CURRENT DEVELOPMENTS OF RILEM TC 254-CMS

‘THERMAL CRACKING OF MASSIVE CONCRETE STRUCTURES’

Eduardo Fairbairn, UFRJ, Brazil – TC Chair
Miguel Azenha, UMinho, Portugal – TC Secretary
SCOPE

- Knowledge integration on thermal cracking of massive concrete in recent years:

1998

2003

2013
SCOPE

• Knowledge integration on thermal cracking of massive concrete in recent years:
SCOPE

• Rather interesting developments in several fields in recent years

- Larger computational power
- New experimental techniques, new knowledge
- Sustainability issues
- Multi-scale modelling
The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM, from the name in French)

- Founded in 1947 – post WW2 effort
- Covers 70+ countries
- Purpose of the association is to advance scientific knowledge related to construction materials, systems and structures and to encourage transfer and application of this knowledge world-wide.
RILEM Technical Committees TC’s

Cluster A. Material Processing and Characterization
Cluster B. Transport and Deterioration Mechanisms
**Cluster C. Structural Performance and Design**
Cluster D. Service Life and Environmental Impact Assessment
Cluster E. Masonry, Timber and Cultural heritage
Cluster F, Bituminous Materials and Polymers
RILEM TC 254-CMS Thermal Cracking of Massive Concrete Structures

Genesis

Created in 2013 by Eduardo Fairbairn (Chair) and Roberto Torrent (Secretary)

Roberto Torrent steps down in 2014 and is replaced by Miguel Azenha
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Main objectives

Initially centred in establishing a state-of-the-art-report (STAR) on principles, criteria, methods and technologies applied worldwide to control thermal cracking in mass concrete, such as concrete dams, nuclear power plants, massive foundations, and massive members of concrete structures (including those in which cracking risk does not arise from large volumes of concrete).

Establishment of guidelines on how to analyse and to control the risk of thermal cracks in mass concrete.

Lifespan of 5 years -> expectable end in 2018/2019
(extension possible)
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Management and members

Chair (Strategic) + Secretary (Executive)

Members – 43 so far – RILEM Membership mandatory

Europe
South America
South Africa
China
Japan!
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Online meetings

Normally up to 20 participants in several of our meetings.
Webcam and screen sharing.
Not a replacement of personal meetings -> rather a complementarity

Some rules

Use headset
Mute microphone when not speaking
Use ‘raise hand’ tool
Often disable camera to increase bandwidth availability
Shared screen with meeting minutes being updated
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Common Data Environment and Collaboration
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Real time collaborative editing of meeting minutes during WEBEX conferencing
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Initial preparation of the STAR – Collaborative editing of chapters in GoogleDrive

- Simultaneous edits were possible
- No need for updating
- Colour code for each author
- Commenting boxes
- Automatic warnings about edits
- Time to concentrate on ‘science’
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Final preparation of the STAR – Transition towards DROPBOX

- STAR to be edited by Springer with specific MSWord templates
- Chapter structure and much content stabilized in January 2016

Migration to Dropbox

Importance of DROPBOX Badge
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Record of meetings and activities

- 1\textsuperscript{st} - Cachan (France) at ENS Cachan – 3\textsuperscript{rd} September 2013
- 2\textsuperscript{nd} – WEBEX – 11\textsuperscript{th} April 2014 – 15 participants
- 3\textsuperscript{rd} - WEBEX – 22\textsuperscript{nd} July 2014 – 18 participants
- 4\textsuperscript{th} – São Paulo (Brazil) – 4\textsuperscript{th} September 2014
- 5\textsuperscript{th} – WEBEX – 21\textsuperscript{st} November 2014 – 19 participants
- 6\textsuperscript{th} - Cachan (France) at ENS Cachan – 18\textsuperscript{th} March 2015

End of meeting 6
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Workshop of RILEM TC-CMS - “Cracking of massive concrete structures”

E-book of presentations available online (>500 slides).
(available in RILEM website)
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Record of meetings and activities

- 7th – WEBEX – 28th September 2015 – 15 participants
- 8th – Rio de Janeiro – 17th December 2015 (mixed WEBEX participation)
- 9th - WEBEX – 25th January 2016 – Only chapter leaders DROPBOX migration
- 10th – WEBEX – 27th April 2016 – 16 participants
- 11th – Lyngby (Denmark) – 25th August 2016
- 12th – WEBEX - 2nd May 2017

During meeting 12
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The state-of-the-art report of RILEM TC 254-CMS

Ch. 1 – Introduction
Ch. 2 – Hydration and heat development
Ch. 3 – Thermal properties
Ch. 4 – Mechanical properties
Ch. 5 – Mixture proportioning for crack avoidance
Ch. 6 – Temperature control
Ch. 7 – Numerical modelling
Ch. 8 – Cracking risk and regulations
Ch. 9 – On-site monitoring
Ch. 10 – Sustainability aspects in mass concrete

From basic science to practitioner point of view

Wide review – Not recommendations

Leading author strategy
2. Hydration and heat development

2.1 Physical phenomena
   2.1.1 Hydration reactions
   2.1.2 Definitions
   2.1.3 Heat generation

2.2 Modelling of hydration development
   2.2.1 Thermal activation of hydration development
   2.2.2 Methods based on the equivalent time
   2.2.3 Models based on affinity laws
   2.2.4 Microstructural models
   2.2.5 Data mining approach
   2.2.6 Inverse analysis approach
3. Thermal properties

Mateusz Wyrzykowski[^1], Agnieszka Knoppik[^2], Wilson R. Leal da Silva[^3], Pietro Lura[^4], Tulio Honorio[^5], Yunus Ballim[^6], Miguel Azenha[^8]

3.1 Heat transport and temperature change
   3.1.1 Thermal conductivity
   3.1.2 Heat capacity
   3.1.3 Exchange of heat with environment

3.2 Coefficient of thermal expansion
   3.2.1 Evolution of CTE during hardening
   3.2.2 Dependence of CTE upon mix composition

[^1]: [Author 1]
[^2]: [Author 2]
[^3]: [Author 3]
[^4]: [Author 4]
[^5]: [Author 5]
[^6]: [Author 6]
[^7]: [Author 7]
[^8]: [Author 8]
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4. Mechanical properties

4.1 Introduction
4.2 Quasi-Static behavior of concrete and steel/concrete bond
  4.2.1 Compressive strength
  4.2.2 Tensile strength
  4.2.3 Young modulus
  4.2.4 Poisson ratio
  4.2.5 Strain capacity
  4.2.6 Fracture energy
  4.2.7 Steel concrete bond
  4.2.8 Multiaxial stress state
4.3 Shrinkage
  4.3.1 Autogenous shrinkage
  4.3.2 Plastic and Drying shrinkage
4.4 Creep
  4.4.1 Basic creep
  4.4.2 Drying creep
  4.4.3 Transient thermal creep
5. Mixture proportioning for crack avoidance

Stéphanie Staquet¹, Brice Delsaute¹, Neven Ukrainczyk², Eduardus A.B. Koenders², E.Fairbairn³, A. Knoppik⁴, Miguel Azenha⁵

5.1 Overview
5.2 Aggregates
5.3 Water to cement ratio
5.4 Admixtures
5.5 Cement
5.6 Supplementary cementitious materials
   5.6.1 Slag / Fly ash
   5.6.2 Silica fume
   5.6.3 Other SCMs
5.7 Mix design methods for conventional mass concrete
5.8 Mix design methods for roller compacted mass concrete
5.9 Specifically tailored mixes in real cases for cold, mild and hot climates
6. Temperature control

Miguel Azenha¹, Ioannis P Sfikas², Mateusz Wyrzykowski³, Selmo Kuperman⁴, Agnieszka Knoppik⁵

6.1 Introduction
   6.1.1 General considerations
   6.1.2 Outline of strategies for temperature control
   6.1.3 Regulatory and non-regulatory frameworks of temperature control

6.2 Pre-cooling of mix constituents and cooling during mixing
   6.2.1 General considerations
   6.2.2 Prediction of mix temperature
   6.2.3 Cooling mixing water
   6.2.4 Introduction of ice in the mix
   6.2.5 Cooling aggregates
   6.2.6 Cooling other constituents
   6.2.7 Cooling by injection of liquid nitrogen

6.3 Transport and placement
   6.3.1 Temperature issues during transport
   6.3.2 Temperature issues during placement

6.4 Surface measures for temperature control

6.5 Post cooling of mass concrete
   6.5.1 Strategic background for post-cooling
   6.5.2 Post cooling with water circulation
   6.5.3 Post cooling with air circulation

6.6 Construction phasing
7. Numerical modelling

Francesco Pesavento¹, Agnieszka Knoppik-Wróbel², Vít Šmilauer³, Matthieu Briffaut⁴, Pierre Rossi⁵

7.1 Introduction

7.2. Thermo-chemo-mechanical models
   7.2.1 Thermal conduction through the concrete
   7.2.2 Constitutive relations / couplings

7.3 Multifield models: single fluid models
   7.3.1 Phenomena taken into consideration
   7.3.2 Coupled formulation and data flow
   7.3.3 Mathematical formulation and constitutive relationships
   7.3.4 Validations of single-fluid models
7.4 Multifield models: advanced multiphase modelling
   7.4.1 Concrete as multiphase porous material
   7.4.2 Heat and mass transfer
   7.4.3 Key points for modelling cement-based materials as multiphase porous media
   7.4.4 Mechanical modelling
   7.4.5 Boundary conditions
   7.4.6 Numerical formulation
   7.4.7 Application of the proposed approach

7.5 Modelling mechanical behaviour
   7.5.1 Damage models
   7.5.2 Plasticity models

7.6 Probabilistic modelling of mechanical behaviour
   7.6.1 Probabilistic explicit and semi-explicit cracking model for concrete
   7.6.2 Concrete-rebar bond model
7. Numerical modelling

Francesco Pesavento, Agnieszka Knoppik-Wróbel, Vít Šmilauer, Matthieu Briffaut, Pierre Rossi

7.6 Probabilistic modelling of mechanical behaviour
   7.6.1 Probabilistic explicit and semi-explicit cracking model for concrete
   7.6.2 Concrete-rebar bond model
   7.6.3 Probabilistic explicit cracking model for FRC
   7.6.4 Example of application of the numerical model related to RC structures
   7.6.5 Example of application of the numerical model related to FRC structures

7.7 Exchange with environment
8. Cracking risk and regulations

A. Knoppik¹, J.-M. Torrenti², S. Asamoto³, E. A. B. Koenders⁴, D. Schliche⁵, L. Ebensperger⁶

8.1 Introduction – significance of cracking
  8.1.1 General considerations about crack width
  8.1.2 Crack width and performance

8.2 Crack risk prediction
  8.2.1 Role of boundary conditions
  8.2.2 Stress approach vs strain approach
  8.2.3 Stress approach and cracking index
  8.2.4 Strain approach and strain capacity
  8.2.5 Simplified method for macrocrack assessment

8.3 Crack width estimation
  8.3.1 Model Code 2010
  8.3.2 Eurocode 2-3
  8.3.3 ACI 224
  8.3.4 JCI Guidelines
  8.3.5 Return on the probabilistic aspects of cracking
8. Cracking risk and regulations

A. Knoppik¹, J.-M. Torrenti², S. Asamoto³, E. A. B. Koenders⁴, D. Schlicke⁵, L. Ebensperger⁶

8.4 Reinforcement design
  8.4.1 Crack width control on the basis of force equilibrium
  8.4.2 Crack width control on the basis of deformation compatibility
9. On-site monitoring

Dirk Schlicke¹, Fragkoulis Kanavaris², Miguel Azenha³

9.1 General remarks
   9.1.1 Opportunities and limitations of on-site monitoring in mass concrete
   9.1.2 General setup of an on-site monitoring
   9.1.3 Analysis of results

9.2 First level of measures: recording of external conditions
   9.2.1 Purpose and benefits / insights
   9.2.2 Common sensors and peculiarities
   9.2.3 Experiences and observations from application
   9.2.4 Verification

9.3 Second level of measures: temperature measurements in the concrete
   9.3.1 Purpose and benefits / insights
   9.3.2 Common sensors and peculiarities
   9.3.3 Experiences and observations from application
   9.3.4 Verification
9. On-site monitoring

Dirk Schlicke¹, Fragkoulis Kanavaris², Miguel Azenha³

9.4 Third level of measures: monitoring of strain histories
   9.4.1 Purpose and benefits / insights
   9.4.2 Common measurement equipment and peculiarities / appropriateness
   9.4.3 Experiences and observations from application

9.5 Fourth level of measures: determination of stress histories
   9.5.1 Purpose and benefits / insights
   9.5.2 Common measurement equipment and peculiarities / appropriateness
   9.5.3 Experiences and observations from application
   9.5.4 Verification

9.6 Selected application examples
   9.6.1 Ground slab Boxberg (vibrating wires and stressmeter)
   9.6.2 VeRCoRS (fibre optics)
10. Sustainability aspects in mass concrete

Neven Ukrainczyk, Eduardus A. B. Koenders

10.1 Introduction
10.2 Materials selection
  10.2.1 Binders: cement, pozzolans and fillers
  10.2.2 Water
  10.2.3 Aggregates
  10.2.4 Fibre reinforcement

10.3 Mix design and material properties
  10.3.1 Ground Granulated Blast Furnace Slag (GGBFS)
  10.3.2 Coal fly ash (FA)
  10.3.3 Woody ash
  10.3.4 Sugarcane bagasse ash (SCBA)
  10.3.5 Rice husk ash (RHA)
  10.3.6 Synergy effect of multi-component binder blends
  10.3.7 Recycled Aggregate Concrete (RAC)
  10.3.8 Fibre reinforcement
10. Sustainability aspects in mass concrete

Neven Ukrainczyk, Eduardus A. B. Koenders

10.4 Life cycle assessment (LCA)
10.4.1 LCA background
10.4.2 LCA limitations
10.4.3 LCA of binders
10.4.4 LCA of aggregates
10.4.5 LCA of concrete
10.4.6 LCA of Reinforced Concrete Structure

10.5 Conclusion

<table>
<thead>
<tr>
<th>Product</th>
<th>Produced amount</th>
<th>Market price</th>
<th>Mass allocation, %</th>
<th>Economic allocation, %</th>
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<tbody>
<tr>
<td>Electricity</td>
<td>2.7 kW h/(kg of hard coal)</td>
<td>0.1 Euro/(kW h)</td>
<td>87.6</td>
<td>99.0</td>
</tr>
<tr>
<td>FA</td>
<td>0.14 kg</td>
<td>20 Euro/t</td>
<td>12.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Steel</td>
<td>1kg</td>
<td>400 Euro/t</td>
<td>80.6</td>
<td>97.7</td>
</tr>
<tr>
<td>GGBFS</td>
<td>0.24kg</td>
<td>40 Euro/t</td>
<td>19.4</td>
<td>2.3</td>
</tr>
</tbody>
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Final remarks

- TC Active since late 2013 at the stage of finalizing STAR (11 meetings so far).
- Online meetings do not replace personal meetings. They help a lot, though.
- Collaborative platforms such as GoogleDrive and DROPBOX used successfully.
- Presentation of the structure of the STAR-> submission to publisher before the summer of 2017.
- Next activity of the TC to be discussed in upcoming meetings -> possibly focused on drafting recommendations for both experimental and numerical topics related to mass concrete. Probable collaboration for a background document on the new annex of Eurocode 2 about early age behaviour of concrete.
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