Development and Use of Georgia Loaded Wheel Tester

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The Georgia Department of Transportation began development of a loaded wheel tester (LWT) in 1985 to better evaluate the rutting susceptibility of asphaltic concrete mixes. It has been believed throughout the industry for some time that Marshall stability tests are inadequate to accurately predict rutting potential of various mixes. With the Georgia LWT, the susceptibility of a mixture to rut can be determined in the laboratory during the design stage, and modifications to the design can be made at that time if needed. The machine can be adjusted for various weight, air pressure, and temperature conditions to simulate and test for performance under the actual field environment. The machine has been made to be a completely portable, self-contained unit with its own environmental heating chamber. Several research projects have been conducted with the Georgia LWT in order to evaluate the effect on performance of aggregate gradation, tire pressure, vehicle loading, and pavement temperature. Testing has been done on specialized mixes such as stone matrix asphalt, which shows that these mixtures are more resistant to rutting than conventional mixes even though Marshall stability test values may be lower. Asphalt mixtures produced under the Strategic Highway Research Program Level I and II volumetric design methods may still be prone to rutting. The Georgia LWT is an economical tool that can be used as a "proof tester" for properly evaluating the rutting resistance of these mixtures before they are placed on the roadway.

The Georgia loaded wheel tester (LWT) is a valuable tool that has been used by the Georgia Department of Transportation (GDOT) to assess the rutting potential of asphaltic concrete mixes. By subjecting asphaltic concrete to a loaded wheel system under repetitive loading conditions and measuring the permanent deformation induced under the wheelpath, the rutting susceptibility of the asphaltic concrete to be used in the field may be determined. This approach to assessing rutting susceptibility was thought to be much more representative of actual field conditions than the Marshall stability test currently used throughout much of the industry. In view of the complexity of the material behavior and the stress induced by traffic loading, the use of loaded wheel type testing can provide a fast and accurate means of simulating rutting at the design stage of the mix rather than waiting until the mix is in place to discover that it has a high potential for rutting.

LWT DEVELOPMENTAL RESEARCH

In order for GDOT to perform LWT research, a machine was needed. When GDOT began considering this approach in 1985, no machine was commercially available, so the Georgia Institute of Technology (Atlanta, Ga.) was contracted by GDOT to develop a LWT that would meet our needs.

Preliminary developmental work by Georgia Tech consisted of literature searches through the Highway Research Information System and draft designs. GDOT had a machine that met the base design criteria specified by Georgia Tech. This machine was previously used by GDOT for design and testing of slurry seals and was originally developed by C.R. Benedict of Benedict Slurry Seals, Inc. (Alpha, Ohio). Minor modifications to the base machine would enable Georgia Tech to perform loaded wheel research.

GDOT initiated research project No. 8503, *Development of a Simplified Test Method to Predict Rutting Characteristics of Asphalt Mixes* (*1*). The objectives of that study were to: (*a*) develop a simplified rut prediction test apparatus, (*b*) evaluate the rut prediction capability of the apparatus from the test results, and (*c*) compare the results obtained from the tests with those from creep tests and repeated load triaxial tests to evaluate rut predicting capability of the test method as compared with the other methods.

The first objective was accomplished by performing four specific tasks. All tasks involved making modifications to the base machine. First, a simple and effective means had to be devised for heating and maintaining a constant temperature in the asphaltic concrete specimens throughout the test period. After these modifications were made, the modified LWT was installed in an airtight room.

This airtight room was thermostatically controlled and heated to 35°C (95°F) with a maximum fluctuation of ±1.1°C (2°F). Georgia's mean summer temperature (hottest days) was 35°C (95°F), thus this temperature was chosen as the testing temperature.

The hard rubber wheel that was on the original machine was replaced with a 76-mm (3-in.) diameter aluminum wheel and a linear tube made of high-pressure rubber to which pressure ranging from 482 kPa (70 psi) to 827 kPa (120 psi) could be applied and controlled. The linear tube was placed stationary on top of the asphaltic concrete specimen and inflated to the desired pressure. Both ends of the tube were held in position with end clamps, which prevented the horizontal movement of the linear tube while allowing vertical flexibility. The aluminum wheel was attached to the reciprocating arm of the machine.

The next step involved developing a suitable means of holding the 76 mm x 76 mm x 381 mm (3 in. x 3 in. x 15 in.) beam sample. This specimen size was chosen because the maximum aggregate size used in Georgia asphaltic concrete mixes is slightly less than 38 mm (1 1/2 in.) and there was a need to adhere to the principle that the mixture thickness should be approximately twice that of the largest stone size in the mix. The kneading compactor to be used was already equipped for this size sample mold, and sample molds were also available that were this size. Beams to be tested were kept on flat steel plates in the test room for 24 hr at 35°C (95°F) for preconditioning.

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A curing and testing temperature of 35°C (95°F) was chosen to simulate the mean summertime temperature in Georgia. (Beams were initially cured at room temperature for 14 days before placement in the airtight room.) After the 24-hr period, the beams were transferred to the testing machine for testing.

Finally, GDOT needed to develop an easy and accurate means by which to measure the rutting profile on the specimens. A measuring channel was machined that would fit over the specimen so that a dial gauge could be used to measure the rutting profile.

The modifications proposed in this study were intended to produce a simplified apparatus to achieve easy and yet accurate predictions of rutting tendency of asphalt mixes.

Because the primary aim of this research was to evaluate the modified LWTs capability in predicting rutting tendencies of asphalt mixes, the initial testing was concentrated on only a few variables that were thought to be significant to potential rut development. These variables were tire pressure, testing temperature, and load.

These variables were controlled as follows:

- Tire pressure: 517 kPa (75 psi) and 689 kPa (100 psi)
- Temperature: 35°C (95°F)
- Load: 22.7 kg, 34 kg, and 45.4 kg (50 lb, 75 lb, and 100 lb, respectively)

During the test, rutting profiles of the beam were measured at predetermined numbers of repetition, such as 0, 40, 100, 400, 1000, and 4000 cycles. Results from the tests were then used to determine if the modified LWT was capable of predicting the rutting potential of asphalt mixtures.

Creep tests and repeated load triaxial tests have been shown to be capable of assessing the rutting potential of asphalt mixtures. These tests were performed in this study so that a comparison could be made between the results obtained from the use of the modified LWT and the results of these two tests.

Based on the characteristics of the results from the LWT tests and creep tests and the repeated load triaxial tests, the LWT test results seemed to produce results more in line with the rutting characteristics experienced on asphalt pavements. Originally, four mixes were chosen for this study with each mix exhibiting different degrees of rutting tendency in four different projects. Comparison between the field rutting characteristics and the magnitude of rutting from LWT tests of each mix provided a means to assess the applicability of the LWT tests in predicting the rutting potential of asphalt mixes. Unfortunately, there were many variables that hindered this effort. The differences in volumetric properties and Marshall stability and flow test results for the projects (Table 1), as well as other variables such as differences in the field compaction efforts and subsequent traffic conditions, were some of the variables that may have contributed to the differences in rutting characteristics of the four mixes in this study. Therefore, attempts to draw a conclusion on the correlation, if any, and the validity of the correlation among these four mixes in terms of the rutting observed in the field versus that from the LWT tests should be made with great caution.

In comparing the LWT with the quasi-static creep test and the repeated load triaxial test, the sample preparation and the testing for the creep test were easier to perform, whereas the repeated triaxial test was more difficult to perform. Unlike the modified LWT, which used a relatively simple loading system and deformation measuring device, the loading system and the deformation measuring device for the repeated triaxial load test used in this study were comparatively more complex.

FORMAL RESEARCH STUDIES

In July 1986, research project No. 8609, *Evaluation of Rutting Characteristics of Asphalt Mixes Using Loaded Wheel Tester* (2), was conducted by Georgia Tech for GDOT. The purposes of this study were to assess the rutting potential of six GDOT intermediate (B) type mixes and to evaluate the rutting resistance of six different modified mixes. These six mixes contained materials such as mineral fillers from Georgia Marble (Tate, Ga.), Trenton Sand Co. (Trenton, Ga.), and Sylacauga Sand (Sylacauga, Ala.). A polymer-modified asphalt cement using Kraton polymer and one handmade blend gradation to manually increase the percent of −300 μm (No. 50)-size particles were used to evaluate the importance of fine aggregate in the 300-μm (No. 50) sieve size range. The handmade gradation provided a straighter line blend between the 1.18-mm (No. 16) to 150-μm (No. 100) sieve sizes when plotted on the 0.45 power gradation chart.

GDOT found that incorporating the mineral filler from Georgia Marble Co., which has low fineness modulus and angular particle

TABLE 1 Comparison of Marshall Stability Test Results

		Stability		Flow		% Air	
Project	% AC	N	(lbs.)	mm	(.01 in.)	Voids	% VMA
IR-20(62)	6.0	8541	(1920)	3.8	(15.0)	2.89	15.13
MPC-401(73)	5.0	5262	(1183)	2.5	(9.7)	5.31	15.23
MPC-403(35) Lot 18	6.2	6032	(1356)	4.3	(17.1)	4.12	16.70
MPC-403(35) Lot 26	5.3	9181	(2064)	5.1	(19.9)	2.80	14.10

shape, into asphalt mixes improves the rutting resistance of the asphalt mixes (Table 2). It is worth noting that the Marshall stability test values of the mixes modified with 3 percent and 5 percent of this type of filler were actually lower than that of the corresponding standard mixes. Also, the benefit of using the handmade mixes over the standard mixes in improving rutting is significant (Table 3). This indicates the importance of the amount of material passing the 300-μm (No. 50) sieve and 150-μm (No. 100) sieve in the mix. The Marshall stability test values for the handmade mixes were lower than that of standard mixes. This reinforces the idea that Marshall stability test alone is inadequate to predict rutting potential of mixes.

As a result of this study, Georgia added specification requirements in January of 1987 for the No. 50 sieve into its current gradation specification requirements for all mixes.

Research Project No. 8706, *Evaluation of the Effect of Gradation of Aggregate on Rutting Characteristics of Asphalt Mixes* (*3*), was performed in early 1987. In this study, the effects of mix gradations on the rutting resistance was evaluated. Six mix gradations with aggregate top sizes ranging from 19 mm to 38 mm (¾ in. to 1½ in., respectively) were used. Also, these mix designs had amounts passing the 2.36-mm (No. 8) sieve ranging from 22 percent to 38 percent.

Results obtained from this study indicated that the modified intermediate coarse mix with a 19 mm (¾ in.) top size and 30 percent passing the 2.36-mm (No. 8) sieve substantially improved the rutting resistance when compared with the standard intermediate mix. This study also demonstrated that other aggregate characteristics such as angularity or surface texture were just as important, or more so, as gradation in reducing rutting potential.

GDOT was convinced that the LWT would be beneficial in assessing the rutting susceptibility of asphalt mixes, but the machine was not a portable, self-contained unit. GDOT Research Project No. 8717, *Development of a Laboratory Rutting Resistance Testing Method for Asphalt Mixes* (*4*), was implemented in late 1987 to address this concern.

The objective of this study was to modify and improve the machine and the sample preparation method and to develop a testing procedure for using this machine. Improvements and modifications made to the LWT included the development of an environmental chamber to house the machine and to maintain a constant elevated temperature during testing. Heat strips inside the environmental chamber were used to elevate the temperature.

Modifications also included the development of a preheating box for preconditioning the test sample to the prescribed elevated temperature. Other minor modifications and improvements were made for the control and operation of the testing machine.

GDOT implemented LWT testing on a routine basis for the interstate projects and major state routes immediately. GDOT's experiences with the LWT allowed us to develop GDT-115, Method of Test for Determining Rutting Susceptibility Using the Loaded Wheel Tester. This method (implemented in 1989) defines the beam preparation procedure, beam testing procedure, and maximum rut depth allowable.

TABLE 2 Comparison of Rutting Resistance of Mixes Containing 3 Percent and 5 Percent Mineral Filler (Georgia Marble) Versus Standard Mix

Mix Type	Rut Depth @ 2000 Cycles mm	(in.)
FS	2.46	(0.097)
F3M	2.26	(0.089)
F5M	2.08	(0.082)
DS	2.31	(0.091)
D3M	2.13	(0.084)
D5M	2.11	(0.083)
CS	2.41	(0.095)
C3M	2.41	(0.095)
C5M	2.08	(0.082)

F = Limestone from Vulcan Materials at Fairmount, Georgia
D = Limestone from Vulcan Materials at Dalton, Georgia
C = Limestone from Vulcan Materials at Chattanooga, Tennessee
S = Standard or Control Mix
3M = Mixture with 3% Mineral Filler
5M = Mixture with 5% Mineral Filler

IN-HOUSE LWT STUDIES

Several "in-house" studies were performed by GDOT from 1987 to 1993. After careful consideration of in-place pavement temperatures during warm summer months, the testing temperature was increased to 40.6°C (105°F) before creating a data base. The 45.4-kg (100-lb) load and 689-kPa (100-psi) hose pressure exerts approximately 689 kPa (100 psi) of contact pressure on the sample. Also, in 1993, GDOT received a triple-track wheel tester developed by Georgia Tech. The in-house studies performed by GDOT were:

- Effects of increased temperature, load, and grade of asphalt cements on LWT Specimens (SP 92001)
- Comparison of AC-20s and 30s typically used in Georgia
- Stone matrix asphalt versus conventional mixes
- Crumb rubber versus conventional mixes

EFFECTS OF INCREASED TEMPERATURE, LOAD, AND GRADE OF ASPHALT CEMENTS ON LWT SPECIMENS

GDOT realized that in previous studies the effects of testing temperatures greater than 40.6°C (105°F) and hose pressures greater than 689 kPa (100 psi) had not been adequately researched, nor had the performance differences in asphalt cement grades (AC-10, AC-20, AC-30). So GDOT performed a research study in which the ele-

TABLE 3 Effects of Handmade Gradation on Rutting

Mix Type	Ruth Depth @ 2000 Cycles		Marshall Stability	
	mm	(in.)	N	(lbs.)
FS	2.46	(0.097)	11076	(2490)
FHM	1.83	(0.072)	9386	(2110)
DS	2.31	(0.091)	9074	(2040)
DHM	1.93	(0.076)	8674	(1950)
CS	2.41	(0.095)	8985	(2020)
CHM	2.26	(0.089)	8185	(1840)

HM = Handmade gradation

vated temperature, increased load, and different grades of asphalt cement were evaluated. It was concluded from this study that varying the hose pressure, temperature, and grades of asphalt cement yielded significant differences in rut depth.

The LWT showed that AC-20 is much more sensitive to temperature variations than AC-30 (Table 4). AC-20 Specimens were tested for an average of 4046 cycles at 48.9°C at 689 kPa (120°F at 100 psi). Testing of these samples was discontinued at this point because of excessive rutting. The rut depth was theoretically projected to 8000 cycles for comparison purposes. The average rut depth for AC-20 increased by 19 mm (0.753 in.) once the temperature was increased to 48.9°C (320°F) as compared with an increase of only 7.6 mm (0.298 in.) for AC-30. AC-10 is not used in Georgia as a hot-mix paving grade, and its use in this study was canceled because of its excessive rutting under standard conditions. Therefore, temperature change has the most pronounced effect on rut depth as determined by the conditions used in this study.

In comparison, if the temperature remained constant at 40.6°C (105°F) and the hose pressure was increased from 689 to 827 kPa (100 to 120 psi), the rut depth only increased by 7.90 mm (0.311 in.) for AC-20 and 2.57 mm (0.101 in.) for AC-30 (Table 5). This showed that increases in tire pressure have a direct effect on pavement rutting but not nearly as much as increases in pavement temperatures.

COMPARISON OF ASPHALT CEMENTS TYPICALLY USED IN GEORGIA

GDOT conducted a study in which different asphalt cements typically used in Georgia were evaluated. The objective of this study was to evaluate the contribution of AC to rutting resistance of a mix. LWT results were used for each asphalt cement and compared to determine which source of materials yields the most favorable results to rut resistance.

Loaded wheel testing by GDOT of these six asphalt cements was performed at both 40.6°C (105°F) and 48.9°C (120°F). Based on rut susceptibility and results of other physical characteristics, GDOT ranked these asphalt cements as follows:

Rank	*Code*
1	B
2	E
3	C
4	A
5	D
6	F

GDOT arranged with the National Center for Asphalt Technology (NCAT) at Auburn University to perform Strategic Highway Research Program (SHRP) binder testing on these asphalt cements. NCAT was chosen because of its proximity to GDOT's Forest Park Laboratory. NCAT concluded that all six asphalts complied with the requirements for SHRP 64-22 specifications. The RTFOT results were related more to rutting resistance than the other test conditions because this represents asphalt cement as it comes out of the asphalt plant. Also, dynamic shear numbers greater than 2.2 kPa indicate greater elasticity.

Rolling Thin-Film Oven Test

Rank	*Dynamic Shear*
1	B
2	C
3	E
4	F
5	A
6	D

The AC-30's all performed better than the AC-20's in this study. Loaded wheel test and NCAT results both agreed that asphalt "B" was the most desirable asphalt cement. This is another indication that the LWT is capable of assessing the rut susceptibility of asphalt mixes.

TABLE 4 Effects of Temperature Change on Rut Depth

Grade of AC	Test Conditions	No. of Cycles Tested	Projected Rut Depth @ 8000 Cycles mm	(in.)
AC-30	40.6°C/689 kPa (105°F/100 PSI)	8000	3.33	(0.131)
AC-30	48.9°C/689 kPa (120°F/100 PSI)	8000	10.90	(0.429)
AC-20	40.6°C/689 kPa (105°F/100 PSI)	8000	4.01	(0.158)
AC-20	48.9°C/689 kPa (120°F/100 PSI)	4046	23.14	(0.911)

STONE MATRIX ASPHALT MIXES

In 1990, GDOT started experimentation with stone matrix asphalt (SMA) mixes. SMA was developed in Europe during the early 1960s. It has a high coarse aggregate content that provides resistance to deformation and efficient load distributions through stone-to-stone contact. The voids in the aggregate structure are filled with a voidless mastic composed of fine-graded, quality mineral filler and crushed fine aggregate. The SMA mix utilizes a high-asphalt cement content that requires the use of stabilizing additives such as polymers or fibers to keep the thick asphalt films from draining off the aggregate during mixing and handling. LWT results on the SMA mix cores versus the conventional mix cores from a test section on I-85 were very distinguishing. All SMA mixes had rut depths approximately one-half that of the conventional mixes.

CRUMB RUBBER

Georgia has also performed research on crumb rubber mixes versus standard mixes. A test section was placed on I-75 in Henry County that contained 6 percent crumb rubber by weight of the AC. The wet process was used to blend −180-μm (No. 80) mesh rubber with an AC-20 asphalt cement. The crumb rubber designs were more rut resistant as compared with the standard mixes. Laboratory designs showed the crumb rubber to rut one-half as much as the standard mixes −1.37 mm versus 2.64 mm (0.054 in. versus 0.104 in., respectively). Field verification of designs differed slightly for the crumb rubber. The average rut depth for beams fabricated from plant mix was 2.21 mm (0.087 in.) for the rubber and 2.62 mm (0.103 in.) for the standard mix. Average rut depths for beams cut from cores were 2.31 mm (0.091 in.) for the mix containing rubber and 2.41 mm (0.095 in.) for the standard mix.

OTHER RESEARCH

Research studies were conducted in which the LWT was used to compare different mix types and modified mixes that were being evaluated in the field. One such project was on I-75 in Whitfield County, Georgia. A test section was placed on the roadway that contained four polymer-modified asphalt cements. The performance of each section was compared with the standard mix. LWT results indicated that each modified mix would be less susceptible to rutting as compared with a standard mix.

GDOT has also worked with the FHWA to develop and improve the LWT. FHWA was interested in the LWT as a economical

TABLE 5 Effects of Pressure Changes on Rut Depth

Grade of AC	Test Conditions	No. of Cycles Tested	Projected Rut Depth @ 8000 Cycles mm	(in.)
AC-30	40.6°C/689 kPa (105°F/100 PSI)	8000	5.89	(0.232)
AC-30	40.6°C/827 kPa (105°F/120 PSI)	8000	3.33	(0.131)
AC-20	40.6°C/689 kPa (105°F/100 PSI)	8000	4.01	(0.158)
AC-20	40.6°C/827 kPa (105°F/120 PSI)	6580	11.91	(0.469)

proof tester of asphaltic concrete mixes. In order to obtain a thorough unbiased assessment of the machine, the FHWA set aside funding for round-robin testing so that other states could evaluate the LWT.

Six states participated in this evaluation. At the end of the evaluation, a technical working group comprised of these states met in Georgia to discuss their findings.

One of the state agencies involved in this evaluation, the Florida Department of Transportation, compared the LWT with: (*a*) actual field performance, (*b*) gyratory shear, and (*c*) Marshall stability test. The LWT results were comparable with the actual field performance and the gyratory shear.

Overall results from this limited scope round-robin test program showed that reasonable consistency of rut-depth results from the LWT was achieved by each participating laboratory. The within-laboratory repeatability coefficient of variation was 12.7 percent. The between-laboratory variability of rut-depth results was quite high, primarily because of large variation of asphalt beam densities between laboratories.

FHWA has developed an expert task group to evaluate the performance of the LWT as an indicator of rut susceptibility. More research is currently being conducted so that more agencies can participate. Eleven agencies are now involved in this study. The round-robin testing will be conducted in two phases. Phase I of the program will evaluate the applicability of the LWT only, whereas Phase II of the program will evaluate the applicability of the rolling compactor machine together with the LWT.

TRIPLE-TRACK TESTER

GDOT now has a triple-track wheel tester that was built by Georgia Tech. It has the capability of testing three samples simultaneously. GDOT needed a machine with three sample testing capabilities so that production could be increased and more than one sample of a given design could be tested at one time.

Also, the sample size has been increased to 127 mm (5 in.) wide to better accommodate testing of coarse mixtures. It was also felt for a long time that a specimen 76 mm (3 in.) wide may not be adequate for base mixes with 38 mm (1 1/2 in.) or larger nominal top sizes. This machine compared identically with the single-track machine.

CONCLUSIONS

GDOT has been working with the LWT for several years and a lot of time, effort, and confidence has been put into this machine as an indicator of mixture rutting susceptibility.

During this 7-year period, GDOT has found that the LWT has several benefits. The first benefit is that it's a proof tester. Asphalt mix can be evaluated in the laboratory instead of under traffic, which allows pavement performance to be predicted and problem mixes identified before being placed in the field.

Another benefit of the LWT is that it can be used as a supplement to SHRP testing. SHRP Level 1 mix designs have no strength test requirements other than for moisture susceptibility testing, and the LWT may be used to proof test these designs.

Also, SHRP mix design criteria identify a forbidden zone through which mix gradations should not pass. This forbidden, or restrictive, zone needs additional study because it is not applicable in all situations. For example, the handmade gradation that was mentioned earlier passes through this zone, but the LWT showed this type of mix to have a low susceptibility to rutting.

The Georgia LWT is also economically feasible. The single-track machine may be purchased from Benedict Slurry Seal for approximately $11,000, not including compactor. The Georgia triple-track machine is being sold by Georgia Tech at a cost of approximately $35,000, including compactor. The French wheel tracker and compactor costs approximately $200,000.

The LWT can give an indication of the rut susceptibility of a mix for a relatively low cost. It can be used in conjunction with the SHRP mix design specification criteria and as a proof tester will be a good supplement to SHRP Superpave mix designs.

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