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Bulletin 344

***Degradation of Aggregates Used
In Highway Base Construction***

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In Highway Base Construction*

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Prevention of Degradation of Basalt Aggregates Used in Highway Base Construction

F. R. COLLETT, C. C. WARNICK, and D. S. HOFFMAN, University of Idaho, Moscow

Highway base course failures due to degradation of basalt base aggregates by weathering is a serious problem in the areas of the United States where the vast deposits of basalt rock must be utilized for this purpose. The work reported in this paper consisted of laboratory weathering tests on asphalt-aggregate mixtures, field testing of an SS-1 asphalt emulsion stabilized base, and surface energy studies of asphalt and aggregate systems. Results show that the asphalt treatments do not completely stop degradation in laboratory weathering tests. However, the stability of the base is improved by treatment, as shown by both laboratory and field tests.

•HIGHWAY ENGINEERS have noted that one of the causes of base failure was the degradation of the base aggregate. This type of failure has occurred frequently in the Northwest where highway engineers must utilize the vast deposits of basalt rock. Some of this basalt is of high quality as a road building material; on the other hand, large deposits of basalt weathers, or degrades, easily thus causing failure of the highway base.

Degradation as used in this paper is the production of very fine particles by weathering action rather than by mechanical wear. The basalt aggregates that are of the poorer quality degrade rapidly producing fines that are smaller than a No. 200 mesh sieve. The fines produced by weathering become plastic when wet and cause loss of stability of the highway base.

The problem of base failures due to degrading basalt aggregates was brought to the attention of the Engineering Experiment Station at the University of Idaho by L. F. Erickson of the Idaho Department of Highways in 1956. Scott (1) reported base failures caused by degradation of secondary minerals. Turner (2) and Sibley (3) studied degradation of various Washington aggregates and gave specific attention to cement-treated aggregates. Idaho Department of Highways has developed a test (4) for measuring susceptibility of aggregates to degradation. Erickson (5) has made a study of the extent of this problem of degradation throughout the various State highway departments. The investigational work covered by this paper has been conducted through a series of graduate theses studies (6 through 11) sponsored by fellowship grants from Phillips Petroleum Company and supported by assistance from the Idaho Department of Highways.

EXPERIMENTAL WORK

The experimental work in this study has been approached in three ways: (a) laboratory weathering tests on asphalt-aggregate mixtures, (b) testing of samples removed from a field installation of an SS-1 asphalt emulsion-stabilized base, and (c) surface energy studies of asphalt-aggregate systems.

Weathering Tests

Several types of asphalts were used to coat the aggregates in an attempt to prevent the degradation of the basalt aggregates. Laboratory weathering tests were set up to evaluate the performance of the various asphalt-aggregate mixtures.

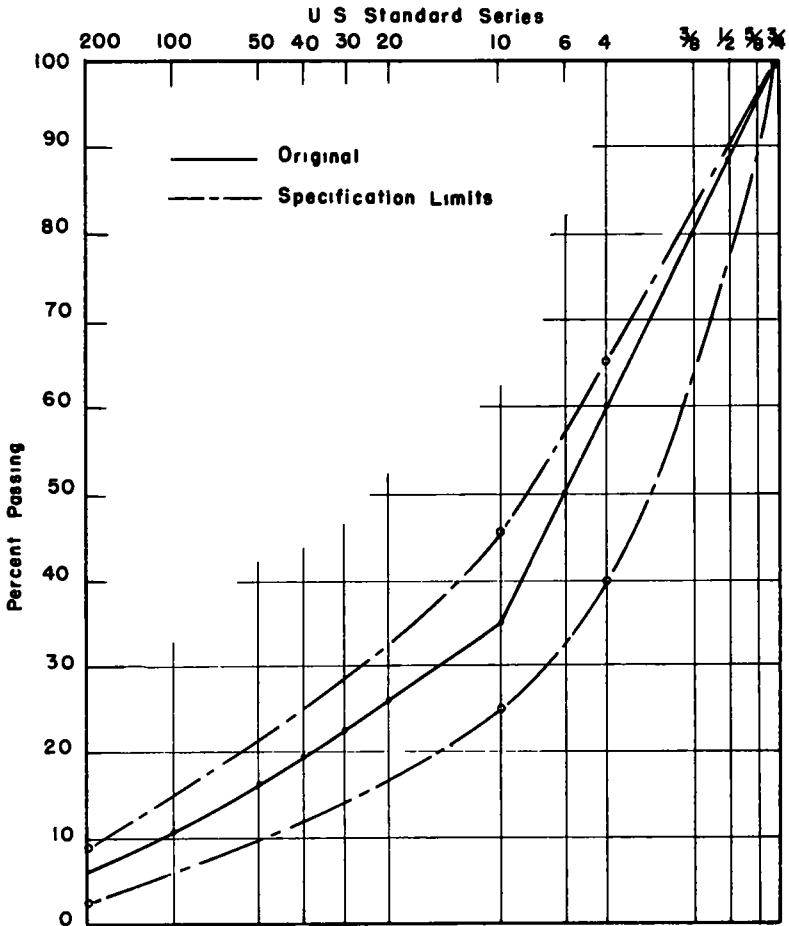


Figure 1. Comparison of particle size distribution of original reconstituted sample and Idaho Department of Highways specifications limits for base aggregate.

The basalt aggregates used in the weathering tests were quarried from Idaho County Pit 93. Representative samples were taken from various parts of the pit and crushed to a 3/4-in. maximum size in the laboratory.

The asphalts used were 85-100 penetration asphalt cement, MC-2, MC-3, and SC-2 cutbacks, a special road oil, SS-1, SS-2, and DM-K asphalt emulsions, and a foamed asphalt. The most extensive and also most recent tests have been with slow-setting asphalt emulsions made from residuals of varying penetrations.

The samples were prepared by first building each sample to the same gradation. The gradation is shown in Figure 1. Individually weighted and prepared samples were used to insure that the percentage of fines in each sample was the same at the beginning of the testing. Tests were run with treated samples in both uncompacted and compacted states. The compacted samples were prepared and left in 4-in. moulds so that they could be subjected to a loading using a kneading compactor during the weathering cycles.

The weathering cycle consisted of periods of moistening, freezing, thawing, loading, and heating or drying. During the moistening period the samples had water available at both the top and bottom of the moulded specimen. They were subjected to the moisture period for 12 hr. The freezing period was for 3 hr at 10 F. The thawing period was at room temperature for 4 hr. During the thawing period the simulated wheel loading was applied with a kneading compactor once every 10 weathering cycles.

The loading consisted of 100 blows of the compactor at a foot-pressure of 250 psi. A small foam rubber disk was placed between the foot and the sample to reduce effect of impact. The heating period was for 4 hr in an oven set at 140 F.

The number of weathering cycles was limited to 45 after noting that the greatest amount of degradation took place during the first 45 cycles.

Immediately after weathering tests were completed, the stability of each compacted specimen was determined with the Hveem stabilometer. The asphalt was then extracted from the samples in reflux-type extractors and the remaining aggregates were resieved to determine the change in particle size due to weathering.

Field Sampling

During 1958 the section of US 95A between Potlatch and Emida, Idaho, was reconstructed, using an asphalt emulsion-stabilized base. The base of the road had been built two years before and surfaced with a single-surface treatment. In two years the base aggregate had degraded to the extent that rutting and potholing had made the road nearly impassable. A 0.25-ft depth of the base material was treated with 5 percent SS-1 asphalt emulsion. Mixing was done in a Woods pugmill-type mixer. Samples were taken at the time of mixing and extractions and gradations run on the aggregate. In 1959, additional samples were taken from the base to determine if degradation was continuing in the treated base. Asphalt in the samples of base material was extracted, and a sieve analysis run to determine the change in particle size that had occurred in one year.

Surface Energy Studies

Surface energy studies have been conducted to characterize the aggregate and determine the type of asphalt best suited for the treatment of degrading basalt aggregates. The surface energy studies have been made by measuring the contact angles of droplets of various asphalts on aggregate surfaces. A technique suggested by Thelen (12) was used. This technique consisted of placing a small drop of asphalt on the surface of an aggregate in a special temperature controlled cell. A lamp and lens system projected the image of the asphalt drop on a screen where the contact angle could be measured or a photographic reproduction made of the image.

The apparatus for the contact angle measurements consisted of a mercury arc lamp, a teflon cell to hold the aggregate sample, and a set of lenses to project the image on a screen. Angle measurements were made on the projected image with a straightedge and protractor.

A spreading coefficient was derived from surface energy relationships which give a measure of relative wetting tendencies of liquids on solids. The spreading coefficient is given by

$$S = (\cos \theta - 1) \gamma_{LG}$$

in which θ is the contact angle and γ_{LG} is the surface tension of the liquid in contact with a gas.

Also related to the contact angle studies was the use of an ion exchange unit to characterize the aggregates according to their surface active ions. Crushed aggregates of sizes between the No. 16 and No. 30 sieve were placed in a vertical lucite percolation column. A sodium chloride solution of known pH was run through the aggregate at a constant rate. The change in the pH of the effluent was determined by making periodic measurements with a pH meter. Three basalt aggregates of known quality based on field experience were used. The degrading-type aggregate from Idaho County Pit 93 was used along with two higher quality basalts from other pits.

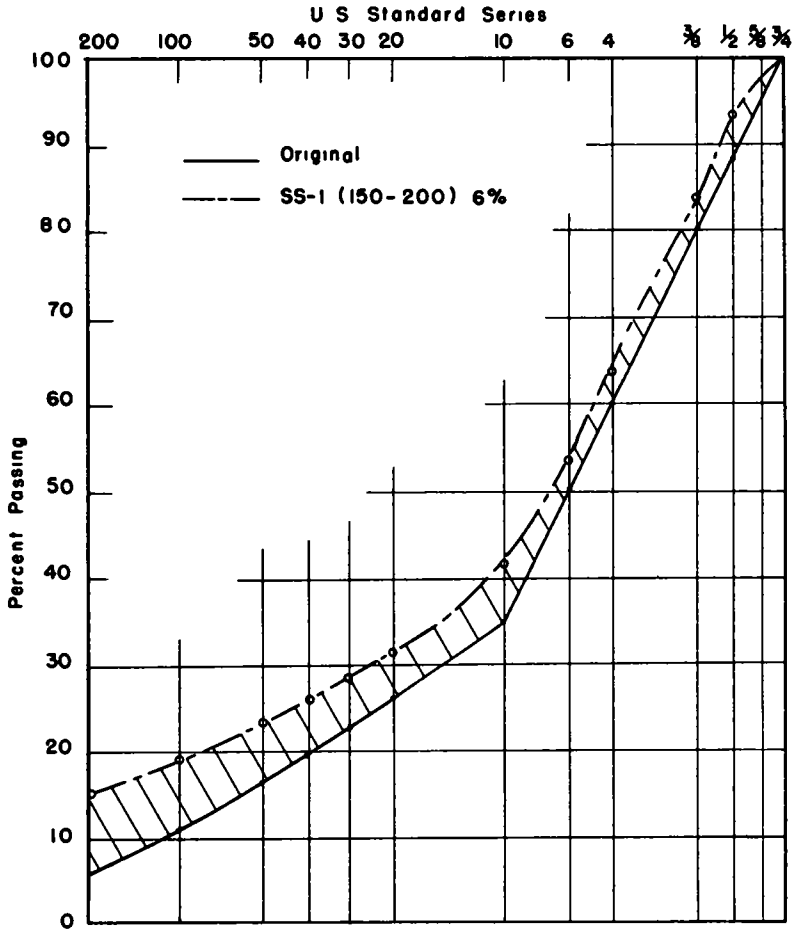


Figure 2. Comparison of particle size distribution of original sample and asphalt emulsion (150-200 pen SS-1 of 6 percent) treated sample subjected to 45 weathering cycles.

TABLE 1
RESULTS OF SAMPLES SUBJECTED TO 45 WEATHERING CYCLES

Identification of Treatment	Empirical Area (No.)	Percent Passing No. 200 Sieve	Hveem Stability
Control samples	31.9	14.2	--
SS-1 (150-200):			
6 percent	26.4	15.2	47
10 percent	28.2	14.5	19
SS-1 (200-300), 5 percent	29.6	16.5	49
SS-1 (50-60), 5 percent	32.5	17.0	45
SS-1 (0-10), 5 percent	27.6	16.4	51
DM-K (50-60), 5 percent	30.7	16.5	36
Foamed asphalt	34.2	15.2	43
SS-1 (150-200):			
6 percent	--	--	50 ^a
10 percent	--	--	34 ^a

^aTested before weathering tests.

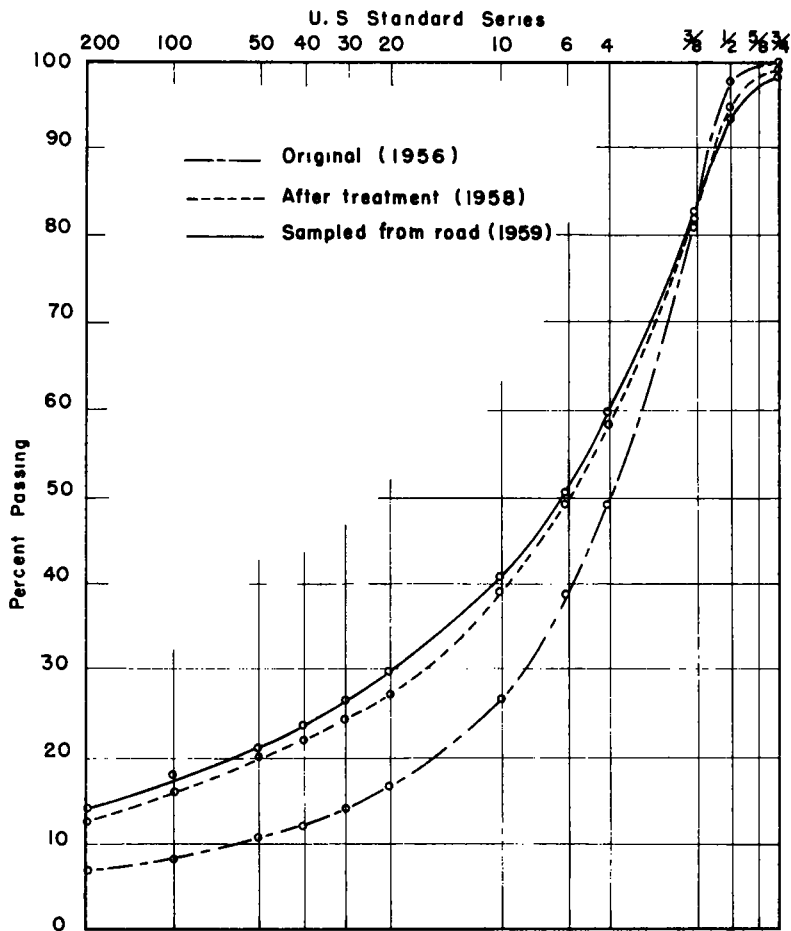


Figure 3. Comparison of average particle size distribution of three different field samplings of aggregate used in asphalt-treated base material for US 95-A.

RESULTS

Weathering Tests

Early experimentation by Keller (6) and Lu (7) with both unconfined and confined samples indicated that treatments with SS-1 and SS-2 asphalt emulsion showed the most promise for preventing degradation. The results of the last tests by Collett (10) showed rather minor improvements in prevention of degradation but a definite retention of stability of the mix.

Results of the weathering tests were expressed in two ways: (a) as the increase in the percentage of material passing the No. 200 sieve, and (b) as an empirical area number which is similar to a fineness modulus for the aggregate. The original gradation of all samples had 6 percent passing the No. 200 sieve. Table 1 gives the percentages passing the No. 200 sieve after 45 weathering cycles for the control samples and a number of asphalt treatments.

The empirical area method uses the area between the original and final gradation curves expressed as tenths of square inches. This area is cross-hatched in Figure 2, which is typical for the many evaluations used in the study. This is a relative number that can be used only for samples with the same original gradation that are all plotted

at the same scale. The results of the empirical area determination are given in Table 1. The lower the number, the less change in particle size; therefore, the less total degradation.

The results of the weathering test show that the average change in minus No. 200 material was from an initial value of 6 percent to a final value of 15 percent. Comparing the untreated to the treated samples, the increases in fines were nearly the same regardless of the type of treatment. Using the empirical area method, the treated samples show less total change in particle size than the untreated samples. The 6 percent treatment using SS-1 asphalt emulsion with a 150-200 penetration residual gave the best apparent results.

The results of the field sampling from US 95A are shown in Figure 3. Results confirm the cause of failure of the original construction to have been a large change in particle size from 1956 to 1958. The degradation was not completely stopped by the treatment between 1958 and 1959 but the total change in particle size during the year of exposed field use was small. The stability of the road has been increased to the point that no sign of failure has occurred at this time (1961).

The results of the Hveem stability tests on the confined moulded specimens are also shown in Table 1. There are no stability results for the untreated samples, but stabilities were run on treated samples before weathering. Although degradation did take place during weathering, there was no appreciable loss of stability. This indicates that the degrading aggregates can be stabilized with asphalt treatments. The 6 percent SS-1 asphalt emulsion-treated sample had the least change in the stability number during the weathering tests and showed the least change in particle gradation and thus appeared to be the best of the various asphalt treatments studied.

Surface Energy Studies

The contact-angle studies indicate that it is difficult to distinguish between basalt aggregates that will or will not degrade. The results of spreading coefficients for various asphaltic materials on aggregate surfaces are shown in Table 2. For complete wetting, the spreading coefficient is zero and for non-wetting the spreading coefficient approached a minus two times the surface tension of the liquid. The cationic emulsion has greater attraction for the degrading type aggregates than the anionic emulsion. The MC-3 liquid asphalt has better spreading coefficients than the asphalt emulsion for all the aggregates investigated.

TABLE 2
EQUILIBRIUM SPREADING COEFFICIENTS OF ASPHALT MATERIALS
ON AGGREGATES AT SATURATED SURFACE DRY CONDITIONS

Aggregate	Asphaltic Material		
	SS-1 Asphalt Emulsion (Anionic)	RS-K Asphalt Emulsion (Cationic)	MC-3 Liquid Asphalt
ID-93 degrading	-18.30	-13.01	-6.37
Np-109 nondegrading	- 5.02	- 7.15	-6.82
Np-x nondegrading	- 7.56	- 8.96	-4.72

The results of the ion exchange tests (11) show that the highway aggregates might be characterized according to their basicity and acidity. The Id-93 basalt aggregate caused a sudden large increase in hydrogen ion concentration of the effluent, indicating that the hydrogen ions on the surface of the rock predominate and were replaced by the sodium ions in the solution. Consequently, the pH value was lowered. Quartzite, although not tested, exhibits similar characteristics and is known to be an acidic aggregate. Almost no change resulted in the pH of the effluent in passing through the sample of Np-109 aggregate (a good basalt). This indicated that the aggregate is neutral or slightly basic. An acidic aggregate will lower the pH value. The Np-X basalt aggregate caused a definite rise in pH value of the effluent indicating it was basic.

CONCLUSIONS

The results of the laboratory weathering tests indicate that asphalt treatments do not completely prevent the degradation of basalt aggregates. Using the area number method of evaluating degradation, there is reduction in the total breakdown and thus benefit due to treatment.

The highway base aggregates are definitely stabilized by asphalt treatment and would in all probability remain stable although slight degradation of the aggregate takes place. Results from the field testing show that some degradation continued after treatment but the highway has remained in good condition under heavy logging-truck traffic. Future field testing now planned may confirm the extent to which degradation continues and the value of asphalt treatment in maintaining stability of the road.

Ion-exchange tests might be used as a means of characterizing the basalt aggregates. It appears from this limited study of three basalt aggregates that basalt of an acidic nature will degrade when used in highway construction, whereas basalts of a basic nature will retain their strength and not degrade in the highway base.

The cationic asphalt emulsions spread easier on the degrading basalt aggregates, whereas the anionic asphalt emulsions have better spreading coefficients on the non-degrading basalts. The MC-3 cutback asphalt spread easily on all aggregates. The contact angle measurements cannot be used as a means of characterizing the aggregates according to their susceptibility to degradation. However, surface energy studies of this nature may have value in relating what type of asphalt will give the best treatment and bonding of asphalt to aggregates. Further study is recommended in this respect.

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A Progress Report on Studies of Degrading Basalt Aggregate Bases

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This paper presents a brief history of aggregate degradation in Idaho, including reference to projects that have failed in service. A laboratory test method which has been developed to anticipate degradation tendencies in base and surfacing aggregates is discussed. In addition, a method is described whereby petrographic examination of preliminary sample is used to determine the quality of a montmorillonite mineral which is associated with degradation. An attempt is made to correlate the results of the laboratory test and petrographic examination to establish minimum standards for acceptance of aggregates.

•**STRUCTURAL FAILURE** of flexible pavements owing to degradation of the aggregates used to build these pavements has been a problem in highway engineering for many years. Construction records in Idaho indicate that in 1948 a pavement built with a shale aggregate failed before construction was completed and had to be reconstructed before being put into service. The problem of degradation came into sharper focus in 1955 when a project on primary route F-4113 in the vicinity of Grangeville showed signs of distress less than a year after construction. It became apparent during the laboratory investigation of this and two subsequent failing projects that none of the conventional laboratory tests for aggregates was suitable for determining the degradation potential of aggregates used. This progress report details some of the work that has been done since 1955 toward solving the problem of predicting by preliminary tests and examinations those aggregates most likely to degrade in service. Most of the aggregates involved in these studies were crushed basalt bases from the northern part of Idaho.

"Degradation" has been defined (1) as "A breaking down and/or disintegration of particles of sand, gravel, or stone, primarily due to the alteration and subsequent decomposition of their mineral components, accelerated by the action of mixers, mechanical equipment, traffic or the elements."

AGGREGATE FAILURE IN SERVICE

The first projects in which base failure was attributed to aggregate degradation and for which data are available were on primary route 4113 in Idaho County near Grangeville. The two projects were contiguous, one being completed in September 1954 and the other in July 1955. Signs of failure began to appear as early as the spring of 1955 on the first project. A bituminous surface treatment rather than a bituminous mat had been used on both projects. Failure appeared in the form of breaks in this bituminous surface resulting in severe potholing and breakup in the base course (1). Tables 1 and 2 give test data on the 3/4-in. crushed basalt aggregate used in the base course. The material was produced from two quarries, one identified as source Id-93 and the other as source Id-90. Both sources are in the same area and represent the same type of basalt. The data in Table 1 show results obtained shortly after the failure was noted in 1955. Table 2 gives data for approximately one year later in the spring of 1956. A comparison of the two tables indicates that the degradation is a progressive phenomenon.

TABLE 1
BASE SAMPLES FROM ROAD, PROJECTS F-4113(2) AND F-4113(4), SPRING 1955

Pit No	Date	Station	Percent Passing Screen												Liquid Plas		Sand		
			3/4-In	1/2-In	3/8-In	1/4-In	No 6	No 10	No 20	No 30	No 40	No 50	No 100	No 200	Limit	Index			
Id-93	266+00	2-23	100	95	83	66	47	36	24	21	19	17	14	12	14	12	NV	NP	55
Id-93	291+00	2-17	100	95	81	60	45	36	26	24	21	20	16	13	23	2	36		
Id-93	298+00	2-23	100	97	84	65	58	37	25	21	19	17	14	11	NV	NP	57		
Id-93	334+50	2-28	94	83	71	55	52	33	23	20	18	16	13	11	22	3	39		
Id-90	429+00	2-28	100	94	80	59	45	35	22	19	18	15	13	10	NV	NP	53		
Id-90	497+85	3-3	100	90	75	55	40	30	20	18	16	14	12	10	NV	NP	43		
Id-90	548+00	2-17	100	93	78	56	39	28	18	16	14	12	10	1	22	2	42		
Id-90	564+00	3-3	100	95	81	63	47	36	24	21	19	17	14	11	22	2	40		
Prod Avg			100	92	76	52	40	31	20	18	16	15	10	7	NV	NP	57		

TABLE 2
BASE SAMPLES FROM ROAD, PROJECTS F-4113(2) AND F-4113(4) APRIL 1956

Station	Percent Passing Screen												Liquid Plas		Sand
	3/4-In	1/2-In	3/8-In	1/4-In	No 6	No 10	No 20	No 30	No 40	No 50	No 100	No 200	Limit	Index	
224	100	97	80	64	49	41	32	29	27	26	20	16	22	2	30
283	100	98	80	63	46	39	28	26	24	22	16	12	25	NP	57
338	100	96	78	61	47	40	29	27	25	23	18	15			
392	100	97	89	66	47	40	28	24	20	17	12	9	24	4	33
457	100	97	81	65	50	42	26	22	20	17	12	8	24	5	31
551	100	96	79	63	46	37	27	24	2	20	16	12	20	2	33

The second project wherein base failure was attributed to aggregate degradation was built on primary routes 4151 and 5152 in northern Idaho about 80 miles north of the projects mentioned. Initial construction was completed in the fall of 1957. By the spring of 1958 evidence of base failure had been noted. This was also a bituminous surface treatment.

Table 3 gives test data for the two basalt quarries that were used on this project. The data are from preliminary, production, and in-place samples. The samples were taken during the spring of 1958 when the failure was first noticed.

It might seem that the base aggregate in a degraded condition would still meet most of the specification requirements for such material. The changes in gradation, Atterberg limits, and sand equivalent do not tell the whole story, however. The breakup of the road surface seemed to derive, in part at least, from a concentration of fines and water just below the bituminous treatment. This "slurry effect" is alluded to in this statement submitted by the district engineer describing the failure:

Several miles of the existing bituminous surface treatment have already broken up badly this spring. Very little penetration or bond to the base material was attained on this surface treatment and the entire treatment appears to be floating and working as the traffic passes.

TABLE 3
COMPARATIVE TESTS ON BASE COURSE AGGREGATES, PROJECTS F-4151(1) AND F-5152(4)

Pit No	Sample	Percent Passing Sieve												Liquid Plas		Shrink	Sand	
		3/4-In	1/2-In	3/8-In	No 4	No 6	No 10	No 20	No 30	No 40	No 50	No 100	No 200	Limit	Index			
Lt-102	Preliminary ^a	100	84	63	52	51	29	16	14	12	10	8	7	NV	NP	0.4	72	
	Conveyer belt avg	100	97	80	49	39	27	17	14	12	11	8	7	20	NP		64	
	In-place, station																	
	400+52	98	92	78	53	48	38	26	22	20	18	15	12	NV	NP		37	
	451+75	98	91	79	55	49	39	27	23	21	18	15	12	21	7	3.4	1.0	36
	505+25	95	86	75	49	44	33	21	19	16	14	12	10	19	6	1.9	0.6	42
	557+25	100	93	76	46	40	30	19	17	14	13	10	8	NV	NP		48	
	662+85	100	95	84	59	53	44	33	30	27	24	18	12	NV	NP	0.4	33	
	668+75	100	93	77	48	42	32	20	18	15	13	10	8	NV	NP	0.6	47	
	715+85	100	95	84	56	49	39	25	22	19	17	13	11	NV	NP	0.8	40	
	821+87	100	91	71	40	35	27	17	15	13	11	9	7	NV	NP	0.6	35	
874+60	100	93	76	46	39	29	18	16	13	12	10	8	NV	NP	0.8	36		
Lt-117	Preliminary ^a	100	83	64	53	43	30	17	15	13	11	9	7	NV	NP	0.4	72	
	Conveyer belt avg	100	99	86	51	41	27	17	14	13	12	9	8	20	NP		55	
	In-place, station																	
	13+50	92	81	71	49	44	35	23	20	18	16	13	10	NV	NP		38	
	85+25	100	90	66	35	31	24	16	14	13	11	10	8	20	2	2.3	0.6	40
	137+25	95	86	77	52	47	37	25	22	20	18	15	13	20	1	1.0	32	
	189+15	99	94	85	60	54	44	29	26	23	20	16	14	20	2.4	0.8	29	
	241+95	97	97	69	41	37	29	19	16	14	13	10	8	22	3.7	1.6	29	
	341+80	93	85	72	46	41	32	21	18	16	14	12	10	21	3	3.7	1.2	31
	393+92	91	80	72	50	45	35	23	20	18	16	13	11	20	9	2.5	0.8	35

^aLA wear = 19

TABLE 4
GRADATIONS OF CONTROL SAMPLES^a, PROJECT S-4769(3), PIT LT-126

Type	Lab. No.	Ident. No.	Station	Depth (ft)	Percent Passing Sieve				Liquid Plas.		Sand Equiv.	
					3/4-In.	No. 4	No. 10	No. 40	No. 200	Limit		Index
A	4-497	117			100	56	29	13	5	NV	NP	56
	4-501	118			100	45	30	15	8	NV	NP	41
	4-502	119			100	46	32	16	7	NV	NP	59
	4-506	120			100	47	32	15	7	NV	NP	61
	Avg.				100	49	31	15	7	NV	NP	54
B	4-483	108			100	51	34	17	8	NV	NP	46
	4-484	109			100	52	34	16	7	NV	NP	53
	4-510	122			100	46	30	14	6	NV	NP	64
	4-511	123			100	44	30	14	6	NV	NP	58
	Avg.				100	48	32	15	7	NV	NP	55
A and B ^b	137194	161-A	245+50	0-0.3	100	55	37	21	11	NV	NP	38
	137196	162-A	246+20	0-0.4	100	52	34	19	11	NV	NP	30
	137198	163-A	291+15	0-0.4	97	48	37	25	16	22.9	4.5	17
	137201	164-A	320+00	0-0.4	100	57	42	26	17	23.9	5.7	17
	137203	165-A	321+85	0-0.4	100	57	44	28	19	19.7	2.2	23
	137205	166-A	350+55	0-0.3	100	55	39	26	16	20.4	1.7	22
	Avg.				99	54	39	24	15			25

^aCrushed rock base, 3/4-in. maximum.

^bMaterial sampled from roadway.

A project on State secondary route 4769 was the third in this general area to show evidence of aggregate degradation failure. Here again the failure showed up less than one year after the initial construction was completed. Table 4 gives test data from the basalt quarry identified as Pit Lt-126 for control samples produced during construction, and for samples taken from the roadway approximately nine months after the material had been placed.

These three projects all received special base treatments before being put into service. The project on route 4113 was reconstructed with the basalt aggregate base being treated with a special road oil. The base aggregate being placed on the projects on routes 4151 and 5152 was treated with an SS-1 emulsified asphalt. On route 4769 an experimental base stabilization project was set up using portland cement, lime, special road oil, and SS-1 emulsion. This project is under continuing study.

DEVELOPMENT OF A LABORATORY TEST

Development of a test or tests that would predict degrading aggregates was recognized as a pressing need since the investigations of failing projects were begun. The first attempt that was made involved the use of the Idaho kneading compactor. In this test a small portion (approximately 2 lb) of aggregate was subjected to 1,000 blows of the tamping foot at an applied pressure of 250 psi. This test has since been discarded because it was felt that the abrading action was much too severe.

The second attempt involved the degradation test using the Los Angeles abrasion testing machine. In this test 30 lb of aggregate are tumbled in the machine without using the metal spheres. This test appeared to have considerable merit, particularly because the sample was large and permitted a number of tests to be run on the degraded material. However, it has been abandoned in favor of the Idaho degradation test which is a wet-abrasion process.

Freezing and thawing tests have also been run in limited numbers. Data from these tests were far from conclusive; however, they showed no marked correlation between freeze-thaw cycles and degradation.

In 1959 the Materials and Research Division of the Washington Department of Highways published information on a test they had designed to predict degrading tendencies in rock (2). The test which is now being used by the Idaho Department of Highways is a modification of the Washington procedure and is described in test method T-15 as the Idaho degradation test (see Appendix). Both rock and gravel aggregates are evaluated in this test.

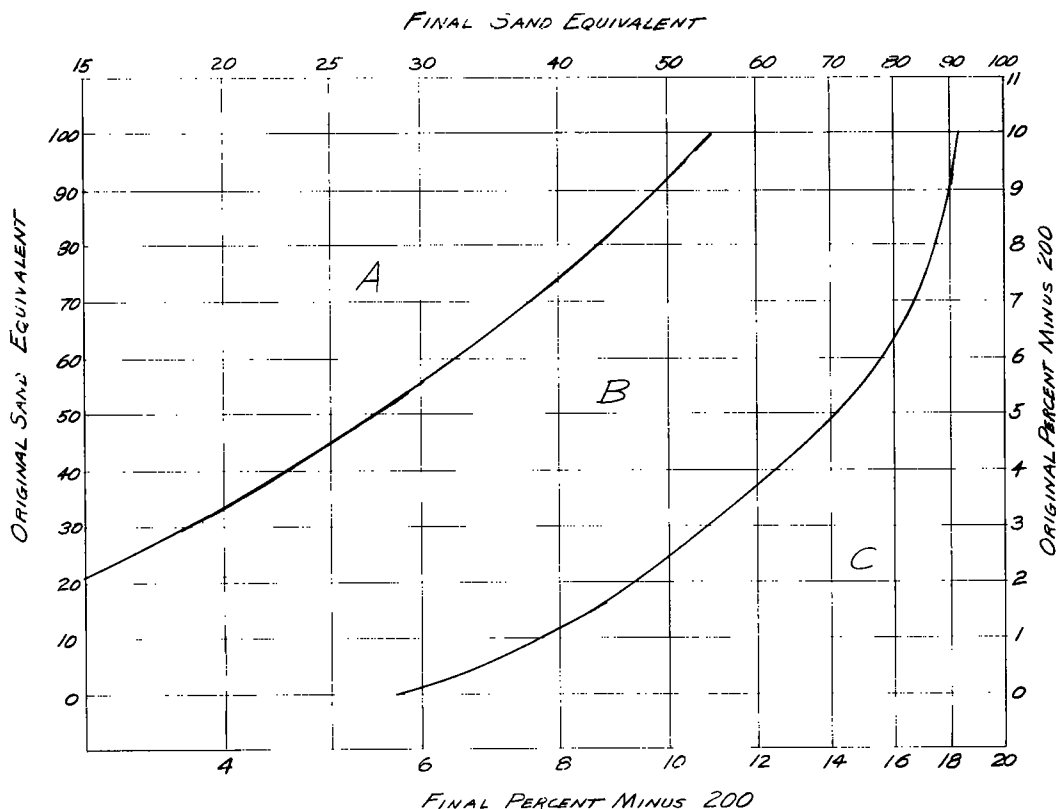


Figure 1.

The Idaho degradation test is run on an 1100-g sample of 3/4-in. maximum aggregate which has been prepared in the laboratory by crushing and screening. Fifty percent of the sample passes the No. 4 sieve. In the case of gravel, both the natural sand and the sand produced in crushing are used in the minus No. 4 fraction. The samples are similar to those prepared as specimens for bituminous mix design.

After the material has been oven dried, it is soaked in water for 16 hr in a 1-gal glass jar. Excess water is then removed so that the sample is just barely covered with water in the jar. The jar is placed in the Deval wet abrasion tester which has been modified for this test. The samples are set to rotate through 1,850 revolutions. The action is that of end-over-end tumbling and the aggregate abrades within itself.

After the tumbling period, the excess water is very carefully decanted, leaving fines in the aggregate undisturbed. The sample is then air dried and a sand equivalent test and a sieve analysis test are run.

The data reported are the original and final sieve analysis and the original and final sand equivalents. This test is time consuming, requiring about three days from start to finish for an individual sample. However, it is possible to run eight samples simultaneously in the modified Deval tester.

TEST RESULTS

A chart (Fig. 1) was devised on which were plotted arbitrary limits for the decrease in sand equivalent and for the increase in percent minus 200 from the degradation test. These limits were determined by considering the test values for sources with marginal and poor service records.

The chart is divided into three zones. If the plotted test results fall in Zone A, the aggregate has undergone a rather large decrease in sand equivalent. If the plotted results fall in Zone C, the increase in percent minus 200 is considered excessive. When the points fall in Zone B, the arbitrary limits for either test have not been exceeded.

In the preliminary testing of an aggregate sample a degradation rating of A or C or A-C is a signal to take a second look at the source.

Where a gravel pit is concerned, it may be that the natural fines have adversely affected the results. To check this possibility, the test is run on the crushed product only and, if necessary, the contract special provisions are written to require wasting natural fines in the crushing operation.

It is also necessary in some cases to use the material and specify that it be treated with cement, asphalt, or other additive. This procedure is recommended only after searching the adjacent areas for a good quality material within economical haul limits.

PETROGRAPHIC ANALYSIS

Basalt quarries in the north of Idaho are located in Columbia River basalt flows. Experience has shown that the quality of the rock can vary significantly not only from flow to flow but within flows. This condition makes it necessary that each site be investigated thoroughly with a field examination of rock exposures and drill core, and with laboratory tests and petrographic studies of each type of material.

Studies made initially with X-ray diffraction and differential thermal analysis apparatus have classified the offending mineral components so that the quantity of each can be determined by microscopic examination of rock-thin sections. The studies have shown that the products of aggregate degradation are clay or clay-like minerals produced through the alteration of the basic minerals in the basalt and through alteration of basaltic glass.

Basalts for the most part are composed of the following basic minerals: plagioclase, augite, hornblende, magnetite, ilmenite, and olivine. Basaltic glass (sideromelane) is another constituent which is found in most of the basalt flows.

Some of these constituents can alter through deuteritic action or through subsequent weathering to the following clay or clay-like minerals:

1. Smectite. — A variety of halloysite which is a clay of the kaolin group closely related to kaolinite. It is produced through the alteration of plagioclase.
2. Kaolinite. — A clay of the kaolin group produced through the alteration of plagioclase.
3. Iddingsite. — A clay-like material having a crystal structure like that of nontronite, the iron-montmorillonite. It is produced from deuteritic alteration of olivine.
4. Chlorophaeite. — A clay-like material that has a crystal structure like that of nontronite and is closely related to chlorite. It is produced through the deuteritic alteration of olivine.
5. Palagonite. — An alteration product caused by the oxidation and/or devitrification of basaltic glass. It can alter further to the clay mineral, montmorillonite, and to any of the four minerals just mentioned.

Several factors would have influenced the amounts of alteration products present in any basalt flow and the differences between flows. The environment that existed when the flow occurred is important in reference to deuteritic action. This would include temperature, rate of cooling, and the amount of moisture present. The elapsed time between flows would influence weathering action by the amount of protection provided by the covering flow. Weathering in the rock is related to the amount of voids and consequent surface exposure provided by vesicles, joints, and contraction cracks.

Through correlation of thin section analyses with service records for a limited number of basalt quarries, the following tentative limits have been established for total percentage of the five alteration products listed 0 to 15, good quality; 15 to 25, borderline quality; and 25 plus, poor quality.

Table 5 gives petrographic data from thin section analyses of several basalt quarries. Only four alteration products are shown because the studies revealed no kaolinite.

TABLE 5
THIN-SECTION ANALYSIS DATA FOR
SEVERAL BASALT QUARRIES

Source No.	Material (%)		Chloro- phaeite	Inter- sertal ^a	Intersertal ^a Material Description ^b	Est. Total Percent of Alteration Products	Quality
	Smec- tite	Idding- site					
Kt-1				67	Fresh, no alteration	0	Good
Kt-1	10			25	Nearly total alteration	35	Poor
Id-93	13	5		15	Nearly total alteration	33	Poor
Id-93	6	3		9	Nearly total alteration	18	Border?
Ben-46	3			39	10% voids, approx. 40% of remainder altered	15	Border?
Ben-46	3			35	10% voids, approx. 40% of remainder altered	13	Good
Ben-46		13		15	Nearly total alteration	28	Poor
Ben-72				14	Nearly 2/3 alteration	10	Good
Ben-72		13		18	Nearly total alteration	31	Poor
Ben-72	4			32	Approx. 50% alteration	20	Border
NP-96	3			11	Fresh, no alteration	3	Good
NP-96	5			10	Nearly total alteration	15	Border
Lt-126			5	42	3% voids, very little alteration	5	Good
Lt-126	4		6	26	3% voids, very little alteration	10	Good
Lt-126			3	40	2% voids, very little alteration	3	Good
Lt-126	5		6	38	6% voids, very little alteration	11	Good
Lt-87			2	36	2% voids, very little alteration	2	Good
Lt-87	6		4	30	6% voids, very little alteration	10	Good
Wn-56					Dense, minerals too small to count, little alteration	0	Good

^aIntersertal = texture of igneous rocks wherein a base or mesostasis of glass and small crystals fills the interstices between unoriented feldspar laths, the base forming a relatively small proportion of the rock.

^bAlteration product referred to is palagonite.

Intersertal material includes undevitrified glass, small particles of unaltered minerals, and void space. The total of the percents in the second through the fifth column establish the quantity of detrimental material. Unaltered or undevitrified basaltic glass is not considered a factor that contributes to aggregate degradation.

Table 5 shows that the total quantity of alteration products can vary widely among several thin sections representing the quarry. This would seem to bear out the contention that rock quality can cover a rather broad spectrum within the source.

This was confirmed by a closer study of two sources, Lt-126 which was associated with the failure on route 4769 described previously, and Lt-87 which has been suspected of degrading tendencies. These sources are about 12 miles apart. The preliminary samples which are given in Table 5 indicate that the rock could be classified as "good quality."

Because the Idaho degradation test had not yet been developed when these sources were explored, there are preliminary results which correspond with the samples in Table 5. However, a degradation test on a sample of material from the road gives the material in Lt-126 a rating of A on the chart.

In Table 6 the results of the analyses of several thin sections from each source are shown. The samples were selected from the open quarries to represent the complete spectrum of quality insofar as possible. It is evident that the range is broad.

Only two of the alteration products were detected in this second series of thin sections, and palagonite is the principal offender. Table 5 showed that in the rock there was a high percentage of basaltic glass which would be classified as "good quality." It is evident from Table 6 that in the poor quality rock this glass has devitrified or altered to palagonite.

TABLE 6
THIN SECTION ANALYSIS DATA FOR
ALL TYPES OF ROCK
IN QUARRIES Lt-126 AND Lt-87

Source No.	Material (%) ^a		Intersertal Material Description	Est. Total Percent of Alteration Products	Quality
	Chloro-phaeite	Intersertal			
Lt-126		41	Fresh appearing, no alteration in evidence	0	Good
	3	43	Fresh appearing, some isolated patches of palagonite, not over 4 % palagonite	5	Good
		49	Predominately glass nearly 100 % altered to palagonite and then weathered, can be crumpled in fingers	49	Poor
		40	Glass well along on alteration to palagonite; can be scratched by knife	32	Poor
Lt-87		52	Some voids; glass in beginning stage of alteration but not very far advanced, fresh	5	Good
		43	Glass just beginning to alter; fresh looking	2	Good
		44	Glass well on way to complete alteration to palagonite; general non-fresh appearance, scratched with a knife	40	Poor
		45	Glass completely altered to palagonite which is weathering rapidly; readily grooved by knife	45	Poor
		74	Glass charged with labradorite and augite; very fresh looking, no alteration noted.	0	Good

^aConsists essentially of glass charged with small fragments of labradorite, augite, and olivine with many ilmenite shards and specks of magnetite.

Although there are no corresponding degradation test results, it seems likely that the specimens showing the highest degree of alteration would fail through attrition. This is evident to a certain extent through megascopic examination.

CONCLUSIONS

It has been shown that in sources Lt-87 and Lt-126 the rock quality varies from good to poor. It has also been shown that all of the preliminary samples indicated good quality. If the factor that the material placed on the road failed or showed strong evidence of degradation is added to these, the conclusion is reached that the sources were not adequately investigated and sampled.

A thorough field investigation, together with laboratory testing and petrographic examination should make possible the isolation of basalt quarries or parts of quarries that contain poor quality rock.

There seems to be little doubt that the index of quality lies in the combined percentage of the mineral alteration products, kaolinite, smectite, iddingsite, chloro-phaeite, and palagonite. It seems likely that these materials must be present in the crushed rock that reaches the road, because there is no indication that alteration takes place in the base courses. The presence of these altered minerals in significant amounts causes the rock to be susceptible to degradation through mechanical abrasion, freeze-thaw, and the presence of moisture.

Although it is not practical to make petrographic analyses of gravel sources, the laboratory degradation test promises to furnish a reliable indication of degrading tendencies in gravel.

ACKNOWLEDGMENTS

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Appendix

IDAHO DEGRADATION TEST

The Idaho degradation test method is intended as a quantitative measure of the resistance of a coarse and fine aggregate to production of plastic fines by abrasion in the presence of water.

Apparatus

1. Deval Machine (Fig. 2).—The standard Deval machine is modified to hold 1-gal jars. The brackets holding the jars are so positioned that the jars rotate end over end. The machine is equipped with an automatic counter which can be set to stop the machine after the required number of revolutions. The machine maintains a substantially uniform speed of 30 to 33 rpm.
2. Wide-mouth 1-gal jars with lids and rubber gaskets.
3. Sieves.—Woven wire cloth sieves with square openings conforming to AASHO Designation M-92. Sizes required are 3/4-in., 1/2-in., 3/8-in., No. 4, No. 6, No. 10, No. 20, No. 30, No. 40, No. 50, No. 100, and No. 200.
4. Sand equivalent apparatus.
5. Scoop, containers, brush, etc.
6. Drying oven.

Preparation of Sample

1. The sample for test has the following gradation and weight:

16.7 percent passing 3/4-in. and retained on 1/2-in.	184 g
16.6 percent passing 1/2-in. and retained on 3/8-in.	182 g
16.7 percent passing 3/8-in. and retained on No. 4	184 g
50 percent passing No. 4	550 g
Total	1,100 g
2. Both the original and the crushed portions of the sample are used.
3. Original and crushed sizes representative of the gradation of the material as intended for use are combined.



Figure 2. Deval apparatus modified for Idaho degradation test.

4. Four pans of material are prepared as follows:

- (a) Original and crushed portions passing 3/4-in. and retained on 1/2-in.;
- (b) Original and crushed portions passing 1/2-in. and retained on 3/8-in.;
- (c) Original and crushed portions passing 3/8-in. and retained on No. 4;
- (d) Original and crushed portions passing No. 4 sieve.

5. For material coarser than the No. 4 sieve, original and crushed portions are thoroughly mixed and weighed out exactly the specified amount.

6. The specified amount of minus No. 4 material is obtained by the method of quartering or by the use of a sample splitter as described in Idaho T-1.

Procedure

1. The prepared oven-dried material (maximum drying temperature 140 F) is placed in a wide-mouth 1-gal jar and enough water added to cover the aggregate to a depth of approximately 1/2 in.

2. The sample is allowed to soak at least 16 hr.

3. After the soaking period the water in the jar is adjusted so the aggregate is barely covered. While the excess water is being poured or siphoned off, care must be taken not to lose any fines from the sample.

4. Lid is placed with rubber gasket on jar and sealed tightly. The jar is fitted into the modified Deval machine, after it is seen that it is securely fastened.

5. The Deval machine which has been preset to stop at 1,850 revolutions is started. The tumbling action of the aggregate as the jar rotates end over end produces the degradation.

6. At the end of the test period, the contents of the jar are emptied over a No. 4 sieve placed over a container to catch all the minus No. 4 material and water.

7. The jar is washed out, and by using as little water as possible, the plus No. 4 material is washed until all the fines sticking to the aggregate are washed into the minus No. 4 portion of the sample.

8. The plus No. 4 material is oven-dried and sieved accurately. If any material passes the No. 4 sieve during sieving, it should be added to the minus No. 4 portion.

9. Minus No. 4 portion is allowed to sit undisturbed until all fines have settled out and the water is clear. Excess water is carefully siphoned off.

10. The sample is spread out in a large baking pan and the material allowed to air dry until it reaches the fluff point. The fluff point is that point where the material is in a free-flowing condition, or when a portion is tightly squeezed in the palm of the hand, it will form a cast that will bear very careful handling without breaking. Drying the sample in a circulating heat oven maintained at 140 F is permissible, providing the sample is stirred occasionally and removed from the oven when the fluff point is reached.

11. Sand equivalent is run on the minus No. 4 portion.

12. Sand equivalent material and solution are retained and returned to minus No. 4 portion.

13. Entire minus No. 4 portion is washed over No. 200 sieve, dried, and sieved.

14. Gradation from 3/4-in. to dust is computed, based on initial oven-dry weight of 1,100 g as prepared.

Report

1. The original gradation and sand equivalent together with the final gradation and sand equivalent are reported. The amount of degradation and type are indicated by the change in test values.

2. All computations are entered on form DH-894.

3. The test results are transferred to form DH-802 for reporting.

Precautions

1. Baking sample during drying process should be avoided.

2. During siphoning or pouring excess water from sample, no fines should be lost.

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