TechBrief

The Asphalt Pavement Technology Program is an integrated national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement suggestions, methods, procedures, and other tools for use in asphalt pavement materials selection, mixture design, testing, construction, and quality control.

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Density Demonstration Projects and Related Specifications

This Technical Brief introduces the FHWA Enhancing Durability of Asphalt Pavements Through Increased In-Place Density Demonstration Project and a series of Technical Briefs Associated with the outcomes of it. Specifically, key overall observations and related specification examples are presented in this Technical Brief.

Introduction

This is the first of four planned Technical Briefs on ***Enhancing Durability of Asphalt Pavements Through Increased In-Place Density*** associated with the Federal Highway Administration (FHWA) Accelerated Implementation and Deployment of Pavement Technologies (AID-PT) program. The AID-PT program advances best practices and technologies for constructing and maintaining high-quality, long-lasting pavements in accordance with six goals established by Congress (1). The overall objective of the demonstration project was to show that additional density could be obtained through improved techniques. This set of Tech Briefs focuses on the importance of mat and joint density, techniques and tools that have been demonstrated to help improve density, examples of specifications, and overcoming obstacles to achieving density. The information used to develop them was obtained through review of the technical literature identified in references in this document, a series of workshops and support of 29 field demonstration projects performed by State Departments of Transportation (DOTs). This is one of a planned series of the four Technical Briefs meant to complement each other that are organized as follows:

1. Density Demonstration Projects and Related Specifications
2. Techniques and Tools for Improving Density
3. Overcoming Obstacles to Achieving Density
4. Improving Longitudinal Joint Performance

Although several factors can influence the performance of an asphalt pavement, one of the most important factors is in-place density (2). A small in-place density increase can potentially lead to a significant increase in the service life of asphalt pavements. Based on studies reviewed in the literature, a 1 percent increase in density (percent of G_{mm}) was estimated to improve the fatigue performance of asphalt pavements between 8 and 44 percent and improve rutting resistance by 7 to 66 percent (4, 5). In addition, based on field data, a 1 percent increase in density would conservatively extend the asphalt pavement service life by 10 percent.

To illustrate the effect of in-place density on the life cycle cost analysis (LCCA) of asphalt pavements, a LCCA was conducted on two alternatives in which the same asphalt overlay would be constructed to 93 percent and 92 percent (densities) of the maximum theoretical gravity (G_{mm}) (3). Using the conservative 10 percent increase in service life described above, the LCCA results revealed that a State DOT would see a net present value cost savings of $88,000 on a $1 million paving project (8.8 percent) by increasing the minimum density criteria by 1 percent of G_{mm}. This calculation does not include savings from operation, maintenance, and road user costs.

A literature search identified practices and new technologies that can help achieve higher densities. These included mixture-design factors, field-compaction techniques, longitudinal joints and tack coats, measurement and payment, and the use of warm-mix asphalt (WMA) additives (5). There have been significant advancements in pavement design technology and techniques as well as construction equipment and real-time operations feedback. These advancements may increase asphalt pavement density and increase both durability and cost effectiveness. Many of these advancements are already being employed; however, in many cases standards for in-place density have remained unchanged. Some circumstances may allow for use of increased in-place density targets using existing practices. Thus, desired mixture durability and pavement service life can be achieved with enhanced density targets.

While increased density can improve performance, it cannot overcome all issues. For example, improvements to in-place density cannot overcome performance issues with asphalt mixtures constructed with high levels of segregation, moisture susceptible mixtures, or unacceptable volumetric properties. Increased density will not have the same benefit in those situations.

FHWA Density Demonstration Project

Recognizing the importance of in-place density in building cost effective asphalt pavements, FHWA initiated a demonstration project for "Enhanced Durability of Asphalt Pavements through Increased In-place Pavement Density." It was done in three phases over four years (4, 5, 6). The objective of this demonstration project was to support DOTs in their evaluation of their existing density requirements for acceptance. It was anticipated that the results might assist DOTs in reviewing and updating, as needed, their current field density acceptance criteria.

Each participating DOT was provided with an Enhanced Durability through Increased In-Place Pavement Density Workshop. The target audience was the DOT, contractors, equipment suppliers, and academia. The workshops included the use of existing practices as well as "new" materials and technologies. A total of 29 workshops were delivered with over 1,800 attendees at locations shown in Figure 1. Project funding of $50,000 was provided to each DOT. It was suggested that there be a minimum 2-inch overlay structurally designed for a minimum of 10 years. It was suggested that the minimum length be 4,000 feet (or approximately 5,000 tons). Construction was to include a control section, built by the contractor to the target in place density based on routine construction practices to meet the State's specifications, and at least one test section using improved paving and compaction techniques to increase density (increased density based on 1 to 2 percent above the control section).

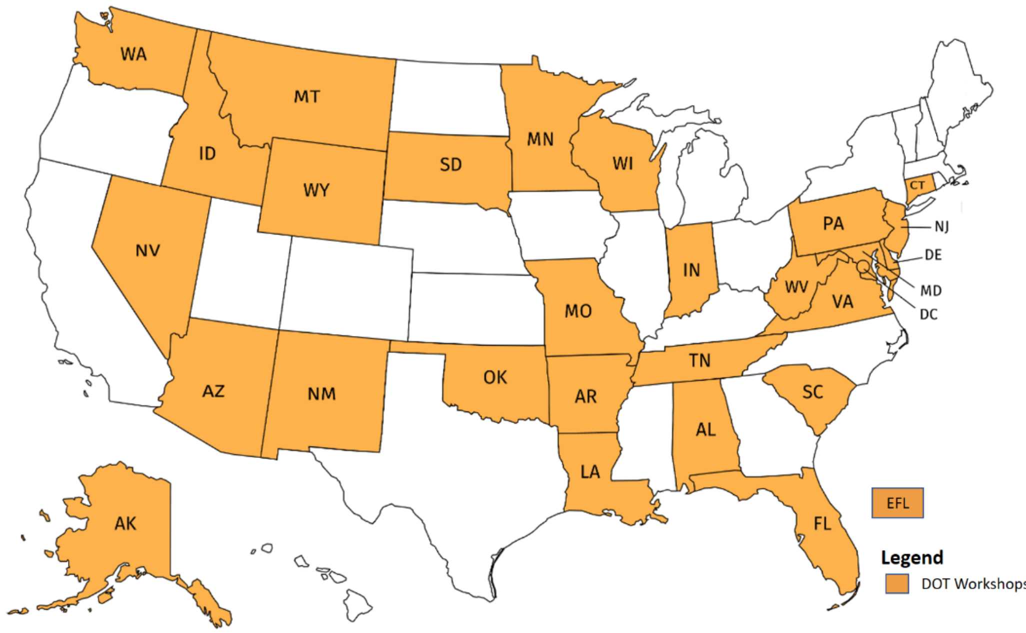

Figure 1. Map of DOT Workshop Locations.

Contractors were encouraged to use techniques that did not involve additional rollers or a higher asphalt content (AC), which would result in significantly increased cost. Increased rolling was supposed to be the only additional compactive effort on the test sections (not additional rollers). DOTs were encouraged to identify an additional test section that used enhanced compaction techniques. DOTs were to conduct their normal testing and frequency to measure density. This included methods for the in-place (or bulk) density and reference density. It was suggested that the in-place densities be based on cores or be referenced to cores for the control and test sections. It was also suggested that the frequency be sufficient to calculate the standard deviation of the relative densities for each section.

The field demonstration projects were intended to support DOTs in evaluating their current density requirements for acceptance. The demonstration projects would allow DOTs to partner with contractors to try techniques that would work best for their situation and allow FHWA to share these success stories with others. The FHWA would use the results from the overall demonstration project to provide information for DOTs to review, update, and improve their field density acceptance criteria for asphalt pavements.

Demonstration Projects

Demonstration projects were constructed in three phases from 2016 to 2018. Some construction projects experienced delays and were constructed in 2019. Twenty-nine demonstration projects were constructed. Three DOTs participated in two phases for a total of 26 unique DOTs. The participating DOTs are shown on the map in Figure 2 by Phase.

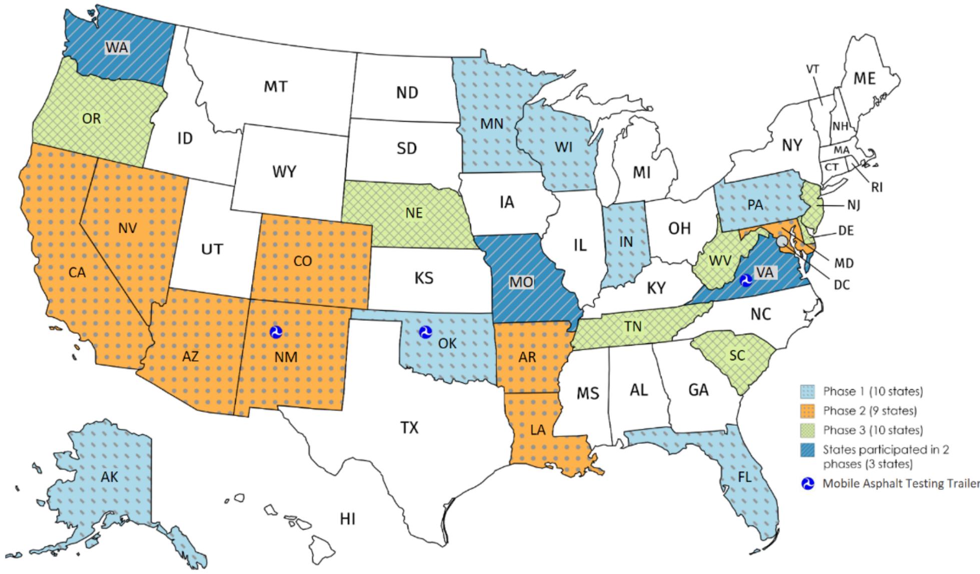

Figure 2. Map of Density Demonstration Project State Locations.

Table 1 shows the demonstration projects summary statistics including 121 experimental sections comprised of 35 control sections and 86 test sections. Control sections were intended to represent what the DOT normally did. The test sections were intended for the DOT and contractor to try other methods to increase density. On some demonstration projects, DOTs constructed more than one control section to examine different techniques. One example was using a conventional paver on one control section and then a spray paver on a second control section. Each of the control sections included three similar test sections to evaluate different compaction techniques. On average, there were 4.2 experimental sections constructed per demonstration project.

Table 1. Summary of the Number of Projects and Experimental Sections.

Statistics	Number
DOTs	26
Demonstration Projects	29
Control Sections	35
Test Sections	86
Experimental Sections	121

There were many variables including mixture type, construction equipment, and procedures between States and within States, making it very difficult to compare the density results between various pavement sections. The number of variables that were intentionally changed within a State was much less than the number of changes between States. This was expected, as it was a demonstration project and not a formal experiment. As a demonstration project, each State (the contractor and agency) was empowered to focus on changes to improve density that they thought would be most beneficial for their situation. So, it was much easier to compare the changes made within a State to show the effect of these changes on in-place density.

Metrics were compiled related to the increase in density (at least 1.0 percent) from the control section and the average density (at least 94.0 percent) in at least one test section. Table 2 summarized the metrics. The number of demonstration projects with at least 1.0 percent increase in density, or that averaged at least 94.0 percent in at least one test section was 24 of 29. As time has passed, 24 of the 26 DOTs have made changes or are in the process of making changes to their density specifications.

Table 2. Metrics from Demonstration Projects.

Description	Demonstration Projects
Increased Density ≥ 1.0% from the Control Section	17 of 29
Test Section Achieved ≥ 94%	23 of 29
Increased Density ≥ 1% from the Control Section OR Test Section Achieved ≥ 94.0%	24 of 29

Examples of Density Specifications

Based on a literature review and a review of State DOT specifications, examples of density specifications were identified.

Literature Review

Aschenbrener and Tran conducted a literature review in "Optimizing In-place Density Through Improved Density Operations" for the Transportation Research Record: Journal of the Transportation Research Board and found a "consensus in research conducted using various evaluation techniques that the minimum in-place density of an asphalt mixture should be 92.0%, and 93.0–94.0% would be preferred after construction" (7). In particular, they observed:[1]

> Linden et al. showed correlations between density and pavement service life using three separate sources of information: the literature on the subject, a questionnaire survey of 48 SHAs on compaction practices, and pavement performance data in the Washington State Department of Transportation pavement management system [(8)]. They concluded that a 1% decrease in density tended to produce about a 10% loss in pavement life when the density level was below 93.0% of the theoretical maximum specific gravity (G_{mm}). . . . Mallela et al. developed a correlation between pavement service life and in-place density [(9)]. The service life of asphalt pavements analyzed was significantly affected when the in-place density was below 93.0%.
>
> Another way to approach the appropriate density requirements is to consider the critical air void level above which voids become larger and connected, allowing water to enter pavements and causing other issues, such as water damage and oxidation. Terrel and Al-Swailmi suggested that asphalt mixtures were relatively impermeable when the in-place density was above 92.0% [(10)]. However, the relationship between in-place density and permeability can be greatly influenced by other factors, such as nominal maximum aggregate size (NMAS) and the relative coarseness or fineness of the gradation. Thus, the minimum in-place density could vary based on the NMAS [(11, 12)].
>
> Other researchers had other ways to approach the appropriate density requirements. Based on historical data, Hughes suggested that realistic target values for density should have an average percent density of 93.0 and a standard deviation of 1.5 for use by agencies that started using end-result specifications with density measurements in the late 1980s [(14)]. In addition, the Asphalt Institute reported that a target density less than 92.0% was considered inadequate [(2)], and Brown et al. suggested that the initial in-place voids for dense-graded asphalt mixtures should not be less than approximately 92.0% to minimize water permeability and binder aging [(13)]. Finally, based on a survey of SHAs, Decker reported that 89% of the respondents had minimum requirements on in-place

[1] The citations within the quoted text have been altered to match the citation numbers in the References section of this document.

density ranging from 91.0 to 93.0%, with 58% of the respondents specifying 92.0% [(15)]. In addition, approximately 77% of the respondents indicated that maximum requirements were between 97.0 and 98.0%, with 58% specifying 97.0%.

Based on the above literature review, research conducted using various evaluation techniques indicates that the minimum in-place density of an asphalt mixture should be 92.0 percent, and preferably 93.0 to 94.0 percent after construction (2, 4, 12, 13, 14, 15, 16). Of course, this will vary based on the NMAS because minimum in-place density recommended for various NMAS gradations increases as NMAS decreases (11, 12, 13). A maximum permeability of 0.00150 centimeters per second has been used to establish minimum in-place density levels for mixtures regardless of NMAS and relative coarseness or fineness of gradation (13).

Example State DOT Specifications

Density acceptance test results were analyzed from DOTs across the country to determine the state of practice for achieving in-place density. The results were used to identify DOTs with in-place density specifications that minimized the amount of test results below the 92.0 percent threshold as discussed in the literature review. The following 12 DOTs were determined to have minimized the amount of test results below the 92% threshold based on a majority of their prior tests coming back above that threshold.

DOTs using lot average specifications included:

- Maryland Department of Transportation State Highway Administration (MDOT SHA)
- Montana Department of Transportation (MDT)
- Tennessee Department of Transportation (TDOT)

DOTs using percent-within limit (PWL) specifications included:

- Alaska Department of Transportation and Public Facilities (ADOT&PF)
- Indiana Department of Transportation (INDOT)
- Maine Department of Transportation (Maine DOT)
- Michigan Department of Transportation (MDOT)
- Missouri Department of Transportation (MoDOT)
- New Jersey Department of Transportation (NJDOT)
- New York State Department of Transportation (NYSDOT)
- Pennsylvania Department of Transportation (PennDOT)
- Puerto Rico Highway and Transportation Authority (PRHTA)

All but two of the DOTs use only agency density test results for acceptance as shown in Figure 4. MoDOT and MDOT SHA use contractor test results validated by the DOT.

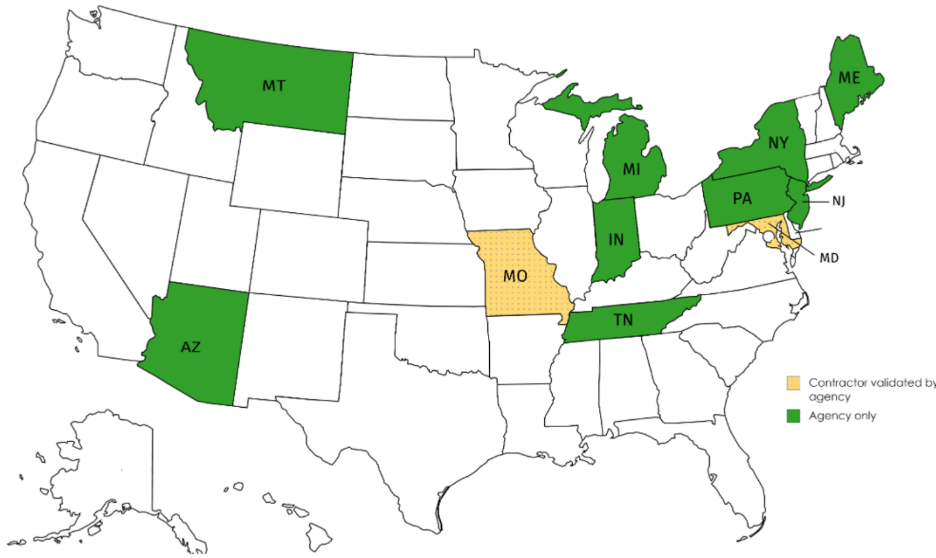

Figure 4. Entities Performing Acceptance Tests.

For comparison purposes, a thirteenth agency referred to as "Example State" was included in this analysis in addition to the twelve DOTs identified above. Density test results from Example State were lower than those from the twelve agencies identified.

DOTs typically have more than one in-place density specification applicable to various types of asphalt mixtures, highways, or projects. The most stringent density specification for each DOT was analyzed, and the information associated with its use in specific projects is summarized in Table 3. Each of the twelve DOTs used its data management system, oftentimes electronic, to collect density results from all the acceptance tests on a project. Additionally, data for one or more construction seasons were provided by the DOTs for this analysis, as shown in Table 4. Thus, for each set of data, the average and standard deviation were calculated for each lot and then the results from each lot were averaged and presented for each DOT. The average density among all DOTs examined is 94.3 percent and the average standard deviation is 1.25 percent. The results were then compared with the 92.0 percent of G_{mm} threshold identified in the literature review. Figure 5 summarizes the percentage of density test results less than 92.0 percent of G_{mm} for each DOT. For the nine DOTs with less than 6.0 percent of their density test results below the 92.0 percent threshold, their average percent density ranged from 93.7 to 94.9.

For each DOT, a histogram like Figure 6 was developed. The histogram shown in Figure 6 is for density data provided by Maine DOT. It shows the variation in percent density results from multiple projects within the period from 2013 to 2017. The distribution of percent density results is shown along with the percentage of results below the 92.0 percent threshold. As shown in Figure 6, there were only 5.8 percent of the density test results below 92.0 percent. This was an example of positive density test results when compared to the 92.0 percent threshold. For comparison, Figure 7 shows a histogram of density test results for Example State during 2016. While the average of 92.6 percent was above the 92.0 percent threshold, more than 25 percent of the density test results were below the threshold. The average, standard deviation and percentage of data points below the 92.0 percent threshold for each data set are shown in Table 4.

Table 3. Project Information and Time Period for Density Data.

DOTs	Year of Data	Mix Type	Type of Projects	Acceptance Testing
Example State	2016	Type C	N/A	Agency only
MDOT SHA	2017	Dense Graded	N/A	Contractor validated by agency
MDT	2007 to 2018	9.5, 12.5 and 19mm	All projects	Agency only
TDOT	2015 to 2017	D-mix (3/8" NMAS)	Interstate and SR Freeways	Agency only
ADOT&PF	2015	Type II 19mm & Superpave 12.5mm	Interstate and principal arterial	Agency only
INDOT	2018	Superpave5	All projects with 9.5 and 19-mm mixes	Agency only
Maine DOT	2013 to 2017	9.5, 12.5 and 19mm	All mainline projects	Agency only
MDOT	2015	9.5, 12.5 and 19mm	All projects greater than 5,000 tons	Agency only
MoDOT	2018	4.75, 9.5, 19 and 25mm	All projects greater than 5,000 tons	Contractor validated by agency
NJDOT	2018	4.75, 9.5, 19 and 25mm	All projects	Agency only
NYSDOT	2015	Series 50 9.5, 12.5 and 19mm	Full or partially controlled roadways	Agency only
PennDOT	2017	High level wearing surface 9.5, 12.5 & 19mm	N/A	Agency only
PRHTA	2017-2019	Superpave	All projects	Agency only

N/A: Not Available

Table 4. Percent Density Specifications and Results from Projects.

DOT	Quality Measure	Limits (Percent G_{mm})	Incentive for Only Density	Max. Incentive (Percent G_{mm})	Avg. (Percent G_{mm})	Std. Dev. of Lots	Less than 92 Percent G_{mm}
Example State	Lot Avg.	91.5 to 95.0	1.50%	92.8	92.6	N/A	25.3%
MDOT SHA	Lot Avg. & Ind. Sublot	92.0 to 97.0	5.00%	94.0	94.0	1.03	5.3%
MDT	Lot Avg. & Range	93.0 to 100.0	8.00%	94.0 to 95.0	94.3	N/A	6.6%
TDOT	Lot Avg.	92.0 to 97.0	2.00%	94.0	93.9	N/A	11.0%
ADOT&PF	PWL	93.0 to 100.0	5.00%	≈ 96.0	94.9	1.76	5.6%
INDOT	PWL	93.0 to 100.0	1.75%	N/A	93.9	N/A	8.4%
Maine DOT	PWL	92.5 to 97.5	2.50%	≈ 93.5	94.5	1.20	5.8%
MDOT	PWL	92.5 to 100.0	2.00%	≈94.5	94.4	1.03	5.5%
MoDOT	PWL	92.0 to 97.0	1.25%	≈ 94.5	93.7	N/A	5.0%
NJDOT	PD	92.0 to 98.0	4.0%	N/A	94.9	N/A	5.4%
NYSDOT	PWL	92.0 to 97.0	5.00%	≈ 94.0	94.2	1.01	5.0%
PennDOT	PWL	92.0 to 98.0	2.00%	≈ 94.0	94.4	1.46	3.1%
PRHTA	PWL	92.0 to 99.0	2.50%	≈ 94.0	94.6	N/A	3.6%

N/A: Not Available

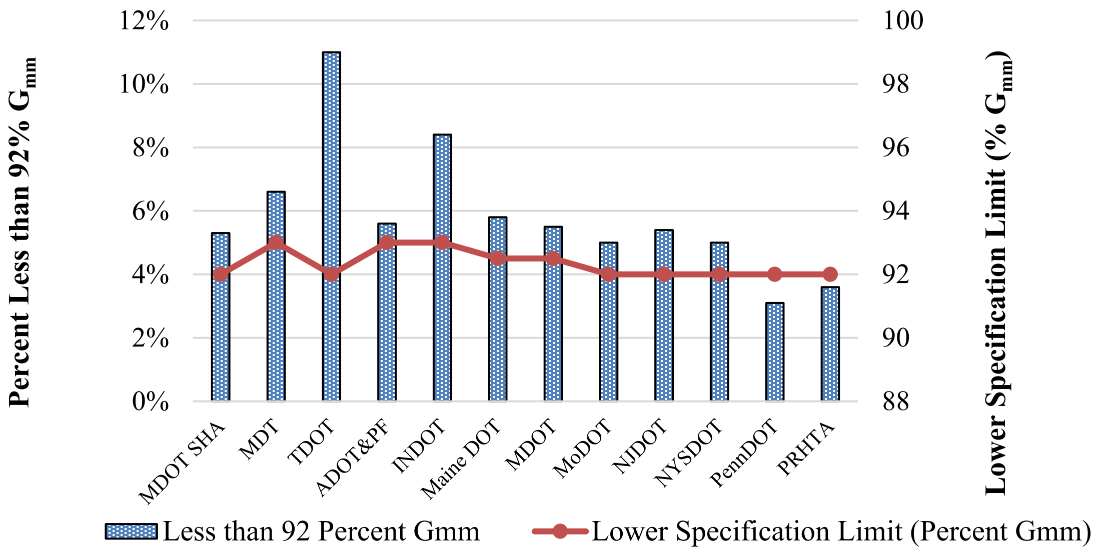

Figure 5. Percent of Tests Less Than 92 Percent.

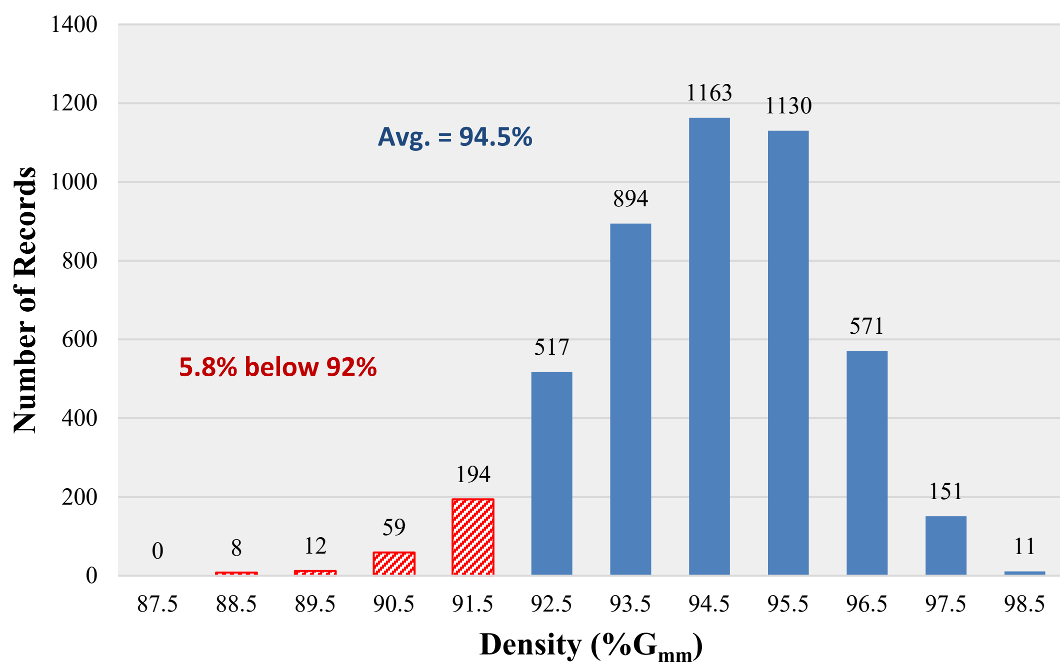

Figure 6. Histogram of Percent Density Results from Maine DOT (2013-2017).

To determine how the 12 DOTs achieved the field density test results observed, their in-place density specifications were reviewed. The density specifications for each DOT and a summary of the project results analyzed for the selected period of the data are shown in Table 4. The following observations are based on the information shown in Table 4:

- Nine DOTs (AKDOT&PF, INDOT, Maine DOT, MDOT, MoDOT, NJDOT, NYSDOT, PennDOT, and PRHTA) used a percent within limits (PWL) or percent defective (PD) specification with a lower limit ranging from 92.0 to 93.0 percent. Only 3.1 to 8.4 percent of the density test results were below the 92.0 percent threshold.

- Three DOTs (MDOT SHA, MDT and TDOT) used a minimum lot average specification with a minimum requirement of 92.0 percent. Each of these DOTs also included an incentive to the contractor. The density test results below the 92.0 percent threshold ranged from 5.3 to 11.0 percent.
- Two of the DOTs which used a minimum lot average specification had an additional requirement. MDOT SHA included a minimum individual sublot requirement of 92.0 percent while MDT included a range requirement. These additional requirements helped minimize the density test results that were below the 92.0 percent threshold. Their results were similar to those of the nine States using the PWL/PD specifications discussed above.
- All twelve DOTs use incentives for the density quality characteristic alone ranging from 1.25 to 8.0 percent.

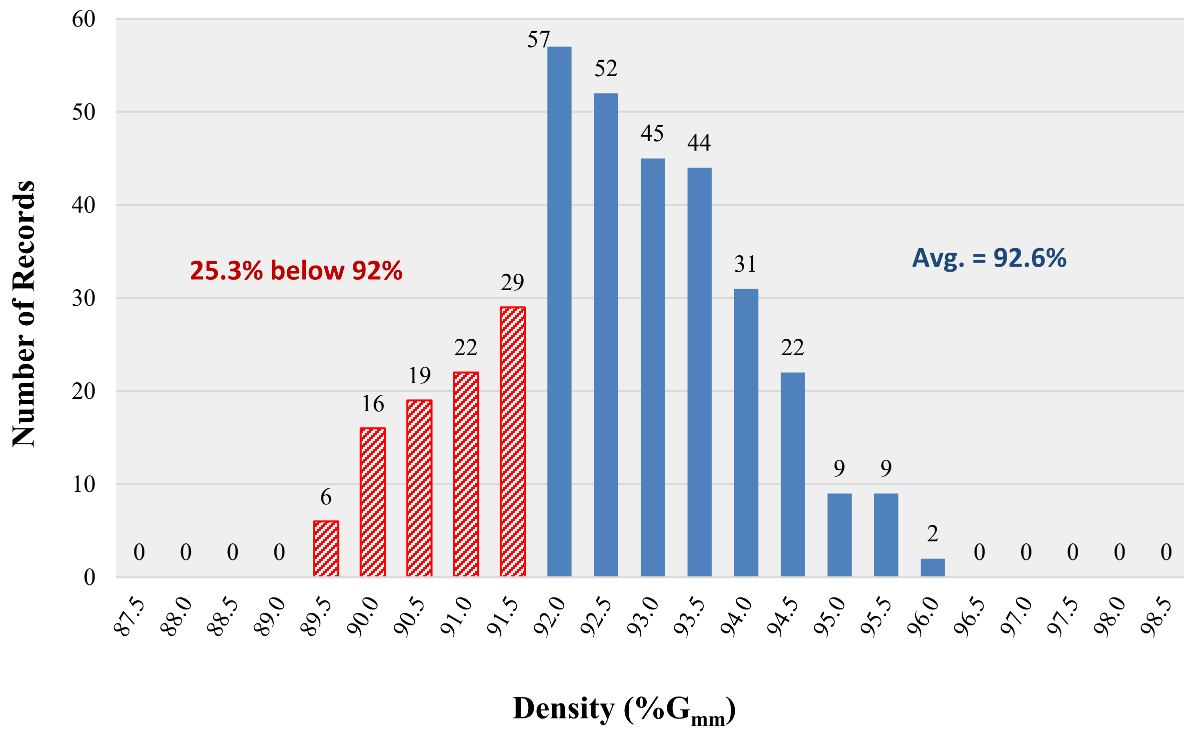

Figure 7. Histogram of Percent Density Results from Example State (2016).

Figure 8 shows the quality measures used by the DOTs. Similar information for Example State was also provided in Table 4 for comparison. Figure 9 shows a comparison of the DOT and Example State upper specification limits, lower specification limits, and average density (percent G_{mm}).

Example State had a minimum lot average specification with a lower limit of 91.5 percent. This resulted in a statewide average of 92.6 percent, with over 25 percent of density test results below the 92.0 percent threshold. The maximum incentive was achieved at 92.75 percent, which was lower than those in the other twelve State. Further analysis of the density test results for Example State showed that over 40 percent of the percent density results were below 92.4 percent, suggesting contractors would “roll until it meets” the specification requirements, which is not surprising as the specification allowed this with incentive. If a State is interested in improving its density specification, examples of changes that could increase density test results are discussed in the following section.

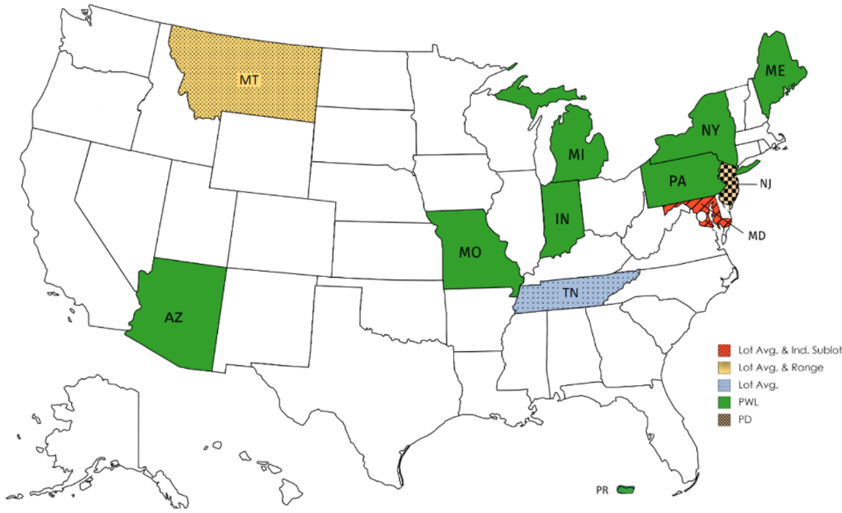

Figure 8. Quality Measures Used by DOTs.

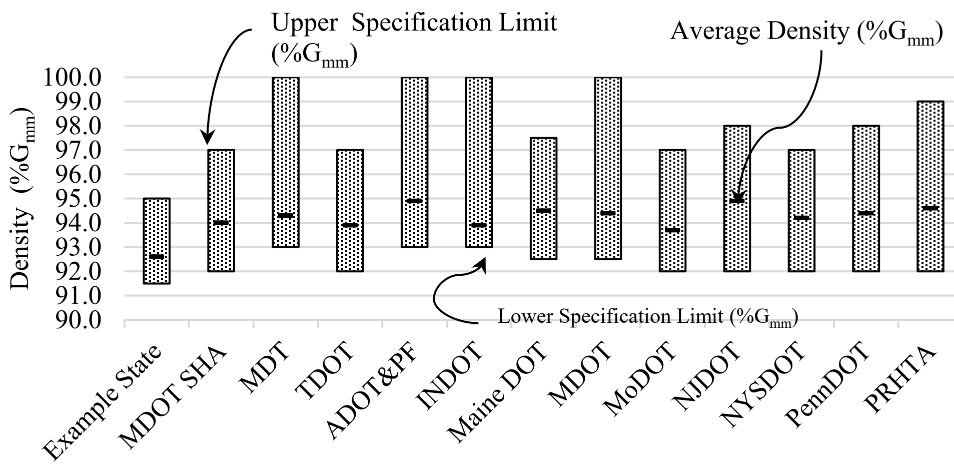

Figure 9. Comparison of Specification Limits and Average Densities.

Several State DOTs constructed multiple test sections to evaluate potential changes to their density specifications to improve overall in-place density test results. During Phase 2 of the FHWA Demonstration Project, State 1 was used as a case study because of its success with in-place density (6). This State had a PWL density specification with a lower limit of 91.0 percent. Density test results from over 9,300 cores taken from projects constructed during the 2017 construction season revealed that the statewide average in-place density was 93.2 percent and 20.0 percent of the results were below the 92.0 percent threshold.

For the density demonstration project sponsored by FHWA, State 1 used a PWL specification with a lower specification limit of 92.0 percent for the entire project, which is 1.0 percent higher than its standard lower specification limit. Density test results from over 1,100 cores were collected. Only 5.7 percent of density test results were below the 92.0 percent threshold, which is a significant improvement observed when the lower specification limit was increased by 1.0 percent, from 91.0 to 92.0 percent. To achieve these results, the contractor increased the number of rolling passes by approximately 20 percent, compared to those typically used in the 2017 construction projects, and followed uniform rolling patterns. Additionally, the aggregate crushing and handling process was improved, and warm mix asphalt was used to extend the paving season by approximately eight weeks.

Considerations for Improved Specifications

Additional information on the density specifications is shown in Table 5. A minimum of seven sublots per lot is encouraged to balance buyer and seller risk. The most common frequency of density testing was every 250 to 500 tons. All of the DOTs used cores, and they all used G_{mm} values from plant-produced material obtained within the lot as the basis to calculate percent density.

Table 5. Additional Percent Density Specification Information.

DOT	Lot Size (tons)	Sublots per Lot	Frequency (tons)	Measuring G_{mb}	Measuring G_{mm}
Example State	2,000	8	250	6-in. cores: 1 per sublot	Avg. of 5 tests: Every 500 tons
MDOT SHA	Day's production	5 min.	500 max.	4 or 6-in. cores	2 per sublot
MDT	3,000	5	600	4 or 6-in cores	2 per sublot
TDOT	1,000	5	200	4 or 6-in. cores: 1 per sublot	Daily Avg.: 2 tests per day
ADOT&PF	5,000	10	500	6-in. cores: 1 per sublot	Ind. test: 1 per lot
INDOT	600/1,000	5	120/200	6-in. cores	1 per sublot
Maine DOT	4,500	5 min.	750 mix 250 density	6-in. cores: 1 per sublot	Ind. test: 1 per sublot
MDOT	5,000	5	1000	6-in. cores: 1 per sublot	Ind. test: 1 per sublot
MoDOT	4,000 min.	4	1000 min.	4-in. cores	Ind. test: 1 per sublot
NJDOT	Day's production	5	Varies	6-in. cores	5 per lot
NYSDOT	1,000	4	250	6-in cores: 1 per sublot	Ind. test: 1 per lot
PennDOT	2,500	5	500	6-in cores: 1 per sublot	Ind. test: Daily value
PRHTA	1,600	4	400	6-in cores: 2 per sublot	Individual test: 1 per sublot

Most DOTs using PWL for determining density pay factors use a PWL of 90 percent to earn a pay factor of 1.0 or 100 percent payment. PWL is influenced by:

- Average lot density.
- Density standard deviation.
- Specification limit(s).

When States use PWL specifications the combination of average and standard deviation influence payment. Table 6 and Figure 10 illustrate how specification limits and density standard deviation affect the average density needed to get a PWL of 90 percent using the AASHTO pay equation. In this example the lower density specification limit is 92.0 percent and there is not an upper specification limit. The density standard deviation is 1.25 percent. Figure 6 shows that the average density needed is 94.0 percent. If a compaction operation were more consistent and a standard deviation of 0.75 were achieved the averaged density needed would only be 93.0 percent. If the DOT were to increase its minimum specification limit from 92.0 to 93.0, then the average density needed with a standard deviation of 1.25 would be 94.6 percent. Similarly, if a compaction operation were more consistent and a standard deviation of 0.75 were achieved, the average density needed would only be 93.6 percent.

Table 6. Lot Average Density Needed for PWL of 90 Percent.

Lower Specification Limit (% G_{mm})	Target PWL (%)	Standard Deviation	Average Density Needed (% G_{mm})
92.0	90	0.75	93.0
92.0	90	1.00	93.2
92.0	90	1.25	93.6
92.5	90	0.75	93.5
92.5	90	1.00	93.8
92.5	90	1.25	94.1
93.0	90	0.75	94.0
93.0	90	1.00	94.3
93.0	90	1.25	94.6

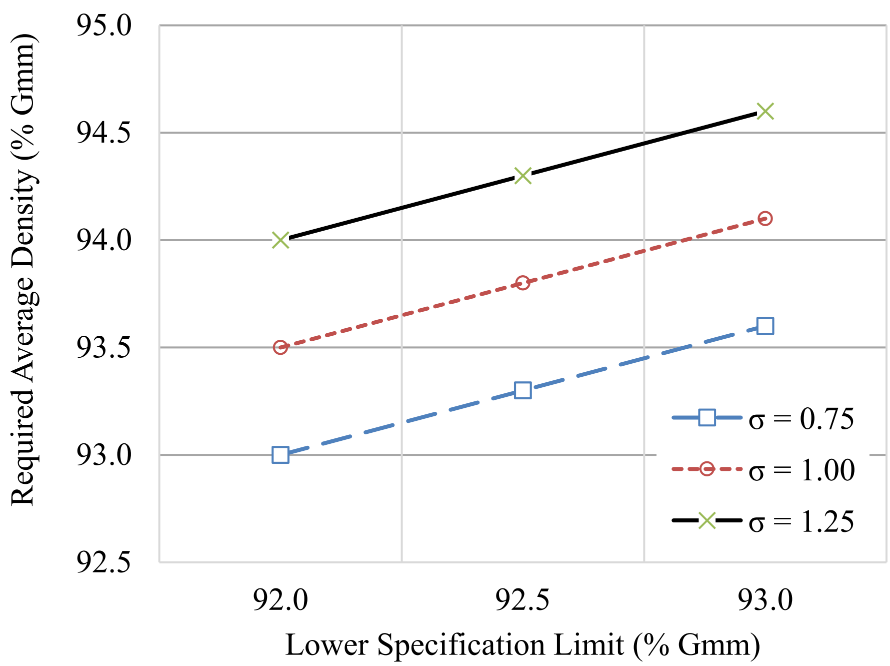

Figure 10. Density Needed for Different Specification Limits and Density Variability.

Summary

In-place density of a dense-graded asphalt mixture is one of the most important construction measures that affects performance throughout its service life. A review of the technical literature suggests that the minimum in-place density of an asphalt mixture should be 92.0 percent, as field density below this critical level could have a detrimental effect on the long-term performance of the mixture (2, 4, 12, 13, 14, 15,16). Thus, one of the practices for improving overall performance of asphalt pavements may include minimizing the in-place density test results that fall below the 92.0 percent threshold.

Twelve DOTs identified thus far have adopted in-place density specifications that minimize the number of test results below the 92.0 percent threshold for their construction projects. The density test results below the threshold in these States ranged from 3.1 to 11.0 percent. For comparison, density test results from a thirteenth DOT, referred to as Example State, were also presented, and more than 25 percent of the test results were found to be below the 92.0 percent threshold.

The State DOT specifications for in-place density in the 12 States play an important role in achieving these results. Nine of these DOTs have a PWL or PD specification. Three DOTs are using a minimum lot average specification, and two also have a minimum individual sublot or range requirement. Financial incentive for achieving in place density were included in all of the specifications, and some of these specifications also include requirements for longitudinal joint density. Another attribute identified in these State DOT specifications included a minimum of seven sublots per lot to balance buyer and seller risk. The most common frequency of density testing was every 250 to 500 tons. All the DOT specifications used cores, and they all used G_{mm} values from plant-produced material obtained within the lot as the basis for density.

For DOTs that are interested in changing their pavement density specifications, lessons learned from this effort suggested that density test results could be significantly improved with appropriate State specifications. The case study presented showed that the density test results below the 92.0 percent threshold for State 1 in Phase 2 of the FHWA Demonstration Project decreased from 20.0 percent to only 5.7 percent when the lower PWL specification limit was increased from 91.0 to 92.0 percent.

References

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Density Demonstration Projects and Related Specifications

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