Effects of Maximum Aggregate Size on Rutting Potential and Other Properties of Asphalt-Aggregate Mixtures

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Many factors affect the properties of asphalt concrete, and one of these is the maximum aggregate size used in the mix. A laboratory analysis of the effect of varying the maximum aggregate size on rutting potential and on other properties of asphalt aggregate mixtures was performed. The aggregate in all mixes evaluated consisted of 100 percent crushed limestone. The five different mix designs evaluated included aggregate having gradations that contained maximum aggregate sizes of ⅜, ½, ¾, 1, and 1½ in. The asphalt content for all mixes was selected to provide an air voids content of 4 percent under a compactive effort in the Gyratory Testing Machine equivalent of 75 blows of a Marshall hammer. All mixes produced with the five gradations were subjected to a testing program that included tests to evaluate Marshall stability and flow, indirect tensile strength, creep, and resilient modulus. Specimens for mix design and evaluation of mixture properties were compacted in a 4-in. diameter mold. In addition, specimens at optimum asphalt content were prepared in a 6-in. diameter mold and were tested by using the indirect tensile test and the creep test. These results were then compared to those from the 4-in. diameter specimens for the same aggregate gradations. Test results indicated that mixes with larger aggregate design with an air voids content of 4 percent were generally stronger than mixes prepared with smaller aggregate. The mixes with larger aggregate also required significantly less asphalt.

The effects of using large aggregate in asphalt mixes have been researched and speculated on for many years. Patents were issued as early as 1903 for bituminous mixes that contained aggregate as large as 3 in. (*1*). Research is sparse, however, when a comparison of mixtures over a range of maximum aggregate sizes is involved.

Although large aggregate mixes have been used in specialized situations, such as storage yards for equipment and materials (*2*), they are not currently used or accepted on a regular basis for highway pavement mixes. The wide acceptance of the Marshall design procedure as well as the Hveem procedure may be a major factor limiting the use of large aggregate because standard 4-in. mold sizes and testing equipment limit aggregate maximum size to 1 in. Production and placement of mixtures containing large aggregate in the field is also a problem and thus discourages the use of large aggregates.

OBJECTIVES

This study was conducted to determine the relationship between asphalt mixture properties and maximum aggregate size. An additional aspect of this study was to compare the differences in test results between 4- and 6-in. diameter specimens for the mixes tested.

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SCOPE

The testing procedures used in this project were chosen to analyze the effects of varying the size of the largest aggregate in a gradation. The tests used in this study included Marshall stability and flow, indirect tensile, static creep, and resilient modulus. All sample preparation and tests for this project were performed in the laboratory.

Gradations were selected to contain maximum aggregate sizes of ⅜, ½, ¾, 1, and 1½ in. The aggregate was sampled so that all sizes came from the same location in the quarry and thus had the same properties. One sample of asphalt was used for all tests. Thus, every precaution was taken to ensure that the test results focused on the effects of maximum aggregate size only and did not include the effects of varying the properties of materials.

REVIEW OF LITERATURE

Causes of Rutting

Modern traffic levels and tire pressures have resulted in higher stresses imposed on pavements, which has caused increased rutting as well as other problems. Brown (*3*), in a paper presented at an AASHTO/FHWA Symposium in Austin, Texas, in 1987, listed several conditions that may be aggravated by these stresses and that may result in rutting. The potential problems included excessive asphalt content caused by improper laboratory procedures, excessive use of natural sand or minus No. 200 material, improperly crushed aggregate, maximum size coarse aggregate that was too small, and density obtained in the field that was too low (*3*).

A study of rutting in Canada by Huber and Heiman (*4*) analyzed the condition of asphalt concrete as it was designed, after it was constructed, and as it existed at the time of their study. They used regression analysis and threshold analysis to identify characteristic values that separated acceptable and unacceptable behavior. They found that the threshold air voids content was 4 percent minimum. The threshold value for voids in the mineral aggregate (VMA) was 13.5 percent minimum, and the voids filled threshold value was approximately 80 percent maximum. An analysis of the fractured faces proved difficult, but the acceptable value that Huber and Heiman eventually determined was 60 percent minimum. The Marshall stability test was shown to be a poor indicator of rutting potential because tests conducted on mixes from rutted and nonrutted asphalt pavements yielded approximately the same stability values. Hveem stability correlated reasonably well with rutting and indicated a threshold value of 37 minimum. The threshold asphalt content was determined to be 5.1 percent maximum (*4*). Performance was directly affected if voids filled were greater than 80 percent, air voids were less than 4 percent, or asphalt content was greater than 5.1 percent. They found that fractured faces, VMA, and Hveem stability appeared secondary and Marshall stability, flow, penetration, and viscosity showed little correlation to rutting resistance.

A British study of roadway bituminous base material by Brown and Cooper (*5*) used various gradations with maximum aggregate size up to 40 mm (1.57 in.) to analyze elastic stiffness, fatigue life, and rutting resistance. They used full-scale field trials and laboratory work in this study. Testing methods included a repeated load triaxial test, triaxial creep, uniaxial creep, and Marshall stability.

The creep results indicated that asphalt mixes prepared with 100 and 200 penetration grade asphalt showed no significant difference in permanent deformation. Aggregate gradation, however, had a significant effect on permanent deformation. Mixes with dense-graded and gap-graded aggregates were compared, and the gap-graded mix experienced significantly more permanent deformation than the dense-graded mix (*5*).

Brown and Cooper's Marshall stability results led to inconsistent conclusions. In one case, Marshall stability gave indications that were opposite those of the triaxial test. They concluded that the inconsistencies were caused by the fact that they were using aggregate larger than that specified in the Marshall procedure (*5*).

Effects of Coarse Aggregate

In a 1986 ASTM paper, Brown et al. (*6*) presented results that listed the advantages of larger aggregate. Their test results showed that both stability and tensile strength decreased as VMA increased. Because VMA is generally higher for smaller aggregate, stability and tensile strength decreased as aggregate size decreased. Other advantages of using large aggregate that were discussed by Brown et al. included improved skid resistance and lower optimum asphalt content.

The effects of using aggregate up to 2½ in. in size were investigated by Khalifa and Herrin (*7*). Their general conclusions were that unit weight increased as aggregate size increased, and VMA and air voids decreased with increased aggregate size for any given asphalt content tested.

A laboratory and field study published by the National Asphalt Pavement Association (NAPA) gave the results with significantly different maximum aggregate sizes of two mixes (*8*). One had a maximum aggregate size of ½ in. and the other a maximum aggregate size of 1½ in. The report described the problems of preparing laboratory mixes with the currently available 4-in. diameter molds. A modified Marshall procedure was used in compacting samples in 4-in. diameter molds by using a vibrating hammer. Most obvious was the improvement in stability for larger maximum aggregate size. In addition, the film thickness remained basically the same between the two mixes, even though the asphalt content for the larger mix was significantly lower. The film thickness was the same because the mix with the larger maximum size aggregate had a smaller aggregate surface area (*8*).

The ASTM procedure for preparing 4-in. diameter specimens by using the Marshall hammer recommends that it be used for aggregate smaller than 1 in. Cross (*9*) studied the effects of maximum aggregate size on specimens of asphalt stabilized base material prepared in 4-in. molds. Cross characterized the limestone mixes according to those with maximum aggregate size greater than 1 in. and those less than 1 in. His test results indicated that the plus 1 in. aggregate yielded a higher stability but that the stability values for the plus 1 in. material were "very erratic."

Kandhal (*10*) reviewed the effects of preparing 6-in. diameter specimens by using a Marshall procedure adapted from the 4-in. diameter procedure. To produce the same amount of energy per unit volume in the 6-in. as in the 4-in. specimens, a 22.5-lb hammer was recommended instead of the standard 10-lb hammer. Drop height remained the same, but the number of blows required was increased by 50 percent. Some crushing of the surface aggregate was observed, but Kandhal did not believe it was sufficient to affect the Marshall properties.

Creep Testing

Van de Loo (*11*) analyzed the relationship between rutting and creep testing. He analyzed data from static and dynamic loads on a test track and static and dynamic creep tests. He found that the stiffness of the mix decreased as the number of load applications increased. When compared at equal asphalt viscosity, the dynamic stiffness modulus of a mix was always higher than the static stiffness modulus. After analyzing the use of results from laboratory-prepared specimens to predict rutting behavior, Van de Loo concluded, "It may be that the main purpose of laboratory test methods must be limited to the ranking of materials rather than the prediction of rut depth" (*11*).

SAMPLE PREPARATION, TEST PROCEDURES, AND RESULTS

Tests were selected to evaluate those properties of asphalt-aggregate mixtures that could be correlated with performance. The test plan to determine these properties is summarized in Figure 1.

Determination of Aggregate Gradation

The aggregate used in this study was 100 percent crushed limestone from the quarry of Vulcan Materials in Calera, Alabama. The gradation specifications for each maximum size aggregate were those of the FHWA and are shown in Table 1 (*12*).

The specific percentages passing each sieve size were determined by using a maximum density curve (0.45 power curve).

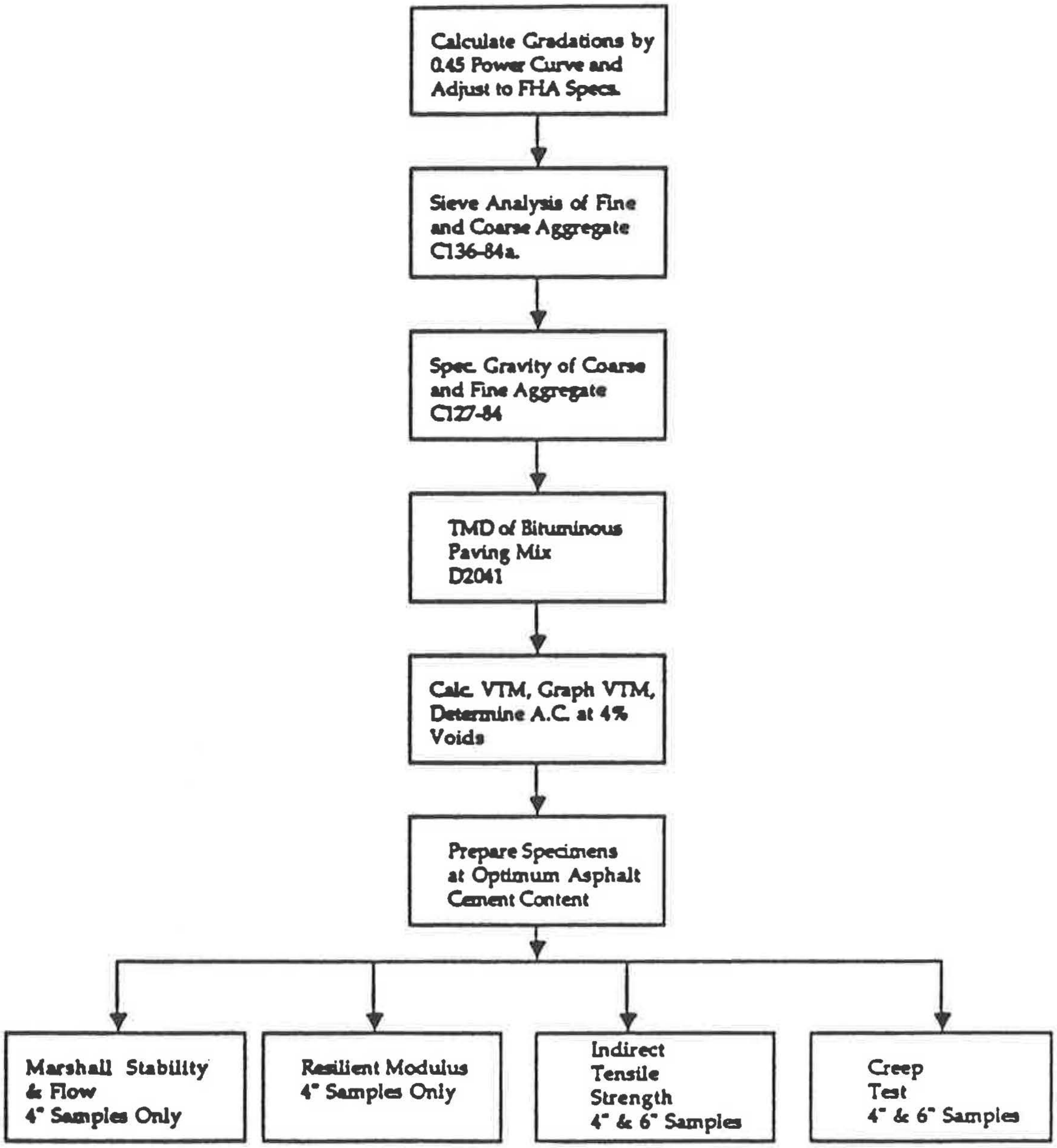

FIGURE 1 Test plan.

The gradation determined to produce the maximum density was

$$P = 100\,(S/M)^{0.45}$$

where

P = percentage passing any particular sieve size,
S = the opening size for that sieve, and
M = the maximum aggregate size in the gradation.

The calculated gradations were compared to the FHWA specifications. The 1½-in. gradation used Grading Designation A (Table 1), the 1-in. used B, the ¾-in. used C, the ½-in. used D, and the ⅜-in. was interpolated between Grading Designations D and E. All the gradations except the one with 1½-in. maximum size aggregate had to be adjusted at the No. 200 sieve size to fit the FHWA specification envelope. That is, the amount of material passing the No. 200 sieve had to be reduced. The final gradations are shown in Table 2.

Properties of the Asphalt Cement

The AC 20 asphalt cement used in this study was produced by the Chevron refinery in Mobile, Alabama. Its specific gravity was 1.032 and pen was 82 at 77°F. Viscosity testing indicated 1940 Poises at 140°F and 403 Cst at 275°F. A Cleveland Open Cup flash test indicated a flash point of 555°F.

Compaction Calibration

The number of revolutions of the gyratory testing machine (GTM) was selected to produce a density equal to that pro-

TABLE 1 GRADATION RANGES FOR ASPHALT CONCRETE MIXES (*12*)

Sieve Designation	Grading Designation A	B	C	D	E
2 inch	100	-	-	-	-
1 1/2 inch	97-100	100	-	-	-
1 inch	-	97-100	100	-	-
3/4 inch	66-80	-	97-100	100	-
1/2 inch	-	-	76-88	97-100	-
3/8 inch	48-60	53-70	-	-	100
No. 4	33-45	40-52	49-59	57-69	97-100
No. 8	25-33	25-39	36-45	57-69	62-81
No. 40	9-17	10-19	14-22	14-22	22-37
No. 200	3-8	3-8	3-7	3-8	7-16

(Federal Highway Administration)

TABLE 2 MIX GRADATIONS AND OPTIMUM ASPHALT CONTENT

Sieve	3/8 inch	1/2 inch	3/4 inch	1 inch	1 1/2 inch
1 1/2"					100
1"				100	83
3/4"			100	87	73
1/2"		100	83	73	61
3/8"	100	87	72	63	54
#4	72	62	52	46	39
#8	51	44	37	33	29
#16	36	31	26	23	21
#30	26	21	19	17	15
#50	18	14	12	12	11
#100	12	9	8	8	8
#200	8.2	5.8	5.2	5.5	6.1
Optimum Asphalt Content	4.5	5.0	4.3	3.8	3.4

duced by a 75-blow compactive effort by using the Marshall procedure. This procedure indicated that approximately 30 revolutions at a pressure of 200 psi and a 1-degree gyratory angle produced a density equal to that obtained with a 75-blow compactive effort.

Mix Design and Specimen Preparation

The specimens to be tested were prepared at the asphalt content (optimum) necessary to produce 4 percent air voids. All specimens were prepared in the GTM set up to provide a density equal to that obtained with 75 blows with the manual hammer. Six-in. specimens were not used in the mix design process but were produced at the optimum asphalt content determined for the 4-in. diameter specimens.

Testing

Marshall Stability and Flow Tests

The Marshall stability and flow tests were conducted following the procedures described in ASTM D 1559-82. The specimens were heated to 140°F in a water bath for 30 min prior to measuring stability and flow. The Marshall stability and flow results are shown in Table 3.

Indirect Tensile Test

The specimens (both 6 and 4 in.) for the indirect tensile test were prepared as outlined. This test was conducted following the procedure described in ASTM D 4123-82 at a temperature of 77°F and a standard load rate of 2 in./min. Three specimens were prepared and tested for each gradation to obtain an average indirect tensile strength for the gradation. The indirect tensile test results are shown in Table 4.

Resilient Modulus Test

The resilient modulus tests were conducted on three specimens for each gradation at three different temperatures. The temperatures were 41°F, 77°F, and 104°F. The load level used for these tests was 10 percent of the indirect tensile strength at 77°F. The procedure used for this test was ASTM D 4123-82 and the value for the Poisson's ratio used in calculating the test results was assumed to be 0.35. The load pulse duration was 0.10 sec and the frequency was 1 pulse/sec. The resilient modulus test results are shown in Table 5.

Creep Test

The creep test was conducted by applying a static load of approximately 50 psi to each specimen for 1 hr at room temperature followed by unloading for 1 hr (*3*).

ANALYSIS AND DISCUSSION OF TEST RESULTS

After completion of tests on the asphalt mixtures, the results were analyzed to determine the expected effects on performance. Because this study consisted only of a laboratory evaluation, actual performance of the various asphalt mixtures was not verified.

TABLE 3 MARSHALL STABILITY AND FLOW RESULTS USING 4-IN. DIAMETER SPECIMENS

Max. Agg. Size (in)	Asp. Con.	Bulk Spec. Grav.	Stability	Flow
3/8	4.5	2.471	2275	13.0
3/8	4.5	2.492	2450	13.0
3/8	4.5	2.479	2450	12.0
Avg.			2392	12.7
1/2	5.0	2.465	2000	13.0
1/2	5.0	2.480	2025	12.0
1/2	5.0	2.509	2365	13.0
Avg.			2130	12.7
3/4	4.3	2.473	1820	12.0
3/4	4.3	2.516	2150	13.0
3/4	4.3	2.505	2162	15.0
Avg.			2044	13.3
1	3.8	2.526	2088	13.0
1	3.8	1.532	2513	14.5
1	3.8	2.530	2188	13.0
Avg.			2263	13.5
1 1/2	3.4	2.535	2000	14.5
1 1/2	3.4	2.531	2075	16.0
1 1/2	3.4	2.549	2626	15.5
Avg.			2234	15.3

TABLE 4 INDIRECT TENSILE TEST RESULTS

	4 inch Samples			6 inch Samples	
Max. Agg. Size (in)	Asp. Con. (%)	Spec. Ht. (in)	Indirect Tensile Str. (psi)	Spec. Ht. (in)	Indirect Tensile Str. (psi)
3/8	4.5	2.471	141.7	3.702	117.5
3/8	4.5	2.488	124.7	3.674	122.0
3/8	4.5	2.499	141.7	3.718	124.8
Avg.			136.0		121.5
1/2	5.0	2.507	134.9	3.714	108.6
1/2	5.0	2.496	140.3	3.720	111.9
1/2	5.0	2.493	140.4	3.709	113.0
Avg.			138.5		111.2
3/4	4.3	2.468	158.0	3.723	106.2
3/4	4.3	2.476	160.7	3.720	109.1
3/4	4.3	2.477	147.8	3.699	110.4
Avg.			155.5		108.6
1	3.8	2.462	137.4	3.697	120.5
1	3.8	2.471	140.1	3.665	118.7
1	3.8	2.470	128.9	3.718	104.7
Avg.			135.4		114.7
1 1/2	3.4	2.467	107.2	3.697	122.7
1 1/2	3.4	2.462	151.9	3.710	123.7
1 1/2	3.4	2,467	166.1	3.707	119.5
Avg.			141.7		121.9

The gradation for the ⅜-in. maximum size aggregate contained approximately 2 to 3 times (8.2 percent compared with 5.2 to 6.1 percent) more minus No. 200 material than the other gradations. Calculation using the 0.45 power curve originally indicated a minus No. 200 content higher than this, but the amount was lowered to meet the FHWA specifications. The high dust content appeared to affect the test results more than the change in maximum aggregate size, and hence the mixes with ⅜-in. maximum aggregate size were eliminated from the analysis.

Marshall Stability and Flow Tests

The results of the Marshall stability test appear to show similar results as those of Huber and Heiman (*4*). They reported no connection between stability and rutting resistance, and the results of the tests for this study indicated that there was a poor relationship between Marshall stability and the maximum size of the aggregate. The linear regression in Figure 2 is almost horizontal, with a coefficient of determination of 0.42.

The relationship between flow and aggregate size (Figure 3, $R^2 = 0.95$) appears to be better than that for stability. Larger aggregate in an asphalt concrete mix produced higher flow, which is an indication of increased flexibility. All of the measured flow values are between 12 and 15, which is normal for typical asphalt mixtures.

Indirect Tensile Test

The indirect tensile test was one of the tests in which both 6- and 4-in. diameter specimens were tested (Figure 4). The two specimen sizes in Figure 4 indicated that there was very little change in indirect tensile strength as the maximum aggregate size changed. Even though the 6-in. specimens had a high R^2 value of 0.83, the increase in strength was only approximately 10 percent as maximum aggregate size increased from ½ to 1½ in. Little change in tensile strength with change in aggre-

TABLE 5 RESILIENT MODULUS TEST RESULTS FOR 4-IN. DIAMETER SPECIMENS

			Resilient Modulus (ksi)		
Test No.	Max Agg Size	Ht. (in)	41°F	77°F	104°F
1	3/8"	2.475	2124	1214	97
2		2.476	2427	1416	101
3		2.494	2824	1059	106
Avg.			2458	1230	101
1	1/2"	2.503	1714	470	50
2		2.496	2246	431	41
3		2.503	1895	491	39
Avg.			1952	464	32
1	3/4"	2.485	2004	231	91
2		2.467	2027	221	54
3		2.479	2017	205	38
Avg.			2016	219	61
1	1"	2.462	2074	529	52
2		2.481	1850	586	49
3		2.464	1957	480	43
Avg.			1960	532	45
1	1 1/2"	2.454	2604	1006	123
2		2.448	2208	762	88
3		2.437	2454	581	79
Avg.			2422	783	97

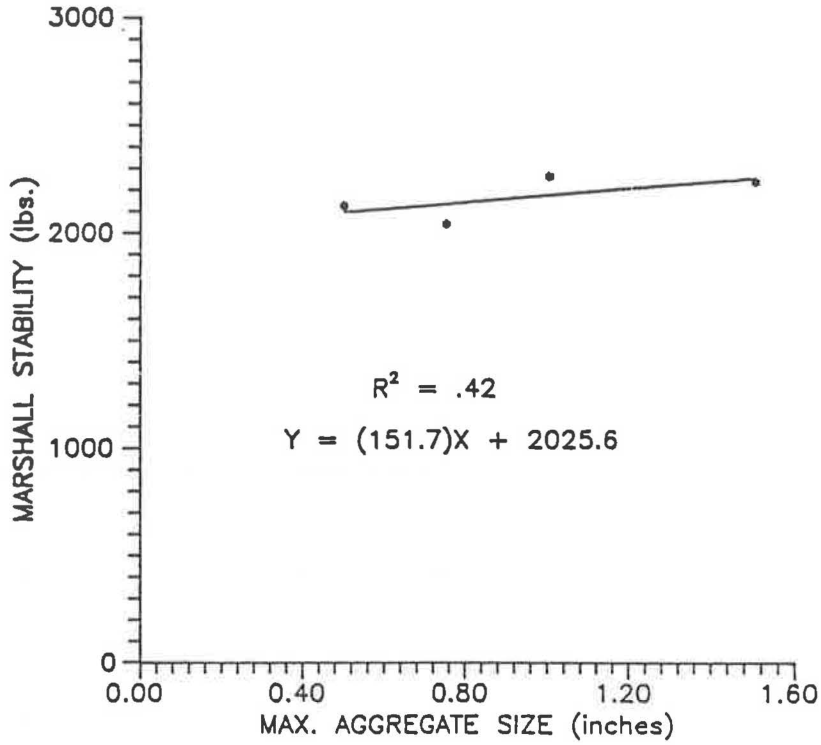

FIGURE 2 Marshall stability for 4-in. diameter specimens.

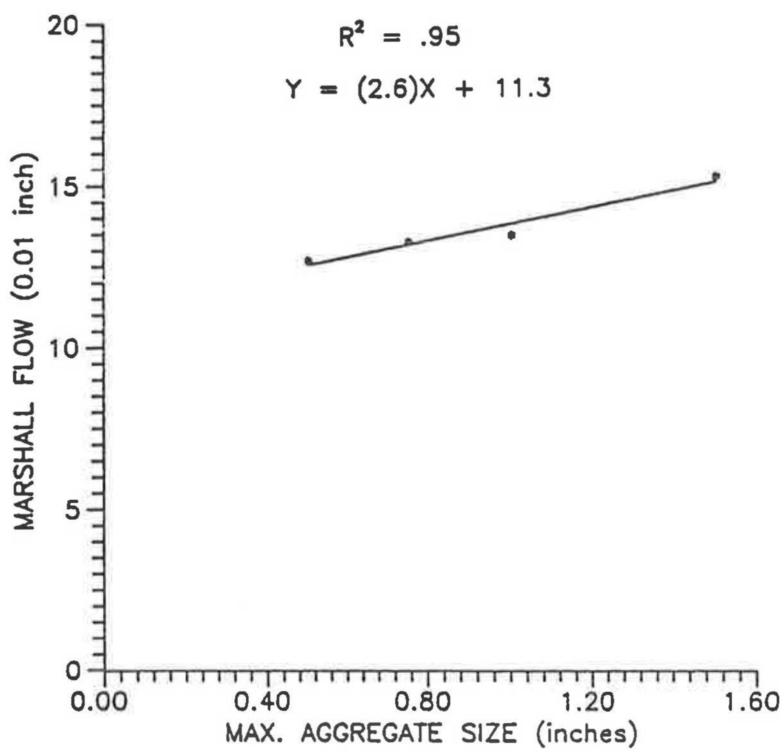

FIGURE 3 Marshall flow for 4-in. diameter specimens.

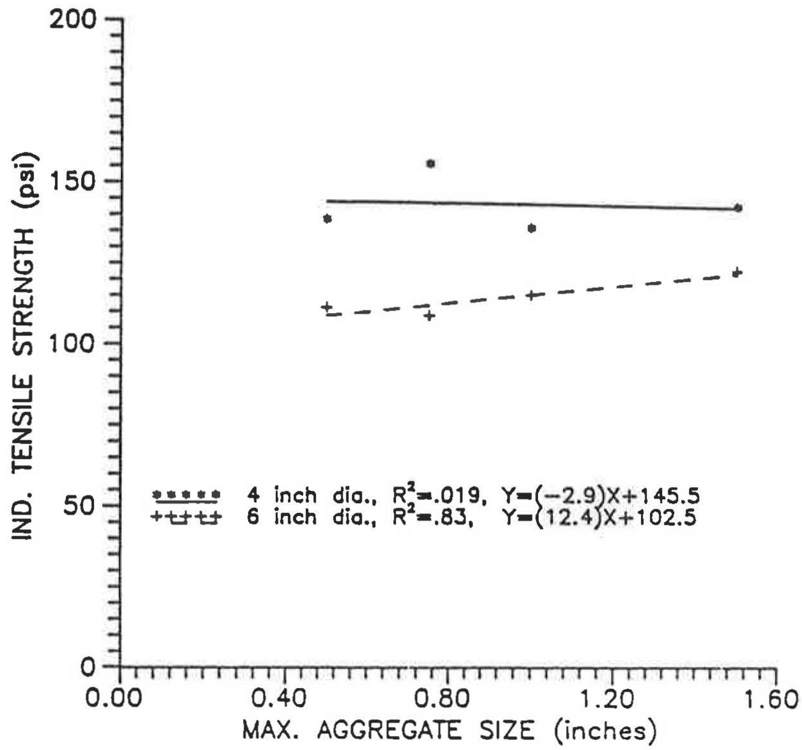

FIGURE 4 Indirect tensile test.

gate gradation was expected because tensile strength is more affected by stiffness of the asphalt cement than by aggregate properties.

Figure 4 also indicates that the tensile strengths for the 6-in. diameter specimens were always lower than those for the 4-in. diameter specimens. One of the differences between the two tests for the specific diameters was in strain rate. Because the loading rate (2 in./min) was the same for both sets of specimens, the strain rate for the 6-in. diameter specimens was 50 percent lower than that for the 4-in. diameter specimens. A lower loading rate should produce a lower tensile strength in the 6-in. diameter specimens, and this was the case for every mix evaluated.

The 6-in. diameter specimens also showed higher tensile strength for higher maximum aggregate size, whereas the 4-in. diameter specimens showed an opposite trend. Because of the higher R^2 value for the 6-in. diameter specimens, it appears that the data for 6-in. specimens are more precise and hence a better measure of tensile strength.

Creep Test

The creep test data plotted in Figure 5 indicate that the 4-in. and 6-in. diameter specimens give opposing results. Permanent strain was calculated by dividing the deformation at 120 min by the original height of the test specimen.

The 4-in. diameter samples in Figure 5 show an increase in permanent strain with an increase in aggregate size, and the 6-in. diameter samples show that permanent strain dereases with increased aggregate size. Results for the 4-in. diameter specimens are likely unduly influenced by the 1½-in. maximum aggregate size mix.

Resilient Modulus Test

The resilient modulus was measured for all mixes and evaluated for the effects of aggregate size.

Figure 6 indicates that there is a good correlation between resilient modulus and maximum aggregate size (R^2 from 0.53 to 0.87). The resilient modulus increased when aggregate size increased from ½ to 1½ in. There was a 53 percent increase at 41°F, a 107 percent increase at 77°F, and an approximately 93 percent increase at 104°F. This increased resilient modulus should result in reduced stresses in the underlying layers.

Comparison of Test Results from 6-in. and 4-in. Diameter Specimens

Comparison of the effects of specimen diameter on mix properties was performed by using two tests: indirect tensile and creep. For 4-in. diameter specimens, the creep test and the indirect tensile test indicated much more variation in results for the 1½-in. maximum aggregate size mixes than in results for mixes with 1-in. and smaller maximum aggregate size. The variability for 1½-in. maximum aggregate size mixes was greatly reduced when 6-in. diameter specimens were used in testing.

The same reduction in variability by using 6-in. rather than 4-in. diameter specimens for 1½-in. maximum size aggregate was accomplished in tests by the Pennsylvania Department of Transportation and reported by Kandhal (*10*). In Kandhal's study, the coefficient of variation for Marshall stability was reduced from 11.1 percent for the 4-in. diameter specimens to 6.1 percent to 6.8 percent for 6-in. diameter specimens.

The 6-in. diameter specimens also had lower variability for specimens using ¾-in. maximum size aggregate for the creep

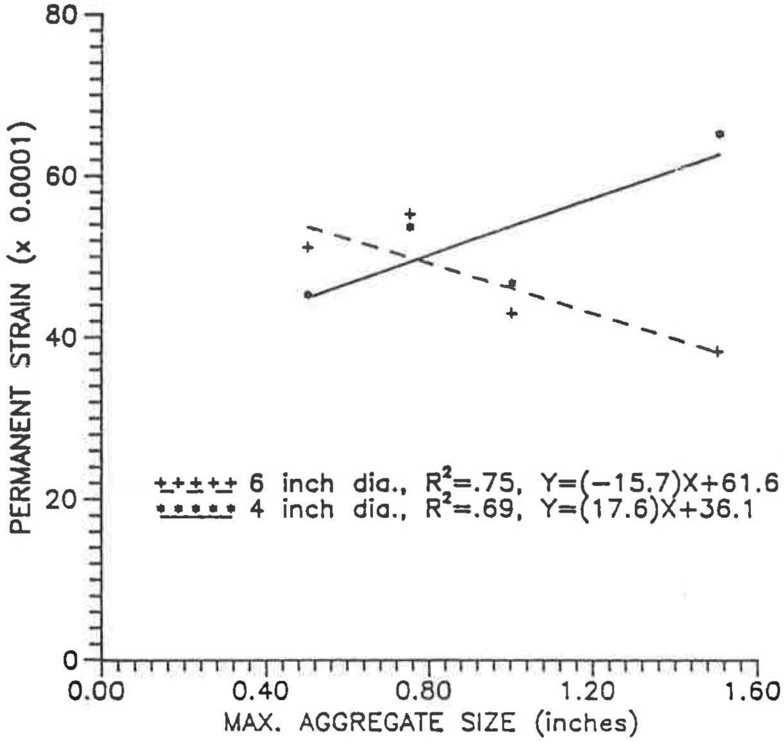

FIGURE 5 Average permanent strain for 4- and 6-in. diameter creep test.

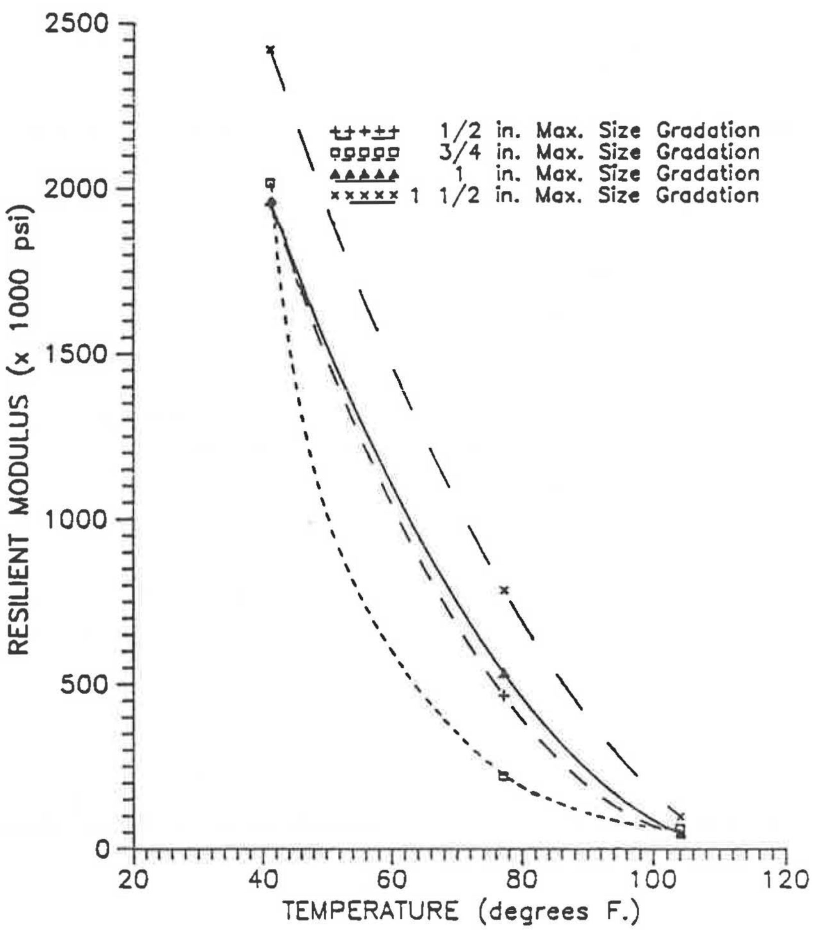

FIGURE 6 Change in resilient modulus with respect to maximum aggregate size for different temperatures at 10 percent of indirect tensile strength.

TABLE 6 CREEP TEST RESULTS FOR 4-IN. DIAMETER SPECIMENS

Max. Agg. Size (in)	Spec. Grav.	Ht. (in)	Max. Defor. (in)	Rebound (in)	Perm. Deform (in)
3/8	2.493	2.476	0.0139	0.0025	0.0115
3/8	2.490	2.479	0.0127	0.0029	0.0098
3/8	2.494	2.486	0.0105	0.0024	0.0080
Avg.			0.0124	0.0026	0.0098
1/2	2.503	2.518	0.0146	0.0024	0.0122
1/2	2.502	2.504	0.0128	0.0025	0.0102
1/2	2.514	2.505	0.0141	0.0025	0.0116
Avg.			0.0138	0.0025	0.0114\
3/4	2.534	2.488	0.0215	0.0023	0.0192
3/4	2/481	2.525	0.0113	0.0017	0.0096
3/4	2.512	2.468	0.0133	0.0021	0.0112
Avg.			0.0154	0.0020	0.0133
1	2.521	2.472	0.0127	0.0020	0.0106
1	2.538	2.464	0.0131	0.0017	0.0114
1	2.533	2.485	0.0150	0.0024	0.0127
Avg.			0.0136	0.0020	0.0116
1 1/2	2.549	2.474	0.0087	0.0021	0.0065
1 1/2	2.530	2.476	0.0158	0.0016	0.0142
1 1/2	2.535	2.470	0.0293	0.0019	0.0275
Avg.			0.0179	0.0019	0.0161

test. The test results for the ¾-in. maximum size aggregate mixes for the 4-in. diameter creep test had approximately twice the range as that for the 6-in. diameter specimens.

Figure 7 indicates that the specific gravity values for the 4- and 6-in. diameter specimens are approximately equal for the ½-in. and the ¾-in. maximum size aggregate but begin to diverge from one another for the other maximum aggregate sizes, especially for the 1½-in. maximum size aggregate. This variation in density could have produced a divergence of results between the 4- and 6-in. diameter specimens for the creep and indirect tensile tests for the larger aggregate.

CONCLUSIONS

The general trend of the data in this study shows that increasing the size of the largest aggregate in a gradation will increase the mix quality with respect to creep performance, resilient modulus, and tensile strength but will not have a significant effect on Marshall stability. A higher flow value was observed for mixes having larger maximum size aggregate.

The indirect tensile test results showed a slight increase in tensile strength for increased maximum aggregate size.

The static creep test, using 6-in. diameter specimens, showed more stiffness and less permanent strain for larger maximum aggregate sizes. On the basis of the 6-in. diameter creep test results, increased maximum aggregate size in a mix should increase the mix's resistance to rutting. This supports the findings that have been observed in the field.

The resilient modulus increased with increased aggregate size. This indicates that mixes with increased maximum aggregate size are stiffer and thus will reduce stresses in the underlying layers.

The comparison of results for 4- and 6-in. diameter specimens indicated that results for 6-in. diameter specimens were less variable than results for 4-in. diameter specimens. The 6-in. diameter specimens generally showed improvement in mix properties for increased maximum aggregate size, whereas the 4-in. diameter specimens generally showed an opposite trend (primarily as a result of the mixes with 1½-in. maximum size aggregate).

TABLE 7 CREEP TEST RESULTS FOR 6-IN. DIAMETER SPECIMENS

Max. Agg. Size (in)	Spec. Grav.	Ht. (in)	Max. Defor. (in)	Rebound (in)	Perm. Defor. (in)
3/8	2.480	3.763	0.0221	0.0038	0.0183
3/8	2.479	3.720	0.0198	0.0042	0.0156
3/8	2.473	3.751	0.072	0.0034	0.0138
Avg.			0.0197	0.0038	0.0159
1/2	2.509	3.714	0.0247	0.0039	0.0208
1/2	2.503	3.729	0.0239	0.0046	0.0193
1/2	2.482	3.732	0.0211	0.0039	0.0171
Avg.			0.0232	0.0041	0.0191
3/4	2.511	3.699	0.0276	0.0045	0.0231
3/4	2.496	3.683	0.0188	0.0040	0.0221
3/4	2.519	3.689	0.0198	0.0037	0.0160
Avg.			0.0245	0.0041	0.0204
1	2.536	3.688	0.0195	0.0039	0.0156
1	2.545	3.686	0.0188	0.0032	0.0156
1	2.540	3.678	0.0203	0.0040	0.0163
Avg.			0.0195	0.0037	0.0158
1 1/2	2.564	3.699	0.0181	0.0035	0.0146
1 1/2	2.554	3.700	0.0180	0.0039	0.0141
1 1/2	2.559	3.663	0.0173	0.0038	0.0135
Avg.			0.0178	0.0037	0.0141

RECOMMENDATIONS

Tighter control on the minus No. 200 material should be exercised in future research relating to the effects of aggregate on the performance of a mix. The factor that led to the deletion of the ⅜-in. maximum size aggregate mixes from the analysis of the test results of this project was the inclusion of too much minus No. 200 material in the mix.

More emphasis should be placed on using larger maximum aggregate size. Many mixes contain maximum aggregate size of ⅜ to ½ in. Steps should be taken in states that use these mixes to use slightly larger aggregate sizes, such as ¾-in. mix. The mix with larger maximum aggregate size will provide better performance if correctly designed and placed.

The effect of the loading rate (strain rate) on the results from the indirect tensile test for different diameter specimens should be evaluated. Changes in the strain rate resulting from a constant loading rate will likely produce different results (higher strain rates will produce higher tensile strength and vice versa).

Steps should be taken to standardize the use of 6-in. laboratory samples. This study indicated that these samples are more reproducible and the results are more indicative of observed performance. Four-in. diameter samples are satisfactory for maximum aggregate size less than 1 in.

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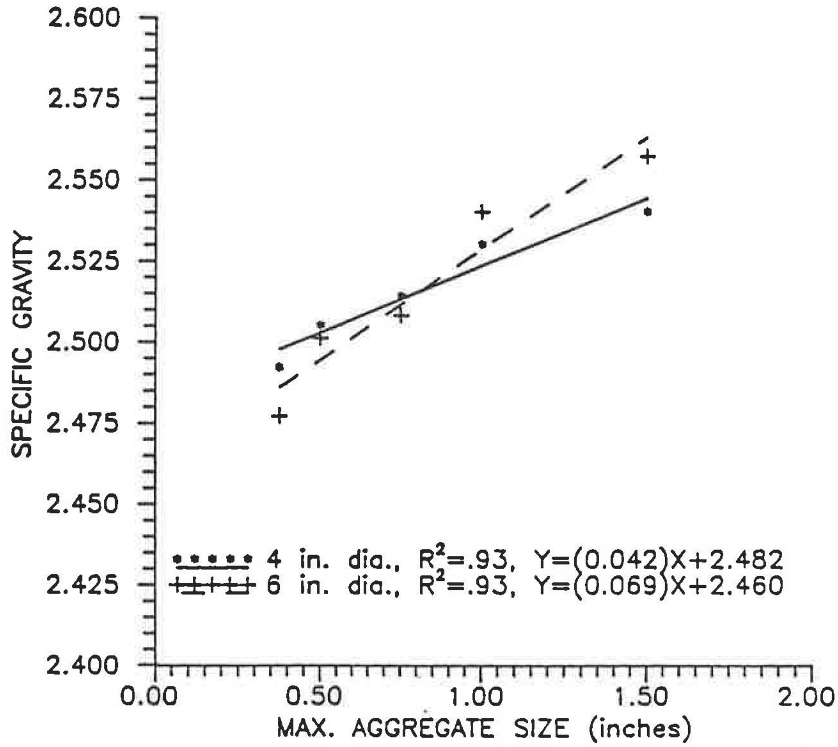

FIGURE 7 Average specific gravity for the 4- and the 6-in. diameter specimens using the creep test and indirect tensile test specimens.

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