Twenty-First Annual Westford Symposium on Building Science
Westford, MA

Vapor Barriers In Compact Roof Assemblies

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Topics

• Problem Statements
• Concrete Basics
• Concrete and Moisture
• Field Examples
• Research
• Recommendations
• Questions
Problem Statements

• The roofing industry has seen a dramatic increase in moisture related failures from roofing over concrete roof decks, both new construction and reroofs.
  • The compressed schedules in new construction have seen General Contractors direct (demand) the installation over green concrete, after only days.
  • Most absurd report to SRI was 3 days!
  • Materials and techniques for installing roofs has changed focusing on labor efficiency and environmental friendly factors
Problem Statements

• The roofing industry has little to no guidance on the acceptance of the concrete substrate as suitable to begin installing a roof system.
  • The guidance that does exist for indirect testing of roof decks is typically legacy specification language tracing its origins to before I was born.
Basics of Concrete
Basics of Concrete

• Portland Cement is not concrete
  • Portland Cement is the binding agent
  • Concrete is the composite material
    • Aggregates
      • Coarse 40%-50% by volume
      • Fine 20% - 30% by volume
    • Portland Cement 15% -20% by volume
    • Water 15% -20% by volume
    • Additional “adds” typically <1%
Basics of Concrete

• Additional components
  • Fibers
  • Accelerators
  • Retarders
  • Water reducers
  • Air entrainment
  • Fly Ash
  • Silica Fume
  • Waterproofing
  • Magic Pixie Dust
Basics of Concrete

• Production of Concrete
  • Each batch plant will have hundreds or even thousands of recipes
    • Based on local aggregates and conditions
    • Requirements of order dictate which one they use
    • Developed over time
    • Science and trial & error

• Forms for roof decks
  • Strippable forms
  • Steel form deck
Curing of Concrete

• **Note** we are discussing curing not drying
• Chemical process of hydration
• All about compressive strength gain
• Loss of moisture during this process can have adverse effects
  • Moist cure
  • Protect from freezing
Curing of Concrete

• Structural Engineer specified strength
  • Typically specified at 28-day compressive strength
  • i.e. 5000psi at 28 days

• 28-days has nothing to do with moisture content only compressive strength
Moisture in Concrete
Factors That Affect Drying

- Climactic conditions
- Concrete surface condition
- Rewetting of concrete
  - Rain, snow, ice, condensate
- Capillary closure
Moisture in Concrete

- Effects of Curing and Drying Environments on Splitting and Tensile Strength of Concrete
  - J.A Hanson
  - 1968
Moisture in Concrete

Effects of Curing and Drying Environments on Splitting and Tensile Strength of Concrete - Hanson
Moisture in Concrete

Steel Form Deck = one way drying

Steel Deck
Moisture in Concrete

Steel Form Deck = one way drying

Vapor Retarder = moisture distribution
Moisture in Concrete

Stripped forms = 2 way drying
Moisture in Concrete

Stripped Forms = Two way drying

↓

Vapor Retarder = one way drying
Moisture in Concrete

• How do we measure moisture content of placed concrete?
  • Surface emission
  • Electrical resistance
  • Electrical impedance
  • Relative Humidity at depth
Moisture in Concrete

- ASTM D4263 Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method
- Very qualitative
  - Environmental conditions can greatly influence results / signal
- Easy and inexpensive
- Can give false negative
Moisture in Concrete
Moisture in Concrete

- ASTM F-1869 Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride
- Dish of Calcium Chloride is weighed before and after 24hr exposure under a clear lid
- Returns pounds of water emitted per 1000ft² per 24 hours
- Very old test
Moisture in Concrete

- Calcium Chloride test
Moisture in Concrete

• ASTM F-2420 Determining Relative Humidity on the Surface of Concrete Floor Slabs Using Relative Humidity Probe Measurement and Insulated Hood

• Uncommon test

• Uses a relative humidity probe placed on top of slab inside a small insulated box

• Gives indication of moisture at surface not what is in the slab

• Uncommon test
Moisture in Concrete

- Humidity Probe Measurement and Insulated Hood

http://www.esellersolutions.com/eSellerManager/images/upload/item/Southsurvey/itemImage_111_7_12_11_48_35.gif
Moisture in Concrete

- Electrical resistance measurement
- Drill two holes in concrete
- “brush” probes inserted and resistance between probes correlated to moisture content
- Not seen in the US currently
Moisture in Concrete

• Impedance measurement of concrete surface
• Electric field is passed through concrete
• Instrument reads out moisture content percentage.
• Only reads top 1.5 inches of slab
Moisture in Concrete

• Tramex CMEX II
Moisture in Concrete

• ASTM F-2170 Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes
• Drill hole in concrete deck
  • 40% of depth
• Relative humidity probe inserted into hole
  • Sealed
  • Recovered / read after 72 hours
    • (24 hours works just fine)
Moisture in Concrete

• ASTM F-2170 (Continued)

• Flooring manufacturers require minimum RH reading delivered via F-2170 before floor is allowed to be installed

• Wide acceptance

• Lots of Research
Moisture in Concrete

• Flooring industry struggled with the issue concrete floors and failures at the turn of the century

• Flooring manufacturers specify at what test values (moisture content) their products can be installed over concrete
  • Typical values range from 80% to 90% RH via F2170
Moisture in Concrete

• However floors and roofs exist in drastically different environments
  • Floors can be left till near the end of the construction cycle
  • Roof needs to go on very early
  • Floor typically has conditioned air
    • Temperature and humidity
  • Roof is exposed to weather
    • Rewetting
Bad and Worse

• So the flooring contractor has it easy right?
• Remember the Hanson graphs?
Bad and Worse

Effects of Curing and Drying Environments on Splitting and Tensile Strength of Concrete - Hanson
Bad and Worse

• Differences between Regular Weight Concrete (RWC) and Light Weight Structural Concrete (LWSC)

• Mass (approximate)
  • RWC 150 lb/ft³
  • LWSC 110 lb/ft³

• Starting water content
  • Regular weight aggregates have 8 - 15 lb/yd³ of concrete
  • Light weight aggregates have 150 – 200 lb/yd³ of concrete

• Both can achieve the same compressive strengths
  • LWSC does it with less weight
Bad and Worse

• Light weight aggregates
  • Expanded shales and clays
  • Alternately referred to as “pre-wetted aggregates”
  • Need to be ponded or soaked for days to months before being batched into a concrete mix
    • Water fills pores and prevents light weight aggregates from interfering with mix properties and performance

• Lightweight structural concrete has repeatedly been shown to take much longer than regular weight concrete to dry.
Recommended Reading

• Engineering Bulletin 119 : Concrete Floors and Moisture
  • Howard M. Kanare
  • 2008, Portland Cement Association
Field examples
(Train Wrecks)
Field Example #1

• Plaza deck on corporate campus
• Light weight structural concrete over steel deck
  • Too late in design to switch to regular weight concrete
• IRMA design with fluid applied and self-adhesive waterproofing sheets
• Deck allowed to cure / “dry” in summer heat for just over 3 months
Field Example #2

- East coast hospital
- Roof deck designed to be floor for future vertical expansion
  - Operating suites below roof deck
- Light Weight Structural Concrete on metal deck
- Fully adhered EPDM with tapered ISO
  - Low rise foam adhesive in ribbons
- In place for 3 years
Field Example #3

- Hospital in the upper Midwest
- Roof deck intended to be a floor for future vertical expansion
- Light Weight Structural Concrete on metal deck
- Fully adhered EPDM with tapered ISO
  - Low rise foam adhesive ribbon
Field Example #3

- Top floor unoccupied
- No leaks reported
- First indication was fully adhered membrane billowing in wind
  - Below design winds
  - 9 months after occupancy
- Manufacturer denied warranty coverage due to trapped moisture (interior moisture)
- Insurance company denied claim as defective construction
Research
Phase 1
Research Sponsors
Research Goals

• Primary Goal
  • Determine what moisture level in concrete decks is appropriate for roofing operations
    • New construction and reroof

• Secondary Goals
  • Study instrumentation capabilities for speed and accuracy in the determination of moisture levels in concrete roof decks
  • Study impact of weather and the phenomena of “rewetting” on moisture levels in concrete roof decks
Research Plan

• 4 Modules of the Phase 1
• Began preparation and planning Spring 2016
• Concrete pours occurred July 11, 2016
• Study is ongoing
  • New information learned reshapes hypotheses and direction of research
  • Phase 2 starting August-September 2017
Research Progress

• Phase 1 Full scale concrete weathering farm and lab samples
  • Received 20.43 inches of rain during the 16 week period
  • Tramex CMEX II - Concrete Moisture Meter used
    • No discernable difference between inside, outside, normal weight, light weight
    • Only was an indicator of recent rain
Research Progress

Tramex CMEX II - Concrete Moisture Meter Readings

Reading on Tramex

Slabs

- A
- B
- C
- D
- E
- F
- G
- H
- I
- J

Dates:
- 9/5/2016
- 9/8/2016
- 9/20/2016
- 10/2/2016
- 10/15/2016
- 10/21/2016
Surface is Dry

Moisture is down here!
Research Progress

• Phase 1
  • Use of F-2170 probes
    • Wagner Meters in Rogue River, Oregon provided hundreds of probes and accessories for this study.
      • Calibrated before use
      • Readings typically taken 1, 2, 3, 6, and 24 hours after placement weekly
        • Pans
        • Slabs
        • Replicates
        • Exterior pans brought in lab and probe again
    • Thousands of readings with confounding variables
    • Promising data need more time to study
Research Progress
F-2170 Inserted into Normal Weight Concrete (15 days after pour)
Research Progress

• Phase 2 Hygrothermal characterization of concrete
  • E96 Vapor Permeability
  • C1794 Water Absorption Coefficient
  • C1498 Hygroscopic Isotherm
  • C1699 Moisture Retention
Research Progress

• Module 2: Hygrothermal characterization of concrete

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<th>Dry Cup</th>
<th>Wet Cup</th>
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ASTM E96 calculated Perm·in
Research Progress

• Module 3 Hygrothermal modeling
  • WUFI 5.3 Pro Hygrothermal program utilized

• Consulting with justSmartSolutions the U.S. partner of the German software vendor

• The data output from the modeling has been validated with Module 1 data

• Let us look at some of the thing we can opine from just the simple graphs!
Normal Weight Concrete – Lab Dry Down (4 Months)
Top 1 inch of slab
Normal Weight Concrete – Outdoor Dry Down (4 Months)
Top 1 inch of slab
Total Water Content per Ft$^2$ of slab Regular Weight Concrete Chicago, IL (4 Mo.)
Total Water Content per Ft² of slab Regular Weight Concrete Phoenix, AZ (4 Mo.)
Total Water Content per Ft$^2$ of slab Regular Weight Concrete Edmonton, CAN (4 Mo.)
Research

- Used hygrothermal data for current generation roofing materials
- Simulated roof slabs outdoors for 28 days then roofed
- With and with out vapor retarders
- 100’s of combinations
Research

• Desert southwest generally ok without a vapor retarder
• Canada...just plan on a vapor retarder
• Southern tier states...maybe
  • Atlanta slab goes down July 1 = ok with no vapor retarder
  • Atlanta slab goes down December 1 = fail without a vapor retarder
• So...do I need a vapor retarder...it depends
Recommendations

• Preliminary findings of concrete research program point to a distinct issue with slabs in northern and humid climates.

• Work on hygrothermal simulations and their validation is ongoing (Phase 2).

• But given the currently available research data and observations from it, this researcher is recommending that:
  • Unless the Designer of Record approves in writing otherwise, a vapor retarder of less than 0.01 perm is necessary over new concrete roof decks.

• The impact of rewetting on existing concrete decks (reroof) and moisture laden roof systems is being determined.
Thank You

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