AN EXPERIMENTAL STUDY OF THE EFFECT OF LUBRICATING OIL UPON ASPHALT SURFACES

Thesis for the Degree of B. S.

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THESIS

Copy 1

New instruments of locomotion, a greater volume of traffic, a greater weight in loads, and vastly increased rapidity in road travel have between them brought us to an issue.

The road is one of the greatest fundamental institutions of mankind. We forget this because we take it for granted. It seems to be so necessary and natural a part of all human life that we forget that it ever had an origin or development, or that it is as much the creation of man as the city and the laws. Not only is the road one of the great human institutions because it is fundamental to social existence, but also because its varied effect appears in every department of the State.

It is the road which determines the sites of many cities and the growth and nourishment of all. It is the road which controls the development of strategics and fixes the sites of battles. It is the road that gives its frame-work to all economic development. It is the road which is the channel of all trade, and, what is more important, of all ideas. In its most humble functions it is a necessary guide without which progress from place to place would be a ceaseless experiment. It is a sustenance without which organized society would be impossible. Hence the road moves and controls all history.

A road system, once established, developes at its points of concentration the nerve centers of the society it serves and the material rise and decline of a state are better measured by the condition in its communications-that is, of its roads-than by any other criterion.

The construction, the trace, and the whole character of the road change with new social needs and habits, with the facilities of natural science, their rise and decline. But this perpetual change, which effects the road as it does architecture and every other work of man, is especially marked by certain critical phases, one of which we have now entered. There are moments in the history of the road in any society where the whole use of it, the construction of it, and its character have to be transformed. One such moment, for instance, was when there first appeared large organized armies. It occurred whenever some new method of progression succeeded the old. It occurred at similar critical turning-points in the history of the road not only when any of these things arose, but also when they declined or disappeared. The appearance of great cities, their sudden expansion or their decay, or the new deeds of a new type of commerce-and its disappearance-bring a whole road system to one of these revolutionary points. We have had five great moments of this kind in the history of the road system: the moment when British trackaway was superseded by the Roman military road; the moment when the latter declined in the Dark Ages; the moment when the mediaval system of local roads grew up on the basis of the old Roman trunk roads and around them; the moment when this in its turn declined in the later sixteenth and seventeenth centuries; and the re-casting of the road system by the turnpike of the eighteenth and early nineteenth centuries. To-day the sixth great change is upon us. The need of a road to withstand the increasing traffic problem.

In our present day civilization our road systems and their construction are far and varied. Climatic conditions, geological formations, and human element, enter into the problem. There are many types of roads, each having properties which make it suitable in regard to locality and the conditions encountered at one place and not do at all at another. However I will treat one phase of road that is prominent now, sheet asphalt pavement, and the effect oil has upon its surface.

Bitumen is a mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide. The word bitumen was at one time applied only to certain naturally occurring materials of more or less solid consistency which were black and sticky, and which were usually associated with rock or clay deposits. In connection with highway work this term now includes that portion of petroleum asphalt and tar products, whether crude or refined, which are soluble in a liquid chemical substance known as carbon disulphide. The term bituminous material is even broader in its scope and is applied both to bitumen and materials containing bitumen. The bituminous materials are used in a variety of ways, in the treatment and construction of highways, the more important being as dust palliatives, in the construction of bituminous mats or carpets, in the highway structure proper, as fillers, as fluxes and as impregnating materials.

Asphalt is a solid or semi-solid sticky product formed by the partial evaporation or distillation of certain petroleums, and if produced by natural agencies it is called native asphalt and often occurs mixed with considerable quantities of water, gas, vegetable matter and earth or clay. If, on the other hand, the asphalt is directly manufactured from petroleum, it is sometimes called petroleum asphalt and is practically pure bitumen. When asphalt occurs impregnating a porous rock such as sandstone or limestone, it is called rock asphalt. This material contains only a limited amount of bitumen and is mostly rock. Native asphalts are widely distributed over the earth, and history records a knowledge of their occurrence and use prior to petroleum. They are known to have been used in 2000 B. C. as a cementing material in construction of brick in the city of Babylon. They were used for a similar purpose by the Incas of South America long before the discovery of the Americas by the white race. Evidence has also been presented of their use in highway construction by these people. They are mainly found at or near the surface of the earth, altho in certain instances they are obtained in an almost pure state from veins or seams in rock formations where they occur in much the same manner as coal. Those at or near the surface of the earth usually contain appreciable quantities of non-bituminous impurities such as water, vegetable matter and mineral matter. It is almost impossible to remove all of these impurities by refining processes so that, unless originally occurring in a pure state, the refined native asphalt does not contain as high a percentage of bitumen as do refined petroleums. Where the asphalt occurs impregnating a porous reservour rock the entire deposit is called rock asphalt. In such cases the percentage of mineral matter is greatly in excess of the pure asphalt. When they occur at the surface of the earth as a seepage into a natural basin they are commonly known as lake asphalts. The lake asphalts are more widely known and are obtained in greater quantities than any other form of native asphalt.

Highways in which asphalt is used is almost invariably composed of two or more courses. The upper or wearing course is called the pavement provided it has a substantial thickness, usually of one or more inches. When asphalt is used in the superficial treatment of any pavements to produce, with a subsequent application of stone chips, snad, etc., a thin blanket course, such a superficial course is called an asphalt carpet or asphalt seal coat.

The bottom course of a highway which is laid directly up on the sub-grade, is ordinarily called the foundation or base and if courses are placed between the foundation and the pavement they are called intermediate courses. When sub-grade conditions are particularly bad a course is sometimes placed below what would ordinarily be considered the foundation, in which case it is termed a sub-base.

Asphalt pavements are laid upon a variety of foundations or intermediate courses which may or may not be of the same type as the pavement proper. The most types of foundation are the broken stone or macadam foundation, the Telford foundation, the cement conctete foundation, and the bituminous conctete foundation. Asphalt pavements are frequently laid upon old pavements such as macadam, cement concrete, brick or sone block, in which case the old highway structure as it exists is usually referred to as foundation.

A sheet asphalt pavement is one having a wearing course composed of a medhanical mixture of asphalt cement with a carefully graded sand and a finely divided mineral filler. This mixture is commonly called topping or surface. Irrespective of the kind of foundation, the wearing course is ordinarily laid upon an intermediate course of asphaltic concrete called the binder. There are two types of binder known as the open binder and close binder. The former, as its name implies, has a rather open or porous texture due to the fact that it consists of a single commercial mix of broken stone, the fragments of which are coated and bound together with asphalt cement. Close binder, which is more commonly used, is composed of a mixture of broken stone and sand with asphalt cement, the proportion of sand being sufficient to fill the large voids in the stone aggregate, thus producing a bituminous conctete of relatively close texture which is more impervious and offers greater resistance to displacement than the open binder. The foundation is ordinarily mewly laid Portland cement conctete, although old pavements such as brick, stone block, conctete and broken stone may often be utilized to produce satisfactory and economical results.

Sheet asphalt pavements are smooth, non-productive of dust, almost noisless, waterproof and easy to clean. They are capable of sustaining very heavy traffic and also last well under light traffic, therefore well adapted for business and residence streets and the facility with which they may be kept clean makes them especially desirable in tenement districts. They are easy to repair and offer but slight resistance to traffic. They are somewhat softer in summer than in winter but when properly laid never become too soft for use even in the hottest weather. When dry and clean the surface is not slippery and its slipperiness in moist or drizzly weather is largely due to the presence of a thin film of mud caused by the collection of street detritus, and this can be greatly reduced by washing or keeping them clean.

The sheet asphalt pavement through many years of use has successfully demonstrated its ability to meet requirements of such wide variations of traffic and climatic conditions that has become one of the most popular and extensively used types of pavement yet developed. As proof of the serviceability of the sheet asphalt pavement, Fifth Avenue, New York, said to carry the heaviest travel of any street in the world is worthy of special mention, although many other striking examples might also be cited. Sections of this pavement from five to twenty years old give wonderful evidence of the adaptibility of sheet asphalt to severe traffic conditions. In addition to the thousands of quick moving business and pleasure vehicles which daily traverse this pavement there are in operation 275 motor buses, each carrying 48 passengers. These buses weigh five tons empty and when full about eight and one-half tons each. In addition to the behavior of the pavement under this traffic, it is of interest to note that the longest recorded tire life for motor buses has been obtained on Fifth Avenue. The great Pershing parade with its ponderous trucks and caterpillar tanks traversed Fifth Avenue producing no permanent injury and marring the surface to such an extent that regular traffic soon obliterated every sign of its passage.

The total thickness of a sheet asphalt pavement is usually made three inches. Sometimes this thickness is proportional to one inch of binder and two inches of topping, but better practice calls for one and one half inches of each. The binder serves to true up unavoidable inequalities in the foundation, prevent slipping or shoving of the topping and increase the stability of the pavement for any given total thickness.

A properly constructed sheet asphalt pavement wears very slowly and uniformly under traffic which accounts for long service record. Fast moving rubber tired vehicles produce but little noticeable wear and in fact the pavement often appears to improve under the traffic providing the grading of the aggregate and the consistency of asphalt have been judiciously controlled. The kneading action of such traffic, if concentrated, together with the mist of oil from the exhaust of motor driven vehicles combine to consolidate and enliven the surface until almost the appearanceof a dense rubber mat. Accumulations of oil drippings from standing vehicles if allowed to collect in excess will, however, soften asphalt to such an extent that disintegration will follow. Such accumulations should therefore not be permitted to occur. Gas leaks will also cause disintegration by similar action. Some traffic is essential to the long life of the pavement as an untraveled street tends to harden more rapidly with age than one constantly kneaded by traffic, and cracking follows with accompanying disintegration due to frost action.

Before the generally accepted grading for paving sands was determined, the question of voids was possibly regarded as of greater importance and interest than at the present. It was at first considered that the total percentage of voids in a sand should be as low as possible and that all the voids should be completely filled with asphalt cement. Of recent years, however, the tendency has been to keep the voids as small as possible in size and use sufficient asphalt cement to thorougly coat all the particles regardless of whether or not this completely filled the voids. A solid rock or stone would possess no voids at all, but it would not be a sheet asphalt pavement; also, of two sands having approximately the same mesh composition and different percentages of voids, the one to be preferred would usually hve the larger total percentage of voids and yet have them smaller in size than the other. So many considerations enter into the selection of a sand for paving use that there is a danger of too great attention being given to the subject of voids, if one becomes an enthusiast on the subject. From a theoretical standpoint a sand composed of spheres of the same size should have approximately 26% of voids, but in practise it is impossible to obtain this figure owing to the difficulty of compacting the spheres to the maximum point, and the nearest approach to it has produced a mixture showing 31% of voids. Where the grains are of uniform size the percentage of voids will vary with the shape of the grains but not with the size of them.

The void theory on asphalt mixtures was worked out and tried out over twenty years ago. Experimental pavements were laid with high dust and low bitumen but while they were more stable, other characteristics made them undesirable excepting for use under abnormal conditions which are seldom met with even in the traffic of to-day. Samples taken from the work showed extremely high density and whenever the bitumen content happened to run a fraction of a percent more than that just required to fill the voids, the pavement flushed under the rollers and the rakers complained of the material being too stiff to rake readily. It has been found that the higher the percent of filler the more rapid is the drop in stability with changes in bitumen contents, and the pavement will not have the life and enduring qualities that can be obtained from a mixture containing more bitumen.

A filler is a material used to fill in the interstices between the grains of sand in the wearing course and render it more compact and dense. Fineness is therefore an essential requirement. As very little of the sand used passes a 200 mesh sieve and as a considerable quantity of it does pass a 100 mesh sieve, it is apparent that the bulk of the filler should pass the former. Most specifications require that at least 66% of the filler shall pass a 200 mesh sieve. The finer the portion which passes the 200 mesh sieve the better the filler, and two fillers, both showing the same amount of 200 mesh material, may vary very greatly in this respect. Generally speaking a filler should be free from organic matter, should be composed of particles to which bitumen will adhere readily and should be capable of packing solidly together when dry. This last property adds greatly to the stability of the mixture to which the filler is added. A great variety of materials have been used as fillers, including rock dust of almost every sort, Portland cement, natural cement, ground silica, slaked lime, clay, marl, fine sand dust from dust collectors and ground waste lime from beet sugar factories.

Sand constitutes from 75 to 80% of a sheet asphalt pavement and takes practically all the wear resulting from traffic. Sand for paving work, therefore, must be hard, clean grained and moderately sharp and must have a suitable meshcomposition. The surfaces of the grains must be of such a character that asphalt cement will satisfactorily adhere to them.

The exhaustive investigations coupled with many years of practical experience have led to the adoption of the following two standard gradings for light and the other for heavy traffic. In actual work, an endeavor is made to approach one these standards closely as possible within specific limits. Typical specifications of the U. S. Bureau of Public Roads, which are essentially the same as the specifications adopted in 1916 by the American Society for Municipal Improvements, calls for the following limitations of grading. A sample sand alone will be seldom found to meet such specific limits and recourse must frequently be had to a mixture of two or more sands in order to secure the desired grading.

Standard Sand Gradings.

Sieves.	Heavy traffic percent.		Light traffic.	
Passing 10 mesh, retained on 20 mesh.	5-		10-	
Passing 20 mesh, retained on 30 mesh.	8	23	10	35
Passing 30 mesh, retained on 40 mesh.	10 -		15-	
Passing 40 mesh, retained on 50 mesh.	13-	43	15-	45
Passing 50 mesh, retained on 80 mesh.	30-		30-	
Passing 80 mesh, retained on 100 mesh.	17-		10-	
Passing 100 mesh, retained on 200 mesh.	17	34	10	20
Passing 200 mesh......................	0-		0-	

In the small city and town the problem of traffic regulation is a simple one and the increase in the street use which occurs on certain days and adds a certain amount of life and interest which is an agreeable change from the monotony of existance in a provincial community. As the town becomes a city and as the city continues to grow the increase in traffic results in congestion with its attendant delays and dangers. The greater speed and flexibility of the motor vehicle has greatly increased the capacity of streets so far as traffic movement is concerned, but the parking of motor cars along the curb, whether parallel therewith or at right angles thereto or in the center of the roadway where its width is sufficient, has reduced the available space for moving traffic, and in many cases roadways have had to be widened at the expense of the sidewalks. As the character of the street surface is generally improved, motor traffic will become more diffused and the problem so far as moving vehicles are concerned will tend to take care of itself.

Under traffic the surface of the pavement is abraded and gradually wears off and the mineral particles exposed on the top are more or less crushed and broken. Where these particles are large this crushing action is plainly noticeable, but with the smaller particles of sand it is hard to detect it. Under heavy traffic and unfavorable weather conditions, these crushed grains become active centers of disintegration. The crushed particles are not bound together by the asphalt cement and are soon swept away. The holes thus made in the pavement serve to retain the moisture and the edges of the holes are eventually more or less broken down, thus enlarging the hole. This condition reproduced all over the surface tends to make it wear away much more rapidly than would otherwise be the case. The effect of this action, which at first glance appears trivial, has been so well established by years of investigation and experience that it has become axiomatic in the paving industry that the heavier the traffic the finer must be the particles composing the mineral aggregate. In hot weather, when the pavement is plastic, the abrasion of the surface is much less than in cold weather, when the pavement is hard and possesses but little plasticity.

The deterioration which eventually renders repairs necessary commences as soon as the pavement is laid and may be broadly classified under the following heads: 1. Defects due to the wear and tear of traffic; 2. defects caused by the deterioration, thru age and exposure of the bituminous cementing material used; 3. defects in construction. I will now endeavor to show you how lubrication oil affects asphalt surfaces.

Assuming that the sheet asphalt pavement is acted upon by heavy traffic, which is the case in summer, then according to the specifications of the U. S. Bureau of Public Roads, the standard sand grading required is the following:

Sieves.	Percent.	
Passing 10 mesh, retained on 20 mesh.	5-	
Passing 20 mesh, retained on 30 mesh.	8	23
Passing 30 mesh, retained on 40 mesh.	10-	
Passing 40 mesh, retained on 50 mesh.	13-	43
Passing 50 mesh, retained on 80 mesh.	30-	
Passing 80 mesh, retained on 100 mesh.	17-	
Passing 100 mesh, retained on 200 mesh	17	34
Passing 200 mesh......................	0-	

However, sand of just that grading was not obtainable, and so a mixture of two sands, A & B was resorted to produce the specified, by making combinations of the individual screenings.

Sieves.	A %		B %	
Passing 10 mesh, retained on 20 mesh.	1.24-		8.12-	
Passing 20 mesh, retained on 30 mesh.	2.36	7.9	31.3	55.22
Passing 30 mesh, retained on 40 mesh.	4.3-		15.8-	
Passing 40 mesh, retained on 50 mesh.	23.0-		23.2-	
		63.43		33.7
Passing 50 mesh, retained on 80 mesh.	40.43-		15.5-	
Passing 80 mesh, retained on 100 mesh.	14.72-		3,98-	
Passing 100 mesh, retained on 200 mesh.	10.58		1.71	6.18
		23.62		
Passing 200 mesh.......................	3.32-		.50-	

In order to obtain a comparison, four fillers, namely, Peerless Portland cement, celite, silica dust, and limestone dust were used in preparing the samples of asphalt surfaces, of different composition and varying percentages of constituents. The asphalt employed was one commonly used in Michigan and known as Indiana Paving Asphalt "B", whose specifications, as given by the Standard Oil Company, are:

Grade Number	3
Penetration at 77°F.	40-50
Penetration at 32° F-N.L.T.	12
Penetration at 115° F.-N.M.T.	250
Melting point. (Ball & Ring method) °F.-N.L.T.	120
Specific Gravity @ 77° F.-N.L.T.	1.00
Flash Point °F.-N.L.T.	460

5 Hr Loss @ 325°F. %-N.M.T.	20
Pen. of Residue(% of orig.) -N.L.T.	60
Ductility @ 77°F.-cms.-N.L.T.	100
Solubility in CS_2 -%-N.L.T.	99.5
Solubility in CCl_4 -%-N.L.T.	99.0

All tests A.S.T.M. Standard.

N.L.T.......... Not Less Than.

N.M.T...........Not More Than.

The lubricating oil with which the experiment and tests were carried out was medium Gargoyle Mobiloil "A", produced by the Vacuum Oil Company, whose specifications are:

Gravity	925
Cold Test.	20
Flash Test.	375
Fire Test.	420
Viscosity at	104-430
Viscosity at	140-173
Viscosity at	210-57-58
Viscosity Engler	13.0 at 40 C , 7.1 at 50 C, 4.6 at 60C, 1.75 at 100C.
Viscosity Redwood	140 F.-145
Color	75.90

The method used in preparing samples of sheet asphalt was carried out in the same manner and identically as commercially employed, except on a much smaller scale, within laboratory means. The sand was warmed to drive away the dust particles and then mixed with the filler, both of which are heated to a temperature of 350°F. The asphalt is melted and brought up to the same temperature. Then the latter is poured into the mixture and the product stirred until uniformly coated. At a temperature ranging from 300 to 325 degrees F., preferably the latter, the asphalt mixture is compressed and rolled into the sheet and form desired on pavement construction. Before applied on the job, A Pat Test is taken of the asphalt mixture, to determine its character.

A small wooden paddle with a blade 3 or 4 in. wide, 5 or 6 in. long, and ½ in. thick, tapered to an edge at one end and with a convenient handle at the other, is used to take as much of the hot mixture from the wagon as it will hold, taking a sample representative of the average mixture. A piece of brown Manila paper with a fairly smooth surface, 10 to 12 in. wide, is creased down the middle and opened out on some very firm and smooth surface of wood not stone or metal, which would conduct heat too rapidly. The hot mixture is dropped into the paper sideways from the paddle and half of the paper doubled over on it. The mixture is then pressed down flat with a block of wood of convenient size until the surface is flat. It is then struck five or six sharp blows with the block until the pat is about ½ in. thick. The paper will be found to be stained to a different degree, depending upon whether there is a deficiency, a proper amount or an excess present. In this way the amount of asphalt cement to use in making a mixture can be readily regulated, and the pat papers obtained will be evidence of the character of the mixture turned out. In the laboratory the same performance is followed through.

The test samples consisted of twenty different combinations of asphalt, sand and filler, using four different fillers, and having five varied proportions to each filler. The asphalt surfaces were prepared under the same conditions and in the manner explained above. A Pat test was made of each. (look into the pocket for the same.) The samples were formed into cubes in a device constructed for that purpose, and compressed to the required force of five thousand lbs to the square inch under a hand operated Rhiele testing machine. Being only five-eights inch in dia. the compression necessary was 1530 lbs, inorder to make them of the same specific gravity. (see drawing.) The prepared samples were allowed to stand alone for a few days, then each was weighed carefully to four decimal places, and suspended into the lubricating oil. (notice drawings.) Every few days the same samples were weighed again, and any change in them noted.

The following are the asphalt mixtures, numbered so as to designate them more easily and rapidly when referring to the same.

#1	#2	#3
15% cement.	16% cement.	15% cement.
12% asphalt.	11% asphalt.	10% asphalt.
73% sand.	73% sand.	75% sand.

#4

14% cement.
11% asphalt.
75% sand.

#5

15% cement.
11% asphalt.
74% sand.

#6

7% celite.
15% asphalt.
73% sand.

#7

6% celite.
15% asphalt.
79% sand.

#8

5% celite.
13% asphalt.
72% sand.

#9

5% celite.
15% asphalt.
80% sand.

#10

5% celite.
14% asphalt.
81% sand.

#11

15% silica dust.
11% asphalt.
74% sand.

#12

15% silica dust.
12% asphalt.
73% sand.

#13

13% silica dust.
11% asphalt.
76% sand.

#14

15% silica dust.
10% asphalt.
75% sand.

#15

14% silica dust.
11% asphalt.
75% sand.

#16

14% limestone dust.
11% asphalt.
75% sand.

#17

15% limestone dust.
11% asphalt.
74% sand.

#18

15% limestone dust.
12% asphalt.
73% sand.

#19

16% limestone dust.
11% asphalt.
73% sand.

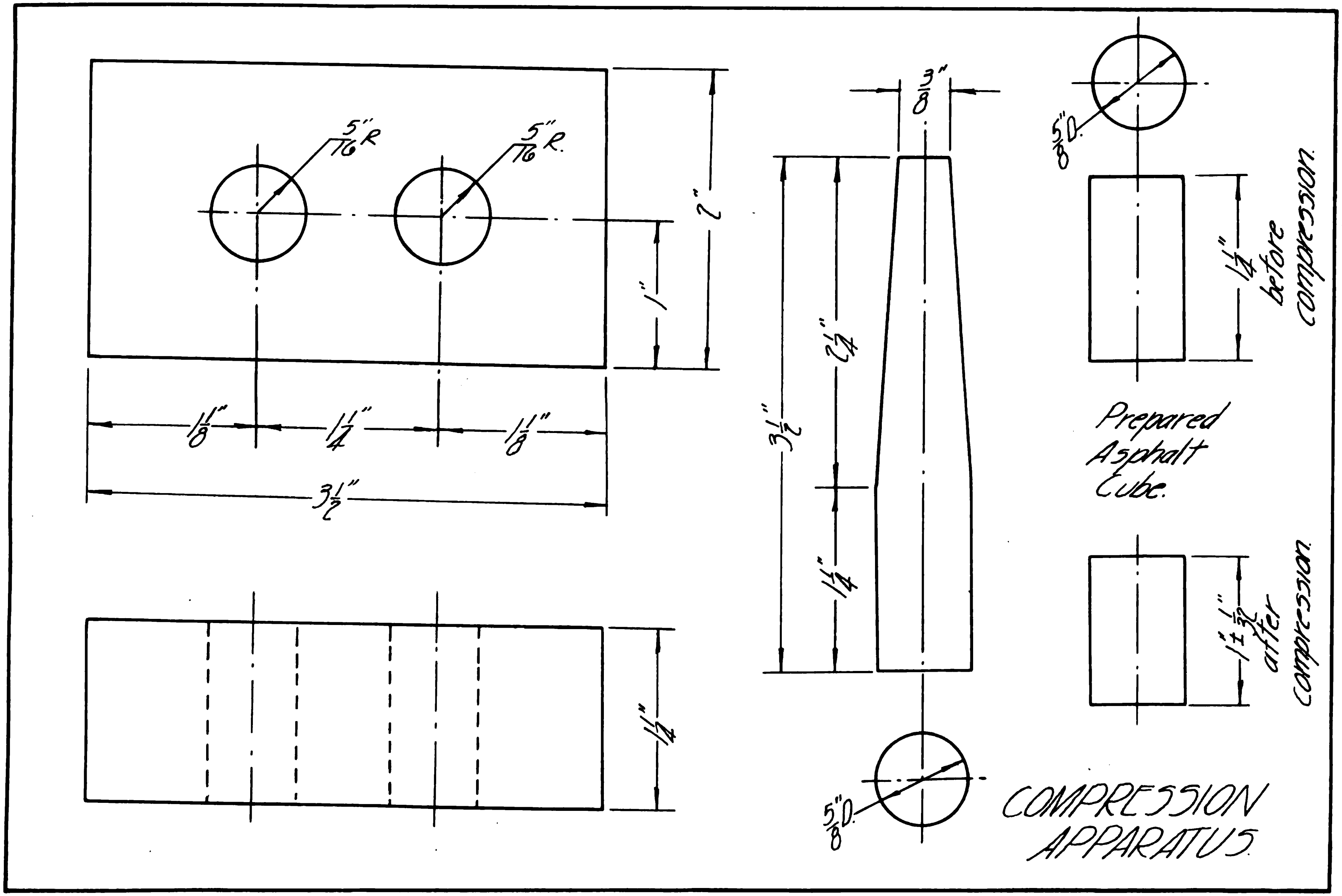
#20

15% limestone dust.
10% asphalt.
75% sand.

DATA.

Deterioration, in %.

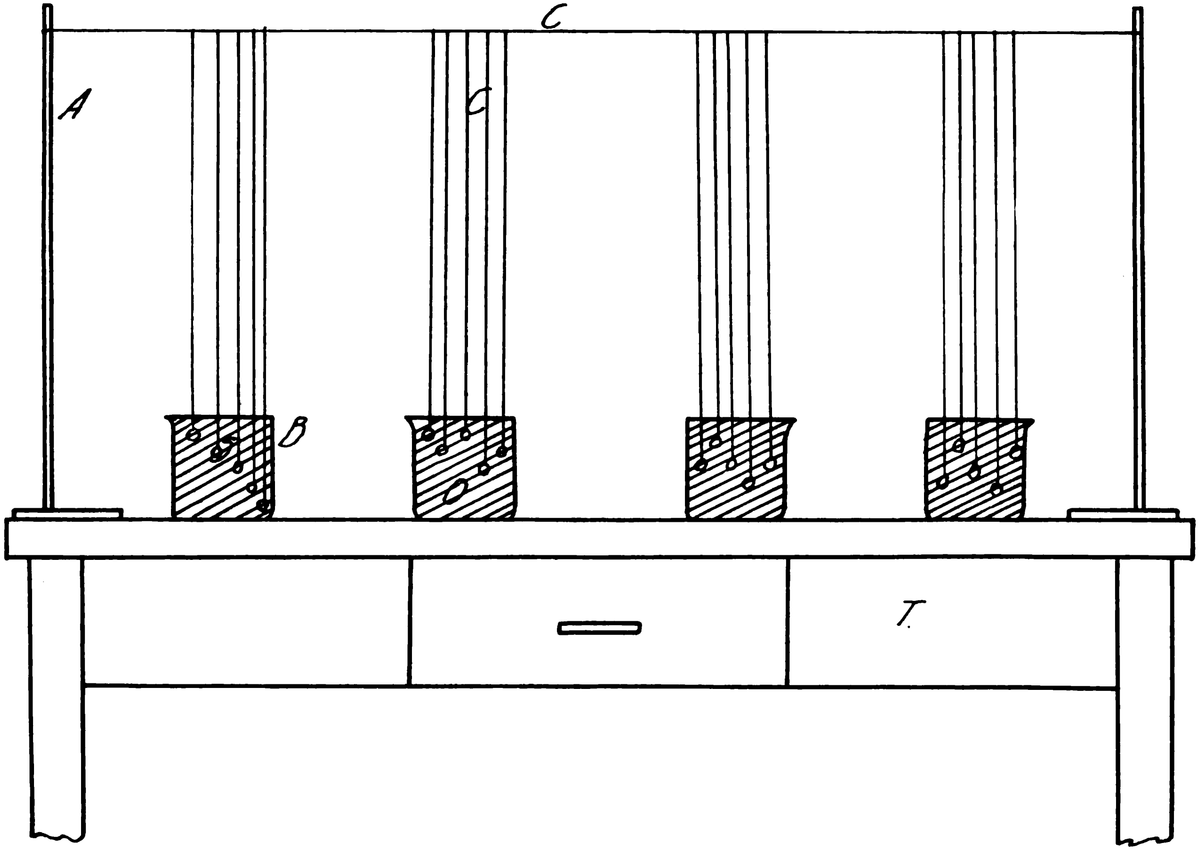
Sample #	Time. 2 days.	6 days	8 days.	12 days
1.	.77	6.19	9.21	14.63
2	2.99	7.19	10.72	14.93
3	2.65	7.96	12.15	17.46
4	1.97	4.87	7.42	10.32
5	1.67	5.39	7.72	11.44
Average/	2.03	6.23	9.44	13.76
6	3.43	9.51	13.77	19.35
7	4.23	8.69	11.17	15.63
8	3.51	7.19	10.15	13.83
9	1.49	7.03	10.02	12.74
10	1.43	6.12	10.64	13.50
Average/	2.82	7.71	11.15	15.11
11	4.95	8.12	13.48	16.67
12	4.03	10.22	16.37	22.56
13	3.44	8.09	11.68	16.33
14	5.33	9.52	14.41	18.60
15	3.82	10,17	14.99	21.34
Average/	4.31	9.22	14.19	19.10
16	5.80	12.01	19.21	25.42
17	4.39	10.44	16.03	22.08
18	8.94	16.75	21.99	29.30
19	2.54	6.98	14.86	19.30
20	2.67	7.59	15.38	20.30
Average/	4.87	10.75	17.49	23.30

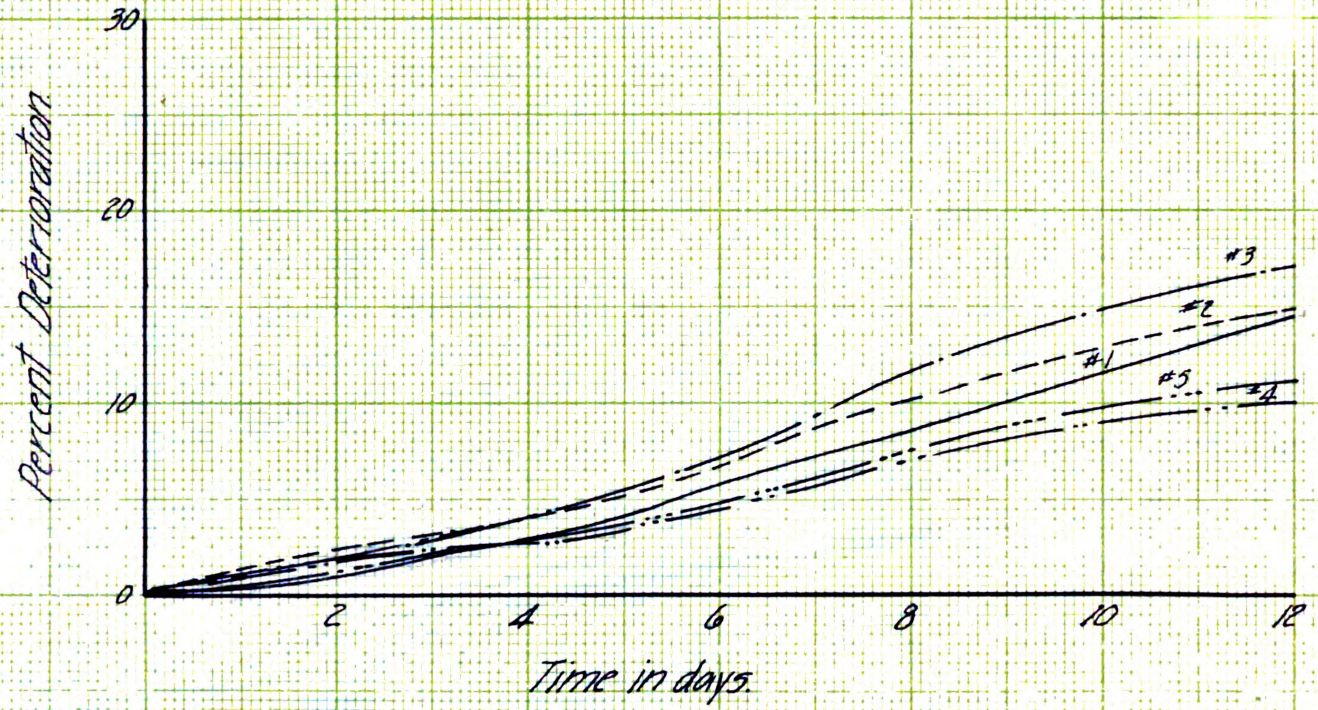


5/16" R
5/16" R.
2"
1"
1 1/8"
1 1/4"
1 1/8"
3 1/2"
1 1/4"
3/8"
3 1/2"
2 1/4"
1 1/4"
5/8" D.
5/8" D.
1 1/4"
before compression.
Prepared Asphalt Cube.
1 1/32"
after compression.
COMPRESSION APPARATUS.

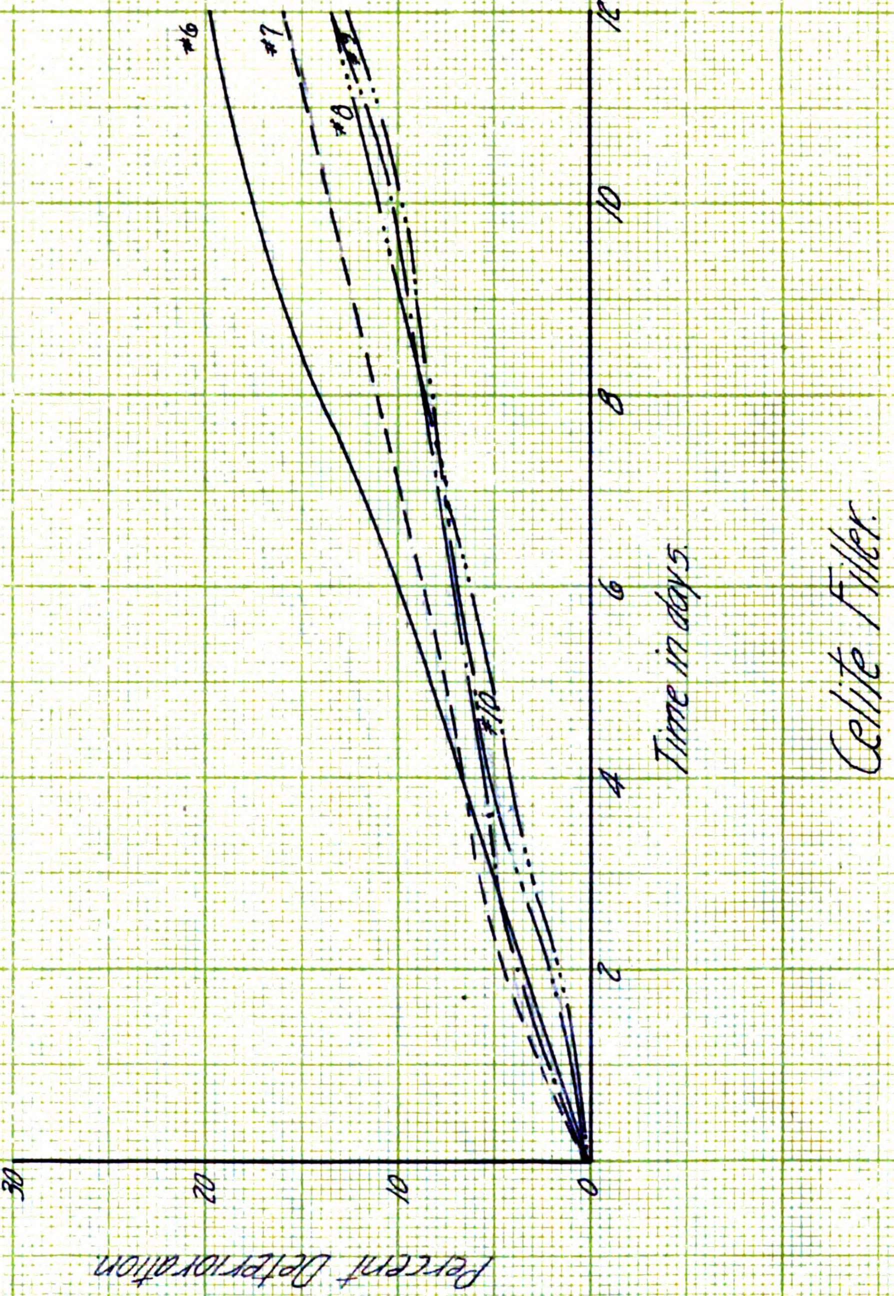
SET-UP.

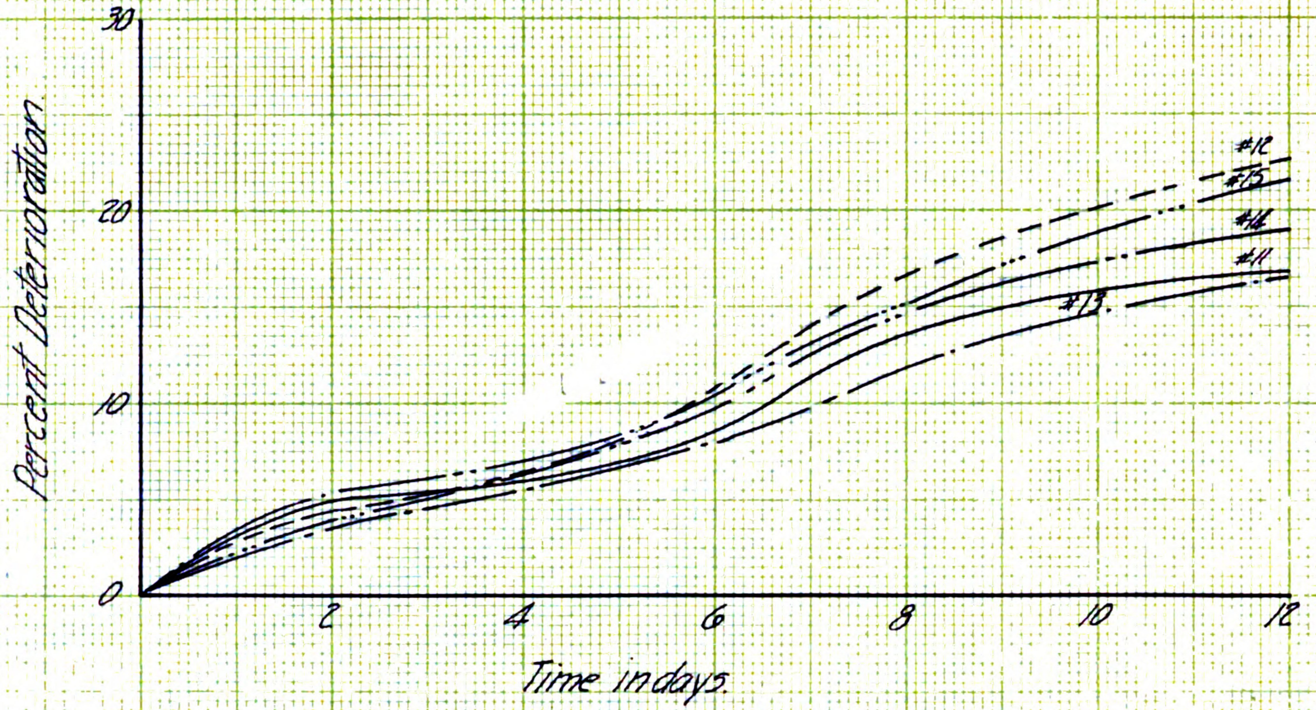
T-Table
B-Beakers
S-Sample cubes
C-String.
A-Stand
O-Oil.





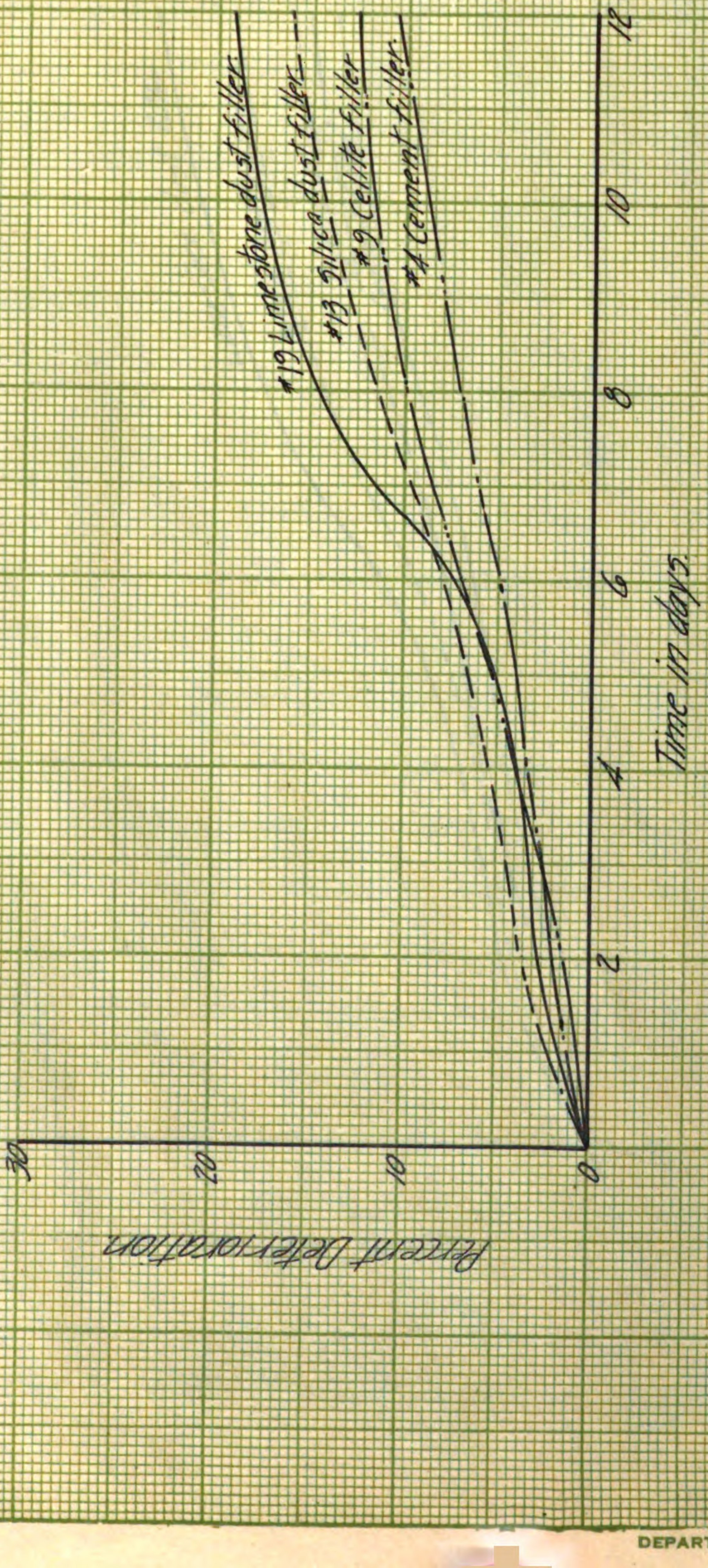
Cement Filler


Celite Filter.
Time in days
Percent Deterioration
0
2
4
6
8
10
12
0
10
20
30
#6
#7
#8
#10

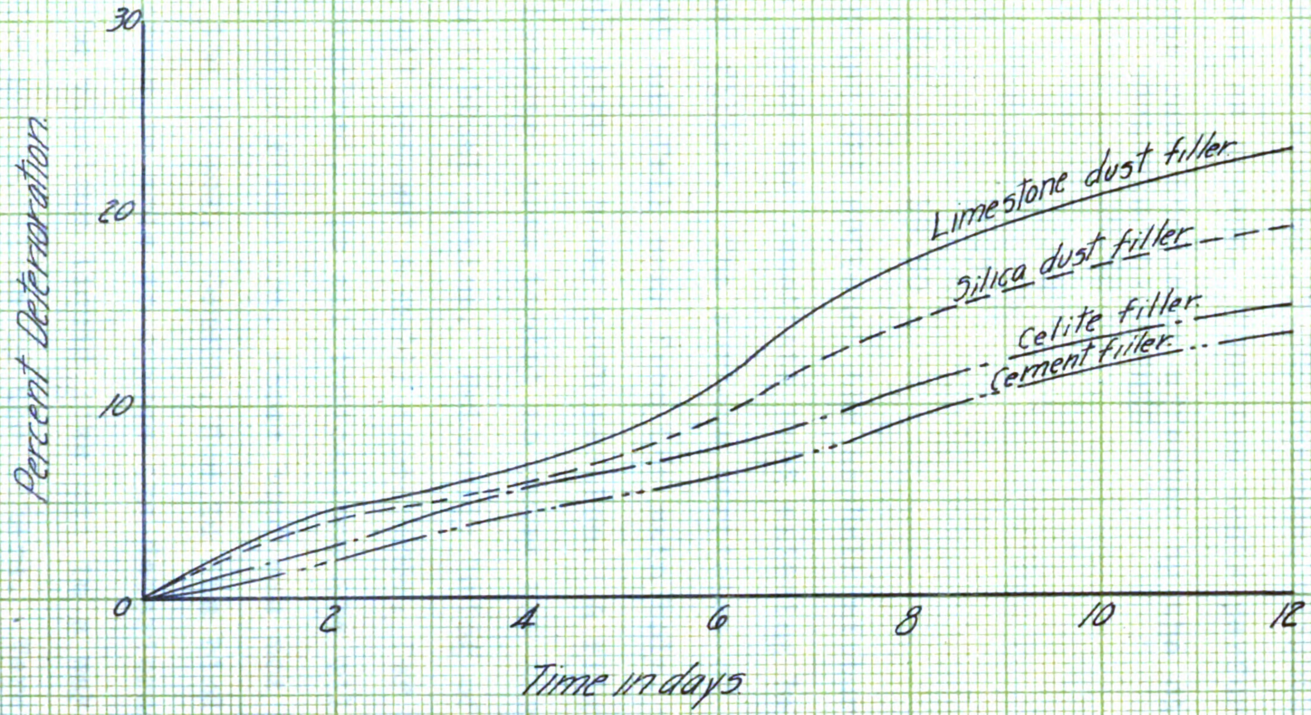


Silica Dust Filler.

Limestone Dust Filler.
Time in days
Percent Deterioration
0
2
4
6
8
10
12
10
20
30
#18
#16
#17
#20
#19



Comparison of Asphalt Surfaces
(smallest deterioration)



Comparison of Asphalt Surfaces
(average deterioration)

Based upon the results obtained, lubricating oil deteriorates sheet asphalt. The mixture using cement as a filler showed the least change of the four, that of 13.76% average, in 12 days time, followed by celite, silica dust and limestone dust, the latter scoring 23.30% average, slightly less than twice as much as cement. From the tests performed the following mixtures rate the least effected by the oil.

	deterioration in%
Cement. #4	10.32
Celite #9	12.74
Silica dust. #13	16.33
Limestone dust. #19	19.30

The lubricating oil softened the asphalt mixture to such an extent as to break the immediate bond existing between the asphalt, sand and filler. The surface particles of the sample disintegrated and fell away from the main body, which appeared minutely like a honey comb section. A slight friction of the oil immersed area tended to cause the sand to break away in individual grains. Naturally being of a fairly dark color, the oil assumed a muddy appearance, for the period of time it had remained. To all indications the oil ate its way into the granular structure, whose bond was not sufficient to withstand the attack. Cement, due to its binding qualities, seemed alone more able to oppose the deterioration, mainly because the viscious liquid like oil in a way formed a cementing action not possible by the others. Were these asphalt surfaces subjected to traction, and the elements, there is no doubt the deterioration would be greater. However, it would be proportional to the existing conditions and the design of the mix, as shown by the results.

All bituminous materials used in paving work deteriorate upon exposure to the elements and to the rotting action of escaping gas, water and street liquids. The lighter oils contained in them gradually volatilize, thus hardening the remaining bitumen. As the hardening process goes on, the pavement loses its plasticity and wears away with increased rapidity. Eventually the bitumen loses its elasticity and the pavement cracks. The edges of these cracks crumble away and the cracks become sufficiently wide to be plainly felt by vehicles passing over them. The bumping action previously described in connection with waviness is produced and adds to the rapidity with which crumbling takes place. In order to guard against this and prolong the effective life of the pavement, the asphalt cement used in its construction is made as soft as possible without rendering the pavement too mushy when new. The extent to which this can be carried depends upon the grading and charactor of the sand employed. With a well sharp sand and plenty of filler, a much softer asphalt cement can be used than with a poorly graded or rounded sand. This is due to the greater inherent stability of the former type ofsand. It is obvious that a mineral aggregate which when dry strongly resists displacement will permit the use of a comparatively soft asphalt cement. Modern traffic conditions have in this particular respect come to the aid of pavement makers. Automobiles in their passage over the pavement are continually dropping a certain amount of oil, which if very small, is very evenly distributed by the large number of vehicles passing over it. This oil is gradually absorbed by the pavement and thus softens the bitumen and counteracts to a large extent the hardening action of time upon it. This is very clearly shown in a certain pavement in Chicago, which, prior to the passage of any considerable number of automobiles over it, about 1910, was so hard and badly cracked as to have practically reached its limit of usefulness. The street in question subsequently developed into an automobile center with the result that the pavement was softened up by the slight dropping of oil upon it, to such an extent that in 1915 it was still giving satisfactory service. Fifth Ave., New York City is a somewhat similar case.

Broadly speaking, the governing principle in the theory of sheet asphalt pavements are: 1. The selection of a mineral aggregate of sufficient hardness and denseness to resist the abrasive action of traffic; 2. binding the various particles of the mineral aggregate together in such a way that the pavement will maintain a smooth surface and resist the disintegrating action of traffic and the elements.

Pocket has:
Samples
1-8, 10-20