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반복하중 크리프시험에 의한 아스팔트 혼합물의 소성변형특성 평가

Rutting Potential Evaluation of Asphalt Mixtures by Repeated-Load Creep Test

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Abstract

Field or laboratory wheel tracking tests have been employed for the evaluation of the rutting potential of asphalt paving mixtures. Compared to field tests, laboratory wheel tracking tests are much less expensive and more manageable for most road projects. However, most test laboratories are not equipped to perform such tests because there does not exist any standard test procedure, and the required equipment is rather expensive. Furthermore, the size of test specimens and the relatively large quantity of test mixture required present difficulties for laboratory specimen mixing and compaction. This paper describes a project conducted to study the feasibility of replacing wheel tracking testsby a repeated-load creep test for rutting potential evaluation. Comparisons were made between the results of the two tests for different test temperatures, loading speeds and applied pressures. Three types of asphalt mixtures were studied in the test program. Favorable conclusions concerning the use of the repeated-load test for rutting potential evaluation were drawn based on the findings of the experimental test results. The correlation between the two types of tests was found to be good for all threeasphalt mixtures. Adopting the repeated-load creep test would lead to cost savings since it employs standard test equipment already available in most laboratories. It would also result in substantial time savings due to the much smaller quantity of mix needed, and the ease in specimen preparation.

INTRODUCTION

Rutting is a major form of distress found in asphalt pavement. One of the most important criteria in the mix design of an asphalt paving mixture is the mix' s ability to resist rutting. There is, however, no single universally accepted standard procedure for testing the rutting resistance of an asphalt mixture. A widely practised method of evaluation for rutting potential is to conduct wheel tracking test [1-3].

Full-scale wheel tracking tests are expensive and impractical for most construction project applications. They are employed more or less exclusively for research purpose [2, 3]. Laboratory wheel tracking tests [4, 5] are much less expensive than full-scale tests, and are more manageable for a typical pavement materials testing laboratory. Laboratory wheel tracking test devices, however, have yet to become standard equipment in a typical highway materials testing laboratory because of the following limitations: (a) the test results in terms of rut depth cannot be easily related to fundamental engineering properties of the test material; (b) test results are sensitive to conditions (such as density and thickness) of test specimens; (c) compared with the normal cylindrical Marshall sizespecimen, the slab specimens needed are much heavier, and larger in size and mix

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quantity, hence requiring special equipment and substantially more effort and time for mix preparation and compaction.

This paper presents the findings of a research project conducted to study the feasibility of replacing laboratory wheel tracking tests by a simpler laboratory test for the evaluation of rutting potential of asphalt paving mixtures. The objective was to overcome the limitations (b) and (c) identified in the preceding paragraph. A repeated-load creep test using Marshall size specimens was adopted for this purpose. The magnitude of load and loading frequency were selected to correspond to those applied in a laboratory wheel tracking test. Comparisons between the results of the two forms of tests were made to establish the applicability of the simpler repeated-load creep test. Three types of asphalt mixtures were tested in the experimental program using the two modes of test under different test temperatures, loading speeds and applied pressures.

EXPERIMENTAL PROGRAM

• Program Plan

Test Program

Two types of tests were included in the experimental program, namely a laboratory wheel tracking test and a repeated-load creep test. As explained in the preceding section, the objective was to establish if the simpler and less time-consuming repeated-load creep test could replace the wheel tracking test for rutting potential evaluation of asphalt mixes. For each of the two test methods, a series of tests each were performed at the following three test temperatures: 28℃, 40℃, and 60℃. These temperatures cover the range of pavement temperature in a typical sunny day in Singapore. In each test series, rutting potential of the test mix was evaluated for different combinations of loading speed and applied pressure. Three loading speeds were considered to represent the wheel tracking speeds of 20, 40 and 60 passes per minute respectively. The three levels of applied pressures included in the test program were 420, 560 and 690 kPa.

Types of Mix Tested

Three mix types were studied in this research. The most common surface course mix used in Singapore, a dense-graded asphaltic mix known as W3B (Mix Type A), was tested in this study. Also included in the test program was a steel-slag mix (Mix Type B) which was used at some busy traffic light intersection to reduce rutting. The aggregate gradation and asphalt binder content of each mix are shown in Table 1. These two mix types offer a comparison of the effect ofaggregate on the test results. To examine the effect of binder, a third mix type was added by replacing the penetration grade 60/70 asphalt binder by a polymer modified asphalt binder (Mix Type C in Table 1), while keeping the aggregate gradation and mix proportion unchanged.

• Laboratory Wheel Tracking Test

Test Equipment

The rutting test equipment used in the present study was a modification of a immersion wheel tracking machine used in the United Kingdom [6]. The major modification was in the rut depth measurement method where an automated electronic system was installed to replace the chart drum and pen recorder system in the original machine. Main features of the equipment include control of the following test parameters: temperature, wheel speed, and wheel loads. Two parallel sets of loading wheels consisting of a free-rotating solid rubber tire each. The rubber tire measured 45mm wide, with a diameter of 200mm.

Test temperature was maintained by means of a water bath heated with an electric heating element. The water bath temperature could be adjusted within a range from room temperature (about 28℃) to 70℃ by an electronic thermostat with a differential setting of 0.2℃. An adjustable weir kept the water level at the top surface of the test specimens. Control of wheel speed was achieved by a constant torque geared motor with electronic speed control. The free-rotating wheels, each measured 45 mm wide and had a diameter of 200 mm, covered a path of 254 mm in a reciprocating motion. A constant test speed within the range of 0 to 80 passes per minute could be selected. A test speed of n passes per minute means that the test wheel will pass a given point on the surface of a specimen n times every minute. Each cycle of the reciprocating motion of the wheel produced two passes for all the points in the wheel tracks. Applied loads in the form metal blocks could be added to vary the tire contact pressure from 420 to 690 kPa.

Preparation of Test Specimens

Prismatic specimens measuring 407mm by 137mm by 90mm were required for the wheel tracking test. Based on earlier research by the authors [7, 8], a static press was employed to compress the test mix under a double plunger action to produce a uniform compaction pressure. The magnitude of applied pressure could be varied, depending on the compacted density desired. For the mixes tested in this study, an initial pressure of about 150 psi (about 1 MPa) was used to set the mixture to the sides of the mould, followed by a sustained pressure of 3000 psi (about 21 MPa) applied for a duration of 5 minutes. This method of compaction was found to produce beam specimens of good uniformity of compacted density, with excellent repeatability in terms of the level of compacted density achieved.

There were 9 test combinations for a selected test temperature. For three test temperatures, the total number of test combinations was 27. Two prismatic specimens were prepared for each test combination, giving rise to a total of 54 prismatic specimens per test mix for the test program. With three test mixes, the total number of prismatic specimens fabricated was 162. The compacted densities of the 162 prismatic specimens varied from 2.289-2.337g/cm^3 for Mix Type A, 2.832-3.054g/cm^3 for Mix Type B, and 2.286-2.325g/cm^3 for Mix Type C. These were within the common range of densities achieved in the field for the mix types.

Test Procedure

The test machine had two parallel sets of wheels and allowed two beam specimens to be tested concurrently. Before theloading began, the water bath was first brought to the desired test temperature. Next, the two prismatic specimens were placed in position for a duration of 2.5 hours. This was to ensure that a uniform test temperature was reached in the test specimens.Rut depths developed in test specimens were measured using an automated data acquisition system with electronic linear voltage transducers (LVDTs). Test records included test temperature, load applied, and rut depth variations with time at five selected points for each wheel path, including the respective mid-points of the wheel paths.

Each wheel tracking test was conducted up to 5,000 wheel passes, or when the rut depth exceeded 20mm, whichever was reached earlier. For a test with wheel speed of 20 passes per minute, the entire test including setting up time would last for more than 5 hours.

• Repeated-Load Creep Test

Test Equipment and Procedure

A universal testing machine with temperature control capability was employed for the repeated-load creeptest. The load The frequency of loading, and the loading and rest periods were specially set to approximate as close as possible the conditions in the wheel tracking tests. Since the actual spot speeds at different points of the wheel path were not the same in the wheel tracking test, the conditions at the mid-point of the wheel path where the maximum rut depth occurred were considered. The loading frequency of the creep test was derived based on the time taken by the wheel in the wheel tracking test topass and back to the mid-point of the wheel path. The loading period of the creep test was obtained by dividing the contact length of the rubber tire by the spot speed of the wheel at the mid-point of the wheel path.

For comparison with the wheel tracking test results, 5,000 load pulses were applied for each creep test except in cases where the accumulative strain exceeded 0.05 before 5,000 load pulses was reached. Depending on the pulse period of the test, the loading test itself took about 6 minutes (for load pulse simulating the wheel speed of 60 passes per minute) to 16 minutes (for load pulse simulating the wheel speed of 20 passes per minute).

Preparation of Test Specimens

The creep test made use of cylindrical specimens prepared by the same procedure as that specified for Marshall specimens in accordance with ASTM Standard Procedure D1559 [9]. Each specimen measured 100mm in diameter and 63.5±1.27mm in height. Compared with the wheel tracking test specimen, it is much easier to prepare the creep test specimen. In addition, each creep test specimen is approximately 10% of the mass of a wheel-tracking test specimen. In the present test study, about 15 creep test specimens could be prepared in a working day. For the wheel tracking test, due to the much large quantity of mix needed, only 2 wheel tracking test specimens could be made per working day.

There were 27 test combinations for each mix type. Three replicate specimens were tested for each mix type, giving a total of 81 cylindrical specimens per mix type, or 243 specimens for three mix types of the entire test program. The compacted densities of these test specimens covered the range of 2.292 to 2.339g/cm^3 for Mix Type A, 2.710 to 3.020g/cm^3 for Mix Type B, and 2.304 to 2.342g/cm^3 for Mix Type C, which were similar in magnitude to those obtained for the wheel tracking test specimens.

ANALYSIS OF TEST RESULTS

In studying the possibility of using the repeated-load creep test as a laboratory procedure to assess the rutting potential of asphalt mixes, the main emphasis was to ascertain if relevant information obtainable from the wheel tracking test could be derived from the creep test. In this regard, the following three main aspects were addressed in this study when examining the experimental results of the wheel tracking and repeated-load creep tests:

(a) Relative test response of a given asphalt mixture

Test response in terms of vertical deformation under the applied load is the logical basis for comparison of the two tests. Considering the measured rut depths in the wheel tracking tests, rut depth was found to increase with increasing test temperature, or increasing applied load, or reducing loading speed, for all three mix types tested. The same trends were observed in the creep test when cumulative strains were considered. Both tests were equally able to reflect the effects of test temperature, loading load, and loading speed.

(b) Deformation characteristics of test specimens

Before failure or yielding occurred, the vertical deformation curves plotted against wheel passes (for wheel tracking test) or load pulses (for creep test)

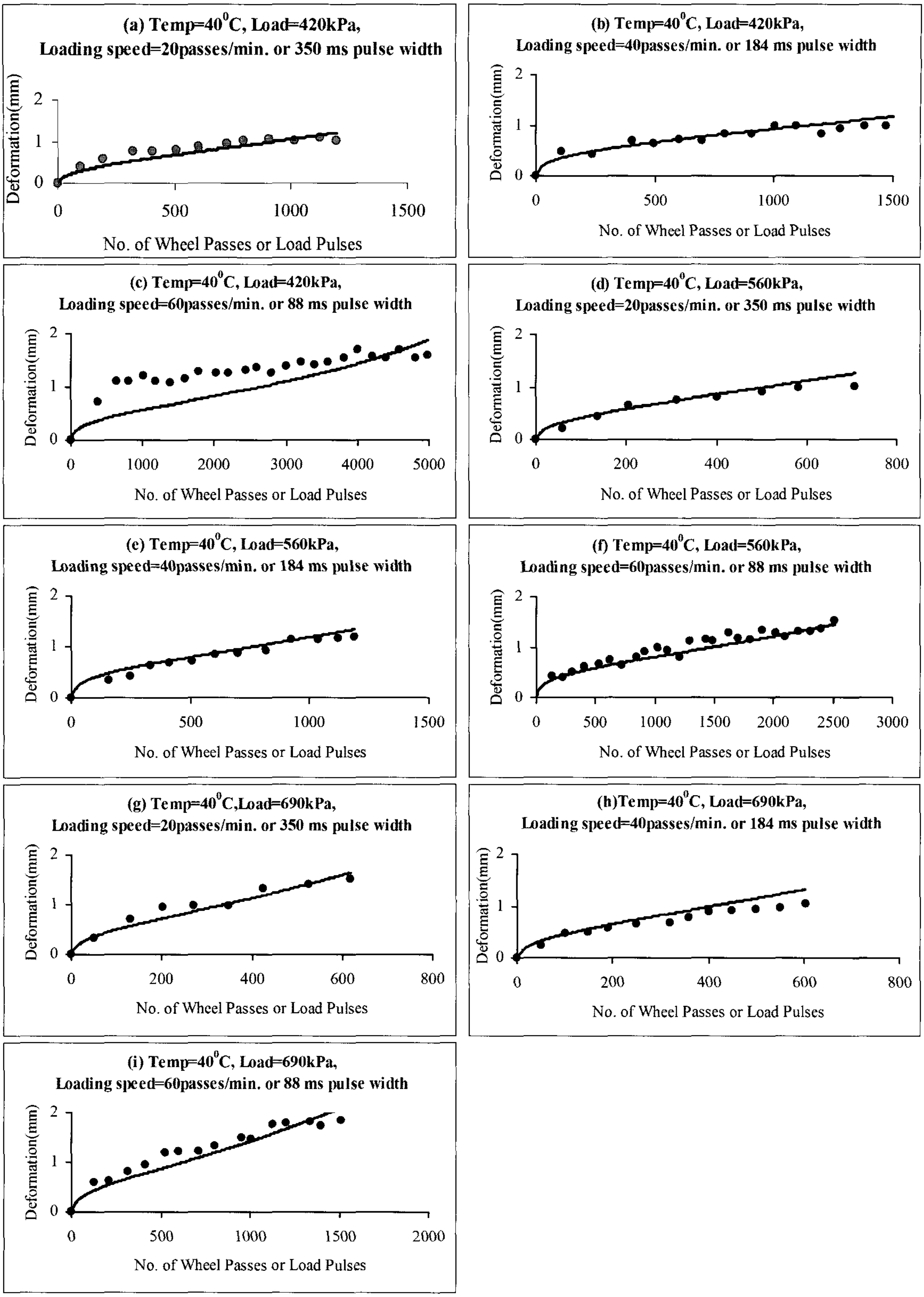

Figure 1. Matching of test results by wheel tracking and creep test for Mix Type A at 40℃

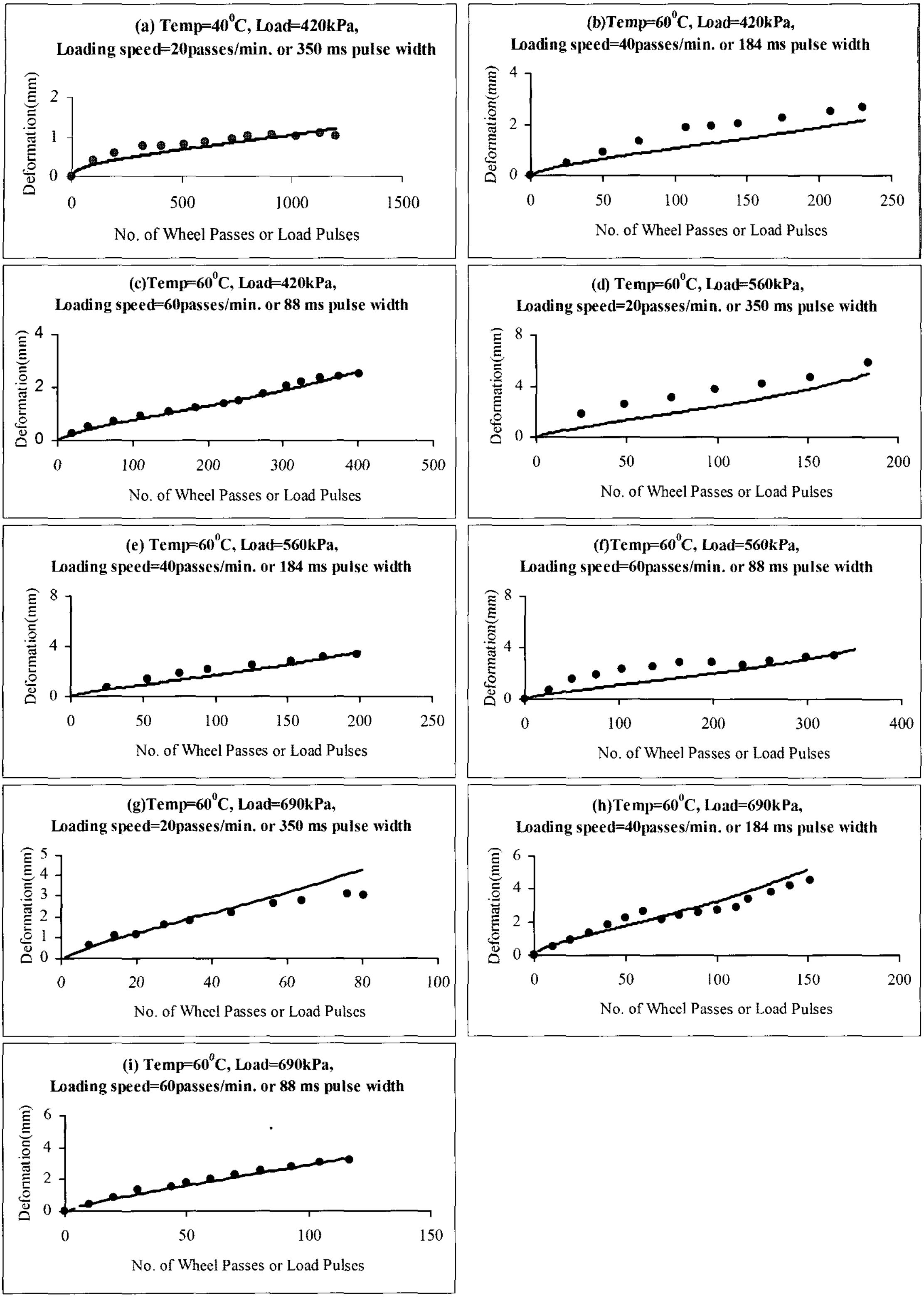

Figure 2. Matching of test results by wheel tracking and creep test for Mix Type A at 60℃

displayed a typical shape with a sharp initial rise followed by gentle development of deformation until yielding. It is of significance to note that the trends of deformation building-up with load repetitions were very similar for the two tests. Very good match of the two sets of curves was achieved by simply applying a constant multiplication factor. Figs. 1 and 2 show that a factor of 1.154 was applicable for Mix Type A tested at 40℃, while 1.58 was applicable for the same mix tested at 60 ℃. Table 2 lists the multiplication factors and the coefficients of correlation between the two tests for various test conditions.

(c) Relative performance of different asphalt mix types

The wheel tracking and the creep test results agreed well regarding the relative performance of the three mix types with respect to load induced permanent vertical deformation. Both tests concluded that Mix Type C was the most resistant to load induced permanent deformation, while Mix Type A had the poorest performance in this regard. The relative performance of the three mix types were consistently reflected in both tests under different combinations of test conditions.

Table 1. Mix Composition of Test Mixtures

(a) Aggregate Gradatiom

Percent Passes			
Aggregate Size (mm)	Mix Type A	Mix Type B	Mix Type C
19	100	100	100
13.2	85.0-95.0	80.0-90.0	85.0-95.0
6.3	58.0-68.0	--	58.0-68.0
3.15	40.0-50.0	--	40.0-50.0
2.36	--	46.0-56.0	--
1.18	21.0-31.0	--	21.0-31.0
0.6	--	16.0-26.0	--
0.3	11.0-17.0	--	11.0-17.0
0.212	--	8.0-18.0	--
0.075	4.0-8.0	6.5-10.5	4.0-8.0

(b) Binder Content

	Mix Type A	Mix Type B	Mix Type C
Binder Type	Penetration Grade 60/70	Penetration Grade 60/70	Polymer Modified Asphalt
Binder Content (% by Wt of Total Mix)	5.0	5.0	5.0

Table 2. Matching of Deformation Curves of Wheel Tracking and Creep Test

Mix Type	Temperature (℃)	Multiplication Factor[1]	Correlation Coefficient ρ
A	40	1.154	0.85
	60	1.580	0.81
B	40	2.054	0.90
	60	5.315	0.88
C	40	1.995	0.766
	60	2.448	0.819

Note (1): Multiplication factor is to be multiplied to creep test deformation to match deformation occurred in the wheel tracking test. Each factor is applicable to all applied loads and loading speeds for the temperature indicated.

(d) Yielding behavior of test specimens

Yielding or failure only occurred in the wheel tracking test under the highest test temperature of 60℃ and the heaviest applied load, and none of the Mix Type C specimens failed under this test. On the otherhand, in creep test, weaker mixes yielded before the full 5000 load pulses were applied. Yielding took place in practically all Mix Types A and B specimens tested at 40 ℃ and 60℃, and some Mix Type C specimens yielded when tested at 60℃. This suggeststhat while wheel tracking test is unable to reach the yielding state for most mixes, the creep test was able to for the weaker mixes. Hence, for creep test, yielding offers another possible indicator for differentiating rutting potential of different asphalt mixtures.

CONCLUSIONS

An experimental test program has been conducted to study the feasibility of adopting repeated-load creep test to replace wheel tracking test as a laboratory evaluation tool for the rutting potential of asphalt paving mixtures. Comparison of the two test methods was made based on their test results on three different mix types each tested under 27 different test conditions. The 27 test conditions represented different combinations of the following test parameters: temperature, applied load and loading speed. Three levels of each of the three test parameters were considered.

The following observations have been made from the analysis of the test results: (a) The two test methods were equally able to differentiate the effects of temperature, applied load and loading speed respectively on the load induced vertical deformation of an asphalt mixture; (b) The development trends of vertical deformation in the two tests were very similar. Very good match between the two sets of curves for a given test temperature was achieved when a constant multiplication factor was applied. (c) Experimental results of the two test methods were also in agreement regarding the relative performance of the three mix types with respect to load induced permanent vertical deformation. (d) The creep test was able to cause yielding in the weaker test specimens under the more severe test conditions. This offers an additional parameter for assessing the rutting potential of the test material.

Based on the findings of the test program, it may be concluded that the repeated-load creep test can be a practical laboratory evaluation tool for the rutting potential of asphalt paving mixtures. All the important information obtained from a common form of wheel tracking test can be derived from the creep test. Compared with wheel tracking tests, the creep test is simpler, less costly, less manpower demanding, and significantly less time consuming.

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