Never forget...

Asphaltic Concrete mixes must be compacted while workable
Binder content makes compaction easier or more difficult, for both HMA or WMA mixes
Differences exist between ‘tough’ and ‘tender’ mixes
Aggregate gradation, NMAS, shape and type are important
Asphalt binder grade, type, viscosity (and additives/modifiers) are also critical
Mix characteristics and properties vary widely

“Tough” mix

A tough or stiff asphalt mix usually refers to a mix that is difficult to compact due to aggregate shape or size, binder properties like viscosity, additives or modifiers, as well as material temperature during the compaction process.
“Tough” mix
A tough or stiff asphalt mix may require more compaction force and/or higher static linear load for steel wheel static or vibratory compactors, or greater psi with pneumatic compactors.

“Tough” mix
High(er) friction between particles and/or binder stiffness causes the mix to be more difficult to compact.

“Tough” mix
The “tough” mix requires more dynamic compaction force (drum energy) from vibratory compactors.
“Tough” mix

Stiff mixes require higher contact pressure (psi) from pneumatic compactors. Heavier ballasted weight, fewer and larger tires, higher tire ply rating and higher tire inflation pressure all contribute to getting density with tough mixes.

“Tough” mix

Difficult to compact mixes demand higher static linear load (pli) from steel wheel static rollers for finish rolling.

“Tender” mix

A “tender” asphalt mix may also be difficult to compact. It can have a tendency to shove ahead of vibratory compactor drums and static roller wheels and/or leave longitudinal cracks at the outside edges of drums/wheels. Deeper tire marks are common with a tender mix being rolled by pneumatic compactors.
“Tender” mix
A lack of friction between aggregate particles due to shape or size, or a lack of shear strength in the mix can contribute to tenderness. Excessive temperature during the compaction process can also lead to temporary mix tenderness.

Achieving density
Achieving density is one of a dozen important flexible pavement characteristics/properties.

The Dirty Dozen
1. Air void content
2. Binder content
3. Density
4. Durability
5. Fatigue resistance
6. Flexibility
7. Impermeability
8. Skid resistance
9. Smoothness
10. Stability
11. VMA
12. Workability
Important paving mix properties
1. Air void content
2. Asphalt binder content

Important paving mix properties
3. Density
4. Durability

Important paving mix properties
5. Fatigue resistance
6. Flexibility
Important paving mix properties

7. Impermeability
8. Skid resistance

9. Smoothness
10. Stability

11. VMA
12. Workability
Let’s concentrate on density!

One way to achieve density... Just do it the old-fashioned way

The really old-fashioned way...
The really old-fashioned way...

Another way to achieve density...

Another way to achieve density...

Use bigger/more compactors!

Use heavier pneumatic compactors!
Another way to achieve density…

Use better/newer technology

Another way to achieve density…

Finish roll with oscillation

“…Just the facts.”

"The facts, Ma’am. Just the facts."
The facts...

• Compaction is a means-to-an-end...to reduce air voids and increase density
• CO DOT 2017 specifications for compaction state:
  – “Compaction shall begin immediately after the mixture is placed and be continuous until the required density is obtained.”
  – “SMA shall be compacted to a density of 93 to 97 percent of the daily theoretical maximum specific gravity.”
  – “All other HMA shall be compacted to a density of 92 to 96 percent of the daily theoretical maximum specific gravity.”
  – “Longitudinal joints shall be compacted to a target density of 92 percent of the theoretical maximum specific gravity. The tolerance shall be ± 4 percent...”

The facts...

• Compaction pavement test strip CTS required in CO for each job mix on projects greater than 2000 tons
• CTS used to evaluate number of rollers, combination of rollers and rolling patterns to achieve density
  – “Both steel wheel and pneumatic tire rollers will be required”
  – “All roller marks shall be removed with the finish rolling.”
  – “Use of vibratory rollers with the vibrator on will not be permitted during surface course final rolling...”

The facts...

• Density is a pay factor in CO (and many other states)
• “SMA shall be compacted to a density of 93 to 97 percent of the daily theoretical maximum specific gravity, determined according to CP 51.”
• “All other HMA shall be compacted to a density of 92 to 96 percent of the daily theoretical maximum specific gravity, determined according to CP 51.”
The facts...

- Density at the joint can result in incentive or disincentive payment in CO
- "The longitudinal joints shall be compacted to a target density of 92 percent of the theoretical maximum specific gravity. The tolerance shall be ±4 percent."
- Temperature one of most important considerations during laydown and compaction operations

The facts...

- Agencies must adopt more common use of PWL specifications
- An attitude to "make it black and don't look back" must be replaced by an attitude to utilize best practices in construction
- Low or inconsistent density across the width and along the length of the pavement, including longitudinal joints, can no longer be acceptable
- Smoothness needs to become a more important incentive and more significant pay factor on major roadways

The facts...

- Use of technology such as infrared thermography and IC systems must become the 'norm' for paving and compaction equipment
- Worker training on best practices needs to be standardized
- Work zone safety needs constant attention – everyone deserves to go home to family at the end of each shift
- Young people must be recruited, encouraged to join work force of local, state and federal agencies, contractors, equipment manufacturers and geotechnical firms before 'tribal knowledge' of mature work force is forgotten and gone forever
Compaction six pack

1. Keep up with paver
2. Make smooth starts, stops, reversals
3. Steer gradually to minimize marks
4. Do not over-roll in breakdown mode
5. Roll at correct speed with vibration
6. Utilize available technology

Keep up with the paver

But not too close...
Make smooth starts, stops...

Steer gradually...

Do not over-roll
Correct speed with vibration

Dual Importance of Speed
- Smoothness (drum impact spacing)
- Production (keeping up with paver)

Use available technology
Take a closer look...

The devil is in the details
German Proverb

Compacting a tough mix

TAC - time available for compaction
Pay attention to temperature

Operator needs to know...

Higher amplitudes for deep lifts
Higher amplitudes...

Higher forces for deep lifts

Higher forces...

High force for deep lifts... high force for tough mixes
Intermediate rolling tradition

Ground Contact Pressure
Dependent upon:
- Ballasted weight
- Number of tires
- Tire size, ply rating, inflation pressure

Uniform Pressure plus Overlap
Take care with tire marks

Intermediate rolling technology

Vibrating Tires

Variable amplitude selections
- Allow more versatility and the ability to easily compact both stiff and tender mixtures.
- Provide more uniform density throughout the pavement layer thickness.

Vibrating tires have dynamic kneading effect on pavements.
Vertical Shear Forces

Oscillating drum maintains constant contact with pavement surface; eliminates “bouncing” effect of vibration.

Where to use Oscillation

<table>
<thead>
<tr>
<th>'Make' or 'Break' zone</th>
<th>Paver screed</th>
<th>Target density zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Temp +/- 300°F</td>
<td>Breakdown</td>
<td>77% density</td>
</tr>
<tr>
<td>Intermediate</td>
<td></td>
<td>88-92%</td>
</tr>
<tr>
<td>Low Temp +/- 175°F</td>
<td>Finish</td>
<td>92-97%</td>
</tr>
</tbody>
</table>

Finish rolling technology

77% density  88-92%  92-97%
Why roller trains have changed...

Need for higher pavement bearing capacity / rutting resistance
Need for higher density at joints
Need for more uniform density across pavement

Compacting a tender mix

‘A, B, C’s’ of tenderness

- Aggregate moisture content
- Binder grade (viscosity)
- Compaction temperature zones
- Design properties of mix (particle shape and texture)
- Excessive binder content
‘A, B, C’s’ of tenderness

• Film thickness of binder (on aggregate)
• Gradation of aggregate (too much natural sand)
• Heat retention in middle of layer
• Inadequate layer bonding (tack coat)
• Just because...

Stay back from the paver

Avoid 190°F - 250°F
Get on the mix hot

Smooth starts, stops, reversals

Tender Mix End-of-Pass Shoving
Science in Compaction

Nijboer factor - tendency to displace or shove mix

Static drum load ideally 15-20 kg/cm² avoids excessive displacement due to plastic deformation

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW161AD-5</td>
<td>19.22</td>
</tr>
<tr>
<td>BW190AD-5</td>
<td>19.62</td>
</tr>
<tr>
<td>BW206AD-5</td>
<td>16.48</td>
</tr>
<tr>
<td>CB10</td>
<td>19.03</td>
</tr>
<tr>
<td>CB13</td>
<td>18.71</td>
</tr>
<tr>
<td>CB15</td>
<td>17.89</td>
</tr>
<tr>
<td>CC4200</td>
<td>17.11</td>
</tr>
<tr>
<td>CCS200</td>
<td>18.90</td>
</tr>
<tr>
<td>CC6200</td>
<td>18.53</td>
</tr>
<tr>
<td>CC7200</td>
<td>16.52</td>
</tr>
</tbody>
</table>

73

74

Science in Compaction

Nijboer factor - tendency to displace or shove mix

Static drum load ideally 15-20 kg/cm² avoids excessive displacement due to plastic deformation

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD+90iVV</td>
<td>18.55</td>
</tr>
<tr>
<td>HD+110VV</td>
<td>20.88</td>
</tr>
<tr>
<td>HD+120VV</td>
<td>15.76</td>
</tr>
<tr>
<td>HD+140VV</td>
<td>14.75</td>
</tr>
<tr>
<td>SW880</td>
<td>15.45</td>
</tr>
<tr>
<td>SW990</td>
<td>15.27</td>
</tr>
<tr>
<td>DD105</td>
<td>20.25</td>
</tr>
<tr>
<td>DD110C</td>
<td>18.85</td>
</tr>
<tr>
<td>DD120C</td>
<td>15.72</td>
</tr>
<tr>
<td>DD140C</td>
<td>16.24</td>
</tr>
</tbody>
</table>

73

74

Arc into supported edge

75
Protect the unsupported edge

Lower forces...

Frequency and Amplitude

Frequency change from low to high
Amplitude change from high to low
Stop/stand at an angle

Carefully roll joints

Support drums on adjacent pass
Utilize technology

• Automation of roller control functions
• IC Intelligent Compaction systems

Roller automation

• Automatic engine idle to conserve fuel and reduce noise

Roller automation

• Automatic engine idle to conserve fuel and reduce noise
• Automatic start/stop of vibration
Roller automation

- Automatic engine idle to conserve fuel and reduce noise
- Automatic start/stop of vibration
- Automatic speed control/limit

Automatic drum wetting

Drum wetting system must function for HMA compaction
Drums must be kept wet or pick-up will occur
Excessive water cools...

As much as 60°F loss in surface temperature recorded by thermal imaging

Reduces TAC...

IC systems

- Automatic control of dynamic forces of compaction to minimize pavement damage
- Automatic control of rollers to optimize compaction productivity
Smart rollers

Newest asphalt compactor technologies
- Ammann ACEplus – compaction measurement and control with navigation
- BOMAG Asphalt Manager 2 – IC system
- Bomag TanGO – tangential oscillation drum
- Caterpillar Compaction Control with GNSS – IC system measures IC MV, passes, temperature
- Dynapac Dyn@lyzer – compaction control and documentation; DCM or DCM with GNSS

Hamm HCQ Navigator – Hamm Compaction Quality IC system with GPS
- Hamm Oscillation – rear drum with oscillation/vibration
- Sakai CIS2 – IC with Topcon GPS positioning
- Sakai ND – both drums with oscillation/vibration
- Volvo Co-Pilot – Density Direct IC system with GPS

IC systems
Pass mapping

Pass mapping

Achieving Density: Handling Tough and Tender Mixes
Dale Starry
Volvo Construction Equipment
Thank you for your attention