Management of Shrinkage and Cracking in Concrete Pavements

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Summary

• Shrinkage Testing: Some History and Background
  • Where did it all start?
  • The ASCP and BG&E MT Project
  • Objectives of the Project
• Measurement of Shrinkage to AS1012.13
  • The AS1012.13 Drying Shrinkage test
  • AS3600 design shrinkage requirements
  • Cracking, influencing factors
• Data from Laboratory Studies
• Data from Field Studies
• The Way Forward
SHRINKAGE TESTING: SOME HISTORY AND BACKGROUND
History

Where did it all start?

• Sydney, late 1960’s
• Investigation of problem cracking identified the cause to be identified with the use of unsound Breccias aggregate
• ACSE developed a Specification that limited drying shrinkage to:
  • A maximum of 650µs for ≤ 32 MPa concrete and
  • 700µs for >32 Mpa concrete
• Subsequent specifications continued to limit drying shrinkage, regardless of aggregate source or properties
• Original premise seems forgotten in design
ASCP & BG&E MT PROJECT
BACKGROUND

- The issue of drying shrinkage and relationship to pavement slab cracking debated since the early 1960’s
- Since then, some work done on:-
  - Shrinkage effects and material components and
  - Constructional process influences
- Not much strategic published research done on shrinkage testing in the last 30 years
- Work done on building structures, industrial pavements and concrete road pavements (UQ)
- Hotly debated issue in design, materials supply and constructional circles
ASCP & BG&E MT Project Objectives

• Develop a better understanding on the issue of drying shrinkage for concrete pavement designers and asset managers

• Develop a strategy to assess concrete shrinkage and cracking in pavements:-
  • Review impact of limestone addition in cements and changes in cement on concrete mix properties with respect to shrinkage and potential for increased cracking tendency in pavements
  • Consider the role of autogenous shrinkage and early age issues

• Ensure concrete pavement construction remains practical and durable
The test: What is does and does not measure

MEASUREMENT OF SHRINKAGE TO AS1012.13
AS1012.13 Test

- Sample made up of three prisms
  - 75 x 75 x 285 mm
  - Cured for 7 days
  - Conditioned at 23°C and 50% RH
  - Length change determined at 7 day intervals up to 56 days
  - Very crude test and high variability
  - Lower results do not mean lower crack potential

- AS1012.13 first published in 1970
- Revised and reissued in 1992
- Minor amendment in 1993
- Nothing since!
Shrinkage Specification

Build Structures and Industrial Pavement Experience

- Extensively used for structure design compliance
- “No result at 56 days shall be greater than 600µs”
- No account for variation in results from test (RH based)
- Referenced in AS3600
  - 800µs ± 30% for Sydney
  - 900µs ± 30% for Brisbane
  - 1000 ± 30% for Melbourne and elsewhere
- Specifications often generic with specified values lower than commonly achievable using local materials
- Cost implications of a low shrinkage mix:-
  - More expensive aggregates
  - Proprietary admixtures
  - Low slump and/or more laborious and/or higher risk placement methods
- Confusion between unplanned early age cracking and drying shrinkage
- Not handled well in contracts
Shrinkage in RMS Specifications

- **RMS R82 (Lean Mix)**

<table>
<thead>
<tr>
<th>Mix type</th>
<th>Maximum shrinkage strain (microstrain με)(^{(1)})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drying period</td>
</tr>
<tr>
<td></td>
<td>21 Days</td>
</tr>
<tr>
<td>GGBFS mixes(^{(2)})</td>
<td>700</td>
</tr>
<tr>
<td>Other mixes</td>
<td>550</td>
</tr>
</tbody>
</table>

**Notes**

1. To be tested only in the trial mixes.
2. For the purpose of this clause, a GGBFS mix is defined as having a minimum of 40% GGBFS (by mass of cementitious material).

- **R83 (Pavement Base)**

<table>
<thead>
<tr>
<th>Mix type</th>
<th>Maximum shrinkage strain (microstrain με)(^{(1)})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drying period</td>
</tr>
<tr>
<td></td>
<td>21 Days</td>
</tr>
<tr>
<td>GGBFS mixes(^{(2)})</td>
<td>580</td>
</tr>
<tr>
<td>Other mixes</td>
<td>450</td>
</tr>
</tbody>
</table>

**Notes**

1. To be tested only in the trial mixes.
2. For the purpose of this clause, a GGBFS mix is defined as having a minimum of 40% GGBFS (by mass).
Concrete Shrinkage:
Experience from Studies on Buildings and Pavements

- High variation in test results (higher than with compressive strength) due to many parameters that influence length change
- AS3600-2009 recognises variability and recommends a ±30% range to be taken into consideration in design
- Shrinkage test measurement begins at 7 days and therefore does not account for early age movement effects
- Shrinkage measured by test specimens does not reflect movement in structural elements
- Early age movement of concrete not reflected in the AS1012.13 test
  - Zero reading taken at 7 days following casting
  - First measurement of shrinkage recorded at 14 days
**What are data from laboratory results telling us?**

**DATA FROM LABORATORY STUDIES**

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Specific gravity</th>
<th>Absorption</th>
<th>1-year shrinkage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>2.47</td>
<td>5.0</td>
<td>0.116</td>
</tr>
<tr>
<td>Slate</td>
<td>2.75</td>
<td>1.3</td>
<td>0.068</td>
</tr>
<tr>
<td>Granite</td>
<td>2.67</td>
<td>0.8</td>
<td>0.047</td>
</tr>
<tr>
<td>Limestone</td>
<td>2.74</td>
<td>0.2</td>
<td>0.041</td>
</tr>
<tr>
<td>Quartz</td>
<td>2.66</td>
<td>0.3</td>
<td>0.032</td>
</tr>
</tbody>
</table>
What Influences Concrete Shrinkage and Cracking?

- Concrete materials
  - Cementitious materials
  - Aggregate
  - Water content
  - Admixtures
- Mix design
- Ambient conditions
- Design & detailing
- Restraint and joints
- Early age influences and site practices
Typical Shrinkage Data and Derived Variations

- Standard deviation of determined at different ages
- For a 95% confidence interval on typical data, require tolerance of ± 100-150 µs
Typical Shrinkage Data from a Sydney Project

- Sample size – 121
Typical Shrinkage Data and RMS B83.8 Shrinkage Requirement

- Non GGBFS mix specification shown
- AS3600 variation recommendations shown for sample size of 121 tests
AS1012.13 Test Data and Pavement Performance

• Work done at University of Queensland
• Aim was to investigate relationship between shrinkage in pavements and the AS1012.13 test on 2 series of lab tests
• 3 types of specimens cast:
  • Standard shrinkage specimens
  • ‘Free shrinkage’ small box slabs, and
  • Large slabs (1800 mmx1500 mmx180 mm) cast on bedding sand, moulds lined with plastic
AS1012.13 Test Data and Pavement Performance

<table>
<thead>
<tr>
<th>Time after casting</th>
<th>Slab Strains (Top) (microstrain)</th>
<th>Small Box Slab Strains (Top) (microstrain)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>HS</td>
</tr>
<tr>
<td>12 hours</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>One day</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>180 days</td>
<td>420</td>
<td>450</td>
</tr>
<tr>
<td>Change in strain from 12 hours</td>
<td>370</td>
<td>390</td>
</tr>
</tbody>
</table>

Change in strain almost identical across all mixes
The greatest shrinkage movement occurs on first drying, in first 6 hours after casting.

Early age shrinkage causes strains within the concrete at a time when its tensile strength is low, hence increased risk of cracking.

Specification of low 56 day AS1012.13 value will not control this phenomenon or guarantee reduced cracking.

Use of aliphatic alcohol significantly reduced the differential strains – other products optimising early age performance thought also to be beneficial.

Focus should be on crack control through good construction practice, managing restraint and appropriate mix design.
What are data from field work telling us?

DATA FROM FIELD STUDIES
Concrete Shrinkage and Cracking

• Early age (plastic) shrinkage
• Autogenous shrinkage
• Drying shrinkage
• Thermally induced movement
• Movement in concrete pavements
  • Early age movement of concrete is inevitable
  • Some degree of restraint is unavoidable
  • Concrete at early age has insufficient tensile capacity
R&D on an Industrial Pavement in Queensland

• Measured and modelled field joint movement
• What was considered
  • Magnitude of joint opening
  • Timing of joint opening
  • Drivers behind joint opening
Long Term Joint Movement and Influence of Temperature

\[ y = -0.2998x + 15.323 \]

\[ R^2 = 0.628 \]
What’s next

WHERE TO FROM HERE?
Current Issues

• Shrinkage data at 21 days appears to have increased over time on projects

• Many reasons for this canvassed:-
  • Potential increase in limestone content in cement
  • Possible change in cement grind and mineralogy over time
  • Variability in the test method itself
  • Demand for smaller aggregate size
  • Other factors

• ASCP, its members and related parties currently involved in investigations
Current Facts

• AS1012.13 first published in 1970 and has not changed much since
• Americans call this test a ‘length change’ test
• Not much research on the test since 1970
• Test originally formulated to get rid of breccia aggregates in concrete

• AS1012.13 favoured by designers, hated by material suppliers
• People are using other tests
  • ASTM C1581 restrained shrinkage ring test
  • Other restrained shrinkage tests (e.g. Bernard)
  • Box specimen test
  • Others
Future Strategy

- Work currently under way to consider a forward strategy
- Data being reviewed and ASCP members involved
- Other related parties also doing a significant amount of work
- There is conjecture and disagreement in the marketplace as to actual causes of observed shrinkage increases
- No additional cracking has been reported in pavements
- Research in this area has not been done for a long time – maybe now is the time to develop new knowledge
Concluding Thoughts

• We want concrete pavements to continue to be durable
• We want to be able to manage cracking
• There is nothing to suggest that pavement performance has reduced over time

• We want to accept good and appropriate materials
• We do not want to reject perfectly good materials
• We do not want to accept sub-standard materials