MODIFICATION OF THE STANDARD LOS ANGELES ABRASION TEST

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The present Los Angeles abrasion test, commonly referred to as the Los Angeles rattler or LAR test, is satisfactory for determining the resistance of an aggregate to dry abrasion. However, some state highway departments have had to develop tests of their own for determining wearability of aggregates under wet abrasion conditions. This paper proposes a modification to the standard LAR test to include 250 revolutions with the aggregate in the dry state plus 250 revolutions after a fixed amount of water has been added. A sedimentation analysis is then run on the entire sample. If the sample passes the sedimentation analysis within specified limits, it is then oven-dried and placed in a sieve shaker. The percent loss through a No. 16 sieve is then determined. Results obtained from the testing of numerous samples, when compared with the Washington degradation test, the standard LAR test, and petrographic analysis, indicate that the proposed modification of the standard LAR test has considerable merit.

•THE NEED for quality tests as a measure of the degree of suitability of aggregates for construction purposes was first recognized in 1780 by Higgins (1). He stated, "I have thought that the small stones, which constitute the gravel chosen for our roads, could not be reduced to dust so soon as they now are by the heavy carriages...."

The Scottish engineer and road builder, John McAdam, noted in 1819 that the workmen determined the proper size of stone for road-building purposes by measuring them with their fists (2).

The Laboratoire des Ponts et Chaussees in Paris developed the first abrasion test for stone in 1870. In 1878 Deval invented a test to determine the resistance of mineral aggregates to abrasion. The American Society for Testing and Materials approved the Deval abrasion test in 1908 (3).

The first highway research to be carried out in the United States was in 1893 at Harvard University under the direction of L. W. Page. He developed a test for the cementing value of broken stone dust and a test for the toughness of aggregates by the Page impact machine (3).

As aggregate testing became standard practice in materials engineering, shortcomings of the Deval test were found. These inadequacies led to the development of the Los Angeles rattler (LAR) test in 1916 by the Los Angeles City Engineer's office (3). This test was rapid and simple and provided consistent results, as confirmed by circular track tests (4). For these reasons the American Society for Testing and Materials adopted the Los Angeles rattler test as a standard test in 1939.

Goldbeck (5) and Woolf (6) observed that there appeared to be a definite relationship between the results of the Los Angeles test and the corresponding road performance record. However, failures occurred on roads containing aggregates that had passed the LAR and other required tests.

The present Los Angeles rattler test determines the abrasive and structural characteristics of dry aggregates, but it is unable to identify some aggregates that have failed because of the large amount of plastic fines that are produced when these aggregates degrade in the presence of water. As a consequence, there have been many attempts to develop degradation tests with water added.

In 1966 Breese did extensive research for the state of Nevada in correlating existing degradation tests with a view toward possible development of a new test (7). The tests that he correlated included the elutriation test devised by Collins (8), the jar-mill test devised by Minor (9), the Washington degradation test (10), and the California aggregate durability test (11).

It is important to note that all four of these degradation tests use a sedimentation analysis of the fines produced. This analysis is based on the principle of Stokes' law (12), which states that the theoretical velocity of vertical settling for a particle can be computed by the following formula:

$$V = gd^2 \frac{(D_1 - D_2)}{18u}$$

where

   g = acceleration due to gravity, cm/sec/sec;
   D_1 = density of settling particle, gram/cm^3;
   D_2 = density of water, gram/cm^3;
   d = diameter of settling particle, cm; and
   u = dynamic viscosity of water, dyne-sec/cm^2.

By analyzing Stokes' law it can be noted that the larger and denser particles have a greater settlement velocity and therefore will travel farther in a specified amount of time. For this reason, in a given time period, coarse-grained particles would provide lower sediment heights than fine-grained particles.

In all four of the degradation tests that Breese studied, a representative sample of the fine particles produced during the mechanical agitation of the aggregate was poured into a sand-equivalent test cylinder. Seven milliliters of sand-equivalent stock solution were added, and the cylinder was filled with water to the 15-in. mark. The cylinder with its contents was thoroughly mixed by 20 inversions in 35 sec and then allowed to settle for 20 min. The sediment (floc) height was then read. Poor aggregates that tend to produce plastic fines were indicated by high sediment heights.

Breese correlated the degradation factors obtained by the various methods and also the sediment heights obtained by each method. Using the linear regression method of correlation, he found that the Washington degradation test produced the highest coefficients of correlation when compared with the other tests (7).

Platts and Lloyd (13) studied six degradation tests in Alaska. From this study, the Washington degradation test was recommended for the following reasons:

1. Test results and field evaluations correlated very well.
2. The test has but one numerical value on which to base the quality of any given aggregate.
3. Although similar to the California durability test, it provides more consistent results.

In 1968 the authors developed a modified LAR test that included wet abrasion, loss determined by a sieve in the standard fine-aggregate sieve series, and a sediment-height test using a specially designed Plexiglas cylinder, 6 in. in diameter by 25 in. high. Conclusions were as follows:

1. The modified LAR test appeared to be as reliable as the Washington degradation test in determining unsatisfactory aggregates.
2. It is not necessary to sieve out the coarse particles before sedimentation, because these settle out very rapidly and have minor effects on the settlement of the fines.

3. The modified LAR test does not produce as many plastic fines as the Washington degradation test; however, the results indicated similar categorization of aggregates.

4. The modified LAR test uses the No. 16 sieve, which is in the standard fine-aggregate sieve series.

Breese's report states that there appears to be universal agreement that the best method for determining potential degradation is by petrographic analysis (7). The drawbacks to such an approach are that it is time-consuming, requires the services of a trained petrographic expert, and is, in general, not adaptable to field laboratory use.

OBJECTIVES OF INVESTIGATION

The objectives of this investigation were (a) to compare the modified LAR test with the standard LAR test, the Washington degradation test, and the petrographic analysis; (b) to determine a sediment-height correction factor for mixture temperature in the sedimentation portion of the modified LAR test; and (c) to determine the reproducibility of the modified LAR test.

AGGREGATES TESTED

In this study aggregate tests were conducted on 51 samples from Idaho, Montana, and Washington supplied by the U.S. Forest Service, Region 1, Missoula, Montana. Most of the samples were crushed basalt, siltstone, quartzite, granite, granodiorite, schist, or gneiss. The major minerals or rocks that composed each of the 51 samples were determined by petrographic analysis. Some additional crushing was necessary to obtain the B gradation used for the modified LAR test.

NEW WASHINGTON DEGRADATION TEST

The procedure used for the new Washington degradation test (10) is as follows:

1. The material to be tested shall be crushed to pass the ½-in. sieve, washed over a No. 10 sieve, and dried to constant weight. Prepare samples graded as follows: ½ in. to ¼ in., 500 grams; ¼ in. to No. 10, 500 grams.

2. Place sample in a 7.5-in. diameter by 6-in. high plastic cannister (Tupperware), add 200 cc water, cover tightly, and place in a Tyler portable sieve shaker (Soiltest C1-300 and 305, suitably motorized to provide agitation described in step 3).

3. Run shaker for 20 min at 300 ± 5 oscillations per minute with a 1.75-in. throw on the cam. At the conclusion of the shaking time, empty the cannister into nested No. 10 and No. 200 sieves placed in a funnel over a 500-ml graduate to catch all water. Wash out the cannister and continue to wash the aggregate with fresh water until the graduate is filled to the 500-ml mark. Caution: The aggregate may drain 50 to 100 ml of water after washing has been stopped.

4. Pour 7 ml of sand-equivalent stock solution into a sand-equivalent cylinder. Bring all solids in the wash water into suspension by capping the graduate with the palm of the hand and turning the cylinder upside down and right side up as rapidly as possible about 10 times. Immediately pour the liquid into the sand-equivalent cylinder to the 15-in. mark and insert the rubber stopper in the cylinder.

5. Mix the contents of the sand-equivalent cylinder by alternately turning the cylinder upside down and right side up, allowing the bubble to traverse completely from end to end. Repeat this cycle 20 times in about 35 sec.

6. At the conclusion of the mixing time, place the cylinder on the table, remove the stopper, and start the timer. After 20 min, read and record the height of the sediment column to the nearest 0.1 in.

Calculation of the new Washington degradation factor is as follows:

$$D = \frac{(15 - H)}{15 + 1.75H} \, 100$$

where D is the new Washington degradation factor and H is the height of sediment (floc) in the cylinder. In this formula the values may range from 0 to 100, with the high values being the best materials. The formula was adjusted to place doubtful materials at about the midpoint of the scale. At the present time, the minimum Washington degradation factor for surface aggregates is 25. All of the Washington degradation factors were determined at the U.S. Forest Service Materials Testing Laboratory in Missoula, Montana. Table 1 gives these data.

STANDARD LOS ANGELES RATTLER TEST

The standard LAR test procedure with B graded material was used according to the American Society for Testing and Materials. The B gradation consists of 2,500 grams

TABLE 1
DEGRADATION TEST RESULTS

Sample No.	Standard LAR No.	Modified LAR Test		Washington Degradation Test	
		Modified LAR No.	Sediment Height at 20 C (in.)	Sediment Height (in.)	Degradation Factor
1801	37	23	6.0	1.3	79
1805	26	29	13.1	9.3	18
1887	17	17	14.5	12.1	8
1909	17	16	6.2	2.7	53
1922	16	14	6.7	2.4	66
1953	18	18	13.5	12.8	6
1959	18	18	6.0	1.7	74
1960	20	17	7.3	2.2	68
2022	—[a]	19	5.7	—[a]	—[a]
2026	25	24	12.2	4.9	43
2074	13	13	7.0	1.1	82
2075	19	18	6.3	0.5	91
2076	15	15	6.1	3.8	52
2079	20	18	14.1	13.8	3
2080	17	19	9.6	2.7	62
2094	38	42	10.1	2.4	66
2096 (2583)	31[b]	28	10.8	8.7	21
2122	20	21	12.3	1.0	84
2123	42	45	7.9	2.0	70
2124	31	27	7.4	1.3	79
2125	21	19	6.1	1.8	73
2126	22	21	13.8	11.4	11
2137	34	30	7.2	1.6	75
2138	35	30	9.8	1.0	84
2139	15	17	6.8	0.4	93
2141	85	69	10.1	0.9	85
2142	60	56	7.8	1.2	81
2144	33	38	7.7	1.1	82
2145	35	33	10.5	2.7	53
2148	23	26	19.1	13.5	4
2180	26	25	15.8	0.8	87
2181	18	18	6.3	1.4	78
2182	22	20	6.7	0.7	88
2183	27	28	6.3	0.9	85
2187	17	18	14.6	11.8	9
2222	17	20	10.5	2.8	61
2516	29	30	13.7	4.2	48
2555	22	20	6.1	2.8	61
2556	28	23	8.0	1.5	77
2557	36	33	7.8	2.8	61
2561	34	30	13.8	8.2	23
2562	68	57	9.7	10.1	15
2563	25	23	10.7	1.6	75
2584	20	21	16.1	11.5	10
2635	23	20	9.7	5.9	36
2756	39	35	9.4	2.4	66
2757	36	42	11.3	5.0	42
2758	26	22	8.8	1.8	73
2759	17	15	6.8	2.0	70
2760	16	17	13.6	13.5	4
2761	28	28	13.2	13.5	4

[a]Data not available.
[b]Obtained from different sample (number in parentheses) but same source.

of material passing the ³/₄-in. sieve and retained on the ¹/₂-in. sieve plus 2,500 grams passing the ¹/₂-in. sieve and retained on the ³/₈-in. sieve. The abrasive charge consists of 11 steel spheres having a total weight of 4,584 ± 25 grams.

The maximum amount passing the No. 12 sieve for the standard LAR test has been specified as 40 percent for surface courses and surface treatment. A maximum passing number of 50 percent has been established for concrete, base courses for concrete pavements, and bituminous macadam pavements.

All of the standard LAR numbers given in Table 1 were determined at the Forest Service Materials Testing Laboratory in Missoula.

MODIFIED LOS ANGELES RATTLER TEST

An initial study by the authors in 1968 established a modified Los Angeles rattler test procedure as follows:

1. Prepare the sample in the same manner as required for the standard LAR test using the B grading.

2. Place the test sample and the abrasive charge into the Los Angeles testing machine. Rotate the machine for 250 revolutions with the aggregate dry. Add 1,000 ml of water and rotate for 250 additional revolutions. A flat rubber gasket cemented to the cover of the machine makes it watertight.

3. Wash the entire contents of the machine into a large pan placed beneath the machine. Then, wash the entire contents of the pan into the large specially designed graduated cylinder previously prepared with 25 ml of sand-equivalent stock solution. The specially designed cylinder is constructed of Plexiglas, 6 in. in diameter and 25 in. high (Fig. 1).

4. After initial settling of the particles, adjust the water in the cylinder to the 20-in. mark by adding or draining water. Cap the graduated cylinder and mix by inverting from end to end 20 times within 30 sec. Suspend a thermometer at the 10-in. mark in the solution and allow the floc to settle. Keep the cylinder out of direct sunlight.

5. After 20 min read the water temperature to the nearest 0.1 of a degree centigrade and record the sediment height to the nearest 0.1 in.

6. Wash the entire contents of the cylinder over a No. 30 sieve and dry the portion retained on the sieve to constant weight.

7. Sieve the dry part over a No. 16 sieve and weigh the amount retained. Subtract this weight from the original weight and calculate the percentage loss.

8. The modified Los Angeles rattler number is expressed as a fraction showing the percent loss/sediment height (for example, 34/10.6).

The maximum allowable percent loss through the No. 16 sieve for the modified LAR test is the same as that prescribed for the standard LAR test. The study indicated that the maximum passing sediment height is about 13.0 in. The results of this test are given in Table 1.

Determination of Sediment-Height Correction Curves

To determine the effect of the mixture temperature on the sediment-height portion of the modified LAR test, the sediment heights vs. the recorded mixture temperatures for 21 samples were observed. Using 20 C as a
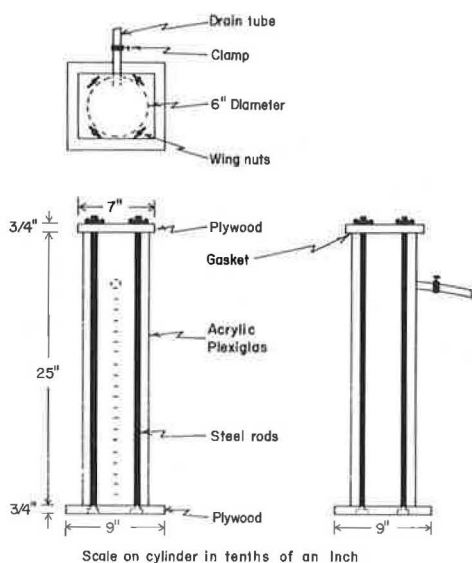

Figure 1. Sediment-height cylinder for modified Los Angeles rattler test.
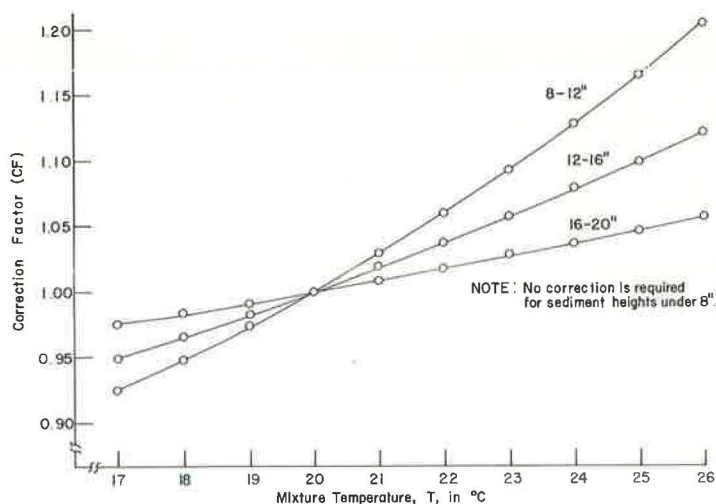
Figure 2. Sediment-height correction factor vs. mixture temperature for three sediment height ranges.

standard temperature, a sediment-height correction factor, CF, was calculated for each sample with temperatures ranging from 17 to 26 C. The average correction factor was calculated for each degree centigrade for each of three sediment-height ranges. These averages vs. the 10 corresponding mixture temperatures are shown in Figure 2.

To apply the sediment-height correction factor after having performed the modified LAR test, use the following formula:

$$S_{20} = (CF) \, S_T$$

where

S_{20} = corrected sediment height at 20 C,
CF = sediment-height correction factor, and
S_T = observed sediment height at T degrees centigrade.

PETROGRAPHIC EXAMINATION OF AGGREGATES

Petrographic examination of aggregate is a visual analysis of the material in terms of both lithology and properties of the individual particles. The procedure requires use of a hand lens and petrographic and stereoscopic microscopes. By petrographic examination, the relative abundance of specific types of rocks and minerals is established; the physical and chemical attributes of each, such as particle shape, surface texture, pore characteristics, hardness, and potential alkali reactivity, are described; and the presence of contaminating substances is determined.

Dr. Donald W. Hyndman at the University of Montana performed the petrographic analysis on all original samples (14). The major minerals or rocks that composed each of the 51 samples were determined. From the petrographic analysis, Hyndman also predicted whether or not the aggregates were acceptable for road surfacing. Those that failed his analysis are given in Table 2.

DISCUSSION OF TEST RESULTS

The primary purpose of this study was to determine if a single test—the modified LAR test—can identify low-quality aggregates which it now takes three tests—the stan-

TABLE 2

COMPARISON OF DEGRADATION TESTS

Passed All Four Tests		Failed Standard Los Angeles Rattler Test	Failed Modified Los Angeles Rattler Test by		Failed Washington Degradation Test	Failed Petrographic Analysis
			Percent Loss	Sediment Height		
1801	2139	2123	2094	1805	1805	1805
1909	2144	2141	2123	1887[a]	1887[a]	1953
1922	2145	2142	2141	1953	1953	2076
1959	2181	2562	2142	2079	2079	2079
1960	2182		2562	2126	2096	2080
2022[b]	2183		2757	2148	2126	2094
2026	2222			2180	2148	2180
2074	2555			2187	2187	2187
2075	2556			2516	2561	2561
2122	2557			2561	2562	2756
2124	2563			2584	2584	2757
2125	2635			2760[a]	2760[a]	2761
2137	2758			2761	2761	
2138	2759					

[a]1887 and 2760—Petrographic analysis unavailable.
[b]2022—Standard Los Angeles Rattler Test and Washington Degradation Test unavailable; therefore, assumed passing.

dard LAR test, the Washington degradation test, and a petrographic analysis—to identify.

The correlation between the standard and the modified LAR percent losses was determined. Using the method of linear correlation (15), the correlation coefficient, r, was found to be 0.956 (Fig. 3), which is quite high and therefore significant. It was felt that the 1,000 ml of water used in the modified test caused enough extra degradation to offset the use of the No. 16 (1.19-mm) sieve instead of the No. 12 (1.68-mm) sieve that is prescribed for the standard test. The standard LAR test yielded 29 specimens higher and 14 specimens lower in percent losses than the modified LAR test. However, the difference between the averages for both tests was only 1.58 percent abrasion loss. This small amount is not considered important because the sample may vary this much from test to test or from sample to sample taken from the same source.

The modified LAR test was correlated with the Washington degradation test because both tests utilize a sedimentation analysis. The parabolic equation, $Y = -3.15 + 0.555X + 0.02X^2$, provided the best index of correlation, $i = 0.745$, as is shown by the solid line in Figure 4.

Sample 2180, the only lightweight aggregate tested (specific gravity = 1.76, percent absorption = 18.97), had a modified LAR test sediment height of 15.8 in. and a Washington degradation test sediment height of only 0.8 in. The reason for this extreme variance is not known; however, it is possible that the aggregates used were from different locations within the same source. For this particular sample, performance records supplied by the U. S. Forest Service indicated that this aggregate had provided 1 to 3 years of service. When this sample was not included in the computations, an index of correlation of 0.804 was found. The par-
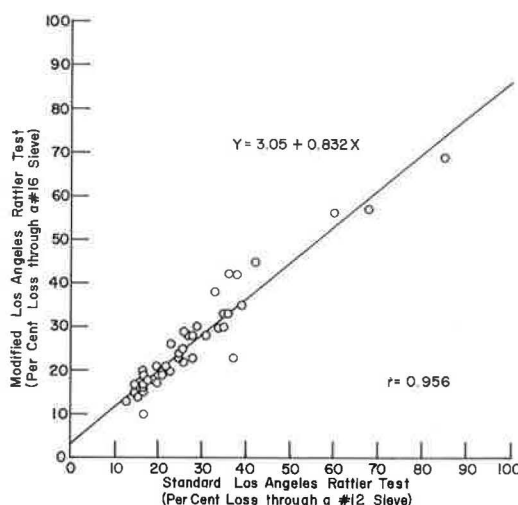

Figure 3. Modified Los Angeles rattler percent loss vs. standard Los Angeles rattler percent loss.

abolic equation for this case was $Y = -2.02 + 0.251X + 0.04X^2$, as shown by the dotted line in Figure 4.

Comparing the modified LAR test with the other tests conducted, only four specimens (2076, 2080, 2096, and 2756) would have passed the modified LAR test but failed one of the other three tests. Samples 2076, 2080, and 2756 failed only the petrographic analysis. Sample 2096 failed only the Washington degradation test. This failure may be explained by the fact that the Washington degradation test was performed on an alternate sample from the same source. The modified LAR test failed one sample, 2516, that none of the other tests termed as failing. This sample is in the "unsure" area because the modified

Figure 4. Washington degradation test sediment height vs. modified Los Angeles rattler test sediment height.

sediment height was 13.7 in. and Washington degradation factor was 48 (Table 1).

The modified Los Angeles rattler test compared with the petrographic analysis better than did the Washington degradation test. Six samples were deemed unsatisfactory by the petrographic analysis yet were approved by the Washington test compared to only three samples approved by the modified LAR test.

All of the aggregates that failed the standard Los Angeles rattler test also failed the modified Los Angeles rattler test by percent loss through the No. 12 and No. 16 sieves respectively. It is important to note that the modified test failed two additional samples. These failures may have occurred because of the water used in the modified test. The same two samples were also found to be unsuitable by the petrographic examination. Also, it is believed that if samples 1887 and 2760 had been available they would have been rejected by the petrographic analysis because both failed the modified LAR test and the Washington degradation test.

Check tests for specific gravity and absorption were made on 32 samples. No significant correlation was found when comparing these results to those of the various degradation tests conducted.

A failing percent loss in the standard and the modified LAR tests usually occurred in coarse-grained igneous or metamorphic rocks such as pegmatite, aplite, schist, granite, or gneiss. The primary minerals in these unsatisfactory aggregates were muscovite, quartz plagioclase, and orthoclase. These belong to the mica and feldspar groups of silicate minerals. The gneisses were usually "fast settling" during the sedimentation analysis.

Sample 2757, a micaceous siltstone, was the only sedimentary rock to fail by percent loss through the No. 16 sieve, whereas several samples failed the sediment-height analysis. This would seem to indicate that the degradation of sedimentary rocks normally cannot be determined without some sort of degradation in the presence of water.

The sedimentary rocks that were determined to be unsuitable were primarily siltstone, shale, sandstone, and limestone. A large amount of plastic fines was produced by these fine-grained rocks, which usually contained the minerals calcite, orthoclase, illite, and quartz. These rocks normally failed the sediment-height analysis in both the Washington degradation test and the modified LAR test.

It is of interest to note that sample 2148, a quartzite, produced extremely high sediment heights. The large quantity of plastic fines that caused these high sediment heights may have been due to a few parallel veins of shale at the sample source. The
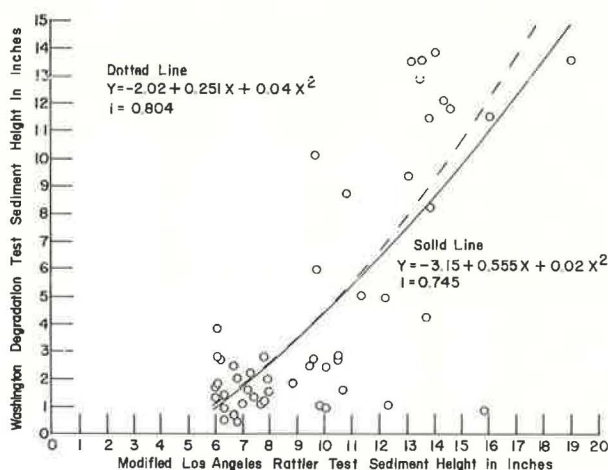
petrographic examination suggested that it was highly recommended as a road aggregate. According to available road-performance records, the aggregate has been used on a logging road for 5 years with excellent service.

To determine sediment-height correction curves, the water was changed in 21 samples. A temperature range of 17 to 26 C was chosen because the probability of a mixture temperature outside of this range was unlikely. All of the samples tested were within this range.

It was felt that applying the same correction factor for two different samples with far different sediment heights at the same temperature would not be correct. A possible solution was to make three curves, each with a different range in sediment heights. Because it was found that a change in mixture temperature had negligible effect on the sediment heights less than 8 in., no correction was needed on these fast-settling mixtures.

The corrected sediment height, S_{20}, was used to determine if an aggregate was desirable or undesirable. The failing corrected sediment height appeared to be about 13.0 in. It was found that the correction factor, CF, affected some of the observed sediment heights by more than 1 in.

To determine the reproducibility of the modified LAR test, 12 samples were tested twice. The four fast-settling samples averaged a variation in sediment height of only 0.1 in. with a range of 0 to 0.3 in. The remaining 8 samples varied by an average of 1.2 in. with a range of 0.2 to 3.0 in. The 12 samples tested varied by an average of 1.2 percent abrasion loss through the No. 16 sieve with a range of 0 to 4.0 percent. This indicates that the modified LAR test can be reasonably reproduced. Because 5,000 grams were used in the modified LAR test, compared to 1,000 grams used in the Washington degradation test, the results should be more representative of the quality of the aggregate. Better reproducibility is normally obtained using a larger, more representative sample.

CONCLUSIONS

From this study the following conclusions have been reached:

1. The modified Los Angeles rattler test is reliable for distinguishing between desirable and undesirable aggregates and, therefore, could possibly replace the standard Los Angeles rattler test, the Washington degradation test, and the petrographic examination.

2. The Washington degradation test does not appear to degrade lightweight aggregate as much as the modified Los Angeles rattler test.

3. If more samples with Washington degradation test sediment heights between 3 and 11 in. had been supplied, a higher index of correlation may have been obtained.

4. The modified Los Angeles rattler test compared with the petrographic analysis better than did the Washington degradation test.

5. The mixture temperature has pronounced effect on the sediment height in the modified Los Angeles rattler test.

6. The maximum allowable sediment height should depend on the use for which the aggregate is intended. However, aggregates producing sediment heights greater than 13.0 in. should be considered unsatisfactory for use on highway surfaces or base courses.

7. The modified Los Angeles rattler test results can be reproduced to within the tentative limits of ±1 percent abrasion loss and ± 1.25 in. in the sediment height.

8. The advantages of the modified Los Angeles rattler test are that (a) sample preparation is simple and quick; (b) the total time to perform the test is less than 1 man-hour; (c) the use of a 5,000-gram test sample increases the probability of obtaining more representative results; and (d) the use of a No. 16 sieve is more compatible with the standard fine aggregate sieve series.

ACKNOWLEDGMENTS

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