SOIL STABILIZATION WITH COAL TAR

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SYNOPSIS

As the result of three soil stabilization experiments conducted in South Carolina in 1935, much practical information about the use of coal tar as a stabilizing agent has been acquired

Two general methods were tried In one a suitable oil or low viscosity tar was first mixed with the dry soil and then a more viscous tar binder was incorporated with the mixture In the other method water was first added to the soil to soften lumps and otherwise prepare the soil for the addition of a viscous tar binder

The experience indicated that the latter, called the wet method, gave the better results

The report describes four other projects in Georgia, North Carolina and South Carolina on which the experience gained in the three experimental projects was utilized In general procedure was as follows Scarification of surface, addition of water to increase the moisture content two or three per cent above that required for maximum density, addition of coal tar as determined by laboratory tests, drying to slightly below moisture content for maximum densification, compaction, surface application of tar, and cover aggregate

The laboratory methods and special shear test apparatus used in acquiring information about the soils are described and discussed

Three important soil stabilization experiments were conducted during the summer of 1935 by the South Carolina Highway Department They furnished a large amount of practical information about the use of coal tar as a stabilizing agent and verified certain conclusions which had been reached from laboratory investigations It was our privilege to suggest the particular method of construction used and observe the results of the experiments

EXPERIMENT NO 1

The first experiment consisted in the tar stabilization of one mile of soil on the road between Johnsonville and Hemingway We were requested by Mr Charles H Moorefield, late State Highway Engineer, to recommend a suitable method for the stabilization of this section with tar

Representative samples of the soil were analyzed, mixed in different proportions with different grades of road tar, and tested for stability, before and after immersion in water, by means of a Koppers Shear Tester (Fig 1). This apparatus employs the principle of the Skidmore shear device but is so constructed that it will test samples 1 in in diameter, weighing only 15 g , and measure their stabilities in ounces

Shear tests with this equipment had indicated, as would be expected, that the stability of a soil-tar mixture varies not only with the tar content but also with the consistency of the tar Maximum stabilities result from the use of viscous tars in minimum amounts required to coat all of the soil particles with the thinnest possible films On this basis it seemed desirable to recommend that a viscous tar be added to the soil under consideration However, the mixing of viscous tars with some dry soils at normal atmospheric temperatures is difficult, even in the laboratory, and it was believed that to attempt such mixing on the road surface would be impractical and, at times, even impossible For this reason two methods for facilitating mixing were considered The first consisted in mixing a suitable oil or low viscosity tar with the dry soil and then incorporating into this mixture a more viscous tar binder The second method considered consisted in adding water to the soil to soften lumps and otherwise prepare the soil for the addition of a viscous tar binder. Hereafter we shall refer to these two methods as dry method and wet method respectively

We decided to use the dry method and the following recommendations were furnished to Mr Moorefield:

1 After completion of grading, scarify road surface to desired depth and harrow or otherwise manipulate the loosened soil to break all lumps as completely as possible
2 Rake out lumps larger than one-half inch and discard or use on the shoulders
3 Apply approximately 5 5 per cent by weight (1 6 gal per sq yd for 4 in loose depth) of coal tar having an Engler specific viscosity of 4 to 8 at 40°C Mix as thoroughly as possible (For sections containing less silt and more sand than the stations sampled, use 2 5 to 3 5 per cent tar by wt or 0 72 to 1 0 gal per sq yd for 4 in loose depth)
4 Apply 3 5 to 4 5 per cent by wt (1 0 to 1 3 gal per sq yd for 4 in loose depth) of coal tar having an Engler specific viscosity of 26 to 36 at 50°C (TC-6) in approximately half gallon portions, mixing each portion with the soil as thoroughly as possible (For sections containing less silt and more sand than the stations tested, use 3 5 to 4 5 per cent or 1 0 to 1 3 gal for 4 in loose depth)
5 Compact and drag frequently during the setting up period to insure smooth driving on the finished surface
6 After the surface has set up sufficiently apply a light seal coat and cover with fine chips, pea gravel or sand

Information concerning the construction of this experimental section has been furnished by Mr J S Williamson Proc Thirty-Third Annual Convention, A R B A 1936) who succeeded Mr. Moorefield as State Highway Engineer. According to his report:

The soil in this project, practically all of which passed the No 10 sieve, contained about 16 per cent silt and 28 per cent clay (by elutriation) Other characteristics were approximately as follows Liquid limit 28, plasticity index 13, field moisture equivalent 19, shrinkage limit 15, specific gravity 2 57 and volume change 23

The average amount of 4 to 8 viscosity tar used was 1 48 gal , 26 to 36 viscosity tar (TC-6) 2 25 gal and total tar 3 73 gal per sq yd The quantity of TC-6 used was somewhat

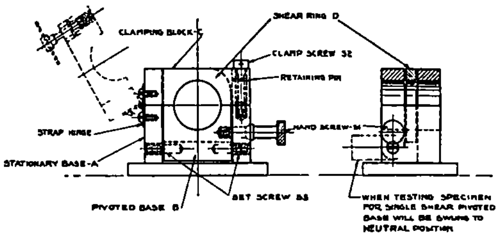

Figure 1. Koppers Shear Tester—Skidmore Type

higher than the quantity recommended, due principally to one half mile section to which an extra 1 0 to 1 5 gal per sq yd was added

It was decided that small lumps of clay soil do not seem to cause trouble if the lumps are surrounded by material impervious to water and protected from traffic

It was noticed that soil mixed with low viscosity tar alone repelled water so completely that rain for two to nine days did not penetrate windrows of the mixture more than ½ in

Three different sections contained, respectively, 2 9 per cent, 7 5 per cent and 5 8 per cent moisture when mixed with the low viscosity tar It was noticed that the section with 7 5 per cent moisture had a "slightly grayish tinge" during mixing rather than the "deep black cast" that had been observed on the section containing 2 9 per cent moisture Furthermore, it appeared to be lean and dusted under traffic (The differences in appearance and behavior of these two sections undoubtedly were due to the fact that the greater moisture content of the second section caused the tar to penetrate the soil, and particularly lumps of soil, more completely in that section)

The equipment used on this project consisted of a disk harrow, tractors and blade graders, retread machine, pressure distributor and trucks

Soon after this project was completed TC-6 was applied to the surface at the rate of 0 26 gal per sq yd and covered with sand No other cover has been applied since that time

At the completion of this experiment it was concluded that the results were satisfactory, but it was generally agreed that attempts to dry the soil following several severe rains had increased construction costs and had made the total construction period unduly long

Having in mind the wet method of construction which had been considered as an alternate for this project, and on the basis of laboratory tests, we recommended that another section be constructed using water instead of the low viscosity tar for the first mixing operation and a viscous tar for the second Specifically it was recommended that the road surface be scarified 4 in deep, mixed with water to approximately the plastic limit and then with tar having a specific viscosity of 26 to 36 at 50°C

EXPERIMENT NO 2

This suggestion was accepted and Experiment No 2 was started on a road at Kingstree, S C about 24 miles from the location of Experiment No 1

The soil in this case varied from sandy at one end to clay at the other There was no opportunity to make laboratory tests before starting construction but moisture determinations were made in the field From these and from visual inspections it was decided to add 2 per cent water to the sandy portion of the road and 4 per cent to the other The final moisture content varied from 10 6 per cent at the sandy end to 18 5 per cent at the clay end The plastic limit varied from 0 to 17 7 per cent in the same direction The clay end complied with our recommendation that the water content should equal the plastic limit However, the sandy end which had no plastic limit and originally contained 8 per cent moisture, obviously, on this same basis did not requre the 2 per cent moisture which had been added

Mixing of the soil and water was accomplished quickly and easily Soil lumps, softened by the water, disintegrated during manipulation by harrow, blade and retread machine and extreme uniformity of texture resulted

To this soil-water mixture coal tar having a specific viscosity at 50°C of 23 1 was added immediately The average quantity was 3 2 gal per sq yd With less mixing by disk harrow, blade grader and retread machine than had been used in Experiment No 1 a more uniform mixture was obtained

An attempt was made to compact this mixture immediately with a sheepsfoot roller but the moisture content, particularly on the clay end, was too high for proper densification Immediately afterwards a heavy rain flooded the road and saturated the subgrade After draining the water from the surface of the road some drying of mix and subgrade was accomplished by windrowing and blading but they did not dry sufficiently to permit the sheepsfoot roller to be used, so the road was shaped and rolled with trucks and roller One short section was coated with tar like that used in the mix and covered with sand The remainder of the project was sealed about two weeks later and covered with shoulder material

Surface cracks developed, particularly at the clay end of the road, soon after it was completed but they disappeared under traffic The road is now one year old and in good condition

From this experiment it was concluded that the addition of water to soil prior to mixing with coal tar helps to eliminate soil lumps, facilitates the mixing of soil and tar, and produces a uniform mixture which should insure maximum waterproofness and stability

EXPERIMENT NO 3

Experiment No 3 was conducted near Kingstree, South Carolina, on a short section of the 24-mile road connecting Kingstree and Hemingway The surface of this road had been mixed with road oil in the manner described by Mr. Williamson in the report previously mentioned The section chosen for this experiment had failed and it was decided to add tar to the mixture of soil and road oil Believing that at least a part of the trouble on this road had been due to a very unstable base, we suggested the following method of construction:

Mix the top four inches of soil containing road oil with coal tar Blade this mix to the shoulders of the road

Remove the next 8 in of soil from one-half the roadway surface at a time, placing this soil on the other half

Apply 0 4 gal of tar to the exposed subgrade and return the 8 in of soil, adding water if necessary and compacting with sheepsfoot roller at the optimum moisture content

Repeat on the other half of the road

Return the 4 in of tar stabilized mixture and compact with sheepsfoot roller

The finished road, built by this method, was intended to have a 4-in stabilized top, an 8-in layer of soil compacted at the optimum moisture content immediately below the 4-in top and a waterproofing membrane of tar at the bottom This method of construction was expected to provide 12 inches of stabilized soil, separated from the unstabilized subgrade by a waterproof membrane We believe that some similar method of construction will be required in many cases where soil stabilization is used on unstable subgrades In the case of this particular experiment weather conditions did not permit proper compaction of the layer of untreated soil at its optimum moisture content so no definite conclusion was reached

These three experiments have been discussed at length because, already, they have influenced the methods of construction used on other roads and because they have contributed information which was needed in order to correlate laboratory data with field practices Following are brief descriptions of four projects completed during the past few months which were influenced by the South Carolina experiments

CANDLER FIELD, ATLANTA, GEORGIA

Soil scarified 3 in deep Water added by means of fire hose and mixed with soil by disk harrow 17 to 19 per cent water gave best workability Coal tar meeting specification TC-4 added at the rate of 1 7 gal per sq yd and mixed with harrow and blade Compacted with rubber tired road maintainer Best moisture content for compaction 14 per cent Surface planed and primed with 0 25 gal per sq yd TC-4 followed by second application of 0 25 gal TC-4 and 15 lb stone screenings per sq yd Rolled with 1500-lb roller

ROUTE U S 601, SURRY COUNTY, N C

From Snow Creek Bridge to 1½ mi south of Dobson 69 per cent passing No 10, 61 per cent passing No 40, plasticity index 9, liquid limit 36, shrinkage limit 19, silt 16 per cent, clay 21 per cent

One-half of section consisted of soil scarified 4 in deep Water was added from sprinkling wagons and mixed with soil by disk harrow Twelve to 15 per cent water used to produce maximum density Coal tar meeting specification TM-2 added at rates of 1 45, 2 05 and 2 4 gal per sq yd and mixed with harrow and blade Compaction by rubber tired equipment and 5-ton roller Best moisture content for compaction about 12 per cent Surface primed with 0 22 gal TM-2 and covered with 20 pounds ½ in. to No 8 granite chips Second application of 0 22 gal TM-2 followed by 12 pounds ½ in to No 8 chips Rolled with 5-ton roller

The second half section had a 1-in layer of tar stabilized soil above and below 5 in of untreated soil compacted at optimum moisture content Six inches scarified soil removed to shoulders Water (12–15 per cent) added to bottom inch and mixed with tooth harrow Coal tar meeting specification TM-2 added at rates of 0 8, 0 9 and 1 0 gal per sq yd , mixed with blades, spread and rolled Soil from shoulders compacted in 1-in layers (12–15 per cent moisture) to depth of 5 in Water and tar added to extra top inch same as in base, mixed, spread 2 ft wider than bottom layer, and rolled Surface primed with 0 27 gal coal tar meeting specification TC-1 Followed with 0 27 gal coal tar TM-2, covered with 20 pounds ½ in to No 8 granite chips and rolled

ROUTE 82, MT CARMEL, S C

95 per cent passing No 10, 92 per cent passing No 40, plasticity index 7, liquid limit 22, shrinkage limit 15, silt 35 per cent, clay 22 per cent

Soil scarified 4 in deep Water (11 to 14 per cent) added from feeder trucks and mixed with soil by disk harrow Coal tar meeting specification TC-4 added at rate of 2 6 gal to one section TM-2 added to other sections at rates of 2 25, 2 0 and 1 5 Mixed with disk harrow and blade, spread, fluffed with harrow and compacted with sheepsfoot roller Best moisture content for compaction 8 to 9 per cent Surface lightly shaved and excess wasted Primed with 0 27 gal. TM-2 and covered with 15 pounds sand per sq yd To be surface treated in spring

PINE MOUNTAIN VALLEY, GEORGIA, BETWEEN CHIPLEY AND HAMILTON

100 per cent passing No. 10, 87 per cent passing No 40, Plasticity index 13, liquid limit 56, shrinkage limit 23, silt 31 per cent, clay 38 per cent

Soil scarified 4 in deep Water added (12–15 per cent) by sprinkling wagons and mixed with disk harrow Coal tar meeting specification TC-4 added at rate of 2 0 gal per sq yd and mixed with harrow and blade. Compacted with rubber tired equipment and 10-ton roller Best moisture content for compaction about 11 per cent. Surface planed and primed with 0 3 gal per sq. yd TC-4

Each of the four projects just described proceeded along the following general lines· scarification of surface, addition of water, if necessary, to increase the moisture content of the soil two or three per cent above the amount required for maximum density on compaction, addition of coal tar in amounts indicated by laboratory tests, drying of soil until moisture content is two or three per cent below the amount required for maximum densification as indicated by the Proctor test, compaction with sheepsfoot roller or other suitable equipment and surface application of coal tar covered with stone, pea gravel or sand

Soil stabilization in general is a new branch of engineering science and soil stabilization with bituminous materials in particular is so new that it is to be expected that any specifications proposed or adopted at this time will be modified or changed as our knowledge of the subject increases For example, it was recommended that the soil for the Kingstree, S C road be mixed with water in the proportion required by the plastic limit This quantity was satisfactory for the mixing operation but was too great for immediate compaction Subsequently, the shrinkage limit was used but that too was somewhat too high for immediate compaction and it was decided to specify, for mixing, slightly more water than the amount required for maximum density by the Proctor test The quantity of water called for by the plastic limit is sufficient to soften and disintegrate most or all soil lumps when harrows, blades and retread machines are used for the mixing operation, but a quantity of water slightly greater than the amount required for maximum density is not sufficient to soften and disintegrate all soil lumps under the same conditions Apparently we need better methods of pulverizing and mixing which will disintegrate all lumps either before or after a quantity of water approximately equal to that required for maximum density is added Devices will be developed which will dry (if necessary), pulverize, screen and, if desired, intimately mix the soil with sand or other aggregate The same devices or others will incorporate the water, or other wetting agents, and tar into the soil or soil-aggregate mixture Some of these will perform their operations on the road surface and others at central stations In either case greater uniformity of texture and, therefore, superior water resistance and greater stability of the finished mixture will result

Construction specifications written now will need to be rewritten later to embody these improvements and others, such as improved methods of compaction Devices which will simulate the tamping action of the sheepsfoot roller but do this in one pass over the road surface are needed A sheepsfoot roller must be run over the road surface many times and the turn-around at each end of the section which is being compacted may be a point of weakness in the finished road This criticism also applies to the harrows, blades, and retread machines (with stationary blades) which must be pulled back and forth on the road surface Traveling machines will be provided which will perform the operations of scarifying, pulverizing, mixing with water and with tar, and compacting by tamping with a single pass over the road surface Separate machines may be provided for these different operations or they may be combined in a single machine

Other specification changes will result from the development and standardization of laboratory apparatus and methods of test At present there are no standard methods for determining the most satisfactory amount of water and the proper amount and grade of tar for use with any particular soil, or the amount of sand or other aggregate which should be added to the soil in order to use less tar if the soil is of a type which requires an excessive amount of tar

Our methods for obtaining such information are as follows

Soil Analyses

Representative samples of the soil under investigation are tested in accordance with the tentative methods of the American Society for Testing Materials for Mechanical Analysis (D 422–35 T), Liquid Limit (D 423–35 T), Plastic Limit and Plasticity Index (D 424–35 T), Field Moisture Equivalent (D 426–35 T) and Shrinkage Factor (D 427–35 T)

These tests help to classify the soil and to indicate the type of treatment required If the soil is of a *sandy* type, low in silt and clay, little or no waterproofing is required, but a tar binder is needed which will provide stability Tars that are viscous at road temperatures, such as TM-1 and TM-2, are suitable for this purpose A viscous tar can be mixed easily with the sandy soil

If the soil is high in *clay*, little or no tar is needed for stability as long as the water content of the soil remains below the plastic limit because stability is provided by the clay However, tar is needed to waterproof the soil and maintain its water content, at some, as yet, undetermined point below the plastic limit, because the clay is no longer a binder or stabilizer when the plastic limit is reached Tars of low viscosity are satisfactory for this purpose (such as TC-1 or TC-2) They can be mixed with the soil containing clay more easily than more viscous tar

If, on the other hand, the soil is high in *silt but low* in clay (and, therefore, highly capillary) tar is needed both for waterproofing and for stability Tars having viscosities intermediate between the two mentioned above are indicated (TC-3 or TC-4) Soils of this type may require so much tar that it is economical to add sand or other suitable aggregate to the soil before adding the tar The amount of tar can be decreased in proportion to the aggregate added

Optimum Moisture for Compaction and Mixing

The method and apparatus developed by Proctor is suitable for determining the amount of water needed to obtain maximum density on compaction for any given soil or soil aggregate mixture, especially when such information is desired in the field However, for laboratory purposes we prefer to mix the soil with varying amounts of water and compact 15-g portions of the mixtures based on untreated dry soil in cylinders one inch in diameter under 200 lb per sq in pressure After compaction, the samples are pressed out of the molds, measured for volume by the displacement of mercury, dried to constant weight, and weighed The moisture content of the sample having the greatest weight of soil per unit of volume is the optimum moisture content for maximum density

In order to compensate for evaporation of water which takes place after the water is added to the soil on a road surface preceding the application of tar, one to four per cent water in excess of the optimum is added, the amount of excess depending upon temperature, atmospheric and weather conditions

Amount of Tar Required for Stabilization

The quantity of tar which will stabilize a given soil or soil-aggregate mixture is the quantity which will waterproof the soil enough to keep the moisture content below the plastic limit and cause the soil to retain or to have sufficient stability at all times to support the loads imposed by traffic

In order to determine what that quantity shall be, we originally proceeded in the following manner· A sample of the soil to be stabilized was dried, pulverized and sieved That portion of the sample which passed through a 40-mesh sieve was mixed with a quantity of water equal to the shrinkage limit of the soil Tar was then added to the soil-water mixture in varying amounts and portions representing 15 g of the 40-mesh soil were compressed at 100 lb pressure in 1-in molds, removed from the molds, dried to constant weight in air and then in an oven at 105°C Briquettes representing each increment of tar were tested for initial stability, using the Koppers Shear Tester of the Skidmore Type (Fig 1) and the remaining briquettes were completely immersed in water At intervals, briquettes were removed from the water, weighed and tested for stability This was continued until water absorption had practically ceased and little or no further change in stability occurred The minimum quantity of tar required to give a stability of approximately 200 ounces after water absorption had ceased was selected as the quantity to be added to that portion of the soil passing a 40-mesh sieve The amount required for the original soil was calculated from the percentage passing the 40-mesh sieve (A stability of 200 ounces was selected from laboratory data too voluminous to include in this report)

The results obtained by this method were quite satisfactory and many of our earlier recommendations were based upon them. However, the time required for the totally immersed briquettes to reach maximum water absorption, which was at least six days in each case, was a disadvantage and the method was modified

The present practice is to mix the 40-mesh soil sample with the quantity of water required for maximum density as determined by the method described above, add tar in varying amounts and compress portions representing 8 g of the 40-mesh soil in 1-in cylinders under 200 lb pressure per sq in The compressed briquettes are then removed from the molds, air dried for 24 hours, or until light in color, next dried in the oven at 105°C and then completely immersed in water At intervals they are removed from the water, weighed and returned to the water This is repeated until the briquettes disintegrate or until water absorption ceases Usually, six to eight hours is sufficient. Those briquettes are considered satisfactory which do not contain more water than the plastic limit if that limit is below 28 However, if the plastic limit is above 28, the water absorption should not exceed approximately 28 This method is more rapid than the one first described, but it does not include stability measurements

On this account, we are now developing a further modification which involves the preparation of 8-g samples in the manner described above but this time the samples are left in the molds in which they were compressed during the time that they are immersed in water At intervals, samples are removed from the water, weighed and tested for stability, using the Koppers Shear Tester of the Hubbard-Field type (Fig 2) The minimum quantity of tar required to obtain a certain minimum stability after water absorption has ceased, will be considered as the proper amount of tar for stabilizing the 40-mesh portion of the soil

Total Immersion versus Contact with Water

In each of the methods just described, reference has been made to complete immersion of the stabilized soil briquette in water We have considered the possibility of contacting the lower surface of the briquettes with a moist surface but do not favor that method for the following reasons:

If a 4-in layer of stabilized soil, covered by a seal coat which prevents evaporation, is in contact with a wet subgrade for several months, it will absorb water until a certain maximum is

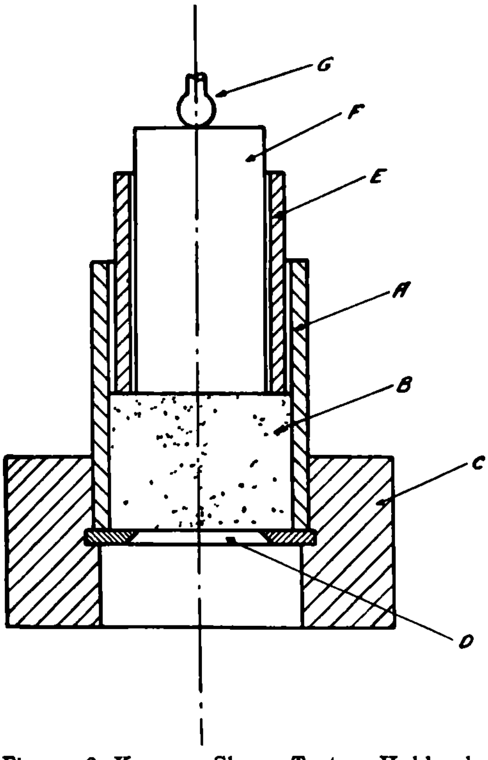

Figure 2 Koppers Shear Tester—Hubbard-Field Type

reached, which depends upon the nature of the soil and the type and amount of stabilization provided That maximum, we believe, is approximately the same amount that a section of the stabilized layer would absorb if completely immersed in water. Furthermore, it is the amount that will cause failure if it is in excess of the plastic limit

If in order to simulate the field conditions mentioned above, a molded specimen of the stabilized soil is placed in contact with a wet surface and the sides and the top are enclosed to prevent evaporation, any time interval selected for the test which is less than the time required for complete absorption of water by the stabilized soil may be entirely misleading, because the stability at that time is greater than it will be later, after water absorption has continued In fact, by this method it should be possible to obtain apparently satisfactory stabilities on a stabilized mixture which will fail in a road if in contact with wet subgrade long enough to reach the point of maximum water absorption

Believing, as we do, that it is this point of maximum water absorption about which we are most seriously concerned, we prefer to use a method which will bring the stabilized mixture to that point in a minimum length of time The use of small briquettes *and complete immersion* in water accomplishes that purpose The use of small samples *without complete immersion* does not accomplish the purpose We have found that 15-g briquettes, stabilized with different bituminous materials, when placed in contact with water and completely covered to prevent evaporation, required from six to more than 56 days to reach the points of maximum water absorption

Advantages of Tar as a Soil Stabilizing Agent·

Coal tar possesses certain inherent characteristics which make it especially suitable for soil stabilization purposes

(1) It penetrates deeply into capillaries and small openings, in and between aggregate and soil particles because of its high surface tension

(2) By adding water to the soil to be stabilized, the tar can be added easily to the soil Furthermore, this can be done without the aid of emulsifying or wetting agents

(3) Tar adheres strongly to aggregate and soil particles, even in the presence of water, and the researches of certain European investigators (Riedel and Weber, *Asphalt and Tar*, 33, 677, 1933) indicate that the degree of adhesion increases with time, due to the fact that tar contains chemically active constituents, called polar compounds, which slowly react with the chemical constituents of the aggregate to form water insoluble compounds at the interface between tar and aggregate

(4) Coal tar possesses cohesion and furnishes cohesion to aggregates and soils to which it is added

(5) Coal tar is practically unaffected by prolonged contact with water