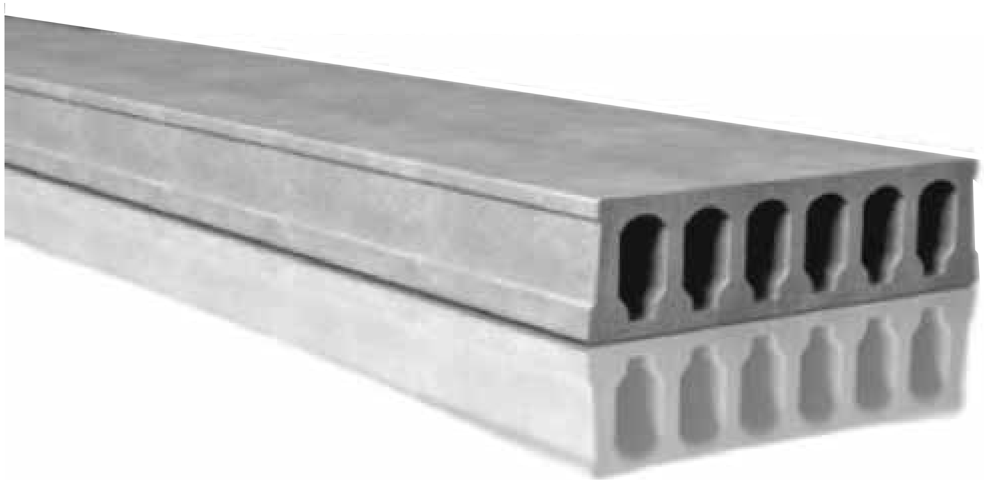
Maturity and quality control



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Maturity - Definition

- **Anton K. Schindler (3)**
  - The maturity method is an approach used to account for the combined effect of temperature and time on the development of concrete mechanical properties and the development of hydration.
- **Short - Maturity Method:**
  - Describes Relationship between:
    - Temperature & Time and
      - Level of Hydration
      - Strength
  - This Presentation:
    - The Term "Maturity" alone means "Level of Hydration"

Maturity – Importance of Temperature

- **'Mathematical Definition**
  - 1889 Arrhenius (1): Chemical Reaction Temperature Dependence:

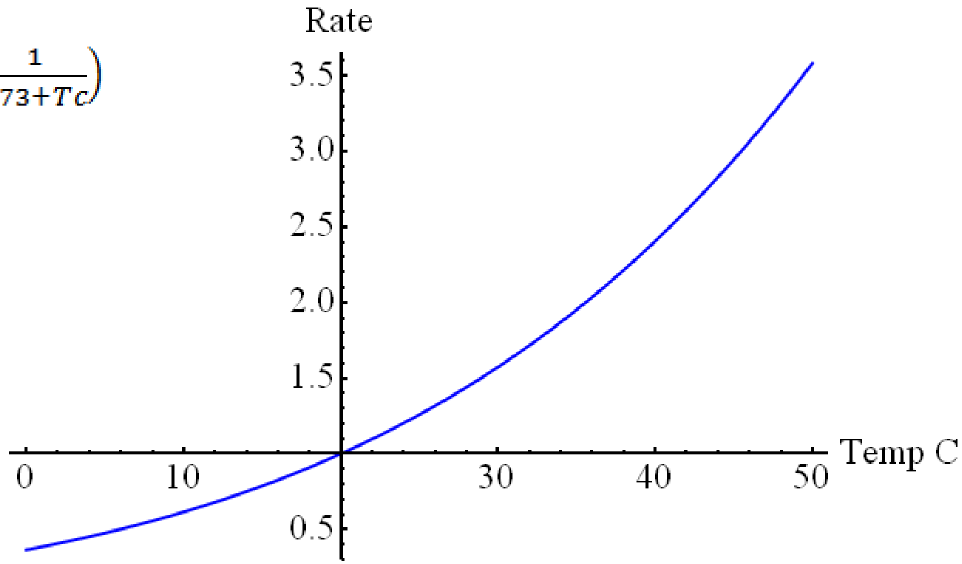
    $\mathrm{k} = \mathrm{A}\, e^{-\frac{Ea}{RT}}$ → Exponential Relationship!

  - 1977: Freiesleben Hansen and Pedersen (3):
    Defined *Equivalent Time (te)* based on Arrhenius Equation:

    $t_e(\mathrm{t}, \mathrm{Tc}) = \sum_0^t e^{\frac{Ea}{R}\left(\frac{1}{273+Tr} - \frac{1}{273+Tc}\right)} \Delta t$

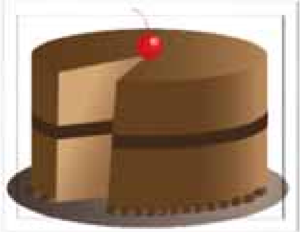
  - Rate defined by: $e^{\frac{Ea}{R}\left(\frac{1}{273+Tr} - \frac{1}{273+Tc}\right)}$

  - Activation Energy (Ea):
    - Controls Rate at Tc <> 20 C
  - Tc = 20 C → te = Real Time:
    - Rate = 1, Independent of Ea



Maturity - Curing

- **The importance of curing:**
  - Evan Gurley's (1) Article "*To cure or not to cure*":
    - Precasters Focus on Creating the Perfect Mix.
    - *Curing Phase does not Receive the Attention Needed*.
- **Curing is like Baking a Cake:**
  - There is a Recipe, and there is Baking / Curing.
    - Insufficient / Too Much Baking can Ruin any Cake.



  - Precast Production: Little or no Curing Data is Collected!
  - Too many Plants are in Conflict with Established Rules
    - Lack of Knowledge and / or Equipment providing Feedback?
  - Today: Equipment Calculating & Documenting Curing Data exists
    - But not used by many…

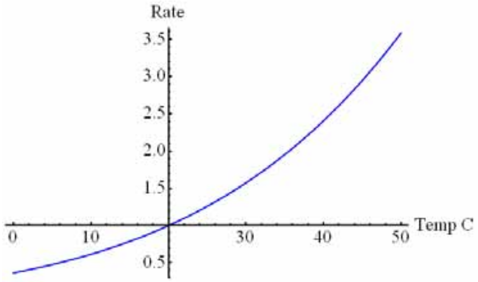
Maturity - Calibration

- **As seen, Temperature Dependency varies with Ea.**
  - Maturity Equipment must know Ea for Calculations.
- **Traditionally, Ea calculations are Time Consuming (Days)**
  - Experts do not agree on Ea values….
    a. Anton K. Schindler (3): "..there are contradictory recommendations in literature regarding the selection of an activation energy value".

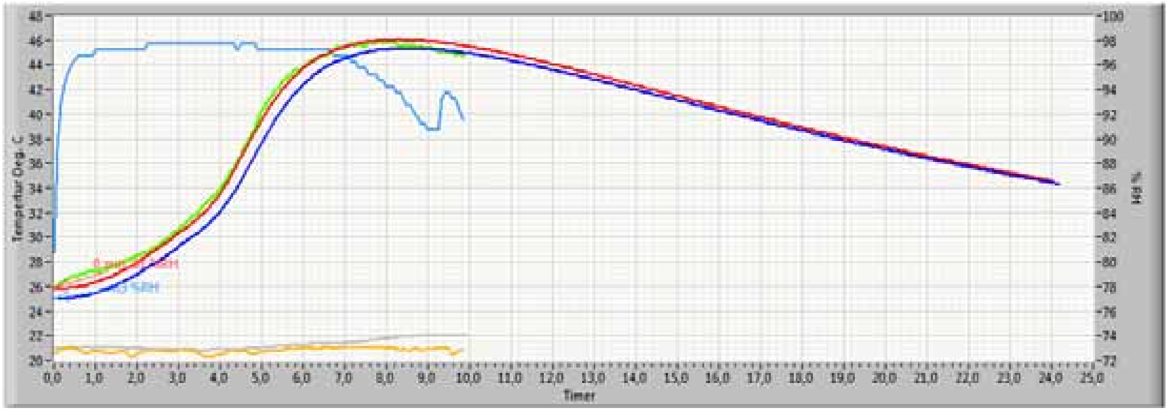
- **Calibration Data not up to Date → Loose Valuable Data:**
  - When Introducing new Recipes
  - When testing changes to Recipes
- **Objective Technology:**
  - Developed Technology to Calculate Ea Parameters for ***HPC-09 v6***.
  - Calibration performed in < 1 Hour.

Maturity – Concrete Temperature

- **How Temperature affects Maturity (Curing)**
  - Concretes with same Equivalent Age (te1) has Same Maturity.
    - Regardless of Temperature to reach te1!
  - Concrete at High Temperature reaches te1 faster.
  - There is no Cross-Over Effect for Maturity (3)



Stable Production: Measured Temp (Green) matches **Amplitude** & **Shape** of Predicted Temp (Red)



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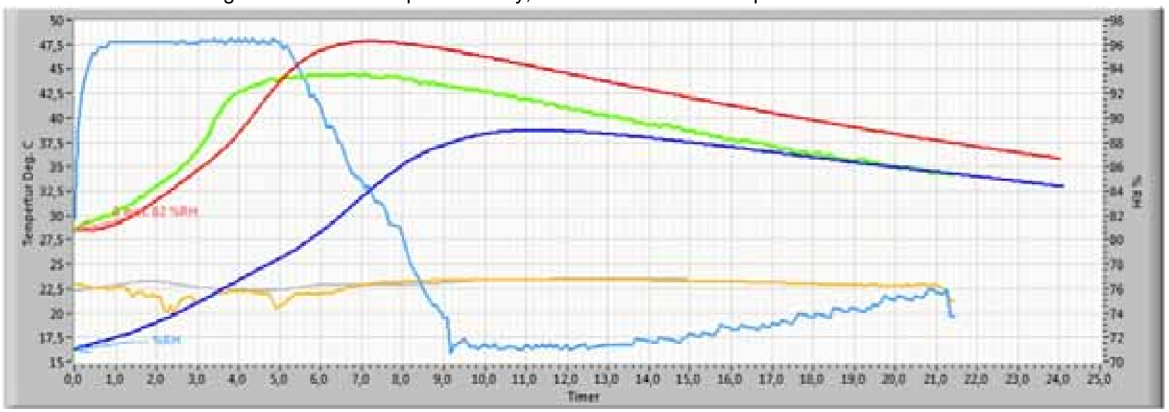
Maturity – Ambient Humidity

- **How Ambient Humidity affects Maturity (Curing)**
  - Ambient Humidity is Relative Humidity (%RH) under Bed Covering
  - Helps keep valuable water in Concrete
    - Important for Low W/C Precast Concrete!
  - Reduces Temperature Loss through Evaporation

Leak Bed Cover: Curing “Dies” – Blue Graph: Humidity, Green: Measured Temperature



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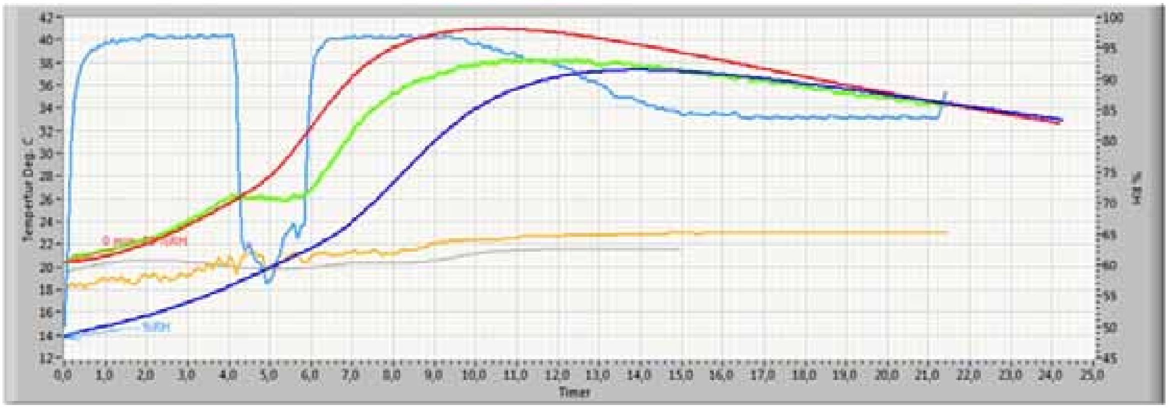
Maturity – Bed Covering

- **How Bed Covering affects Maturity (Curing)**
  - Helps keep the Relative Humidity (%RH) High
  - Keeps Water in Concrete for Curing Process to Complete.
  - Immediate Covering → %RH Rises to > 90% in 20-25 minutes
  - 30 min Delayed Covering → ~ 30 min prolonged Curing Time!

Bed Cover Removed 4-6 Hours – Blue Graph: Humidity, Green: Measured Temperature



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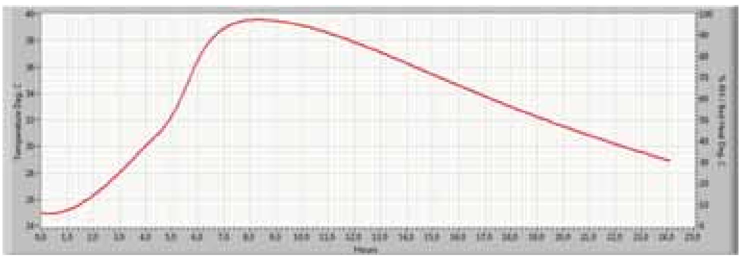
Maturity – Ambient Conditions

- **How Ambient Temperature & Draft affect Curing Time**
  - Lower Ambient Temperature
    - Increases Temperature Loss through Convection → Slows Curing
  - Wind Accelerates Evaporation & Increases Convection
    - Temperature Drops → Slows Curing
  - Example Fly Ash Concrete: 25 C Pouring Temp, 20 C Ambient Temp
    - 1 m/s wind→ ~ 04:10 Hour prolonged Curing Time!



HPC-09 v6 Data: 0 m/s Wind. Curing Time 16:50

Corrected Meas. Ta / HH.MM	Corrected Measured %RH	Corrected Meas. Ts	Corrected Bed Heat Time	Corrected Calc. Curing Time	Corrected Calc. Tmax	Corrected Calc. tmax
20,0	----	25,0	00:00	16:50	39,5	08:37

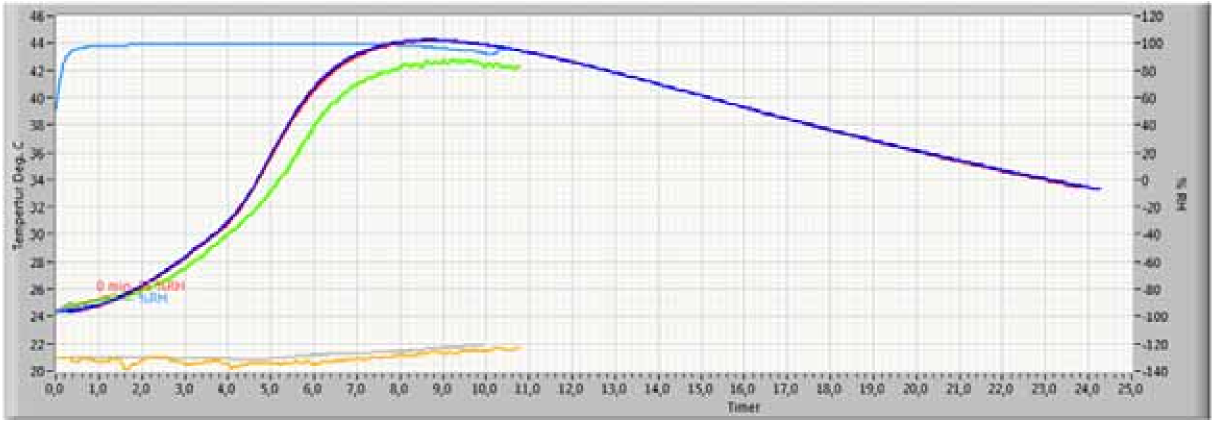
HPC-09 v6 Data: 1 m/s Wind. Curing Time: 21:00

Corrected Meas. Ta / HH.MM	Corrected Measured %RH	Corrected Meas. Ts	Corrected Bed Heat Time	Corrected Calc. Curing Time	Corrected Calc. Tmax	Corrected Calc. tmax
20,0	----	25,0	00:00	21:00	34,3	08:02

Maturity – Other Variables

- **Recipe (Mix)**
  - Amount of C3A & C3S in the Recipe:
    - *C3S content may vary up to 22% between suppliers and between batches from the same supplier. C3A content may vary up to 16%! (5)*
- **Water / Cement Ratio, Amount of Cement & other Ingredients**
  - Varies due to Tolerances and / or Errors in Dosing Equipment

Too little Cement: Variation due to Problems with Cement Weight.
Red Graph (under Blue): Predicted Temperature, Green Graph: Measured Temperature.



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Quality - Observations

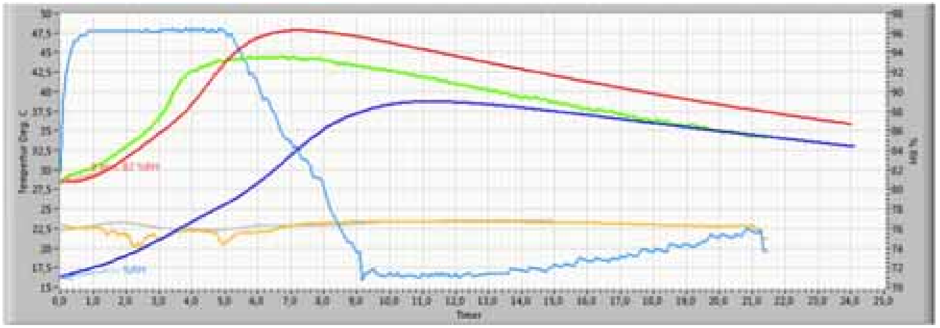
- **Quality is Not an Accident!**
- **Where Does Quality Start?**
  - At the Management Level?
  - At Production Level?
  - None of the above:
    - It must be Implemented at all Levels of the Organization Simultaneously!

- **Equipment Alone does Not Guarantee Quality!**
  - But Equipment <u>can</u>:
    - Provide Valuable Feedback to a Quality Focused Organization
    - Make Production more Efficient
    - Provide valuable Documentation to Customers
      - E.g. Provide Documentation of the “Baking” (Curing)
      - And not Only on the Recipe (From mixing equipment)
- **Tweet, Sept. 22. 2014 (Geir Ove):**
    - Engineers Measure to diagnose systems:
      Concrete Mixers have few or no "Curing Tools" in their Toolbox.

Quality – Detecting Discrepancies (1/6)

- **Measured Concrete Temperature may Reveal:**
  - Deviation in Amount of Cement
  - Deviation in Cement Percentage C3A / C3S
  - Deviation in Water / Cement Ratio

Leak Bed Cover: Curing “Dies” – Blue Graph: Humidity, Green: Measured Temperature



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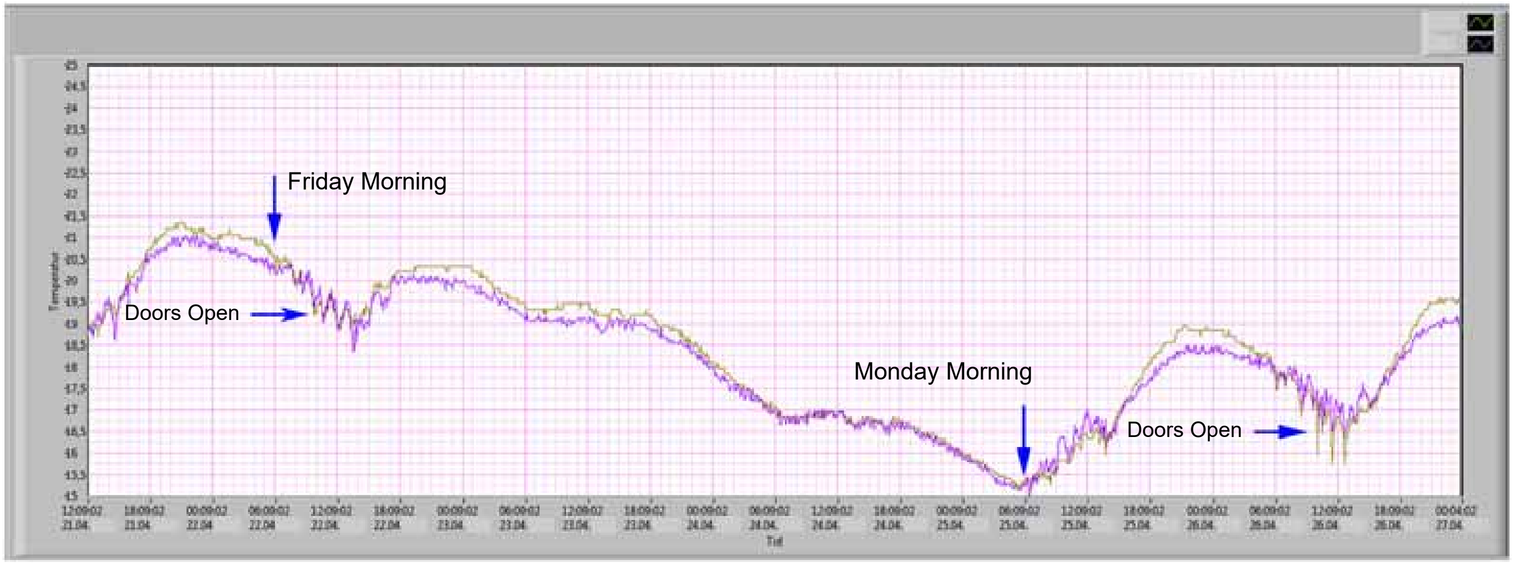
  - Alarming in Case above:
    - Parts of Concrete may contain too Little Water for Curing to Complete
      - Maturity Strength Calculations is then Not Valid!

Quality – Detecting Discrepancies (2/6)

- **Measured Ambient Air Temperature (Ta) may Reveal (1/2):**
  - Door Opening in Production Environment →
    - Temperature Drops, Draft Increases → Increases Heat Loss
    - Graph below shows Ta over a Period of 6 Days:
    - Example below shows how Ta drops over weekend to 15 C on Monday
    - Door Opening Friday Afternoon Drops Hall Temp. ~1.5 C.
    - Door Opening Tuesday at Noon is very Limited

Ambient Air Temperature over a Period of 6 Days: Green / Blue Graph : End 1/ End 2 of Production Environment

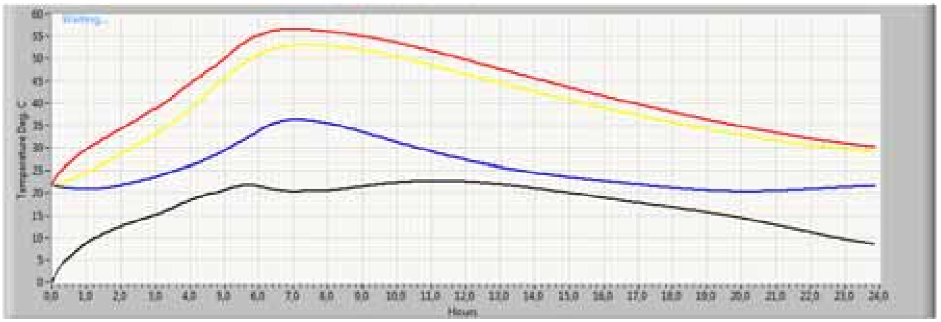


HPC-09 v6 Data

Quality – Detecting Discrepancies (3/6)

- **Measured Ambient Air Temperature (Ta) may Reveal (2/2):**
  - Door Opening in Production Environment →
    - Prolonged Curing Time
    - Increases Cross Sectional Temperature Difference
    - Max = 20 C according to EN-13369

Red Graph: Temp. Bottom, Yellow: Temp. Center, Blue: Temp. Edges, Black: Max Difference



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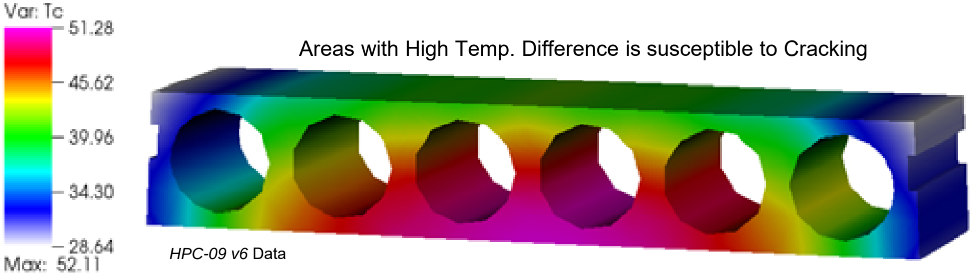
Areas with High Temp. Difference is susceptible to Cracking



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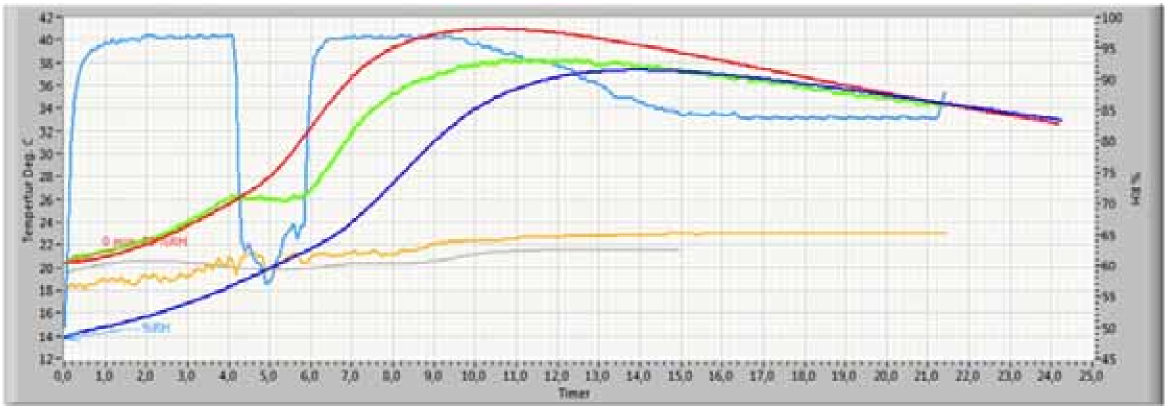
Quality – Detecting Discrepancies (4/6)

- **Measured Ambient Humidity may Reveal:**
  - Time for adding / removing Bed Cover
    - Should be added at the latest 10 min after Extruder
    - Should be left on until Target Strength Reached
  - Leak Bed Cover
  - Too Low Water / Cement Ratio

Bed Cover Removed 4-6 Hours – Blue Graph: Humidity, Green: Measured Temperature

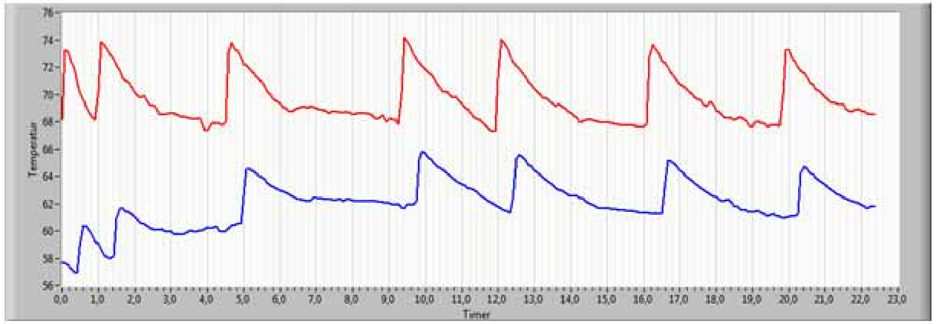


HPC-09 v6 Data

Quality – Detecting Discrepancies (5/6)

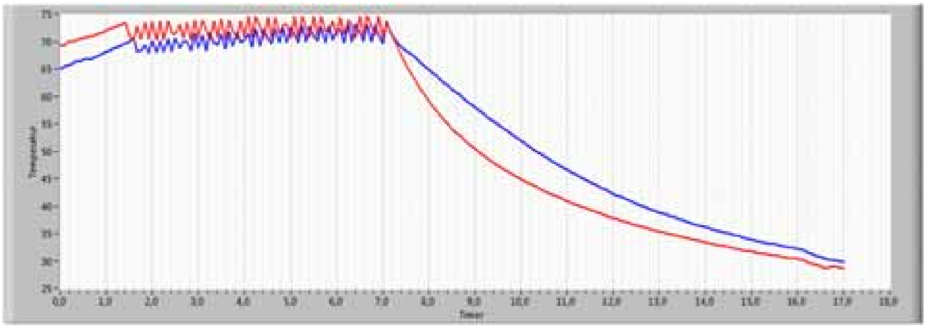
- **Measured Fluid Based Bed Heating may Reveal:**
  - Insufficient Capacity of Bed Heating System with respect to:
    - Ramp Up Speed: Bed Heat Temp. First ~30 minutes Critical!
    - Total Available Energy
    - Temperature Regulation: Fast / Slow
    - Flow Speed

Slow Circulation Time : ~30 min from Graph → Large Temp. Diff. between In and Out



HPC-09 v6 Data

Fast Regulation & Circulation Time : ~8 min from Graph → Low Temp. Diff. between In and Out

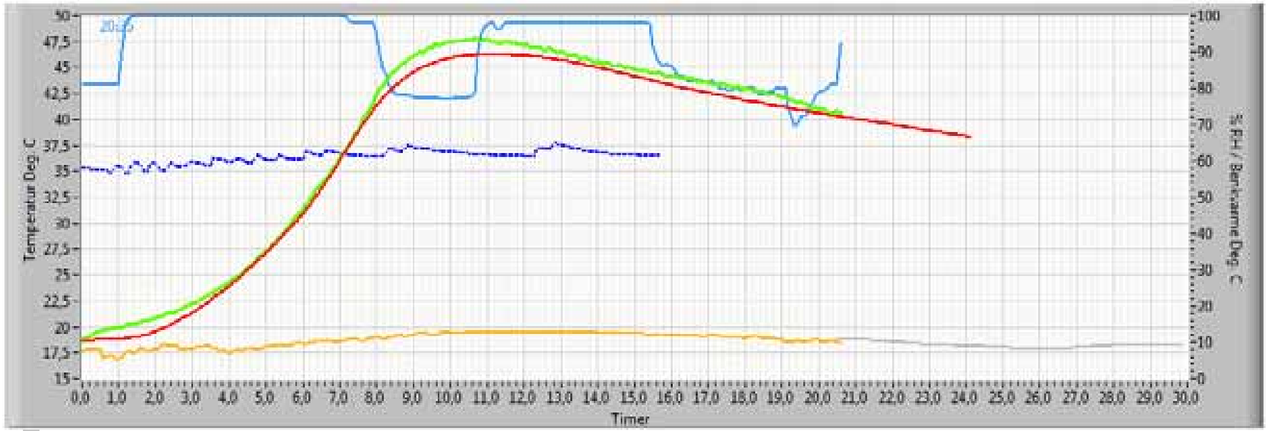


HPC-09 v6 Data

Quality – Detecting Discrepancies (6/6)

- **Reliable Discrepancy Detection Requires:**
  - A Sound Model
  - Performing Recalculation of Prediction using Available Data:
    - Actual Measured Ambient Air Temperature
    - Actual Measured Bed Water Temperature
  - Discrepancy when:
    - Shape of Measured Concrete Temp. (Tc) Deviates from Predicted
    - Amplitude of Tc Deviates from Predicted

Delayed Corrected Prediction (Red Graph), Measured Concrete Temperature (Green Graph)
Actual Measured Air (Orange Graph) and Bed Water Temperature (Dark Blue):
Grey Graph: Predicted Air Temperature



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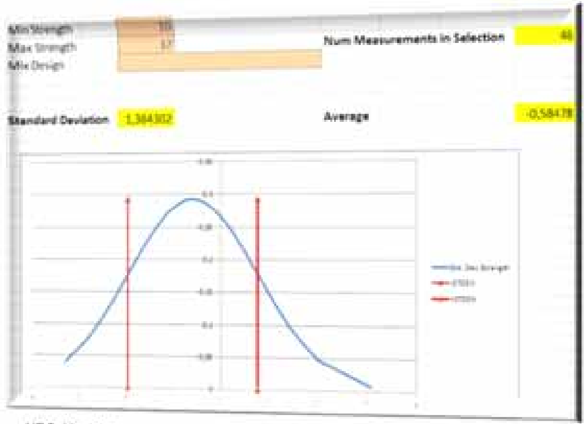
Quality – Stable Production

- **A Stable Production Controls the following Parameters:**
  - (In Addition to parameters already controlled by internal Quality Regime)
  - Ambient Temperature & Draft
  - Ambient Humidity / Bed Covering
  - Measured Concrete Temp. Shape & Amplitude == Predicted Temp.
- **Stable Production is characterized by:**
  - Low 28 day Strength Standard Deviation
  - Low (< 20 C) Cross Sectional Temperature Difference
  - Strength at Lifting Zone > Requirement
  - %RH (> 90%) from t=20 min to tmax (*)

(*) Legend:

- %RH - % Relative Humidify (Under Bed Cover)
- t = Time
- tmax = Time when Concrete Temp reaches Max



HPC-09 v6 Data

Discussion

- **Time for Questions!**

References

(1) **Predicting Temperature Rise and Thermal Cracking in Concrete**

- Graduate Thesis by Michael Edward Robbins 2007
  Department of Civil Engineering
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(2) **To Cure or Not to Cure?**

- Evan Gurley. May-June 2011 Issue of Precast Inc. Magazine.
  http://precast.org/2011/07/to-cure-or-not-to-cure/

(3) **Effect of Temperature on Hydration of Cementitious Materials**

- Anton K. Schindler. ACI Materials Journal, Title no. 101-M09
  a. Quotes: The ASTM C 1074 procedure is based on strength tests, and the question becomes whether or not these test results are valid for use during hydration prediction.
  b. The use of an activation energy determined from strength testing is not recommended for the purpose of predicting the progress of hydration.

(4) **HPC-09 v6 – Calibration Technology**

- http://www.objective.no/cal

(5) **Variation in Cement Properties and Its Effect on Quality of Concrete**

- Thushara PRIYADARSHANA and Ranjith DISSANAYAKE
  University of Peradeniya, 20400, Sri Lanka