SOIL STABILIZATION BY THE USE OF ROSIN

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FOREWORD

In a letter to the Administrator, Civil Aeronautics Administration, dated April 3, 1942, the Director of Base Services, Army Air Forces, approved the inauguration by the Technical Development Division, Civil Aeronautics Administration, of an investigation for the purpose of developing natural or synthetic chemical substances, either organic or inorganic, that would be effective as soil stabilizing agents Endorsement of this project and certification that it was of high importance and necessary to National Defense were given by the Secretary of War to the Secretary of Commerce in a letter dated April 21, 1942.

Since this investigation is classified as being of as emergency nature, special attention has been given to the following factors in the selection of the various subjects to be studied

1 Effectiveness and ease of application of the material under adverse construction conditions;

2. Proximity of sources of the material to areas in which it may be used,

3 Ease of transportation to the site where the material may not be locally available;

4 Quantity of the material available for use

The first phase of this study to become sufficiently conclusive to merit formal release was that dealing with the properties of stabilizing agents derived from rosin Because of the outstanding performance of some of these materials it was deemed advisable to make the test results available to the Armed Forces as expeditiously as possible. Consequently, a Special Report entitled "Soil Stabilization by the Use of Rosin", dated June, 1943 was prepared and transmitted to the various military services. The data and information contained in this report has now been re-edited and is herewith presented as Technical Development Note No. 34. The laboratory experimentation was conducted under Government contract by the University of Missouri, Columbia, Missouri

SOIL STABILIZATION BY THE USE OF ROSIN

SUMMARY

Because of the availability of rosin in several zones of combat, an investigation was conducted to determine the possible utilization of this material as a soil stabilizing agent.

A comprehensive series of laboratory tests were made with wood rosin either as such or with wood rosin which had been partially or completely neutralized with sodium-, potassium-, or ammonium-hydroxide. Also, the soil stabilizing power of insoluble rosinates formed from alkali rosin dispersions, by addition of salts of bi- and tri-valent metals, was investigated

The most noteworthy results of this investigation may be summarized as follows

1 The soil stabilizing power of rosin increases with decreasing particle size of the rosin and depends on the uniformity of its dispersion throughout the treated soil

2 There exists an optimum ratio of alkali to rosin with respect to stabilizing power. For the sodium and potassium rosin compounds, this ratio appears to correspond to the complex salt one rosinate - three rosin acids. For the ammonium rosin compounds, good results are obtainable over a wider range of composition

3 The stabilizing power of alkali rosinates, even those of the optimum alkali-rosin ratio, may be improved by flocculation in the soil by means of iron and aluminum salts

4 Of the rosinous materials showing good stabilizing effectiveness, the sodium rosin compound corresponding to a complex salt of one sodium rosinate to three rosin acids is produced commercially in a powdered form by the Hercules Powder Company, Wilmington, Del.[1] Good stabilization has been obtained in several cases with as low an amount of this material as two-tenths of 1 percent on the basis of the dry weight of the soil Despite the excellency of this material, there is considerable evidence that it does not represent the best stabilizing agent that can be produced from rosin

5 On the basis of the results of this laboratory study, it appears that the soil stabilizing power of rosinous materials are very promising. Of particular interest from the point of view of possible use for foreign military construction is the small quantities of the agents required On the basis of unit weight of material necessary for successful treatment, rosinous materials may be 20 times more effective than cement and 12 times more effective than bitumen, the two agents now commonly employed for soil treatment

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[1] It is not known whether or not this product is manufactured at the present time

INTRODUCTION

Fundamentally, soil stabilization is a method of processing available materials for the production of low-cost roads and airfields. It involves the manipulation, treatment, and compaction of a soil in such a manner that it will remain in its compacted state without detrimental change in shape or volume when subjected to the stresses imposed by traffic and the disintergrating forces of weather.

The modern development of soil stabilization dates back some 15 years to the use of sand-clay mixtures in the southern states Since that time, through extensive experimentation with numerous mixtures and admixtures, this type of construction has progressed rapidly until today it is used to a considerable extent for temporary wearing surfaces and for base courses underneath bituminous surfaces The admixtures now most commonly employed as stabilizing agents are portland cement and bituminous materials Both of these agents have their limitations of application, but each has been proven an effective stabilizer when applied under suitable conditions.

Soil stabilization is of particular interest to the military engineer charged with the responsibility of building roads and airfields under adverse conditions because of two factors First, it is a type of construction that can be speedily completed with a minimum of heavy equipment, and second, it utilizes available local materials and in this way minimizes the quantity of materials that must be transported to the project site.

Because of the availability of naval stores products[2] in several zones of combat, it was decided to investigate the efficiency of such materials when used as soil stabilizing agents. It was felt that experimentation with such material was justified only if the quantity required for satisfactory results was 2 percent or less of the weight of the soil treated This self-imposed limit is several times less than the maximum percentages now employed in soil-cement and soil-bitumen mixes

The data presented in this report are not an evaluation of the stabilizing effectiveness of any one particular material Rather, they are the results of experiments performed for the purpose of exploring the possibilities of rosin and its derivatives and should be reviewed in this light

DESCRIPTION OF MATERIALS

Rosin

Rosin is obtained either from pine stumps and top wood or from the sap of living trees According to its source, it is called wood rosin or gum rosin. Since both types exhibit similar characteristics, only wood rosin was employed in this investigation

The melting point of rosin is not well defined but it softens at a temperature of 70° to 80° C., becomes semi-fluid in boiling water, and melts completely at a somewhat higher temperature It is a transparent or translucent material with a specific gravity of approximately 1.07 The color, which is used as a means of grading, varies from a very pale amber to a dark reddish brown. The letters of the alphabet are used to denote the different grades, which vary from grade B, the darkest and most impure type, to W W , which is water-white, the double letters being used for special grades In this investigation, two similar grades, Belro and grade B, were used. Since their properties vary only slightly, no distinction has been made between the tests using the two different grades

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[2] Naval stores products are materials derived from the processing of either the oleoresin extrusion of certain species of pine trees or the stumps and top wood of these same trees The most common of these products are rosin and turpentine.

The chemical composition of rosin has been studied by many investigators. Ellis[3] states that the principal constituents of American rosins are abietic acid (more than 90 percent) and a small amount of non-acid materials called resenes. The general formula for abietic acid is $C_{20} H_{30} O_2$

Of interest for chemical purposes is the acid number of rosins. This number represents the milligrams of potassium hydroxide needed for rapid neutralization of the rosin acids contained in 1 gram of rosin The rosins used in this investigation were assumed to have an acid number of 158

Abietic acid forms salts with sodium and potassium hydroxide which, upon complete neutralization, are soluble in water in low concentration but form gels at higher concentrations. Ammonium rosinates in aqueous solution posses a greater tendency to gel formation than the sodium and potassium rosinates It is claimed that oxidation of the rosin favors the formation of ammonium rosinates.

Rosins form insoluble salts with bi- and tri-valent metal ions These insoluble salts can be easily obtained by adding aqueous solutions of the corresponding metal salts to solutions of alkali rosinates The chemistry of these salts is still awaiting thorough investigation Only such compounds as are of interest in the manufacture of sizing for the paper industry have been studied to any considerable extent.

Soils

The majority of the experiments on the soil stabilizing effect of rosin were conducted with a silty-loam type of soil known pedologically as Grayson silty loam and designated in this report as soil G In order to determine the effectiveness of rosin with other types of soils, selected tests were performed on 8 additional soils which varied in type from silty-sand to a heavy soil containing 40 percent clay. The characteristics of the soils used are given in table 1 and the grain size-distribution curves are shown in figure 1

Reagents

The chemicals employed were all of C P quality Distilled water was used in all experiments, with the exception of the tests in which sea water was used.

TESTING PROCEDURES

The evaluation of the effectiveness of rosin as a soil stabilizing agent was done by means of strength data derived from unconfined compression tests on specimens 2 inches in diameter and 2 inches in height[4]. The test specimens in which insoluble rosinates were used as the stabilizing agent were formed by mixing the rosin dispersions with one-half of the soil required to form the specimen and the salt with the remaining soil These two parts were combined and thoroughly mixed just prior to compaction in the specimen mold. The water required was equally divided between the two parts. Other specimens were prepared by combining the rosin directly with the total amount of soil required All specimens were compacted to the predetermined optimum density and then cured by air-drying for 7 days At the end of this curing

[3] Ellis, Carlton, 1935, The Chemistry of Synthetic Resins, Reinhold Publishing Corporation.

[4] It had been previously found that, with the majority of soils used in this investigation, specimens constructed with a height-diameter ratio of one gave satisfactory results for comparative purposes

period, tests were made to determine the compressive strength of the air-dried specimens and of wet specimens that had been subjected to the following conditions:

(a) Complete immersion in water for 2 hours.
(b) One cycle of wetting and drying.[5]
(c) Four cycles of wetting and drying
(d) One cycle of freezing and thawing [6]
(e) Four cycles of freezing and thawing.[7]

Unless noted, all test values reported are the average for two specimens

The exactness with which the results obtained from these tests reflect the field performance that may be expected from similarly treated soils is, of course, questionable However, since the procedures used do reproduce to some degree the types of destructive action imposed by nature, it is believed that they do provide an adequate means of obtaining laboratory data of a relative nature

In reporting the test data obtained, the response of the natural, untreated soils have been omitted since all such specimens failed when subjected to the 2-hour immersion test - the least severe test employed

INFLUENCE OF THE DEGREE OF FINENESS OF THE ROSIN

Whether the stabilizing effect of rosin is due to a mechanical blocking of the capillaries, or to the formation of a water-repellent film over the internal soil surfaces, or both, is not fully known However, in either case it is reasonable to suppose that the size of the rosin particles would be of considerable influence To evaluate this factor, tests were performed in which the rosin used was of 3 degrees of fineness. These different degrees of fineness were obtained by (1) mechanical grinding until the rosin passed a two-hundred mesh sieve, (2) precipitation of the rosin from an alkaline solution by means of acid; and (3) the precipitation of the rosin from an alcoholic solution The largest-sized particles were obtained by the mechanical grinding and the smallest-sized by the precipitation from the alcoholic solution. Intermediate-sized particles were obtained by the precipitation from an alkaline solution, however, because of the possible formation of rosinate-rosin complexes in this method of treatment, the test data obtained are not strictly comparable with those from the specimens composed of rosin prepared by the other methods The results of these tests are given in table 2. They show that a decrease in the particle size of the rosin increases its stabilizing effect This increased effectiveness is probably due to the better dispersion of the finer rosin in the soil.

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[5] One wetting and drying cycle consisted of 5 hours immersion in water followed by 43 hours oven-drying at 70° C.

[6] One freezing and thawing cycle consisted of 22 hours of freezing at -23° C followed by 22 hours thawing in a moist room During the thawing period the specimens had access to moisture by capillarity

[7] The results of an extensive series of experiments on soil-cement samples have shown that, with specimens 2 inches in diameter and 2 inches in height, the destructive force of 4 cycles of wetting and drying or 4 cycles of freezing and thawing is approximately equivalent to 12 such cycles on specimens of the standard Proctor size (4.0-inch diameter and 4 6-inch height)

EFFECT OF TYPE AND AMOUNT OF ALKALI EMPLOYED IN NEUTRALIZING THE ROSIN ACID

Tests were conducted to determine the soil stabilizing effect of rosin, the acid number of which had been either partially or completely neutralized by the addition of various hydroxides of alkali and alkaline earths The quantity of hydroxide required to neutralize either all or a part of the rosin acid is based upon the acid number of the rosin, which, for this investigation, was assumed to be 158 The hydroxides of sodium, potassium, calcium, barium, and ammonium were used in these tests and were combined with the rosin in such proportions as to give ratios of the amount of alkali used to that required to completely satisfy the acid number of the rosin of 1 to 1, 1 to 2, 1 to 4, and 1 to 8. The quantity of the various hydroxides needed for complete neutralization were computed to be

Sodium hydroxide	11 3%
Potassium hydroxide	15 8%
Calcium oxide	7 9%
Barium hydroxide	24 2%
Ammonium hydroxide solution (sp g of 0 9)	17.2%

Complete Neutralization of Rosin Acid

The compressive strengths of specimens composed of soil G, 2 percent rosin, and a quantity of various hydroxides sufficient to completely neutralize the rosin acid, are shown in table 3 As may be seen from the table, all specimens, except those made with ammonium hydroxide, failed when immersed in water The poor showing of the alkali rosinates (sodium and potassium) is probably due to their solubility in water The treatment of the rosins with the hydroxides of calcium and barium formed rosinates that were lumpy and difficult to disperse throughout the soil This difficulty probably influenced the failure of these specimens when immersed in water The ammonium rosinate may be considered to be somewhat better than the other agents tested

Partial Neutralization of Rosin Acid

Tests were performed to determine the soil stabilizing effect of rosin complexes that were prepared by the partial neutralization of the rosin acid with alkali hydroxides These complex salts consisted of a rosinate (that part of the rosin neutralized by the hydroxide) and the unreacted rosin The ratio of rosinate to unreacted rosin depended upon the quantity of hydroxide used The results obtained are given in tables 4 and 5

Sodium and potassium rosinates Tests were performed on specimens treated with 2 percent rosin and various quantities of sodium and potassium hydroxide These data show that the complex rosin salt formed by a particular ratio of rosin to hydroxide is very effective as a soil stabilizer Deviation from this ratio results in large decreases in strength For the potassium hydroxide, 6 of the 8 soils tested were most favorably treated by the complex rosinate formed by the reaction of one equivalent of hydroxide with four equivalents of rosin acid Soil V was little affected by changes in the degree of neutralization while soil G showed an optimum ratio of 1 2 For the tests on soil G employing sodium hydroxide, the most favorable ratio was 1 4

With regard to the response of the different soils to treatment, it will be noted that those in the intermediate range, i e , those not containing an excess of sand or an excess of clay, were most benefited

Ammonium rosinate Tests were conducted to determine the stabilizing ability of ammonium rosinates These rosinates were formed by the reaction of rosin with each of the following ammonia compounds ammonium hydroxide, ammonium carbonate, and partly fermented urine The experiments with the hydroxide show that a variation in the ratio of the hydroxide to the acid number of the rosin, in contrast to the results obtained from the sodium and potassium rosinate, does not produce a well defined optimum ratio at which the compressive strength is considerably higher than at any other ratio This effect may be explained by the fact that since the ammonium is very volatile, quantities used in excess of the optimum will, over an extended period of time, be lost from the soil by evaporation, and in this way the same stabilizing power will probably be attained as if the optimum proportions had been used The volatility of the ammonium affords it a distinct advantage over the other alkalis, in that it acts as a good dispersing agent which after drying does not leave a soluble and water-attractive residue behind

The experiments conducted with ammonium carbonate did not give as good results as those conducted with the hydroxide Theoretically, the action of ammonium carbonate on the rosin is considerably different from that of the hydroxides. Insufficient experiments were conducted to fully explain the action of the carbonate

The formation of ammonium rosinate by reacting rosin and partly fermented urine is feasible but, because of the problem involved in the collection and storage of the required quantities of urine, this type of treatment was considered impracticable

EFFECT OF VARIOUS SALTS ON THE EFFECTIVENESS OF ROSIN DISPERSED IN DIFFERENT HYDROXIDES

From earlier experiments, the stabilizing efficiency of rosinous materials had been found to depend on the degree of dispersion in the soil system and on the water affinity of the deposited material It was therefore decided to make tests in which the rosin was first dispersed in the soil as a more or less water soluble alkali compound, and then rendered insoluble by exchange reaction with salts of bi- and trivalent metals The insoluble rosinates used in the tests were formed by the flocculation of sodium, potassium, and ammonium rosinates by the addition of the salts of calcium, barium, aluminum, magnesium, iron and zinc. The amount of alkali used corresponded to the full amount, to one-half, and to one-fourth, respectively, of that required to satisfy the acid number of the rosin. The amount of salt used in each case was equivalent to the amount of alkali employed. The percentages of alkali per dry weight of rosin employed for satisfaction of the acid number, and the corresponding amounts of salts are given below

		Percent (Dry wt of rosin)
Base	$NaOH$	11.3
	KOH	15.8
	NH_3	4.8
Salt	$CaCl_2$	15 7
	$BaCl_2$	29.6
	$AlCl_3$ $6H_2O$	22 6
	$MgSO_4$ $7H_2O$	37 0
	$FeSO_4 . 7H_2O$	39 2
	$ZnSO_4$ $7H_2O$	40 0

The data obtained from specimens prepared from soil G, in which the above-named salts were used to flocculate completely neutralized sodium, potassium and ammonium rosinate solution, are given in table 6

These tests showed that the rosinates formed by the use of iron and aluminum salts were the best stabilizing agents Consequently, the efficiency of iron and aluminum rosinates prepared from rosin dispersions in potassium hydroxide solutions was determined for various types of soils

The results obtained from these tests are shown in table 7 Best resistance to wetting and drying was obtained when the amount of alkali and the corresponding amount of salt was in the ratio of 1 to 4 with respect to the acid number of the rosin

However, the specimens making the best showing during the freezing and thawing test had alkali-acid number ratios of 1 to 2 or 1 to 1 These results may be explained by the fact that the reaction between alkali rosinates and metal salts results in the formation of soluble salts that possess a great affinity for water The quantity of these salts present is proportional to the amount of alkali and salt used While this property of the salt lowers the resistance of the soil to wetting and drying, in the case of freezing and thawing tests it tends to bind the water so strongly that it does not freeze and, therefore, the system is less affected by low temperatures.

It appears to be of special interest that treatment with iron or aluminum salts improved the stabilizing efficiency of even the best potassium rosin complex

Such treatment with these metallic salts not only is feasible but would be economical in areas in which the salts exist Ferrous sulfate is a waste product from a number of industries, such as the paint and steel industry, and probably is easily available close to any industrial center This salt is also found in nature, either in crystal form or dissolved in water, in the vicinity of iron mines Aluminum chloride is used in the anhydrous form in the refining of petroleum products As soon as it has absorbed water it becomes unusable for this specific purpose, representing a waste in that industry, and would be available for use in soil stabilization construction

EFFECT OF POWDERED SODIUM ROSINATE COMPOUND (ONE SODIUM ROSINATE - THREE ROSIN ACIDS)

Because of the remarkable results obtained with the 1 3 sodium rosin compound prepared in situ in the soil, it was decided to incorporate the powdered form of this compound with the soil in various percentages and note its stabilizing effect. This particular substance was furnished by the Hercules Powder Company of Wilmington,Del.

The powdered substance was added dry to the pulverized soil and well distributed in the latter by dry mixing This was followed by wet mixing after addition of water corresponding in amount to the optimum moisture content, and by compaction to the previously determined Proctor density The amount of stabilizer employed varied from about 0 2 percent to 1 2 percent on the basis of the dry weight of the soil The results of the tests performed on two soils (E and G) are given in table 8. The data obtained indicate a very remarkable stabilizing power of this substance at the lowest percentages employed From theoretical considerations it appears probable that even this stabilizing power may be increased by addition of very small amounts of ammonia to the mixing water Experiments testing this hypothesis are now being conducted.

Because of the excellent results obtained with this material, it appeared desirable to formulate a theoretical concept of the stabilizing mechanism occurring in this type of soil treatment in order to be able to make similarly acting substances from all types of natural and artificial resinous materials. As far as this mechanism is concerned, it is indicated that the following phenomena play an important role

1 The slight alkalinity of the stabilizer will tend to disperse the aggregated clay particles and thus permit the formation, by compaction, of a denser system having a smaller permeability This latter is also decreased if a sodium ion is transferred from the rosin to a clay particle by exchange reaction As a result of these reactions the penetration of water into the treated soil is impeded by mechanical as well as physicochemical factors

2 The deteriorating effect of water on soil is to a great extent a function of the attraction of the internal soil surface for water, this attraction is closely related to the amount and kind of exchange ions present in the soil If the rosin substance enters into any direct reaction with the soil constituents at all, the most probable reaction is with the exchangeable ions This reaction would result in a decrease of the accessibility of these ions and, therefore, in a decrease of the attraction forces for water It is not suggested that all the water attraction centers on the soil constituents are shielded by the stabilizer; rather, a certain number

of these must be considered unshielded or only partially shielded in order to account for the cohesion and the consistency properties of the treated soils

EFFECT OF VINSOL RESIN

Vinsol resin is a product of the Hercules Powder Company, Wilmington, Del. Since it is a resinous material, it appeared desirable to compare its soil stabilizing ability with that of rosin Consequently, tests were performed in which soil G was treated with 2 percent of vinsol, with and without the addition of alkali. The types and amounts of alkali used were 1.7 percent of sodium hydroxide and 2.4 percent of potassium hydroxide (based on weight of rosin) These amounts were in a ratio of approximately 1 to 4 of the amount required to completely satisfy the acid number of the vinsol. The results of these experiments are given in table 9

Because of the superior stabilizing effectiveness of insoluble rosin salts prepared by the flocculation of alkali rosinates with iron and aluminum salts, corresponding experiments were made with vinsol Two percent of vinsol, dispersed in various percentages of potassium hydroxide (15.8, 7.9, and 4 0 percent - 10 percent required for satisfaction of acid number), was used The amounts of iron and aluminum salts used were equivalent to the amount of potassium hydroxide in the system. The tests were made with both soils G and N. Table 10 shows the results obtained

All specimens made with vinsol alone were compacted and cured in compliance with the specifications issued by the producer for soil treatment with vinsol. The moisture of compaction was consequently 90 percent of the Proctor value, and the testing was started when the samples still contained 60 percent of the optimum moisture content In contrast to this procedure, the specimens treated with iron and aluminum salts were air-dried for 7 days before testing.

Commenting on the results shown in table 9, it is apparent that the addition of alkali to the soil-rosin system has a beneficial effect. Whether this influence is due to the formation of a complex salt of the alkali with the vinsol, or only to a better dispersion of the rosin, is not revealed by the data available

If the results obtained with vinsol alone are to be compared with those obtained from specimens treated with rosin and with the insoluble compounds of vinsol with iron and aluminum, it must be kept in mind that the latter specimens were completely air-dried before being subjected to the tests. Air-dried vinsol-treated specimens do not, normally, stand up upon immersion in water. Any specimen treated with rosin and giving any wet strength at all must, therefore, be considered superior to a vinsol-treated specimen of comparable composition.

The data (table 10) show that insoluble vinsol resinates prepared by the flocculation of an alkali rosinate with iron and aluminum salts are considerably more effective stabilizing agents than untreated vinsol Best results for soil G were obtained with about 8 percent of potassium hydroxide and the corresponding amount of iron sulfate A similar optimum appears to exist in the case of aluminum chloride

The test data for the specimens prepared with soil N were not as promising as those obtained with soil G. However, considering that the normal treatment with vinsol does not give water resistance to the air-dried soil samples, the data obtained with soil N indicate that the soil stabilizing power of vinsol was definitely increased by this type of treatment.

EFFECT OF SEA WATER

Since in some areas where airfield construction is contemplated fresh water may be difficult to obtain, experiments were conducted to determine the effect of sea water when used in rosin-soil stabilization. These tests were designed to evaluate the change in effectiveness of the rosin when various quantities of sea water (in proportion to fresh water) were used. Also, the effect of soil type was determined by the use of six different soils Artificial sea water consisting of the following constituents was used.

Salt	grams/liter	mols/liter
NaCl	27.5	0.5035
KCl	0.705	0.0095
$MgCl_2 \cdot 6H_2O$	6 8	0.0334
$MgSO_4$ $7H_2O$	4.7	0 0191
$CaSO_4 \cdot 2H_2O$	1 85	0.0109

The results obtained from tests on five soils, in which the quantity of sea water used was varied for two different basic dispersions of the rosin, are given in table 11. In most cases, the use of sea water in any amount decreased the compressive strength of the specimens. However, with certain soils, the sea water increased the resistance of the specimens to wetting and drying and freezing and thawing.

Considering all factors involved, it appears that sea water can influence rosin stabilization beneficially or adversely, depending upon the soil conditions and the type of destructive weathering agencies encountered. For this reason, when the use of sea water is contemplated, preliminary tests should be performed in which its effect can be determined

APPENDIX

MANUFACTURE AND AVAILABILITY of NAVAL STORES PRODUCTS

Manufacture of Rosin

Rosin is obtained either from pine stumps and top wood, or from the sap of living trees. According to the source, it is called wood rosin or gum rosin

Extraction of wood rosin. The extraction of rosin from the pine stump and from top wood is being done in two different ways The oldest method employs heating and charring of the woody materials. The volatiles produced, such as water, wood alcohol, acetic acid and others, are condensed and recovered. The pitch and rosin collect at the bottom of the kiln in which the destruction of the wood takes place and are conducted into vats, where the different materials separate by gravity.

A more recent process makes use of ground wood The turpentine is distilled off mostly by steam. The remaining wood is then extracted by organic solvents These solvents are in the main distillates of petroleum or of coal tar. The solvents are recovered by distillation from the rosin, which remains in the still. The rosin is then run into barrels in which it is shipped

Extraction of gum rosin V-shaped cuts are made into the trunk of pines to obtain the sap of the tree The sap is generally collected in cups which are emptied every 4 weeks during the season. The season lasts from early spring until fall. The average yield per cup is about 6-1/2 pounds per season Recently it has been shown that the yield of rosin can be materially increased by keeping the wound of the tree acid. Brushing with dilute sulphuric acid has been proposed The collected sap is filtered off and distilled. Steam distillation or distillation under constant addition of water is used The sap yields approximately 12 percent of water, which distills off with about 20 percent of turpentine About 68 percent of the raw materials representing the rosin remain as residue in the still. The rosin is then run into barrels.

Other sources for rosin are the sulfite liquor of the pulp and paper manufacture, and pits from which discarded rosin can be recovered In some places, relatively large amounts of rosin were discarded at times when the production of turpentine was the main object and the rosin was considered as a waste product

Availability of Rosin

The quantity of rosinous material required for the construction of an emergency or temporary airport is relatively small For a flight strip sufficiently large to accommodate fighter planes (4000' x 150'), it appears that with the best rosinous stabilizer known at the present time about 30 tons (2 percent by weight of soil treated) is required to treat the soil to a depth of 6 inches Since this amount is not large, many areas in which the production of rosin is usually considered insignificant from the point of view of world trade may have sufficient capacity to supply the needs of construction projects The following table shows the leading rosin-producing countries and their output for 1937-38

Estimated 1937-38 Production of Rosin[5]

Country	Rosin (Tons)
United States	595,500
France	112,500
Spain	41,000
Portugal	54,250
Greece	26,750
Austria	5,425
Mexico	20,925
Poland	20,825
India	7,250
Germany	4,175
Russia	66,725
Sumatra	3,725
Miscellaneous	7,750

In addition to the countries mentioned above, it is reported that rosin is produced in Norway, Sweden, Finland, Algeria, and Madagascar While the production capacity of these countries is not available, it is believed that there exists an amount sufficient for the construction of emergency airfields and roads

The naval stores industry of India has been expanded considerably in the past few years until, at the present time, they are able to fulfill their entire domestic demands Chief centers of production are at Jallo in the Punjab and Browali and Barielly in the United Provinces Undoubtedly, some of this material would be available for use in soil-stabilization construction

Manufacture of Vinsol Resin

Vinsol resin is a product of the Hercules Powder Company, Wilmington, Del. It is obtained, in addition to other materials, in the extraction of pine stumps with benzol From the resulting solution, the benzol, the turpentine, the oleorosins and other materials are distilled off The residue containing rosin and vinsol is treated with a mixture of hydrocarbons and furfural which are mutually insoluble The rosin dissolves in the hydrocarbons, the vinsol in the furfural. The respective solutions

[5] Van Romaine, Eldon, 1939, Naval Stores 1919-39 Chemical Industries 45.

are separated as in a separating funnel The wood rosin represents the residue left after the distillation of the hydrocarbon solution, the vinsol, the distillation residue from the furfural The furfural and the hydrocarbons are recovered for further use.

Vinsol is classified as a resin and not as a rosin because it does not give the Liebermann-Storch reaction It is generally assumed that it is contained in the wood as such and is recovered almost unchanged The constituents of vinsol appear to be of phenolic character and to be related to lingnin It may contain abietic acid only as an impurity

Analysis shows that it has a very high content of oxygen as compared with the oxygen content of rosin

The acid number and the saponification number of vinsol are of the same importance as the respective indices for rosins The acid numbers for pure abietic acid, FF-wood rosin, and vinsol are about 184, 158, and 100, respectively

The action of vinsol when incorporated in the soil does not produce a new structural material, and the strength of the resulting mass is entirely dependent upon the strength characteristics of the untreated soil However, it does impart a degree of water resistance to the soil that in some cases is sufficiently beneficial to permit its use as a temporary paving material Laboratory and field tests have shown that this material is effective only with the better types of soils, and even with these the soil-moisture content must be held within a particular range if a satisfactory job is to be obtained With regard to this moisture content range, the producers of vinsol specify that the treated soil shall be compacted at a moisture content of 90 percent of Proctor's optimum It has been found that moisture in excess of this amount renders the vinsol less effective. In addition to this requirement, the treated soil mass must be cured until its moisture is approximately 60 percent of optimum before maximum effectiveness is obtained

TABLE 1

PHYSICAL-CHEMICAL CHARACTERISTICS OF THE DIFFERENT SOILS

	Gradation - %				Atterberg Limits						
Soil	Sand	Silt	Clay	Col-loid	L L	P L	P I	S L	Specific Gravity	Organic Matter %	Base Ex. Capacity (1)
P	77	12	11	9	19.0	17 0	2 0		2 65	1.00	5.62
B	67	11	22	14	22.1	18 1	4.0	14.4	2 66	1.36	9 28
E	50	32	18	14	22 5	18 3	4.2	15.3	2 63	2 47	8 84
L	55	28	17	9	23 0	18 0	5.0	16 3	2 64	1 47	8 71
G	30	53	17	7	25.0	18 6	6.4	15 6	2 65	1 38	12.86
U (2)	39	41	20	12	31 8	20.1	11 7	14.9	2 68	1 32	10 15
M	45	30	25	12	32.1	18.4	13.7	15.6	2 65	1 79	16 24
N	33	27	40	19	45 0	19 0	26 0	12 6	2.68	1 95	13 59
V	34	21	45	20	53.5	22 4	31 1	12.7	2 72	3 02	18 48

(1) Mili-equivalents per 100 gm (2) This soil contains free $CaCO_3$

TABLE 2

EFFECT OF THE DEGREE OF FINENESS OF THE ROSIN

Preparation of Rosin	Fineness	Compressive Strength lbs/sq in		
		Wet	Wet 4 W-D	Wet 4 F-T
Mechanically ground	Coarse	95	--	--
Precipitated from basic dispersion by acid	Inter-mediate	184	130	4
Precipitated from alcoholic disper-sion by water	Fine	205	20	12

-- Specimens failed
Batch Composition Soil G - 2% Rosin

TABLE 3

EFFECT OF COMPLETE NEUTRALIZATION OF THE ROSIN
ACID BY ADDITION OF VARIOUS BASES

Kind and Amount of Base (1)	Compressive Strength lbs/sq in	
	Dry	Wet
11 3% NaOH	810	--
15 8% KOH	701	--
7 9% CaO	722	--
24 2% $Ba(OH)_2$	850	--
17 2% $NH_4(OH)$ solution sp g = 0 9	856	64

-- Specimens failed
(1) Amount based on wt of rosin
Batch Composition Soil G - 2% Rosin - kind and amount of base as shown

TABLE 4

EFFECT OF DIFFERENT DEGREES OF NEUTRALIZATION OF THE ROSIN ACID BY THE ADDITION OF VARIOUS BASES

Soil	Type of Base	Amount of Base Percent (1)	Ratio Base to Rosin (2)	Compressive Strength in lb/sq in					
				Dry	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
G	NaOH	11 3	1 1	810	--	--	--	--	--
		5 66	1 2	912	127	124*	--	--	--
		2 84	1 4	959	379	117	186	25	--
		1 40	1 8	915	120	--	--	8	--
B		15 5	4 4	408	189	231	84	64	6
		11 5	3 4	497	242	236	140	76	12
		7 74	2 4	607	263	140*	--	75	9
		3.78	1 4	625	252	190	87	81	9
E		15 5	4 4	591	373	266*	184	181	42
		11 5	3 4	575	355	50	68	178	41
	NH_4OH	7 74	2 4	654	387	44	75	149	46
		3 78	1 4	597	379	23	31	122	32
	Solution								
L		15 5	4 4	527	113	46	93	23	10
	Sp g 0 9	11 5	3 4	476	200	199	180	75	15
		7 74	2 4	494	357	363	197	91	27
		3 78	1 4	470	336	25	74	73	13
N		15 5	4 4	1059	158	--	--	21	--
		11 5	3 4	1100	124	--	--	35	--
		7.74	2 4	1254	211	168	--	52	--
		3 78	1 4	970	91	--	--	--	--
B		34 0	4 2	301	--	--	--	--	--
		26.0	3 2	305	27	--	--	--	--
		17 0	2 2	400	120	4	--	12	3
		8 5	1 2	393	60	--	--	--	2
E		34 0	4 2	491	--	--	--	--	--
		26 0	3 2	551	--	--	--	--	--
		17 0	2 2	531	20	8	8	5	2
	Ammonium	8 5	1 2	684	244	50	70	74	8
L	Carbonate	34 0	4 2	318	--	--	--	--	--
		26 0	3 2	338	--	--	--	--	--
		17 0	2 2	416	45	--	9*	--	--
		8 5	1 2	492	187	3*	17	32	6
N		34 0	4 2	990		All specimens failed upon immersion in water			
		26 0	3 2	1038					
		17 0	2 2	1026					
		8 5	1 2	1043					
G		All urine**		769		All specimens failed upon immersion in water			
		3	1	899					
		1	1	625					
	Urine	1	3	978					
		1	8	815					
N		All urine**		1364	138	--	--	8*	--

-- Specimen failed
* One test only
** Amount of urine used corresponded to either all or a portion of the liquid required to produce optimum moisture

(1) Based on weight of rosin
(2) Ratio of amount of base used to amount required to completely satisfy the acid number of the rosin

Batch Composition
2% Rosin - Type of soil and type and amount of base as shown

TABLE 5

EFFECT OF DIFFERENT DEGREES OF NEUTRALIZATION OF THE ROSIN ACID BY THE ADDITION OF POTASSIUM HYDROXIDE SOLUTION - DIFFERENT SOILS

Soil	Percent of KOH(1)	Ratio Alkali to Rosin (2)	Compressive Strength in lb/sq in					
			Dry	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
P	15 8 7 8 4 0	1 1 1 2 1 4	370 350 322	-- -- 105	-- 5 37	-- -- 18	-- 3 14	-- 1* 9*
B	15.8 7 8 4.0	1 1 1 2 1 4	435 524 471	41 279 285	6 216 282	6* 155 180	13 114 120	40* 50 38
E	15 8 7 8 4 0	1 1 1 2 1 4	602 627 719	16 85 487	7 37 113	6 6 9	25 39 37	6 7 11
L	15 8 7 8 4 0	1 1 1 2 1 4	592 577 658	14 24 192	-- 41 189	-- 13 135	-- 3 25	-- 3 5
G	15 8 7.8 4 0	1 1 1 2 1 4	701 880 889	-- 445 226	-- 304 32	-- 269 --	-- 55 28	-- -- --
U	15 8 7.8 4 0	1 1 1 2 1 4	276 378 393	All samples failed when submerged in water				
M	15 8 7.8 4.0	1 1 1 2 1 · 4	904 903 1189	20 34 325	-- 24 261	-- 33 196	-- 10* 53	-- -- 5
N	15.8 7.8 4 0	1 1 1 2 1 4	810 974 1225	322 373 437	-- -- --	-- -- --	6* 5 6*	3* 3* --
V	15.8 7.8 4.0	1 1 1 2 1 4	743 754 749	136 166 162	All samples failed in the wetting and drying and freezing and thawing cycles			

-- Specimens failed
* One test only
(1) Base on weight of rosin
(2) Ratio of amount of alkali used to amount required to completely satisfy the acid number of the rosin.

Batch Composition
2% Rosin - Type of soil and amount of KOH as shown

TABLE 6

EFFECT OF VARIOUS SALTS ON THE EFFECTIVENESS OF ROSIN DISPERSED IN SODIUM, POTASSIUM AND AMMONIUM HYDROXIDE SOLUTION

Base		Salt		Ratio Alkali to Rosin (2)	Compressive Strength in lb/sq in					
Kind	Percent(1)	Kind	Percent(1)		Dry	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
NaOH	11 3	No Salt		1 1	721	--	--	--	--	--
	5 6			1 2	787	4	--	--	3	--
	2 8			1 4	930	325	57	96	18	5
	11 3	$CaCl_2$	15 7	1 1	690	196	5	3	18	3
	5 6		7 8	1 2	613	--	--	--	--	--
	2 8		4 0	1 4	731	258	10	6	42	6
	11 3	$BaCl_2$	29 6	1 1	660	182	7	5	16	4
	5 6		14 8	1 2	836	239	25	9	42	4
	2 8		7 4	1 4	790	156	5	3*	13	3
	11 3	$AlCl_3$ $6H_2O$	22 6	1 1	616	364*	16	17	100	12
	5 6		11 4	1 2	775	407	369	335	125	25
	2 8		5 2	1 4	770	479	233	--	143	27*
	11 3	$MgSO_4$ $7H_2O$	37 0	1 1	735	--	--	--	--	--
	5 6		18 5	1 2	736	--	--	--	--	--
	2 8		9 2	1 4	927	283	100*	19*	27	6
	11 3	$FeSO_4$ $7H_2O$	39 2	1 1	622	226*	13	3	45*	8
	5 6		19 6	1 2	768	316	203	340	126	29
	2 8		9 8	1 4	899	591	22	163*	150	9
	11 3	$ZnSO_4$ $7H_2O$	40 0	1 1	751	169	5	2	13	8
	5 6		20 0	1 2	899	12	4	--	6	4
	2 8		10 0	1 4	875	353	65	163*	86	31
KOH	15 8	No Salt		1 1	454	--	--	--	--	--
	8 0			1 2	703	--	--	--	--	--
	4 0			1 4	579	89	3	1	15	5
	15 8	$CaCl_2$	15 7	1 1	554	215	6*	--	15	6
	8 0		7 8	1 2	660	167	8	--	20	2
	4 0		4 0	1 4	720	288	192	205	47	15
	15 8	$BaCl_2$	29 6	1 1	580	62	--	--	10	6
	8 0		14 8	1 2	550	9	--	--	6	4*
	4 0		7 4	1 4	634	200	29	--	34	7
	15 8	$AlCl_3$ $6H_2O$	22 6	1 1	585	257	54	162	90	36
	8 0		11 4	1 2	658	276	49	38	108	30
	4 0		5 6	1 4	621	316	16	7	139	21
	15 8	$MgSO_4$ $7H_2O$	37 0	1 1	506	--	--	--	--	--
	8 0		18 5	1 2	692	48	2	--	5	2*
	4 0		9 2	1 4	947	89	9	1*	9	2
	15 8	$FeSO_4$ $7H_2O$	39 2	1 1	582	281	30	28	128	22
	8 0		19 6	1 2	671	300	173	56	98	34
	4 0		9 8	1 4	697	350	31	11	146	20
	15 8	$ZnSO_4$ $7H_2O$	40 0	1 1	701	137	9	3	29	8
	8 0		20 0	1 2	761	267	5	6	32	7
	4 0		10 0	1 4	794	241	18	10*	45	5
NH_4OH Solution Sp G -0 9	17 2	No Salt		1 1	856	64	20	5*	12	--
	8 6			1 2	1035	331	390	381*	50	5
	4 4			1 4	1067	509	389	320*	96	9
	17 2	$CaCl_2$	15 7	1 1	702	329	217	20	46	7
	8 6		7 8	1 2	727	3	5	1	3	--
	4 4		4 0	1 4	715	3*	--	--	1	--
	17 2	$BaCl_2$	29 6	1 1	556	200	30	1	21	5
	8 6		14.8	1 2	726	3*	5	3	2	--
	4 4		7 4	1 4	589	--	--	--	--	--
	17 2	$AlCl_3$ $6H_2O$	22 6	1 1	568	247	81	17	85	14
	8 6		11 4	1 2	643	353	211	167	80	10
	4 4		5 6	1 4	848	321	48*	7	53	8
	17 2	$MgSO_4$ $7H_2O$	37 0	1 1	1030	141	10	--	10	--
	8 6		18 5	1 2	782	6	3	1*	3*	--
	4 4		9 2	1 4	768	4	--	--	2	--
	17 2	$FeSO_4$ $7H_2O$	39 2	1 1	622	264	46	147	56	14
	8 6		19 6	1 2	583	372	207	148	75	17
	4 4		9 8	1 4	736	327	208	149	59	9
	17 2	$ZnSO_4$ $7H_2O$	40 0	1 1	705	254	59	159	10	4
	8.6		20 0	1 2	811	404	138	133	50	4
	4 4		10 0	1 4	801	26	5	3	5	3

-- Specimen failed
* One test only
(1) Based on weight of rosin
(2) Ratio of amount of alkali used to amount required to completely satisfy the acid number of the rosin

Batch Composition
Soil G - 2% Rosin Type and amount of base and salt as shown

TABLE 7

EFFECT OF IRON AND ALUMINUM SALTS ON THE EFFECTIVENESS OF ROSIN DISPERSED IN POTASSIUM HYDROXIDE SOLUTION - DIFFERENT SOILS

Soil	Kind of Salt	Ratio Alkali to Rosin (1)	Compressive Strength in lb/sq in					
			Dry	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
P	$AlCl_3$	1 1	152	18	10	11	8	8
		1 2	122	41	12	11	11	12
		1 4	184	80	12	12	18	10
	$FeSO_4$	1 1	228	79	8	55	15	15
		1 2	232	88	11	12	16	17
		1 4	249	100	39	38	33	11
B	$AlCl_3$ (2)	1 1	297	201	196	190	90	45
		1 2	404	302	264	245	113	40
		1 4	487	353	150	139	146	40
	$FeSO_4$ (2)	1 1	400*	270	68	191	54	24
		1 2	415	323	257	235	95	28
		1 4	488	356	163	183	119	16
E	$AlCl_3$	1 1	461	113	113	43	42	28
		1 2	617	212	68	54	45	24
		1 4	609	249	133	310	194	48
	$FeSO_4$	1 1	479	227*	86	No test	32	24
		1 2	496	238*	143*	133	32	27
		1 4	589	371*	106	323	168	43
L	$AlCl_3$	1 1	492	132	142	78	59	16
		1 2	655	407	235	180	125	33*
		1 4	626	329	331	291	85	22
	$FeSO_4$	1 1	459	198	44	64*	53	20
		1 2	643	295	262	172	58	15
		1 4	570	287	251	258	68	11
G	$AlCl_3$	1 1	585	257	54	163	90	36
		1 2	658	276	49	39	108	30
		1 4	621	316	16	7	139	22
	$FeSO_4$	1 1	582	281	30	28	128	22
		1 2	671	300	173	56	99	33
		1 4	697	350	31	11	144	20
U	$AlCl_3$	1 1	234	--	--	--	--	--
		1 2	491	163	3	--	--	--
		1 4	484	--	--	--	--	--
	$FeSO_4$	1 1	385	--	--	--	--	--
		1 2	344	--	--	--	--	--
		1 4	579	54	57	--	4	3
M	$AlCl_3$	1 1	794	338	20	No test	42	24
		1 2	905	274	53	92*	65	10
		1 4	706	75	12	40*	23	9
	$FeSO_4$	1 1	574	137	106	144*	68	13
		1 2	770	229	214	--	12	7
		1 4	1138	625	423	392	126	9*
N	$AlCl_3$	1 1	863	529	--	--	42	4
		1 2	852	418	--	--	8	3
		1 4	871	238	--	--	13	2
	$FeSO_4$	1 1	785	398	--	--	12	2
		1 2	778	270	--	--	7	2*
		1 4	834	92	--	--	3	--
V	$AlCl_3$	1 1	737	364	--	--	15	--
		1 2	746	411	--	--	--	--
		1 4	949	335	--	--	12*	--
	$FeSO_4$	1 1	823	155	--	--	2*	--
		1 2	981	237	--	--	5	--
		1 4	1056	205	--	--	6*	2*

-- Specimen failed
* One test only
(1) Ratio of amount of alkali used to amount required to completely satisfy the acid number of the rosin
(2) $AlCl_3$ $6H_2O$
$FeSO_4$ $7H_2O$

Batch Composition
For ratios of alkali to rosin - - -

Ratio Alkali to Rosin	Percent KOH	Salt Kind	Salt Percent
1 1	15 8		22 6
1 2	7 8	$AlCl_3$	11 4
1 4	4 0		5 6
1 1	15 8		39 2
1 2	7 8	$FeSO_4$	19 6
1 4	4 0		9 8

TABLE 8

EFFECT OF VARIOUS AMOUNTS OF POWDERED SODIUM ROSINATE COMPOUND
(ONE SODIUM ROSINATE - THREE ROSIN ACIDS)

Soil	Amount of Admixture Percent (1)	Compressive Strength in lb/sq in					
		Dry	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
E	0.2	558	346	390	352	111	40
	0.4	509	380	467	375	138	55
	0.6	466	350	423	387	138	72
	1.2	449	387	525	462	151	44
G	0.2	475	90	--	--	9	6
	0.4	698	260	238*	167	10	10
	0.6	745	390	473	463	12	13
	1.2	654	492	779	655	13	17

-- Specimen failed
* One test only
(1) Based on weight of soil

Batch Composition
Soil and amount of admixture as shown

TABLE 9

EFFECT OF VINSOL RESIN WITH AND WITHOUT ALKALI

Kind and Amount of Base (1)	Compressive Strength in lb/sq in					
	Moist (2)	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
None	359	144	111	39	9	--
1.7% NaOH	336	146	209	80	20	--
2.4% KOH	299	161	169	54	19	--

-- Specimen failed
(1) Based on weight of Vinsol
(2) Specimens possessed from 50 to 60% of optimum moisture content

Batch Composition
Soil G, 2% Vinsol, kind and amount of base as shown

TABLE 10

EFFECT OF IRON AND ALUMINUM SALTS ON THE EFFECTIVENESS
OF VINSOL DISPERSED IN POTASSIUM HYDROXIDE SOLUTION

Soil	Kind of Salt	Amount of Salt Percent (1)	Amount of KOH Percent (1)	Ratio Alkali to Rosin (2)	Compressive Strength in lb/sq in					
					Dry	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
G	$FeSO_4 \cdot 7H_2O$	39.2	15.8	1:1	565	396	390	523	145	34
		19.6	7.8	1:2	717	445	474	618	125	13
		9.8	4.0	1:4	785	127	378	316	17	5
	$AlCl_3 \cdot 6H_2O$	22.6	15.8	1:1	569	305	377	290	69	25
		11.4	7.8	1:2	730	319	530	461	59	7
		5.6	4.0	1:4	784	26	181	126	11	2
N	$FeSO_4 \cdot 7H_2O$	39.2	15.8	1:1	880	372	--	--	20	3
		19.6	7.8	1:2	681	102*	--	--	--	2
		9.8	4.0	1:4	953	--	--	--	--	2*
	$AlCl_3 \cdot 6H_2O$	22.6	15.8	1:1	836	316	278*	--	17	3
		11.4	7.8	1:2	1250	376	--	--	6	2*
		5.6	4.0	1:4	970	11*	--	--	--	--

-- Specimen failed
* One test only
(1) Based on weight of Vinsol
(2) Ratio of amount of alkali used to amount required to completely satisfy the acid number of the rosin

Batch Composition
Soil N - 2.0% Vinsol
Kind and amount of alkali and salt as shown

TABLE 11

EFFECT OF DIFFERENT PROPORTION OF SEA WATER ON THE EFFECTIVENESS OF ROSIN DISPERSED IN SODIUM AND POTASSIUM HYDROXIDE SOLUTION - DIFFERENT SOILS

Soil	Kind of Base	Ratio Alkali to Rosin (1)	Proportion Sea Water to Fresh Water (2)	Compressive Strength in lb/sq in. Dry	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
P		1:4	Fresh water	321	105	37	18	14	5
	KOH	1:1	1:1	226	--	--	--	--	--
		1:2		172	--	--	--	--	--
		1:4		152	2	--	--	--	--
		1:1	1:3	138	All specimens failed upon immersion in water.				
		1:2		175					
		1:4		206					
		1:1	1:7	152	All specimens failed upon immersion in water.				
		1:2		134					
		1:4		135					
	NaOH	1:1	1:1	254	All specimens failed upon immersion in water.				
		1:2		129					
		1:4		116					
		1:1	1:3	230	All specimens failed upon immersion in water.				
		1:2		242					
		1:4		254					
		1:1	1:7	241	All specimens failed upon immersion in water				
		1:2		175					
		1:4		173					
E		1:4	Fresh water	719	488	113	9	36	10
	KOH	1:1	1:1	444	39	49	10	15	5
		1:2		443	158	61	18	24	11
		1:4		447	269	166	30	81	12
		1:1	1:3	622	32	22	28	13	6
		1:2		563	93	101	89	24	7
		1:4		489	180	93	22	36	12
		1:1	1:7	451	30	36	28	24	4
		1:2		475	41	85	74	24	9
		1:4		473	107	156	45	40	11
	NaOH	1:1	1:1	432	15	13	5	8	4
		1:2		464	73	50	21	15	7
		1:4		456	147	137	43	38	10
		1:1	1:3	492	15	6*	3*	9	3
		1:2		523	44	64	23	27	9
		1:4		517	164	182	57	65	15
		1:1	1:7	457	10	10*	2*	10	2
		1:2		621	221	301	77	31	12
		1:4		600	179	270	81	36	14
G		1:4	Fresh water	579	89	3	2	16	6
	KOH	1:1	1:1	775	--	--	--	--	--
		1:2		725	2	--	--	3	--
		1:4		895	3	2	--	19	3
		1:1	1:3	854	--	--	--	--	--
		1:2		699	--	--	--	--	--
		1:4		812	--	--	--	7	3
		1:1	1:7	669	--	--	--	--	--
		1:2		590	--	--	--	--	--
		1:4		635	4	2	--	16	5
	NaOH	1:1	1:1	810	--	--	--	--	--
		1:2		740	2	--	--	4	2
		1:4		640	--	2	--	5	4
		1:1	1:3	987	--	--	--	--	--
		1:2		744	--	--	--	--	--
		1:4		476	--	2	--	12	4
		1:1	1:7	464	All specimens failed upon immersion in water.				
		1:2		771					
		1:4		1016					

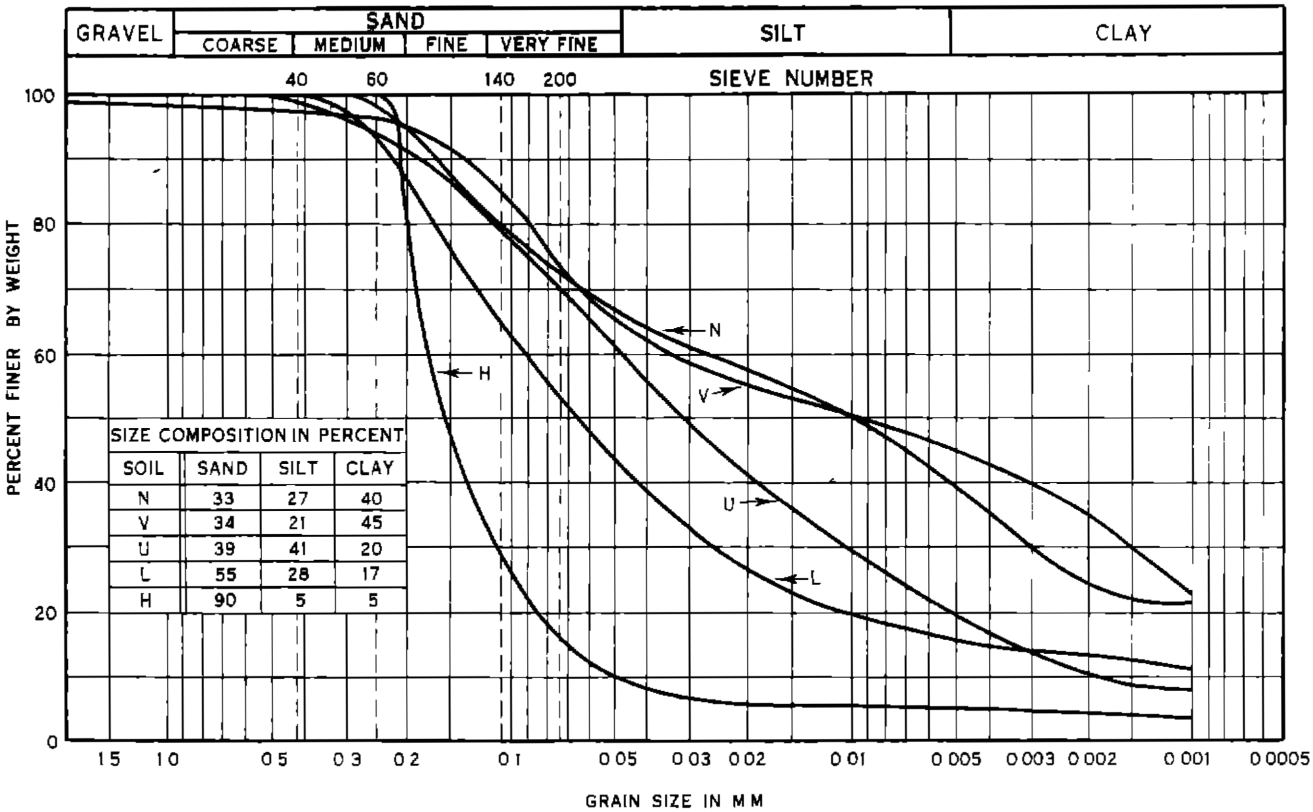
TABLE 11 (Continued)

EFFECT OF DIFFERENT PROPORTION OF SEA WATER ON THE EFFECTIVENESS OF ROSIN DISPERSED IN SODIUM AND POTASSIUM HYDROXIDE SOLUTION - DIFFERENT SOILS

Soil	Kind of Base	Ratio Alkali to Rosin (1)	Proportion Sea Water to Fresh Water(2)	Compressive Strength in lb/sq in. Dry	Wet	Wet 1 W-D	Wet 4 W-D	Wet 1 F-T	Wet 4 F-T
N	KOH	1:4	Fresh water	1225	437	--	--	6	--
		1:1	1:1	666	All specimens failed upon immersion in water.				
		1:2		1005					
		1:4		1050					
		1:1	1:3	1083	--	--	--	--	--
		1:2		878	--	--	--	--	--
		1:4		1389	167	--	--	16	--
		1:1	1:7	999	75	--	--	--	--
		1:2		1042	--	--	--	--	--
		1:4		1058	255	5	--	4	--
	NaOH	1:1	1:1	974	All specimens failed upon immersion in water				
		1:2		1053					
		1:4		1037					
		1:1	1:3	1064	--	--	--	--	--
		1:2		979	--	--	--	--	--
		1:4		1077	252	--	--	3	--
		1:1	1:7	1100	--	--	--	--	--
		1:2		985	--	--	--	--	--
		1:4		1008	90	--	--	3	--
V	KOH	1:4	Fresh water	749	162	--	--	--	--
		1:1	1:1	683	All specimens failed upon immersion in water				
		1:2		694					
		1:4		895					
		1:1	1:3	662	--	--	--	--	--
		1:2		683	92*	--	--	6	--
		1:4		665	139	14*	--	15	4
		1:1	1:7	721	--	--	--	--	--
		1:2		626	--	--	--	10	3
		1:4		871	99	--	--	24	4
	NaOH	1:1	1:1	833	All specimens failed upon immersion in water.				
		1:2		855					
		1:4		789					
		1:1	1:3	701	--	--	--	--	--
		1:2		684	--	--	--	--	--
		1:4		792	11	--	--	10*	3
		1:1	1:7	886	--	--	--	--	--
		1:2		803	17*	--	--	9*	--
		1:4		785	48*	--	--	16	1*

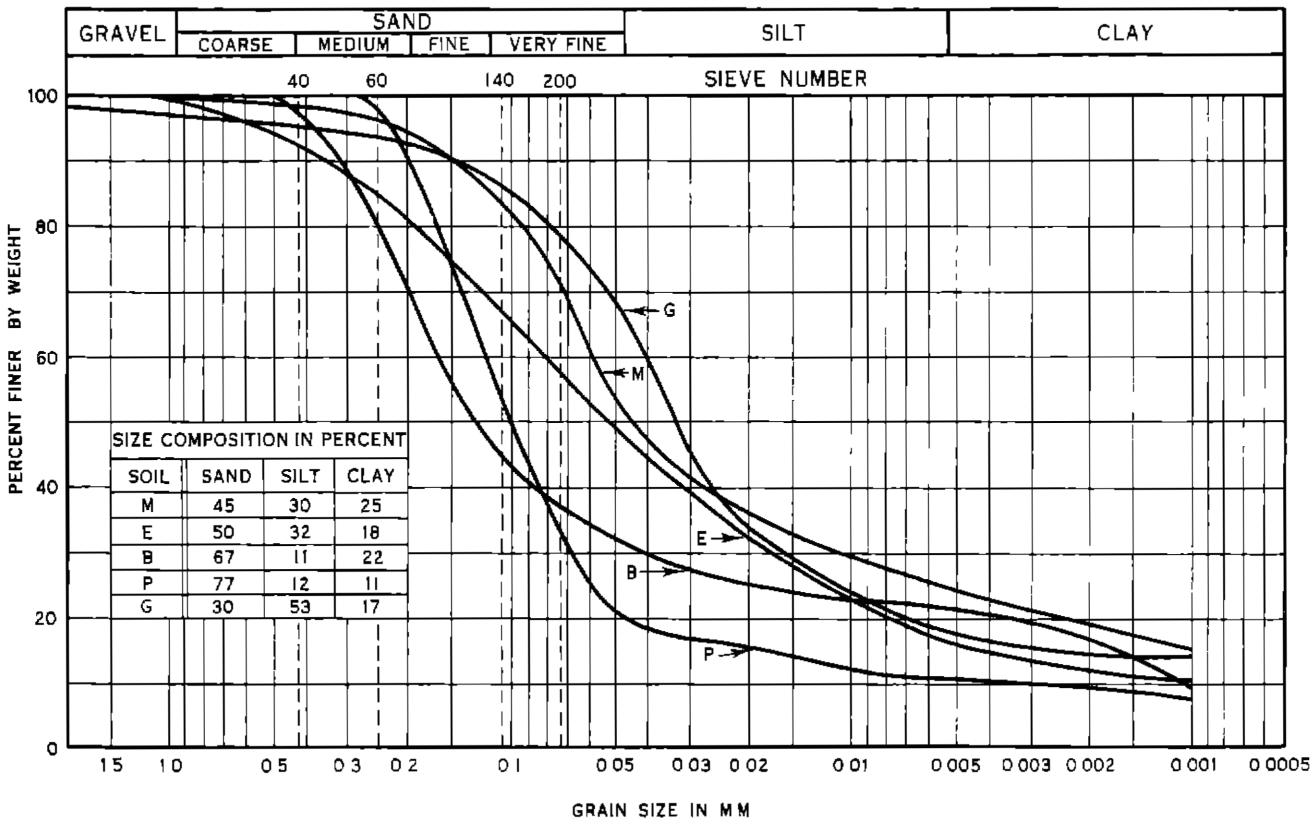
— Specimen failed.
* One test only
(1) Ratio of amount of alkali used to amount required to completely satisfy the acid number of the rosin
(2) Total amount of water used was that required to produce optimum moisture content

Batch Composition
2% Rosin - Type of soil, type and amount of alkali, and proportion of sea water to fresh water as shown.



SIZE COMPOSITION IN PERCENT

SOIL	SAND	SILT	CLAY
N	33	27	40
V	34	21	45
U	39	41	20
L	55	28	17
H	90	5	5



SIZE COMPOSITION IN PERCENT

SOIL	SAND	SILT	CLAY
M	45	30	25
E	50	32	18
B	67	11	22
P	77	12	11
G	30	53	17

Figure 1 Grain Size Distribution Curves of the Different soils

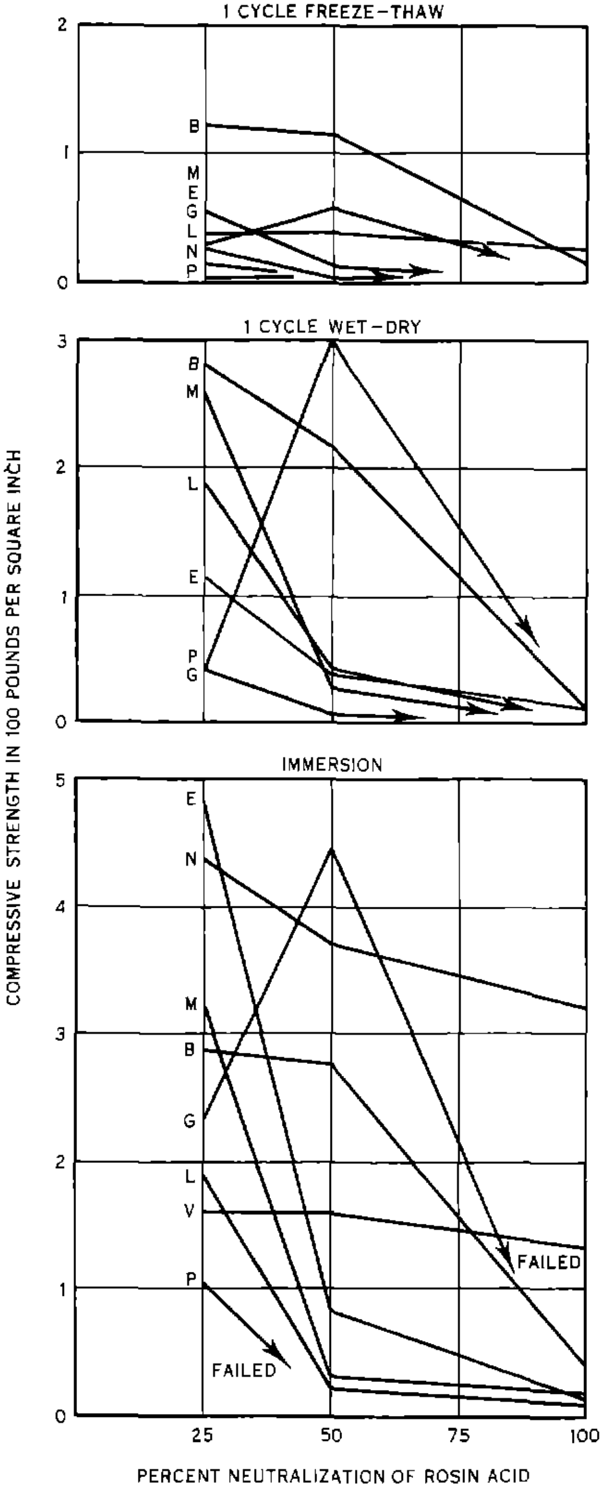


Figure 2 Effect of Different Degrees of Neutralization Potassium Hydroxide Solution

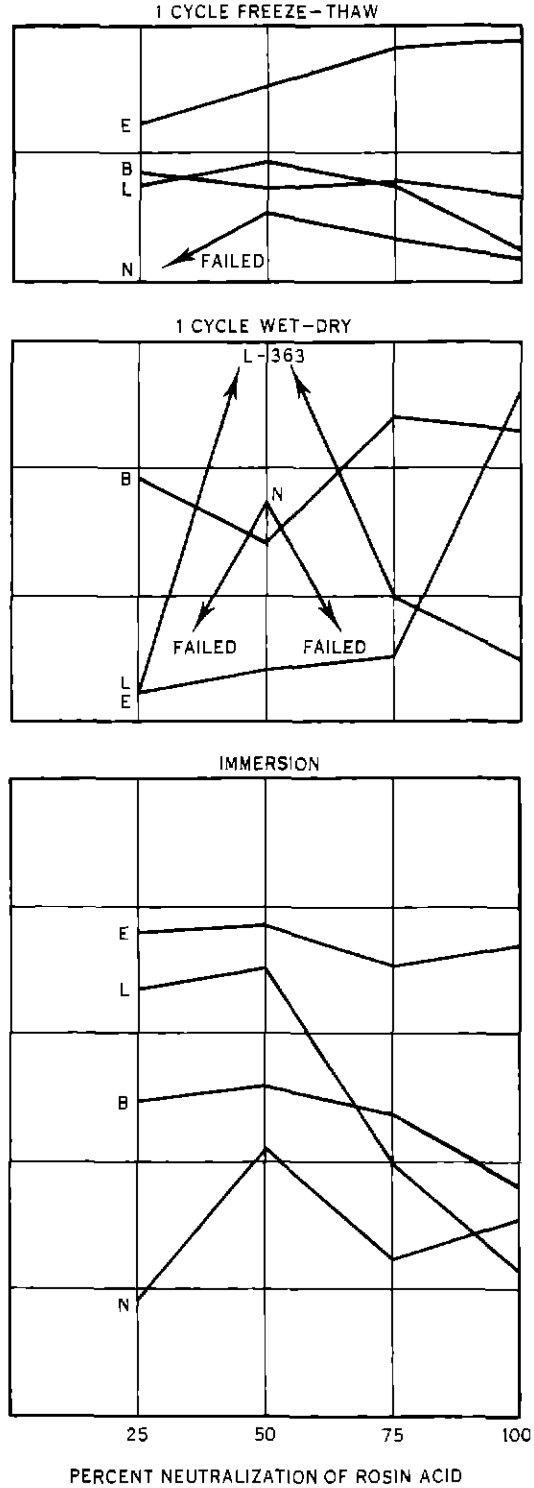


Figure 3 Effect of Different Degrees of Neutralization Ammonium Hydroxide Solution

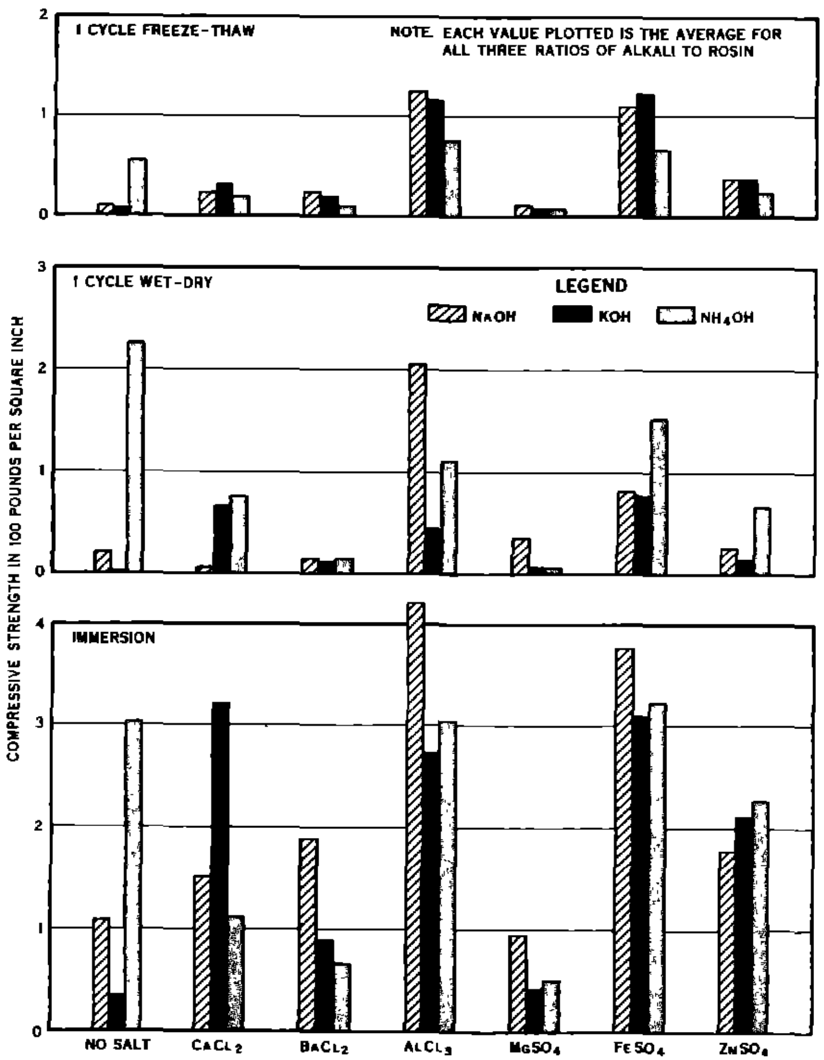


Figure 4 Effect of Various Salts on the Effectiveness of Rosin Dispersed in Sodium, Potassium and Ammonium Hydroxide Solutions

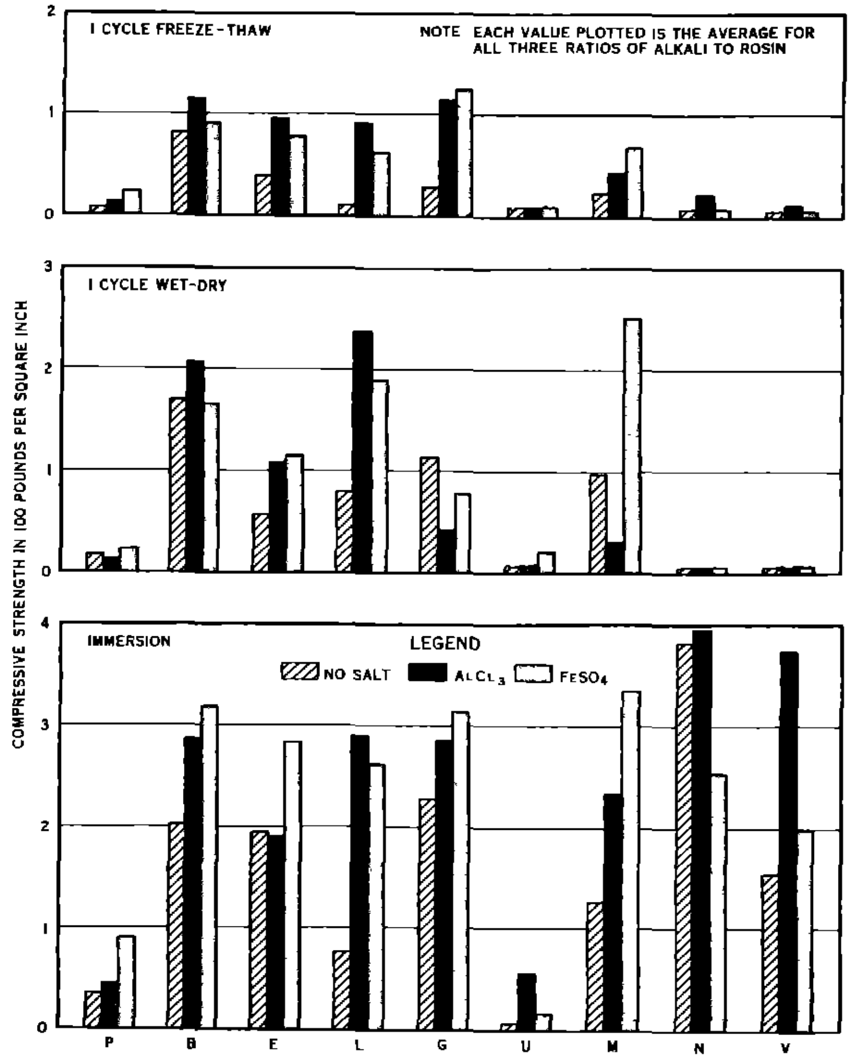


Figure 5 Effect of Iron and Aluminum Salts on the Effectiveness of Rosin Dispersed in Potassium Hydroxide Solution Different Soils