RILEM Technical Committee 206 - ATB

Task Group 2: Mixture Design & Compaction

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October 19-20, 2009, Warsaw, Poland
Outline

• Project overview
• Project progress
  – Imaging Software & Analysis
  – TG2 Member Feedback
  – Initial Analysis
  – Development of Standard Procedure
  – State-of-art Report
• Moving forward
Project Overview

• **Essential Tasks:**
  – Comparison of compaction temperature & pressure
  – Comparison of compaction methods
  – Comparison of laboratory compaction to field samples

• **Measurements**
  – **Aggregate Structure**: contact points, orientation, & segregation
  – Density
  – Mechanical Properties

• **State-of-the-art report**
  – Lab compaction methods
  – Field compaction methods
Project Overview- Steps

1. Establishing protocols for compaction methods
2. Shipping, preparing and compacting loose LCPC mix.
3. Coring and shipping field samples from LCPC – France.
4. Performing x-ray tomography on lab and field samples.
5. Performing scanned image (2D) analysis.
6. Performing gamma-ray analysis on lab and field samples.
7. Performing mechanical testing
   - On samples with high variability in internal structure.
8. Collecting, analyzing and compiling the results into a common database.
Project Status - Samples

- Specimens from Superpave gyratory, German Steel Sector, Marshall, and Kneading Compactor (UW, AIT, UC-Davis, MTU, TU-B) have been:
  - X-rayed at Turner Fairbank Highway Research Center
  - Shipped to UW, cut and 2D imaged with flatbed scanner.
  - Processing and analysis is underway.

- Specimens from French roller, CE Gyratory, German Sector, and Marshall (LCPC, EMPA, TU-B, Parma)
  - at LCPC for gamma-ray density scanning
Project Status – Samples

• Nottingham and Palermo have completed compaction
  – Specimens at Palermo are being sawn and imaged for 2D analysis

• Additional material sent to TU-Braunschweig for further compaction and mechanical testing
# Specimen Status - Updated Oct ’09 - 12 Labs

<table>
<thead>
<tr>
<th>LAB No.</th>
<th>LAB name</th>
<th>Gyrotory - US</th>
<th>Gyrotory - CE</th>
<th>French Roller</th>
<th>German sector</th>
<th>Marshall</th>
<th>Hveem</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>AIT</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>At UW via FHWA</td>
</tr>
<tr>
<td>14</td>
<td>UC – Davis</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>Hveem @ UW via FHWA, French Roller specs compacted &amp; on hold</td>
</tr>
<tr>
<td>2</td>
<td>EMPA</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compaction data received, waiting for update/request from group</td>
</tr>
<tr>
<td>7</td>
<td>LCPC</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>Compaction data received</td>
</tr>
<tr>
<td>9</td>
<td>Liverpool</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Compaction data received</td>
</tr>
<tr>
<td>3</td>
<td>Michigan Tech</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>At UW via FHWA</td>
</tr>
<tr>
<td>10</td>
<td>Technical Univ. of Braunschweig</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Compaction completed, German sector at UW via FHWA, Gyrotory</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&amp; Marshall at LCPC</td>
</tr>
<tr>
<td>5</td>
<td>Total-France</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>8</td>
<td>UFC – Petrobras</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>Unsure</td>
</tr>
<tr>
<td>11</td>
<td>Univ. of Parma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>At LCPC</td>
</tr>
<tr>
<td>1</td>
<td>UW – Madison</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Comaption data received, additional specimens used for compaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>temp/pressure analysis</td>
</tr>
<tr>
<td>16</td>
<td>Nottingham</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Comaption completed, no additional news</td>
</tr>
<tr>
<td>21</td>
<td>Univ. of Palermo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Delayed due to lab move/construction</td>
</tr>
</tbody>
</table>

October 19-20, 2009

Coenen, Mahmoud, Kutay & Bahia
Project Status – Software

- Completed major improvement 2D Software
- Latest version distributed to TG2 members.
  - Trials performed by members, feedback is used in next iteration of software.
- Analysis of gyratory specimens complete, data analysis underway.
  - Variables include: compaction temperature & pressure, NMAS, ESALs, binder grade and aggregate type.
- Draft ASTM standard completed (hard copies available)
Imaging Software & Analysis

- Updated 2D Software distributed to TG2 Members along with:
  - Step-by-step instructions for installation & use
  - Two trial images and accompanying files
  - Survey for members to provide feedback

Files still available for download through:

http://www.uwmarc.org
International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM)

MARC members serve on several RILEM technical committees, including Technical Committee 206-ATB on Advanced Testing and Characterization of Bituminous Materials. Hussain Bahia chairs this committee's Task Group 2 on HMA compaction methods and models.

Task Group 2 Web page
RILEM Technical Committee 206-ATB Web site

Image Analysis Software

- Software installation package [EXE, 261 MB]
- Supplementary files, including an instruction manual (with a feedback survey) and sample images [ZIP]
Survey Response

<table>
<thead>
<tr>
<th>Question</th>
<th>No</th>
<th>Not Sure</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the software easy to use?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Was the Step-by-step procedure easy to follow?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>How much time did you spend adjusting filtering values to obtain what you considered acceptable?</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

For those new to image processing, 25 or more minutes for the first attempt but much less (15 minutes) by the second trial.

For those with prior imaging experience, 10-15 minutes was the typical time.

*ONLY A HANDFULL OF FEEDBACK SURVEYS HAVE BEEN RECEIVED, PARTICIPATION AND COMMENTS ARE STILL WELCOME*
Survey sent to...

- AARON R COENEN
- ALLEX ALVAREZ
- ANDREW HANZ
- ANTONIO MONTEPARA
- ARIANNA COSTA
- ARTAMENDI IGNACIO
- BERND OLDE SCHEPER
- BERTRAND POUTEAU
- CARL MONISMITH
- CHANTAL DE LA ROCHE
- CHICHUN HU
- CHRISTIANE RAAB
- CLARA CELAURO
- DAVID HELDT
- EDITH ARAMBULA
- EMAD KASSEM
- EMMANUEL CHAILLEUX
- ENAD MAHMoud
- EYAD MASAD
- FERHAT HAMMOUM
- GILLES GAUTHIER
- GORDON AIREY
- HAIZHU LU
- HUSSAIN A. KHALID
- HUSSAIN U. BAHIA
- HYUNWOOK KIM
- IAN RICKARDS
- IRWIN GUADA
- JAMES GRENFELL
- JANILLA LUTIF
- JEAN-PASCAL PLANCHE
- JOHN HARVEY
- JORGE SOARES
- JOSEPH ANONCHIE-BOATENG
- KITAE NAM
- KONRAD MOLLENHAUER
- KUNNAWEE KANITPONG
- LINBING WANG
- LUIS NASCIMENTO
- M. EMIN KUTAY
- MANFRED PARTL
- MASSIMO LOSA
- MICHAEL P. WISTUBA
- MICHELE DAL TOE
- CASAGRANDE
- MURAT GULER
- PETER RENKEN
- ROLF LEUTNER
- SANJEEV ADHIKARI
- SHU WEI GOH
- SILVIA RASTELLI
- XINJUN LI
- YONGRAK KIM
- YU LIU
- ZHANPING YOU

RED names indicate individuals that have provided feedback via survey. Thank you!
Software Updates of ’09

Clear distinction of two parts to software

(1) Image processing
(2) Image analysis
Software Updates of ’09
Detail of two part process

(1) Image **processing**

(2) Image **analysis**

- Contact points
- Orientation
- Segregation
Software Updates of ‘09
Accounting for specimen properties
Software Updates of ‘09
Entering laboratory aggregate gradation of mix
Software Updates of ‘09
Matching of laboratory gradation & volumetric fraction with image based findings
Sample Output: Orientation (uniform radial)
Sample Output: Orientation (uniform horizontal)
Sample Output: Segregation
Initial Analysis – Aggregate Orientation

*Procedures after Tashman et al. 2001-AAPT*

Currently working on data presentation for better understanding by readers/viewers. This is done by converting from original histogram to polar coordinate system by fitting a harmonic function to data.


Harmonic Fit Calculations
After Masad et al. 1998

Frequency Fit:

\[
 freq_{\text{harm}} = freq_{\text{ave}} (1 + a \cos^2 \theta + 2b \sin \theta \cos \theta - a \sin^2 \theta)
\]

where: \(a = \frac{2 \sum_{k=1}^{N} \cos(2\theta_k)}{N}\), \(b = \frac{2 \sum_{k=1}^{N} \sin(2\theta_k)}{N}\)

and \(N=\) total number of aggregates accounted for in image

A, Amplitude: \(= \text{MAX}(freq_{\text{harm}}) - \text{MIN}(freq_{\text{harm}})\)

\(\delta\), peak position: \(e_x [\text{MAX}(freq_{\text{harm}})]\) or angle of the \(\text{MAX}(freq_{\text{harm}})\)
Harmonic Fit Parameters

\[ \delta = \text{Predominant angle, } A = \text{Severity of angle dispersion} \]
Polar Representation

- **Major Axis** - Identifies predominant aggregate orientation & represents maxima of harmonic fit.

- **Minor Axis** - Represents minima of harmonic fit.

- Difference between max & min represents (A=amplitude of harmonic fit). It indicates level of uniformity.

- A uniform distribution is represented by a perfect circle in Polar coord.

- As angles deviate more from uniform, the ellipse is more “pinched” in Polar coordinates.
Initial Analysis-
Effect of Compaction Method on Orientation

Frequency

Angle, Degree from Horizontal

Marshall - AIT
German Sector, TU-B
US Gyratory, MTU
Effect of Compaction Method – Initial Analysis

$\delta$: Indicates the predominant orientation angle

$A$: represents the amplitude or severity of deviation from uniform (zero=uniform)

<table>
<thead>
<tr>
<th>Compaction Method</th>
<th>$\delta$</th>
<th>$A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kneading Compactor</td>
<td>126</td>
<td>2.78</td>
</tr>
<tr>
<td>Marshall</td>
<td>125</td>
<td>2.76</td>
</tr>
<tr>
<td>German Steel Sector</td>
<td>167</td>
<td>0.22</td>
</tr>
<tr>
<td>Superpave Gyratory</td>
<td>90</td>
<td>5.54</td>
</tr>
</tbody>
</table>
Preliminary Results

• Effect of Compaction Method on Orientation
  – The software is capable of measuring the orientation angle with respect to two reference points, from horizontal & from the radial arm from center of image

• We need to work more on the polar plots or the harmonic representation
  – Least square fit of harmonics will be tried
  – Improve d representation of dispersion
Standard Procedure

- A Standard Procedure has been drafted to detail:
  - Image processing
  - Image analysis
  - Critical parameters
  - Consistent reporting format/units
Standardization is Underway

Standard Method for

Determining Aggregate Structure in Asphalt Mixes by Means of Planar Imaging

Designation: xx-xx

1. SCOPE

1.1. This standard covers the measurement of aggregate structure indicators of asphalt mixes using digital image analysis techniques.

1.2. This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS
State-of-Art Report: Outline

- Introduction
  - Motivation for Study
  - History of Laboratory Compaction
  - Engineering Considerations (e.g. How to approximate field compaction efforts)
- SuperPAVE Gyratory Compactor
  - History
  - Engineering Principles - Concepts behind using compactor
  - Standard Procedure - Standards/Specifications etc.
  - Current Usage – Distribution of usage, frequency of usage
- Marshall Compactor
  - Same
- California Kneading Compactor
  - Same
- French Roller Compactor
  - Same
- German Sector Compactor
  - Same
Outline Continued

- Laboratory Comparison, testing results, and ability to estimate field conditions
- Relating laboratory compaction to field compaction & to mechanical properties and imaging
  - Application of Imaging Technology to compare laboratory and field compaction
  - Effect of Compaction Methods on Air Void Distribution Using Image Analysis Techniques
  - Relationship of Field Compaction Pattern to Air Void Distribution
  - Effect of compaction method on mechanical properties of asphalt mixtures
  - Comparison of Laboratory and Field Mechanical properties: Hamburg test, overlay test, and permeability
- Image Capturing and Analysis Related to Internal structure
  - Digital Camera
  - X-Ray Tomography
  - Air Void Distribution (effect of compaction method)
  - Aggregate Orientation (angle of inclination and vector magnitude)
  - Aggregate Contacts
  - Aggregate Segregation
- Imaging Standard
- References
Summary of Outline
Section assignments/sources

- Introduction
- SuperPAVE Gyratory Compactor
- Marshall Compactor
- California Kneading Compactor
- French Roller Compactor
- German Sector Compactor
- Laboratory Comparison, testing results, and ability to estimate field conditions
- Literature Review relating lab to field compaction & both to mechanical properties and imaging

Application of Imaging Technology to improve the laboratory and field compaction of HMA
Effect of Compaction Methods on Air Void Distribution Using Image Analysis Techniques
Relationship of Field Compaction Pattern to Air Void Distribution
Comparison of Lab and Field Mechanical properties: Hamburg test, overlay test, and permeability
Effect of compaction method on mechanical properties of asphalt mixtures

- Image Capturing and Analysis Related to Internal structure
- Imaging Standard
- References

UW Graduate Student Underway

TTI Report

European Synthesis Report

Paper in progress, Coenen
In preparation, Mahmoud & Kutay
Moving forward...

- Completed preliminary analysis of effects of compaction temperature and pressure as well as compaction method
  - Subsequent studies to include laboratory comparison with field cores
- Mechanical testing of specimens
- Development of relation between lab and field compaction
- Draft State of the Art report by March 2010
Thank you!

• Questions?

• For more information,
  Please contact Mr. Aaron Coenen:
  – arcoenen@wisc.edu
Next Year Meeting – Would like to welcome you to UW - Madison
Madison- A city between lakes
Engineering Complex
Logistics

- Two hotels within walking distance
  - Many within a short bus ride or drive
  - Parking next door to building
- One of the most beautiful capital buildings within 25 minutes walk
- Free campus bus morning to mid night
- 40,000 + students running around
- October is when fall tree colors peak
Fly to Chicago or to Madison

- Bus from Chicago airport terminal to campus
  - 6 times a day
- Many direct flights to Madison airport (MSN)
  - United, AA, NWA-Delta, Continental,
    - Washington DC
    - Detroit
    - Dallas
    - Newark and NY –LaGuardia
    - Minneapolis
Possibility of organizing workshops
Site visits

- Rilem TGs
- ISAP working groups
- One of the largest Recycling HMA plants
- Weekend before –
  - Chicago cultural tour – one day
  - Frank Lloyd Wright Museum – ½ day