
# Quality Characteristics and Test Methods for Use in Performance-Related Specifications of Hot Mix Asphalt Pavements

**DETAILS**

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properties of the as-designed and in-place HMA. Thus, the key questions are (1) what quality characteristics of the HMA or the pavement should be measured to best predict the future performance of the pavement and, (2) what are the most appropriate methods for their measurement once these quality characteristics are identified?

Ideally, the test methods employed in measuring quality characteristics should be rapid, reliable, and relatively inexpensive. The importance of rapid measurement of the quality characteristic cannot be overemphasized. A primary focus of a contractor in meeting the "bottom line" is to be able to quickly determine when the production and construction processes begin to go out of control. Inability to identify these problems and to make adjustments quickly increases the possibility that large quantities of material will be produced and placed that do not meet specification requirements. When this situation occurs, the specifying agency might penalize the contractor and even require the removal of the unacceptable material at a significant cost to the contractor.

NCHRP Project 9-15 was tasked with identifying HMA quality characteristics and associated test methods that could be conducted quickly and efficiently to assist in the prediction of HMA pavement performance and the identification of unacceptable mixtures.

## SUMMARY OF THE WORK PLAN

The goal of Phase I of the project was to identify which quality characteristics and test methods were most applicable and appropriate for use with PRS. The research team conducted a critical review of the literature and personal interviews with key researchers and organizations to assess the results of completed and ongoing PRS development and related research projects. It evaluated a wide range of available construction-related quality characteristics (and related test methods) with the potential to affect the long-term performance of in-place HMA pavements as well as those quality characteristics thought to influence pavement performance through the compositional, volumetric, and fundamental engineering properties of as-produced HMA.

The research team recommended the following quality characteristics for further study in Phase II of the project:

- Segregation
- Initial Ride Quality
- Lift Thickness
- Asphalt Content/Effective Asphalt Content
- In-Place Pavement Density
- Aggregate Gradation
- Asphalt Binder Viscosity
- Longitudinal Join Air Voids
- Permeability k-Value
- Low Temperature Tensile Strength
- In-Place Stiffness
- Fracture Temperature
- Dynamic Modulus

Based on the resources available, the NCHRP project panel directed the research team to concentrate in Phase II on the evaluation of five quality characteristics, namely, segregation; initial ride quality, or smoothness; in-place pavement density; air voids content, or density, at longitudinal joints; and permeability.

In the Phase II field experiment, the selected quality characteristics were measured with candidate test methods to

1. Estimate the reliability of the test measurements;
2. Identify and quantify the restrictions or limitations, if any, of the method;
3. Determine flaws that were not apparent from the Phase I review;
4. Validate the feasibility of each test method in terms of its use in a PRS;
5. Establish preliminary specification criteria and threshold values for the test methods; and
6. Estimate the number and frequency of the required measurements required and their use within a PRS.

## FIELD EXPERIMENT AND DATA ANALYSIS

Table 1 presents the quality characteristics, field equipment, and test parameters evaluated in the Phase II field experiment; the objective of the field experiment was to gather and statistically analyze real-time test data for each of these quality characteristics.

Table 2 presents information on the four HMA construction projects used in the Phase II field experiment.

A three-part analysis of the data from the field experiment was conducted. The first part was the evaluation and comparison of the quality characteristics

**Table 1** Quality characteristics, field equipment, and test parameters examined in Phase II of NCHRP Project 9-15

| Quality Characteristic | Field Equipment | Test Parameter |
|---|---|---|
| Segregation | ROad Surface ANalyzer (ROSAN) | Estimated Texture Depth (ETD) |
| Initial Smoothness | Lightweight Profiler (LWP) | International Roughness Index (IRI) |
| In-place mat density | Pavement Quality Indicator (PQI) | Density |
| Longitudinal joint density | PQI | Density |
| In-place permeability | NCAT[1] Field Permeameter | K-value |

[1]National Center for Asphalt Technology (NCAT).

from different types of equipment that measure the same property (e.g., the nuclear density gauge [NDG] and the PQI). The second part was the more detailed evaluation as to the primary operating conditions of each device, noting the successes and failures in measuring the quality characteristics for use in PRS. The last part of the data analysis was the variability analysis associated with setting the initial specification criteria and threshold values.

## FINDINGS

On the basis of the test results obtained during the field experiments, supplemented by information obtained from the literature review, surveys, and personal interviews conducted in Phase I, initial specification limits were developed for each selected quality characteristic. In addition to the recommended specification values, the reported variability from the field projects indicates the capability of the test device to provide measurements within the specification limits.

In developing these recommended specification criteria, consideration was given to the ability of producers and contractors to perform the production, mixing, and laydown operations within the levels defined by the specification. In addition, the specification levels also assume that appropriate performance levels are achieved. However, further validation of these performance levels must be completed in the future using long-term performance data from more extensive field experiments.

Detailed information on the results of the field experiment and their analysis can be found in the full final report for Project 9-15, available for loan on request to NCHRP.

### Segregation

The development of surface texture ratios for various levels of segregation using the ROSAN unit is described in *NCHRP Report 441, Segregation in Hot-Mix Asphalt Pavements.* The ratios shown in Table 3 are the specification values presented in *NCHRP Report 441*. These values were further validated by comparison with ratios reported by the Ontario Ministry of Transportation. This comparison showed that the segregation levels reported in the two studies were very similar.

The average surface texture ratios for the field projects in Colorado and Illinois were as follows:

| | | |
|---|---|---|
| Colorado | 12.5 mm (0.5 in.) | None < 1.1 |
| | | Low = 1.27 |

**Table 2** Phase II field projects

| State | Route | Testing Dates | HMA NMAS | Field Equipment |
|---|---|---|---|---|
| Maryland | US 220 | August 21–25, 2000 | 12.5 | PQI[1] |
| Washington | US 395 | September 25–29, 2000 | 19.0 | PQI, Field Permeameter, LWP |
| Colorado | US 50 | August 20–24, 2001 | 12.5 | PQI, Field Permeameter, LWP, ROSAN |
| Illinois | SR 336 | September 24–28, 2001 | 12.5 | PQI, LWP, ROSAN |
| | | | 19.0 | PQI, Field Permeameter, LWP, ROSAN |

[1]Testing on all field projects was conducted with a PQI model 300.

**Table 3** Initial specification criteria and thresholds for segregation as measured by the ROSAN

| Segregation Level | Surface Texture Ratio |
|---|---|
| None | <1.16 |
| Low | 1.16 to 1.56 |
| Medium | 1.57 to 2.09 |
| High | >2.09 |

| | | |
|---|---|---|
| Illinois | 19.0 mm (0.75 in.) | None < 1.1<br>Low = 1.29<br>Medium = 1.64<br>High = 2.14 |
| Illinois | 12.5 mm (0.5 in.) | None < 1.15<br>Low = 1.23 |

As shown, these values fall in line with the ratios suggested as specification criteria in *NCHRP Report 441*. The variability of the ROSAN device determined from the field project results indicates that its coefficient of variation (COV), shown in Table 4 at each level of segregation, can be more than 20% using at least 3 passes.

## Ride Quality

A survey of ride quality specifications from Texas, Pennsylvania, and Indiana, all of which utilize IRI as a pay item, suggests that the specification values shown in Table 5 are applicable to HMA pavements. The values in this table were derived by reviewing pay schedules from several state specifications and determining the point at which maximum payment occurred, the range in which incentives were applied, the point (or range) where 100% payment occurred, the range in which disincentives were applied, and the point at which rejection occurred. It is recommended that these values be applied to newly constructed, reconstructed, or thick overlay asphalt concrete pavements. In addition, these specification values are also recommended for high-traffic or high-speed facilities like Interstate roadways, primary arterials, or other highway routes; low-traffic or lower-speed facilities, which account for many HMA pavements, may require very different specification criteria.

**Table 4** Reported COV for the ETD measured by the ROSAN device

| | COV, %, by level of segregation | | | |
|---|---|---|---|---|
| Project | None | Low | Med | High |
| CO | 16.6 | 17.7 | — | — |
| IL 19.0 | 9.1 | 11.8 | 21.8 | 23.3 |
| IL 12.5 | 55.3 | 19.3 | — | — |
| Average | 27.0 | 16.3 | 21.8 | 23.3 |

*Note:* Cells with a dash indicate that the projects evaluated had no medium or high segregation.

**Table 5** Initial specification criteria and thresholds for ride quality as measured by the LWP device

| Ride Quality | IRI (in./mi) |
|---|---|
| Very Good | <40 |
| Good | 40 to 60 |
| Fair | 60 to 80 |
| Poor | 80 to 100 |
| Very Poor | >100 |

From the analysis conducted using the data collected from the field projects in Colorado and Illinois, an average COV of approximately 15% over a range of smoothness values from 1.58 m/km (100 in./mi) to 0.63 m/km (40 in./mi) was determined for measurements made with the lightweight profilometer.

## In-Place Pavement Density

There is significant information currently available regarding the important effect that in-place density (or air voids content) has on the performance of HMA pavements. Whether the in-place density is specified as a percent of laboratory, control strip, or maximum theoretical density, it is well known and documented that density that is either too high or too low will lead to pavement failure. Here, the maximum theoretical density (which is the unit weight of the mix with no air voids) will be used as the basis of the specification criteria. The in-place pavement density as a percent of maximum theoretical density (MTD) is calculated as the ratio of the in-place density to the maximum theoretical density as shown:

$$\text{Percent of MTD} = \frac{\text{In-Place Density}}{\text{Maximum Theoretical Density}} \times 100 \quad (1)$$

Many studies have shown that the initial in-place voids should be no more than approximately 8% and that the in-place voids should never fall below approximately 3% during the life of the pavement. High voids lead to permeability to water and air, resulting in water damage, oxidation, raveling, and cracking. Low voids lead to rutting and shoving of the HMA. In addition, a review of several state DOT specifications has shown that in-place densities, measured as a percent of maximum theoretical density, range between 91 and 98% (with many falling between 92 and 97%), confirming the previous statement.

The results from the field projects conducted as part of NCHRP Project 9-15 showed that the variation between the PQI, NDG, and core measurements were statistically the same. These results are only applicable to dense-graded HMA mixtures. Some studies have reached different conclusions; but, within the confines of this project, it has been demonstrated that the expected variability among the three different measurement methods is similar, even if the measured means are not equal in all cases. The average standard deviations shown in Table 6 for the cores, NDQ, and PQI are within the limits of other studies conducted and are considered applicable to newly constructed dense-graded HMA pavement layers with NMAS between 9.5 mm (0.38 in.) and 37.5 mm (1.5 in.). However, further validation is warranted. In addition, it is important to limit the amount of surface and underlying moisture within the pavement system when using the PQI Model 300 to prevent the results of the device from being unduly affected. Within this study, measurements taken with moisture readings from the gauge greater than or equal to 15% were considered unreliable. Other studies have suggested that measured moisture levels above 5% are unreliable, but results in this study indicate that this value is too conservative.

In developing a test method for the PQI that can be used in a PRS, the PQI should be correlated to the actual in-place density using the most reliable method available. To date this is typically done by measuring the bulk density of extracted cores. Some bulk density methods have problems with high air voids or highly absorptive mixtures; therefore, special care is required when dealing with these types of mixtures. This normally includes the use of paraffin to coat the specimen, but there are known difficulties with this method. One measurement method that has shown promise in achieving more accurate bulk densities of high voids or absorptive mixes is the use of vacuum-sealed plastic bags over the core. A device called the CoreLok has been used successfully when dealing with high voids or highly absorptive mixtures and is recommended as an alternative to paraffin coating.

The specification criteria shown in Table 7 for the PQI were developed using the variation statistics mentioned above and threshold values for unacceptable mixtures established through the review of several state acceptance specifications, as well as research studies conducted by many organizations.

## Longitudinal Joint Density

Several studies have been completed over the years that have evaluated the differences in density in and around the longitudinal construction joint and the pavement mat (typically at the center of the travel lane). A method that has been utilized to compare joint and mat densities across different mixture types, joint construction techniques, cross slopes, and compaction methods is the percentage of relative density method. The percent relative density is computed as shown below:

$$\%\ Relative\ Density = \frac{Joint\ Density}{Pavement\ Density} \times 100 \qquad (2)$$

**Table 6** Average standard deviations for in-place density as measured by the PQI, nuclear gauge, and cores as determined from the field projects

| | Standard Deviation, g/cm³ (lb/ft³) | | | COV, % | | |
|---|---|---|---|---|---|---|
| State | PQI | Nuclear | Core | PQI | Nuclear | Core |
| MD | 0.03 (1.88) | 0.06 (3.99) | 0.03 (2.14) | 1.36 | 2.90 | 1.55 |
| WA | 0.01 (0.93) | 0.03 (2.01) | 0.03 (1.88) | 0.64 | 1.40 | 1.28 |
| CO | 0.02 (1.30) | 0.02 (1.56) | 0.02 (1.23) | 0.91 | 1.09 | 0.86 |
| IL | 0.02 (1.07) | 0.02 (1.50) | 0.02 (1.53) | 0.71 | 1.02 | 1.04 |
| Avg. | 0.02 (1.30) | 0.04 (2.27) | 0.03 (1.69) | 0.90 | 1.60 | 1.18 |

**Table 7** Initial specification criteria and thresholds for in-place density as measured by the PQI device

| In-Place Density | %MTD |
|---|---|
| Good | 93.2 to 95.8 |
| Fair | 92 to 93.2, 95.8 to 97 |
| Poor | < 92 or > 97 |

**Table 8** Initial specification criteria and thresholds for the longitudinal joint density as measured by the PQI device

| Joint Density | Relative Density, % |
|---|---|
| Good | >97 |
| Fair | 93 to 97 |
| Poor | <93 |

For the four field projects in this study, the average percent relative density and standard deviation for the measurements taken directly on top of the surface longitudinal joint and within the pavement mat for each of the measurement methods was determined to be as follows:

| | | Avg. | Std. Dev. |
|---|---|---|---|
| PQI | = | 97.4% | 1.15% |
| Nuclear | = | 91.5% | 3.97% |
| Cores | = | 95.5% | 2.31% |

The standard practice on each project was to calibrate each device to the same set of cores. At no time were the PQI and nuclear gauges calibrated to each other.

Studies completed by the National Center for Asphalt Technology (NCAT) and state DOTs and for the FAA indicate that performance of longitudinal construction joints is a function of both compacted joint density and the joint construction technique. In addition, the density measurement method has been shown to influence both the measured mean and associated variability, causing the different measurement methods (primarily nuclear gauges and cores) to provide statistically different results. At the four field projects conducted within this research project, more than half of the instances have computed means that were statistically different between the PQI, the nuclear gauge, and the cores. However, in fewer than half of the instances, the computed variability between the measurement methods was statistically different.

To develop appropriate specification limits and threshold values, some information regarding long-term joint performance in relation to joint density should be known. However, at the present time there is not much information available to relate long-term joint performance with variation in compaction level. There is some data available that relates joint construction technique with joint performance in terms of longitudinal cracking and raveling around the joint, and this information can be used to infer applicable compaction levels for the joint if the measurement method is either through the use of cores or the nuclear density gauge. There is no long-term data relating joint performance with compaction measured by the PQI. Therefore, the recommendations for specification criteria are made assuming that the measured mean values from the cores and PQI are similar (although not necessarily the same statistically).

The known variability in measuring joint density with the PQI must also be a part of the specification criteria. The four field projects show that the standard deviation of the relative density may range from just over 1% to nearly 4% depending on the measurement method. Data from other sources indicate that the standard deviation of the percent relative density may range from approximately 0.7% to 2.9% for core and NDG measurements.

Table 8 provides the recommended specification criteria for longitudinal joint density using the relative density as determined from the PQI.

## Permeability

In recent years a few state DOTs have measured the permeability of HMA in the laboratory to provide an indication of how well the pavement will resist aging and oxidation from water and air. In-situ measurements using the NCAT permeability device have shown it to be an effective tool for obtaining rapid, accurate measurements of permeability outside of a laboratory setting. Data from three of the four field projects for which the NCAT device was available and studies conducted by NCAT throughout the United States have demonstrated that the device is capable of obtaining results over a wide range of permeabilities and air void levels.

## CONCLUSIONS

Five quality characteristics for HMA pavements have been identified that are candidates for use in a PRS. They are segregation, ride quality, in-place density, longitudinal construction joint density, and in-place permeability. These quality characteristics were selected because of their importance in determining the overall performance of HMA pavements.

Test methods for measuring each of these quality characteristics and initial specification criteria and threshold values were recommended for use in a PRS and are presented in Appendix C of the final report for Project 9-15. The specification criteria and threshold values are based upon data collected in Project 9-15 and on information gained from other sources. Further and continued validation of these specification criteria is critical, as is further refinement of the test methods.

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