Performance-based design of asphalt mixes

Principles and goals of performance-based design

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Doha, July 10, 2018
Outline

• Introduction to the design of asphalt mixes
  • Focus, goals and methods
  • Common features
• Principles of performance-based design
• Goals of performance-based design
  • Optimization of aggregate structure
  • Consideration of binder rheology and ageing
  • Assessment of binder-aggregate interactions
  • Evaluation of mixture compactability
  • Measurement of relevant mixture properties
Introduction to the design of asphalt mixes

- Laboratory-based selection of appropriate combination of aggregates, binder and other components = Job Mix Formula (JMF)

- Ultimate goals:
  - Guarantee adequate performance in the field (structural and functional)
  - Provide terms of reference for QC/QA

- Available methods differ in terms of:
  - Approach: empirical/performance-based
  - Procedures: test protocols and analysis methods

- Relevance of engineering judgement and experience
Introduction to the design of asphalt mixes

- Common features to all approaches and procedures:
  - Consideration of mixture volumetrics
  - Recognition of the effects of aggregate and binder type
  - Analysis of densification aptitude
  - Assessment of mechanical behaviour in compacted state
Principles of performance-based design

- Thorough understanding of pavement (and asphalt) performance in the field by means of adequate modelling tools (qualitative and quantitative)

  = theoretical analysis component

**Santagata et al. (2001)**

**First stress invariant ($\theta$)**

**Deviatoric stress ($\sigma_d$)**

**Subgrade**

**Sub-base**

$\rho_O = 700 \text{ kPa}$

$a = 13.5 \text{ cm}$

**Al-Qadi et al. (2003)**
Principles of performance-based design

- Identification of explicit links between materials’ (or components’) characteristics and various aspects of performance (e.g. occurrence of distresses) = empirical component

\[ N_f \] (number of loadings to failure)

Initial strain (microstrain)

Data set 1
Data set 2
Data set 3
Dense wearing (v = 3%)
Wearing (v = 5.4%)
Intermediate (v = 7.4%)

\[ y = 1371.6x^{0.0253} \]
\[ R^2 = 0.9657 \]

Santagata et al. (2002)

Ali (1994)
Goals of performance-based design

- Optimization of aggregate structure which:
  - influences compaction and volume available to the binder
  - is responsible for load-carrying capacity and shear resistance of mixes
  - can affect permanent deformations (e.g. through stone-to-stone contact)

Dense-graded asphalt

Stone matrix asphalt

Kutay et al. (2014)

QSD-ANAS test site
Goals of performance-based design

• Design requirements and opportunities related to aggregate structure:
  • Use of laboratory compaction techniques which replicate the 3D structure and volumetrics achieved in the field (e.g. gyratory, slab compaction, pressbox)
  • Optimization through evaluation of different aggregate combinations (e.g. SUPERPAVE)
  • Evaluation of performance-related properties of aggregates and of alternative mix components which may contribute to the aggregate structure (e.g. RAP)

QSD Laboratory

Cominsky et al. (1994)
Goals of performance-based design

- Consideration of binder rheology (and ageing) which:
  - affect lubrication during mixing and compaction
  - influence load-carrying capacity of mixes
  - have an impact on mixture resistance to several distresses (e.g. fatigue, permanent deformation, thermal cracking)

Santagata et al. (2011)

Santagata et al. (2012)
Goals of performance-based design

- Design requirements and opportunities related to binder rheology (and ageing):
  - Use of defined relevant/reliable rheological testing protocols and of simulative ageing treatments (may be non-standard for non-standard binders)
  - Reference to rheological selection criteria linked to temperature and loading conditions (intensity and speed) (e.g. SUPERPAVE)

Santagata et al. (2002)

\[ \varepsilon_c = \text{PCC Logt + TNC} \]
\[ \varepsilon_s = \text{PCS Logt + TNS} \]

\[ \Delta \varepsilon_l \]

\[ |G^*|/|G_0| \]

Delta \( G^* \) values:
- \( \Delta G^*_{\text{0}} = 0\% \)
- \( \Delta G^*_{\text{0}} = 5\% \)
- \( \Delta G^*_{\text{0}} = 30\% \)
- \( \Delta G^*_{\text{0}} = 10\% \)
- \( \Delta G^*_{\text{0}} = 50\% \)
- \( \Delta G^*_{\text{0}} = 70\% \)

Santagata et al. (2016)
Goals of performance-based design

- Design requirements and opportunities related to binder rheology (and ageing):
  - Use of modifiers to tailor binder rheology and of additives which can mitigate/control oxidation and polymerization
  - Possible use of models to relate binder rheology to mix behaviour
  - Additional information available through chemical analysis (e.g. SARA)

Santagata et al. (2017)
Santagata et al. (2003)
Goals of performance-based design

• Assessment of binder-aggregate interactions which:
  • affect all mixture properties in service
  • have a specific impact on moisture sensitivity

Goals of performance-based design

- Design requirements and opportunities related to binder-aggregate interactions:
  - Use of specific techniques to quantify the interactions for comparative purposes or for assessment against selection criteria
  - Use of additives which can maximize adhesion and stripping resistance
  - Additional information available through chemical analysis of binder (e.g. SARA) and aggregate mineralogy (e.g. thin sections)

Goals of performance-based design

- Design requirements and opportunities related to binder-aggregate interactions:
  - Need of additional investigation tools to analyse interactions of binder with other components of the aggregate skeleton (e.g. time-dependent diffusion of binder through bitumen films in RAP)
  - Use of additives which can optimize the interaction with additional components (e.g. rejuvenating agents in the case of RAP)

Rad et al. (2014)
Goals of performance-based design

- Evaluation of mixture compactability which:
  - affects laying operations and achievement of field volumetrics
  - is related to the shear resistance of the mixture

PoliTO test sites
Goals of performance-based design

- Design requirements and opportunities related to mixture compactability:
  - Use of laboratory compaction techniques which replicate the 3D structure and volumetrics achieved in the field (e.g. gyratory, slab compaction, pressbox) and allow quantification of workability
  - Use of additives which can control aggregate lubrication
  - Possible use of models which quantitatively describe compaction phenomena

Santagata et al. (2001)  
Masad et al. (2010)
Goals of performance-based design

• Measurement of mixture properties which affect structural and functional response (and performance) in the field:
  • Stiffness
  • Shear resistance
  • Fatigue resistance
  • Resistance to crack propagation
  • Rutting resistance
  • Thermal cracking resistance
  • Resistance to moisture
  • **Micro- and macro-texture**

_PoliTO Laboratory_
Goals of performance-based design

- Design requirements and opportunities related to mixture properties:
  - Fundamental (preferred) or simulative tests
  - Tests at representative compaction levels
  - Consideration of production/construction variability

Santagata et al. (2016)
Goals of performance-based design

- Design requirements and opportunities related to mixture properties:
  - Link to pavement design
  - Reference to field-calibrated limiting criteria and lab-to-field shift functions
  - Possible use of models which predict mixture properties

<table>
<thead>
<tr>
<th>Temperature</th>
<th>$R^2$</th>
<th>$S_p/S_o$</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>5°C</td>
<td>1.34</td>
<td>1.55</td>
<td>Very Poor</td>
</tr>
<tr>
<td>20°C</td>
<td>0.29</td>
<td>0.86</td>
<td>Poor</td>
</tr>
<tr>
<td>35°C</td>
<td>0.82</td>
<td>0.43</td>
<td>Good</td>
</tr>
<tr>
<td>50°C</td>
<td>0.02</td>
<td>1.00</td>
<td>Very Poor</td>
</tr>
</tbody>
</table>

$y = 0.6882x$
$R^2 = 0.92758$

$c = 1834.2N^{0.2737}$
$R^2 = 0.936$

$e = 2990.8N^{0.2451}$
$R^2 = 0.9229$

Yousefdoost et al. (2013)
Santagata et al. (2004)
Thank you