Density of Asphalt Pavements: How to Specify and Measure to Ensure Pavement Performance

NCHRP 20-07/Task 382
by
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In-Place Density is the single most important property of the asphalt mixture in the pavement.
NCHRP Study Objectives

- Collect information on current practices
- Evaluate how density is measured and specified

Through
- Literature Search
- Technical Survey
Report Topics

- General Issues in Density of Asphalt Pavements
- Specification Types for Control of Density
- Density Measurements Techniques
- Construction Parameters Affecting Density
- Longitudinal Joint Construction
- Emerging Technologies in Determination of In-Place Density
Pavement Life

- 10 percent decrease in pavement life for each 1 percent increase in air voids
  - Multiple researchers have confirmed
Cost and Performance

- Cost of Aggregate and Binder are significantly higher than cost of compaction

BUT

- Effect of achieving density is equal in importance to aggregate and binder in terms of pavement performance.
Definitions

- **Density** – weight per unit volume
- **Compaction** – process of increasing density of mix through paving and rolling operations
- **Reference Density** – value to which in-place density is compared
- **Percent Density** – percentage of reference density achieved during compaction process
Project Survey

- State DOT
  - Materials
  - Construction
- NAPA Membership
- State Asphalt Pavement Associations
- Ministries of Transport Canada
- International Pavement Associations

100 Responses (50 DOT’s plus DCDOT)
General Issues in Density of Asphalt Pavements
Factors Affecting Density

- Materials
- Initial Density
- Traffic
Factors Affecting Density

- Materials
  - Asphalt Binder
    - Temperature Susceptibility
    - Rheology
  - Aggregate
    - Surface Texture
    - Shape
    - Maximum Size
    - Gradation
    - Absorption
## Factors Affecting Density

- **Initial Density (Construction)**

  - Subgrade Support
  - Lift Thickness
  - Equipment
  - Rolling Sequence
  - Rolling Procedures
  - Base Temperature

- **Moisture**
- **Wind Velocity**
- **Ambient Temperature**
- **Pavement Temperature**
- **Time of Year**
Factors Affecting Density

- Traffic
  - Vehicle Weight and Type
  - Axle Configuration
  - Lane Distribution
  - Daily Distribution
  - Yearly Distribution
Survey Says...
Issues Related to Density

- Roller Operations 5.45
- Mix Design 5.17
- Binder Content 5.06
- Aggregate Properties 3.44
- Paver Operations 3.22
- Environmental Factors 2.87
- Binder Stiffness 2.83
Weaknesses

- Trained Operators: 78.8
- Adequate Quality Personnel: 46.5
- Method of Density Measurement: 45.5
- Density Measurement Equipment: 33.3
- Other: 28.3
- Compaction Equipment: 27.3
- Laydown Equipment: 15.2
Weaknesses

“Other” included:

- Effect of underlying layers
- Unplanned schedule interruptions
  - Accidents, weather, breakdowns, etc.
- Low bid contract environment encouraging low binder content
- Specifications requiring overly stiff and dry mixes
Balancing Production Rates
Balancing Production Rates

- Trucking
- HMA Facility
- Paving
- Compaction
Problem Getting Density?

- Most respondents said they generally don’t have a problem achieving density.
  - Comments were that density may be marginal.
  - Some contractors using asphalt content to adjust density.

Most believe their density spec is adequate.
Under/Over Compaction?

- 98% believe under compaction is a problem
- Only 64% believe over compaction is a problem
- Literature clearly recommends both an upper and lower specification limit for density
Specification Types for Control of Density
Density Specification

- All have a density specification
- 60% waive for thin lift application
- 80% have end-result specification
- Pay factor range from 25-50%
  - 90% between 35 and 50%
  - 70% between 40 and 50%
- 75% both incentive and disincentive
- 12 agencies use disincentive only
Density Specifications

Comments

- Incentives only offset disincentives
- “Bonuses are awarded too often”
- We only use penalties
- Agencies should want bonus as it indicates better quality work
Measurement Responsibility

- 94% say QC is responsibility of contractor
- 87% say assurance is responsibility of agency
  - 12 agencies use contractor results for acceptance
Reference Density

- Use of Gmm widely recommended in literature
- Recommended to be based on plant produced mix
- 92% use Gmm
- Only 74% from plant produced mix
Where is Gmm sample taken?

- Truck at plant: 42.7
- Uncompacted behind paver: 39.3
- At plant discharge: 12.4
- Truck at paver: 5.6

- Some are not following AASHTO/ASTM requirements for sampling location
Frequency of Gmm Test

- Brown/Cominsky: Routinely test/every sample
- 67% test on every sample
- 88% either every sample or daily
- Some rarely test (or never)
Control Limits

- TRB E-C173 describes
  - Engineering Limits
  - Specification Limits
  - Acceptance Limits

Response rate was low
Perhaps confusion on differences
Specification Limits

- 89% of respondents
  - Lower limit: 91-93% density
  - 57% lower limit: 92%
- 77% of respondents
  - Upper limit: 97-98% density
  - 21% no upper limit
Acceptance Limits

- 88% of respondents
  - Lower limit: 90-92% density
  - 46% lower limit: 92%
- 71% of respondents
  - Upper limit: 97-98% density
  - 46% upper limit of 97%
  - 35% no upper limit
Density Measurements Techniques
PATTERN DECISIONS:

1. How many passes?
2. How many repeat passes?
3. How to be sure mix is rolled at correct temperature?
4. How fast to roll?
Quality

- Quality cannot be tested or inspected into the mix; it must be “built in”.

- Cominsky 1998
Density Measurement

- Cores
- NDT
  - Nuclear
  - Electromagnetic

Cores are historical standard
How to patch core holes not well established
Coring

- Cores used to determine density of compacted mix for quality control and payment
- Core density usually different from nuclear density, but a correlation can be made between them
# Density Measurement

<table>
<thead>
<tr>
<th>Tool</th>
<th>Quality</th>
<th>Control</th>
<th>Acceptance</th>
<th>Acceptance</th>
<th># Agencies</th>
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<tr>
<td>Cores</td>
<td>Allowed</td>
<td>Commonly Used</td>
<td>Allowed</td>
<td>Commonly Used</td>
<td>51</td>
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<tr>
<td>Nuclear</td>
<td>80</td>
<td>71</td>
<td>33</td>
<td>32</td>
<td>20</td>
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<tr>
<td>Thin Lift</td>
<td>58</td>
<td>42</td>
<td>22</td>
<td>20</td>
<td>13</td>
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<tr>
<td>Electromagnetic</td>
<td>4846</td>
<td>38</td>
<td>12</td>
<td>6</td>
<td>5</td>
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</table>
Core Drying

- Literature recommends vacuum drying to achieve most accurate measurement of Gmb
- 70% use oven drying
- 44% use vacuum drying
Core Absorption

- 18% have a limiting value of 1%
- 30% have a limiting value of 2%
- 15% use dry back procedure
- 21% have no absorption evaluation

Absorption testing not commonly done
May create problems in volumetric control of mix
Random Sampling

- 94% use random sampling
- Most will relocate core if too close to pavement edge
- Only 67% will relocate if too close to road hardware
NDT Gauges

- Nuclear: Calibration, Standardization, and Correlation
- Electromagnetic: Standardization and Correlation
- 16% don’t correlate gauge to cores!

<table>
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<tr>
<th>Procedure</th>
<th>% Responses</th>
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<td>Calibration</td>
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<tr>
<td>Standardization</td>
<td>40.0</td>
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<tr>
<td>Correlation</td>
<td>83.5</td>
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Sample Size

- 52% use 4” Cores
- 58% use 6” Cores

It is known that the large volume sample is more representative
%Density Comparison

- 54% use PWL
- 46% use Average
- 11% use lowest single measurement
Construction Parameters Affecting Density
Factors Affecting Density

- Materials
- Initial Density
- Traffic
Importance of Compaction

- Improve Mechanical Stability
- Improve Resistance to Permanent Deformation
- Reduce Moisture Penetration
- Improve Fatigue Resistance
- Reduce Low-Temperature Cracking Potential
Mix Compaction

- Asphalt binder holds particles together
  - Provides lubrication at high temperatures
  - Provides cohesion at in-service temperatures
- Prevents air and water intrusion into mat
AGGREGATES

“DENSE GRADED” MIXES ARE MOST COMMON...
ASPHALT CEMENT

AT PAVING TEMPERATURES ASPHALT CEMENT IS A LUBRICATING FLUID!

AS IT COOLS, ASPHALT CEMENT BECOMES A GLUE-LIKE BINDER!
AGGREGATE

ASPHALT CEMENT

AIR Voids

FRACTURED OR CRUSHED FACES ARE BEST!
Density Growth

- Primary compaction
- Aggregate movement
- Some additional compaction
- Binder movement
- Minimal additional compaction
- Smooth surface
Lift Thickness

~70% of respondents indicated a lift thickness to NMAS ratio of 3:1

A concern expressed:
- If ¾” mix is designed at 4” thick and project requires two 2” lifts, ratio is violated
<table>
<thead>
<tr>
<th>Response</th>
<th>Percent</th>
<th>Responses</th>
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<tr>
<td>Required</td>
<td>Yes</td>
<td>39.4</td>
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<tr>
<td>Used</td>
<td>No</td>
<td>50.5</td>
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Establish Roller Pattern

- 84% use NDT to establish roller pattern
- 64% have no formal procedure for establishing roller pattern
- 94% say contractor is responsible to establish roller pattern
- 79% say contractor is responsible to ensure roller pattern

Inspector role varies
Roller Pattern Adjustments

- Mix Type 89.2%
- Air Temperature 67.5
- Wind Speed 60.2
- Base Temperature 60.2
- Inspector On Site 42.2

83% have no roller training requirements
## Roller Types

<table>
<thead>
<tr>
<th>Position</th>
<th>Percentage Responses</th>
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</thead>
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<tr>
<td></td>
<td>DDV</td>
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<tr>
<td>Breakdown</td>
<td>93.5</td>
</tr>
<tr>
<td>Intermediate</td>
<td>65.2</td>
</tr>
<tr>
<td>Finish</td>
<td>23.3</td>
</tr>
</tbody>
</table>
Roller Issues

- 92% said contractor makes roller type decision
- Ability to achieve density is chief driver
- 76% do not verify weight of roller
- 79% do not verify the frequency of DDV
Compaction Additives

- WMA the primary additive
- 2016: 1/3 of total market
- 75% of WMA is foaming
- 82% use additives to enhance density achieved
- WMA often used at hot mix temperatures
Production

- 66% place less than 2,000tpd
- 73% place less than 3,000tpd

Comments:
- Significant variability exists
- Mix, weather, lane closure time, MOT, project staging
Paver Operations

- 88% said paver speed was 20-40fpm
- Europe: 10-15fpm
- Interesting to note that comments indicated that slower speed was used for PWL job
- 72% think a slower speed would improve density
- Same percentage said there shouldn’t be a max speed specification
Longitudinal Joint Construction
Longitudinal Joints

- **AI Study**
  - one of the highest reasons for premature failure
  - Overband or joint sealer if density is less than 92% of Gmm

- 41% have specification
- 44% don’t
- Many are considering specification
Longitudinal Joints

- 78% take cores at joint
  - 13 used NDT
- 77% determined location by statistical lot
- Significant variation in frequency of testing
Longitudinal Joints

- 52% minimum density of 90%
  - Remaining are divided +/-
- Within 2% of mainline is common
- 41% use both incentive and disincentive
- 20% disincentive only
- Decision to use:
  - 33% Agency specification writer
  - 36% in standard specifications
Emerging Technologies in Determination of In-Place Density
Emerging Technologies

- IC is the main density related issue
- Two elements:
  - Density Control
  - Roller Management
- Research to date has shown that density control is not reliable in determination of density
- Tamping bar screed not widely used
Intelligent Compaction

- 65% indicated that IC is not being used
- 72% have no IC specification
- Some pilot/demonstration projects
- New technology needs time to evolve
Summary – General Issues

- 3 Most important issues: Roller Ops, Mix Design and Binder Content
- Major weaknesses: Trained Operators, Adequate QC/QA personnel and method of density measurement
- Density not a routine problem
- Density specification is adequate
- Incentives work
Summary – Specification

Types

- In-place density common specification
- Thin lifts are problematic
- End-result spec with pay factor most common
- Composite pay factor varies widely
- Contractor responsible for QC, Agency for acceptance
- Many do not use Gmm from plant produced mix
Summary – Specification Types

- **Primary sampling locations**
  - truck at plant
  - uncompacted behind paver

- Gmm test procedures vary

- Some do not measure Gmm routinely
Summary – Specification Types

- **Specification Limits**
  - Lower: 91-93
  - Upper: 97-98

- **Acceptance Limits**
  - Lower: 90-92
  - Upper: 97-98

- 35% have no upper limit for specification or acceptance limits
Density Measurement

- Nuclear density gauge most commonly used tool for QC
- Core samples most commonly used for acceptance
- Oven drying most common
- Vacuum drying should be considered
- Random sampling used by most
Density Measurement

- Correlation using cores not uniformly performed for NDT
- Frequency of NDT not uniform
- Use of 4” vs. 6” cores evenly distributed
- PWL and average most common approaches to compare to acceptance
Constitution Parameters

- Minimum lift thk to NMAS: 3:1
- Vibrating screed used by about half
- Roller pattern established using NDT
- No formal procedure for establishing roller pattern
- Roller pattern established and controlled by contractor
Construction Parameters

- Breakdown position: DDV
- Intermediate position: DDV and PTR
- Finish roller: DDS
- Contractor decides roller type
- Weight and frequency not verified
- WMA commonly used
- Typical tonnage: <3,000 tpd
- Typical paver speed: 20-40 fpm
Longitudinal Joints

- Increasing in use
- Joint Specification being considered by many
- Typical Specification: % density
- Cores most commonly used for density
- Specification: 88-92%
  - Most common minimum 90%
- Both incentive and disincentive factors
Emerging Technologies

- Most agencies do not have an IC spec
- Most are not currently using IC
- Density control not currently reliable
- Roller management is useable
- Tamping bar screeds not widely used
Recommendations

- QC/QA activities should be uniformly performed
- Training for all personnel is key
- Frequency of testing is highly variable
- Density testing should be performed for all projects
- Both a minimum and maximum density should be specified
Recommendations

- Absorption evaluation of all cores should be performed
- Testing for Gmm should be performed during plant production of mix
- Standard procedures for NDT should be followed
- Ensure adequate testing is performed
Recommendations

- Consider requiring a vacuum drying procedure
- Roller management should be used to ensure consistency of roller patterns
- Consider requiring joint sealer for all longitudinal joints
Thanks to All who Participated!

- Results published in NCHRP Report 856
Thank You!

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