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by Kentucky Rock Asphalt Co.

A Study of the Effect of Shape of Mineral Aggregate on Stability of Asphalt Paving Mixtures

By Victor Nicholson
Engineering Chemist, Department of Public Works,
Chicago, Ill.

The following paper was read by Mr. Victor Nicholson, at the Fifth Annual Asphalt Paving Conference, held at Washington, D. C., Nov. 8-12, 1926 and later published in Circular No. 43 of the Asphalt Association.

In reprinting the article we have emphasized Mr. Nicholson's findings and conclusions concerning Kentucky Rock Asphalt by setting the matter in *italics*.

While Lake Michigan has been the source of at least ninety per cent of the sand entering sheet asphalt pavements laid by the City of Chicago in the past, and ordinarily runs good, still there are times when this sand runs different, causing the rejection of this material owing to the fact that it does not pass grading as set forth in the specifications. It seems that the storms on the lake have a decided influence on the character of the sand taken from any particular spot in the lake, with the consequence that even though the sand is taken from the same spot, it varies from one shipment to another. The year 1926 was no exception to this rule. It is comparatively simple to reject the material, but it is not so easy to keep the plants running when all the sand is being condemned.

In order to improve the technique of the asphalt mixes when using this kind of sand and to test out new sources of supply, the city was prevailed upon to obtain the necessary apparatus to run stability tests soon after Hubbard published his first paper on the subject. The problem before us is so to modify our mix containing sand or other aggregate that we can keep our three asphalt plants going continuously without interruption. It is in connection with this problem that the present study was made and when a report is made on it the matter herein will be included.

In the opinion of the writer the question of the sharpness of mineral aggregate has always been shrouded in mystery, being condemned by some, favored by others and not mentioned at all by most writers. This is a most natural attitude to take, for no facilities have been available to study this effect until the various forms of apparatus had been designed for testing it.

> *Even though this matter for the most part has been ignored, the writer is led to believe that this has an important bearing on stability by the action of some rock asphalt pavements that have been laid by the street department of our city. Some of these have been down nearly three years and after close examination of them, none show signs of instability.*
>
> *This material, being a cold laid one, contains a soft asphalt with mineral matter that has a grading unlike any of our standard sheet asphalt mixes and a shape of particle that is different from lake sand.*

Bearing this in mind the writer decided to give this detail of asphalt pavement mixtures more careful study than had heretofore been given to it.

Types of Material Tested

In order to make results applicable to our needs as a city this study was restricted to types of material that could be obtained in Chicago without too much difficulty. Samples studied are as follows: (1) Sample of a friable sandstone given to the laboratory by a traveler through Ottawa, Ill. (2) Lake sand as delivered to the city asphalt plants by the Material Service Co. of Chicago. (3) *Mineral matter obtained by extracting bitumen from rock asphalt as furnished by the Kentucky Rock Asphalt Co.* (4) Crushed quartz passing a 10 mesh screen from the Wausau Abrasives Company quarry at Wausau, Wis. (5) Crushed granite or screenings finer than ¼ inch from the Waushara Granite Co. at Lohrville, Wis. The method used in making the tests was the same as Hubbard's modified method as given before the A. S. T. M. in 1926 with the following exceptions:

Testing Equipment

An Olsen 20,000 pound, hand-driven compression machine with 5,000 pound, indicating device was used instead of the machine used by Hubbard. The reason for doing this, was, that at the time the compression machine was ordered, it was intended for other compression tests in the laboratory as well as the stability tests. However, after running just a few stability tests on the regular machine, it became apparent that this type would not do for stability tests, so after considerable correspondence the manufacturers had the indicating device made and attached it to the machine in the laboratory. The indicating device consists of a four and one-half pound dial, spring scale that has been carefully calibrated by the manufacturers on the same type of compression machine as furnished to the city, to read in increments of 25 pounds to 500 pounds.

In running the compression machine to make the briquette the gear is turned at the uniform rate of a turn a second which lowers head at the rate of 1/32 of an inch, and in extruding the briquette, the load is applied at the rate of one revolution per second on the countershaft or 1/192 of an inch at the head. The latter speed is used to make the readings on the indicator easier to take. (See Fig. 1.)

Instead of storing the prepared briquettes in the room at ordinary temperatures it was found better to store samples in an air bath at a temperature maintained constantly from 75 to 79 deg. F. When comparing tests made in winter to tests made in summer of the same asphalt mixes there is a chance for variation in stabilities due to difference in air temperatures at those times. All this air bath consists of is a copper container with a hand hole and cover, inserted in a home-made electric constant temperature oven con-

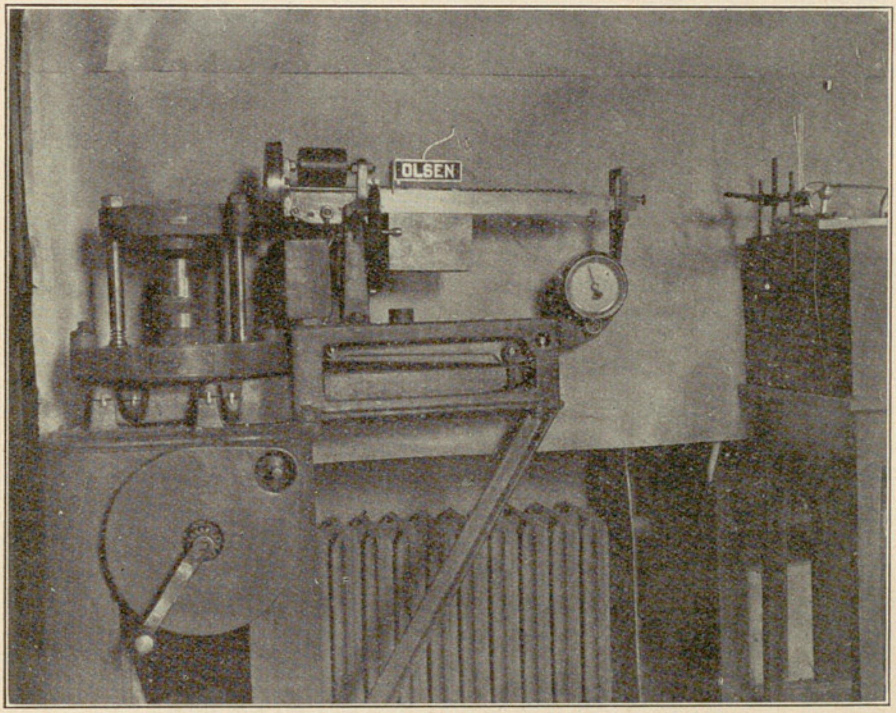


Figure 1
Photograph of Compression Machine showing indicator. Apparatus at right is constant temperature bath containing the air bath maintained at 77 deg. F.

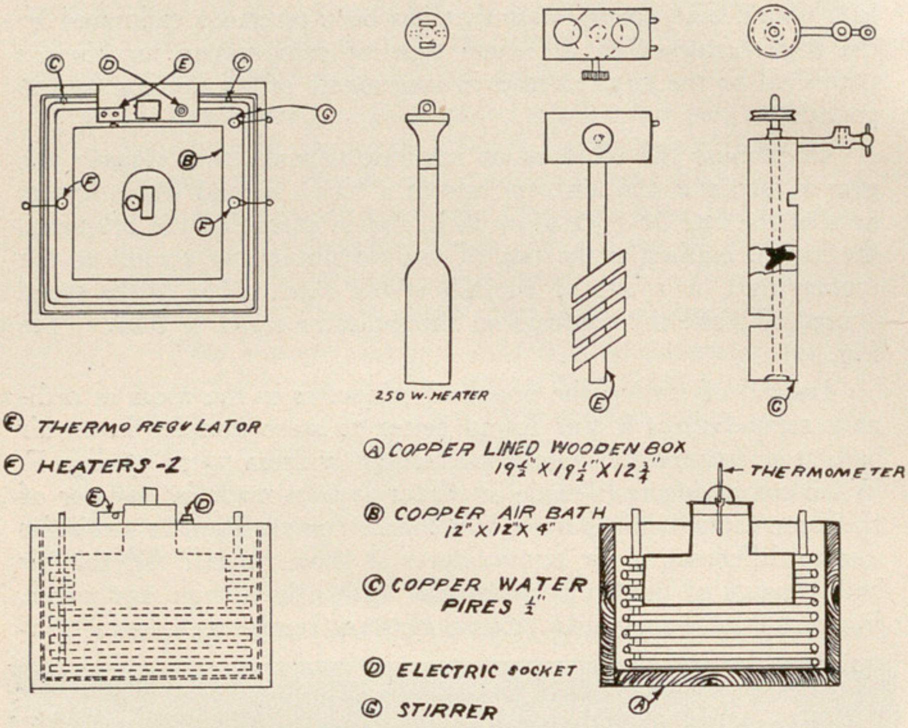


Fig. 2. Constant Temperature Air Bath.

structed according to the sketch. This can be made cheaper than to buy one already manufactured; it serves its purpose satisfactorily and, when not in use for the air bath, can be converted easily into a constant temperature bath for almost any temperature by simply removing the copper container and adding one or more electric heating units. (See Fig. 2.)

Testing Method Outlined

Instead of heating samples directly on the machine at sixty degrees C. according to Hubbard's method, these tests were run by heating the briquettes in a Cenco constant temperature apparatus at the same temperature for the prescribed sixty minutes, then transferring to the extrusion mold, which, together with the plunger, has been brought to the right temperature in water placed in a 50 pound white-lead pail, and then placing the pail with its contents under the head of the compression machine and applying the load as stated before. This is the only difference in method from that given by Hubbard and yields satisfactory results. All tests were made in triplicate, individual tests not varying over 5 per cent from the average and this average recorded as the stability of the mix.

Following are the tests, or physical characteristics, of the materials used in this test, the asphalt used throughout these tests being an oil asphalt that had the following characteristics:

Penetration at 77 deg. F.	42
“ “ 115 “ F.	160
“ “ 32 “ F.	15
“ after 5 hrs. 325 F.	36
Loss on heating, 5 hrs. 325 F.	.05%
Specific gravity at 60 deg. F.	1.04
Ductility at 77 deg. F.	115 ctm.
Solubility in CCl^4	99.68%

The filler used was a ground limestone dust furnished under our specifications. It had the following fineness:

Passing 200 mesh	82%
“ 100 “	96%

All aggregate was put through a 20 mesh sieve to make results comparable with each other. It happens that the Ottawa sandstone grain practically all passes a 20 mesh, *and the same condition exists with the mineral matter of Kentucky rock asphalt.* Crushed granite also contained considerable amounts of 200 mesh material, so far two series this was sieved out.

In order to make the sand compare with that obtained on contract last year, the lake sand was sieved into its various sizes and then recombined to give the gradings shown below:

GRADING OF SANDS

	200 mesh	80 on 200 mesh	40 on 80	20 on 40 m.
Lake Sand	0	35	55	10
Ottawa Sand	0	5	55	40
Crushed Granite	0	31	32	37
Crushed Quartz	2	15	37	46
Rock Asphalt (Mineral Matter)	4	15	66	15

By examining these grains under the microscope we found that lake sand is sharp in sizes smaller than 60 mesh but as the sizes get larger the sand becomes more round. Ottawa sand is almost completely round in all sizes. Quartz and granite are sharp and angular in all sizes. Surfaces of these materials show a marked difference, quartz being smooth and almost glassy, and granite almost completely rough. *Kentucky rock is sharp and angular in practically all sizes down to* 40 *mesh* when it seems to show some evidence of water wear.

Photo-micrographs of the various aggregates are shown in illustrations, series 1 to 5 inclusive. All photographs show a magnification thirteen times original.

On examining these figures it is shown that even though lake sand contains the least amount of voids the stability is by far the lowest. The results obtained from granite were rather surprising and the only explanation for them is the relatively rough and sharp surface grain. *The result given under rock asphalt explains in a large measure the reason for the stability of this type of pavement.*

In order to show the relative stability of the aggregates two sets of briquettes were made up, using the aggregates as given under the grading of sands, one plain and one with limestone dust. The one using 8 per cent of the asphalt with 92 per cent of the aggregate, shows results as given under Table 1.

Tests of Aggregate

The set of briquettes containing the limestone dust was made up using 8½ per cent of the asphalt with an aggregate of 91½ per cent composed of the material given under the gradings, to which enough stone dust had been added to make 20 per cent passing 200 mesh in the finished mix. Results obtained are given under Table 2.

Table 1.

TEST OF AGGREGATE

Everything coarser than 20 mesh taken out and no further addition of minerals put in.

	Lake Sand	Crushed Quartz	Crushed Granite	Rock Asp. Min. Matter
Voids in aggre.	34.7	37.4	38.1	34.7
% Asph. to fill	18	19.9	19.9	17.9
Ht. of Briquette ins.........	1 1/64	1 1/64		1
S. G. of Briquette	1.925	1.92		1.92
Lbs. Stability	408.	1512	1917	1750

Table II.

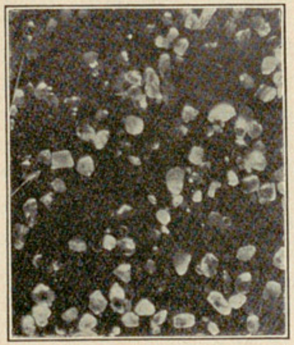
TEST OF AGGREGATE

With enough 200 mesh added to make 20% passing the 200 mesh.

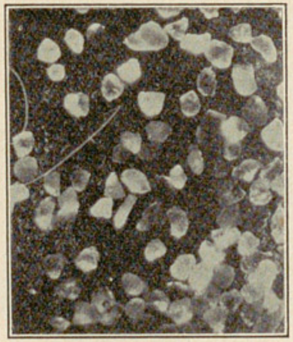
	Lake Sand	Crushed Quartz	Crushed Granite	Rock Asp. Min. Matter
Voids in aggre.	27.2	28.6	27.2	
% Asph. to fill	12.6	13.6	13.3	
Ht. of Briquette, ins.	⅞	57/64	59/64	⅞
S. G. of Briquette	2.28	2.20	2.10	2 216
Lbs. Stability	2150	2808	3383	4000

These results show the stabilizing influence of limestone dust, but at the same time they show the effect of using a rounded mineral aggregate. As before stated, under Table 1, lake sand even though it produces the densest mix, does not necessarily produce the most stable mix:

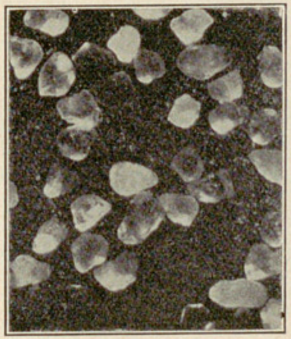
SERIES 1. LAKE SAND.



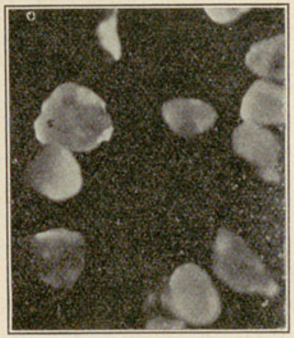
80 *Mesh and Finer.*



60 *on* 80 *Mesh.*



40 *on* 60 *Mesh.*



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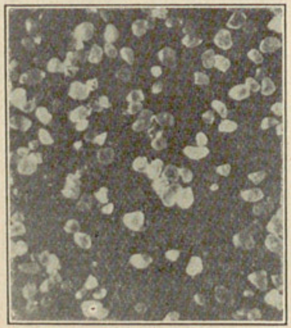
SERIES 2. OTTAWA SAND.



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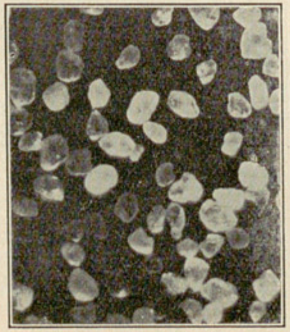
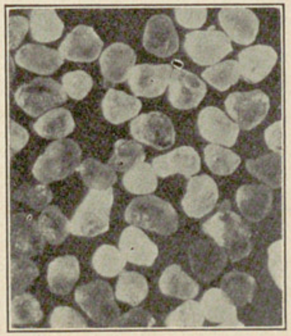
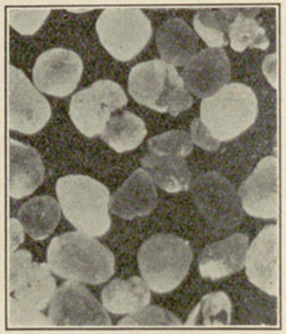


60 *on* 80 *Mesh.*

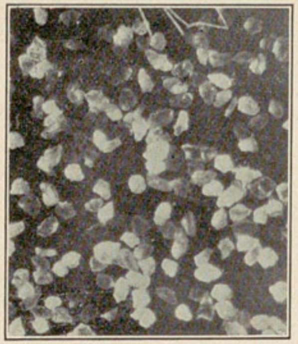


40 *on* 60 *Mesh.*

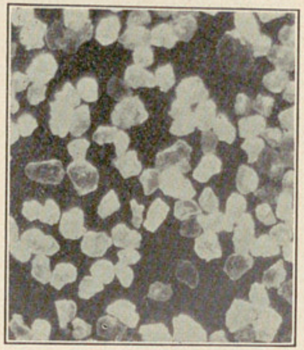


20 *on* 40 *Mesh.*

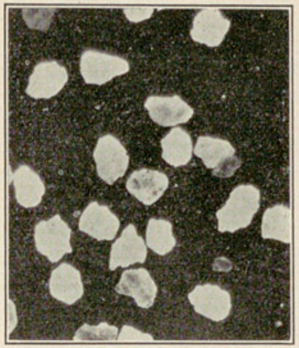
SERIES 3. CRUSHED GRANITE.



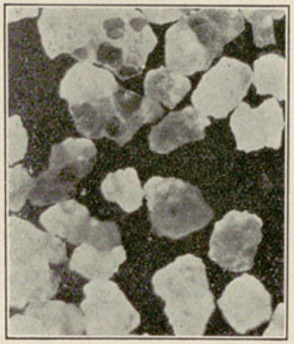
80 *Mesh and Finer.*



60 *on* 80 *Mesh.*

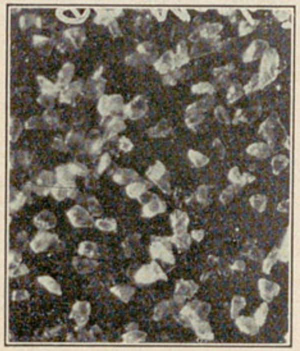


40 *on* 60 *Mesh.*



20 *on* 40 *Mesh.*

SERIES 4. CRUSHED QUARTZ.



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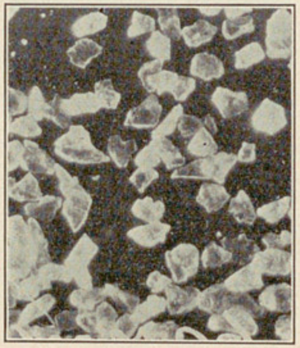
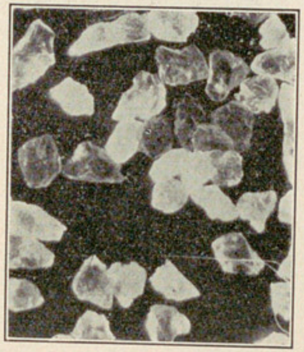
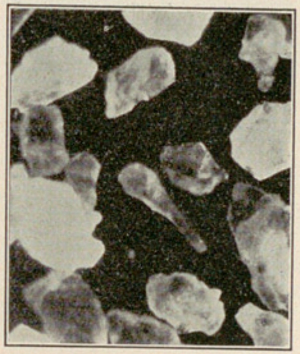


60 *on* 80 *Mesh.*

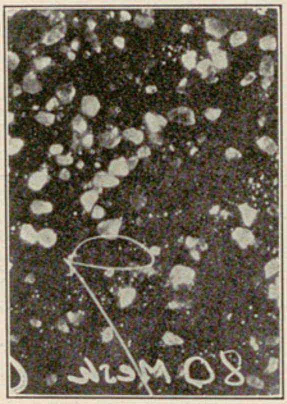


40 *on* 60 *Mesh.*



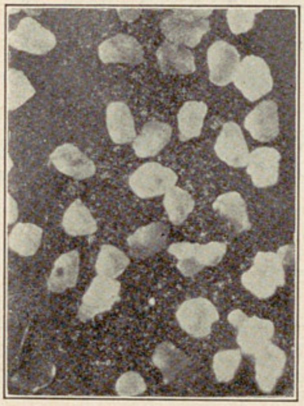
20 *on* 40 *Mesh.*

SERIES 5. KENTUCKY ROCK ASPHALT.

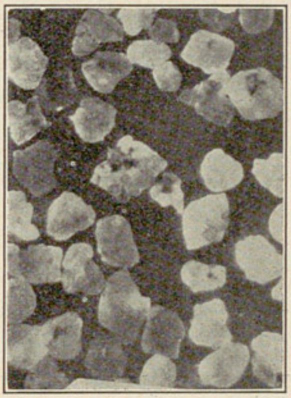


80 *Mesh and Finer.*

60 *on* 80 *Mesh.*



40 *on* 60 *Mesh.*



20 *on* 40 *Mesh.*

> *The extremely high stability given with rock asphalt mineral matter is surprising and should be the basis for further study.*

The reason for selecting the 8½—91½ per cent mix was based on Hubbard's results when working with increasing amounts of filler. The lower specific gravity on crushed granite is also something that has not been explained.

Two sets of briquettes were made up using the aggregate as before, but sieved and regarded to conform to the typical grading of the lake sand. As before, two seats were made up, one plain and the other with limestone dust. The series made up by using

8 per cent of the asphalt with 92 per cent of the mineral matter gave results as shown in Table 3.

TABLE III.

TEST OF AGGREGATE

Made of different materials but graded to standard mix.

	Lake Sand	Sand Stone	Crushed Quartz	Crushed Granite
Voids in aggre.	34.7		39.4	34.7
% Asph. to fill	18%		20.8%	18%
Ht. of Briquette	1 1/64″	1″	1 1/16″	1 1/16″
S. G. of Briquette	1.92	1.93	1.847	1.86
Lbs. Stability	408	175	1275	1708

This table includes the Ottawa sand, which could not be included in the other tests on account of lack of material. For the same reason, rock asphalt mineral matter had to be eliminated from this study. The striking feature of this test seems to be the denseness of the Ottawa and lake sand briquettes, and their low stability. The comparatively high specific gravity of sandstone grains seems to indicate that a well rounded grain packs better than a sharp one.

A set of briquettes containing the limestone dust was made up as before, in the proportion of 8½ per cent asphalt and 91½ per cent of aggregate composed of materials as given to which enough 200 mesh material had been added to make 20 per cent passing 200 mesh in the finished mix. Results of this test are given in Table 4.

TABLE IV.

TEST OF AGGREGATE

Graded to standard mix and adding enough 200 mesh to make 20% pass.

	Lake Sand	Crushed Quartz	Crushed Granite	Sand Stone
Voids in Agg.	27.2%	31.3%	30.6%	
% Asph. to fill	12.6%	15.5%	14.7%	
Ht. of Briquette	⅞″	15/16″	29/32″	⅞″
S. G. of Briquette	2.28	2.14	2.16	2.27
Lbs. Stability	2150	2558	3475	2500

These tests show again the stabilizing influence of the stone dust and that a sand with no inherent stability, as for example, the sandstone, by such treatment can be made suitable for pavement purposes. As before, crushed granite gives the highest stability, even though the specific gravity of the briquette is the lowest.

In order to show the relative stabilities of a given mesh size of any of the aggregates, briquettes were made up of material obtained by screening through a 20 mesh and retaining on a 30 mesh and mixing with the asphalt in the proportion of 6 per cent asphalt and 94 per cent sand. Results are given in Table 5.

TABLE V.

TEST OF AGGREGATE

Aggregates sieved to pass 20 mesh and be retained on 30 mesh.

	Lake Sand	Crushed Quartz	Crushed Granite	Standard Ottawa
Ht. of Briquette	1 1/32″	1 1/32″	1 1/32″	1 1/16″
S. G. of Briquette	1.87	1.89	1.90	1.87
Lbs. Stability	850	1525	1725	100

These results show that standard Ottawa sand, as compared to the others, has a negligible stability.

The higher stability of the lake sand as compared to that given in Table I *seems to indicate that a graded sand is not always the most stable.*

As before, granite gives the highest results.

Summing up, it can be said that sharpness of grain has a marked influence on the stability of the asphalt mix. This influence persists even after the addition of limestone dust. A sand lacking in stability can be greatly improved by the addition of 200 mesh material. *Relative stability is not dependent upon the density of the asphalt mix.*

A Study of American and European Rock Asphalts

By Victor Nicholson, Engineering Chemist, Department of Public Works, City of Chicago

The following paper was read by Mr. Victor Nicholson before the 33rd Convention of the American Society for Municipal Improvements, held at Dallas, Texas, November 14-18, 1927.

This article is reprinted from the year book of American Society for Municipal Improvements, Volume 33.

IT is about four and a half years ago that a sub-committee of the Chicago City Council made an extended trip through Europe studying the various types of pavements in use in the cities over there. On their return, the individual members of this committee were enthusiastic in their praise of European Rock Asphalt pavements, being especially pleased with the smoothness and easy riding qualities of same.

Having heard such glowing reports on this material in use, I determined at that time to make a rather careful research into the merits or defects in this pavement when the opportunity presented itself, but not having the necessary samples or equipment for testing same at that time, this study could not be made or written up until the present time.

Since the report of aforesaid committee was made I have found that in many localities in Europe the pavement wears badly, at the same time freeing a disagreeable dust, which in wet weather turns into a slimy mud causing great slipperiness on the surface of the road. During the last summer I have been told of transverse upheavals at intervals along the length of rock asphalt pavements laid in the City of Berlin, which leads me to believe that this pavement is effected with expansion troubles.

On account of the enthusiastic report on rock asphalt pavements by said committee and the prohibitive cost of European Rock Asphalt, it was decided by the Street Department of our City to try some American Rock Asphalt that same year. The type selected was a cold laid one from Kentucky and the result obtained in smoothness and comfort in riding from the resultant pavement were so satisfactory that many square yards of our streets have since then been resurfaced with this material. See photos 1 and 2. This material has also been used as a wearing surface material by the South and West Park Boards of this City. The famous outer drive in Grant Park in the downtown section of the City, which receives a very large amount of automobile traffic, has been surfaced with this material for a large part of its distance and is showing up very well after three years of use. See Photo No. 3. The West Park Board only this summer laid a large tonnage of this material on park driveways (See Photo No. 4, 5 and 6) and sidewalks, but being laid so recently it is a little early to judge results. The rock asphalt being a cold laid one has also been used by our Ward Repair Forces in cold-patching macadam, brick, concrete and even sheet asphalt strees, with results quite beneficial to the City.

Having used only * one kind of American Rock Asphalt it is only fair that all available ones from this country should be included in this study.

The big disadvantage of American Rock Asphalt Deposits is their great distance from the large centers of population, which adds to their cost and difficulty in delivery. On account of this remoteness it is not surprising that pavements made from this material have not received the attention given to other paving materials. With the development of waterways this seeming remoteness may be removed.

While cold-laid American Rock Asphalt as obtained from Kentucky, has been used intermittently since the year 1889, the results obtained with it in those early days were not always satisfactory. This is readily understood in view of our present knowledge in laying this material, for it is known that in order to produce best results, pavement after laying must be protected against narrow-tired, heavy loaded vehicles and standing horse traffic during the period necessary for the rock asphalt to reach its density, or else be kicked and rutted all out of shape. As this comprised practically all the traffic in those early days it is not surprising that no better results were obtained. In an attempt to get around this difficulty it was required in cities such as Buffalo to add sufficient asphalt to bring the bitumen content to 10%. This was further augmented by an addition of limestone dust, which of course, practically turned the rock asphalt into a sheet asphalt pavement. Tillson, in his book on street pavements and paving materials, recommends mixing German rock or Texas Rock Asphalt with the cold-laid material prior to laying, and while this probably would produce a good pavement still the author has seen many miles of road laid with cold-laid material, some of it in Chicago and some in other cities in perfect condition even after from four to fifteen years use. Texas Rock Asphalt to which a light asphaltic flux is added is laid cold and heavy traffic turned onto it immediately after laying.

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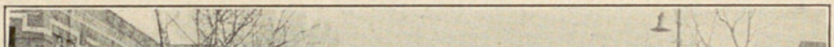
*Publisher's Note: The Kentucky Rock Asphalt referred to in this paragraph and elsewhere in this article, as being in use in Chicago, is the original KYROCK brand.

No. 1
Sacramento Blvd. Chicago, Ill.



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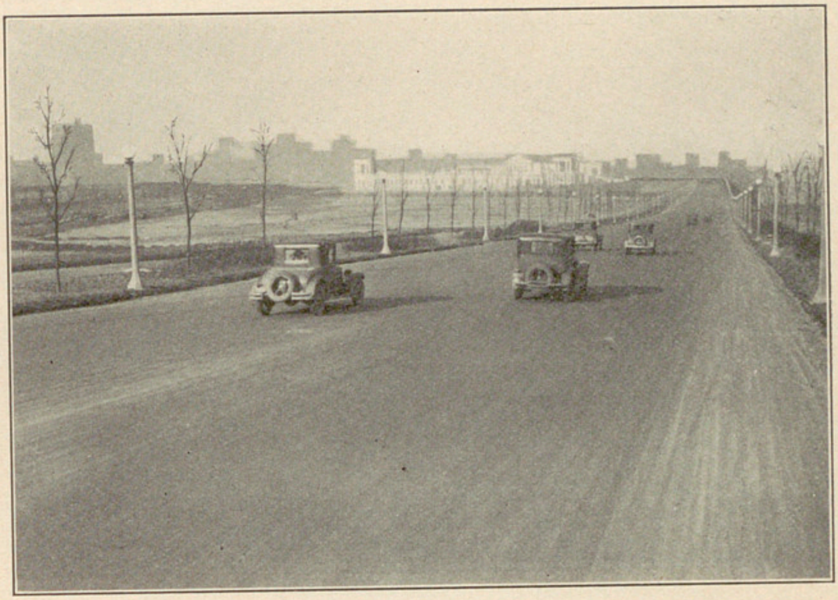


No. 3
Outer Drive, Chicago, Ill.

No. 4
Washington Blvd. Chicago, Ill.

No. 5
Logan Blvd. Chicago, Ill.

No. 6
Walkways, West Park, Chicago, Ill.

Hot laid American Rock Asphalt being laid like sheet asphalt does not require the same care in order to reach maximum density.

Rock Asphalt being a comparatively new material in the art of road building in this country, has but a meager bibliography of articles dealing with it. Most of the text books deal only slightly with it, Tillson devoting most space to it, so with the exceptions of this book and articles on testing by Prevost Hubbard and Chas. S. Reeves, the literature on this subject has almost entirely been neglected in the preparation of this paper.

In order to make this study as complete as possible the following samples of European Rock Asphalt were obtained from the following companies:

1-3 lb. sample of Seyssel (French) Asphalt Rock, from Mines D'Asphalt de Syssel, Pyrimont-Seyssel (Ain).
1-10 lb. slab of German Rock Asphalt pavement from the United Limmer and Vorwohle, Hamburg, Germany.
1-1 lb. sample of Val de Travers Asphalt Rock.
1-1 lb. sample of Val de Travers Asphalt pavement.
Both of the above from the Neuchatel Rock Asphalt Co. New York, N. Y.
1-2 lb. sample Sicilian Rock Asphalt, Sicilian Rock Asphalt Co., N. Y.

The following cold-laid rock asphalts were obtained:
No. 1 from Bear Creek Deposit, Edmonson Co., Ky.
No. 2 from Hardinsburg, Breckinridge Co., Ky.
No. 3 from Green River Deposit, Edmonson Co., Ky.
No. 4 from Nolin River Deposit, Edmonson Co., Ky.

The following hot-laid American Rock Asphalts:
No. 5 from Cline, Texas.
No. 6 from Muscle Shoals, Ala.
No. 7 from California, exact location unknown.

The following American bituminous minerals which have been suggested for use as paving materials:
No. 8 1-20 lb. sample of asphalt rock from Arkansas, exact location unknown.
No. 9 A small very soft sample from Western Canada.
No. 10 A small sample from Pike Co., Arkansas.

It will be well in this connection to give the method used in the laying of the various substances used in this study. According to Tillson, European Rock Asphalt is shipped in its raw state to the cities using it, where it is crushed up to a fine powder by passing through disintegrators and sieving. The powder is then heated in a revolving cylinder at a temperature of from 250 to 280 degrees F., hauled to the job in covered wagons and spread to a depth of two to three inches without the use of a binder. Then it is given a light rolling sufficient to stand the weight of the men who then ram the pavements with hot heavy rams or tampers, and finally rolled with a ten-ton roller. Tillson in his book remarks that the pavement loses in thickness but not in weight for a period of years. Very evidently the pavement gains in density during this period. According to all the information I have been able to obtain, no carpet coat is used with European Rock Asphalt.

American hot-laid rock asphalt as used in Texas is laid in much the same manner as the above, the rock requiring crushing at the point of use, when the powder is heated to a temperature between 280 and 330 degrees F., accompained by an addition of enough flux to bring the penetration of the contained asphalt to between 20 to 50 penetration, the exact penetration being determined by climatic conditions. The hot rock asphalt is then hauled to the job and spread raked and rolled like ordinary sheet asphalt.

Cold laid rock asphalt as obtained from Kentucky and laid in Chicago is laid on the cold surface which has been treated with either cut back or hot-applied asphalt. In using cut-back asphalt it is necessary to have the solvent evaporate before the application of the rock asphalt. The cold laid rock asphalt is dumped on the street, shoveled into place and raked out to be as nearly free from lumps as possible, when it is rolled sufficiently to stand the weight of a man. Pavement then reaches its true density on the application of the traffic. The time taken for the pavement to reach this density will vary with the amount of the traffic using the pavement and the temperature and dryness of the weather. This settling period is thus a very important part in the laying of rock asphalt and precautions, as stated before should be strictly observed. Being comparatively unstable during this period it is easily seen that it is absolutely necessary to have a fairly rigid foundation or the wearing surface will be badly damaged even before it has reached its density. A pavement lacking this traffic during the period of reaching its density will harden before the voids have reached a minimum, thus causing an open surface which will not weather well. It is during this initial period that this pavement reaches the smoothness, characteristic of this type.

Rock asphalts like other asphalt paving mixtures, are composed of mineral aggregates with more or less fluid bitumen, so the tests outlined consists of a study of the rock asphalts as delivered and laid and then a study of its components. This involves an extraction with a suitable solvent and a study of the recovered bitumens and mineral matters.

It is fortunate for this study that during the last few years an admirable test for the determination of the stability of aggregates has been developed by which the actual load required to displace the pavement at any desired temperature can be determined.

Some of the rock asphalt wearing surface becoming actually stone-like in hardness, it was thought desirable to include a study of the matter of toughness. This test assumes an added importance in view of the conclusions of Prevost Hubbard and F. H. Jackson in their paper on "The Relation Between the Properties of Hardness and Toughness of Road Building Rock" where they show that the percentage of wear bears a certain definite relation to the toughness or impact value of the aggregate. Chas. S. Reeve and Richard H. Lewis in their Bulletin on the "Toughness of Bituminous Aggregates" show that aggregates in themselves possessing slight toughness can by compression with a suitable binder in proper amount attain more toughness than a much tougher aggregate with the same amount of bitumen.

As shown by the author in his paper as read before the 1926 meeting of the Asphalt Association on "The effect of the Shape on the Stability of Aggregates" a microscopic study of the mineral matter is very important.

All the rock asphalts were crushed to make them pass a 10 mesh sieve in order to make results comparative. This procedure, while a little bit severe on some rock asphalts such as hot applied rock asphalt No. 5, is that which has been specified by some American Engineering Societies for this type of material.

In grading the asphalt, 25 grams were extracted with cold carbon disulphide and graded according to the standard method.

All large extractions were made in a Dulin Rotarex using 500 grams of the rock asphalt with not over five portions of 300 cc each thiophene free benzol. The last extraction in every case came out clear. This follows the procedure as described by Abraham in his book on Asphalt where he shows that carbon disulphide, the ordinary solvent, reacts with the asphalt.

In order to recover the bitumen, the extract was filtered in a six-inch glass funnel into three 500 cc. Florence flasks, papers washed clean with benzol and burnt. The remaining mineral matter was then added to that in the dish of the Rotarex. At the same time most of the benzol was distilled off and residue in flasks then poured and washed into weighed 8 oz. Deep Gill style tin cans. After the contained mixture was brought down as far as it would go over a steam bath, the can and its contents was put on a hot plate and brought up to a temperature of 325 degrees F. when a match was applied which ignited all the remaining benzol. While it seems to be a rather simple test I found it impossible to check myself on the consistencies of the residues of two successive extractions of the same material, so did not attempt to determine the consistency at that time but let all the residues accumulate and only determined the consistency before and after the heating loss at five hours at 325 degrees F. I have been told that this matter was taken up at the last meeting of the A. S. T. M. at West Baden where a good deal of dissatisfaction was expressed.

The extracted bitumen was tested for its specific gravity and heat loss at five hours at 325 degrees F. The mineral matter was then submitted to such tests as microscopic study, grading, specific gravity, stability and impact.

Knowing the specific gravity of the mineral aggregate and the bitumen entering into the rock asphalt it is possible by means of a simple calculation to determine the percentage of voids in any given briquette by running a specific gravity on the same.

The specific gravity of the mineral matter was determined by using a brass Hubbard specific gravity bottle and kerosene at 77 degrees F.

Stability was determined using the Hubbard method with a special tamping device newly designed, according to Illustration No. 1, and a regular Olsen 20,000 lb. compression machine equipped with an indicating device, as described in my paper before mentioned. See Illustration 2. It is generally recognized that the tamping part of making briquettes is one of the most important sources for error in this determination, so it is in order to eliminate it that this device was made. All it consists of is a weighed plunger, the bottom part of which corresponds in measurement to that given by Hubbard, working through a brass bearing and connected at its upper end with a rope by which it can be lifted and dropped. In making the briquette the forming mold is placed beneath the plunger together with its contained asphalt mixture, when the briquette is made by dropping and raising the plunger the required number of times. Briquettes so tamped are then compressed still further under a total pressure of 9425 lbs. or 3000 lbs. to the square inch. These are then stored in an air bath over night and stability run after maintaining a temperature of 140 degrees F. for one hour previous to and during the test.

Reeves and Lewis in their study using the impact test on bituminous aggregates, used a standard Paige impact machine but not the standard hammer, using instead of the specified 2 kilogram hammer one which weighed only 500 grams. The results therefore, are not standard but only relative. On attempting to use the standard 25x25 millimeter briquette in the Paige machine equipped with the standard 2 kilogram hammer, I found results very unsatisfactory so instead of using this size briquette I made up the regular stability briquette two inches in diameter and one inch high and broke these under the machine. Results obtained thereby and included herein are therefore not standard, but show how one rock asphalt acts under this test in comparison with the others.

It has been noticed that water in rock asphalt retards the setting time of cold laid rock asphalt, so determined this by weighing out fifty grams in a 3 oz. can and drying in an oven at 212 degrees F.

In order to show the relatve action under heat this same sample was then submitted to a temperature of 325 degrees F for five hours.

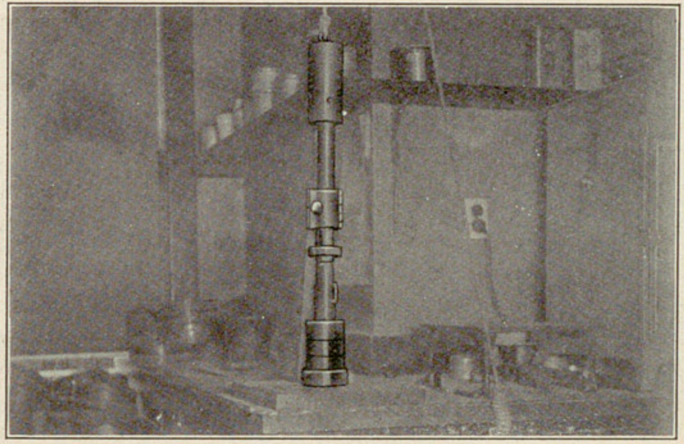


Illustration 1. Tamping Device.

This is a very severe test on the bitumen, for the bitumen coating the mineral matter as it does, is present in very thin films, exposing great areas of bitumen to the action of the heat. An ordinary sheet asphalt mixture under the same test becomes so hard as to make it impossible to remove sample from the can at cold temperatures. The mineral matter being inert, whatever loss occurs is due to the bitumen, so by figuring the amount of bitumen in the sample from the analysis of the mixture it is possible to figure the heat loss which the asphalt suffers in this test.

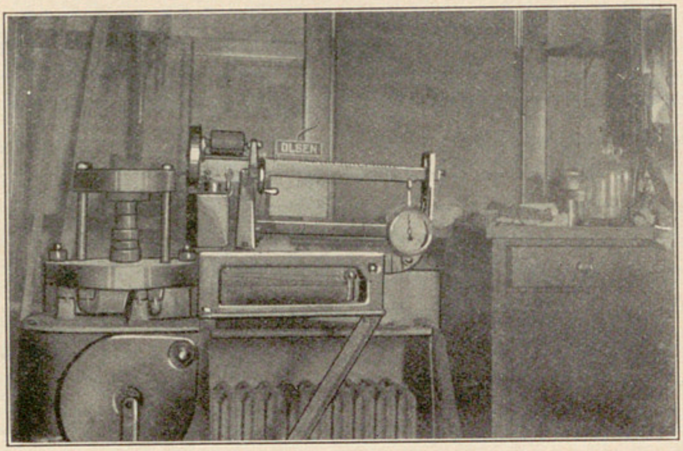


Illustration 2. Compression Machine With Indicating Dial.

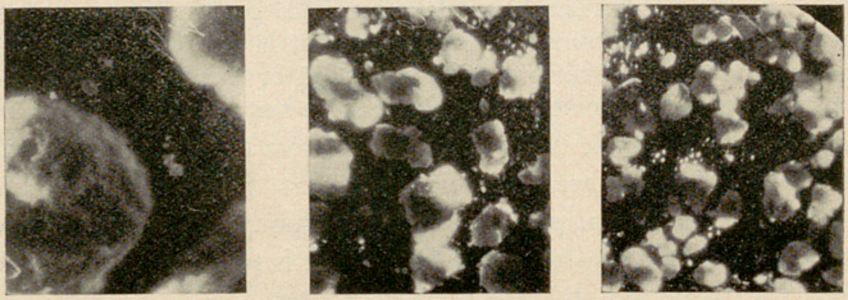
A description of the appearance of the samples under the microscope, will help in understanding the photomicrographs attached herewith. Photomicrographs on material finer than 20 mesh are not included.

Seyssel asphalt in all meshes presents a beautiful crystalline irregular surface looking very much like sugar, as it appears to the naked eye.

Seyssel Rock Asphalt—Mineral Matter

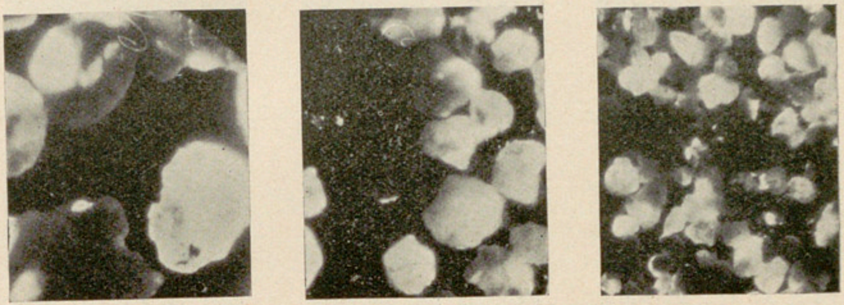
Pass. 20 *ret.* 40 *mesh.* *Pass.* 40 *ret.* 80 *mesh.* *Pass.* 80 *ret.* 200 *mesh.*

Sicilian Rock Asphalt—Mineral Matter.



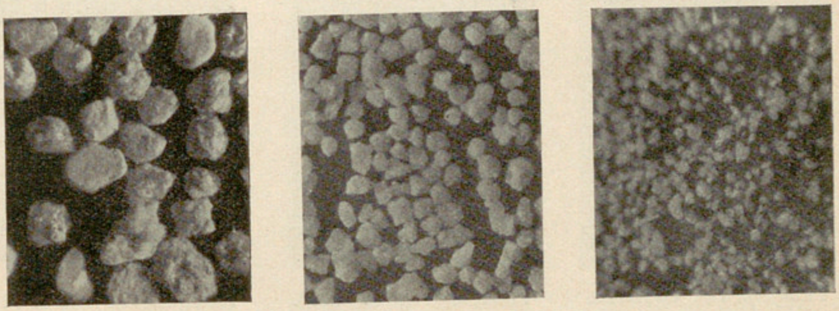
Pass. 20 *ret.* 40 *mesh.* *Pass.* 40 *ret.* 80 *mesh.* *Pass.* 80 *ret.* 200 *mesh.*

German Rock Asphalt
Mineral Matter.



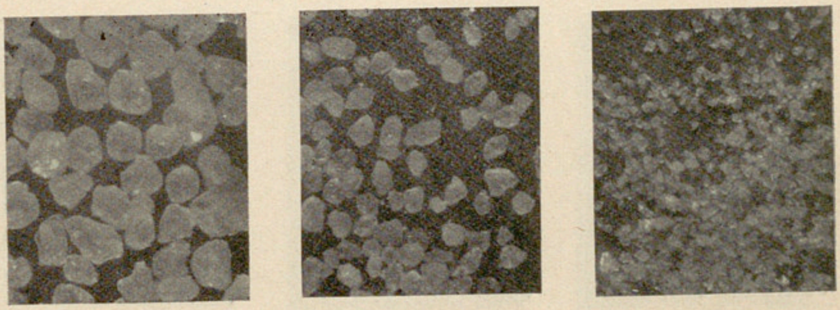
Pass. 20 *ret.* 40 *mesh.* *Pass.* 40 *ret.* 80 *mesh.* *Pass.* 80 *ret.* 200 *mesh.*

Val de Travers Rock Asphalt
Mineral Matter.



Pass. 20 *ret.* 40 *mesh.* *Pass.* 40 *ret.* 80 *mesh.* *Pass.* 80 *ret.* 200 *mesh.*

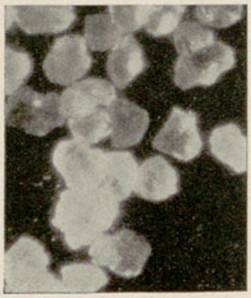
Cold Laid American Rock No. I

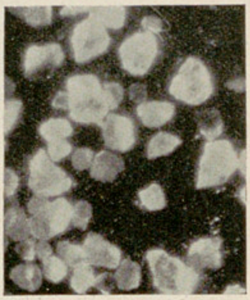


Pass. 20 *ret.* 40 *mesh.* *Pass.* 40 *ret.* 80 *mesh.* *Pass.* 80 *ret.* 200 *mesh.*

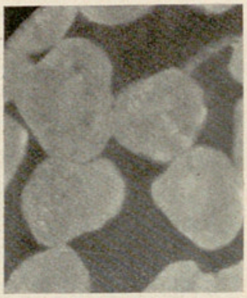
Cold Laid American Rock No. 2


Pass. 20 *ret.* 40 *mesh.*


Pass. 40 *ret.* 80 *mesh.*


Pass. 80 *ret.* 200 *mesh.*

Cold Laid American Rock No. 3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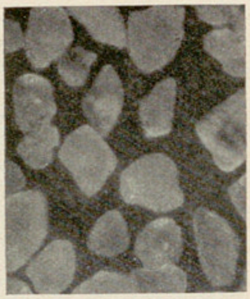
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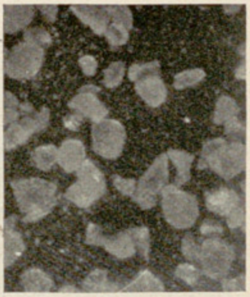
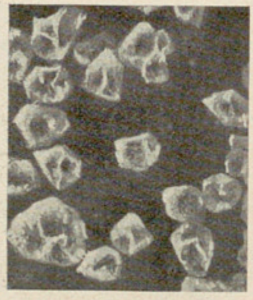

Pass. 80 *ret.* 200 *mesh.*

American Cold Laid No. 4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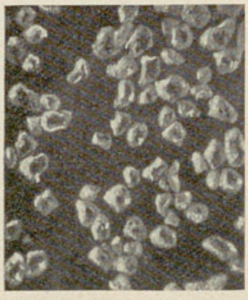
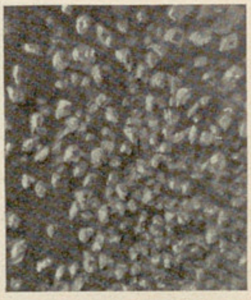
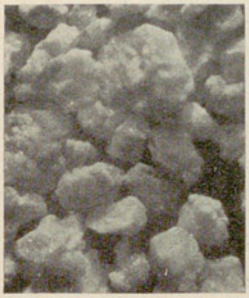
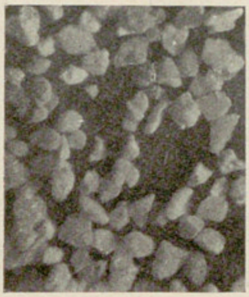
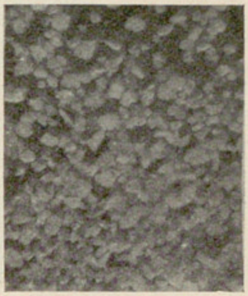

Pass. 40 *ret.* 80 *mesh.*


Pass. 80 *ret.* 200 *mesh.*

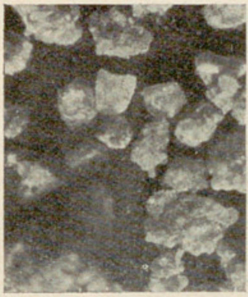
American Hot Laid No. 5

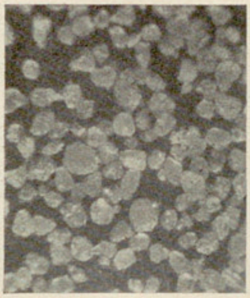

Pass. 20 *ret.* 40 *mesh.*

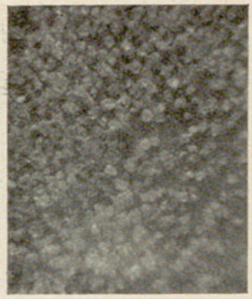

Pass. 40 *ret.* 80 *mesh.*


Pass. 80 *ret.* 200 *mesh.*

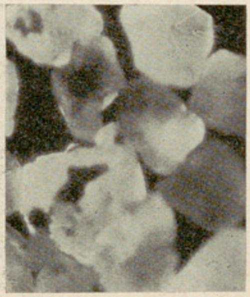
American Hot Laid No. 6


Pass. 20 *ret.* 40 *mesh.*


Pass. 40 *ret.* 80 *mesh.*


Pass. 80 *ret.* 200 *mesh.*

Hot Laid Asphalt No. 7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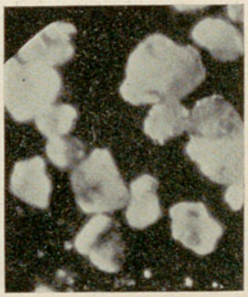
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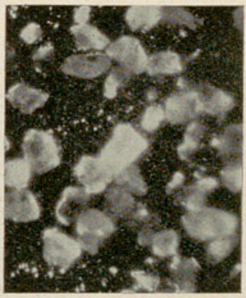
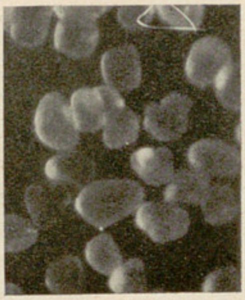
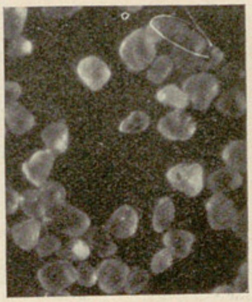
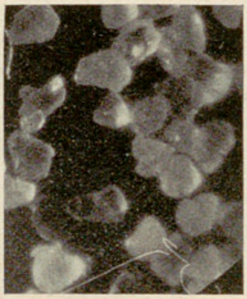

Pass. 80 *ret.* 200 *mesh.*

Asphalt 8


Pass. 40 *ret.* 80 *mesh.*


Pass. 80 *ret.* 200 *mesh.*

Asphalt 9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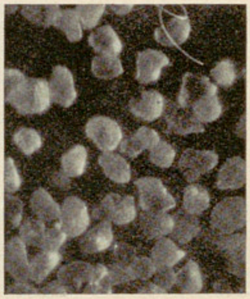
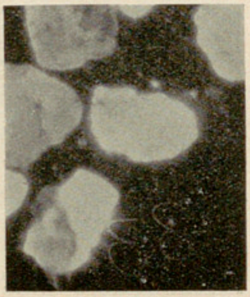
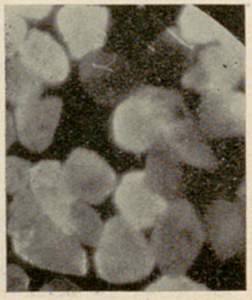
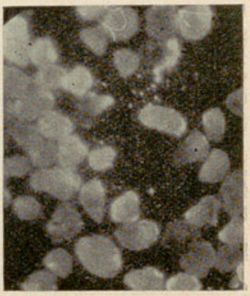

Pass. 80 *ret.* 200 *mesh.*

Asphalt No. 10


Pass. 20 *ret.* 40 *mesh.*


Pass. 40 *ret.* 80 *mesh.*


Pass. 80 *ret.* 200 *mesh.*

Sicilian asphalt presents an irregular surface that looks more or less porous. Looks like pumice stone.

German Rock Asphalt having been given to me in the form of a slab of pavement, had been compressed, so looked especially close for rounded particles—the only ones found were a few in the 80-200 mesh size, all the rest were angular almost cubical in size with roughened surfaces. Some of the grains looked kind of porous.

Val de Travers in sizes up to forty mesh seemed to be agglomerations of finer crystals. These crystals were sharp with roughened surfaces.

On account of the opacity of the limestone entering European rock asphalt it was impossible to get micrographs in such a way as to show distinctly the character of the grain.

Cold Laid Rock Asphalt No. 1 shows a shape of grain which is almost cubical, but showing some wear in sizes even up to eighty mesh. Coarse grains are massive and not composed of smaller ones.

Cold laid rock asphalt No. 2 is characterized by being composed of small grains agglomerated together in the 20 to 40 mesh sizes, the smaller sizes appearing in just about the same shape as that shown in No. 1.

Cold Laid Rock Asphalt No. 3 has just about the same characteristics as No. 1 but a little more rounded.

American Cold Laid No. 4 shows a shape with about the same general characteristics as No. 1 but somewhat sharper. There seems to be a little pyrites in some of the coarser grains. All grains are more or less cubical with roughened surfaces, and edges of same do not show much wear.

American hot Laid No. 5 shows a grain in coarse sizes made up of more or less porous particles, shape is entirely crystalline with beautiful texture.

American Hot Laid No. 6 in the coarse sizes shows aggregations of fine grains into one mass to make this size, shape of smaller grains seem to be alright being about the same as those in cold laid No. 4.

Hot laid asphalt No. 7 is an irregular shaped sand with roughened surfaces.

Rock asphalt No. 8 was round in all sizes.

Rock asphalt No. 9 was considerably rounded in the 40 to 80 mesh size.

Rock asphalts as given under 8 and 9 showed practically no stability.

American Rock Asphalt No. 10 in the 20 to 40 mesh size is slightly rounded cube like in shape whereas all the finer sizes are sharp.

Tables 1, 2 and 3 give the results in using European Rock Asphalt.

Table 1.
GRADING AND ANALYSIS OF EUROPEAN ROCK ASPHALT

Kind	Seyssel Rock	Sicilian Rock	German Rk. Asp. Pavem't.	Valde Travers P.
Color	Black	Lt. Brown	Brown	Brown
Specific Gravity	2.155	1.8255	2.156	2.2003
Loss 1 Hour at 212°F	.56%	.22%	.16%	.12%
GRADINGS				
Passing 200 Mesh	66.04	34.00	44.04	65.36
Passing 80 M Retained 200	11.88	24.88	25.96	12.08
Passing 40 M Retained 80	7 88	11.64	16.00	8.52
Passing 20 M Retained 40	2.48	12.48	2.32	4.68
Passing 10 M Retained 20	.52	8.28	.60	1.20
Per Cent Bitumen	11.20	8.72	11.08	8.16
Total	100%	100%	100%	100%
Character of Mineral Matter	White Limestone	White Limestone	White Limestone	White Limestone
Spec. Grav. Mineral Matter	2.68	2.563	2.615	2 69
Loss 5 hrs. 325° Rock Asphalt%	.56	.36	.42	.40
Loss Based on Bitumen%	5.00	4.13	3.75	4.76
Spec. Grav. of Recovered Asp.	1.023		1.023	
Consistency Before Heating	212 N. P.		3 Min. 5 Sec. Float @ 122°	
Loss on Htg. Bitumen @ 325°	2.56%		.70%	
Consistency After Heating	120 Pen		4 Min. 45 Sec. Float @ 122° F	
Loss in Cons. After Heating	41.7%		1 Min. 40 Sec. Float @ 122° F	
Duct. of Bitumen After 5 Hrs. 325°F	115 CTM		115 CTM.	

The results of gradings show that this class of pavements is different from anything we prepare in this country for the same purpose having such a preponderance of two hundred mesh material and no grading of coarser material to talk of. The low specific gravity of the sicilian rock is no doubt due to its porous structure as pointed out in the microscopic study. The high loss at two hundred and twelve as shown by the Seyssel Asphalt while it may be due to a loss in the asphalt content is probably due to water of constitution in the rock itself.

The results of the examination of the bitumens extracted show that while these have a relatively high heating loss both in the stone and in the extract both losses come well within the mark as set forth for soft asphaltic materials in modern asphalt specifications. It is safe to say that these bitumens are much softer than any used in this country for sheet asphalt purposes, being highly ductile in nature and showing a satisfactory loss in penetration after heating.

Table 2.

TESTS ON EUROPEAN ROCK ASPHALT PAVEMENTS

Kind	German	Valde Travers
BRIQUETTES CUT FROM PAVEMENT		
Theoretical Density	2.240	2.375
Density of Briquette	2.099	2.147
Voids in Pavement	5.8%	9.60%
Lbs. Stability	4050	3600
BRIQUETTES MADE FROM CRUSHED AND REHEATED PAVEMENTS		
Theoretical Density	2.240	2.375
Density of Briquette	2.240	2.277
Voids in Briquette	None	4.12%
Lbs. Stability	5400+	5400+
Impact	45	10
BRIQUETTES MADE FROM EXTRACTED MINERAL MATTER AND ASPHALT		
Per Cent Asphalt Used	10.7%	
Theoretical Density	2.256	
Density of Briquette	2.216	
Voids in Briquette	1.77%	
Lbs. Stability	3450	

The results on the Rock Asphalt Pavements show that in cutting the core through the pavement the structure is somewhat disturbed as shown in the lower density of briquettes as compared to those in Table 1. This effects both the voids and the stability, the voids being lower than shown and the stability somewhat between that shown under caption "Briquettes cut from pavement," and "Caption Briquettes made from crushed and reheated pavement." Results under the second caption show that pavement as laid had not reached maximum density and neither had it reached its maximum stability. The Impact tests shown here indicate that this property is independent of stability and that it varies widely between asphalts. If Hubbards relation is true as mentioned some while back the Val de Travers Asphalt will not wear as well as the German Rock Asphalt. I might say in this connection that these two stability values could not be determined exactly as my machine only registered as far as the figure noted and the briquette was still not completely extruded. On making the briquettes from extracted German Rock mineral matter and oil asphalt of 42 penetration and 1.05 sp. gr. it was impossible to reach the stability value as determined on the reheated rock asphalt pavement. This is undoubtedly due to the greater lubricating action of the softer asphalt present in the original rock asphalt.

Results as given in Table 3 are interesting showing such wide differences in results. The briquettes made from the Seyssel Rock asphalt showed that there was too much asphalt present, more than was required to fill the voids, consequently the stability was very low as is usual with this condition. The voids thus could not be determined in the usual way, as part of the originally contained asphalt had been extruded in the mold. The high result given by the Sicilian Rock asphalt is remarkable, and is probably due to the greater adherence of the particles to each other caused by the porosity of the grain. The briquettes made from extracted Seyssel and asphalt show that while as high results have not been reached as in the case with some other aggregates still it is high enough to make a good pavement. All the impacts given in this table are about the same so all should wear about equally well.

Table 3.

TESTS ON CRUSHED EUROPEAN ROCK ASPHALT

Kind	Briquettes Made From Crushed Rock		Made From Ext. Mineral & 11% Asp.
	Seyssel	Sicilian	Seyssel
Theoretical Density		2.271	2.289
Density of Briquette	2.225	1.983	2.253
Voids in Briquette		12.7%	1.57%
Lbs. Stability	566	4533	2200
Impact	30	27	30

Summarizing on the European Rock asphalts we can say that they are composed of a fine high stability limestone aggregate mixed with a much softer asphalt than we have been accustomed to using, which seems to be asphaltic in nature, showing high ductility and coming well within the standard specifications for loss on heating at five hours at three hundred and twenty five degrees and loss in consistency but not all showing the same resistance to impact.

Table No. 4 give the gradings and analysis of American Cold Laid Rock Asphalts.

Table No. 4
GRADINGS AND ANALYSES OF COLD LAID ROCK ASPHALTS FROM KENTUCKY

GRADINGS				
No.	1	2	3	4
Passing 200 Mesh	7.80	12.76	5.32	10.44
Passing 80 M Retained 200 M	9.72	48.08	8.16	11.40
Passing 40 M Retained 80 M	58.60	30.40	44.04	64.76
Passing 20 M Retained 40 M	14.80	1.20	26.76	5.60
Passing 10 M Retained 20 M	2.16	1.20	9.20	1.28
Bitumen	6.92	6.36	6.52	6.52
Total	100.00	100.00	100.00	100.00
Character of Ext. Min. Matter	White Silica	White Silica	White Silica	White Silica
Specific Gravity Mineral Matter	2.65	2.642	2.66	2.665
HEAT TESTS ON ROCK ASPHALTS				
Loss 1 Hour At 212°F.	.16%	.32%	.18%	.04%
Loss 5 Hours At 325°F.	.42%	.56%	.46%	.54%
Loss 5 Hours @ 325°F Based On Bitumen	6.77%	9.33%	7.08%	8.31%
CHARACTERISTICS OF RECOVERED BITUMEN				
Specific Gravity Of Asphalt		1.017	1.028	1.025
Consistency		2 Min. 54 Sec.	155° Pen 77°F.	1 Min. 50 Sec.
Loss On Heating Bitumen 5 Hours 325°		2.17%	2.08%	3.90%
Consistency After Heating		3 Min. 52 Sec. Float Test	78	3 Min. 38 Sec. Float Test
Loss In Consistency		58 Sec. Float Test	50%	1 Min. 48 Sec. Float Test
Ductility Of Residue		115 CTM.	115 CTM.	115 CTM.

These do not seem to be similar to each other, none seem to correspond to any standard grading for sheet asphalt and all show a lower percentage of bitumen than any used in sheet asphalt work. All seem to show about the same specific gravity of mineral matter and all of course are composed of silica.

None of this class seem to show a high loss on heating at 212° F but all of them show a considerable higher loss at 325° F. when based on the bitumen. The bitumen seems to be of low specific gravity probably because a little softer than European asphalt but the heat loss and penetration loss after 5 hrs. 325° on extracted bitumen still comes within the recognized limits for a good fluid asphalt. In common with the European Rock bitumen it shows plenty of ductility even after heating at 5 hrs. at 325° F.

During the summer I had run stabilities of cores cut from some pavements laid with Cold laid material with results as shown in Table 5.

Table 5
TESTS OF BRIQUETTES CORED FROM ROCK ASPH. PAVEMENTS AT DIFF. TIMES

Locations	Date Laid	Density	Stability
Garfield Pk. South End	9-3-27	1.792	25 lbs.
Garfield Pk. Band Stand	7-4-27	1.92	162 lbs.
Waveland at Clark Street	8-1-25	2.008	725 lbs.
West 13th St. And Karlov	9-1-24	2.044	1250 lbs.

It is very evident from an examination of this table that cold laid rock asphalt has a low density and stability as newly laid, both of which increase with the age of the pavement.

Bearing this in mind the following set of briquettes were made up to show the temperature at compression in its relation to density and stability.

Table 6.
ROCK ASPHALT FROM KENTUCKY

Relation of Temperature at Compression to Stability And Density

Temp.	70		120		140		170		200		225	
Briquette	1	2	1	2	1	2	1	2	1	2	1	2
Density	1.894	1.908	1.973	1.97	2.0158	2.0186	2.0193	2.0062	2.0157	2.0323	1.9934	2.0329
Stability	525	600	1075	975	1325	1225	1325	1225	1250	1375	850	1250

This table shows that while the stability increases with increasing temperature the density also increases which of course means that the voids decrease. Applying this table to our study it is seen that while briquettes made below 170 deg. F. check quite closely on density and satisfactorily on the stability, the results above this temperature become more erratic one briquette giving high results, its mate at the same temperature giving lower results so for the briquettes on cold laid rock the temperature of 160 deg. F. was adopted as that at which maximum density occurs. The reason for these erratic results at higher temperatures is that the asphalt sticks to the plunger in the same manner that a roller does on an asphalt pavement which is too hot, so instead of applying pressure the action of the plunger is to suck the particles apart. In order to duplicate conditions as close as possible as they are on the street, briquettes of cold laid asphalt were made at room temperature, the temperature of maximum density or 160 deg. Fahr. and then after the rock asphalt had hardened some by heating sample to 325 F. for 1 hour making the briquettes at 225 F. Another set was made up using the extracted mineral matter with 6½% of the regular 42 pen asphalt after mixing at 325 F. and compression at 275 F. This amount of asphalt was determined on after the following set of briquettes had been studied.

Table 7.

EFFECT OF VARYING AMOUNT OF ASPHALT ADDED TO MINERAL MATTER FROM ROCK ASPHALT

% Asphalt Added	5	5½	6	6½	7	7½	8
Average Density	1.864	1.928	1.932	1.935	1.960	1.972	1.987
Average Stability	800	900	800	800	750	687	600
Average Impact	13	20	23	23	23	24	30

The above briquettes were made using a mixture of the extracted bitumens which had a float test of 4 minutes and 25 seconds at 122 degrees F. This follows the work of Reeves and Lewis in using the impact. Study again shows that stability and impact do not seem to bear any relation to each other. It is rather astonishing that the 5½% bitumen seems to give the highest stability but it is undoubtedly true. Using a larger briquette than that used by either Lewis and Reeves or the standard method for impact, it is my opinion that results above 7% are incorrect as the sphere on impact machine sank into the briquette considerably before the impact break took place. 6½% was adopted as the ideal percentage because it gave highest impact without squeezing, highest stability and then came nearer the average of bitumen contents for the rock asphalts studied than any other proportion.

Results of tests of briquettes made to embody all the results of the preliminary study on this matter are given in Table 8.

Table 8.

TESTS OF COLD LAID ASPHALTS FROM KENTUCKY

BRIQUETTES MADE AT 70°F

No.	1	2	3	4
Theoretical Density	*2 388	2.412	2.405	2.413
Density of Briquette	1.905	1.897	1.894	1.901
Voids in Briquette	20.2%	21.35%	21.24%	21.22%
Pounds Stability	533	525	325	562

BRIQUETTES MADE AT 160°F

Theoretical Density	2.338	2.412	2.405	2.413
Density of Briquette	1.994	1.979	2.005	2.0185
Voids in Briquette	16.3%	17.95%	16.63%	16.35%
Pounds Stability	1116	875	813	1275
Impact	24	12	17	24

BRIQUETTES MADE AT 220°F AFTER HEATING ROCK ASPH. 1 HR. @ 325°F

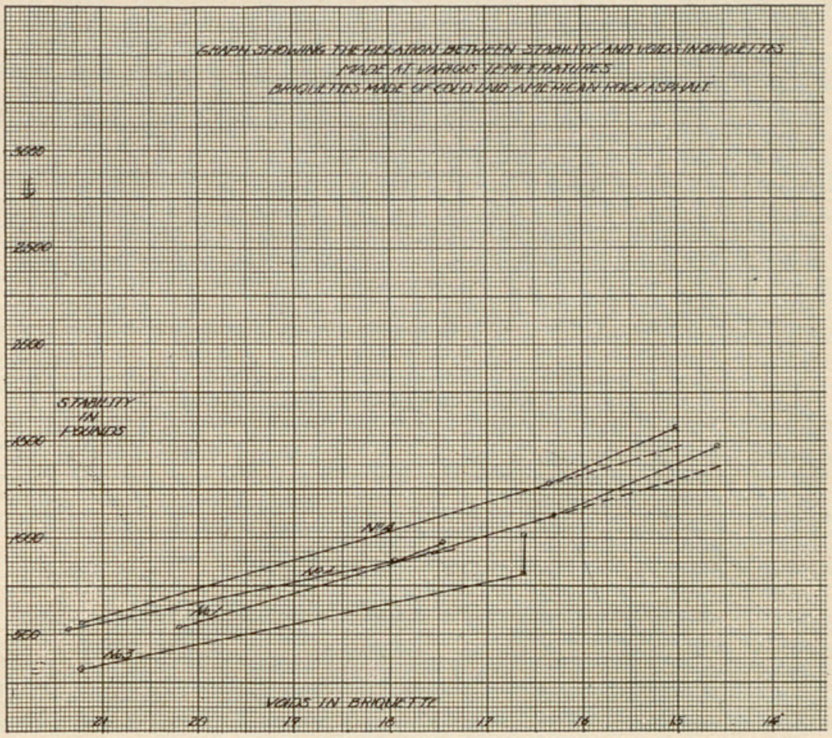
Theoretical Density	2.388	2.412	2.405	2.413
Density of Briquette	2.040	1.990	2.006	2.05
Voids in Briquette	14.57%	17.45%	16.62%	15.05%
Pounds Stability	1475	975	1008	1575

BRIQUETTES MADE AT 275°F USING EXTRACTED MIN. MATTER AND 6½% ASP.

Theoretical Density	2.411	2.383	2.4190	2.425
Density of Briquette	1.993	1.940	2.0069	1.99
Voids in Briquette	17.3%	18.60%	17.02%	17.94%
Pounds Stability	1205	1750	1300	2017

* This density was figured assuming a specific gravity of bitumen of 1.025.

Each particular rock asphalt has its own peculiar set of stabilities at the different temperatures. As stated before under Table 6 stability increases with the increase in density or decrease in voids. The graph given herewith will help to interpret the results. This graph is made by plotting the voids obtained at the three different temperatures against the stability. If the relation is true that stability is dependent on the voids present then a line passing through the 70 degree point and 160 degree point should be in a straight line with that including the higher temperature. The point representing the higher temperature however is always above



this extended line so the increase above this line is the increase in stability due to the heating. In the case of No. 1 it amounts to about 100 lbs., No. 2 to 50 lbs., No. 3 200 lbs., and No. 4 100 lbs. The results with No. 3 are undoubtedly due to the harder asphalt which it contained, which make this rock asphalt undesirable. The grading probably causes the high voids in No. 2 which persist throughout the tests, thus giving low stabilities and impact. As shown by tests No. 4 give the best results giving high stabilities at all temperatures the lowest voids and a satisfactory impact test. No. 1 give next best results which on account of its more rounded surface gives lower results than No. 4. The result of 1205 lbs. obtained on briquettes made of its mineral matter with the 42 pen asphalt seems incorrect but after having checked myself three times this result stands, together with the other ones for this rock asphalt.

Table 9.

GRADINGS AND ANALYSES OF AMERICAN HOT LAID ROCK ASPHALT

GRADINGS			
No.	5	6	7
Passing 200 Mesh	3.88	9.72	4.00
Passing 80 M Retained 200 M	5.48	32.52	16.12
Passing 40 M Retained 80 M	16.64	17.60	45.40
Passing 20 M Retained 40 M	44.28	10.40	22.48
Passing 10 M Retained 20 M	21.08	22.88	
Bitumen	8.64	6.88	12.00
Total	100.00	100.00	100.00
Character of Mineral Matter	Porous White Limestone	Impure White Sand	White Sand
Specific Grav. Of Min. Matter	2.60	2.65	2.589
Specific Grav. Of Rock	2.019		1.89
HEAT TESTS ON ROCK ASPHALTS			
Loss 1 Hour At 212°F.	.04%	.14%	.30%
Loss 5 Hrs. At 325°F.	.14%	.48%	.38%
Loss 5 Hours 325° Based on Bt.	1.62%	7.0%	3.16%
CHARACTERISTICS OF RECOVERED ASPHALTS			
Sp. Gr. of Recovered Asphalt	1.077	1.031	
Pen. Before 5 Hours @ 325°F.	19	29	1
Pen. After 5 Hours @ 325°F.	11	18	
Loss in Pen. After 5 Hours @ 325°.	42.2%	38%	
Loss in Wt. After 5 Hours 325°F.	.70%	1.42%	
Ductility After 5 Hours 325°F.	10 CM.	11 CM.	

Cold Rock asphalts in general are a more or less sharp not very carefully graded mineral aggregates impregnated with very soft, ductile asphalts having heat losses considerable above ordinary oil asphalt, and a little bit more volatile than European bitumen mixed in much leaner proportions than in ordinary sheet asphalt. They do not all give same stability and impact values this being to a large measure governed by the nature of the bitumen as to penetration, and to the character and grading of the mineral matter, sharp and roughened sand grains giving highest results. The influence of heat and exposure is not very severe as shown by increase in stability due to this factor, heat increasing the density and consequently the stability. All the cold laid rock asphalts have comparatively high voids, the ones giving the lowest other things being equal giving best results. The action under impact is influenced by character of bitumen but more so by grading and character of grains as shown in 2, which shows a coarse material made up of fine material agglomerated together.

Table 9 and 10 gives results of grading and testing of American Hot laid Rock Asphalt.

Table 10.
TESTS ON AMERICAN HOT LAID ROCK ASPHALT

	Briquettes Made From Crushed Rock at 275°F.			Briquettes Made From Extr. Min. Mat. And Oil Asph.		
No.	5	6	7	5 with 8½ Bit.	6 with 6½ Bit.	7
Theoretical Density	2.317	2.392		2.310	2.41	
Density of Briquette	2.28	2.141	2.01	2.234	2.12	1.91
Voids in Briquette	1.60%	10.5%		3.29%	12.3%	
Pounds Stability	3425	3400	5400	4033	3150	1575
Impact	19	12	8			

Examining the results in these two tables it is easily seen that No. 7 while having a sand grading much like that used for sheet asphalt and giving an extremely high stability has too hard an asphalt which makes it as brittle as it is under the impact test. The early sheet asphalt pavements laid with plain Trinidad asphalt and sand undoubtedly would have acted in much the same way under test and they are known to have worn away in a very short time. The gradings of the others, unlike as they are have not much significance, except that they are both coarser than any we have so far investigated. The low impact on No. 6 is no doubt due to the mineral matter breaking down as pointed out under the miscroscopic study. No. 5 is the best hot laid rock asphalt tested which having a hard bitumen must be mixed with flux to soften the asphalt prior to laying. While the sample showed bitumen in amount as set forth voids rapidly overfill on addition of much flux so it is necessary to soften the character of the flux instead of increasing amount to soften the bitumen or this overfilled condition will become evident. As shown, bitumen while hard has the proper hardening qualities and ductility. Since coming to Texas for this meeting, have seen many miles of this kind of pavement many of them over ten years old and they have left a very satisfactory impression on me.

Table 11 give the results of gradings and tests I have made on other materials which have been proposed for use in the same capacity as rock asphalts.

Table 11.

GRADINGS AND TESTS ON ROCK ASPHALTS WHICH HAVE BEEN PROPOSED FOR USE IN STREET

GRADINGS			
No.	8	9	10
Passing 200 M.	2.20	2.12	5.92
Passing 80 Retaining 200 M	72.92	57.00	34.88
Passing 40 Retaining 80 M	12.20	23.08	40.76
Passing 20 Retaining 40 M	3.68		1.88
Passing 10 Retaining 20 M			.76
Bitumen	9.00	17.80	15.80
Total	100.00	100.00	100.00
Loss in Heating 5 Hours 325 F.	.48%	7.64%	.66%
Heating Loss Based on Bit.	5.33%	7.64%	4.18%
Stability of Min. Matter @ 160	00	00	*675
Stability of Min. Matter @ 275	50 lbs.		

On account of the extreme roundness of mineral matter in Sample 8 together with its being practically all one mesh size this asphalt showed no stability when made at 160 F for even when its mineral matter was mixed with asphalt and made at 275 F a stability of only 50 lbs. was shown. Samples of both nine and ten had too much bitumen present causing serious overfilling of voids so it is not surprising that they did not show up better. The grading of No. 9 being fine and the character of its grain being unsatisfactory it is not surprising that briquette could not be removed from its mold without warping out of shape. That No. 10 showed any stability at all is on account of the fact that it had a better character of mineral matter. It is my opinion that if the proper amount of bitumen were present this rock asphalt would show a much higher stability.

Table 11 shows some tests on cores on pavements laid with rock asphalt which have been laid for some time.

Table 12.

TESTS OF CORES FROM AMERICAN ROCK ASPHALT PAVEMENTS

Type	No. 4	No. 5 Hot Laid	No. 5 Cold Laid
Date Laid	1890	1918	1918
Density	1.96	1.92	2.11
Stability	800 lbs.	1525 lbs.	1100 lbs.

No. 4 being the cold laid type had evidently hardened before it had reached its maximum density, giving the low density and stability as shown. No. 5 containing the very hard asphalt can be used either as a cold or hot laid asphalt at will by simply varying the character of the flux. Results in above table show that neither pavements had been compressed anywhere near maximum density and still giving very satisfactory results for surfacing material. I wish to point out at this time that even though the hot laid sample showed a low density still its surface was absolutely impervious to water.

Table 13.

EFFECT OF COMPRESSING BRIQUETTES ON GRADING MINERAL AGGREGATE

Gradings	Sicilian		Valde Travers		Amer. Cold Laid No. 1		Amer. Cold Laid No. 4		Amer. Hot Laid No. 5	
	Before	After	Before	After	Before	After	Before	After	Before	After
Passing 200 M	34.00	38.40	25.48	65.36	7.80	16.16	9.08	9.40	5.12	14.40
Passing 80 M Ret. on 200 M	24.88	27.56	38.32	12.08	9.72	19.48	13.80	16.12	7.40	10.04
Passing 40 M Ret. 80 M	11.64	14.52	24.12	12.52	58.60	41.00	62.60	61.00	16.92	22.12
Passing 20 Ret. on 40	12.48	6.96	3.68	1.88	14.80	15.00	6.52	5.20	27.80	24.64
Passing 10 Ret. on 20	8.28	3.68			2.16	1.40	1.28	1.56	31.48	17.84
Bitumen	8.72	8.88	8.40	8.16	6.92	6.96	6.72	6.72	11.28	10.96
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Having samples of both Val de Travers Rock as it came from the mine and also the pavement made with it I was surprised at the difference shown on grading, which prompted the work done in Table 13.

Val de Travers Rock Asphalt changes markedly on laying and compression into pavement as shown by the table, as it is very evident that the coarser particles in the rock crush up into fine material on compression. The other rock asphalt shown in Table were studied by grading the plain rock asphalt before making the briquette and then analyzing the briquette after compression and extrusion for stability. The other rock asphalts while not alike in their crushing action did not crush up anywhere near as bad as the first mentioned asphalt. American Hot Laid No. 5 being laid in the same manner as European Rock Asphalt, the results obtained with it are interesting. While it crushed up some, it was not nearly as bad as the first mentioned asphalt. Sicilian Rock Asphalt showed a little crushing, the 200 mesh material increasing at the expense of the coarse particles. American Cold Laid No. 1 showed considerable increase in 200 mesh material which seemed to be at the expense of the 40 to 80 mesh material. Cold Laid No. 4 showed the least crushing of any of the rock asphalts tested, showing only a little increase in 80 and 200 mesh material at the expense of the 40 and 20 mesh material. A comparison of these materials with the microscopic study shows that rock asphalts with high crushing properties as a rule are made up of agglomerations of finer materials in the coarser sizes which very evidently break down. See Photomicrographs under Sicilian, Val de Travers, Cold Laid 1, 2 and 4, and hot laid 5 and 6. The lower impact value given with most of these materials showing this agglomeration of grains is probably due to the crushing effect which exposes surfaces of grain not covered with bitumen and prevents them from holding together. It is possible that an asphalt showing this agglomeration and crushing may test out alright, when we consider that it is possible to have all the particles very nearly covered with asphalt and held together by a slight mineral bond, which even when they crush down will still be coated with bitumen and consequently show proper impact. It is also possible that the mineral bond between the agglomerated particles is so strong as to resist crushing to a large extent. A combination of these last two conditions is probably the reason why Hot Laid No. 5 shows a satisfactory resistance to impact.

One thing which cannot be tested for in a study like this, but which should be stressed is the matter of the uniformity of the rock asphalt. Rock Asphalt as it comes from the quarry is quite irregular in composition, so it is necessary that some mixing of the various rocks must be done at the mine to make the finished product show the proper amount of bitumen to hold the grains together. The selection of the rocks entering the rock asphalt prior to mixing is therefor very important, for different results will be obtained on the street even though the bitumen content on analysis is satisfactory by mixing a very lean rock with a very rich rock, than is the case where one just a little below requirements is mixed with one just a little above requirements. Where the lean one is mixed with the rich one, there will be a lot of particles left uncoated and if any of these lean lumps are left in the mixed rock asphalt they will break down much sooner under traffic than properly selected lumps on account of the inability of this stone to stand impact, due to its weaker bond, and then pretty soon the pavement will be presenting a pitted appearance and look quite unsatisfactory. This matter of proper selection and mixing of various rocks is important enough to warrant having an inspector stationed at the plant producing the rock asphalt to see that these precautions are carried out.

European Rock Asphalts make hot laid pavements, possessing high stability but not all possessing the same resistance to impact, which are compressed with difficulty but continue to increase in density for a period of years under traffic. They are composed of more or less fine grains of limestone, sometimes agglomerated in the coarser sizes, which varies in stability within certain limits, and which in some cases crushes quite badly and a soft highly ductile asphalt coming within the standard 5% heat loss after 5 hours at 325 deg. Fahr. and 50% loss in penetration after said heating.

American Hot Laid Rock Asphalt, possess high stability and vary as the European in their ability to resist impact and are more easily compressed than the European Rock. They are composed of a sand or limestone of a coarser graduation than the European, which possess high stability but not always the same degree of resistance to impact. As before the coarser particles are sometimes agglomerated together which sometimes crush down quite badly. The mineral aggregate is mixed with a harder asphalt than the European which in cases must be fluxed to soften for use. The bitumen passes the standard specifications for hard asphalt in its ability to withstand heat losses.

American Cold Laid Rock asphalts as freshly laid possess slight stability but under the action of the traffic the density and stability increase until a density is reached beyond which the pavement does not compress further. Cold laid Rock Asphalt at maximum density possesses a stability, which while not as high as either the hot laid European or American types, is quite high enough to withstand all the stresses imposed on the road by modern automobile traffic. This stability at maximum density varies widely from one rock asphalt to another and all rock asphalts of this type do not show the same resistance to impact. They are composed of varying gradations of more or less sharp silica sand with roughened surfaces, which as in the other types mentioned are sometimes agglomerated together in the coarser sizes, but not crushing as bad as the other two classes, together with a very soft asphalt showing a satisfactory heat test at three hundred and twenty five degrees Fahrenheit.

Every dark sticky stone does not possess the qualities required to make a satisfactory pavement wearing surface, as it is necessary in addition to sand and asphalt that the pavement must withstand traffic and wear as shown by the stability and impact test.

As shown by this study rock asphalts are not a uniform material, which means that great care must be used in selection of same for any particular type of pavement work. It is necessary in order to achieve best results on the street, to insist on the proper kind and amount of bitumen with the most suitable mineral matter in the rock asphalt itself, which in combination will produce in the pavement the least amount of voids and maximum stability and resistance to impact which the particular type of rock asphalt selected will give.