Compaction of Asphalt Mixtures, State of Practice

Dave Johnson, P.E.
Senior Regional Engineer, Asphalt Institute
Billings, Montana

Importance of Compaction

“Compaction is the single most important factor that affects pavement performance in terms of durability, fatigue life, resistance to deformation, strength and moisture damage.” – C. S. Hughes, NCHRP Synthesis 152, Compaction of Asphalt Pavement, (1989)

“The amount of air voids in an asphalt mixture is probably the single most important factor that affects performance throughout the life of an asphalt pavement. The voids are primarily controlled by asphalt content, compactive effort during construction, and additional compaction under traffic.” – E. R. Brown, NCAT Report No. 90-03, Density of Asphalt Concrete—How Much is Needed? (1990)
Introduction to Compaction

• Compaction is the final step in the construction process of an asphalt pavement.

• Compaction is the process by which the freshly placed asphalt mat is compressed (or densified) to reduce the in-place air voids in the mat.

• During the compaction process, aggregate particles in the mat are reoriented closer together and locked into place to provide a strong skeleton for the asphalt mixture with increased shear strength providing resistance to permanent deformation (rutting) and cracking.

The primary goals of the compaction process are to:

◦ consolidate the mat
◦ increase in-place density, which reduces in-place air voids
◦ smooth out the asphalt pavement

Going forward, we will use the terms **density** and **air voids**. It is understood that we are referring to in-place density and in-place air voids.
Current Technologies that Influence Compaction...

- **SHRP2 IR Bar**
- **Dialnetic Porfiling System**
- **Balanced Mix Design**
- **Warm Mix Asphalt**
- **IC**
- **Tack Coat**
- **Long Joint**

Density = Durability

**Density vs. Loss of Pavement Service Life**

For both thicker and thinner, reduced in-place density at the time of construction results in significant loss of Service Life!
NCAT Report 16-02 (2016)

Literature Review on connecting in-place density to performance

- 5 studies cited for fatigue life
- 7 studies cited for rutting
- “A 1% decrease in air voids was estimated to improve the fatigue performance of asphalt pavements between 8.2 and 43.8%, to improve the rutting resistance by 7.3 to 66.3%, and to extend the service life by conservatively 10%.”
“...to ensure that permeability is not a problem, the in-place air voids should be between 6 and 7 percent or lower. This appears to be true for a wide range of mixtures regardless of NMAS and grading.” – NCHRP 531

Getting Compaction
What is a balanced paving operation?
The synchronized balance of the four phases of asphalt paving to provide continuous paving operations. The four phases are mixture production, mixture hauling, paving operations, and compaction.

Factors in Affecting Compaction

• Base Condition
• Lift Thickness vs. NMAS
• Laydown Temperature
• Ambient Conditions
• Cooling Rates
• Balancing Production Through Compaction
• Paver Operations
General Mechanics of Compaction

- The mechanics of compaction involve three main forces that can have a major impact on the compaction process:
  - Compressive force of the rollers
  - Resistive forces within the mixture
  - Supporting forces exerted by the stable surface below the mat (subgrade, aggregate base or the existing pavement)

- Optimum conditions for compaction of the asphalt mat will be achieved when:
  - Asphalt mat is stable enough at compaction temperatures to be densified without excessive movement
  - Underlying materials adequately support the compactive forces being applied by the rollers

Importance of Underlying Support
Subgrade & Base Support

• Good support critical to obtain proper density
• Spongy or unstable support
  • Provides little resistance to the rollers
  • Mixture not confined, energy dissipated
• Mixture moves and cracks rather than compacts

Lift Thickness’ Effect on Compaction

• Aggregates need room to densify
• Too thin vs. NMAS leads to:
  ◦ Roller bridging
  ◦ Aggregate lockup
  ◦ Aggregate breakage
  ◦ **Compaction Difficulties**
• NCHRP Report 531 (2004)
  ◦ Fine Graded Mix—**Minimum** Thickness = 3 X NMAS
  ◦ Coarse Graded Mix—**Minimum** Thickness = 4 X NMAS
  ◦ SMA Mix—**Minimum** Thickness = 4 X NMAS
The Temperature Effect

• Charles F. Parker (1959)
  ◦ 275°F – standard temperature – reference air voids
  ◦ 200°F – doubled the air voids
  ◦ 150°F – quadrupled the air voids

• Kim A. Willoughby, et.al. (2001)
  ◦ Mix temperature differentials
  ◦ ≤ 25°F – generally consistent air voids
  ◦ ≥ 25°F – greater air void spread
    • Pneumatic rollers reduced spread
    • End dumps showed a greater spread

• Robert Schmitt, et.al. (2009)
  ◦ Most important factor in achieving density
Mat Temperature

- Compacting asphalt in the correct temperature range is critically important
- Temperatures must be neither too hot nor too cold
- Optimum compaction temperatures vary depending on many factors
  - Start compaction: 310 – 280°F
  - Stop compaction: 180 – 175°F
  - WMA will lower these ranges depending on the technology

Environmental Factors and Compaction

Several factors come into play regarding how fast the mix cools onsite, affecting time available for compaction:

- Ambient air temperature
- Temperature of the existing surface
- Wind speed
- Lift thickness
- Mix temperature
- Solar Radiation
Material Cooling

- Thicker = More Time for Compaction
- Free tools for estimating compaction time
  - PaveCool—single lift (generation 1)
    - PC
    - iOs App
    - Google App
  - MultiCool—multiple lifts (generation 2)
    - PC
    - Google App
    - Mobile Web

PaveCool Example

- Key Inputs
  - Temperature
    - Air
    - Base
    - Mix Delivery
  - Wind Speed
  - Lift Thickness

- Output
  - Cooling Curve
  - Estimated Compaction Time
PaveCool Example

2.5 Inch Lift
50°F Air, Surface Temp
Mix Delivery temp - 300°F
39 minutes to complete compaction operations

2 Inch Lift
50°F Air, Surface Temp
Mix Delivery temp - 300°F
28 minutes to complete compaction operations

Forces of Compaction and Roller Types
Balanced Roller Vibration

• Optimum compaction occurs when all forces are accepted by the asphalt layer
• Balance between forces of compaction and the asphalt layer

Drum Bouncing

• When using vibratory rollers:
  ◦ Forces out of balance create drum bounce
  ◦ Inefficient operation
  ◦ Solve bouncing:
    - change speed
    - lower amplitude
    - higher frequency
    - one drum static
    - both drums static
Roller Equipment

• Forces of Compaction
• Roller Type
  ◦ Steel Drum
    • Static
    • Vibratory
  ◦ Pneumatic
  ◦ Newer Technology
    • Vibratory Pneumatic
    • Oscillatory Steel Drum

Note: screed operator walking along side
Forces of Compaction

Compaction forces
- Low force
  - Static pressure
  - Manipulation
- Higher forces
  - Impact
  - Vibration

Effect of Roller Type, Size, Passes

Roller type and size affects:
- Magnitude of the load
- Manner the load is imparted to the pavement

Number of passes:
- Increases the density
- To optimum point after a number of passes
  - Lowers compaction
  - If continued, damages mat
Roller Types

- **Pneumatic**
  - Reorients particles through kneading action
  - Tire pressures:
    - ~80 psi (cold) for compaction
    - ~50 psi (cold) for finish rolling
    - Range of tire pressures not to exceed 10 psi
  - Used as Intermediate or as Breakdown Roller
  - Tires must be hot to avoid pickup
  - Tires must be smooth - no tread
  - Not used for PFC mixes or SMA

- **Vibratory**

- **Static Steel-Wheeled**
• Many experts believe kneading action helps in providing a tighter surface that is more dense and less permeable compared to drum rollers.
  ◦ Research supports this
• But must keep these away from the unsupported edge to avoid excessive lateral movement of mat.
• Use during intermediate rolling of the supported edge.
  ◦ Not finish rolling

---

Vibratory Rollers

• Commonly used for initial (breakdown) rolling
• 8-18.5 tons, 57-84 in wide (“heavy” rollers)
  — 50-200 lbs/linear inch (PLI)
• Frequency: 2700-4200 impacts/min.
• Amplitude: 0.016-0.032 in.
  — For thin overlays (≤ 2 in.) use low amplitude or static mode
• Operate to attain at least 10 impacts/ft
  — 2-4 mph
### Drum Impacts per Foot

<table>
<thead>
<tr>
<th>Frequency</th>
<th>2 MPH</th>
<th>3 MPH</th>
<th>4 MPH</th>
<th>5 MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 vpm</td>
<td>11.36</td>
<td>7.58</td>
<td>5.68</td>
<td>4.55</td>
</tr>
<tr>
<td>2200 vpm</td>
<td>12.50</td>
<td>8.33</td>
<td>6.25</td>
<td>5.00</td>
</tr>
<tr>
<td>2400 vpm</td>
<td>13.64</td>
<td>9.09</td>
<td>6.82</td>
<td>5.45</td>
</tr>
<tr>
<td>2600 vpm</td>
<td>14.77</td>
<td>9.84</td>
<td>7.39</td>
<td>5.91</td>
</tr>
<tr>
<td>2800 vpm</td>
<td>15.91</td>
<td>10.61</td>
<td>7.95</td>
<td>6.36</td>
</tr>
<tr>
<td>3000 vpm</td>
<td>17.05</td>
<td>11.36</td>
<td>8.52</td>
<td>6.82</td>
</tr>
<tr>
<td>3200 vpm</td>
<td>18.18</td>
<td>12.12</td>
<td>9.09</td>
<td>7.27</td>
</tr>
<tr>
<td>3400 vpm</td>
<td>19.32</td>
<td>12.88</td>
<td>9.66</td>
<td>7.72</td>
</tr>
<tr>
<td>3600 vpm</td>
<td>20.45</td>
<td>13.64</td>
<td>10.22</td>
<td>8.18</td>
</tr>
<tr>
<td>3800 vpm</td>
<td>21.59</td>
<td>14.39</td>
<td>10.80</td>
<td>8.63</td>
</tr>
<tr>
<td>4000 vpm</td>
<td>22.72</td>
<td>15.16</td>
<td>11.36</td>
<td>9.10</td>
</tr>
</tbody>
</table>

### Other Compaction Technologies

- In addition to the standard roller types, there are a number of innovative and new compaction technologies now available:
  - Oscillatory rollers
  - Combination rollers
  - Vibratory pneumatic (rubber) tire rollers
**Oscillatory Rollers**

- Oscillatory rollers are typically equipped with an oscillating drum and vibratory drum.
- The oscillatory drum generates Compactive force based on:
  - Weight of the roller
  - Tangential dynamic force from offset spinning eccentric weights
- Can be used effectively in both intermediate and breakdown.
- Tangential Compactive force is desirable in scenarios where:
  - Vertical force is not practical
  - Compaction at lower cessation temperatures are desired

**Combination Rollers**

- Combination rollers are rollers that are equipped with both a steel drum and pneumatic (rubber) tires.
- Advantages of “combi” rollers:
  - Desirable qualities of both vibratory and rubber tire in a single roller
  - Provide rapid density increases from vibratory drum
  - Kneading action that both densifies mat and provides a tight finish from rubber tires
Vibratory Rubber Tire Rollers

- Vibratory pneumatic (rubber) tire rollers are rubber tire rollers that are equipped with vibration amplitude and frequency
- Advantages of vibratory rubber tire rollers
  - Advantages of both rubber tire and vibratory rollers in a single roller
  - Kneading action that densifies mat and provides a tight finish from rubber tires
  - Rapid density increases from dynamic forces generated by the vibratory drum
  - Avoid bridging at cold joints

Roller Operations & Roller Procedures
Compaction Variables at the Roller

• Roller Patterns
  ◦ Sequencing
  ◦ Passes—A roller passing over one point in the may one time
  ◦ Roller Speed

• Rolling Zone

• General Rolling Operations

Traditional Roller Operations Sequencing

• Breakdown Rolling
• Intermediate Rolling
• Finish Rolling
Pattern Decisions

• How many passes?
• How to be sure mix is rolled at correct temperature?
• How fast to roll?

Establishing Breakdown Rolling Pattern

Goal: 93.5% $G_{mm}$

Select: 3 Passes
(Intermediate will get the rest of the density)
Rolling Pattern

- Speed and lap pattern for each roller
- Number of passes for each roller
  - One trip across a point on the mat
  - Set minimum temperature each roller finishes

**IMPORTANT:**
- Paver speed must not exceed compaction!!
- Paver makes single pass
- Roller pattern requires 3-7 passes

Roller Speed is Critical – **SPEED KILLS DENSITY!!**

![Graph showing density vs. number of passes for two speeds (2 MPH and 4 MPH). Slower = More Compaction/Pass.]
Breakdown Rolling

• First roller behind paver
• Gets most of density
• Begin at highest temperature without huge mat distortion
• May have to work very close to paver for some mixes
• May be performed with two coordinated rollers

Breakdown Rolling

• Historically 3-wheel steel
• D/D vibratory most common
• Vibration most productive during breakdown
• Pneumatics
  • Used on base courses
  • Leveling courses
    • Forces mix into cracks
    • Compacts without bridging minor ruts
• Can leave marks – may be harder to roll out
Echelon Vibratory Rollers

Intermediate Rolling

- Final step in getting density and initial smoothness
- Mat hot enough to allow aggregate movement
- Mat already close to final density
- Too much force will fracture aggregate
- Typical roller type:
  - Traditionally pneumatic
  - Vibratory at low amplitude and/or static mode
Pneumatic Roller

Main purpose
• Minimal compaction
• Smoothness
• Removal of any marks
• Once smooth, stop rolling

Typical roller types:
• Tandem steel-wheel
• Pneumatic w/lower pressure
• Vibratory static mode only

Finish Rolling
General Rolling Procedures

For best results
- Roll at highest temperature without excessive displacement
- Stay close to paver
- Monitor weather
- Keep up but not too fast
  - Slower paver speed
  - Not faster roller speed

General Rolling Procedures

Overlaps
- 6” overlap assures uniform compaction
- Include overlap selecting drum width
- Roller should cover mat in no more than 3 passes
General Rolling Procedures

Reversing Directions
• Avoid straight stops
• Turn toward center of mat
• Don’t turn drum while stopped
• Next pass should roll out any marks created by reversing

Compact the Mat While It Is Hot!

Stay Close to the Paver with Breakdown Rollers.
Always Stop and Reverse Directions at an Angle!
General Rolling Procedures

“Birdbath” from roller stopping on hot mat

Why Rollers Need to Turn to Stop
Summary of “Good Practice”

- Compact mat when it is hot!
- Conduct a density control strip at the beginning of the project
  - Determine optimum roller pattern
  - Stick with roller pattern throughout project unless something changes in the conditions
- Reverse directions properly
  - Turn into stops
  - Do not turn while standing
- Do not stop roller on hot mat
- Use proper technique when compacting longitudinal joints

Questions?