THE NATURE AND EFFECTS OF SURFACE COATINGS ON COARSE AGGREGATES

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SYNOPSIS

This report discusses the surface coatings which are sometimes found on coarse aggregates including (1) Stone dust (2) Clay or silt (3) Organic coatings (4) Alkali coatings (5) Bituminous oil impregnations and coatings (6) Calcareous incrustations (7) Sugar coatings (8) Miscellaneous Available tests indicate that stone dust may decrease the strength of concrete up to 2 per cent for each 1 per cent of stone dust in the mixture Clay admixtures seem not to be harmful in lean mixtures of concrete but cause decrease in strength in rich mixtures When occurring as a coating not easily removed, clay probably prevents proper adhesion Bituminous oil coatings of the nature and extent studied decreased the strength of the concrete This may or may not be serious, depending upon the percentage of surfaces coated Alkali coatings are not definitely proven to be harmful Sugar coatings are most decidedly harmful as are also coatings of organic matter Miscellaneous coatings include coal dust and dirt from improperly cleaned railroad cars There is a dearth of information on the effect of surface coatings and the desirability of investigations on this subject is strongly indicated

Specifications rather generally recognize the possibility that surface coatings on coarse aggregates may be harmful Practically never are these coatings described in specifications except in such general terms as "adherent surface coatings" or as "material removed by decantation" Unquestionably, some coatings are harmful in certain types of construction while others may not be deleterious Therefore, it becomes pertinent to inquire as to the nature of these coatings and their effects and to suggest investigations designed to supply more definite information regarding them

SURFACE COATINGS FOUND ON COARSE AGGREGATES

The surface coatings which occur on coarse aggregates may be listed as follows

Stone dust resulting from the crushing and screening operations or from long storage under dusty conditions

Clay or silt resulting from

(a) Overburden or seams in quarries and gravel pits
(b) The presence of clay or silt in the original gravel deposit,
(c) Storage on the uncovered earth surface,

. Organic coatings such as result in certain gravel deposits subjected to seepage from overlying layers of organic material, or from the action of streams carrying organic matter.
Alkali coatings resulting from alkali-bearing water.
Bituminous oil impregnations and coatings
Calcareous incrustations frequently containing embedded or cemented sand
Sugar coatings. (Most likely to occur in samples of material shipped in sugar sacks)
Miscellaneous incrustations

In addition to the above, aggregates may become coated to some extent from improperly cleaned railroad cars in which other materials such as coal, earth, etc , have previously been shipped.

Each of the above coatings has definite characteristics and it seems best to discuss them separately. Obviously, in a limited discussion, covering so wide a field, it will be impracticable to give all of the test results bearing on the subject Accordingly, only certain typical but enlightening results will be brought forward without going into too much detail A list of references, however, will be found in the files of the Highway Research Board

STONE DUST

Stone dust results from the crushing and screening of rock and from its subsequent handling Most of this dust is screened out in the normal production process and is to be found in the screenings However, a certain amount of dust clings to the surface of the stone and this is particularly true if the stone is in a wet condition before it is crushed and screened A thin film of dust may then be formed which produces an unsightly appearance If the stone is rained on while in this condition, the dust film may be displaced and again be accumulated in a layer a short distance beneath the surface of the pile, thus increasing the percentage of dust in this particular portion

Properties of Stone Dust Stone dust when mixed with water has a certain amount of cementing value, that is, the particles cling together more or less tenaciously after they have become wet and have then been dried. Naturally, the characteristics of the dust vary with the characteristics of the parent rock Thus siliceous dust, such as results from quartzite or siliceous rock has very little cementing value and is displaced easily from the surface of the rock merely by rinsing. Limestone and trap rock dust have either high or low cementing value depending upon their characteristics Furthermore, the surface roughness of the rock has much to do with the tenacity with which the dust adheres

In general, the softer the rock the more dusty it will be, because of the ease with which abrasion takes place in the crushing and screening

operations Dust is removed from some limestones merely by dipping them in water while others may require mechanical washing to dislodge the dust coating Each case must be judged separately to determine the possibility of deleterious effect

The Effect of Stone Dust-coated Stone on the Properties of Concrete It frequently has been stated by engineers that stone dust is harmful to concrete in several different ways First, the film of dust prevents the proper adhesion between stone and the mortar and thus the strength of the concrete is impaired Further, it is claimed that stone dust is carried readily to the surface of the concrete during the placing and finishing operations, thus forming a weak surface layer and increasing the amount of laitance which forms on the surface of the wet concrete If this claim is correct, the wearing properties of the concrete surface would be diminished and there would be a likelihood of the weak surface layer pealing off in the form of a surface scale or of wearing unduly under traffic

There seem to have been very few tests laid out for the purpose of investigating the effect of dust-coated stone on the properties of concrete This subject, however, has been investigated by the National Crushed Stone Association in the following manner

Dust was first prepared from three different kinds of rock, limestone, granite and a sample of fine grained gneiss The coarse aggregate was moistened and thoroughly mixed with the dust in amounts up as high as 5 7 per cent by weight of the coarse aggregate The dust film was in a damp condition when the stone was mixed with cement, sand and water in the proportions of 1 2 3½ by volume For crushing strength 6 by 12 in cylinders were made and 6 by 6 by 36 in beams were likewise made for modulus of rupture tests These specimens were broken at the age of 28 days and also at the age of one year and after storage in the moist room at 70°F Without going into the details of the results, the conclusions drawn from the 28-day tests were.

That the decrease in modulus of rupture due to the dust is from 1 to 1½ per cent for each increase of one per cent in dust

That the decrease in crushing strength is from 0 to 2 per cent for each increase of one per cent in dust up to the limit of 5 7 per cent of dust used in these tests

Comparative wear tests were likewise made on the surface of the broken beams by the use of a special wearing tool designed for this purpose The wear testing machine consisted of a number of emery wheel dressers mounted on a horizontal axle and held against the specimen under a load of 100 pounds while the wearing tool was revolved There was a slight tendency for the amount of wear to increase with increasing percentages of stone dust This increase in wear for the specimens containing 5 7 per cent of dust as compared with the speci-

men having 0 7 per cent amounted to 0 06 of an inch at the end of the test when approximately 0 3 in wear had taken place This amount of wear would occur under normal traffic only after a long term of years The general conclusion was drawn that in these tests, dust up to 5 7 per cent by weight of stone did not cause any serious decrease in resistance to wear The one-year strength tests were quite similar to the 28-day tests in relative value All of the specimens gained in strength, even those containing 5 7 per cent of dust by weight of stone

Effect of Crusher Dust on the Strength and Other Properties of Mortars and Concretes Made from Crushed Granite (University of Colorado, Boulder) Crusher dust (of the same material as the aggregates 0–100 grading) was added to mortars and concretes as a check on the extent to which accidental concentrations of dust might be harmful to the quality of the concrete At a constant water-cement ratio the dust strengthened the concrete but stiffened it materially. At constant slump the increase in strength from adding dust was about equal to the decrease from increasing the water-cement ratio up to an amount of dust equal to 15 or 20 per cent of the total fine aggregate The conclusion from these tests and materials is that no ordinary concentration should be injurious but it may complicate the control of mixing water and workability The results from these tests should not be extended to other conditions and materials without experimental verification, however (A C I Proceedings, 1931, January Journal)

W. K Hatt in a letter to Engineering News-Record dated January 5, 1922, cites two instances in Indiana where failure of concrete piers and retaining walls occurred. The concrete did not harden Soft limestone containing large amounts of crusher dust was used as the aggregate Laboratory specimens using this aggregate did not indicate failure It is not clear, therefore, whether or not the dust was at fault in this instance.

It would seem that the case for or against dust coatings on crushed stone aggregate is not very definite, although such test results as have been obtained do not show any serious effects However, it is suggested that additional investigations be performed and that the dust coating be dried on the stone in order to simulate the condition which occurs after the stone has been in storage under the action of the hot sun Possibly a coating such as this may not be easily displaced in the concrete mixer and this is a point which needs further research A wide range of aggregates and stone dusts should also be investigated to determine the effect of aggregate surface on the adhesion of the dust during the mixing of the concrete Freezing tests as well as wear tests should likewise be conducted and the concrete specimens should have a range in consistency

The effect of dust-coated stone in bituminous construction is more definite than when such stone is used as concrete aggregate. Observa-

tion in the field has shown that badly dust-coated stone prevents the proper adhesion of the bituminous material and dust coatings are to be avoided for most bituminous types of construction, particularly bituminous macadam and surface treatment involving the use of stone as a cover material.

CLAY COATINGS

Clay coatings may occur on either crushed stone or gravel In crushed stone production, it is found that some quarries have clay seams or they may be improperly stripped and the clay may reach the stone from the overburden In the case of gravel, clay may be present due to improper stripping or to the presence of clay seams in the gravel Insufficient water used in the washing process or the repeated use of wash water without adequate sedimentation may also result in a coating of clay on the gravel.

It is somewhat difficult to make any definite statement with regard to the effect of clay coatings on gravel for so much depends upon the characteristics of the clay, which is an extremely variable material It may be quite tenacious and not easily displaced or it may slake very easily upon immersion in water and be readily removed from the gravel during the process of mixing the concrete Tests results on clay coated gravel are not numerous judging from the published literature on this subject Some tests have been made, however, on the effect of admixtures of clay with concrete. Tests were reported in 1904 in Engineering News by G J Friesnauer These tests were made in the laboratory of the Chicago, Milwaukee and St. Paul Railroad on sands to find the effect of clay or loam The tests showed loamy or clayey sands usually gave higher tensile strength in mortars than the cleaner sands In commenting on these tests it is pertinent to remark that mortar tests are usually made on lean mortars and other investigators have found that the presence of clay favorably affects the strength of lean mortars but may unfavorably affect the strength of rich mortars Similar tests were made at the University of Kansas and reported in the 1905 issue of Engineering News. The tests indicated that clay or loam, from 2 to 10 per cent, does not lower the strength of 1 3 mortar but rather adds to it.

In one case the presence of an extremely finely divided colloidal clay coating on sand seemed to interfere with its handling due no doubt to the tenacious crust formed by the dried colloidal material Thorough washing removed this difficulty The strength of the concrete did not seem to be affected by this coating.

The question of the effect of clay coatings is by no means settled. We have no adequate definition for such coatings nor do we know definitely how serious their effect may be Obviously there are different kinds of clay coatings just as there are different kinds of clays and their effects must be correspondingly different.

In general, clay coatings are difficult to displace and tests made with clay admixtures are not necessarily indicative of the effect of this same clay when it occurs as a coating If the coating is of such a nature that it is easily scoured loose in the concrete mixer no particular harm may result as far as loss of strength is concerned. The clay may, however, increase the amount of laitance and be provocative of a weak surface layer A definite series of tests should be carried out covering a range of clays occurring in different percentages.

ORGANIC COATINGS

Organic coatings or admixtures are known to be harmful to concrete However, whether all kinds of organic coatings are equally bad is not at all settled As a matter of fact, the tests of organic coatings seem rather meager The most conclusive ones have employed artificial coatings of tannic acid D A. Abrams (1) has shown that as little as 0 1 per cent of tannic acid by weight of aggregate may be seriously harmful It has been stated (2) that the chief organic substances in soils investigated are dihydroxystearic acid, "gelbsaure" substances similar to tannic acid and gallic acids and complex humous compounds known as humic and ulmic acids They are extractable with or are suspendable in water, possess colloidal properties and prevent union between sand and cement if coated on the former The chief remedies are washing, burning or the addition of small amounts of inorganic salts or mineral acids such as CaO or dilute HNO_3 to cause flocculation of colloidal matter The investigations of Abrams on the effect of different kinds of mixing waters show that organic matter is not always harmful Thus sewage-contaminated water seemed to cause no appreciable loss in strength, possibly due to the small percentage of organic matter present but also possibly due to the nature of that organic matter

ALKALI AND SALT COATINGS ON COARSE AGGREGATE

Under the term "alkali" are included magnesium sulfate, sodium sulfate and also the carbonates of these salts The sulfates, particularly, are known to be very detrimental to concrete which is exposed to the action of these salts in solution The maximum action takes place near the water-line due to the concentration of the salt within the pores of the concrete The literature on the deleterious effects of alkali salts in solution is very extensive and there can be no doubt that when there is an opportunity for these salts to crystallize within the pores of the concrete, disintegration proceeds rapidly

The question of the effect of surface coatings of these alkalis on the coarse aggregate is, however, a somewhat different matter and a review of the bibliography on this subject has not revealed any tests made particularly to determine the effects on concrete of different percentages of alkalis present on the aggregate as a surface coating If the coating

is light, it would seem that there is little chance of building up alkali crystals within the pores of the concrete, for this requires that the alkali solution be concentrated There is, of course, the possibility of water penetrating the concrete mass by capillarity, carrying off the alkali into solution and concentrating it on the surface of the structure, and in this way being the cause of some harm In this case, however, the action probably would not be progressive

Perhaps the closest approach to tests which have a bearing on the subject of alkali coatings are those reported by D A Abrams entitled, "Tests of Impure Water for Mixing Concrete" (3) In the summary of conclusions he states that—"Sulfate waters produced little or no ill effects until an SO_3 concentration of about one per cent was reached For a concentration of 0 5 per cent, the average reduction in strength was about four per cent, a concentration of one per cent was required to produce a reduction in strength of more than ten per cent

In the absence of definite tests on this question, it would be well to avoid the presence of alkali coatings on aggregates and most specifications recognize that precautions should be taken in this matter by specifying that the aggregates "shall be free from alkali " This seems to be a wise precaution to take in view of our definite knowledge that concentrated alkali solutions under certain circumstances are harmful in creating rapid disintegration of concrete On the other hand, our lack of definite knowledge respecting alkali coatings may result in the rejection of aggregates which may really be entirely suitable and if this is actually happening it would be worth while to institute a series of tests to determine the effect of alkali coatings on the aggregate

Common salt incrustations might occur in some aggregates Abrams' tests (3) show that concrete made with solutions of common salt and cured in a moist room until test, showed a slight increase in strength at three days for solutions of ten per cent or less. Solutions of low concentration (1 and 2 per cent) also showed a slight increase in strength at seven days, after seven days, however, all concentrations gave material reduction in strength. Tests would be desirable on salt incrusted aggregates such as might occur on certain types of material dredged from salt water deposits. The percentage of salt on such deposits is very low and should not seriously affect the strength of concrete made with this material.

BITUMINOUS OIL IMPREGNATIONS AND COATINGS

In the middle western part of the United States and perhaps elsewhere, deposits of limestone are to be found containing impregnations and pockets of oil. When this stone is prepared for the commercial market by crushing and screening a portion of some of the fragments will be found coated with an oil film to which the dust of fracture may also adhere The use of this stone for concrete in some instances has

been questioned and the query arises as to the effect of such coatings on the strength and other properties of the concrete. Several series of tests have been made (4) but the only tests available at this time are those of the National Crushed Stone Association and the following report covers those investigations

Tests on Limestone Partially Coated and Impregnated with Bituminous Material (1929) The object of these tests was to determine the suitability of a particular stone for concrete road construction. This stone is partially impregnated with asphaltic material and portions of it are also coated and the question arises as to whether this asphaltic coating so interfers with the bond of the stone with the mortar as to seriously affect the strength of the concrete To determine the effect of the coating, a portion of the sample was thoroughly washed with gasoline which removed the asphaltic material. This sample is referred to later under the number 22W.

TABLE I

EFFECT OF BITUMINOUS COATINGS ON CRUSHED LIMESTONE
TESTS BY NATIONAL CRUSHED STONE ASSOCIATION

Specimen	Crushing strength		Modulus of rupture	
	28 days	3 months	28 days	3 months
	lbs per sq in	*lbs per sq in*	*lbs per sq in*	*lbs per sq in*
Untreated No 22 N	5040	6030	645	841
Gasoline Washed No 22 W	5340	6110	692	823

The portion of the stone in its natural state is referred to as 22N. This stone was received graded to comply with the Indiana State Highway Specifications and was made into 1 2 3 concrete by volume, the fine aggregate being a good grade of Torpedo sand acceptable to the Indiana State Highway Department and the cement was a local brand of portland cement passing the standard specifications The water cement ratio was 1 to 2 2 by weight The average results are given in Table I

The percentage of gain in strength at 3 months over 28 days for the two samples is therefore

Specimen no	Compressive strength	Modulus of rupture
22N	19 6	30 4
22W	14 4	19 0

Apparently the coated stone shows a substantial increase in strength, both in compression and in modulus of rupture and the strength values are all quite high. Judging from these results alone, this material should be satisfactory for concrete road construction.

Freezing Tests In order to determine the possibility of displacement of the coated particles from the surface of the concrete, broken ends of the beam specimens, 6 inches in cross-section and approximately 14 inches long, were subjected to 50 alternations of freezing and thawing In this test the specimens were immersed in water in a can having a cross-section 6½ inches square and this can in turn was immersed in alcohol contained in the compartment of a Frigidaire ice cream cabinet provided with a special compressor The alcohol may be reduced in temperature to −14°F and the freezing under these conditions takes place very rapidly.

There were no deleterious effects on the surface of the specimens after 50 alternations and judging from the behavior of similar specimens made with other materials, the bituminous-coated stone concrete, made with sand which would normally be used with this stone, is very durable

In conclusion, it is believed that the percentage of decrease in strength due to the coated particles will depend upon the percentage of coated particles present This is difficult to ascertain However, by water-washing the stone and hand-separation, it was found that roughly 14 per cent of the sample was totally coated or practically so, 47 per cent was coated over a small area on each particle and 39 per cent of the particles had no coating Although the percentage of bitumen was not determined in the sample of stone tested, such an investigation has been made elsewhere showing 0 39 to 0 93 per cent

It is hoped that a discussion of this report will bring forth the results of similar tests made on this same kind of material.

With regard to the effect of oil coatings on bituminous construction there seem to be no test data. However, one successful type of bituminous macadam construction involves the use of a coating of light oil before the application of heavy bituminous material and it is believed that the light oil aids in creating a more thorough coating of the stone than in the standard bituminous macadam construction No tests seem to be necessary on this particular point and thus far the use of oil-coated stone has not been questioned in any type of construction other than concrete

CALCAREOUS INCRUSTATIONS

Still another type of coating found on gravel consists of a calcareous incrustation in which are frequently found cemented fragments of sand. This coating varies from a mere spot, covering a small percentage of the area of the fragment and of little thickness, up to a comparatively thick coating containing embedded particles of sand and covering the entire area of the fragment The investigations which have been made to determine the effect of coatings of this nature on the strength of concrete are not very extensive Tests have been made by the Portland Cement

Association on samples of gravel taken from a deposit which contains calcareous coated gravel No test results have been made available to the writer on this material and it is understood that the results are not entirely conclusive Tests have been made by the Minnesota State Highway Department on samples of gravel containing calcareous incrustations and Table II gives typical results

Sample No 1, gravel with partially coated pebbles varying from medium to light on one side only.

Sample No 2, pebbles of light coating on approximately 10 per cent of the gravel

Sample No 3, natural pit-run gravel

All coarse aggregate was washed, screened and combined in the following proportions:

	per cent
2 in to 1 in	32
1 in to ½ in	34 5
½ in to ¼ in	33 5

The same sand was used with all three gravels and the concrete was mixed in the following proportions.

Cement	663 lbs
Sand	1525 lbs
Gravel	1922 lbs
Water	5 gal per sack of cement

TABLE II

AVERAGE 28-DAY AND 90-DAY STRENGTH RESULTS

Effect of Incrustations—Tests by Minnesota Highway Department

Gravel sample no	Corrected water-ratio	Compressive strength		Modulus of rupture	
		28 days	90 days	28 days	90 days
	gallons	*lbs per sq in*	*lbs per sq in*	*lbs per sq in*	*lbs per sq in*
1	4 81	5410	5434	843 4	841 4
2	4 83	5141	5036	900 0	867 6
3	5 08	5556	5210	973 8	910 6

It is difficult to determine from the test results in Table II if the coatings described have actually been deleterious It is true, the beam strength results from the coated gravel specimen are lower than from the gravel (No 3) which was uncoated However, this gravel was from a different source than the coated material and possibly its particular characteristics influenced the higher strength results obtained It would seem that before any definite conclusions may be drawn, it will be necessary to make tests on gravel from identically the same source, using in

one sample only those fragments which are coated and in the other sample, that portion of the deposit containing fragments which are uncoated It is stated that certain portions of the calcareous film may be removed with ease, while in other cases the film seems to adhere tightly to the gravel pebble and is removed only with difficulty

Probably each case of calcareous coated gravel must be regarded as a separate one and should be given a special investigation to determine whether the particular coating which occurs is really harmful Certainly, at this time it is impossible to make any all-inclusive statement regarding the effect of calcareous coatings on gravel It is suggested that further investigations be made along the lines above described so that more definite information may be obtained with regard to this type of coating on coarse aggregates

SUGAR COATINGS ON AGGREGATE

Sugar has been recognized for a long time as being a deleterious material in concrete, even in very small amounts Perhaps the most recent tests along this line were those made by the Kentucky State Highway Department at the University of Kentucky Tests were made on sand, cement and coarse aggregate which were sent to the laboratory in sugar containers, such as sacks and syrup buckets It was found that very small amounts of sugar reduced the strengh of mortar to almost nothing and that very unreliable results are obtained on the material shipped on such containers

A failure of concrete foundations in Cuba was traced to the fact that one of the freight cars which carried the sand had previously hauled sugar so that there is some actual danger from this source

MISCELLANEOUS INCRUSTATIONS

Other coatings or incrustations are found on aggregates in addition to those above mentioned Occasionally, samples of fine and coarse aggregate containing coatings which obviously have acted adversely on the strength of concrete made from these materials are received in various testing laboratories Test results obtained in the laboratory of the National Sand and Gravel Association on a sample of sand illustrate this point The sand was tested in the form of mortar briquettes, mortar cubes and also was used in concrete specimens Although the following results apply to mortar briquettes, they are typical of the results likewise obtained in compression from mortar specimens and also from concrete specimens The values given are strength ratios stated in terms of Ottawa sand mortar

The sand was first tested in its condition as received, also after being washed with water, likewise after washing with sodium hydroxide. And finally another portion was washed with dilute hydrochloric acid in which it was boiled for 15 minutes, washed with water, again boiled

in dilute hydrochloric acid for 15 minutes and finally washed free from acid (See Table III)

It will be noted that washing this sand with water was not effective in removing the deleterious coating, nor was the treatment in hydroxide at seven days, but the treatment with dilute hydrochloric acid seems to have been effective in removing the coating and thereby creating a high strength ratio This coating was evidently a ferrugineous clay in a very finely divided condition and there was evidence also of organic matter being present And perhaps it should be referred to as an organic-iron coating

In conclusion, it is evident that the existing knowledge of surface coatings and their effects is not at all extensive There is room for much investigational work on this subject and this statement applies to almost all of the coatings which are to be found on aggregates In the absence of more definite knowledge it is well to write specifications

TABLE III

Treatment	Strength ratios		
	7 days	28 days	91 days
None	76 0	77 1	85 7
Water	76 0	76 6	84 4
Hydroxide	86 9	94 4	98 7
Acid	99 0	96 1	101 0

prohibiting what we must now refer to as adherent coatings of a deleterious nature. Almost no coarse aggregate is entirely free from some kind of surface coating and yet many specifications require that the aggregate be in that condition of cleanliness. Such specifications must have the most liberal interpretation for otherwise practically no material would be available for use It is suggested that the Committee on Materials outline investigations on the effect of surface coatings to the end that more definite knowledge might be acquired on this particular subject.

REFERENCES

(1) Effect of Tanic Acid on the Strength of Concrete, A S T. M., 1917, Part I.

(2) Possible Explanation of Defective Sands, E E Free, Eng News, V. 67, p. 1024, 1912

(3) Structural Materials Research Laboratory Bulletin No 12

(4) Bureau of Public Roads, Indiana State Highway Department, National Crushed Stone Association

DISCUSSION

ON

SURFACE COATINGS ON COARSE AGGREGATES

MR P D. MIESENHELDER, *Indiana State Highway Commission* One of the types of surface coating on coarse aggregate mentioned in this paper was bituminous impregnations and coatings Crushed stone of this character was encountered in Indiana While it seemed probable that the oil coating which was present might affect the strength of concrete because of an influence upon the bond between the stone and the mortar, no data could be found with the results of tests on this or similar material Consequently a study was instituted to learn what effect, if any, this particular aggregate might have upon the strength of concrete

Compressive and flexural strength tests of the concrete were made at the ages of 7 days, 28 days, and 6 months In order that there might be a standard, or basis of comparison, parallel specimens were made of six different concretes in which the aggregate used was free from oil In three of these concretes the coarse aggregates were crushed stone and in three they were gravel All of them were from acceptable sources Four individual tests were averaged in determining the strength for each age and each aggregate There was a total of 168 individual tests in compression and flexure

The results of tests on concrete made with the stone having oil present, when expressed as a percentage of the average strength of the concretes made with the six aggregates without oil, were as follows·

Age at test	Modulus of rupture	Compression
7 days	80 5	80 5
28 days	86 1	82 1
6 months	88 8	76 1

After the completion of these tests a cooperative study was conducted jointly by the Bureau of Public Roads and the Indiana State Highway Commission to obtain additional information concerning this subject.

This second investigation included 132 individual tests in that portion of the series conducted in our laboratory The results tend to confirm those of the original investigation

MR. E F. KELLEY, *U S Bureau of Public Roads.* The purpose of the cooperative investigation to which Mr Miesenhelder referred was two-fold:

1 To determine the effect of the oil coating on strength of concrete

2 To determine the strength of concrete in which oil coated aggregate was used, as compared with the strength of concrete in which uncoated aggregates, available in the same locality and of unquestioned quality, was used

To answer the first question, comparative strength tests of concrete were made, using oil-coated aggregate and the same aggregate from which the oil had been removed by washing with gasoline or carbon disulphide

To obtain comparison of strengths obtained with oil-coated stone and with other aggregates locally available, tests were made with three representative crushed stones, each from a different quarry, and three representative gravels, each from a different pit

Flexural and compression tests were made in each laboratory and, in addition, tension tests were made in the Bureau laboratory

The same coarse aggregates were used in each laboratory but the cements and fine aggregates were different A constant workability as measured by flow table was maintained in each laboratory but the flow used in the Bureau laboratory was somewhat less than that used in the State laboratory

The cement factor was maintained at 1 7 barrels in all cases, in accordance with the requirements of the State specifications All tests were made at the age of 28 days

For each test combination there were six specimens made in each laboratory, the total number of specimens being 192 Tests for crushing strength in the Bureau laboratory were made on portions of the 6 by 21 inch cylinders remaining after the tension test

The comparisons which will be given are therefore based on the average of twelve test results for each case except in the case of the tension tests where the results are based on the average of six tests for each case

Taking the average strength of the six uncoated aggregates (three crushed stones and three gravels) as 100 per cent, the range of average modulus of rupture for the six aggregates was from 98 per cent to 106 per cent On the same basis the oil-coated stone showed an average modulus of rupture of 86 per cent and the washed stone an average modulus of 99 per cent

The average crushing strength for the six uncoated aggregates ranged from 98 per cent to 103 per cent of the average for the whole group The oil-coated stone showed an average compressive strength of 92 per cent and the washed stone 102 per cent

In tensile strength the average values for the uncoated stone and gravel aggregates ranged from 95 per cent to 109 per cent of the average of the group The oil-coated stone gave an average tensile strength of 85 per cent and the washed stone an average value of 98 per cent

It is concluded that in concrete of the proportions used in this investigation the effect of the oil coating on the stone was to reduce the strength. This conclusion applies to stone from one particular quarry and therefore has no general application but it suggests that oil coatings on coarse aggregate for concrete may be viewed with some suspicion until it has been shown by investigation that they are not harmful.

MAGNESIUM SULPHATE ACCELERATED SOUNDNESS TEST ON CONCRETE AGGREGATES

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SYNOPSIS

Although several accelerated tests of aggregates have been devised to simulate weathering, no true laboratory measure of soundness has yet been evolved The use of magnesium sulphate solution is proposed as a substitute for the commonly used sodium sulphate, because the solubility of the former only varies from 26 2 per cent to 29 per cent for temperatures from 68 to 86°F , whereas the solubility of sodium sulphate varies from 19 4 per cent to 40 8 per cent within the same range of temperature Moreover the magnesium sulphate has only one crystalline form at these temperatures while sodium sulphate has three A direct relationship was found between a freezing and thawing test and the magnesium sulphate test The data show that the loss in a five cycle magnesium sulphate test was about twice the loss under a 60 cycle freezing and thawing test The absorptive power of sand was also found to bear a general relation to the results of the soundness test The results of the proposed test have been correlated with the service records of pavements in New York State A number of concrete roads built between 1921 and 1931 with fine aggregate having a magnesium sulphate test loss of 20 per cent or more showed poor service records On the other hand, concrete pavements in which the fine aggregate showed losses of 17 per cent or less in this test have good service records

This paper is a discussion of the magnesium sulphate accelerated soundness test for the quality and durability of fine aggregates I shall attempt to show how and why this salt test is superior to the sodium sulphate soundness test, what our laboratory results mean in the light of field service records obtained with these aggregates, and finally what the future specification on aggregates will be

Several accelerated tests simulating weathering have been developed by various investigators, but no true laboratory measurement has been devised for determining the quality of concrete aggregates Inorganic salts such as sodium chloride, calcium chloride, sodium nitrate, and sodium sulphate have been tried but each has had its shortcoming because of chemical activity or physical inactivity As a result of our