considerable factual material collected by highway and runway engineers, most of which has been published in the *Proceedings* of the annual meetings of the Highway Research Board of the past ten years (*1*, *2*),[1] shows that the moisture content of a subgrade built at an optimum moisture content may become appreciably different some time later. Some cases of destruction of pavements due to accumulation of moisture under the pavements, even in desert regions, have been reported (*3*)

Assuming that water does not penetrate through a pavement, the sources from which additional moisture may come to a subgrade (or the sink toward which it moves from the subgrade) are (a) the water table, and (b) the edges of the pavement In both cases, capillarity is a predominant factor, though some horizontal movement from the edges of a pavement under the action of a hydraulic head, however small, also should be considered. Again, capillarity has to be studied in conjunction with its sister phenomenon, condensation of water vapor, since capillary moisture moves in both liquid and gaseous phases, and a source of moisture at the edges of a pavement from a saturated atmosphere is quite a possibility

If a program of the study of accumulation of moisture under pavement should be prepared, the beforementioned items such as capillarity, both vertical and horizontal, and condensation should be included in it. The obscure phenomenon of splitting of the capillary moisture into a fluid phase and a gaseous phase and the estimation of the quantity of the latter, are worthy of consideration. Finally, the provenance (or location of the original sources of supply) of water or water vapor that causes increase of the moisture content

[1] Italicized figures in parentheses refer to list of references at the end of this paper