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PERFORMANCE TESTING FOR HOT MIX ASPHALT (EXECUTIVE SUMMARY)

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BACKGROUND

The Superpave Mixture Design and Analysis System was developed in the early 1990's under the Strategic Highway Research Program (SHRP). Originally, the Superpave design method for Hot-Mix Asphalt (HMA) mixtures consisted of three proposed phases: 1) materials selection, 2) aggregate blending, and 3) volumetric analysis on specimens compacted using the Superpave Gyratory Compactor (SGC). It was intended to have a fourth step which would provide a method to analyze the mixture properties and to determine performance potential, however this fourth step is not yet available for adoption. Most highway agencies in the United States have now adopted the volumetric mixture design method. However, as indicated, there is no strength test to compliment the Superpave volumetric mixture design method. The traditional Marshall and Hveem mixture design methods had associated strength tests. Even though the Marshall and Hveem stability tests were empirical they did provide some measure of the mix quality. There is much work going on to develop a strength test (for example NCHRP 9-19), however, one has not been finalized for adoption at the time this report was prepared and it will likely be several months to years before one is recommended nationally. Considering that approximately 2 million tons of HMA is placed in the U.S. during a typical construction day, contractors and state agencies must have some means as soon as practical to better evaluate performance potential of HMA. These test methods do not have to be perfect but they should be available in the immediate future for assuring good mix performance.

Research from WesTrack, NCHRP 9-7 (Field Procedures and Equipment to Implement SHRP Asphalt Specifications), and other experimental construction projects have shown that the Superpave volumetric mixture design method alone is not sufficient to ensure reliable mixture performance over a wide range of materials, traffic and climatic conditions. The HMA industry needs a simple performance test to help ensure that a quality product is produced. Controlling volumetric properties alone is not sufficient to ensure good performance.

There are five areas of distress for which guidance is needed: fatigue cracking, rutting, thermal cracking, friction, and moisture susceptibility. All of these distresses can result in loss of performance but rutting is the one distress that is most likely to be a sudden failure as a result of unsatisfactory hot mix asphalt. Other distresses are typically long term failures that show up after a few years of traffic.

Due to the immediate need for some method to evaluate performance potential, the NCAT Board of Directors requested that NCAT provide guidance that could improve mixture analysis procedures. It is anticipated that this guidance can be adopted until something better is developed in the future through projects such as NCHRP 9-19 and others. However, partly as a result of warranty work, the best technology presently available needs to be identified and adopted. This report provides a first step in identifying appropriate tests. It is anticipated that the findings in this report will be renewed on a regular basis to determine if improved guidance is available and needs to be implemented.

OBJECTIVE

The purpose of this project is to evaluate available information on permanent deformation, fatigue cracking, low-temperature cracking, moisture susceptibility, and friction properties, and as appropriate recommend performance test(s) that can be adopted immediately to ensure improved performance. Emphasis is placed on permanent deformation.

SCOPE OF STUDY

The following tasks were conducted to reach the objectives of this project:

Task 1. Conduct a literature search and review the information relevant to the test methods for evaluating the permanent deformation, fatigue cracking, low-temperature cracking, moisture susceptibility, and friction properties of Hot Mix Asphalt pavements.

Task 2. Compare and assess the available tests regarding specific considerations, such as simplicity, test time, cost of equipment, availability of data to support use, published test method, available criteria, and so on.

Task 3. Select test types with most potential to be used to evaluate mixes to estimate performance of HMA; validate these potential test types based on documented studies and evaluate four mixes with known relative performance in the laboratory to determine if the selected test methods show the right trend in permanent deformation performance. Based upon this assessment, recommend performance test(s).

Task 4. Submit a final report that documents the entire effort. The report should provide the HMA mix designers and QC/QA personnel with the best answers at this time about how to analyze permanent deformation, fatigue cracking, low-temperature cracking, moisture susceptibility and friction properties during mix design and QC/QA. The proposed methods should emphasize QC/QA testing where applicable. The focus of the report is on permanent deformation and all other distresses are secondary.

COMPARISON OF METHODS TO EVALUATE PERMANENT DEFORMATION

As illustrated in Task 4, the focus of the report is on permanent deformation. Methods that have been used to evaluate permanent deformation were discussed in detail in the report. The tests that appeared to have some potential for predicting rutting performance were selected for further evaluation with four mixes with known relative performance. The information on the known relative performance was obtained from general knowledge and experience. The crushed granite provides more rut-resistant mixes than uncrushed gravel, and over-asphalt mixes have more rutting potential than mixes with optimum asphalt content. Detailed test results are available in the report.

A summary of the advantages and disadvantages of each of the tests considered for permanent deformation is provided in Table 1.

Table 1. Comparative Assessment of Test Methods

	Test Method	Sample Dimension	Advantages	Disadvantages
Fundamental: Diametral Tests	Diametral Static (creep)	4 in. diameter × 2.5 in. height	• Test is easy to perform • Equipment is generally available in most labs • Specimen is easy to fabricate	• State of stress is nonuniform and strongly dependent on the shape of the specimen • Maybe inappropriate for estimating permanent deformation • High temperature (load) changes in the specimen shape affect the state of stress and the test measurement significantly • Were found to overestimate rutting • For the dynamic test, the equipment is complex
	Diametral Repeated Load	4 in. diameter × 2.5 in. height	• Test is easy to perform • Specimen is easy to fabricate	
	Diametral Dynamic Modulus	4 in. diameter × 2.5 in. height	• Specimen is easy to fabricate • Non destructive test	
	Diametral Strength Test	4 in. diameter × 2.5 in. height	• Test is easy to perform • Equipment is generally available in most labs • Specimen is easy to fabricate • Minimum test time	
Fundamental: Uniaxial Tests	Uniaxial Static (Creep)	4 in. diameter × 8 in. height & others	• Easy to perform • Test equipment is simple and generally available • Wide spread, well known • More technical information	• Ability to predict performance is questionable • Restricted test temperature and load levels does not simulate field conditions • Does not simulate field dynamic phenomena • Difficult to obtain 2:1 ratio specimens in lab
	Uniaxial repeated Load	4 in. diameter × 8 in. height & others	• Better simulates traffic conditions	• Equipment is more complex • Restricted test temperature and load levels does not simulate field conditions • Difficult to obtain 2:1 ratio specimens in lab
	Uniaxial Dynamic Modulus	4 in. diameter × 8 in. height & others	• Non destructive tests	• Equipment is more complex • Difficult to obtain 2:1 ratio specimens in lab
	Uniaxial Strength Test	4 in. diameter × 8 in. height & others	• Easy to perform • Test equipment is simple and generally available • Minimum test time	• Questionable ability to predict permanent deformation

(continued) Table 1. Comparative Assessment of Test Methods

	Test Method	Sample Dimension	Advantages	Disadvantages
Fundamental: Triaxial Tests	Triaxial Static (creep confined)	4 in. diameter × 8 in. height & others	• Relatively simple test and equipment • Test temperature and load levels better simulate field conditions than unconfined • Potentially inexpensive	• Requires a triaxial chamber • Confinement increases complexity of the test
	Triaxial Repeated Load	4 in. diameter × 8 in. height & others	• Test temperature and load levels better simulate field conditions than unconfined • Better expresses traffic conditions • Can accommodate varied specimen sizes • Criteria available	• Equipment is relatively complex and expensive • Requires a triaxial chamber
	Triaxial Dynamic Modulus	4 in. diameter × 8 in. height & others	• Provides necessary input for structural analysis • Non destructive test	• At high temperature it is a complex test system (small deformation measurement sensitivity is needed at high temperature) • Some possible minor problem due to stud, LVDT arrangement. • Equipment is more complex and expensive • Requires a triaxial chamber
	Triaxial Strength	4 or 6 in. diameter × 8 in. height & others	• Relative simple test and equipment • Minimum test time	• Ability to predict permanent deformation is questionable • Requires a triaxial chamber

(continued) Table 1. Comparative Assessment of Test Methods

	Test Method	Sample Dimension	Advantages	Disadvantages
Fundamental: Shear Tests	SST Frequency Sweep Test – Shear Dynamic Modulus	6 in. diameter × 2 in. height	• The applied shear strain simulate the effect of road traffic • AASHTO standardized procedure available • Specimen is prepared with SGC samples • Master curve could be drawn from different temperatures and frequencies • Non destructive test	• Equipment is extremely expensive and rarely available • Test is complex and difficult to run, usually need special training • SGC samples need to be cut and glued before testing
	SST Repeated Shear at Constant Height	6 in. diameter × 2 in. height	• The applied shear strains simulate the effect of road traffic • AASHTO procedure available • Specimen available from SGC samples	• Equipment is extremely expensive and rarely available • Test is complex and difficult to run, usually need special training • SGC samples need to be cut and glued before testing • High COV of test results • More than three replicates are needed
	Triaxial Shear Strength Test	6 in. diameter × 2 in. height	Short test time	• Much less used • Confined specimen requirements add complexity
Empirical Tests	Marshall Test	4 in. diameter × 2.5 in. height or 6 in. diameter × 3.75 in. height	• Wide spread, well known, standardized for mix design • Test procedure standardized • Easiest to implement and short test time • Equipment available in all labs.	• Not able to correctly rank mixes for permanent deformation • Little data to indicate it is related to performance
	Hveem Test	4 in. diameter × 2.5 in. height	• Developed with a good basic philosophy • Short test time • Triaxial load applied	• Not used as widely as Marshall in the past • California kneading compacter needed • Not able to correctly rank mixes for permanent deformation
	GTM	Loose HMA	• Simulate the action of rollers during construction • Parameters are generated during compaction • Criteria available	• Equipment not widely available • Not able to correctly rank mixes for permanent deformation
	Lateral Pressure Indicator	Loose HMA	• Test during compaction	• Problems to interpret test results • Not much data available

(continued) Table 1. Comparative Assessment of Test Methods

	Test Method	Sample Dimension	Advantages	Disadvantages
Simulative Tests	Asphalt Pavement Analyzer	Cylindrical 6 in. × 3.5 or 4.5 in. or beam	• Simulates field traffic and temperature conditions •Modified and improved from GLWT • Simple to perform • 3-6 samples can be tested at the same time • Most widely used LWT in the US • Guidelines (criteria) are available • Cylindrical specimens use SGC	• Relatively expensive except for new table top version
	Hamburg Wheel-Tracking Device	10.2 in. × 12.6 in. × 1.6 in.	• Widely used in Germany • Capable of evaluating moisture-induced damage • 2 samples tested at same time	• Less potential to be accepted widely in the United States
	French Rutting Tester	7.1 in. × 19.7 in. × 0.8 to 3.9 in.	• Successfully used in France • Two HMA slabs can be tested at one time	• Not widely available in U.S.
	PURWheel	11.4 in. × 12.2 in.× 1.3, 2, 3 in.	• Specimen can be from field as well as lab-prepared	• Linear compactor needed • Not widely available
	Model Mobile Load Simulator	47 in. × 9.5 in.× thickness	• Specimen is scaled to full-scaled load simulator	• Extra materials needed • Not suitable for routine use • Standard for lab specimen fabrication needs to be developed
	RLWT	6 in. diameter × 4.5 in. height	• Use SGC sample • Some relationship with APA rut depth	• Not widely used in the United States • Very little data available
	Wessex Device	6 in. diameter × 4.5 in. height	• Two specimens could be tested at one time • Use SGC samples	• Not widely used or well known • Very little data available

The tests that were evaluated in this study can be classified as one of six types of tests. These general test types include: 1) Diametral tests, 2) Uniaxial tests, 3) Triaxial tests, 4) Shear tests, 5) Empirical tests, and 6) Simulative tests. The results of the analysis and discussion on all of these tests are provided below.

The diametral tests involved creep, repeated load permanent deformation, dynamic modulus, and strength test. The diametral test does not appear to be a suitable test for evaluating permanent deformation. This is a tensile type test that is likely to be more affected by changes in binder properties than one would expect to see in the field. Since this is a tensile test it is not reasonable that it would be a good predictor of rutting. The cost of equipment to conduct the diametral tests is relatively low when repeated loading is not required. If repeated loading is required then the cost is considerably higher and the difficulty of the testing is increased. Little performance data is available to show that any diametral tests are useful in predicting rutting. Data is available to indicate that there is a trend between this type of test and performance but other test methods are more suitable. Tests conducted as a part of this study show that these tests don't measure up to the reasonableness test. Laboratory tests show that the indirect tensile strength test results and the repeated load tests do not match the expected performance. While these tests may have some applicability in indicating performance, other tests are more likely to be successful. These tests should not be considered for immediate adoption.

A second type of test that can potentially be used to predict performance is the uniaxial test. The four types of test that were considered were creep, repeated load permanent deformation, dynamic modulus, and strength test. One of the biggest problems with this type of test is its questionable ability to predict performance because of the amount of load and temperature that can be used for testing. It is believed that the temperature and stress applied in the laboratory should be similar to that which the mixes are actually subjected to in the field. The load and/or temperature must be decreased significantly from that expected in the field, otherwise these tests cannot be conducted without immediate failure of the samples. The test is simple and inexpensive to conduct when using static loads, however, the complexity and cost increase considerably when dynamic loads are required. There is little information available for these tests that correlate test results to performance. Due to the lack of performance information, none of these tests are recommended for immediate adoption to predict permanent deformation, however some of these tests are being studied in NCHRP 9-19 and may prove to be acceptable when this study is completed.

A third type of test that was considered is the triaxial test. The difference between this series of tests and the uniaxial tests discussed above is that the triaxial tests include confining pressure. Applying a confining pressure allows one to more closely duplicate the in-place pressure and temperature without prematurely failing the test sample. There is some rutting information available for the confined creep and repeated load tests. There is less information available for the dynamic modulus and strength tests. These traxial tests are complicated somewhat by the requirement for a triaxial cell but this does not preclude the use of this test. The confined creep and repeated load tests have been used and do have some potential in predicting rutting. Both of these tests are being studied in NCHRP 9-19 and may be considered for use in the future. The confined creep test is simple and easy, but the correlation with rutting is not very good. It has been recognized widely that the confined repeated load deformation test is better correlated with performance but more difficult to conduct. At this time these tests are not recommended for immediate adoption. At the conclusion of NCHRP 9-19, sufficient data will be available to adopt one or more of these tests if appropriate and to provide details concerning test procedures.

A fourth type of test that was considered was shear test including the Superpave shear test (SST). The SST test is very complicated, expensive and does not presently have an acceptable model to predict performance. This test is not reasonable for QC testing. At this time none of the SST tests are finalized sufficiently for immediate adoption.

A fifth series of tests that were considered were empirical including Marshall stability and flow, Hveem stability, GTM, and lateral pressure indicator. Marshall and Hveem tests had been used for years with very limited success. The GTM has had limited use for many years. It does have some potential but sufficient information is not available for immediate adoption. The lateral pressure indicator (LPI) is a new test that does show some promise but more research is needed. It requires very little additional effort and very little cost. However, more work is needed to show that the LPI is related to performance. None of these tests should be selected for use at the present time.

The final series of tests involve simulative tests which primarily include wheel tracking tests. The Asphalt Pavement Analyzer (APA), Hamburg Wheel-Tracking Device (HWTD), and French Rutting Tester (FRT) appear to provide reasonable results and do have some data correlating with performance. Although the wheel tracking tests are not mechanistic they do seem to simulate what happens in the field. Mechanistic tests are being studied by others (NCHRP 9-19) and may be available for adoption in the near future. It is also interesting to point out that most tests that have been evaluated for their ability to predict performance have actually been compared to one of these wheel-tracking devices since they do simulate rutting in the laboratory. Based on all available information it is recommended that the APA, HWTD, and FRT be considered for use in mix design and QC/QA. Sufficient data is available to set criteria and this is provided later in the recommendations. The simulative tests (wheel tracking tests) appear to be the only type of test that is ready for immediate adoption. These tests are not the final answer but they can serve the industry until a better answer is available.

RECOMMENDED PROCEDURES TO EVALUATE AND OPTIMIZE PERFORMANCE

Predicting performance of HMA is very difficult due to the complexity of HMA, the complexity of the underlying unbound layers and varying environmental conditions. Presently, there are no specific methods being used nationally to design and control HMA to control rutting, fatigue cracking, low-temperature cracking, and friction properties. There are moisture susceptibility tests that are being used nationally but these tests are not very effective. Some additional guidance is needed to minimize the occurrence of these distresses.

This report is not meant to be taken as a final document on performance. It is really just a starting point. In fact the recommendations in this report will continue to be evaluated along with new research findings to improve the existing recommendations. There are several studies underway, that should be completed in the near future, to develop additional tests to predict performance. When these improved tests are developed then the guidance provided in this report may be superseded regarding the additional guidance be provided. However, until better tests and methods of analysis are available the guidance discussed below is available, as a starting point, to help provide some indication of performance. Specific guidance is only provided for permanent deformation. The authors believed that this guidance is the best available at this time.

Permanent Deformation

Permanent deformation is probably the most important performance property to be controlled during mix design and QC/QA. Permanent deformation problems usually show up early in the mix life and typically result in the need for major repair whereas other distresses take much longer to develop. Several tests were considered for measuring rutting potential. Tests that appear ready for immediate adoption include the following three wheel tracking tests: Asphalt Pavement Analyzer (APA), Hamburg Wheel-Tracking Device (HWTD), and French Rutting Tester (FRT). Several factors were used to select these tests: availability of equipment, cost, test time, applicability for QC/QA, performance data, criteria, and ease of use.

The tests and criteria shown in Table 2 are recommended for immediate use however some experience with local materials is recommended before adoption. The tests are listed in priority order.

Table 2. Recommended Tests and Criteria for Permanent Deformation

Performance Tests		Recommended Criteria		Test Temperatures
1st choice	Asphalt Pavement Analyzer (APA) (See Appendix A)	8 mm	@ 8,000 wheel load cycles	high temperature for selecting PG grade
2nd choice	Hamburg Wheel-Tracking Device (HWTD) (See Appendix B)	10 mm	@ 20,000 wheel passes	50°C
3rd choice	French Rutting Tester (FRT) (See Appendix C)	10 mm	@ 30,000 wheel load cycles	60°C

The tests are listed in order of priority for recommended use. The information shown in Table 2 is based on limited field results and specific methods of conducting the tests in the laboratory. Any change in test method will likely result in a needed change in criteria. These recommended criteria are developed in general for higher traffic so they are not necessarily applicable for lower traffic areas.

Before adopting the criteria, tests should be conducted with local materials and mixes to develop an understanding of what type of results to expect. The criteria provided are reasonable based on past test results for specific mixes that have been evaluated in the past but may need to be modified slightly based on local experience. There is more experience with wheel tracking tests than with any other type of test to predict rutting. Other tests such as creep and repeated load tests have promise but more work is needed to finalize details before this type of test is utilized for mix control (research is underway to do this).

One recommended approach is to use the APA with cylinders compacted in the Superpave Gyratory Compactor. Samples compacted for volumetric testing could be tested thus minimizing number of samples required. This will allow QC/QA tests to be quickly conducted without requiring additional compacted specimens. Related information on the recommended performance tests for permanent deformation is provided in appendices A, B, and C.

Fatigue Cracking

There has been much research done on the effects of HMA properties on fatigue. Certainly the HMA properties have an effect on fatigue but the most important factor to help control fatigue is to ensure that the pavement is structurally sound. Since the classical bottom-up fatigue is controlled primarily by the pavement structure there is no way that a mix test can be used alone to accurately predict fatigue. However steps can be taken to minimize fatigue problems. Some of these steps include: use as much asphalt in the mix as allowable without rutting problems, select the proper grade of asphalt, do not overheat the asphalt during construction, keep the filler to asphalt ratio lower, compact the mix to a relatively low void level, etc. This is general guidance but this is the approach that is generally used to ensure good fatigue resistance. A more definitive way to control fatigue is needed but is not presently available.

Thermal Cracking

Thermal cracking is a problem in colder climate and guidance is needed to minimize this problem. At the present time the best guidance to minimize thermal cracking is to select the proper low temperature grade of the PG asphalt binder for the project location. Other steps during construction can be helpful. For example do not overheat the asphalt. This will result in stiffening of the binder and will therefore encourage thermal cracking. It is also important to compact the HMA to a relatively low air void level to minimize any future oxidation. At this time there is no specific test to be recommended for thermal cracking but in the future better guidance should be available.

Moisture Susceptibility

Moisture susceptibility is typically a problem that can cause the asphalt binder to strip from the aggregate leading to raveling and disintegration of the mixture. AASHTO T-283 has been used for several years to help control stripping. This test does not appear to be a very accurate indicator of stripping but it does help to minimize the problem. The Hamburg test has also been shown to identify mixes that tend to strip.

There are things during the construction process that can help to minimize stripping potential. Of course liquid and lime anti strip agents can be used. Other items include good compaction and complete drying of aggregate.

Friction Properties

Friction is one of the most important properties of an HMA mixture. There are good methods to measure the in-place friction but there are not good methods to evaluate mixes in the lab for friction. Several state DOTs have methods that they use but these have not been adopted nationally. More work is needed to evaluate these local procedures for national adoption.

There are several things that can be done in design and construction to improve friction. The primary concern is friction during wet weather. Use of a mix such as open-graded friction course (OGFC) has been shown to be effective in increasing friction in wet weather. Other methods that can be used are to use aggregate that does not tend to polish, use mixes that are not over asphalted, use crushed aggregates etc. Coarse textured mixes such as SMA have been shown to provide good friction in wet weather. At the present time past experience with local materials is the best information available for providing good friction.

Appendix A: Asphalt Pavement Analyzer

Equipment: Asphalt Pavement Analyzer

Manufacturer: Pavement Technology Inc.

Costs: approximately $ 75,000-$100,000 for the full size equipment. The simplified "Table-Top Rut Tester" is approximately $25,000-$50,000 (this cost does not include beam compactor but Superpave Gyratory Compactor can be used to compact cylinders)

Test Procedure Reference: proposed ASTM standard

Test Time: 2 hrs 15mins (8,000 cycles @ 1 cycle/second)

Table 3. Description of Available Criteria for APA

Criteria	Test Condition				
	Hose Pressure	Load	Specimen Size (mm)	Load Cycles	Temperature
8 mm	100 psi	100 lb	115 × 150 Cylinder and 300 × 125 × 75 Beam	8,000	High temperature for selecting PG grade

Note: When conducting a test, be aware that the performance criteria listed above was established for a specific set of conditions. If tests are conducted at different conditions, new criteria may need to be established otherwise this could lead to inaccurate pass/fail values. This test procedure is presently being used by several state DOTs to control mix quality.

Recommended specimen size in this report: cylinders using standard compactive effort as provided in Superpave criteria. When using beams the beams should be compacted to 5 percent air voids.

Appendix B: Hamburg Wheel-Tracking Device

Equipment: Hamburg Wheel-Tracking Device

Manufacturer: Helmut-Wind Inc. Hamburg, Germany

Costs: approximately $50,000-$75,000 (this cost does not include beam compactor but Superpave Gyratory Compactor can be used to compact cylinders)

Test Procedure Reference: there is not a national test procedure

Test Time: 6 hrs 18 mins (20,000 wheel passes @ 53±2 wheel passes/min) or until 20 mm (0.8 in) of deformation occurs

Table 4. Description of Available Criteria for HWTD

Criteria	Test Condition				
	Wheel	Load	Specimen Size (mm)	Wheel Passes	Temperature
10 mm	Steel, 204 mm diameter. 47 mm wide	154 lb	320 × 260 × 80 Beam, 115 × 150 Cylinder	20,000	Wet, 50°C

Note: When conducting a test, be aware that the performance criteria listed above was established for a specific set of conditions. If tests are conducted at different conditions, new criteria may need to be established otherwise this could lead to inaccurate pass/fail values.

Several newly developed devices based on the design of Hamburg Wheel-Tracking Device (Wessex Engineering, Evaluator of Rutting and Stripping in Asphalt) can accommodate both beam and cylindrical samples. This device is used on a limited basis to help evaluate mix quality but has not been widely used.

Recommended specimen size in this report: cylinders using standard compactive effort as provided in Superpave criteria.

Appendix C: French Rutting Tester

Equipment: French Rutting Tester

Manufacturer: Laboratoire Central des Ponts et Chaussées (LCPC), France

Costs: approximately $75,000-$100,000 (this cost does not include compactor).

Test Procedure Reference: there is not a national test procedure

Test Time: 8 hrs (30,000 cycles @ 67 cycles/min)

Table 5. Description of Available Criteria for FRT

Criteria	Test Condition				
	Wheel	Load	Specimen Size (mm)	Cycles	Temperature
10 mm	Pneumatic (600 kPa) 400 mm diameter, 90 mm wide	1124 lb (5000 N)	500 × 180 × 100	30,000	Dry, 60°C

Note: When conducting a test, be aware that the performance criteria listed above was established for a specific set of conditions. If tests are conducted at different conditions, new criteria may need to be established otherwise this could lead to inaccurate pass/fail values. This device has very limited use in the US.

Recommended specimen size in this report: 500 mm × 180 mm × 100 mm

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