

Effects of Crushed Particles in Asphalt Mixtures

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One of the most serious impediments to the continued successful use of hot-mix asphalt (HMA) pavements is rutting. The Iowa Department of Transportation has required 85 percent crushed particles and 75-blow Marshall mix design in an effort to prevent rutting on Interstate roadways. Relationships between the percent of crushed particles and resistance to rutting in pavement through the use of various laboratory test procedures must be developed. HMA mixtures were made with 0, 30, 60, 85, and 100 percent crushed gravel, crushed limestone, and crushed quartzite combined with uncrushed sand and gravel. These aggregate combinations were used with 4, 5, and 6 percent asphalt cement (ac). Laboratory tests included Marshall stability, resilient modulus, indirect tensile, and creep. A creep resistance factor (CRF) was developed to provide a single numeric value for creep test results. The CRF values relate well to the amount of crushed particles and the perceived resistance to rutting. The indirect tensile test is highly dependent on the ac with a small effect from the percent of crushed particles. The Marshall stability from 75-blow compaction relates well to the percent of crushed particles. The resilient modulus in some cases is highly affected by grade of ac.

Hot-mix asphalt (HMA) concrete has been used to produce high-quality pavements for both high- and low-volume roadways. Approximately 94 percent of the paved roads in the United States are asphalt surfaced. Properly designed and constructed, the asphalt pavements have provided smooth, durable roads and streets.

In recent years, rutting of HMA pavements on roadways with a high volume of trucks has resulted in premature failure and the need for rehabilitation or reconstruction. On the other hand, some roadways constructed of HMA have carried large volumes of truck traffic with very little rutting. Severe rutting on high-volume Interstate HMA pavements has caused some concern as to whether HMA is an appropriate construction material for these roadways. Rutting is a major impediment to the continued successful use of HMA pavements. The good performance of some HMA pavements on high-volume Interstate roadways leads the authors to believe that with the proper specifications, materials, design, and construction HMA can be used on high-volume roads without rutting.

Some seem to believe that using a harder grade of asphalt cement (ac) will increase the capacity of a HMA pavement to carry load. Even AC 20, a hard ac, will not retain its shape at room temperature (70°F) but will exhibit plastic flow. Without aggregate, the AC 20 will not support a load of significant magnitude without deformation.

In an effort to reduce the problem of rutting (1–3), the Iowa Department of Transportation (DOT) in recent years

has specified a minimum of 85 percent crushed particles and a 75-blow Marshall design in HMA used on Interstate roadways. A general review of projects with increased percent of crushed particles would indicate that the roads are not as prone to rutting. The increased amount of crushed particles has resulted in some change in the contractor's operation. To obtain density, the compaction rolling has been moved closer to the laydown machine, and 40,000-lb and higher rubber roller weights are being used. In general, these 85 percent crushed-particle HMA mixtures have been very effective in resisting rutting. Unfortunately, there is little research available relating percent of crushed particles, current test results, and actual field performance.

OBJECTIVE

The objective of this research and paper is to develop relationships between the percent of crushed particles and resistance to rutting in pavement through the use of various laboratory test procedures.

MATERIALS

Numerous factors affect the load-carrying capacity of HMA. One important factor is the material. Therefore, an essential project aim was to locate an uncrushed material that would produce a crushed material of similar rock type. In Iowa, the best quality gravels are found on the Mississippi River. Aggrecon Corporation operates the Turner Pit (approximately 90 percent igneous) (NE 1/4, Section 7, Township 84N, Range 7E) near Sabula, Iowa, in Jackson County (specific gravity = 2.63). Tests on the gravel portion yield absorptions of about 1.05 percent, Los Angeles abrasions of about 15, and an Iowa DOT "A" freeze-and-thaw loss of 1. This source was selected because the production uses no crushing, and all size selection is accomplished by screening.

A windblown hillside deposit blow sand (Woodbury County west of Floyd Boulevard, Section 15, Township 47, Range 89) was used to provide the balance of the required uncrushed sand retained on the No. 200 and No. 100 screens. This was a rounded sandy material, which for this research was better than using an earthy type No. 100 and No. 200 sized material.

The crushed limestone (sp. gr. = 2.59) was from the Kaser Corporation, Sully Mine, in Jasper County (SE 1/4, Section 16, Township 79N, Range 17W). The material was from beds 36–41. Tests yield absorptions of about 3.85 percent, Los Angeles abrasions of about 33, and an Iowa DOT "A" freeze-and-thaw loss of 1.

Crushed quartzite (sp. gr. = 2.64) was obtained from the Everist Inc., Minnehaha County Quarry, Del Rapids, S. Dak. (SW 1/4, Section 10, Township 104N, Range 49W). Tests yield absorptions of about 0.22 percent, Los Angeles abrasions of about 21, and an Iowa DOT "A" freeze-and-thaw loss of 1.

Unless otherwise noted, the ac was an AC 10 from Koch Refining Company, St. Paul, Minnesota. A few specimens for comparison were made by using AC 2.5 and AC 20 grade Koch Refining Company ac.

GENERAL MIX DESIGN CRITERIA

Again, a number of factors affect the results of this research. Therefore, it is necessary to limit the scope. The research was aimed at the type of mix design currently being used by the Iowa DOT on Interstate highways. All specimens were made by using 75-blow Marshall compaction. In addition to the 4, 5, and 6 percent ac contents used in the mix design, an ac content intended to yield 4 percent calculated voids was used to make a series of specimens.

The target aggregate gradation for all asphalt mixtures was 100 percent passing the 3/4 in., 42 percent passing the No. 4, and 4 percent passing the No. 200. The complete gradation is given in Table 1, and a 0.45 power graphical plot is given in Figure 1.

Both the crushed and the uncrushed materials essentially met the intended gradation with the actual gradations included in Table 1. Most crushed gravel material was obtained by crushing material passing a 3-in. screen and retained on a 1-in. screen. In all cases, the crushed material passed a screen at least 1/4 in. smaller than the screen on which the uncrushed material had been retained.

The intent was to test asphalt mixtures containing 0, 30, 60, 85, and 100 percent crushed particles.

PREPARATION OF AGGREGATE

All materials were dry screened on all individual screen sizes as noted in Table 1. Even in a relatively dry condition it was found that some fine material would adhere to larger particles.

To obtain the crushed gravel, the uncrushed gravel passing the 3-in. screen and retained on the 1-in. screen was crushed in a small laboratory jaw crusher with the jaws set relatively wide open (3/4 to 1 in.). All crushed gravel was dry screened and saved by screen size. The partially crushed material retained on the 3/4-in. screen was returned to the jaw crusher. After sufficient amounts of the larger-sized crushed gravel were obtained, the jaw opening was reduced to produce finer material.

The crushed limestone was produced by using a hammer mill at the production site. This product was dry screened in the laboratory.

Everist Inc. produced the crushed quartzite in a cone crusher. The quartzite again was sized in the laboratory by dry screening.

Recognizing that fines would adhere to the larger particles, percentages of each screen size were added to yield a 1,000-gm sample. A washed gradation of the built-up 1,000-gm sample was conducted. On the basis of the resulting gradation, the percentages used in the 1,000-gm sample were adjusted to produce the desired gradation more closely. Percentages of dry screened material that would yield the desired washed gradation were determined. The resulting gradations are shown in Table 1.

TESTING EQUIPMENT

Marshall Equipment

The hammer used to compact the Marshall specimen for the study was an Iowa DOT Materials Laboratory Machine Shop

TABLE 1 GRADATIONS OF AGGREGATES USED FOR HOT-MIX ASPHALT MIXTURES

Sieve Size	% Passing				
	Intended	Uncrushed Gravel	Crushed Gravel	Limestone	Quartzite
3/4"	100	100	100	100	100
1/2"	85	86	85	85	85
3/8"	64	64	64	63	64
4	42	43	43	42	41
8	27	30	29	27	28
16	20	21	21	19	20
30	13	14	14	12	12
50	8	8.6	8.7	7.7	7.9
100	6	5.8	6.1	6.0	5.8
200	4	3.9	4.1	4.2	3.6

Creep Test Device

The creep test device used in this study was fabricated by Iowa DOT Materials Laboratory Machine Shop and Instrumentation personnel. The device consists of three pneumatically actuated load units mounted on a load frame and is capable of testing three samples simultaneously. An air regulator with digital display is capable of delivering pressure from 0 to 120 psi to the load units. The load units have a 12.4 to 1 force/pressure conversion ratio and a maximum output of 1,500 lb in the linear range. A compression load cell was used to calibrate the load units and develop the force/pressure conversion ratios. A brass load plate is centered on the frame directly under each of the load unit rams. A specimen is centered on the load plate, and another load plate is placed on top of the specimen. The specimen and top load plate are aligned directly beneath a load unit ram through which a vertical force of 0 to 1,500 lb can be applied. Dial gauges readable to 0.001 in. are mounted on the load unit rams, and vertical deformation of the specimen as a function of time is determined. The lower load frame and test specimens are contained in an insulated tank filled with a temperature-controlled water bath. The operational range of the water bath is from 25°F to 140°F.

TEST PROCEDURES

Specimen Preparation and Marshall Testing

The test specimens were prepared in accordance with AASHTO T245-82 except that four specimens were made from a 13,000-gm batch. Maximum specific gravity of the mixes was determined in accordance with AASHTO T-209 by using a volumetric flask, and bulk specific gravities were determined by using AASHTO T166-83, Method A.

Resilient Modulus Testing

The testing temperature for the resilient modulus was targeted at 77° ± 2°F. The only temperature control used was the ambient air temperature of the laboratory itself. The temperature of the specimen was determined by sandwiching a thermocouple wire between two specimens. If the indicated temperature was not 77° ± 2°F, the test was not performed.

After confirming that the temperature was within the desired range, a template was used to mark three 60-degree divisions on the diameter of the specimen. Specimen thickness was determined to 0.01 in. by using a height comparator. Each specimen was placed in the frame and was tested with the transducers directly opposite each other. After an individual test was completed, the specimen was reoriented by rotating 60 degrees, and the test was repeated. Each specimen was again rotated 60 degrees, resulting in a total of three tests per specimen, each at an orientation of 60 degrees from the other two.

Each test consisted of 20 load cycles of 0.10 sec and a frequency of 0.33 Hz. Before this study it was determined that preconditioning by subjecting the sample to a number of the cyclic loads had no effect on the outcome; consequently, the practice of preconditioning as recommended in ASTM D-

4123 was not used. The three sets of 20 cycles were each repeated at loads of 50 and 75 lb.

This testing pattern was performed on each of the three specimens of an individual asphalt content for a particular mix design. All results were then averaged to yield a single resilient modulus value for each asphalt content. Final results were expressed in terms of thousands of pounds per square inch (ksi).

Because the resilient modulus test is considered nondestructive at low loadings and moderate temperatures (the key factor being low horizontal deformation and accumulated deformation), the same Marshall specimens were then used for the creep test procedure when resilient modulus testing was completed.

Indirect Tensile Test Procedure

Indirect tensile strength was determined only for Marshall specimens of mixes at asphalt contents intended to produce 4.0 percent voids. From the time the specimens were compacted until the testing was conducted, all specimens were stored in open air at room temperature. For testing, the samples were immersed in a 77°F water bath for 30 min. Each sample was removed from the water bath, dried with a damp towel, and tested with the Baladi apparatus in the Rainhart Marshall stability loading machine within a 30-sec period. The load was applied at a rate of 2.0 in./min until the maximum compressive strength was achieved (as indicated by a peak on the X-Y recorder). Because the Baladi device employs ½-in. steel loading strips, the tensile strength was calculated by using the formula found in AASHTO T283-85, Section 11.1:

$$S_t = \frac{2P}{\pi tD}$$

where

- S_t = tensile strength (psi),
- P = maximum load (lb),
- t = specimen thickness (in.), and
- D = specimen diameter (in.).

Indirect tensile strength results were calculated for each of three specimens in a set, and those results were averaged to provide a single indirect tensile strength number for a particular mix.

Creep Test Procedure

Specimen faces were first polished by laying them on a belt sander and using No. 50 grit paper to remove surface irregularities that would result in uneven, internal stress distribution and to allow the surface to be made as frictionless as possible. Surface friction reduction was further enhanced by the application of a mixture of No. 2 graphite flakes and water-and temperature-resistant silicon gel lubricant to the polished specimen faces.

Sets of three specimens of the same mix design and asphalt content were tested simultaneously. Testing temperature was 104°F, and the specimens were conditioned in 104°F water for ½ hr before testing.

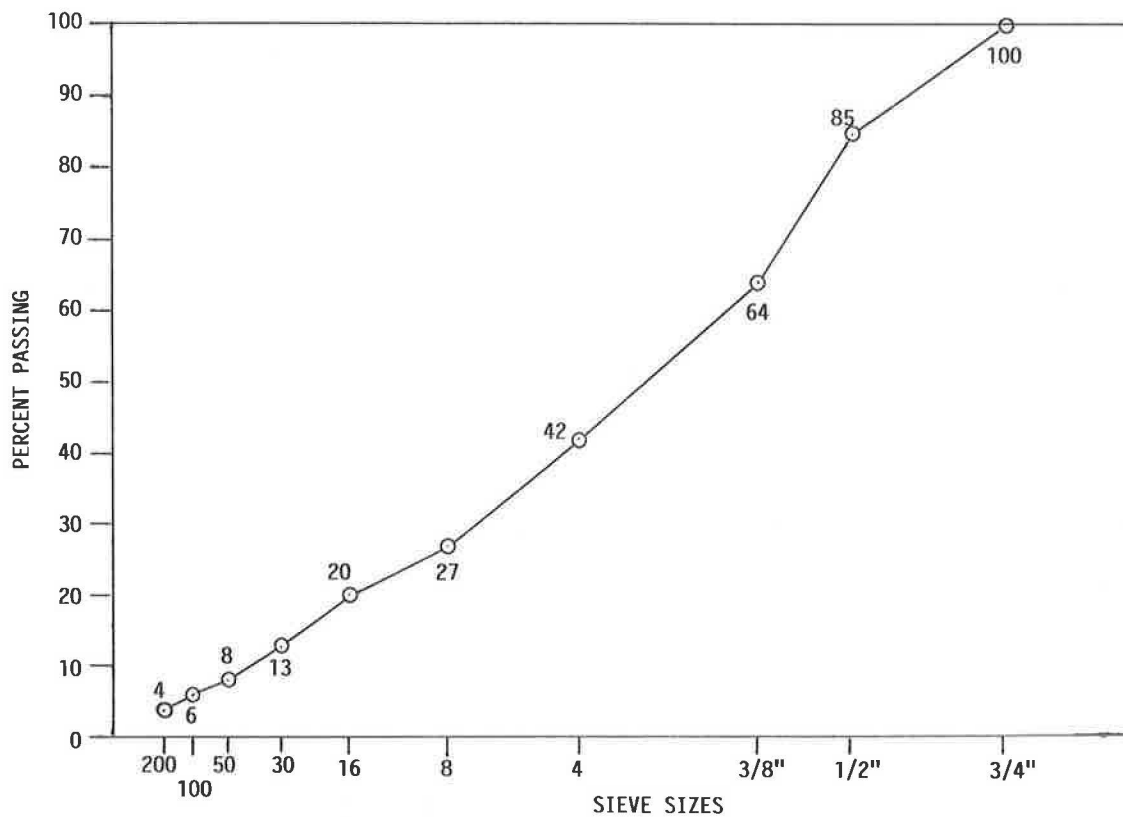


FIGURE 1 A 0.45-power plot of the intended gradation.

fabricated mechanical hammer with a flat face and stationary concrete base. The mechanical hammer was calibrated every 3 months by correlation with a hand-held Marshall hammer of the type described in AASHTO T245-82.

The stability equipment was a Rainhart load frame and stability head and a Heath model SR-207 X-Y recorder, calibrated weekly with a proving ring and dial gauge.

Resilient Modulus Apparatus

The resilient modulus testing was performed by using a Retsina Mark VI resilient modulus nondestructive testing device, purchased in 1988 from the Retsina Co., Oakland, Calif. The Retsina device was selected among numerous resilient modulus testing systems because of its low cost, simplicity, and ease of operation. As was described in ASTM D-4123, diametral loading results in a horizontal deformation for a cylindrical specimen related to resilient modulus by the formula

$$M_r = \frac{P(\nu + 0.2734)}{t(d)}$$

where

- M_r = resilient modulus,
- P = vertical load,
- ν = Poisson's ratio,
- t = specimen thickness, and
- d = horizontal deformation.

The device operates by applying a load pulse (0 to 1,000 lb range) diametrically through the specimen. Load duration (0.05 or 0.10 s) and frequency (0.33, 0.5, or 1.0 Hz) are controlled by the operator. Horizontal deformations are sensed by transducers mounted on a yoke connected to the specimen. The number of cycles to be used in a test can be set by the operator. Results are calculated by a microprocessor and are presented by both printer and digital display.

Indirect Tensile Apparatus

For indirect tensile strength determination, the Iowa DOT Materials Laboratory Machine Shop fabricated the indirect tensile device developed by G. Y. Baladi of Michigan State University (4). The device consists of a load piston and four frictionless guide pins inserted through a framework of upper and lower stationary plates. The sample rests diametrically within the frame on a 1/2-in. loading bar. The load piston then rests on top of the specimen, and the entire apparatus is positioned in a Marshall loading frame where a load is applied at the standard rate of 2.0 in./min and the maximum compressive load is recorded on an X-Y plotter.

The Baladi device was chosen for this test because the frictionless guide system prevents rocking or rotation of the upper load strip and thus yields more accurate results than are achievable by using other indirect tensile testing equipment.

The specimens were then subjected to a preload of 15 psi contact pressure for 2 min. To achieve contact pressures as high as 200 psi, a 3-in. diameter top-load plate was used instead of a 4-in. diameter plate. After preloading (which was intended to seat the specimen properly, load plates, and ram and to compress any final minute surface protrusions), the specimens were removed from the apparatus and their height measured to the nearest 0.0001 in. by using a height comparator. The samples were then placed back in the apparatus, dial gauges were adjusted to read 0.500 in., and the creep loads were applied.

Contact pressure was increased from 0 to 40 psi in step loads of 8 psi applied for 1 min each (Figure 2). After 40 psi was reached, the dial gauges were read at 10-min intervals until 1 hr had passed. At this time, 8-psi step loads of 1-min duration were again applied until a contact pressure of 80 psi was attained. Dial gauge readings were again taken at 10-min intervals for 1 hr. This entire sequence was repeated until the final step of 200 psi for 1 hr was achieved or when specimen failure occurred. Specimen failure was indicated by a rapid increase in height reduction or change in height of more than 0.05 in. Total elapsed time in minutes, the applied pressure at the time of failure, and the measured reduction in height just before failure were recorded. If failure did not occur, total reduction in height at the end of the test (325 min) was used to calculate the creep resistance factor (CRF). The CRF was developed by the Iowa DOT to provide a single quantitative number value to creep test results. The formula for the CRF is

$$CRF = \frac{t}{325} [100 - c(1000)]$$

where

CRF = creep resistance factor,

t = time in minutes at failure, at 0.05-in. height change, or at 325 min if failure did not occur, and

c = change in height in inches or at 0.05 in. if failure occurred.

For example, if failure did not occur, but total change in height was 0.037 in.

$$\begin{aligned} CRF &= \frac{325}{325} [100 - (0.037)(1000)] \\ &= 63 \end{aligned}$$

In another example, if failure occurred at 265 min, then

$$\begin{aligned} CRF &= \frac{265}{325} [100 - (0.050)(1000)] \\ &= 41 \end{aligned}$$

DISCUSSION OF RESULTS

By using 100 percent crushed gravel, the outer edges of the specimens were somewhat friable. With 100 percent crushed

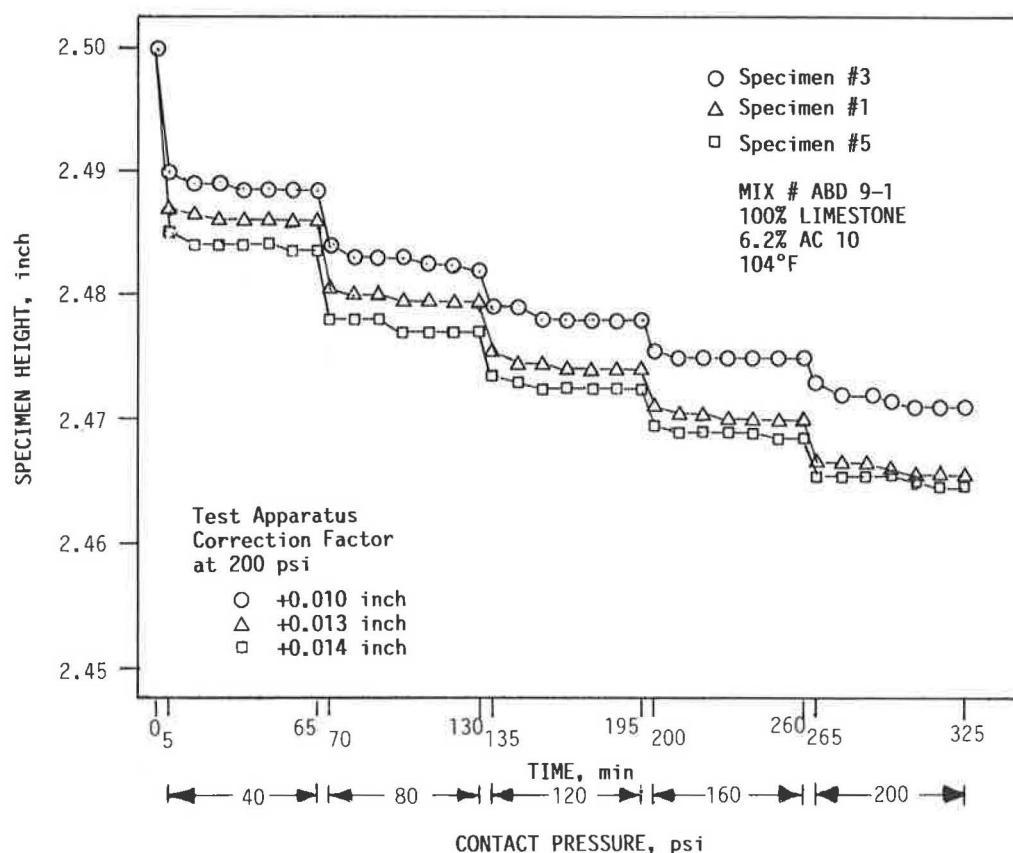


FIGURE 2 Change in height plotted against time for a creep test.

gravel (Table 2), 5.85 percent ac could be used to obtain approximately 4 percent voids (3.80 percent). Only 3.40 percent ac was used to obtain 4.40 percent voids in the 100 percent uncrushed gravel mix. The percent of ac that results in 4 percent voids is very dependent on the amount of crushed particles. The greater angularity of the crushed particles yielded much greater voids (8.85 percent) at low ac contents than the uncrushed materials (2.89 percent voids).

The voids of the limestone mixes (Table 3) were similar but slightly higher, ranging from 1.20 at 6 percent ac and 0 percent crushed to 11.02 percent voids at 4 percent ac and 100 percent crushed. There was difficulty in selecting the proper ac content to yield 4 percent voids. For construction project control, another mix would have been made to select an ac content that would have more closely yielded 4 percent voids. Owing to a very limited amount of material, no additional mixes were made. With other factors being equal, the greater angularity of the limestone yielded slightly greater void contents than the crushed gravel.

Somewhat surprisingly, with other factors being constant, the quartzite (Table 4) produced lower void contents than the

crushed gravel. The 6 percent ac content in the quartzite mixes yielded void contents below 2 percent, well below the Iowa DOT design criteria.

Density

The densities (Tables 1–3) varied from 2.27 to 2.45 gm/cm³. The laboratory densities appeared to have very little significance in regard to the stability or the capacity to carry load. The 100 percent uncrushed yielded the highest densities but the lowest Marshall stabilities and CRFs. The densities of the limestone mixes were in general just slightly lower but yielded the highest Marshall stabilities. The laboratory densities (Figure 3) were inversely related to the percent of crushed aggregate.

Even though the laboratory density and voids did not correlate with stability or strength, the proper void content is important in HMA pavement to prevent bleeding and instability during hot weather. Adequate field compaction to obtain high density and laboratory voids is essential.

TABLE 2 SUMMARY OF RESULTS WITH CRUSHED GRAVEL AND UNCRUSHED GRAVEL

Uncrushed Gravel %	Crushed Gravel %	% of A.C.	Lab. Density lbs/cu.cm	Calc. Voids %	Marshall Stability Pounds	Flow inx100	Resilient Modulus ksi	Indirect Tensile psi	Creep Resistance Factor
0	100	4.00	2.27	8.85	2460	10	229		85
0	100	5.00	2.30	6.56	2335	12	252		89
0	100	5.85	2.33	3.80	2490	11	243		90
0	100	6.00	2.33	3.76	2480	12	260		77
15	85	4.00	2.29	8.14	2175	8	257		57
15	85	5.00	2.32	5.52	2150	10	250		70
15	85	5.25	2.34	4.44	2167	11	244	124.5	53
15	85	6.00	2.35	3.03	2165	12	248		44
40	60	4.00	2.32	7.24	2050	8	362		54
40	60	4.85	2.37	4.33	1925	10	345	124.5	55
40	60	5.00	2.36	4.32	2035	10	350		39
40	60	6.00	2.37	2.38	2110	10	361		37
70	30	3.75	2.38	5.41	1708	7	415	108.9	27
70	30	4.00	2.39	4.70	1605	7	326		31
70	30	5.00	2.41	2.67	1568	9	220		29
70	30	6.00	2.39	1.89	832	14	126		24
100	0	3.40	2.43	4.40	1283	6	341	121.7	19
100	0	4.00	2.45	2.89	995	8	219		21
100	0	5.00	2.44	1.88	860	12	132		16
100	0	6.00	2.42	1.20	575	6	81		12

Marshall Stability

The Marshall stability is a relatively good measure of the potential load-carrying capacity of an asphalt mixture. Unfortunately, with other factors remaining the same, argillaceous limestone aggregate will yield stabilities higher than nonargillaceous limestone. The aggregates used in this research were relatively hard, high-quality aggregates.

The Marshall stabilities of all mixes ranged from 575 to 4,020 lb. For the crushed gravel (Figure 4) it increased from 900 lb at 0 percent crushed to almost 2,500 lb for 100 percent crushed. The percentage of ac had very little effect on the Marshall stability until at 6 percent ac the mixture became highly overasphalted with 30 percent or less crushed gravel. With that exception, the 4, 5, and 6 percent ac mixtures yielded nearly the same stabilities.

The crushed quartzite mixes (Figure 5) yielded Marshall stabilities very similar to the crushed gravel, ranging from 900 to 2,300 lb. Again, in general, until the mixtures became highly overasphalted, the percent of ac had very little effect on the stabilities.

With 30 percent or more crushed limestone (Figure 6), the Marshall stabilities were much higher than those of the crushed gravel or quartzite. The percent of ac in the limestone mixtures had a greater influence on the resulting stabilities. The 4 percent ac yielded Marshall stabilities approximately 400 lb higher than those for the 6 percent ac. The amount of crushed material was again the dominant factor with an increase of approximately 400 lb for each additional 10 percent of crushed limestone.

Three pairs of mixes (two limestone and one quartzite) were made and tested to determine the effect of the grade of ac

(Tables 3 and 4). AC 20 produced stabilities approximately 400 lb greater than those of the AC 2.5 mixture (Figure 7). This is again very small when compared with the effect of crushed particles in the mixture.

Resilient Modulus

The resilient modulus of the crushed gravel mixes (Figure 8) increased with increasing crushed material from 0 to 60 percent. Above 60 percent crushed gravel, the resilient modulus decreased.

With crushed limestone (Figure 9) there again was a relatively uniform increase of resilient modulus up to 60 percent crushed and then there was a more gradual increase.

The crushed quartzite mixes yielded relatively low resilient moduli (Figure 10) with less relationship to the amount of crushed material than with the gravel and limestone mixtures.

With 5 percent asphalt cement in all mixtures (Figure 11), the resilient modulus exhibited a straight line increase up to 60 percent crushed material. Crushed limestone mixtures yielded resilient moduli substantially higher than those for crushed gravel or for crushed quartzite. Over the 0 to 60 percent crushed aggregate range the resilient modulus did not correlate well with the percent of crushed material.

On the basis of the limestone mixtures (Table 3), the resilient modulus was highly dependent on the grade of asphalt cement. AC 2.5 yielded resilient moduli of about 200 ksi. AC 10 resilient moduli were about 450 ksi, and AC 20 resilient moduli were about 900 ksi. Resilient moduli are more dependent on grade of asphalt cement than percent of crushed aggregate.

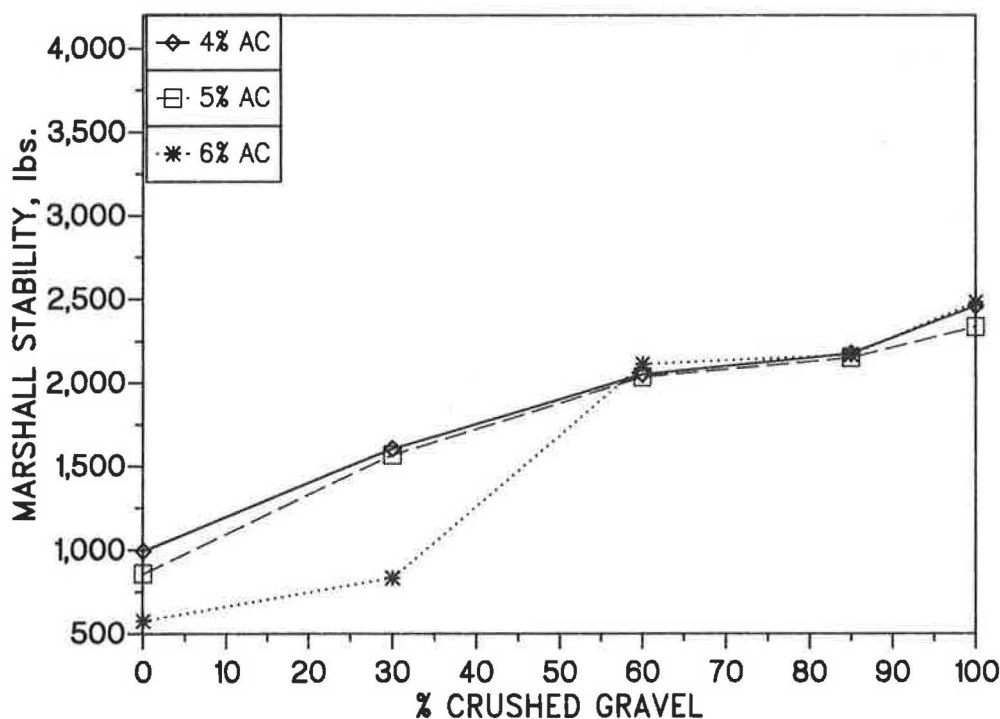


FIGURE 4 Marshall stabilities for crushed gravel mixes by percent of crushed particles.

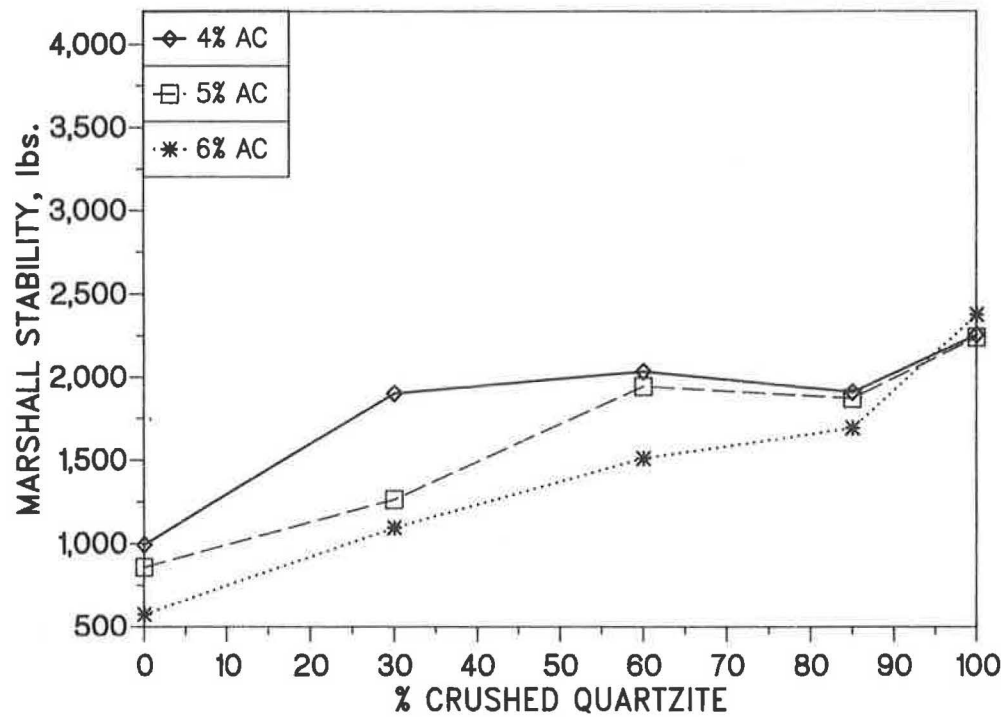


FIGURE 5 Marshall stabilities for crushed quartzite mixes by percent of crushed particles.

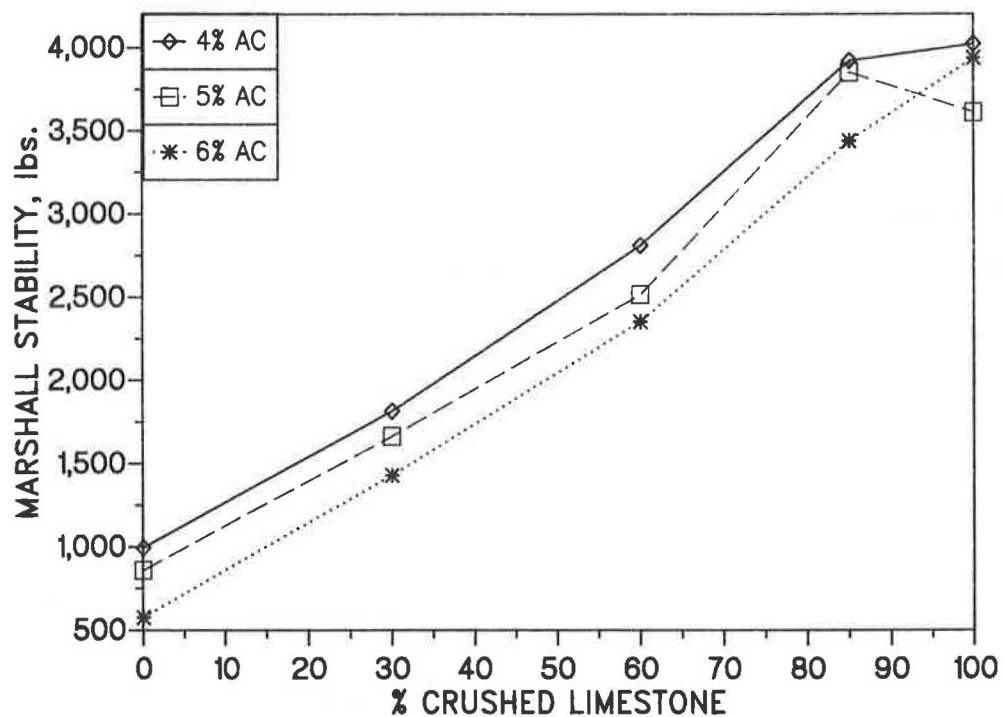


FIGURE 6 Marshall stabilities for crushed limestone mixes by percent of crushed particles.

TABLE 3 SUMMARY OF RESULTS WITH CRUSHED LIMESTONE AND UNCRUSHED GRAVEL

Uncrushed Gravel %	Limestone %	% of A.C.	Lab. Density lbs/cu.cm	Calc. Voids %	Marshall Stability Pounds	Flow in x100	Resilient Modulus ksi	Indirect Tensile psi	Creep Resistance Factor
0	100	4.00	2.28	11.02	4020	9	633		84
0	100	5.00	2.30	8.93	3610	9	693		83
0	100	6.00	2.32	6.58	3935	11	543		84
0	100	6.25	2.35	5.26	3708	12	356	148.2	80
15	85	4.00	2.30	9.93	3920	9	487		79
15	85	5.00	2.33	7.55	3850	10	557		74
15	85	5.85	2.36	4.95	3185	10	425	148.1	72
15	85	6.00	2.36	5.06	3435	11	453		78
40	60	4.00	2.35	7.71	2810	7	635		83
40	60	4.70	2.38	5.69	2667	8	575	134.5	69
40	60	5.00	2.38	4.94	2515	7	550		76
40	60	6.00	2.39	3.14	2350	10	375		50
70	30	3.70	2.39	6.24	1762	8	473	130.0	38
70	30	4.00	2.41	4.98	1813	7	394		23
70	30	5.00	2.41	3.22	1663	8	340		32
70	30	6.00	2.41	2.10	1427	10	153		16
15	85 (2.5)	5.85	2.37	2.22	3480	10	198	87.4	77
15	85 (20)	5.85	2.35	3.25	3712	12	889	205.0	83
70	30 (2.5)	3.70	2.39	6.03	1577	6	208	61.8	30
70	30 (20)	3.70	2.37	6.70	2000	7	960	131.7	44

TABLE 4 SUMMARY OF RESULTS WITH CRUSHED QUARTZITE AND UNCRUSHED GRAVEL

Uncrushed Gravel %	Quartzite %	% of A.C.	Lab. Density lbs/cu.cm	Calc. Voids %	Marshall Stability Pounds	Flow inx100	Resilient Modulus ksi	Indirect Tensile psi	Creep Resistance Factor
0	100	4.00	2.31	7.00	2255	9	146		52
0	100	5.00	2.35	4.20	2240	12	131		73
0	100	5.30	2.36	3.13	2223	10	128	104.3	84
0	100	6.00	2.37	1.90	2375	12	105		40
15	85	4.00	2.32	6.74	1910	10	212		52
15	85	5.00	2.36	3.98	1873	11	132		50
15	85	5.10	2.37	3.22	2042	11	197	116.5	51
15	85	6.00	2.37	1.96	1693	10	93		25
40	60	4.00	2.36	5.69	2035	8	255		33
40	60	4.45	2.39	3.61	1833	8	236	109.1	42
40	60	5.00	2.40	2.71	1945	9	217		34
40	60	6.00	2.39	1.49	1510	12	145		27
70	30	4.00	2.41	6.51	1903	7	283		24
70	30	5.00	2.41	3.87	1265	8	179		20
70	30	6.00	2.41	2.48	1095	11	120		13
70	30 (2.5)	3.70	2.39	5.87	1492	5	193	69.9	
70	30 (20)	3.70	2.38	6.51	1903	7	223	156.8	

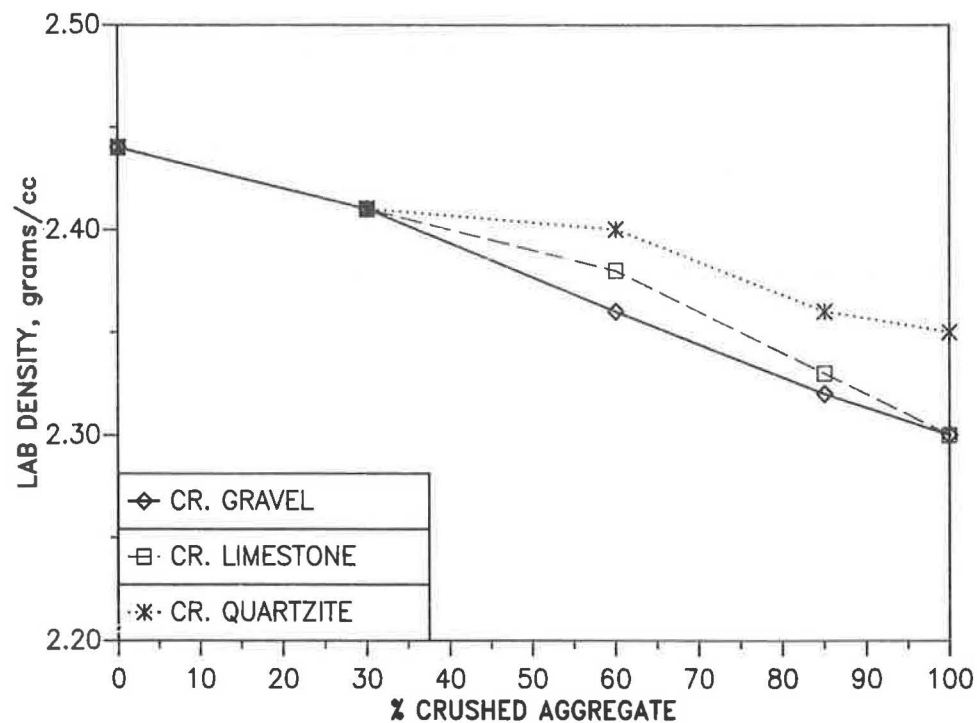


FIGURE 3 Calculated laboratory density versus percent of crushed aggregate (5 percent asphalt cement).

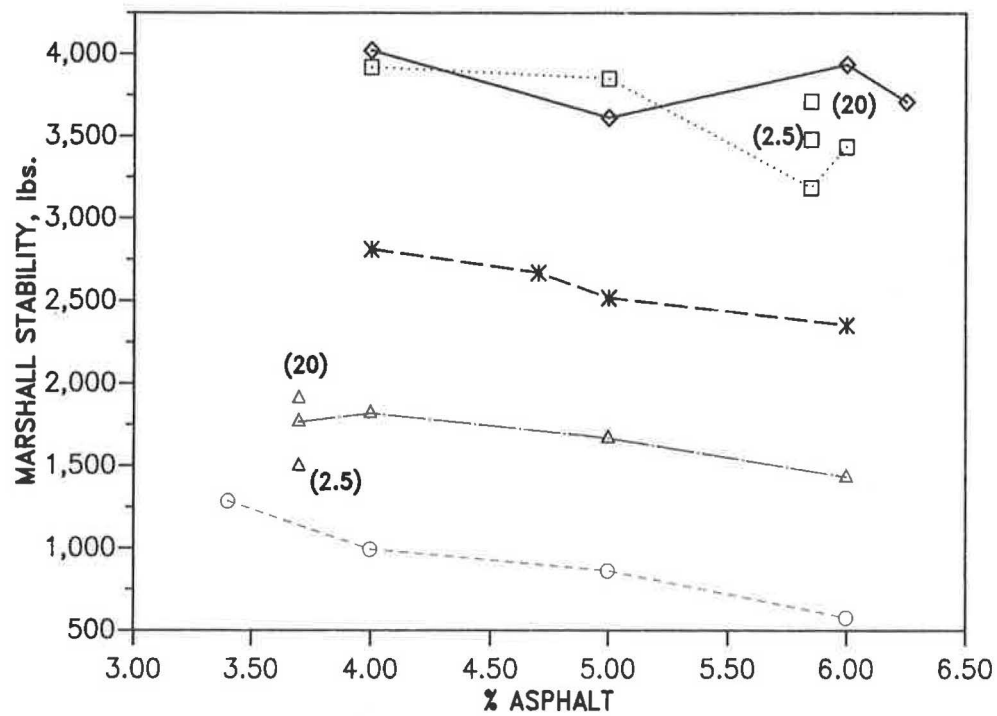


FIGURE 7 Marshall stabilities for crushed limestone mixes by percent and grade of asphalt cement.

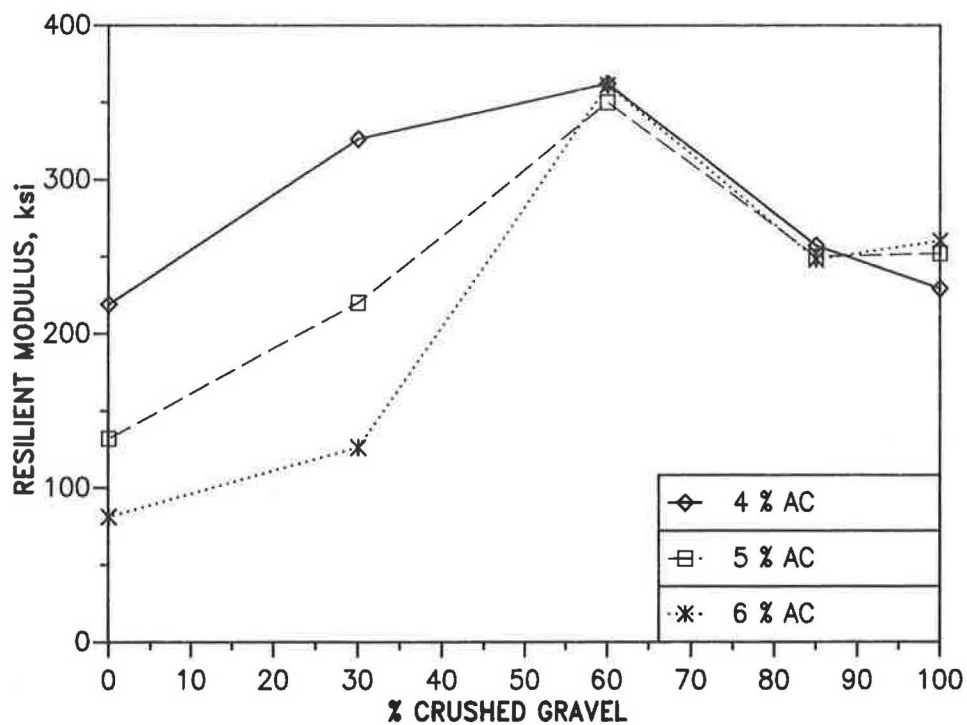


FIGURE 8 Resilient modulus for crushed gravel mixtures.

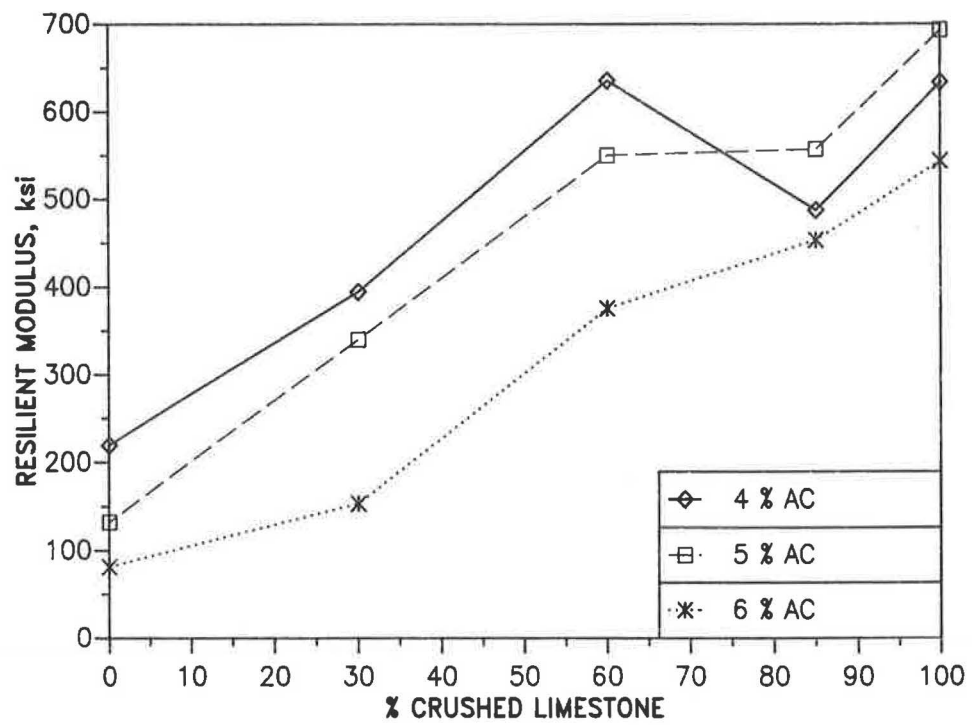


FIGURE 9 Resilient modulus for crushed limestone mixtures.

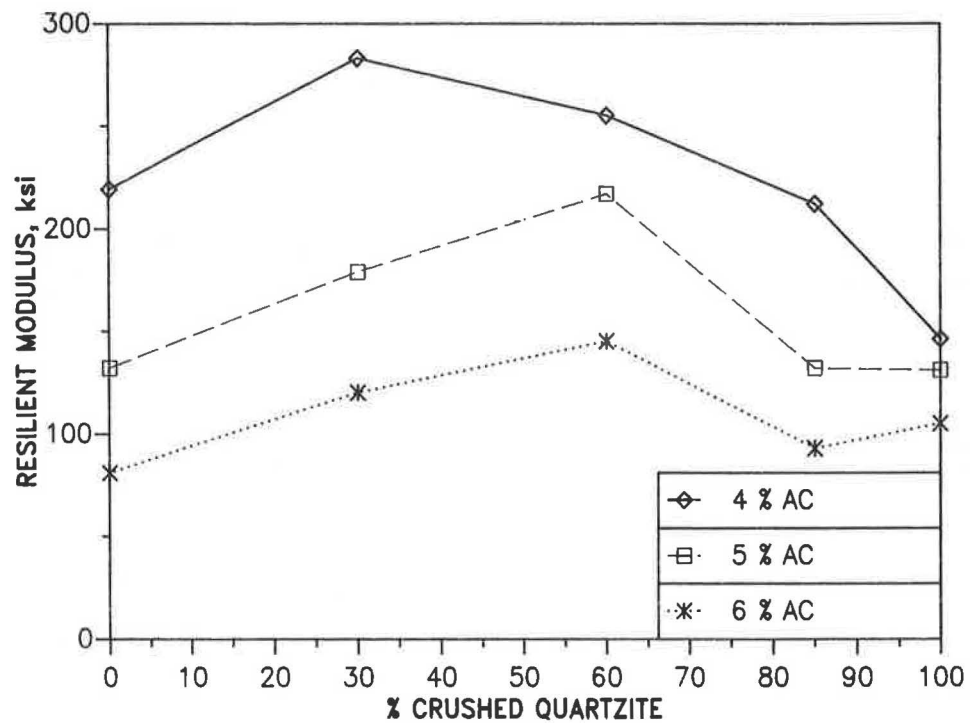


FIGURE 10 Resilient modulus for crushed quartzite mixtures.

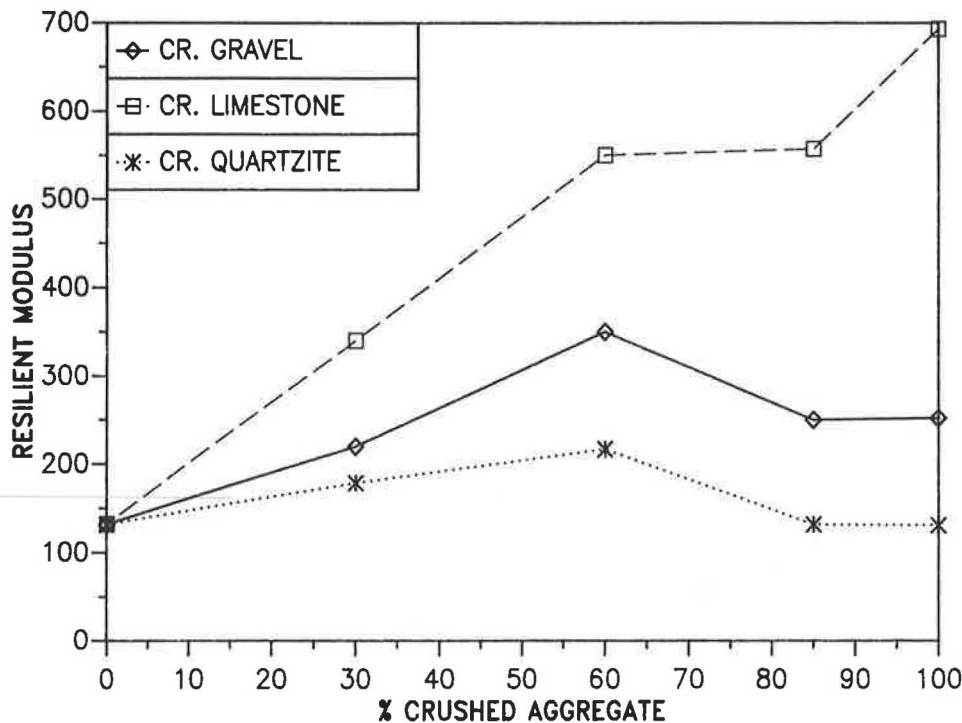


FIGURE 11 Resilient modulus for gravel, limestone, and quartzite mixtures with 5 percent asphalt cement.

Indirect Tensile

Indirect tensile testing (Tables 2–4) was conducted on only one mix of each crushed to uncrushed proportion. The values ranged from 104 to 148, with the highest values from the limestone mixes and the lowest from the quartzite mixes. A greater range (62 to 205) resulted from the use of AC 2.5 and AC 20 grade ac. The indirect tensile values were highly dependent on the ac and relatively unaffected by the percentage of crushed particles. Again, those data do not seem to indicate that the indirect tensile values are related to load-carrying capacity.

Creep Resistance Factor

Creep testing (5) was new to the Iowa DOT in 1989. The CRF was developed to provide a quantitative number value for the results of the test. The creep test is a very time-consuming test (7 hr), with the completion of one mixture (three specimens) per day.

The CRF data look promising in evaluating a mixture's resistance to rutting. The CRF (Tables 2–4) ranged from less than 21 for 100 percent uncrushed gravel to 83 or above for 4 and 5 percent asphalt cement with 100 percent crushed gravel or limestone.

The CRF was highly dependent on the percent of crushed materials (Figure 12), with only minor dependence on the percent or grade of asphalt cement (Table 3). With crushed gravel the CRF exhibited a gradual increase with increased

crushed material to about 75 percent. A more rapid increase of CRFs occurred above 75 percent crushed gravel.

In general, the crushed limestone mixtures (Figure 13) yielded higher CRFs than crushed gravel or quartzite. HMA mixtures with 60 percent or more crushed limestone yielded relatively high CRFs.

Increasing percentage of crushed quartzite yields a gradual increase in CRFs. The CRFs of crushed quartzite mixtures (Figure 14) appear to be more adversely affected by increased asphalt cement content or decreased crushed material than are the gravel or limestone mixtures. The maximum CRF for quartzite was 84 with 5.5 percent ac and 100 percent crushed (Table 4). With 100 percent crushed and 5.0 percent ac, the CRF was 73. All other quartzite CRFs were 52 or less.

With 5 percent asphalt cement in all HMA mixtures, the CRFs ranged from 16 with 0 percent crushed aggregate to near 80 with 100 percent crushed material (Figure 15). The crushed limestone yielded the highest CRFs and the quartzite yielded the lowest.

The creep test should be a more severe test than the Marshall stability. The limited data available show that it relates to Marshall stability when crushed gravel, limestone, or quartzite are considered separately but would not correlate because of substantial differences between crushed gravel and limestone mixtures.

In a study following this laboratory research, field core samples were taken from pavements that were experiencing rutting and others that were performing well without rutting. These samples will be used to assist in relating the CRF to the minimum criteria necessary to alleviate rutting on high traffic volume roadways.

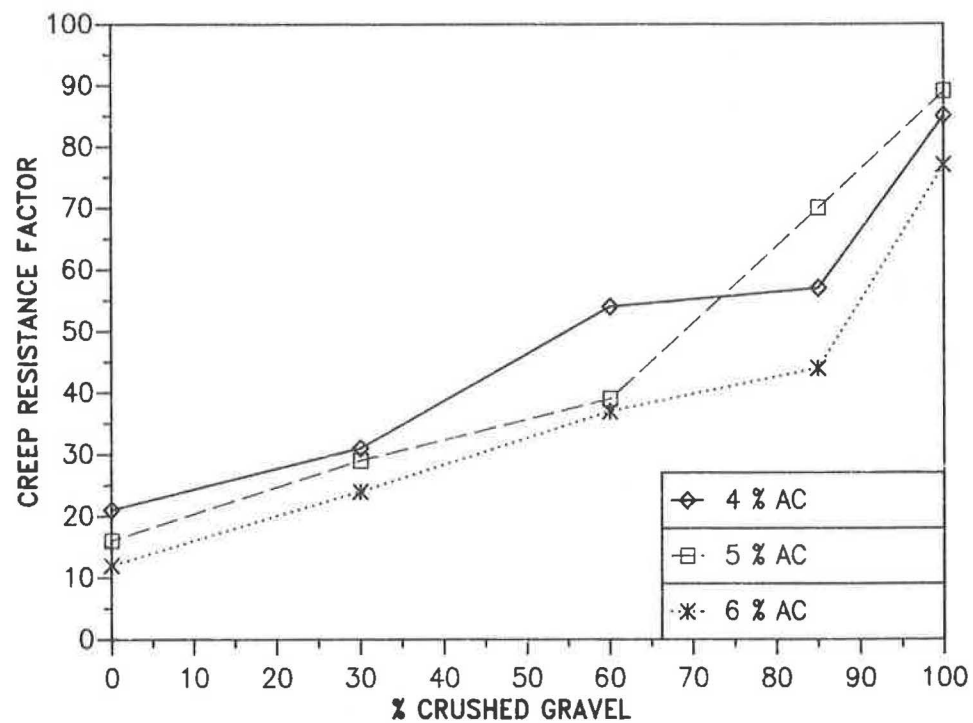


FIGURE 12 Creep resistance factors for crushed gravel mixtures.

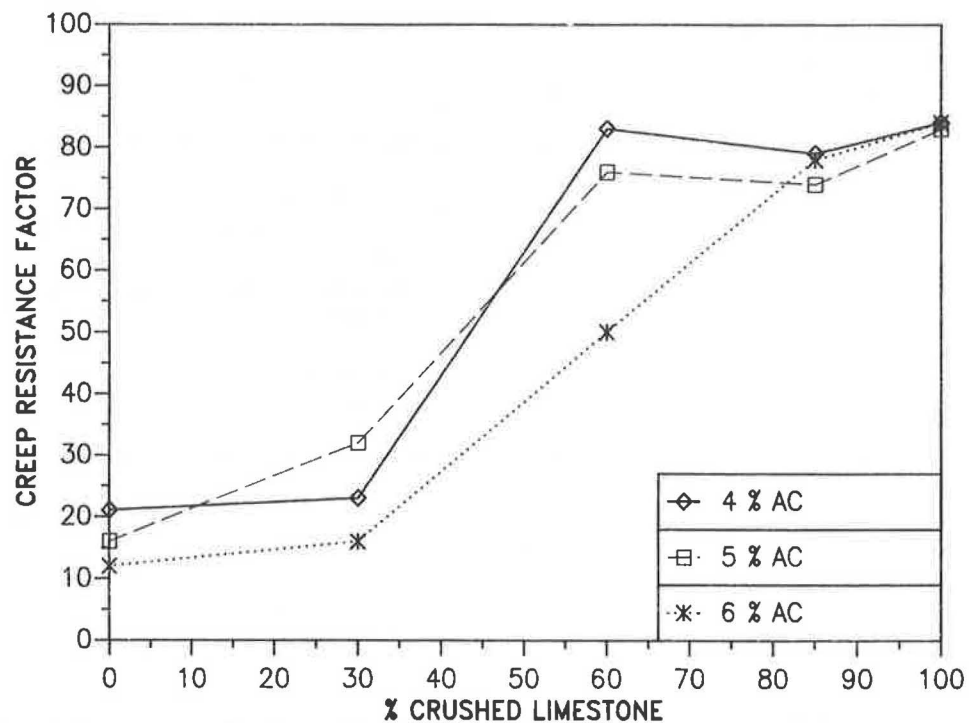


FIGURE 13 Creep resistance factors for crushed limestone mixtures.

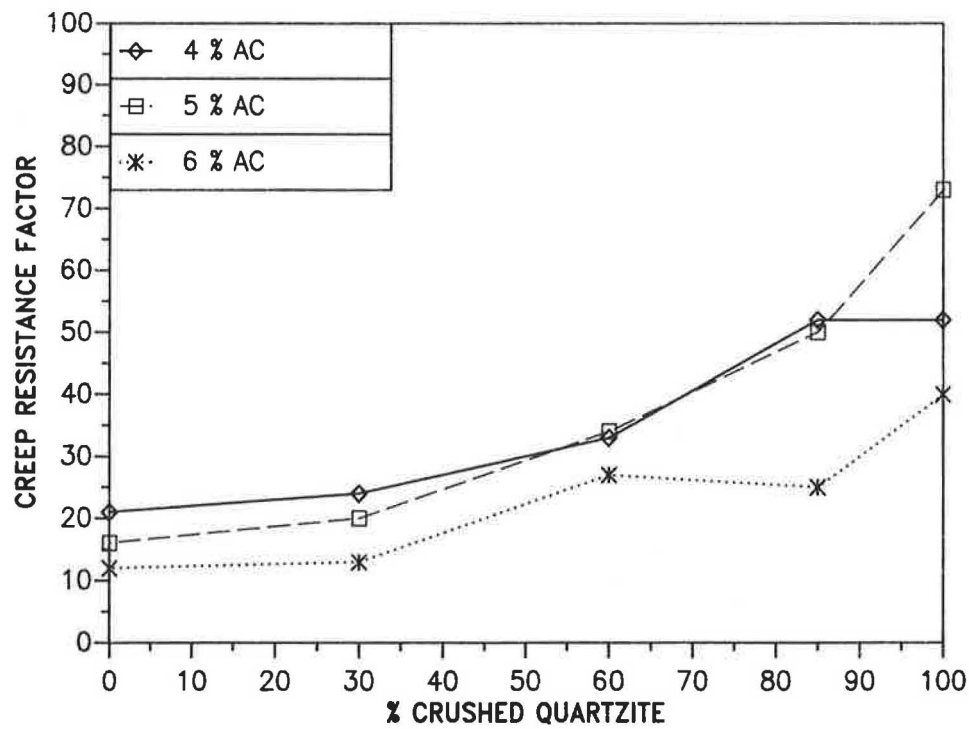


FIGURE 14 Creep resistance factors for crushed quartzite mixtures.

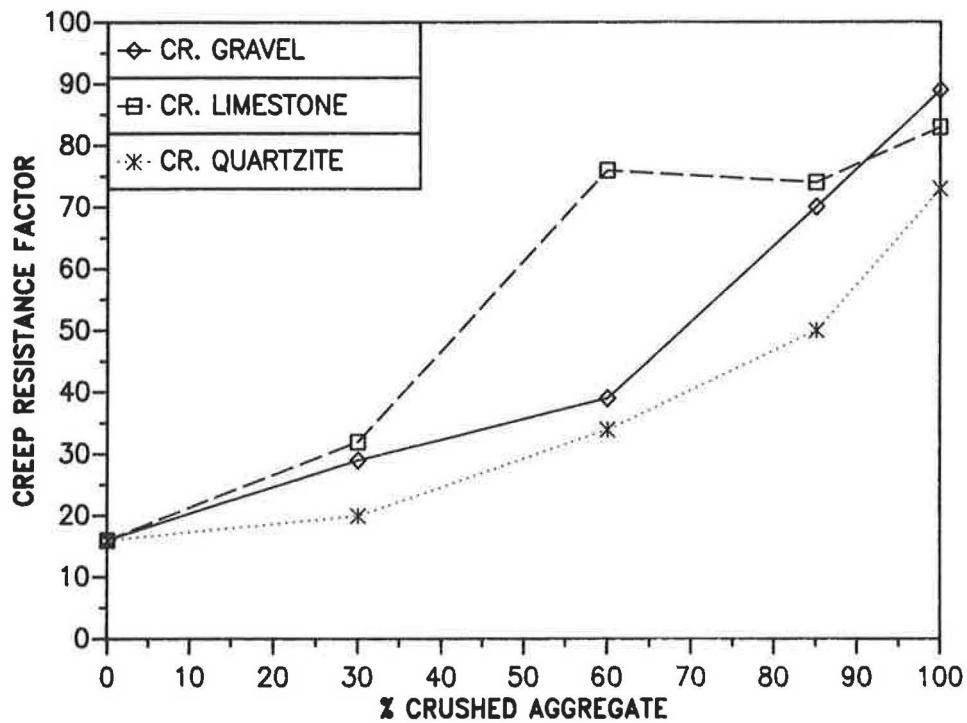


FIGURE 15 Creep resistance factors for gravel, limestone, and quartzite mixtures with 5 percent asphalt cement.

CONCLUSIONS

This research supports the following conclusions concerning crushed particles in asphalt mixtures and tests:

1. Strengths or stabilities of asphalt mixtures are inversely related to laboratory densities of 75-blow Marshall compacted specimens.
2. The Marshall stabilities are directly related to the percent of crushed particles in the mixture. Increased percent of crushed particles yields a substantial increase in stabilities.
3. The percent of ac in the mixture has a minimal effect on Marshall stabilities until there is an excess of ac.
4. A harder grade of ac will yield a small increase in Marshall stability in comparison with larger stability increases caused by higher percentages of crushed particles.
5. Crushed limestones yield much higher Marshall stabilities than crushed gravel or crushed quartzite.
6. The resilient modulus data do not correlate with percent of crushed aggregate or perceived resistance to rutting.
7. The resilient modulus and indirect tensile test are highly dependent on the grade of ac.
8. The CRF is directly related and very dependent on the percent of crushed aggregate.
9. The grade or content (unless highly overasphalted) of asphalt cement has a relatively small effect on the CRF.

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