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Marginal Aggregates in Flexible Pavements: Field Evaluation

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16. Abstract

The purpose of this study was to evaluate the utilization of substandard or marginal aggregates in flexible pavement construction of airport pavements. This investigation was undertaken to evaluate the effects of using lower quality aggregates such as rounded uncrushed gravels and sands on the rutting of flexible pavements. The scope of this research study included a review of available literature and existing data (Phase I), a laboratory evaluation organized to determine the effects of marginal aggregates and potential techniques to upgrade these substandard materials (Phase II), and a field evaluation involving test sections utilizing the most promising techniques (Phase III).

This report summarizes the field evaluation (Phase III) that was conducted to determine the effects of aggregate properties on rutting potential of marginal aggregate asphalt mixtures under actual aircraft loads. Based on the findings of the laboratory evaluation, seven aggregate blends and two asphalt binders were selected to evaluate marginal aggregate properties. The test section mixtures were selected to determine the effects of aggregate gradation, amount of crushed coarse aggregate and natural sand in the aggregate blend, and the benefits of asphalt modification.

The findings of this laboratory evaluation indicated that asphalt rutting is influenced by multiple factors (i.e., aggregate properties, gradation, in-place voids, and binder stiffness) and cannot be predicted with individual aggregate and asphalt mixture properties. The data from the field test sections indicated the shape of the gradation curve, percentage of crushed coarse aggregate, and the amount of natural sand in the blend influence the rutting potential. Asphalt modification did not produce equivalent pavement performance in the marginal aggregate mixtures.

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PREFACE

This report was sponsored by the U.S. Department of Transportation, Federal Aviation Administration (FAA) under Inter-Agency Agreement No. DTFA01-90-Z-02069, "Durability Criteria for Airport Pavements." The study was performed by the Airfield and Pavements Division (APD), Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, during the period October 1990 to March 1995. Dr. Xiagong Lee was the FAA Technical Monitor.

This study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL and Dr. G. M. Hammitt II, Chief, APD. This report was prepared under the direct supervision of Mr. T. W. Vollor, Chief, Materials Analysis Branch, APD. APD personnel engaged in the laboratory testing included Messrs. Bill Burke, Jerry Duncan, Roosevelt Felix, Herbert McKnight, and Joey Simmons. Instrumentation Services Division support was provided by Mr. Tommy Carr and Ms. August Williamson. The project's Principal Investigator and author of this report was Dr. Randy C. Ahlrich.

The Director of WES during the preparation and publication of this report was Dr. Robert W. Whalin. The Commander and Deputy Director was Colonel Bruce K. Howard, EN.

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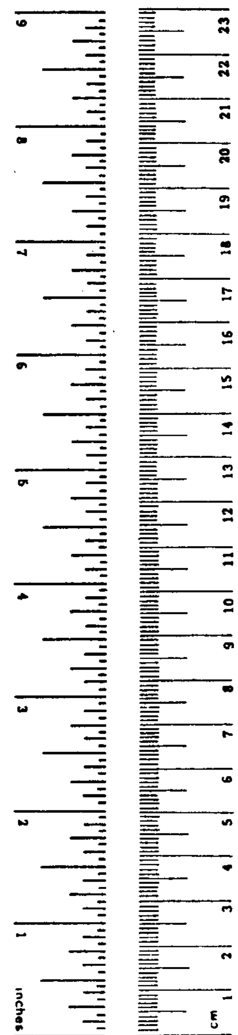
Approximate Conversions to Metric Measures

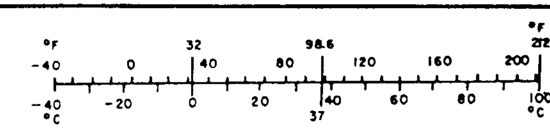
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in. = 2.54 (exactly). For other exact conversions and more detailed tables, see NBC Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

Current airport flexible pavement specifications require high-quality aggregates in asphalt concrete mixtures, and high-quality aggregates are becoming increasingly scarce and expensive in many areas. In an increasing number of cases, locally available aggregates are not meeting applicable specifications, and to meet the specifications, high-quality aggregates are being imported to construction sites.

The use of marginal aggregates in flexible pavement construction is one of the possible answers to the lack of high-quality aggregate sources. This research study determined in engineering terms the impact of using marginal aggregates in asphalt concrete mixtures for airport pavements.

The purpose of this study was to evaluate the utilization of marginal aggregate asphalt mixtures and to determine if poor quality aggregates could be improved to provide equivalent and acceptable pavement performance.

This report summarizes the field evaluation (Phase III) that was conducted to determine the effects of aggregate properties on rutting potential of marginal aggregate asphalt mixtures. Based on the findings of the laboratory evaluation, seven aggregate blends and two asphalt binders were selected to evaluate different marginal aggregate properties. The test section mixtures were selected to determine the effects of aggregate gradation, amount of crushed coarse aggregate and natural sand in the aggregate blend, and the benefits of asphalt modification.

The trafficking of the test section was conducted with a load cart assembly that simulated heavy aircraft loads and tire pressures. The load cart assembly was comprised of a single wheel loaded with 40,000 lb at a tire inflation pressure of 200 psi. Performance of each test item was monitored and evaluated using rut depth measurements taken at various intervals and at the completion of trafficking (12,000 passes).

The findings of this laboratory evaluation indicated that asphalt rutting is influenced by multiple factors (i.e., aggregate properties, gradation, in-place voids, and binder type and stiffness) and cannot be predicted with individual aggregate and asphalt mixture properties. The data from the field test sections indicated the shape of the gradation curve, percentage of crushed coarse aggregate, and the amount of natural sand in the blend influence the rutting potential. Asphalt modification did not produce equivalent pavement performance in the marginal aggregate mixtures.

Based on the findings of this investigation, the following recommendations were made: (1) current Federal Aviation Administration (FAA) specifications could be improved by implementing performance-related aggregate characterization properties determined by Particle Index test and the National Aggregate Association (NAA) and modified NAA particle shape and texture tests, (2) current FAA specifications should be modified and shifted to include finer gradations, (3) the confined repeated load deformation test and/or lab rut testing device should be used in conjunction with current FAA specifications to analyze rutting potential of asphalt mixtures, and (4) relaxing the criteria for aggregate materials should not be considered for airport pavements subjected to aircraft weighing 60,000 lb or more or to tire pressures greater than 100 psi.

INTRODUCTION

BACKGROUND.

High-quality aggregates are becoming increasingly scarce and expensive in many localities. Traditional flexible pavement specifications require high-quality aggregates in asphalt concrete mixtures for airport flexible pavements. In an increasing number of cases, locally available aggregates are not meeting applicable specifications, and aggregates that meet the specifications must be imported to the site at considerable expense.[1]

The use of marginal aggregates in flexible pavement construction is one of the possible answers to high pavement construction costs and a lack of quality aggregate sources. A broad definition of a marginal aggregate is "any aggregate that is not normally usable because it does not have the characteristics required by the specification, but could be used successfully by modifying normal pavement design and construction procedures."[2] For this study, marginal or substandard aggregates were defined as aggregates that do not meet the Federal Aviation Administration's (FAA) specification requirements for airport pavements.

Using local available marginal materials is often very tempting, but the decision to use or reject these materials should be made only after a complete evaluation. The decision should be based on an evaluation of the material characteristics and how these characteristics will affect the design, performance, and construction of the pavement. Potential problem areas must be clearly identified or any expected cost savings will be lost.[3]

Current FAA specifications were developed at times when high-quality aggregates were readily available. However, this is no longer the case in many areas. This study will attempt to define in engineering terms the impact of using marginal aggregates in asphalt mixtures for flexible pavements. Strategies for improving the performance of marginal aggregates to equal that of standard aggregates were evaluated. The primary emphasis of this study was on the use of marginal or substandard aggregates in asphalt concrete mixtures.

PURPOSE.

The purpose of the research study was to evaluate the utilization of marginal aggregates in asphalt mixtures for flexible pavement construction for airport pavements. Marginal aggregates have been defined as aggregates that do not meet FAA specification requirements. The current FAA guidance for airport pavement construction is provided in FAA Advisory Circular 150/5370-10A, "Standards for Specifying Construction of Airports."[4] Specific requirements for asphalt concrete mixtures are provided in Item P-401 (Plant Mix Bituminous Pavements). Marginal aggregates can have one or more of the following deficiencies: improper gradation, lack of fractured faces, flat and elongated particles, high natural-sand content, high Los Angles (LA) abrasion and soundness values, and excessive amounts of No. 200 material. This research determined the effects of aggregate properties on permanent deformation and the performance of marginal aggregate asphalt mixtures.

OBJECTIVES.

The research documented in this report was executed to achieve the following objectives:

a. To evaluate the performance of marginal aggregate asphalt mixtures under actual aircraft loading conditions in field test sections.

b. To evaluate the influence of aggregate properties on permanent deformation characteristics of asphalt concrete mixtures.

c. To evaluate the benefits of asphalt modification on permanent deformation characteristics of asphalt mixtures produced with marginal aggregates.

SCOPE.

The overall research study for marginal aggregates in flexible pavements was conducted in three phases. Phase I was a review of available literature and existing data. These findings are documented in FAA report number DOT/FAA CT-94/58.[5] Based on the literature review, a laboratory study (Phase II) was conducted using poor quality, less than acceptable aggregates that do not meet FAA requirements. The marginal aggregates were compared to proven, accepted aggregates to evaluate the effectiveness of these materials in asphalt concrete mixtures for flexible pavements. The findings of the laboratory evaluation are documented in FAA report number DOT/FAA/AR-95/6.[6] The final phase, Phase III, took the concepts and techniques using marginal aggregates that exhibited the greatest potential and evaluated these materials in field test sections.

This report summarizes the field evaluation (Phase III) that was conducted to determine the effects of aggregate properties on rutting potential of marginal aggregate asphalt mixtures. Based on the findings of the laboratory evaluation, seven aggregate blends and two asphalt binders were selected to evaluate different marginal aggregate properties. The test section mixtures were selected to determine the effects of aggregate gradation, amount of crushed coarse aggregate and natural sand in the aggregate blend, and the benefits of asphalt modification.

The trafficking of the test section was conducted with a load cart assembly that simulated heavy aircraft loads and tire pressures. The load cart assembly was comprised of a single wheel loaded with 40,000 lb at a tire inflation pressure of 200 psi. Performance of each test item was monitored and evaluated using rut depth measurements taken at various intervals and at the completion of trafficking (12,000 passes).

DESCRIPTION OF TEST ITEMS

As a part of the FAA research project, “Marginal Aggregates in Flexible Pavements,” a test section was constructed and trafficked to evaluate marginal and substandard aggregate materials in asphalt concrete mixtures. The field evaluation was conducted to evaluate asphalt concrete mixtures with different aggregate properties under actual aircraft traffic loading conditions. These aggregate properties included gradation, percent crushed coarse particles, and natural-sand content. The field evaluation also evaluated the benefits of asphalt modification to improve rutting characteristics of asphalt concrete mixtures with substandard aggregates. The field evaluation was conducted in five phases:

a. Mix Designs.
b. Construction.
c. Laboratory Evaluation of Test Item Mixtures.
d. Trafficking.
e. Evaluation of Field Performance of Ten Test Items.

The field evaluation plan is illustrated by flow chart in figure 1.

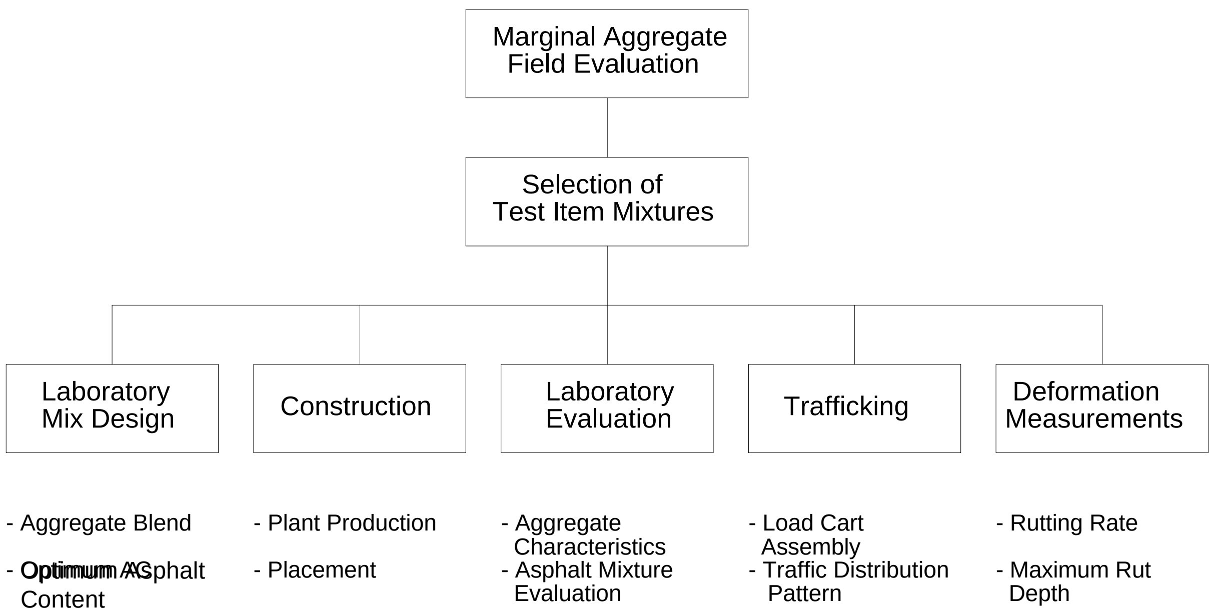


FIGURE 1. MARGINAL AGGREGATE FIELD EVALUATION RESEARCH PLAN

Based on the laboratory evaluation, seven aggregate blends were selected to determine the affects of aggregate properties on permanent deformation. A Styren-Butadiene-Styrene (SBS) -modified AC-20 asphalt binder was used with five of these aggregate blends to evaluate the benefits of asphalt modification on asphalt concrete mixtures with selected aggregate mixtures. The descriptions of the ten field test items are presented in table 1.

Seven aggregate stockpiles were used in various combinations to produce the seven test item aggregate blends. The stockpiles consisted of crushed limestone (No. 458, No. 56, and screenings), crushed gravel screenings, uncrushed coarse gravel, and two natural-sand materials (concrete and mason). The gradation, specific gravity, and absorption values of each stockpile material are summarized in table 2. The composition of each test item aggregate blend was produced with the stockpile percentages listed in table 3.

TABLE 1. DESCRIPTION OF FIELD TEST ITEMS

Item Identification	Laboratory Mix Identification (*)	Asphalt Binder	Description
1	1	AC-20	Center of FAA gradation band
2	3	SBS-modified AC-20	Upper limit of FAA gradation band
3	6	AC-20	Upper limit of FAA gradation band with excessive No. 200 material
4	10	AC-20	Center of FAA gradation band modified with 20 percent natural sand
5	10	SBS-modified AC-20	Center of FAA gradation band modified with 20 percent natural sand
6	12	AC-20	Center of FAA gradation band modified with 40 percent natural sand
7	12	SBS-modified AC-20	Center of FAA gradation band modified with 40 percent natural sand
8	19	SBS-modified AC-20	Center of FAA gradation band Coarse—100 percent uncrushed gravel Fine—100 percent crushed limestone and gravel
9	21	AC-20	Center of FAA gradation band Coarse—50 percent uncrushed gravel; 50 percent crushed limestone Fine—100 percent crushed limestone and gravel
10	21	SBS-modified AC-20	Center of FAA gradation band Coarse—50 percent uncrushed gravel; 50 percent crushed limestone Fine—100 percent crushed limestone and gravel

(*) Reference DOT/FAA/AR-95/6, “Marginal Aggregates in Flexible Pavements: Laboratory Evaluation.”

TABLE 2. GRADATIONS AND SPECIFIC GRAVITIES FOR AGGREGATE STOCKPILE MATERIALS

	Percent Passing						
Sieve Size	Crushed Limestone No. 458	Crushed Limestone No. 56	Crushed Limestone Screenings	Crushed Gravel Screenings	Uncrushed Coarse Gravel	Concrete Sand	Mason Sand
1 in.	100	100	100	100	100	100	10
3/4 in.	100	100	100	100	73.9	100	100
1/2 in.	54.6	98.5	100	99.6	37.5	98.7	100
3/8 in.	31.3	80.1	100	98.1	17.9	97.9	100
No. 4	6.9	29.7	96.3	90.0	0.5	92.6	100
No. 8	2.3	6.3	59.3	64.2	0.5	81.9	99.9
No. 16	1.4	2.2	34.6	38.0	0.5	75.5	98.6
No. 30	1.0	1.2	27.1	23.9	0.5	63.6	87.8
No. 50	0.8	0.8	21.8	10.8	0.4	15.4	18.0
No. 100	0.5	0.6	17.9	6.8	0.3	2.9	2.1
No. 200	0.5	0.5	15.3	5.3	0.3	1.7	1.1
Apparent	2.764	2.750	2.688	2.641	2.597	2.634	2.648
Bulk (Saturated Surface Dry)	2.752	2.7	2.676	2.560	2.564	2.619	2.638
Bulk	2.745	2.729	2.671	2.512	2.544	2.614	2.631
Absorption	0.3	0.3	0.2	1.9	0.8	0.3	0.3

A Marshall mix design was conducted for each test item mixture to determine the optimum asphalt content. The optimum asphalt content was selected at 4 percent air voids (voids total mix). This void criteria was selected to insure that the asphalt binder content did not influence the performance of the asphalt mixtures or overshadow the effects of the aggregate properties. All laboratory samples were compacted with the Gyratory Testing Machine (GTM)[7] using a compactive effort equivalent to a 75-blow Marshall compactive effort. The selected test item aggregate gradations and optimum asphalt content values are listed in table 4.

The test section mixtures were selected to evaluate the effects of aggregate gradation, percent crushed coarse aggregate, natural-sand content, and asphalt cement modification. The comparisons of the test items used to evaluate these variables are illustrated in figure 2.

TABLE 3. COMPOSITION OF TEST ITEM AGGREGATE BLENDS

Item Identification	Composition	
1	20% crushed limestone No. 458 37% crushed limestone screenings	28% crushed limestone No. 56 15% mason sand
2	8% crushed limestone No. 458 47% crushed limestone screenings	20% crushed limestone No. 56 25% mason sand
3	13% crushed limestone No. 458 62% crushed limestone screenings	20% crushed limestone No. 56 5% mason sand
4	25% crushed limestone No. 458 21% crushed limestone screenings 20% concrete sand	18% crushed limestone No. 56 16% crushed gravel screenings
5	25% crushed limestone No. 458 21% crushed limestone screenings 20% concrete sand	18% crushed limestone No. 56 16% crushed gravel screenings
6	25% crushed limestone No. 458 20% crushed limestone screenings	15% crushed limestone No. 56 40% concrete sand
7	25% crushed limestone No. 458 20% crushed limestone screenings	15% crushed limestone No. 56 40% concrete sand
8	30% crushed limestone screenings 25% uncrushed coarse gravel	45% crushed gravel screenings
9	12% crushed limestone No. 458 45% crushed gravel screenings	30% crushed limestone screenings 13% uncrushed coarse gravel
10	12% crushed limestone No. 458 45% crushed gravel screenings	30% crushed limestone screenings 13% uncrushed coarse gravel

TABLE 4. MIX DESIGN VALUES FOR TEST ITEM MIXTURES

Sieve Size	Percent Passing									
	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10
3/4 in.	100	100	100	100	100	100	100	100	100	100
1/2 in.	91	96	94	88	88	88	88	84	86	86
3/8 in.	81	91	87	79	79	79	79	79	80	80
No. 4	60	77	72	60	60	63	63	70	70	70
No. 8	39	54	43	41	41	46	46	47	47	47
No. 16	29	42	27	29	29	38	38	28	28	28
No. 30	24	35	22	23	23	31	31	19	19	19
No. 50	11	15	15	10	10	11	11	12	12	12
No. 100	7	9	11.4	6	6	5	5	9	9	9
No. 200	6.0	7.6	9.7	4.6	4.6	3.9	3.9	7.1	7.1	7.1
Optimum Asphalt Content Percent	4.3	4.8	5.0	4.8	5.0	4.8	4.8	6.2	6.0	6.1

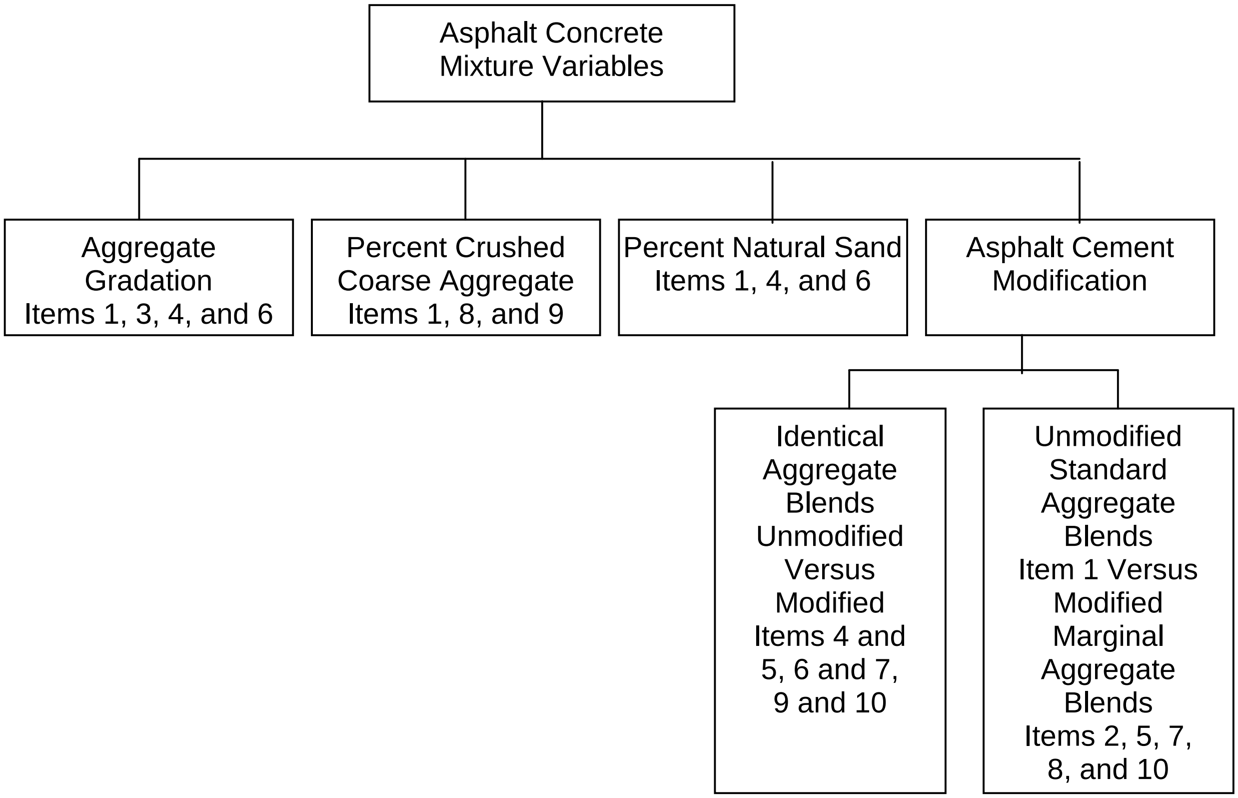


FIGURE 2. VARIABLES FOR MARGINAL AGGREGATE ASPHALT MIXTURES

CONSTRUCTION OF TEST ITEMS

The test section was constructed in May 1994 as an overlay on top of an existing test section located at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. The existing pavement was structurally sound and was designed to carry military cargo aircraft (C141) loads. This pavement section provided a structurally adequate base for the asphalt concrete test items and insured that pavement deformation would occur in the surface layers as densification or plastic flow. A layout of the ten test items is illustrated in figure 3. The typical cross section of the test section is illustrated in figure 4.

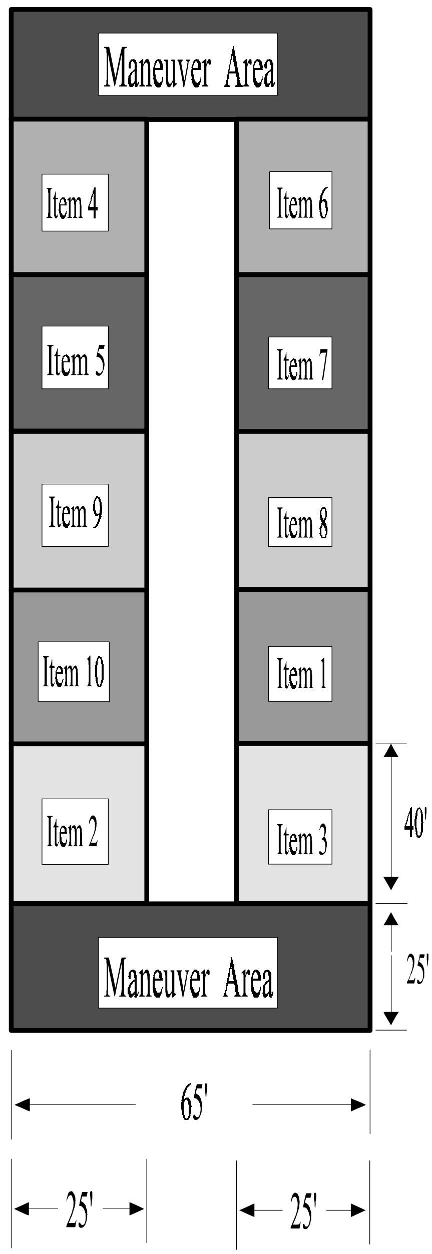


FIGURE 3. LAYOUT OF FIELD TEST ITEMS

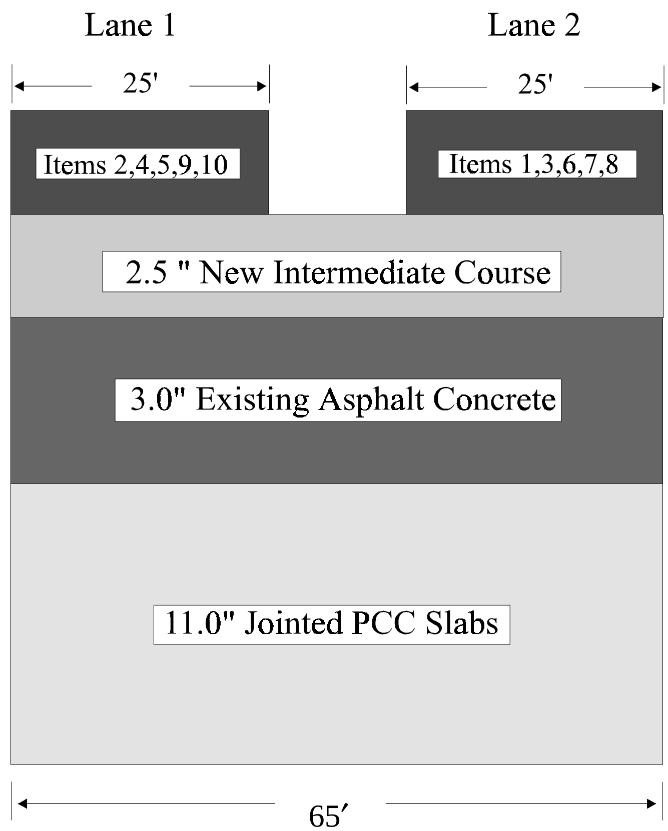


FIGURE 4. TYPICAL CROSS SECTION OF TEST SECTION

The test section was constructed by APAC-Mississippi in two phases. First, a 2.5-in. intermediate course layer was placed over the entire test area (65 by 250 ft). This asphalt mixture was composed of crushed limestone (85 percent), mason sand (15 percent), and AC-30 binder. This layer of asphalt concrete provided a dense, smooth foundation for the test items. The test section was produced, placed, and compacted using conventional asphalt concrete placement and laydown procedures and techniques. The construction equipment used to construct the test items is shown in figures 5-7.

Each test item consisted of approximately 50 tons of material and was placed on an area 25 by 40 ft. The thickness of each test item was approximately 2.5 in. The completed test section is shown in figure 8. Details concerning asphalt mixture temperatures and rolling procedures are presented in table 5.

FIGURE 5. PLACEMENT OF ASPHALT CONCRETE MIX

FIGURE 6. DUAL STEEL-WHEEL VIBRATORY ROLLER

FIGURE 7. TWELVE-TON RUBBER-TIRED ROLLER

FIGURE 8. OVERALL VIEW OF COMPLETED TEST SECTION

TABLE 5. MIX TEMPERATURES AND COMPACTION METHODS FOR TEST ITEM MIXTURES

Phase of Construction	AC-20 Mix Temperature (°F)	SBS-Modified AC-20 Mix Temperature (°F)	Equipment and Number of Passes
Discharge at Plant	320	330	
Paver Hopper	280-320	280-300	
Behind Paver Screed	280-320	280-300	
Breakdown Rolling	240-275	270-300	Vibratory Steel-Wheel Roller 2 passes
Intermediate Rolling	190-240	175-225	Vibratory Steel-Wheel Roller 4 passes Rubber-Tired Roller 4 passes (SBS mix below 175°F)
Finish Rolling	150-160	150-160	Static Steel-Wheel Roller 2 passes
Average Field Compaction (percent of lab density)	97.3	96.6	

EVALUATION OF TEST ITEM ASPHALT CONCRETE MIXTURES

A sample of plant-mixed asphalt concrete material was obtained from loaded asphalt trucks for each test item and evaluated to characterize the asphalt concrete mixtures. The laboratory evaluation of the plant-mixed asphalt concrete material focused on characterizing the aggregate and the asphalt mixture properties. The aggregate characterization tests included gradation, percent crushed particles, natural-sand content, NAA and modified NAA particle shape and texture, direct shear, and unit weight and voids in aggregate (shovel method). The asphalt concrete mixtures were evaluated with volumetric properties, Marshall stability and flow, gyratory compaction properties, direct shear strengths, and confined repeated load deformation properties. A detailed description and discussion of each test method are presented in FAA Report Number DOT/FAA/AR-95/6.[6]

AGGREGATE CHARACTERIZATION.

This section presents the results of the aggregate characterization tests conducted on the extracted test item aggregates. The aggregate characterization tests determined the shape of the gradation curve and quantified the aggregate particle shape and texture characteristics. Aggregate gradations determined using ASTM C 117[8] and C 136[9] are presented in table 6. Table 7 presents the percentages of crushed particles as determined by visual inspection for the composite blend, and coarse and fine aggregate fractions (CRD-D 161).[10] The natural-sand content of each aggregate blend was determined from cold feed bin percentages. The coarse aggregate fraction of each test item blend was characterized with the modified NAA particle shape[7] and texture and ASTM C 29 (shovel)[11] test methods. These tests for the coarse aggregates were conducted on material passing

TABLE 6. EXTRACTED AGGREGATE GRADATIONS FOR TEST SECTION ASPHALT CONCRETE MIXTURES

Sieve Sizes	Percent Passing									
	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10
3/4 in.	100	100	100	100	100	100	100	100	100	100
1/2 in.	94.0	95.3	92.7	92.9	92.3	92.9	90.9	85.7	91.3	86.3
3/8 in.	86.4	89.0	86.6	81.0	83.6	85.2	82.8	79.6	86.1	80.9
No. 4	69.9	75.4	72.2	65.4	66.3	70.3	67.2	68.8	78.0	73.5
No. 8	44.5	50.8	42.0	47.0	44.3	54.7	50.1	47.2	55.0	54.4
No. 16	30.4	37.2	23.6	36.6	31.8	46.7	42.2	29.3	35.5	35.9
No. 30	23.9	30.6	16.7	27.3	25.0	38.0	34.6	20.5	25.2	25.8
No. 50	9.1	11.4	10.1	6.0	8.5	6.7	7.5	10.8	10.2	12.1
No. 100	5.6	6.5	8.0	2.5	4.7	1.9	2.5	7.3	5.6	7.1
No. 200	4.5	5.2	6.6	1.9	3.4	1.3	1.6	5.8	3.6	4.8

TABLE 7. PERCENT CRUSHED PARTICLES AND NATURAL-SAND CONTENT FOR TEST SECTION ASPHALT CONCRETE MIXTURES

Item	Percent Crushed Particles			Natural-Sand Content
	Composite Gradation	Coarse Aggregate Fraction	Fine Aggregate Fraction	
1	85	99	79	15
2	75	100	67	25
3	94	98	93	5
4	79	96	69	20
5	78	95	69	20
6	57	95	41	40
7	57	92	40	40
8	72	11	100	0
9	88	47	100	0
10	88	55	100	0

the 3/4-in. sieve and retained on the No. 4 sieve. The uncompacted void contents for these two methods are presented in table 8. The fine aggregate fraction (passing the No. 4 sieve)[12] of each test item blend was characterized by the NAA particle shape and texture (ASTM C 1252) and direct shear test methods (EM 1110-2-1906).[13] The test results from these fine aggregate tests are presented in table 9.

TABLE 8. UNCOMPACTED VOID CONTENTS FOR COARSE AGGREGATE FRACTION

Item	Modified NAA Method 1 Percent	ASTM C 29 Method 1 Percent
1	46.9	45.5
2	47.3	45.5
3	46.9	45.4
4	46.7	45.0
5	46.9	45.1
6	47.2	45.9
7	46.8	45.6
8	44.8	42.8
9	44.1	42.5
10	42.2	40.8

TABLE 9. TEST RESULTS FOR FINE AGGREGATE FRACTION

Item	NAA Method A Percent	NAA Method C Percent	Direct Shear (ϕ)
1	42.6	36.9	40.5
2	40.0	34.7	39.0
3	44.5	39.3	47.5
4	40.6	34.5	36.0
5	41.4	35.6	37.0
6	38.6	34.4	29.5
7	39.3	33.5	30.5
8	42.5	37.6	43.5
9	42.2	37.4	40.5
10	41.9	36.2	42.0

ASPHALT CONCRETE MIXTURE EVALUATION.

This section presents the results of the asphalt concrete mixture evaluation tests on the plant-mixed asphalt material. These mixture tests were conducted to determine the asphalt mixture's strength and permanent deformation properties. Asphalt mixture material from each test item was compacted with the Gyratory Testing Machine[7] to produce Marshall size specimen (4 in. diameter and 2.5 in. thick). The compacted specimens were evaluated to determine Marshall and volumetric properties[14] (table 10), gyratory compaction properties[7] (table 11), direct shear results[6] (table 12), and confined repeated load deformation test results[6] (table 13). Three field cores (4 in. diameter) were also taken from each test item and evaluated with the confined repeated load deformation test. The results of these tests are presented in table 14.

TABLE 10. SUMMARY OF VOLUMETRIC AND MARSHALL PROPERTIES FOR TEST SECTION ITEMS

Item	Extracted Asphalt Content Percent	Bulk Specific Gravity	Theoretical Specific Gravity	Voids Total Mix Percent	Voids in Mineral Aggregate Percent	Voids Filled Percent	Unit Weight (pcf)	Stability (lbs)	Flow (0.01 in.)
1	4.2	2.422	2.533	4.4	14.3	69.2	151.1	2,081	7.7
2	4.9	2.471	2.498	2.4	14.1	83.0	152.1	2,389	11.0
3	4.8	2.400	2.515	4.6	15.8	70.9	149.8	1,971	8.7
4	4.4	2.347	2.514	6.6	16.7	60.5	146.5	874	6.7
5	5.0	2.427	2.484	2.3	14.2	83.6	151.4	1,980	10.3
6	5.2	2.298	2.475	7.2	18.8	61.7	143.4	369	5.3
7	4.9	2.362	2.492	5.2	16.5	68.5	147.4	743	6.8
8	5.7	2.341	2.425	3	16.6	78.9	146.1	1,950	18.7
9	6.1	2.343	2.420	3.2	17.1	81.3	146.2	1,324	9.5
10	6.1	2.355	2.413	2.4	16.5	85.5	147.0	1,928	15.3

TABLE 11. SUMMARY OF GYRATORY COMPACTION PROPERTIES FOR TEST SECTION ASPHALT CONCRETE MIXTURES

Item	Thickness (in.)	Gyratory Stability Index (GSI)	Gyratory Elasto Plastic Index (GEPI)	Gyratory Shear Strength (psi)
1	2.503	0.99	1.28	149
2	2.471	1.00	1.40	147
3	2.544	1.00	1.20	132
4	2.580	0.98	1.45	163
5	2.490	0.99	1.40	152
6	2.623	0.97	1.61	156
7	2.550	0.97	1.47	157
8	2.588	0.99	1.38	147
9	2.584	0.99	1.43	158
10	2.563	1.02	1.36	136

TABLE 12. SUMMARY OF DIRECT SHEAR DATA FOR TEST SECTION ASPHALT CONCRETE MIXTURES

Item	Angle of Internal Friction (ϕ)	Cohesion Y-Axis Intercept (psi)	Shear Strengths at Normal Stress Levels		
			100 psi (psi)	200 psi (psi)	300 psi (psi)
1	13.7	48.5	73.4	96.2	122.2
2	17.5	58.5	91.8	118.3	154.9
3	15.5	52.1	80.3	106.5	135.9
4	15.9	20.9	50.3	76.1	107.3
5	17.1	44.2	77.4	100.6	138.8
6	17.1	35.7	49.5	61.8	76.3
7	11.7	30.9	53.1	69.3	94.5
8	13.9	50.1	76.1	96.9	125.5
9	13.5	41.1	65.4	88.7	113.5
10	14.7	51.2	78.5	101.5	130.9

TABLE 13. SUMMARY OF CONFINED REPEATED LOAD DEFORMATION TEST DATA FOR TEST ITEMS—LAB COMPACTED

Item	Asphalt Type	Thickness Percent	Voids Total Mix Percent	Total Strain (in/in.)	Permanent Strain (in/in.)	Creep Modulus Based on Deviator Stress (psi)	Slope of Creep Curve (M)
1	AC-20	2.506	4.4	0.0194	0.0194	10,309	0.146
2	AC-20 + SBS	2.466	2.4	0.0216	0.0216	9,259	0.092
3	AC-20	2.568	4.6	0.0289	0.0289	6,920	0.199
4	AC-20	2.579	6.6	0.0179	0.0178	11,173	0.099
5	AC-20 + SBS	2.479	2.3	0.0217	0.0216	9,217	0.095
6	AC-20	2.633	7.2	0.0248	0.0248	8,065	0.082
7	AC-20 + SBS	2.549	5.2	0.0195	0.0195	10,256	0.054
8	AC-20 + SBS	2.589	3.5	0.0208	0.0207	9,615	0.145
9	AC-20	2.575	3.2	0.0212	0.0212	9,434	0.157
10	AC-20 + SBS	2.561	2.4	0.0384	0.0383	5,208	0.329

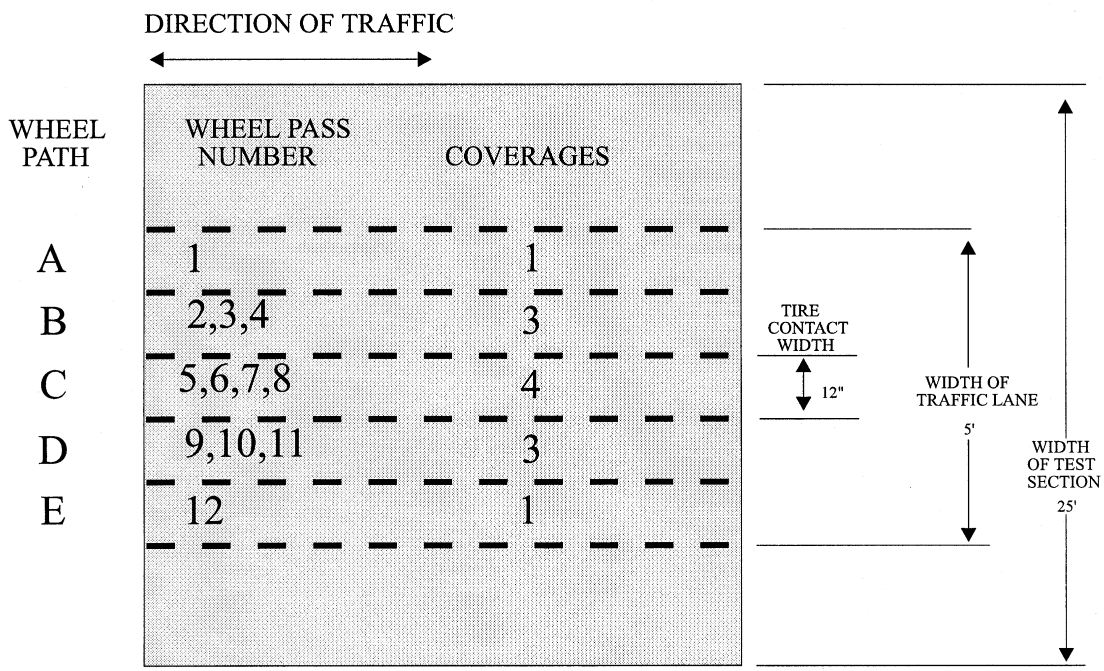
TABLE 14. SUMMARY OF CONFINED REPEATED LOAD DEFORMATION TEST DATA FOR TEST ITEMS—FIELD COMPACTED

Item	Asphalt Type	Thickness (in.)	In-Place Voids	Total Strain (in/in.)	Permanent Strain (in/in.)	Creep Modulus Based on Deviator Stress (psi)	Slope of Creep Curve (M)
1	AC-20	2.896	9.5	0.0270	0.0270	7,407	0.121
2	AC-20 + SBS	2.645	7.5	0.0401	0.0401	4,988	0.123
3	AC-20	2.483	9.9	0.0584	0.0583	3,425	0.172
4	AC-20	2.572	7.4	0.0249	0.0249	8,032	0.123
5	AC-20 + SBS	2.705	5.7	0.0315	0.0315	6,349	0.126
6	AC-20	2.664	9.4	0.0513	0.0513	3,899	0.092
7	AC-20 + SBS	2.740	7.8	0.0406	0.0406	4,926	0.106
8	AC-20 + SBS	2.654	6.3	0.0616	0.0616	3,247	0.123
9	AC-20	2.753	8.3	0.0522	0.0521	3,831	0.136
10	AC-20 + SBS	2.316	7.5	0.0472	0.0471	4,237	0.184

DESCRIPTION OF TRAFFIC

Traffic tests were conducted from June to October 1994 to allow trafficking to take place during high ambient temperatures and pavement surface temperatures. The pavement surface temperature ranged between 75 and 140°F during the traffic tests. The traffic tests were conducted with a load cart assembly that simulated aircraft loads and tire pressures. The load cart was assembled with a single aircraft tire (12 in. wide) with a load of 40,000 lb and a contact pressure of 200 psi (figure 9). The test traffic was applied by driving the load cart assembly forward and then in reverse over the entire length of the test section (1 pass). The lateral traffic pattern was applied with a distribution shown in figure 10. The traffic lane for each test item was 60 in. wide with five wheel paths. A total of 12,000 passes was applied to each test item.

FIGURE 9. FORTY THOUSAND-POUND SINGLE-WHEEL LOAD CART



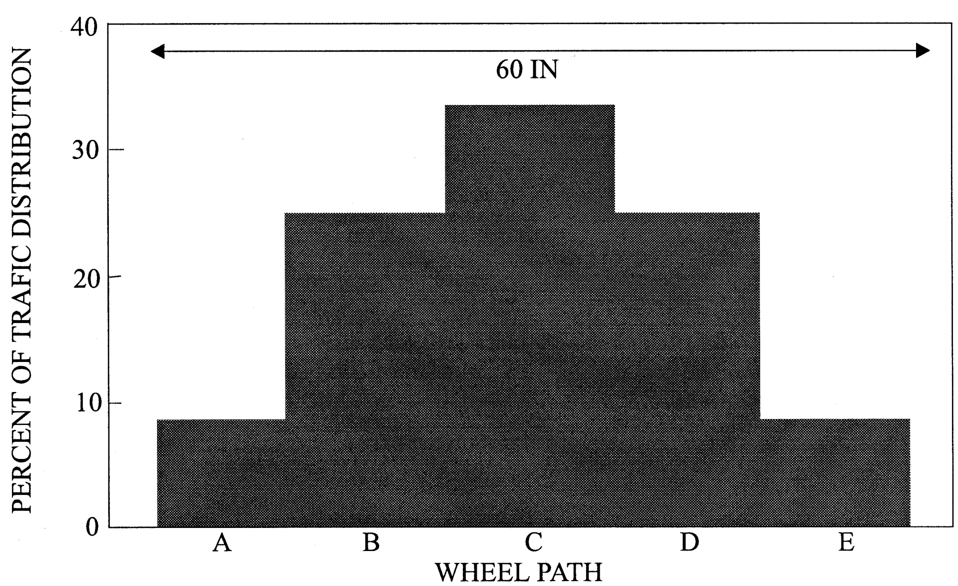


FIGURE 10. TRAFFIC PATTERN DISTRIBUTION

PERFORMANCE MEASUREMENTS OF TEST ITEMS

The focus of this study was on rutting and permanent deformation of asphalt concrete mixtures. The performance of the test items was based on rut depth measurements. Rut depth measurements were taken at various intervals and at the completion of trafficking. Measurements were taken transversely across the traffic lane of each test item. Rut depth measurements were made by placing a 12-ft metal straightedge flat across the test item and measuring the maximum rut depth with a ruler (figure 11). The rut depth measurements for each test item at various traffic levels are presented in table 15. This rut depth included both permanent deformation caused by densification and plastic flow.

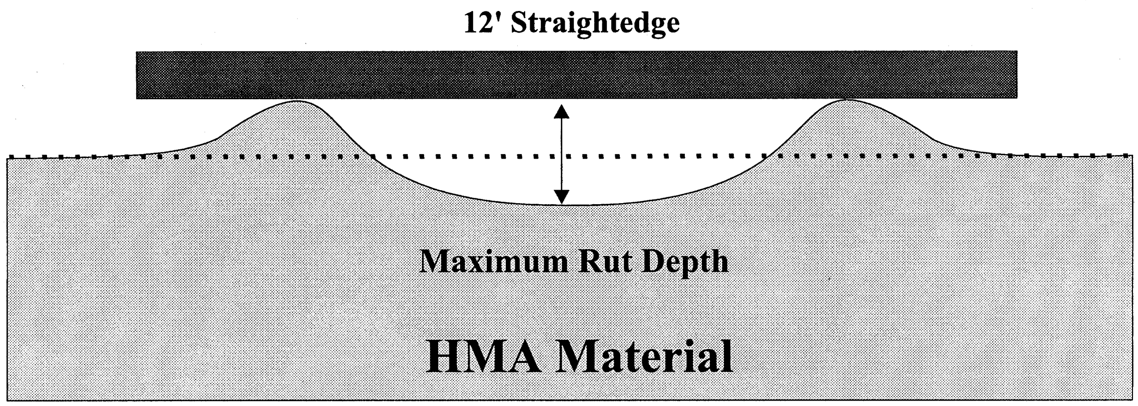


FIGURE 11. SCHEMATIC OF RUT DEPTH MEASUREMENT WITH STRAIGHTEDGE

TABLE 15. MAXIMUM RUT DEPTH MEASUREMENTS AT VARIOUS TRAFFIC LEVELS

Item	Rut Depth (in.)						
	600 Passes	1,200 Passes	2,400 Passes	4,800 Passes	7,200 Passes	9,600 Passes	12,000 Passes
1	0.21	0.22	0.26	0.27	0.29	0.29	0.29
2	0.19	0.24	0.30	0.41	0.54	0.54	0.54
3	0.29	0.33	0.44	0.47	0.47	0.53	0.53
4	0.20	0.24	0.26	0.40	0.81	0.88	0.94
5	0.17	0.22	0.28	0.40	0.48	0.65	0.69
6	0.32	0.38	0.58	0.65	0.71	0.71	0.71
7	0.26	0.30	0.35	0.63	0.69	0.73	0.73
8	0.25	0.31	0.50	0.75	0.81	1.02	1.02
9	0.14	0.17	0.22	0.33	0.58	0.58	0.60
10	0.17	0.21	0.27	0.40	0.54	0.58	0.58

Rutting in asphalt concrete pavements is generally characterized by the maximum depth of the deformation or by the rate at which the deformation occurred (rutting rate). The rutting rate is defined as the slope of log cumulative rut depth versus log pass level curve. For this study, the rutting rate was determined for the initial traffic levels (0 to 4,800 passes). The rutting rate values and maximum rut depth values after 12,000 passes of the load cart are presented in table 16 and shown graphically in figures 12 and 13.

TABLE 16. MAXIMUM RUT DEPTH MEASUREMENTS AFTER 12,000 PASSES AND RUTTING RATE VALUES

Item Number	Rut Depth (in.)	Rutting Rate
1	0.29	0.13
2	0.54	0.37
3	0.53	0.25
4	0.94	0.31
5	0.69	0.41
6	0.71	0.37
7	0.73	0.42
8	1.02	0.54
9	0.60	0.41
10	0.58	0.41

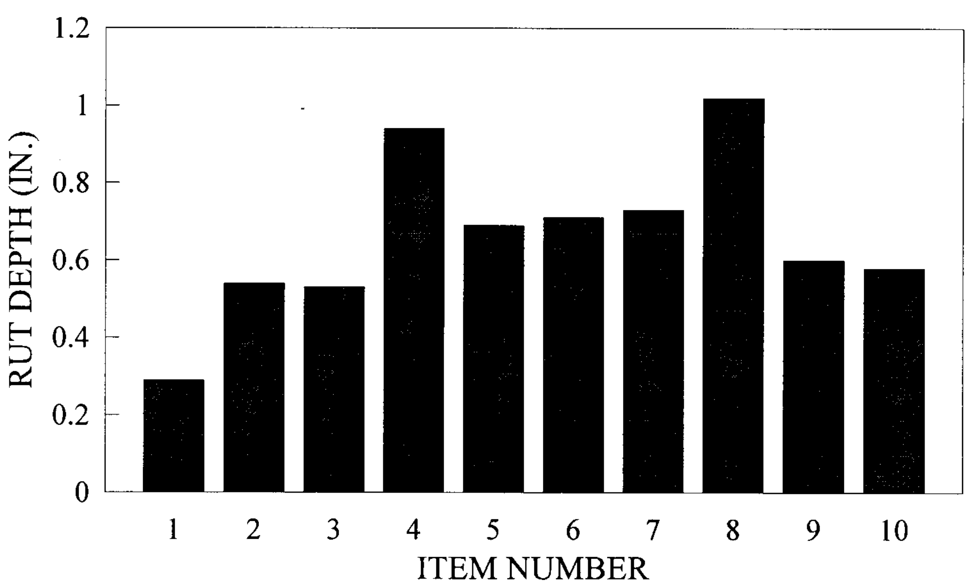


FIGURE 12. RUT DEPTH VALUES AFTER 12,000 PASSES OF AIRCRAFT LOADS

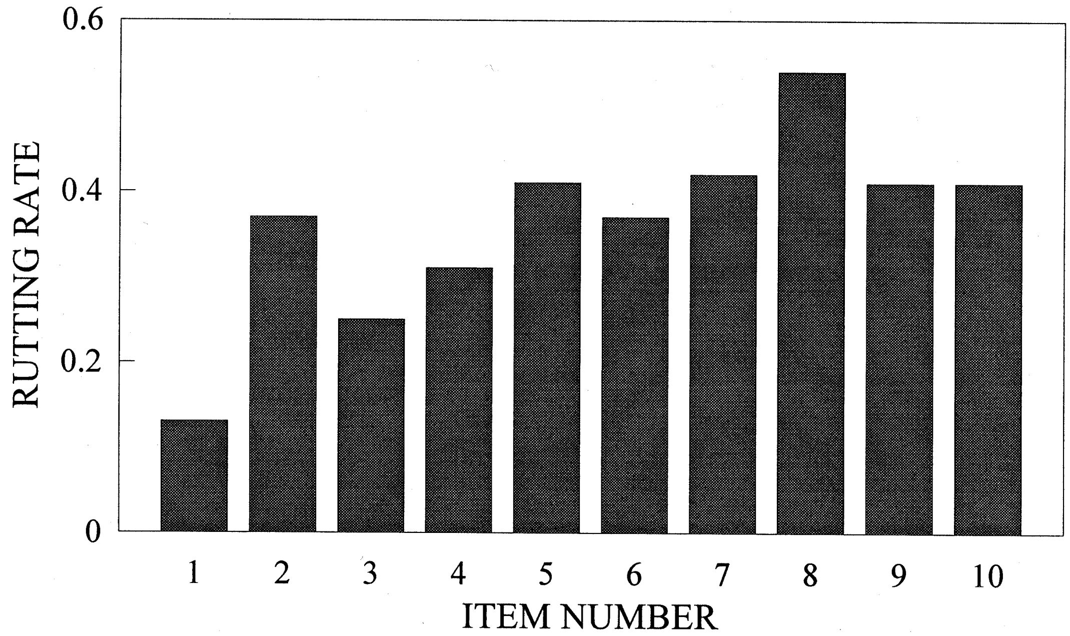


FIGURE 13. RUTTING RATE VALUES FOR TEST ITEM HMA MIXTURES

ANALYSIS AND DISCUSSION

The field evaluation was conducted to evaluate asphalt concrete mixtures under actual traffic loading conditions and to determine which aggregate and/or asphalt concrete mixture properties influenced the amount of rutting. The laboratory test results for these test section mixtures indicated that the plant-mixed asphalt concrete mixtures were not as consistent as the lab-produced asphalt concrete mixtures (laboratory evaluation). The aggregate gradations and air void contents for the test item mixtures were inconsistent and varied from the desired target values. This variation in mix properties introduced additional variability that affected the performance of the test items. Field compaction (level of compaction) also added to the variables of the test items. This variability added to the complexity of evaluating asphalt concrete mixtures and indicated that pavement performance (rutting potential) is affected by many factors including material properties, asphalt concrete production, and asphalt concrete placement and compaction.

The analysis of the test results from the field evaluation included determining the effect of aggregate gradation, percent crushed coarse aggregate, natural-sand content, and asphalt modification on the rutting characteristics of asphalt concrete mixtures. This portion of the evaluation emphasized the trends and performance demonstrated by these different variable groups. The analysis also included correlating individual aggregate and asphalt concrete mixture properties with rut depth and rutting rate values. Since the test items were produced and constructed with many variables, the critical aggregate and asphalt concrete mixture properties that influenced the rutting characteristics are summarized and presented in table 17.

TABLE 17. CRITICAL AGGREGATE AND ASPHALT MIXTURE PROPERTIES OF TEST ITEMS

Item	Asphalt Binder Type	Percent Crushed Coarse Particles	Natural-Sand Content	Percent Air Voids			Rut Depth (in.)	Rutting Rate
				Lab Compacted	After Construction	After Traffic		
1	AC-20	99	15	4.4	9.5	4.1	0.29	0.13
2	SBS-modified AC-20	100	25	2.4	7.5	2.8	0.54	0.37
3	AC-20	98	5	4.6	9.9	2.6	0.53	0.25
4	AC-20	96	20	6.6	7.4	3.5	0.94	0.31
5	SBS-modified AC-20	95	20	2.3	5.7	1.6	0.69	0.41
6	AC-20	95	40	7.2	9.4	6.5	0.71	0.37
7	SBS-modified AC-20	92	40	5.2	7.8	4.9	0.73	0.42
8	SBS-modified AC-20	11	0	3.5	6.3	3.7	1.02	0.54
9	AC-20	47	0	3.2	8.3	3.5	0.60	0.41
10	SBS-modified AC-20	55	0	2.4	7.5	1.8	0.58	0.41

SHAPE OF AGGREGATE GRADATION CURVE.

As discussed previously in the literature reviews[5] and laboratory evaluation,[6] the shape (particle distribution) of the aggregate gradation greatly influences the performance of asphalt concrete mixtures. Due to the limited number and inconsistency of the test items, only a partial evaluation of aggregate gradation was achieved. The effect of aggregate gradation was evaluated in Test Items 1, 3, 4, and 6. These items were selected because each mixture had the same asphalt binder and similar air voids and demonstrated the influence of the fine aggregate portion (passing the No. 4 sieve) of the gradation. These aggregate gradations are shown graphically in figures 14-17.

The performance of these four test items indicated that two parts of the aggregate gradation influenced the amount of rutting. First, a sufficient amount of material passing the No. 16 sieve is required to produce a mixture that will be less susceptible to rutting. Aggregate blends produced near the coarse limit of the FAA gradation (Item 3) and below (Items 4 and 6) produced significant rutting. The rut depth increased from 0.29 in. for Item 1 to 0.53 in., 0.75 in., and 0.67 in. for Items 3, 4, and 6 respectively. Second, aggregate gradations with a significant decrease in percent passing

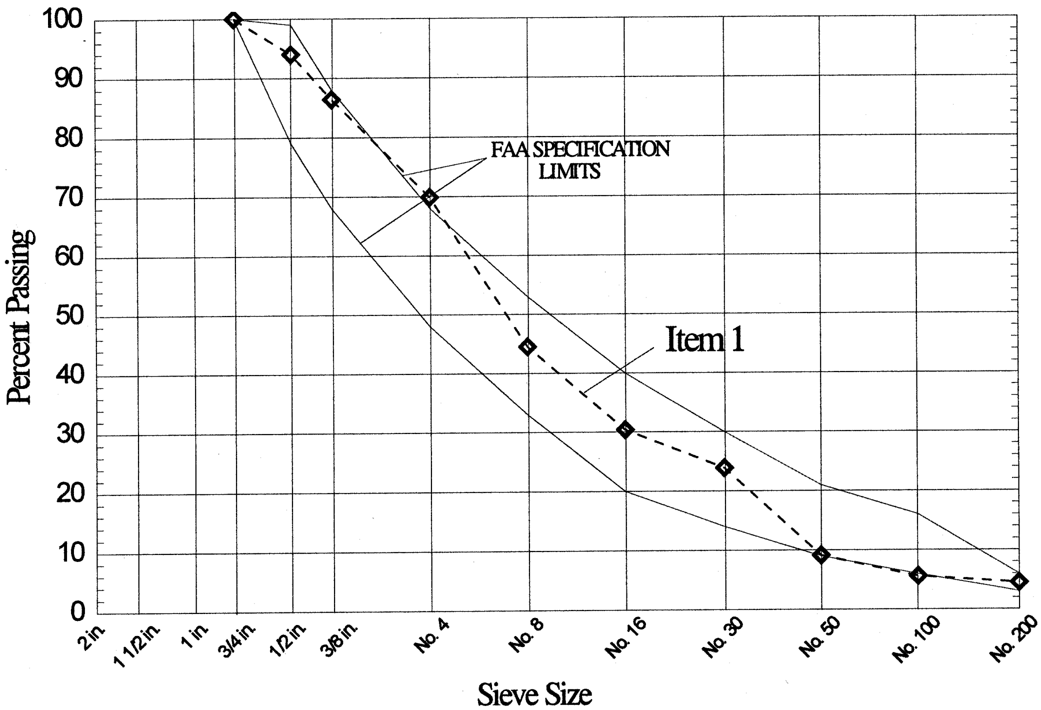


FIGURE 14. AGGREGATE GRADATION FOR ITEM 1

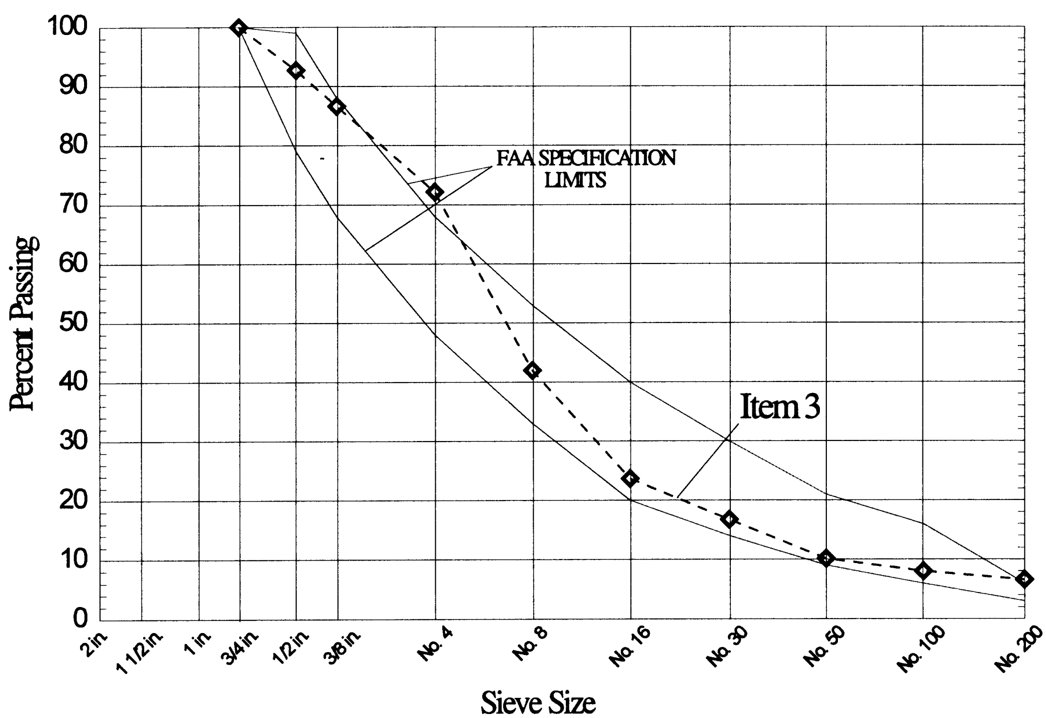


FIGURE 15. AGGREGATE GRADATION FOR ITEM 3

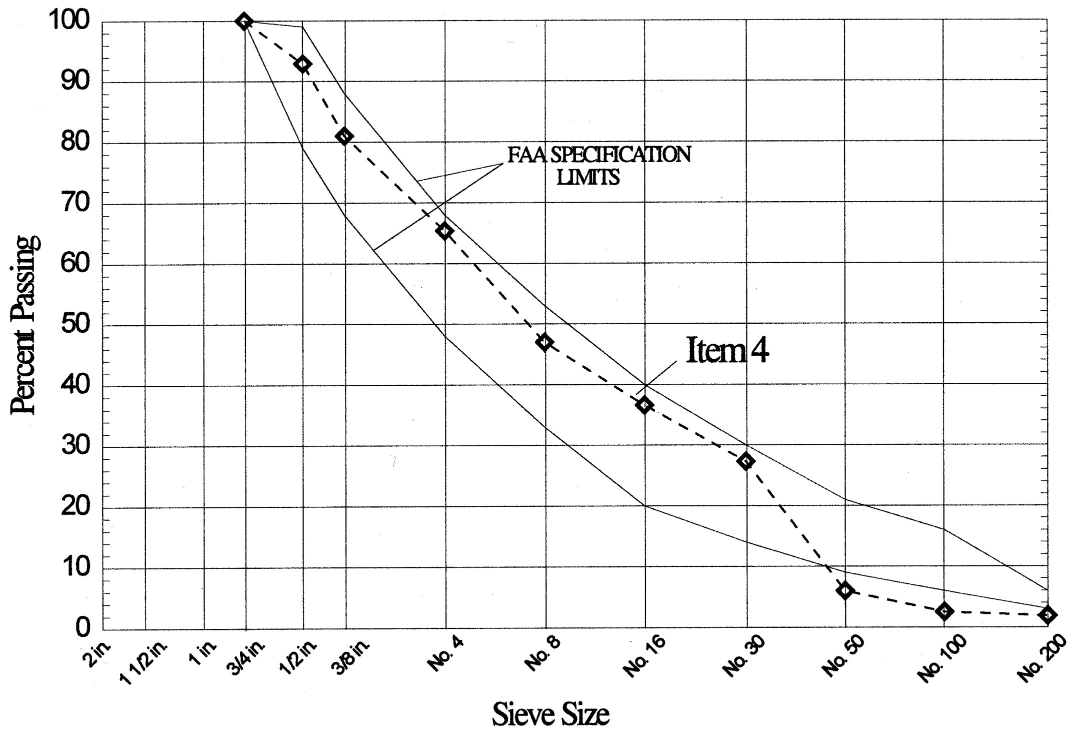


FIGURE 16. AGGREGATE GRADATION FOR ITEM 4

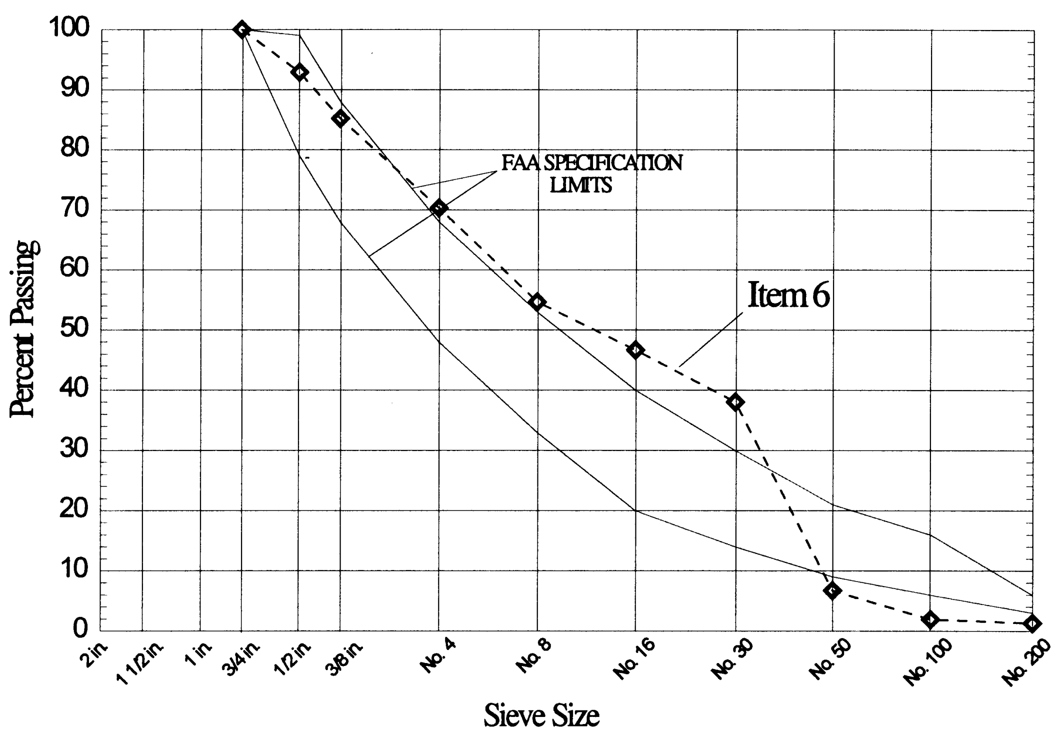


FIGURE 17. AGGREGATE GRADATION FOR ITEM 6

or have a "hump" near the No. 30 sieve produced tender mixes that were very susceptible to rutting (Items 4 and 6). These findings agreed with the results of the laboratory evaluation which showed asphalt concrete mixtures with aggregate gradations on the fine side of the FAA gradation band had less rutting potential than asphalt concrete mixtures with gradations near the coarse side of the band.

PERCENTAGE OF CRUSHED COARSE AGGREGATE.

Based on the findings in the literature[5] and the results of the laboratory evaluation,[6] the percentage of crushed coarse aggregate has a significant influence on rutting potential of asphalt concrete mixtures. This aggregate property was evaluated in Items 1, 8, and 9. The field performance of these test items indicated that the percentage of crushed coarse aggregate did affect the rutting characteristics of these asphalt concrete mixtures. The rut depth measurement approximately doubled (0.29 to 0.60 in.) when the percent crushed coarse aggregate was decreased from 99 to 47 percent. The rutting rate significantly increased when the percent crushed coarse aggregate (CA) decreased from 99 percent to below 50 percent. The overall trend was that rutting potential increased as the percentage of crushed coarse aggregate decreased. This trend is shown graphically in figures 18-20.

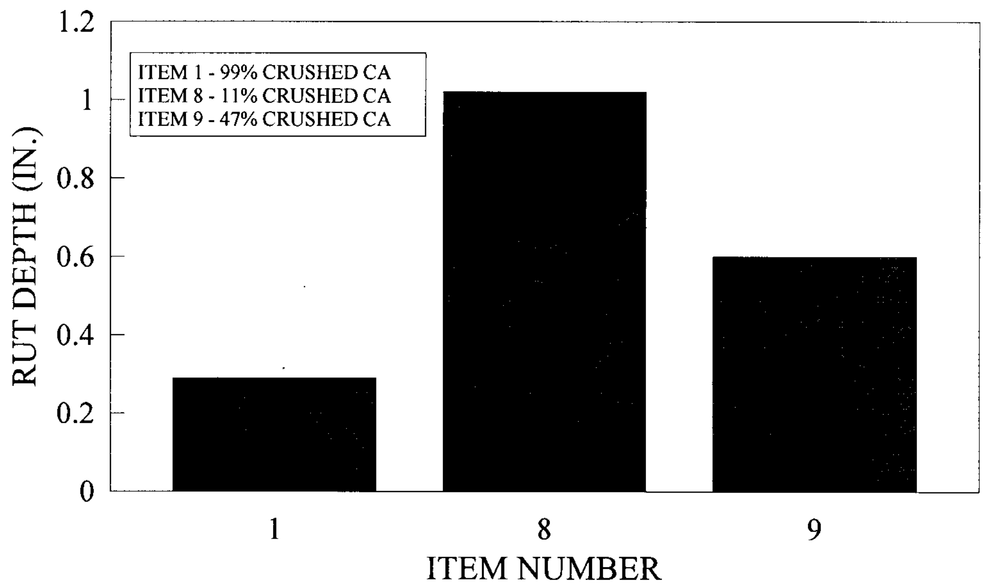


FIGURE 18. EFFECT OF PERCENT CRUSHED COARSE AGGREGATE ON RUT DEPTH VALUES

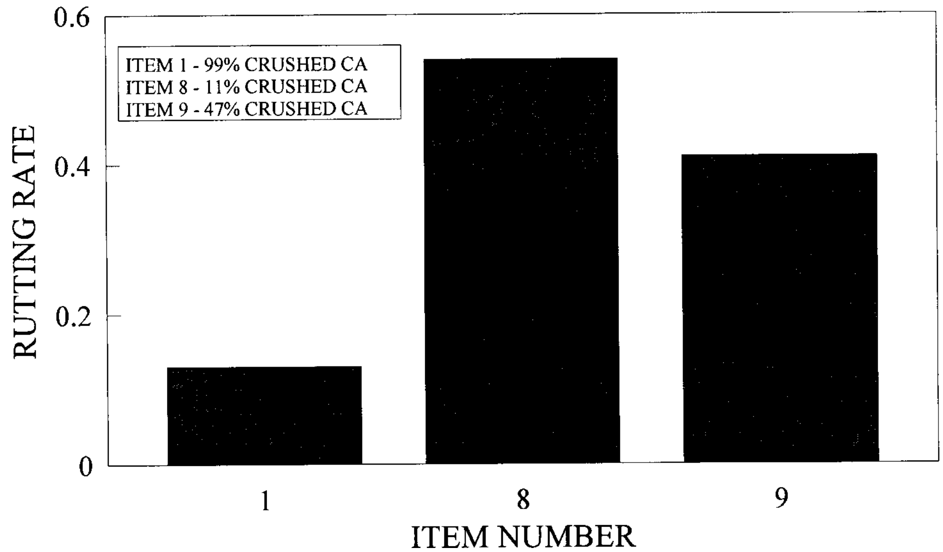


FIGURE 19. EFFECT OF PERCENT CRUSHED COARSE AGGREGATE ON RUTTING RATE VALUES

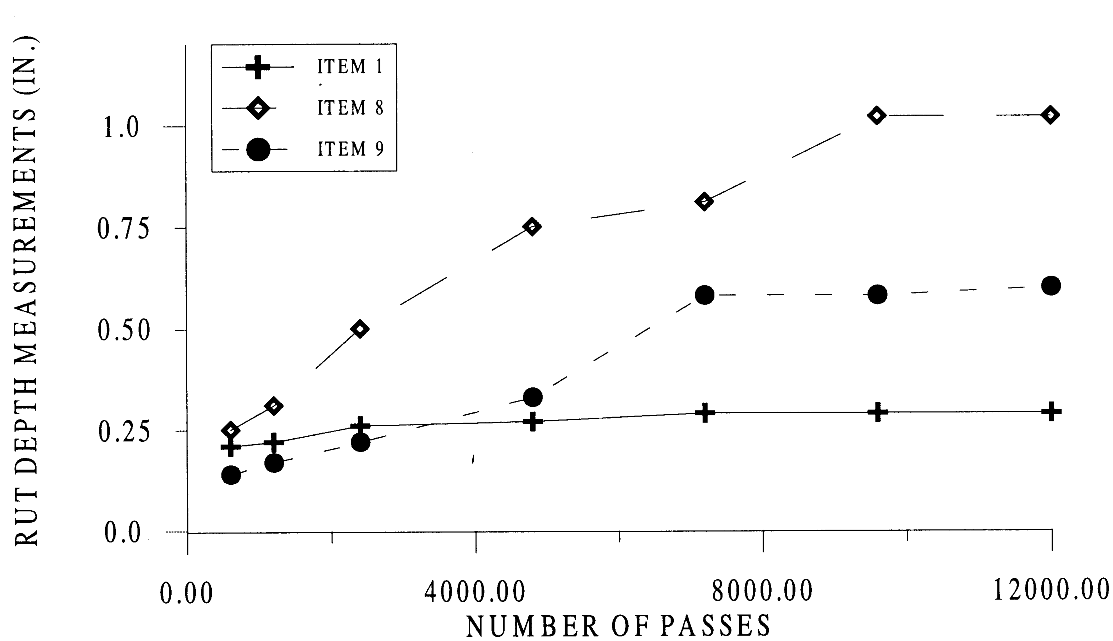


FIGURE 20. CUMULATIVE RUT DEPTH VALUES FOR VARIOUS CRUSHED COARSE AGGREGATE MIXES

AMOUNT OF NATURAL-SAND MATERIAL.

The effect of the amount of natural-sand material in an aggregate blend was evaluated in Items 1, 4, and 6. This evaluation combines the effects of particle shape and texture and fine aggregate gradation on the rutting characteristics of asphalt concrete mixtures. The performance of these test items indicated that the rutting potential increased when the amount of natural-sand material was 20 percent or greater. The rut depth and rutting rate values indicated a significant increase in rutting potential when the natural-sand content was greater than 15 percent. This increase in rutting potential is shown graphically in figures 21-23.

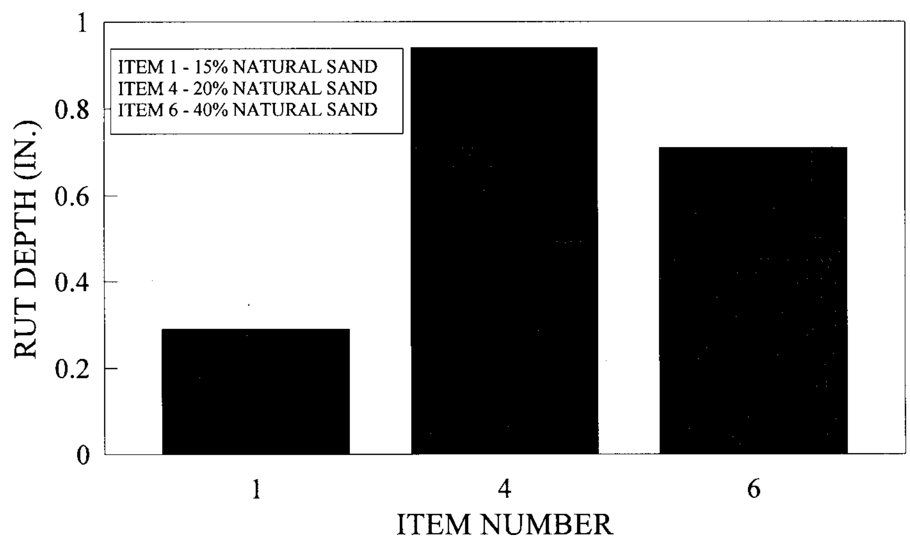


FIGURE 21. EFFECT OF NATURAL-SAND CONTENT ON RUT DEPTH VALUES

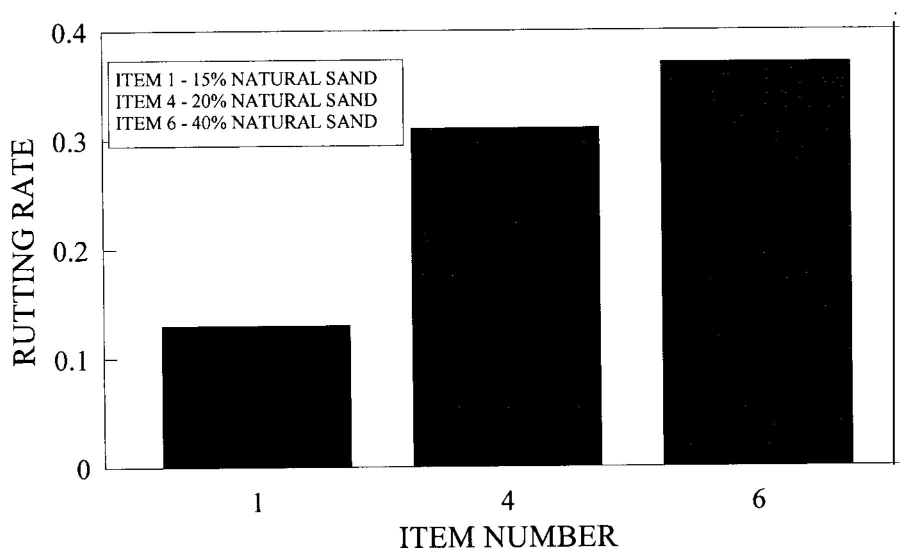


FIGURE 22. EFFECT OF NATURAL-SAND CONTENT ON RUTTING RATE VALUES

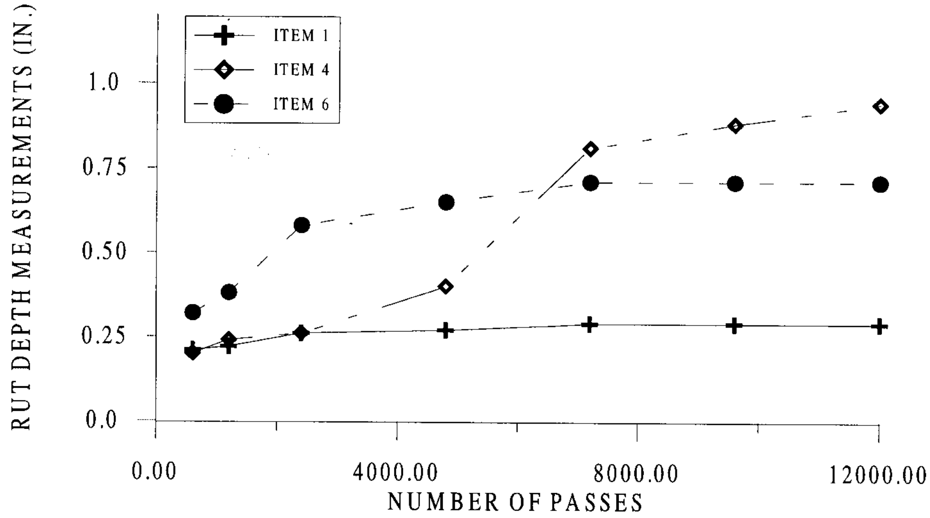


FIGURE 23. CUMULATIVE RUT DEPTH VALUES FOR VARIOUS NATURAL-SAND MIXES

BENEFITS OF ASPHALT MODIFICATION.

The benefits of asphalt modification were evaluated for two conditions: (1) direct comparison of AC-20 and SBS-modified AC-20 mixtures with similar aggregate blend and (2) comparison of mixtures with substandard aggregate blends produced with SBS-modified AC-20 to a control mix (Item 1). The direct comparison was conducted on three aggregate blends, 20 percent natural sand (Items 4 and 5), 40 percent natural sand (Items 6 and 7), and 50 percent crushed coarse aggregate (Items 9 and 10). The comparison of modified substandard aggregate blends to the control mix was conducted with Items 1, 2, 5, 7, 8, and 10.

The effect of asphalt modification on the test item asphalt concrete mixtures is shown in figures 24-27. The findings of this analysis indicate that asphalt modification had an insignificant positive influence on the rutting potential of these asphalt concrete mixtures. These findings are biased because of the multiple variables included in these mixtures and may not represent the actual effect of asphalt modification. These findings are also contrary to the findings of the laboratory evaluation.

CORRELATION OF AGGREGATE AND ASPHALT CONCRETE MIXTURE PROPERTIES WITH PERMANENT DEFORMATION VALUES.

One focus of the analysis procedure consisted of performing correlation analyses to determine if the independent variables were significantly correlated to the dependent variables rut depth and rutting rate. The independent variables were analyzed in four groups: (1) aggregate gradation, (2) aggregate characterization properties, (3) asphalt concrete mixture properties, and (4) confined repeated load deformation properties. The data were analyzed using SigmaStat statistical software package.[15] The coefficient of determination (R^2) was used to determine how strong the relationship was between

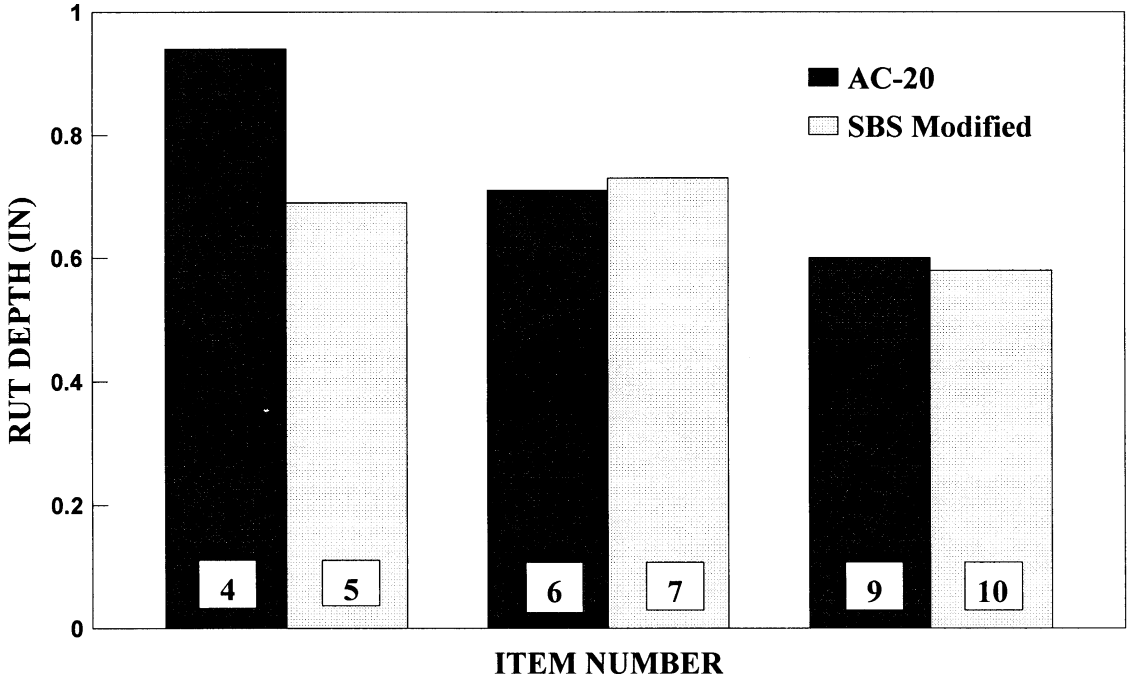


FIGURE 24. EFFECT OF ASPHALT MODIFICATION ON RUT DEPTH

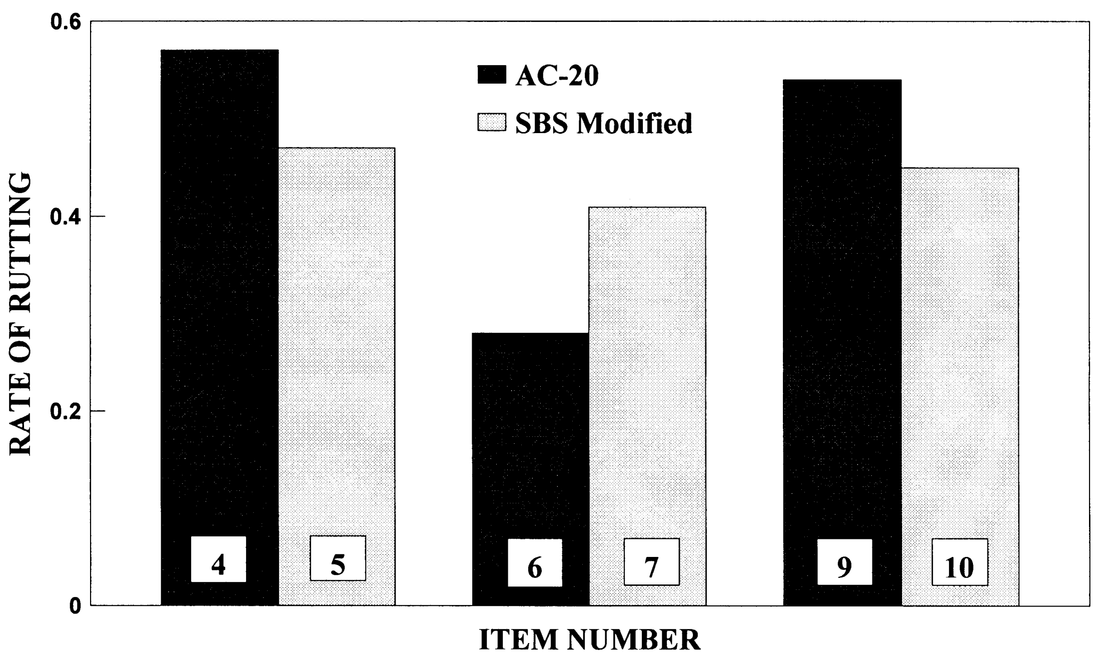


FIGURE 25. EFFECT OF ASPHALT MODIFICATION ON RUTTING RATE VALUES

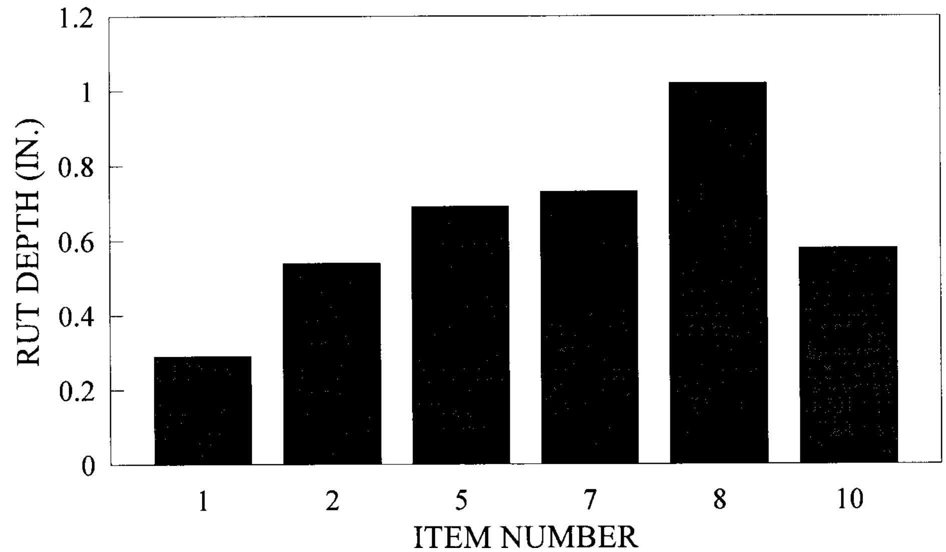


FIGURE 26. EFFECT OF ASPHALT MODIFICATION ON RUT DEPTH OF SUBSTANDARD AGGREGATE BLENDS

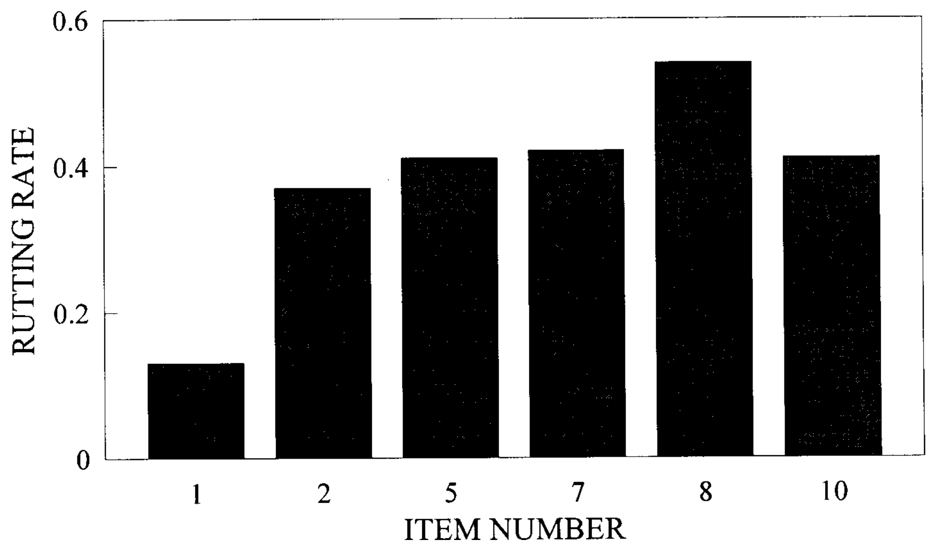


FIGURE 27. EFFECT OF ASPHALT MODIFICATION ON RUTTING RATE OF SUBSTANDARD AGGREGATE BLENDS

the independent variables and the dependent variables. The R^2 value indicated the strength of the linear correlation. The R^2 values closer to 1 indicate a better relationship between independent and dependent variables.

The analysis of the aggregate gradation and aggregate characterization properties was conducted without Items 2, 5, and 10. These asphalt concrete mixtures were produced with air voids below 2.5 percent. The low air voids would influence the asphalt concrete performance and overshadow the effects of the aggregate properties. The values of these test items were included in the analysis of the asphalt concrete mixture properties.

AGGREGATE GRADATION.

The performance of asphalt concrete mixtures is greatly affected by the aggregate gradation because the gradation controls the void structure (matrix). Although the gradation is important to the performance of asphalt concrete, the effect of the gradation is often difficult to quantify. For this study, the percent passing each sieve size was analyzed to determine the effect of aggregate gradation on rut depth. A summary of coefficients of determination for aggregate gradation is presented in table 18. The R^2 values indicated that only the 0.5 and 3/8 in. sieves had any statistically significant relationships with rutting. The R^2 values for the 0.5 and 3/8 in. sieves with rut depth were 0.448 and 0.812. The correlations for rutting rate indicated the similar trends with R^2 values of 0.718 and 0.410 for the 1/2 and 3/8 in. sieves.

TABLE 18. SUMMARY OF COEFFICIENTS OF DETERMINATIONS FOR AGGREGATE GRADATION

Parameter	n	Rut Depth R^2	Rutting Rate R^2
Percent passing 0.5 in. sieve	7	0.448	0.178
Percent passing 3/8 in. sieve	7	0.812	0.410
Percent passing No. 4 sieve	7	0.194	0.001
Percent passing No. 8 sieve	7	0.039	0.255
Percent passing No. 16 sieve	7	0.050	0.080
Percent passing No. 30 sieve	7	0.017	0.034
Percent passing No. 50 sieve	7	0.042	0.026
Percent passing No. 100 sieve	7	0.046	0.003
Percent passing No. 200 sieve	7	0.044	0.014

AGGREGATE CHARACTERIZATION PROPERTIES.

As previously reported in the laboratory evaluation,[6] aggregate properties (shape and texture) have a significant affect on the rutting potential of asphalt concrete mixtures. One of the objectives of this study was to characterize and quantify aggregate properties and to determine the influence of these properties on the performance of asphalt concrete mixtures. Several aggregate characterization tests were conducted on extracted aggregates from test item mixtures and correlated with rut depth and rutting rate. A summary of R^2 values for aggregate characterization properties is presented in table 19. The percent crushed particles (composite blend and coarse aggregate fraction) produced only moderate correlations with rut depth. The R^2 value for percent crushed coarse particles was 0.249 for rut depth values. The percent crushed coarse, modified NAA, ASTM C 29 (shovel) produced the strongest correlations with rutting rate. R^2 values for these aggregate characterization tests were 0.572, 0.350, and 0.353.

TABLE 19. SUMMARY OF COEFFICIENTS OF DETERMINATION FOR AGGREGATE CHARACTERIZATION PROPERTIES

Parameter	n	Rut Depth R^2	Rutting Rate R^2
Percent crushed particles-composite	7	0.177	0.235
Percent crushed particles-coarse	7	0.249	0.572
Percent crushed particles-fine	7	0.002	0.001
Natural-sand content	7	0.001	0.002
Modified NAA	7	0.078	0.350
ASTM C 29 shovel	7	0.124	0.353
NAA Method A	7	0.109	0.088
NAA Method C	7	0.097	0.028
Direct shear	7	0.036	0.030

ASPHALT CONCRETE MIXTURE PROPERTIES.

Because rutting is a very complicated process, several types of asphalt concrete mixture properties (i.e., voids, strength, deformation) were determined to evaluate asphalt concrete properties with rutting. Traditional volumetric and Marshall properties along with gyratory compaction and direct shear properties were used to analyze the test item asphalt concrete mixtures with rut depth and rutting rate. A summary of R^2 values for asphalt concrete mixture properties is presented in table 20. The R^2 values indicated that the stability/flow ratio was the only asphalt concrete mixture property that had a strong relationship with rut depth. This correlation had a R^2 value of 0.528 for rut depth. In-place air voids before traffic (after construction) and the stability/flow ratio produced the strongest linear correlations with rutting rate. These correlations had R^2 values of 0.486 and 0.505.

CONFINED REPEATED LOAD DEFORMATION PROPERTIES.

One of the primary objectives of this research study was to validate the confined repeated load deformation test with field cores and rutting after traffic. This test method had been reported to be one of the best procedures to evaluate permanent deformation since this type test more closely simulates the in situ pavement conditions under traffic. The confined repeated load deformation test was conducted on plant-mixed asphalt concrete material compacted in the laboratory and field compacted with conventional asphalt rollers (vibratory and rubber-tired). The correlations indicated weak relationships between the confined repeated load deformation test results and actual rutting in the field. The field compacted specimen produced better correlations than the lab compacted specimen. These results are logical because the laboratory compacted specimens are compacted to approximately 100 percent lab density while the in-place pavement is compacted to approximately 95 percent lab density.

In order to simulate field conditions, the confined repeated load deformation test should be conducted on laboratory samples that are compacted to densities that approximate field conditions.

TABLE 20. SUMMARY OF COEFFICIENTS OF DETERMINATION FOR ASPHALT CONCRETE MIXTURE PROPERTIES

Parameter	n	Rut Depth	Rutting Rate
		R^2	R^2
Air voids—lab compacted	10	0.070	0.081
Voids in mineral aggregate	10	0.219	0.118
Voids filled	10	0.029	0.190
Stability	10	0.160	0.016
Flow	10	0.086	0.342
Stability/flow	10	0.528	0.505
GEPI	10	0.204	0.201
Gyratory shear strength	10	0.148	0.017
Angle of internal friction	10	0.001	0.005
Direct shear strength	10	0.145	0.008
In-place air voids after construction	10	0.340	0.486
In-place air voids after traffic	10	0.019	0.003
Permanent strain lab compacted	10	0.060	0.005
Creep modulus lab compacted	10	0.073	0.008
Slope lab compacted	10	0.069	0.008
Permanent strain field compacted	10	0.043	0.237
Creep modulus field compacted	10	0.014	0.281
Slope field compacted	10	0.070	0.008

SUMMARY.

The results of the statistical analysis indicated that few individual aggregate and asphalt concrete mixture properties have a significant relationship with pavement rutting. Although the correlations were weak, most aggregate and asphalt concrete properties appeared to have definite trends. It was evident from the data that rutting is influenced by multiple factors (i.e., percent crushed particles, gradation, stiffness of asphalt concrete, and in-place voids) and cannot be predicted with individual aggregate and asphalt concrete mixture properties. Surprisingly, the Marshall stability/flow ratio had the single best individual correlation with rutting in asphalt concrete pavements. A major factor affecting the analysis was varying laboratory air voids for the test items.

CONCLUSIONS

The objective of this research study was to evaluate the utilization of marginal aggregates in asphalt concrete layers for airport pavements. The primary focus of this evaluation was to characterize and quantify aggregate and mixture properties and develop relationships between these properties and rutting potential. This study also determined whether marginal mixtures could provide or be improved to provide equivalent pavement performance. The following conclusions were derived from the analyses of the field evaluations.

a. Rutting potential was influenced by the shape of the aggregate gradation. Aggregate blends produced near and below the coarse limit of the FAA gradation band developed significant rutting. Aggregate gradations that had a “hump” near the No. 30 sieve produced tender mixes that were susceptible to rutting.

b. The percentage of crushed coarse aggregate had a significant effect on rutting potential of the field test items. As the percentage of crushed coarse aggregate decreased, the potential for rutting increased.

c. The amount of natural sand also had a significant effect on the rutting of the field test items. Rutting potential significantly increased when the natural-sand content was greater than 15 percent.

d. Asphalt modification had an insignificant positive effect on marginal (substandard) aggregate mixtures.

e. The statistical analysis of the field test section indicated that few individual aggregate and asphalt concrete mixture properties had a significant relationship with pavement rutting. It was obvious from the analyses that rutting in asphalt concrete pavements is a complicated process and is influenced by many parameters.

f. The Marshall stability/flow ratio had the best individual mixture property correlation with rutting. The R^2 values for this asphalt concrete mixture property with rut depth and rutting rate were 0.528 and 0.515, respectively.

g. The results of the confined repeated load deformation test did not predict the rutting potential of the test items with much accuracy. Test results did indicate stronger relationships with rutting were produced when test samples were compacted to field conditions.

RECOMMENDATIONS

Based on the conclusions derived from the results of the overall research study which included the literature review,[5] laboratory evaluation,[6] and the field evaluation study, the following recommendations were made:

a. Current FAA aggregate specifications could be improved by implementing performance-related quantitative aggregate characterization properties determined by the Particle Index text (ASTM D 3398) and the NAA (ASTM C 1752) and modified NAA particle shape and texture tests. Initial preliminary guidance and criteria could be implemented based on values determined in this laboratory study, but final criteria should be verified based on additional research involving a variety of aggregate types and sources. The recommended aggregate requirements should be a Particle Index of 14, a modified NAA, and a NAA-Method A on compacted void contents of 45.

b. Current FAA gradation bands should be modified and shifted to include finer gradations. The coarse limit of the current specification produced a very low quality mixture. Mixtures finer than the current specification produced very low rut susceptible mixtures. A new gradation band for surface course mixtures is presented in table 21.

c. Additional research is needed to fully evaluate the poorly graded mixtures and the potential of large aggregate mixtures and stone mastic asphalt (SMA) mixtures.

d. Current FAA requirements for percent crushed particles and amount of natural-sand material in the aggregate blend may allow rut susceptible asphalt mixtures to be used. The confined repeated load deformation test and/or laboratory rut testing device should be used in conjunction with the Marshall procedure to analyze the rutting potential of the asphalt mixture.

e. Modified asphalt binders did improve the rutting characteristics of marginal aggregate mixtures in the laboratory. Further research is needed to evaluate new and different asphalt modification techniques and to establish criteria for selecting the modifier type and dosage rate.

f. Relaxing the criteria for aggregate materials should not be considered for airport pavements subjected to aircraft weighing greater than 60,000 lbs or to tire pressures higher than 100 psi.

TABLE 21. NEW AGGREGATE GRADATION BANDS

Sieve Size	1 in. Max.	3/4 in. Max	1/2 in. Max
1 in.	100	—	—
3/4 in.	76-96	100	—
1/2 in.	66-88	78-96	100
3/8 in.	58-82	69-89	78-96
No. 4	43-67	51-73	58-78
No. 8	30-54	36-60	38-60
No. 16	24-44	24-48	26-48
No. 30	15-35	18-38	18-38
No. 50	9-25	11-27	11-27
No. 100	6-18	6-18	6-18
No. 200	3-6	3-6	3-6

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