Effects of Los Angeles Abrasion Test Values on the Strengths of Laboratory-Prepared Marshall Specimens

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In the United States, approximately 93 percent of hard-surfaced roads are surfaced with asphaltic concrete mixtures. These mixtures are a combination of high-quality aggregates and an asphalt cement. The aggregates must be able to resist abrasion and degradation during manufacturing, placing, and compacting. For decades, researchers studied the resistance of aggregates to abrasion and impact. The most common test used to measure this resistance is the Los Angeles (LA) abrasion test. The LA test has been used for many years throughout the United States and has a local history. From this history, acceptance specifications have been written. The objectives were to determine (a) the extent of the use of LA values in the United States; (b) any discernible difference in the level of performance (i.e. strengths) between laboratory-prepared Marshall specimens using different aggregate sources; and (c) the level of degradation of extracted aggregates. In general, the majority of states use the LA abrasion test for writing specifications. In some cases, there were not significant differences between the dry and wet indirect tensile strength and resilient modulus values of specimens prepared with aggregates with low LA values versus specimens prepared with aggregates with high LA values. The gradation analysis of the recovered aggregates indicated that no major degradation of aggregates occurred with various compactive efforts.

In the United States, approximately 93 percent of hard-surfaced roads are surfaced with asphaltic concrete mixtures. This percentage accounts for nearly 2 million miles of flexible pavements (*1*). Flexible pavements are a combination of an asphalt cement and high-quality aggregates. The aggregates must be able to resist abrasion and degradation during manufacturing, placing, and compaction of the asphaltic concrete mixtures. In addition, the aggregates must be able to resist the forces applied by the traffic during the service life of the pavement (*2*). As a result, there is a constant demand for high-quality aggregates. For decades, research has been directed toward determining quantitatively the effects of aggregate properties on asphaltic concrete mixtures. One property studied is the resistance of aggregates to abrasion and impact.

Toughness can be defined as the ability of an aggregate to resist the impacting and grinding forces applied during manufacturing, placing, and compacting. The tests to measure the toughness of aggregate particles are described in ASTM C131, *Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine;* ASTM C535, *Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine;* and AASHTO T96, *Resistance to Abrasion of Small Size Coarse Aggregate by Use of Los Angeles Machine.*

The Los Angeles (LA) degradation test measures an aggregate's resistance to wear or abrasion. In this test (i.e., ASTM C535), approximately 10,000 g of sample is placed in the Los Angeles abrasion testing machine and rotated 1,000 revolutions at 30 to 33 rpm. The abrasive and impacting forces are applied by 12 steel spheres averaging 1.84 in. in diameter and weighing between 390 and 445 g, and having a total weight of approximately 5000 g. The percentage wear (LA value) is calculated using the following relationship:

$$\text{Percentage LA Loss} = [(\text{Original weight} - \text{Final weight})/(\text{Original weight})] \times 100$$

BACKGROUND

Before the LA abrasion test was tentatively adopted in 1937, the Deval method of testing was the only accepted method to determine the toughness of aggregates. The Deval test was developed in France in the 1870s and was adopted as a standard test for use on road materials by ASTM in 1908 and revised in 1926 (*3*). Because the LA abrasion test related closer with the performance of aggregates in pavements than the Deval test, in 1940 this test was adopted as a standard test for measuring the wear of aggregates (*3*).

Woolf (*4*) and Woolf and Runner (*5*) reported that a relation exists between the abrasion loss from the LA abrasion test and the service records of materials used in bituminous construction, surface treatment, and portland cement concrete. They also concluded that this test gives an accurate indication of the quality of materials tested and that the results can be used in specifications controlling the acceptance of coarse aggregates.

Hatt (*6*) also reported that a relation exists between the results of the LA abrasion test and the action of the road roller on the aggregates in place. Hatt found a large amount of degradation of aggregates in bituminous surface treatments caused by the compaction efforts of rollers. Hatt also noted the gradual degradation of aggregates in the surface treatment tested because of traffic conditions.

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However, the results of a laboratory-field study by Goode and Owings (*7*) indicated that the degradation of aggregates caused both by compaction and traffic was insignificant in most instances and in no instance was sufficient to affect the service behavior of the respective pavements.

In 1971, to obtain information regarding aggregate degradation, Committee A2G201, Mineral Aggregates, of the Highway Research Board, prepared and distributed a questionnaire on aggregate degradation (*8*). The responses among agencies that were using solely an abrasion test (e.g., the LA abrasion test) indicated that only 36 percent felt protected against accepting problem aggregates. The level of confidence increased to 87 percent when the abrasion test was used in combination with soundness and wet abrasion tests (*8*).

Lappalainen (*9*) studied the factors influencing wear resistance of pavements. He concluded that in many cases the strength values (i.e., from the LA abrasion test) determined in the laboratories have proved to be misleading. He also noted that the strength and wear resistance of aggregates cannot be determined only on the basis of rock type.

Woodside and Peden (*10*) studied the integrity of standard tests used in Ireland. Ten quarries were used to obtain the aggregate samples to calculate the LA abrasion loss. The authors found that the LA abrasion test was a consistent method of detecting weak materials and was a means of predicting aggregate impact value and aggregate crushing value.

Wylde (*11*) reviewed and investigated the road failures, aggregates, and test methods used in Australia. He concluded that the absolute significance of test results was not apparent. He also found that the consensus was that the results of a range of test methods should be interpreted in the light of experience with the aggregate in service.

West et al. (*12*) investigated tests for evaluating degradation of base course aggregates. They concluded that the LA abrasion test appears to be a good indicator of the degradation properties of carbonate rocks, but not of basalt rocks. They also noted that the textural parameters (e.g., grain size and roundness) were related to the LA abrasion wear value.

OBJECTIVES

The objectives of this research study were to

1. Conduct a survey, through a questionnaire, to determine the use of LA test results in various state highway agencies throughout the United States;
2. Evaluate the effects of low and high LA values on the strengths of asphaltic concrete mixtures; and
3. Evaluate the effects of low and high LA values on the degradation of aggregates by using different compactive efforts (blows per side) on the laboratory-prepared Marshall specimens.

SCOPE

A questionnaire was sent to all state and federal highway agencies throughout the United States. This survey was conducted to obtain specific information regarding the use of the LA test for highway specifications.

In addition, 288 laboratory-prepared Marshall specimens were made and tested. Four aggregate sources with a range of LA values from 28 to 55 were selected for this study. Four different compactive efforts (i.e., 25, 50, 75, and 100 blows per side) were used to prepare the specimens. The specimens were divided into two moisture conditioning groups: dry and wet. The Tunnicliff and Root (*13*) method of moisture conditioning was used for testing the wet specimens.

In order to study the effects of high and low LA values on the degradation of aggregates, the aggregates were extracted from randomly selected laboratory-prepared Marshall specimens made with various compactive efforts. Gradation analyses were performed to determine the amount of degradation.

For each specimen, the dry and wet resilient modulus (MR), and dry and wet indirect tensile strength (ITS) values were obtained. The tensile strength retained (TSR) and resilient modulus ratio (MRR) were calculated for each pair of dry- and wet-conditioned specimens prepared with the same aggregate source and number of blows per side.

MATERIALS

The materials used in the preparation of laboratory-prepared Marshall specimens included four aggregate sources (denoted as A, B, C, and D) and one asphalt cement source (AC–20). Aggregates A, B, C, and D (all granite) had LA values of 55, 48, 30, and 28, respectively. The LA value was determined using aggregates of Grading B from each source. All of the mixtures are used for surface courses in South Carolina.

TESTING PROCEDURES

For each aggregate source, the Marshall method of mix design was performed to obtain the optimum asphalt content according to the Asphalt Institute's Manual Series 2 (MS–2) (*14*). A total of 288 specimens were prepared and tested. The specimens were randomly selected and separated into two testing groups; wet and dry. Dry specimens were placed in a temperature control cabinet (77°F ± 2°F) for 24 hr. Wet specimens were subjected to Tunnicliff and Root's (*13*) moisture susceptibility test. This test requires each specimen to be submerged in water with a vacuum of 20 psi for 5 min. Then, the specimen must be placed in a water bath (140°F ± 2°F) for 24 hr and then placed in another water bath (77°F ± 2°F) for 1 hr before testing.

Both wet and dry specimens were tested, at 77°F ± 2°F, for MR (ASTM D–4123) using a Retsina Mark VI resilient modulus testing machine. Each specimen was placed on its circular side in the measuring yoke. Horizontal deformations were measured when the specimen was subjected to repeated vertical loads (10 repetitions in 30 sec) of approximately 70 lb. Each specimen was then turned 90 degrees on its circular side and tested again. The mean of the two test values was used as the MR value for that specimen.

All specimens were then tested for ITS (at 77°F ± 2°F) after 2 hr of dry or wet storage. The ITS was obtained using a Marshall testing machine (deformation rate of 2 in./min) with a testing head that was modified by the addition of half-inch metal strips.

The TSR and MRR were calculated by dividing the wet strength value by the respective dry value. These values indicated the percentage of strength that is retained when the specimen is saturated. Four of the samples within each group (i.e., aggregate source and number of blows per side) were randomly chosen and sieve analyses (ASTM C–136) were performed on the extracted aggregates.

STATISTICAL DESIGN

A complete random design (CRD) was used for the statistical design because the laboratory-prepared specimens were essentially homogeneous. The laboratory treatments (i.e., aggregate sources and number of blows per side) on some of the physical characteristics (ITS, MR, TSR, and MRR) of the asphaltic concrete mixtures were measured using analysis of variance (ANOVA).

Figure 1 shows the experimental design used to prepare and test the specimens. In this project, there were 32 combinations of variables (i.e., 4 aggregate sources × 2 moisture conditions × 4 blows per side). There were 288 Marshall specimens (32 combinations × 9 replicates) made and tested. Thirty-two specimens were prepared and tested each day. The preparation order within each replicate was randomly selected to ensure that the preparation was not biased. During Tunnicliff and Root's testing procedures, one of the specimens (i.e., A–55, 25 blows per side) fell apart in 140°F water bath.

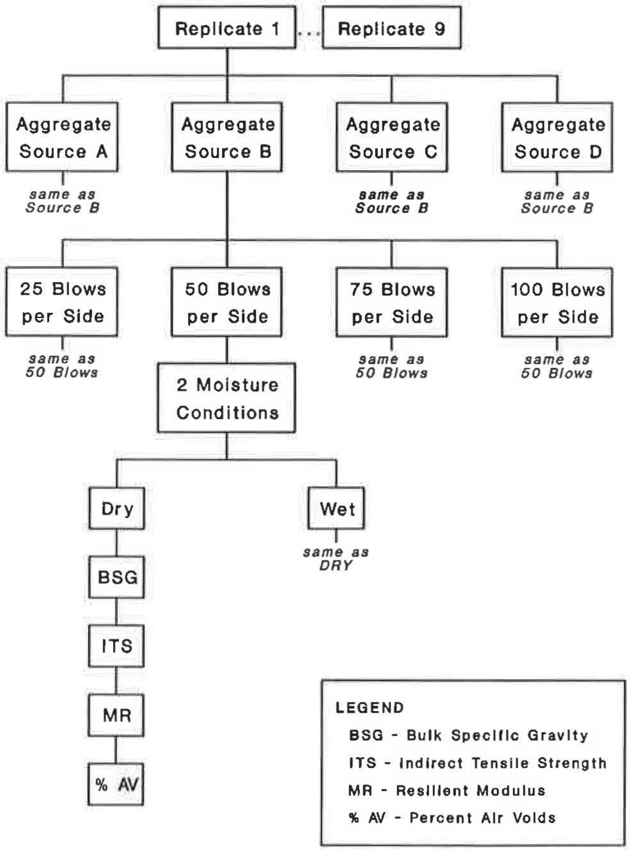


FIGURE 1 Flow chart of the experimental design for the laboratory-prepared Marshall specimens.

ANALYSIS OF QUESTIONNAIRE

Seventy-three questionnaires were sent to various authorities including all of the state highway agencies in the United States. The response rate was approximately 68 percent. The questions on the questionnaire and a summary of responses were as follows:

1. Does your department use LA abrasion loss as a specification requirement? If so, what maximum value is allowed?

Number of Responses	*Response Rate (%)*	*Maximum Allowable Loss (%)*
4	8	30
20	40	35
21	42	45
3	6	>45 but <55
2	4	Do not use LA abrasion as a specification requirement

2. How was this value established?

Number of Responses	*Response Rate (%)*	*Source*
20	43	past experience or historical data
12	25	Unaware of the origin
13	28	Adopted from ASTM, AASHTO, or FHWA
2	4	Conducted research to establish the value

3. What do you think is the major cause of deterioration of aggregates used in the surface course (impact, abrasion, grinding, etc.)?

Number of Responses	*Cause of Deterioration*
23	Abrasion caused by rolling wheel
8	Freeze thaw
7	Wear due to studded tires
6	Impact
5	Aggregate crushing (heavy load)
4	Grinding
4	Weathering of aggregates
4	Chemical action of deicing agents
6	No deterioration of aggregates

Most of the responses quoted one or more of the above forms of deterioration.

4. Do you think that surface moisture and skid resistance are given sufficient weighage in pavement and mix design procedures?

Only 4 responses indicated that they were not satisfied with the present mix design procedures.

5. Can you comment on the performance of two major roads in your area, where aggregates of high LA value and low LA value have been used?

Few responded to this question. However, none of the responses indicated that there was a correlation between the performance of flexible pavements and LA value. In addition, the answers indicated that in some cases aggregates with high LA value performed well in the field, and in some other cases those with low LA values failed in the field.

6. Do you feel that LA abrasion loss should be a specification requirement, and, if so, what value should be used for the specification limits?

> Almost all of the respondents indicated that the LA abrasion loss should be a specification requirement and that they were satisfied with the value that their agency had adopted.

STATISTICAL RESULTS

A summary of statistical results (mean, standard deviation, and coefficient of variance) of dry and wet ITS, dry and wet MR, TSR, and MRR values are presented in Tables 1–3. In addition, Table 4 indicates the sieve analyses results conducted on the original (i.e., from the quarry) aggregates and the extracted aggregates. The effects of low and high LA values on strength of laboratory-prepared Marshall specimens and degradation of aggregates due to different compactive efforts are described in the following sections.

Effects of LA values on Strength of Marshall Specimens

The statistical results of analyses of least squares difference (LSD) comparisons, at the 5 percent level, for each aggregate-blows per side combination are shown in Tables 5–7. The letters "*N*" and "*S*" in these tables indicate "not significantly different" and "significantly different" at the 5 percent level, respectively. In addition, the numbers in parentheses indicate the probability of obtaining a *t*-value as large as the one computed if the means are actually equal. Each cell in these tables is based on the average of nine specimens with the exception of aggregate Source A (25 blows per side) in wet condition which contained eight specimens.

For instance, Table 5 indicates that the difference between average dry ITS of specimens made with aggregate Source A versus Source D (both 25 blows per side) is significant at the 5 percent level [i.e., Row 1, column 4; *S* (0.0003)]. However, the difference between average dry ITS of specimens made with aggregate Source A versus Source C (both 25 blows per side) is not significant at the 5 percent level [i.e., Row 1, Column 2: *N* (0.2522)].

Figures 2–4 show the effects of various LA values on dry and wet ITS, dry and wet MR, TSR, and MRR values. Figure 2a indicates that in all cases of compactive efforts (i.e., 25, 50, etc.), specimens prepared with aggregate Sources A (LA = 55) and B (LA = 48) had higher dry ITs values than specimens prepared with aggregate Source C (LA = 30). However, Table 5 indicates that only 3 out of 8 comparisons were significantly different at the 5% level.

Figures 2b and 3 indicate that in all cases the specimens prepared with aggregate source B (LA = 48) produced higher wet ITS, dry and wet MR values than specimens containing aggregate Source C (LA = 30). Tables 5 and 6 indicate that only 2 out of 12 comparisons were significantly different at the 5 percent level.

In all cases, except one, the specimens prepared with aggregate Source D (LA = 28) produced higher dry and wet ITS and MR values than those of specimens prepared with other aggregate sources (Figures 2 and 3). However, Tables 5 and 6 indicate that 39 out of 48 comparisons were significantly different at the 5 percent level. Figure 4 indicates that in most cases the specimens prepared with aggregate Sources C (LA = 30) and D (LA = 28) produced higher TSR and MRR values than specimens made with aggregate Sources A (LA = 55) and B (LA = 48). Table 7 indicates that 11 out of 24 comparisons were significantly different at the 5 percent level.

Degradation of Aggregates Because of Compactive Efforts

Figures 5–7 show the effects of compactive efforts for each aggregate source. In most cases, specimens prepared with

TABLE 1 MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIANCE OF DRY AND WET ITS VALUES FOR LABORATORY-PREPARED MARSHALL SPECIMENS (*N* = 9)

Aggregate Source - LA Value	Blows/Side	$\bar{X}$ ITS Dry (psi)	STD DEV (psi)	COEF VAR (%)	$\bar{X}$ ITS Wet (psi)	STD DEV (psi)	COEF VAR (%)
A-55	25	70.1	12.2	17.4	34.3*	13.3	38.8
	50	89.4	22.6	25.3	46.5	21.8	47.0
	75	112.1	16.2	14.4	50.6	29.5	58.4
	100	108.7	18.5	17.0	66.3	27.1	41.0
B-48	25	90.7	16.1	17.8	45.8	11.2	24.4
	50	96.3	25.1	26.1	65.3	21.6	33.1
	75	120.3	15.8	13.1	78.8	12.2	15.5
	100	118.8	12.1	10.2	104.8	24.2	23.1
C-30	25	60.5	10.4	17.3	45.3	10.7	23.7
	50	81.8	16.2	19.8	53.5	12.3	23.1
	75	96.2	21.4	22.2	74.5	13.3	17.8
	100	99.5	22.3	22.4	88.8	15.1	17.0
D-28	25	101.4	12.9	12.8	77.2	14.2	18.4
	50	122.5	14.5	11.8	108.6	17.2	15.8
	75	141.8	22.7	16.0	116.1	37.1	32.0
	100	135.7	15.2	11.2	135.2	25.1	18.6

TABLE 2 MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIANCE OF DRY AND WET MR STRENGTHS FOR LABORATORY-PREPARED MARSHALL SPECIMENS ($N = 9$)

Aggregate Source - LA Value	Blows/Side	$\bar{X}$ MR Dry (ksi)	STD DEV (ksi)	COEF VAR (%)	$\bar{X}$ MR Wet (ksi)	STD DEV (ksi)	COEF VAR (%)
A-55	25	138.2	42.2	30.5	55.4*	24.3	43.9
	50	157.6	29.1	18.4	85.1	45.1	53.0
	75	200.4	50.6	25.2	73.0	40.7	55.8
	100	213.5	81.3	38.1	118.0	42.0	35.6
B-48	25	256.2	144.4	56.4	100.2	36.4	36.3
	50	238.2	60.5	25.4	136.4	61.8	45.3
	75	267.8	77.6	29.0	157.7	49.2	31.2
	100	287.8	95.4	33.2	275.7	114.3	41.8
C-30	25	142.4	47.5	33.4	87.6	34.9	39.8
	50	182.1	54.1	29.7	110.6	34.0	30.7
	75	218.8	74.2	33.9	146.3	37.2	25.5
	100	241.6	92.6	38.3	204.0	59.4	29.1
D-28	25	236.7	51.6	21.8	150.0	42.1	28.1
	50	250.3	46.9	18.7	202.2	46.9	23.2
	75	305.7	103.9	34.0	232.5	51.6	22.2
	100	289.4	58.7	20.3	323.7	154.1	47.6

* n=8

TABLE 3 MEAN, STANDARD DEVIATION, AND COEFFICIENT OF VARIANCE FOR THE INDIRECT TSR AND THE MRR VALUES FOR LABORATORY-PREPARED MARSHALL SPECIMENS ($N = 9$)

Aggregate Source - LA Value	Blows/Side	$\bar{X}$ TSR (%)	STD DEV (%)	COEF VAR (%)	$\bar{X}$ MRR (%)	STD DEV (%)	COEF VAR (%)
A-55	25	49.1*	16.3	33.1	44.7*	30.2	67.7
	50	54.1	30.8	57.0	58.3	41.5	71.1
	75	46.6	30.5	65.4	42.4	33.8	79.6
	100	62.1	25.3	40.7	65.4	37.7	57.6
B-48	25	51.2	13.2	25.8	45.6	26.1	57.2
	50	68.9	17.9	26.0	60.5	29.6	48.8
	75	65.8	9.3	14.1	62.6	26.0	40.8
	100	89.1	22.1	24.8	111.2	80.0	71.9
C-30	25	77.1	25.2	32.7	65.6	28.3	43.1
	50	66.0	11.8	17.9	64.7	30.9	47.8
	75	82.5	31.9	38.7	74.0	33.9	45.9
	100	93.4	29.0	31.1	91.5	33.5	36.7
D-28	25	77.6	20.3	26.1	66.8	27.8	35.5
	50	88.8	10.4	11.7	83.7	26.7	32.0
	75	81.5	21.4	26.2	80.8	25.2	31.2
	100	100.9	23.1	22.9	112.5	44.9	39.9

* n=8

Note: 1. TSR = (ITS wet / ITS dry)*100%
2. MRR = (MR wet / MR dry)*100%

TABLE 4 MEAN AND STANDARD DEVIATION OF SIEVE ANALYSES (PERCENT PASSING) FOR THE ORIGINAL AGGREGATES AND FOR EXTRACTED AGGREGATES OF LABORATORY-PREPARED MARSHALL SPECIMENS (*N* = 4)

	Percent Passing (Standard Deviation)									
	Aggregate Source - Blows/Side									
Sieve	LA = 55					LA = 48				
Size	ORG*	A-25	A-50	A-75	A-100	ORG	B-25	B-50	B-75	B-100
3/8in	78.8	89.2 (2.9)	86.8 (3.0)	87.3 (2.4)	90.3 (1.5)	93.3	94.2 (2.0)	96.8 (1.9)	95.4 (1.0)	94.8 (1.2)
#4	65.0	69.1 (6.8)	67.1 (3.8)	65.5 (3.7)	65.0 (5.0)	61.5	63.7 (2.0)	67.4 (4.2)	65.5 (2.0)	66.9 (3.1)
#8	53.0	56.7 (7.6)	54.3 (3.4)	53.0 (3.7)	51.5 (5.3)	48.3	49.8 (1.9)	53.6 (4.8)	51.9 (1.6)	53.2 (3.0)
#30	-	33.4 (5.4)	31.8 (2.3)	30.9 (2.3)	31.7 (4.1)	-	33.2 (1.4)	32.3 (3.7)	35.6 (1.2)	36.4 (2.2)
#100	-	12.8 (2.2)	11.9 (0.9)	11.3 (0.9)	11.9 (1.7)	-	14.1 (0.5)	13.2 (1.7)	16.3 (0.5)	16.8 (1.0)
#200	-	6.3 (1.1)	5.7 (0.3)	5.2 (0.4)	5.5 (0.8)	-	7.3 (0.2)	6.7 (0.8)	8.8 (0.3)	9.2 (0.5)

	Aggregate Source - Blows/Side									
Sieve	LA = 30					LA = 28				
Size	ORG	C-25	C-50	C-75	C-100	ORG	D-25	D-50	D-75	D-100
3/8in	94.8	95.4 (1.9)	95.4 (0.5)	95.7 (1.8)	96.1 (1.7)	99.0	99.2 (0.3)	99.0 (0.3)	99.1 (0.2)	99.1 (0.9)
#4	65.8	68.8 (5.5)	67.6 (3.8)	69.4 (5.6)	70.5 (4.4)	73.3	77.8 (1.3)	77.7 (3.5)	76.9 (2.5)	77.9 (3.6)
#8	49.8	53.1 (5.8)	52.0 (5.1)	51.7 (5.5)	54.1 (5.6)	53.2	56.7 (1.6)	55.6 (3.8)	56.7 (3.4)	54.9 (4.0)
#30	-	25.1 (3.3)	25.4 (1.7)	23.8 (4.8)	26.6 (5.0)	-	35.2 (1.1)	32.9 (2.7)	34.9 (2.5)	33.6 (2.9)
#100	-	9.2 (1.2)	8.7 (0.6)	8.5 (1.7)	10.6 (2.0)	-	18.5 (0.6)	16.3 (1.4)	19.0 (1.4)	17.9 (1.6)
#200	-	4.9 (0.5)	4.6 (0.3)	4.6 (0.9)	5.8 (1.1)	-	10.1 (0.3)	8.9 (0.8)	10.8 (0.8)	10.3 (0.9)

* ORG: Original (i.e., from the quarry) gradation

TABLE 5 LEAST SIGNIFICANT DIFFERENCE COMPARISONS ($\alpha = 0.05$) OF DRY AND WET ITS VALUES FOR LABORATORY-PREPARED SPECIMENS (*N* = 9)

Aggregate Source - Blows/Side	Dry ITS			Wet ITS		
	B-25	C-25	D-25	B-25	C-25	D-25
A-25	S(.0149)	N(.2522)	S(.0003)	N(.2545)	N(.2755)	S(.0001)
B-25	-	S(.0004)	N(.2000)	-	N(.9596)	S(.0015)
C-25	-	-	S(.0001)	-	-	S(.0013)
	B-50	C-50	D-50	B-50	C-50	D-50
A-50	N(.4064)	N(.3639)	S(.0001)	N(.0557)	N(.4735)	S(.0001)
B-50	-	N(.0835)	S(.0021)	-	N(.2276)	S(.0001)
C-50	-	-	S(.0001)	-	-	S(.0001)
	B-75	C-75	D-75	B-75	C-75	D-75
A-75	N(.3261)	N(.0587)	S(.0005)	S(.0044)	S(.0149)	S(.0001)
B-75	-	S(.0045)	S(.0112)	-	N(.6643)	S(.0002)
C-75	-	-	S(.0001)	-	-	S(.0001)
	B-100	C-100	D-100	B-100	C-100	D-100
A-100	N(.2293)	N(.2725)	S(.0015)	S(.0001)	S(.0221)	S(.0001)
B-100	-	S(.0225)	S(.0443)	-	N(.1011)	S(.0022)
C-100	-	-	S(.0001)	-	-	S(.0001)

Notes:
1. N and S denote not significantly and significantly different at the 5 percent level, respectively.
2. The numbers in parentheses indicate the probability of obtaining a t-value as large as the one computed if the means are actually equal.
3. Wet ITS of aggregate source A (LA=55) and 25 blows per side: n=8

TABLE 6 LEAST SIGNIFICANT DIFFERENCE COMPARISONS ($\alpha = 0.05$) OF DRY AND WET MRR VALUES FOR LABORATORY-PREPARED SPECIMENS ($N = 9$)

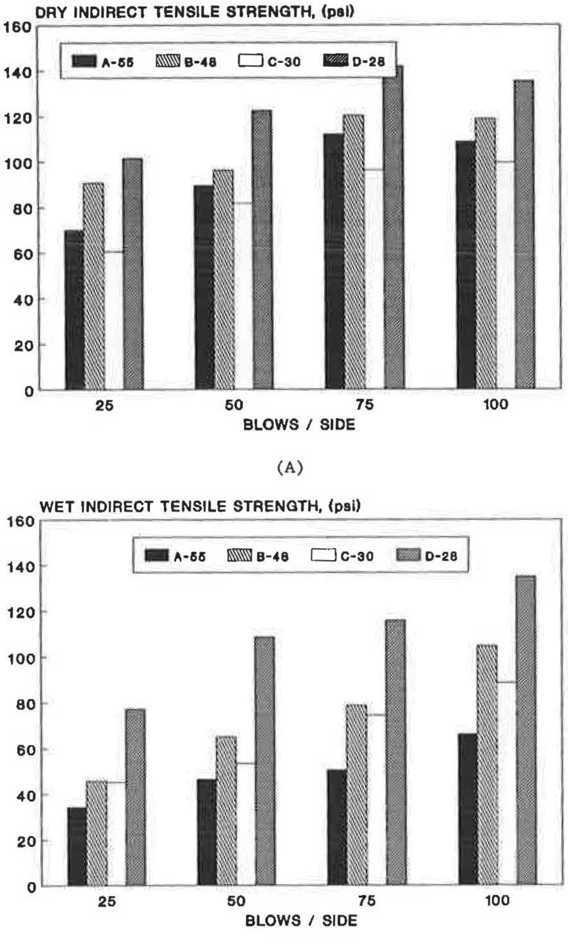
Aggregate Source - Blows/Side	Dry MR			Wet MR		
	B-25	C-25	D-25	B-25	C-25	D-25
A-25	S(.0011)	N(.9068)	S(.0061)	N(.1498)	N(.3001)	S(.0028)
B-25	-	S(.0016)	N(.5808)	-	N(.6743)	N(.1024)
C-25	-	-	S(.0086)	-	-	S(.0408)
	B-50	C-50	D-50	B-50	C-50	D-50
A-50	S(.0242)	N(.4898)	S(.0097)	N(.0900)	N(.3964)	S(.0002)
B-50	-	N(.1146)	N(.7312)	-	N(.3928)	S(.0299)
C-50	-	-	N(.0555)	-	-	S(.0028)
	B-75	C-75	D-75	B-75	C-75	D-75
A-75	N(.0584)	N(.6024)	S(.0034)	S(.0055)	S(.0159)	S(.0001)
B-75	-	N(.1678)	N(.2850)	-	N(.7034)	S(.0140)
C-75	-	-	S(.0152)	-	-	S(.0048)
	B-100	C-100	D-100	B-100	C-100	D-100
A-100	S(.0374)	N(.4275)	S(.0334)	S(.0001)	S(.0049)	S(.0001)
B-100	-	N(.1936)	N(.9625)	-	S(.0216)	N(.0986)
C-100	-	-	N(.1782)	-	-	S(.0001)

Notes: 1. N and S denote not significantly and significantly different at the 5 percent level, respectively.
2. The numbers in parentheses indicate the probability of obtaining a t-value as large as the one computed if the means are actually equal.
3. Wet MR of aggregate source A (LA=55) and 25 blows per side: n=8

TABLE 7 LEAST SIGNIFICANT DIFFERENCE COMPARISONS ($\alpha = 0.05$) OF TSR AND MRR VALUES FOR LABORATORY-PREPARED SPECIMENS ($N = 9$)

Aggregate Source - Blows/Side	TSR			MRR		
	B-25	C-25	D-25	B-25	C-25	D-25
A-25	N(.8495)	S(.0112)	S(.0099)	N(.9610)	N(.2494)	N(.2230)
B-25	-	S(.0154)	S(.0135)	-	N(.2555)	N(.2278)
C-25	-	-	N(.9624)	-	-	N(.9446)
	B-50	C-50	D-50	B-50	C-50	D-50
A-50	N(.1616)	N(.2594)	S(.0013)	N(.8993)	N(.7150)	N(.1495)
B-50	-	N(.7836)	N(.0622)	-	N(.8114)	N(.1881)
C-50	-	-	S(.0329)	-	-	N(.2803)
	B-75	C-75	D-75	B-75	C-75	D-75
A-75	N(.0706)	S(.0009)	S(.0012)	N(.2284)	N(.0736)	S(.0300)
B-75	-	N(.1159)	N(.1411)	-	N(.5536)	N(.3270)
C-75	-	-	N(.9189)	-	-	N(.6970)
Blows/Side	B-100	C-100	D-100	B-100	C-100	D-100
A-100	S(.0118)	S(.0037)	S(.0004)	S(.0099)	N(.1386)	S(.0080)
B-100	-	N(.6858)	N(.2666)	-	N(.2609)	N(.9417)
C-100	-	-	N(.4788)	-	-	N(.2314)

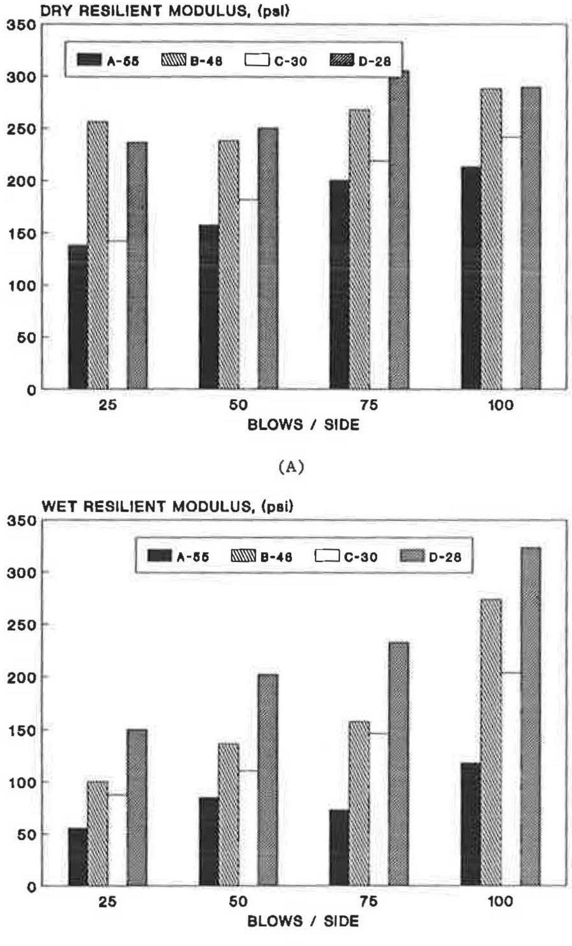
Notes: 1. N and S denote not significantly and significantly different at the 5 percent level, respectively.
2. The numbers in parentheses indicate the probability of obtaining a t-value as large as the one computed if the means are actually equal.
3. MRR and TSR of aggregate source A (LA=55) and 25 blows per side: n=8



(A)

(B)

FIGURE 2 Mean of (a) dry ITS, and (b) wet ITS, of laboratory-prepared Marshall specimens compared by levels of compactive effort.



(A)

(B)

FIGURE 3 Mean of (a) dry MR, and (b) wet MR, of laboratory-prepared Marshall specimens compared by levels of compactive effort.

compactive efforts of 25 blows per side, for each aggregate source, produced lower dry and wet ITS, dry and wet MR, TSR, and MRR values than other compactive efforts. The statistical analysis indicated that 32 out of 72 comparisons were significantly different at the 5 percent level.

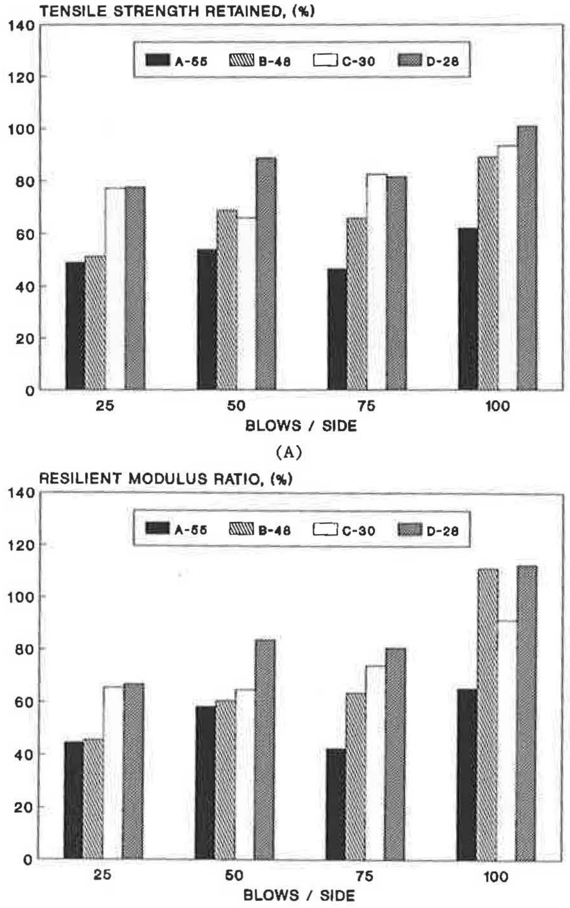
Four randomly selected specimens were used from each combination of aggregate source and compactive effort to obtain a representative sample for extracted aggregate gradation analyses. The statistical results indicated that for all aggregates and all compactive level efforts, for certain sieves (i.e., ⅜-in. Nos. 4, 8, and 30) there were not significant differences for percent passing of extracted aggregates. This result indicated that no major degradation occurred because of compactive efforts for these aggregates. However, the results indicated that various compactive efforts for aggregate Sources A and B, for sieves Nos. 100 and 200, produced significantly different percent passing. Aggregates (Sources C and D) with lower LA values produced similar results.

SUMMARY AND CONCLUSIONS

Seventy-three questionnaires were sent to all state and federal highway agencies in the United States to determine the use of LA abrasion test values in their specifications. The response rate was approximately 68 percent (i.e., 50 surveys were returned).

The effects of low and high LA values on the strengths of laboratory-prepared Marshall specimens were investigated. In addition, different compactive efforts were used to prepare the laboratory specimens to study the effects of low and high LA values on the degradation of extracted aggregates. Four aggregate sources with LA values of 55, 48, 30, and 28 and four compactive efforts (i.e., 25, 50, 75, and 100) were used in this research study. The following conclusions could be drawn:

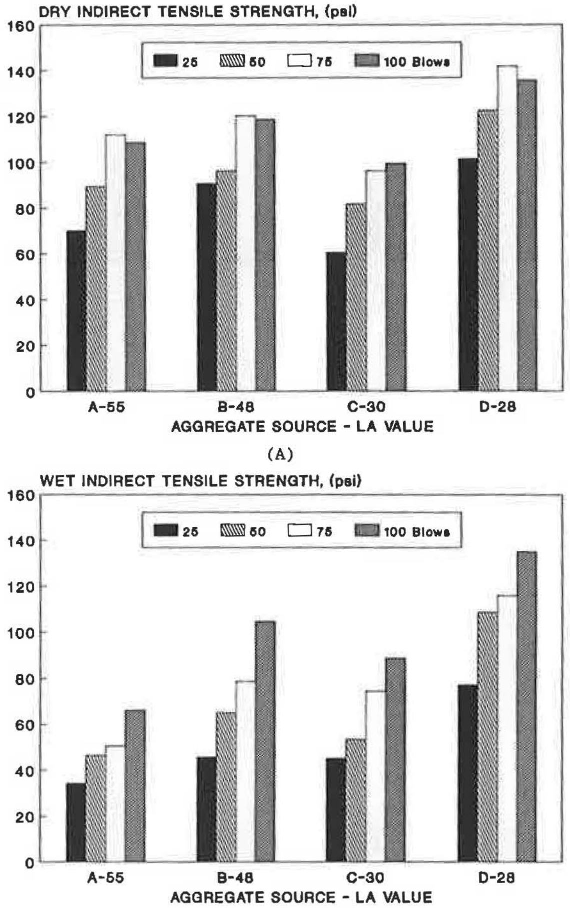
1. The results of the survey indicated that the majority of state highway agencies in the United States use the LA abrasion loss value as a specification requirement.
2. Approximately 26 percent of the surveyed agencies indicated that they were unaware of the origin of the LA values used for their specifications. Approximately 43 and 27 percent of the responses indicated that the LA values were based on past experiences and adopted from ASTM or similar organizations, respectively.
3. Most of the responses indicated that the major cause of deterioration of aggregates used in the surface course was



(A)

(B)

FIGURE 4 Mean of (a) TSR, and (b) MRR, of laboratory-prepared Marshall specimens compared by levels of compactive effort.



(A)

(B)

FIGURE 5 Mean of (a) dry ITS, and (b) wet ITS, of laboratory-prepared Marshall specimens compared by aggregate source.

abrasion caused by compaction. In addition, almost all states indicated that the LA abrasion loss should be a specification requirement and they were satisfied with the value that their agency had adopted.

4. The laboratory results indicated that in all compactive efforts, the specimens prepared with aggregates Sources A, B, and C (LA values of 55, 48, and 30, respectively) produced significantly lower, at a 5 percent level, dry and wet ITS values (Figure 2), than the specimens made with aggregate Source D (LA = 28).

5. In most cases, the specimens prepared with aggregate Source A (LA = 55), at all compactive efforts, produced significantly lower TSR and MRR values than the specimens made with aggregate Source D (LA = 28), as shown in Figure 4.

6. In general, the results indicated that specimens made with aggregate Source D (lowest LA value) produced significantly higher dry and wet ITS values (Table 5 and Figure 2). However, only in 50 percent of cases, the TSR values of the specimens prepared with this aggregate were significantly different (Table 7 and Figure 4a).

7. In most cases, specimens prepared with compactive efforts of 25 blows per side for each aggregate source produced significantly lower dry and wet ITS values compared with other compactive efforts (Figure 5). In most cases, there were no significant differences between TSR and MRR of specimens made with 25 blows per side compared with specimens prepared with 50, 75, and 100 blows per side (Figure 7).

8. In general, the results indicated that dry and wet ITS values of specimens prepared with aggregates of high LA value were not, in every case, lower than dry and wet ITS values of specimens made with aggregates of low LA value.

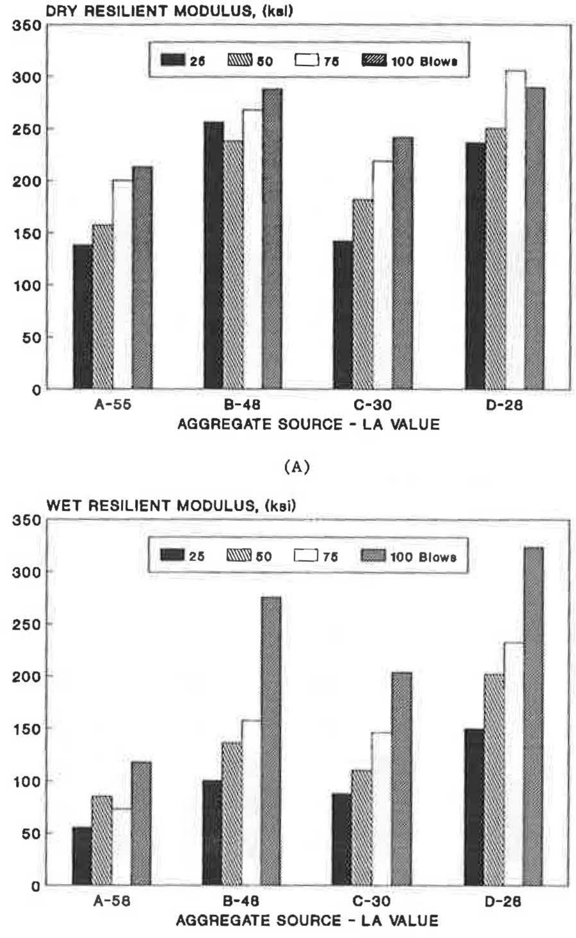
9. In general, the dry and wet MR results indicated that the strengths of specimens did not increase with a decrease in LA value of aggregates used to prepare the specimens.

10. Overall, TSR and MRR results indicated that, in most cases, specimens prepared with aggregates of low LA did not necessarily produce higher TSR and MRR values than those specimens made with aggregates of high LA.

11. The results of the sieve analyses on the extracted aggregates indicated that with the exception of percent passing sieves Nos. 100 and 200, there were no significant differences between various compactive efforts.

12. When considering the degradation of the aggregates, the results indicated that there were not significant differences between aggregates with high LA and those with low LA values.

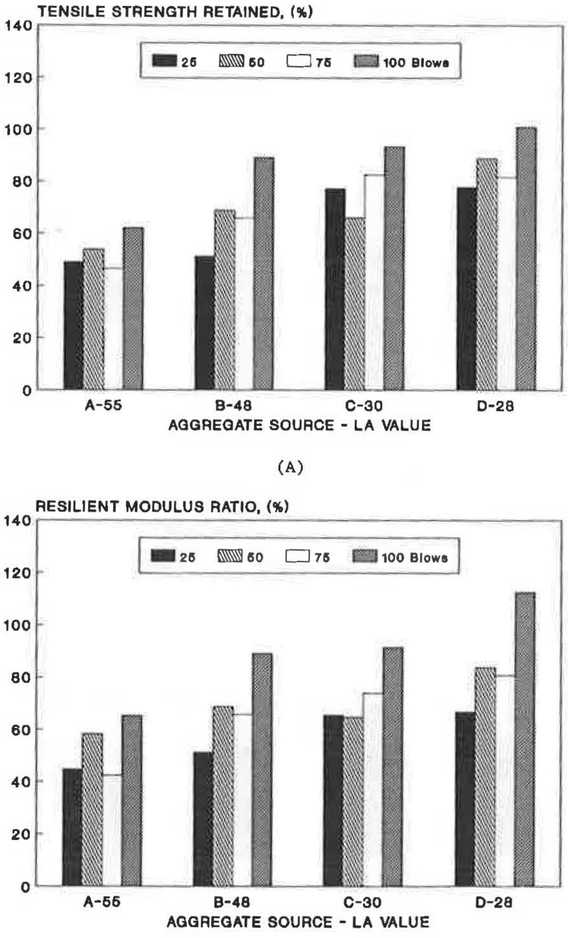
13. Overall, these results indicated that, in most cases, for all aggregates tested, the TSR and MRR values were not influenced by compactive efforts.



(A)

(B)

FIGURE 6 Mean of (a) dry MR, and (b) wet MR, of laboratory-prepared Marshall specimens compared by aggregate source.



(A)

(B)

FIGURE 7 Mean of (a) TSR, and (b) MRR, of Laboratory-Prepared Marshall specimens compared by aggregate source.

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Publication of this paper sponsored by Committee on Mineral Aggregates.