COMPARISON OF CREEP AND RESILIENT MODULUS LABORATORY RESULTS WITH FIELD CORES

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COMPARISON OF CREEP AND RESILIENT MODULUS LABORATORY RESULTS WITH FIELD CORES

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8. ABSTRACT

This is Part 3 of a study of creep and resilient modulus testing of hot mix asphalt concrete. The creep and resilient modulus testing in Part 1 showed the improved load carrying characteristics of crushed particles. Cores from pavements drilled in Part 2 exhibited a poor correlation with rutting and creep/resilient modulus on pavement with a range of rut depths.

The objective of Part 3 was to determine the relationship of creep and resilient modulus for 1) Marshall specimens from laboratory mixing for mix design; 2) Marshall specimens from construction plant mixing; and 3) cores drilled from the hot mixed asphalt pavement. The creep and resilient modulus data from these three sources exhibited substantial variations. No meaningful correlations of the results from these three sources were obtained.

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DISCLAIMER

INTRODUCTION

Approximately 94% of all U.S. paved roads are asphalt surfaced. In general, hot mix asphalt (HMA) concrete has provided high quality pavements for both high and low traffic volume roadways.

Researchers have identified numerous variables in asphalt concrete pavement design and construction having varying degrees of importance in regard to pavement performance. These variables include the aggregate (type, porosity, gradation and hardness), the crushing (jaw, cone and hammer), the asphalt cement (content, grade and quality), the mixing (drum or pugmill and temperature) and the lay down and compaction to mention just a few. This large number of variations is one reason for the difficulty in developing a test that will relate HMA mix design to pavement performance. Laboratory tests sometimes exhibit potential for evaluating the performance of HMA. Resilient modulus and creep testing are two tests that in recent years have been considered for effective evaluation of HMA.

This research is part 3 of a three part study of creep and resilient modulus testing of HMA. Part 1 reported in January 1990 (1) was a laboratory study of HMA mixtures made with 0, 30, 60, 85 and 100% crushed gravel, crushed limestone and crushed quartzite combined with uncrushed sand and gravel. These aggregate combinations were used with 4, 5 and 6% asphalt cement (AC). Marshall specimens, 2½ inches high by 4 inches in diameter, were made using 75 blow compaction. Laboratory testing of these specimens included creep and resilient modulus testing. A creep resistance factor developed in part 1 seemed to relate well to the percent of crushed particles and the perceived resistance to rutting.

Cores were drilled from 41 projects exhibiting varying rut depths for part 2 of this research (2). The rut depths were compared to the creep and resilient modulus of the four and six inch diameter cores. This comparison yielded a poor correlation.

OBJECTIVE

The objective of part 3 was to determine the relationship of creep and resilient modulus for 1) Marshall specimens from laboratory mixing for mix design; 2) Marshall specimens from construction plant mixing; and 3) cores drilled from the HMA pavement.

PROJECTS

Six projects were selected ranging from a high traffic volume interstate to a low traffic volume state park road. The intent was to evaluate HMA designs with as wide a range of resilient modulus and creep factor as possible. The projects were:

Dallas - IR-80-3(67)
Warren - F-65-3(24)
Mahaska-Keokuk - FN-92-7(31)
Washington-Johnston - FN-1-5(45)
Ida - FN-20-2(41)
Jackson - SP-605-0(10)

TESTING EQUIPMENT

Marshall Equipment

The hammer used to compact the Marshall specimen for the study was an Iowa DOT Materials Lab fabricated mechanical hammer with a flat face and stationary concrete base. The mechanical hammer is calibrated every three months by correlating with a hand held Marshall hammer of the type described in AASHTO T245-82.

Resilient Modulus Apparatus

The resilient modulus testing for this study was performed using a Retsina Mark VI Resilient Modulus Non-Destructive Testing Device, purchased in 1988 from the Retsina Co., Oakland, California. The Retsina Device was selected among numerous resilient modulus testing systems due to its low cost, simplicity, and ease of operation. As described in ASTM D-4123, for a cylindrical specimen, diametral loading results in a horizontal deformation which is related to resilient modulus by the formula:

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

where: M = resilient modulus, psi

P = vertical load, pounds

ν = poissons ratio

t = specimen thickness, inches

d = horizontal deformation, inches

The device operates by applying a load pulse (0 to 1000 lb range) diametrically through the specimen. Load duration (0.05 or 0.10 sec.) 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 both by printer and digital display.

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 simultaneously testing three samples. An air regulator with digital display is capable of delivering line pressure from 0 to 120 psi to the load units. The load units have 12.4 to 1 force/pressure conversion ratio and a maximum output of 1500 lbs 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 from 0 to 1500 lbs can be applied. Dial gauges readable to 0.001 inch are mounted to 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 containing 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 are made from a larger 13,000 gram batch.

Resilient Modulus Testing

Testing temperature for resilient modulus was targeted at 77±2°F. The only temperature control utilized was the ambient air temperature of the lab itself. At this time, the Iowa DOT does not have the capability for testing resilient modulus at elevated temperatures. The temperature of the specimen was determined by sandwiching a thermocouple 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° divisions on the diameter of the specimen. Specimen thickness was determined to .01 inch using a height comparator. Each specimen was placed in the frame and tested with the transducers directly opposite each other. After an individual test was completed, the specimen was reoriented by rotating 60° and the test was repeated. Each specimen was again rotated 60°, resulting in a total of three tests per specimen, each at an orientation of 60° from the other two.

Each test consisted of twenty load cycles of 0.10 sec. and a frequency of 0.33 hz. Prior to 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 utilized. The three sets of twenty cycles were repeated at loads of 50 and 75 pounds.

This same testing pattern was performed on each of the three four inch and three six inch diameter cores. All results for a set of three cores were then averaged to yield a single resilient modulus value. Final results were expressed in terms of thousands of pounds per square inch (Ksi).

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

Creep Test Procedure

After the 4 inch diameter cores were sawed with a diamond saw blade to obtain a 2½ inch thick slice, the flat faces were polished on a belt sander using #50 grit paper. This was done 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 #2 graphite flakes and water/temperature resistant silicon gel lubricant to the polished core faces. Sets of three cores of the same diameter from the same site were tested simultaneously.

Other than the fact that the Marshall specimens were used at the thickness they were removed from the mold, they were prepared the same as the cores. Testing temperature was 104°F, and the specimens were conditioned in 104°F water for 1/2 hour prior to testing.

The specimens were then subjected to a preload of 40 psi contact pressure for 2 minutes using a 4 inch diameter load plate prior to testing. In order to achieve contact pressures of 200 psi during testing, a 3 inch diameter top load plate was used instead of a 4 inch diameter plate. After preloading, which was intended to properly seat the specimen, load plates and ram, and compress any final minute surface protrusions, the specimens were removed from the apparatus and their height measured to the nearest 0.0001 inch using a height comparator. The samples were then placed back in the apparatus; dial gauges were adjusted to read 0.500 inch; and the creep loads were applied.

Contact pressure was increased from 0 to 40 psi in step loads of 8 psi applied for 1 minute each. After 40 psi was reached, the dial gauges were read at ten minute intervals until 1 hour (which included the five minute loading period) had passed. At this time, 8 psi step loads of one minute duration were again applied until a contact pressure of 80 psi was attained. Dial gauge readings were again taken at ten minute intervals for one hour. This entire sequence was repeated until the final step of 200 psi for 1 hour was achieved, or specimen failure occurred. Specimen failure is indicated by a rapid increase in height reduction or change in height of more than 0.05 inch. Total elapsed time (min.), the applied pressure at the time of failure and the measured reduction in height just prior to failure were recorded. If failure did not occur, total reduction in height at the end of the test (300 minutes) 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 reasoning in developing the CRF was that a mixture that failed prior to the 200 psi loading at 300 minutes was less resistant to permanent deformation than one that would withstand the 200 psi loading with limited deformation. Secondly, if two mixtures did not fail prior to the 200 psi loading, the amount of change in height was related to the resistance to deformation and the mixture with the least change should result in the higher single quantitative CRF. The formula for the CRF is:

$$CRF = \frac{t}{300}\,[100-c(1000)]$$

where: CRF is Creep Resistance Factor

t is time in minutes at failure,
0.05 inch height change, or
300 if failure did not occur.

c is change in height in
inches or 0.05 inch if
failure occurred.

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

$$CRF = \frac{300}{300}\,[100-(0.037)\ (1000)]$$

$$= 63$$

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

$$CRF = \frac{265}{300} [100-(0.050)\ (1000)]$$

$$= 44$$

DISCUSSION

Resilient Modulus

The resilient modulus data is given in Table 1. Samples of HMA mix were taken from two different locations on the roadway. Three four inch diameter cores were taken from the finished pavement at each of these same two locations. As can be seen from the data in Table 1, there are many instances of substantial variation in results at the two locations on the same project. Two sets of Marshall specimens were made with 50 blow and 75 blow compaction for both the laboratory mixed and construction plant HMA mix. The resilient moduli of cores was much less than the resilient modulus of Marshall specimens of the same material.

A correlation of the 50 blow Marshall specimens from the laboratory mix with those from the construction plant mix yielded a Coefficient of Determination $R^2 = 0.28$. An average of the two values from the two project locations was used in the correlations. An $R^2 = 0.14$ was obtained when comparing 75 blow Marshall laboratory mix with construction plant mix. The resilient moduli of the cores were correlated with both the 50 blow and 75 blow laboratory Marshall specimens. This yielded R^2s of 0.07 for both correlations. The resilient moduli of the cores yielded R^2s of 0.25 and 0.24 when compared to the respective 50 blow and 75 blow Marshall specimens from the construction plant mixed material. The correlations of resilient moduli data yielded R^2s that ranged from 0.07 to 0.25. All of these are considered to be very poor correlations. Obviously there is far too much variation to have confidence in the relationship of laboratory to field data.

The Creep Resistance Factor data is given in Table 2. All cores and Marshall specimens were subjected to creep testing after the resilient modulus testing. The Creep Resistance Factor of cores was much less than the Creep Resistance Factor of Marshall specimens from the same material.

The correlation of the 50 blow Marshall specimens from the laboratory mix with those from the construction plant mix yielded an R^2 of 0.20. An R^2 of 0.39 was obtained when comparing 75 blow laboratory mix specimens with construction plant mix.

The Creep Resistance Factors of the cores yielded R^2s of 0.00 and 0.24 when compared to laboratory mix 50 blow and 75 blow Marshall specimens. When the cores were compared to the 50 blow and 75 blow Marshall specimens from construction plant mix, R^2s of 0.05 and 0.15 were obtained.

The R^2s of the Creep Resistance Factors ranged from 0.00 to 0.39. Again, these indicate very poor correlations or very little confidence in knowing one and predicting the other.

CONCLUSIONS

This research on resilient modulus and creep testing of HMA supports the following conclusions:

1. Resilient moduli for (1) Marshall specimens from laboratory mixed HMA (2) Marshall specimens from construction plant mixed HMA and (3) cores drilled from the HMA pavement yield very poor correlations.

2. There is substantial variability of resilient moduli of specimens made from the same HMA plant production.

3. Creep Resistance Factors for (1) Marshall specimens from laboratory mixed HMA (2) Marshall specimens from construction plant mixed HMA and (3) cores drilled from HMA pavement yield very poor correlations.

4. There is substantial variability of Creep Resistance Factors of specimens made from the same HMA plant production.

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TABLE TITLES

TABLE 1
Resilient Modulus, Ksi

	Dallas IR-80-3(67)	Warren F-65-3(24)	Mahaska-Keokuk FN-92-7(31)	Washington-Johnson FN-1-5(45)	Ida FN-20-2(41)	Jackson SP-605-0(10)
Lab Mixed 50 blow	920	430	430	530	1140	252
Lab Mixed 75 blow	1150	550	520	740	1180	380
Plant Mixed (1) 50 blow	810	1090	590	580	1100	350
Plant Mixed (1) 75 blow	940	1340	790	570	980	410
Plant Mixed (2) 50 blow	1100	1040	720	520	600	280
Plant Mixed (2) 75 blow	1280	1230	920	520	820	380
Cores (1)	284	ND	120	265	259	550
Cores (2)	300	263	130	207	277	ND

ND - not determined
(1) (2) - denotes location where samples were taken

TABLE 2
Creep Resistance Factors

	Dallas IR-80-3(67)	Warren F-65-3(24)	Mahaska-Keokuk FN-92-7(31)	Washington-Johnson FN-1-5(45)	Ida FN-20-2(41)	Jackson SP-605-0(10)
Lab Mixed 50 blow	84	84	41	44	82	88
Lab Mixed 75 blow	79	89	88	86	93	92
Plant Mixed (1) 50 blow	87	87	89	75	80	86
Plant Mixed (1) 75 blow	81	86	88	81	89	92
Plant Mixed (2) 50 blow	86	86	82	77	77	90
Plant Mixed (2) 75 blow	88	90	86	80	87	89
Cores (1)	18	ND	18	ND	26	2
Cores (2)	31	21	17	16	17	4

ND - not determined
(1) (2) - denotes location where samples were taken