RILEM TC HFC, SUBCOMMITTEE 2: DURABILITY OF STRAIN HARDENING FIBER-REINFORCED CEMENT-BASED COMPOSITES, SHCC

Conclusions of meetings and discussions during the HPFRCC Workshop in Honolulu, Hawaii, May 2005

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1. INTRODUCTION

Maintenance cost of reinforced concrete (R/C) structures has been growing steadily, to the current significant portion of total construction industry expenditure. The annual direct cost of maintenance of bridges in the US exceeds $ 8 billion. US drivers pay more than $ 54 billion annually in addition for vehicle repair and operating cost (ASCE report 2005). Forty percent of the German infrastructure needs repair measures. There, the average intervention-free service life is reported to be 18.5 years, which does not compare well with Roman bridges, which had service lives of 2000 years, e.g. a Roman bridge in Augusta Treverorum, Trier. Roughly fifty percent of the total expenditure for construction is needed for maintenance and repair in many industrial countries.

This situation motivates great care when developing new construction materials, such as strain hardening fibre-reinforced cement-based composites (SHCC). In the first place such materials should inherently be durable, and in addition contribute to more durable structures. In this regard SHCC in particular presents a strong potential, by the very nature of pseudo strain hardening, which physically is controlled micro-crack formation. It is argued that this potential of SHCC is put under the spotlight in the research efforts towards characterizing and improving the durability of these materials.

During this International RILEM Workshop on High Performance Fibre Reinforced Cementitious Composites (HPFRCC) in Structural Applications, held in Honolulu, Hawaii in May 2005, several papers were presented on different aspects of durability of SHCC (see titles and authors of these papers in the appendix to this document). Results described in these papers provide a first basis for estimating durability of structural members made of SHCC. But it has been pointed out that our present knowledge on durability of normal concrete has been compiled from results of more than 100 years of intense research carried out in many research centres all around the world. It will take us some time of course to reach a similar comprehensive understanding of deteriorating processes and resistance of SHCC under combined mechanical and environmental loads.

2. ELEMENTS OF A WORKING PROGRAM FOR SC 2

At the first meeting of TC HFC in September 2004, in Varenna, Italy, already, the major durability topics to be dealt with were summarized in working programs, with the eventual deliverables including input for SC 1 and SC 3, appropriate test methods for durability, realistic material laws with respect to durability and a final report on durability of SHCC.

The wide field to be covered may be subdivided into six major topics. It was outlined that the decisive parameters concerning durability will depend strongly on the type of application of SHCC. Most important topics for practical applications will have to be selected from the following list of different topics in the future.

T 1: Durability and micro-crack formation (ductility)
- Ductility as compared with the sum of possibly imposed strains
- Average and maximal opening of micro-cracks during strain hardening
- Width of micro-cracks in loaded and unloaded specimens
- Influence of width of micro-cracks on permeability and capillary suction
- Self-healing of micro-cracks

T 2: Durability under chemical loads
- Chloride penetration, if reinforced concrete is to be protected in particular
- Resistance with respect to sulfate attack
- Alkali aggregate reaction
- Hydrolysis, leaching
- Ageing (accelerated testing)

T 3: Durability under thermal loads
- Behavior at elevated temperatures
- Thermal gradients
- Fire resistance
- Behavior at low temperatures
- Frost resistance and action of de-icing salts

T 4: Durability under combined loads
- Mechanical and chemical loads
- Mechanical and thermal loads
- Mechanical, chemical, and thermal loads

T 5: Durability of structural elements and structures
- Characteristic mechanical, environmental, and combined loads
- Characteristic material properties to predict long-term durability and service-life

T 6: Durability, economical, ecological, and social aspects (life-cycle considerations)
- Life-cycle cost versus cost of construction
- Recycling
- Sustainability

3. GENERIC AND FUNDAMENTAL ASPECTS

To set out principles and focus points for the envisaged activities of sub committee 2, general themes were discussed, before delving into specific aspects of the working programs outlined in section 2. Consensus was reached during lively discussions on the following statements:

- Costs for maintenance and repair of conventional reinforced concrete buildings and structures have become a serious economical, ecological and social problem.
- Necessary durability is not consistently reached in applications of conventional steel reinforced concrete.
- Based on life-cycle considerations, many economical, ecological and social problems may be solved by the application of SHCC.
- The term SHCC stands for ductile materials with apparent strain hardening, originated by micro-crack formation.
- Elaboration of guidelines with respect to durability design will accelerate engineering applications of SHCC.
- It is suggested that a two level approach is followed:
  (a) Simplified material laws for routine design (eg. strain and crack width limitations)
  (b) Realistic material laws for numerical structural design (material-based design)
- Material properties of SHCC have to be formulated on a probabilistic basis.
- SHCC is a new family of materials; It should be subdivided into classes for appropriate design.
- Environmental actions should be classified according to their severity.

The following conclusions could be drawn form the presentations on durability during the HPFRCC Workshop and the subsequent discussions:

- Ductility versus strength: Existing codes are strength-based. In order to achieve durability, the emphasis is to be placed on ductility. This will need substantial changes in codes.
- There is a need for accelerated ageing tests. It is difficult to reach reliable predictions. Validation of prediction models by exposure sites is required.
- To characterize properties of SHCC, it is suggested to use direct tension, or four-point-bending. When specimens with a notch are used, essential information on apparent strain-hardening is getting lost.
- The instrumented ring test is a suitable material design tool in case of imposed shrinkage strain being the dominant action.
- The evolution of micro crack width (average value and standard deviation) under sustained load is to be investigated as a key parameter for durability (creep and stress-relaxation in the stage of apparent strain hardening),

4. Tasks of the Preliminary Comparative Tests: Durability and Micro-crack formation

To initiate this programme, several tasks were set out, with the main focus on developing objective test methods for durability testing and characterization of SHCC. It was generally accepted that during a first stage methods as established in different laboratories should be compared. On the basis of the results of these first comparative test series formal and well-defined round robin tests shall be performed. For the rather informal first tests different tasks have been formulated:

Task 1: Test methods to characterize durability

- Test methods: direct tension, 4pb (diffuse cracks)
- Test method: splitting (single crack)

Investigating groups:
Prof V. C. Li (M. Lepech) (permeability in the strain hardening regime)
Prof F Wittmann (capillary suction in the loaded and unloaded state)
Prof Oh
Prof. V. Mechtcherine
Prof. G. Van Zijl
D. Rosignoli, Tecnochem Italiana, agreed to provide standard material for the comparative tests

Main parameters to be varied (to be defined more precisely later):
Impose the following strains under tension: 0, 1%, 2%, 3%
Standard material: Same matrix, with V_f = 1%, 1.5%, 2%

Task 2: Micro-crack width

- Influence of
    - Composition
    - Imposed strain
    - Sustained load
- Investigating groups
    V. C. Li (M. Lepech)
    R. D. T. Filho
    G. van Zijl
    D. Rosignoli

Main parameters to be varied (to be defined more precisely later):
Impose the following strains under tension: 0, 1%, 2%, 3%
Standard material: Same matrix, with V_f = 1%, 1.5%, 2%

Task 3: Influence of crack width on gas permeability

- CO2 permeability
- Investigating groups
  G. van Zijl in co-operation with M. Alexander?
  Prof. Oh

Main parameters to be varied (to be defined more precisely later):
Impose the following strains under tension: 0, 1%, 2%, 3%
Standard material: Same matrix, with V_f = 1%, 1.5%, 2%

5. Additional tasks, state-of-the-art report

Task 4: Literature survey,
- Current level of understanding
- Deteriorating processes
- Test methods
- Applications for more durable constructions

Task 5: Durability of PVA fibers
D Hoshiro of Kuraray Co. will report back on their findings

6. Final Conclusions

It has been agreed upon that different groups should run first test series. The intention is to submit results of these preliminary test series to the subcommittee 2 chairman, Professor Wittmann, before October 1st 2005 As several members of subcommittee 2 will attend the international workshop on "Durability of Reinforced Concrete Structures under Combined Mechanical and Climatic Loads" (CMCL) to be held at Qingdao Technological University in Qingdao, China, on October 27 and 28, 2005 a subcommittee meeting is planed to be held immediately after this workshop in Qingdao on October 31st 2005. During this subcommittee meeting first results shall be evaluated and discussed and on the basis of the results more precisely defined comparative test series shall be planed and carried out (round robins).

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Appendix: Contributions to the HPFRCC Workshop focusing on durability aspects of SHCC (Task Group B, Durability)

Optimizing Material Properties by Means of the Instrument Ring Test	*F. Wittmann, K. Furtwängler, and X. Mao*
Role of Fibers During Non-Uniform Drying of Cement Composites	*Z. Li, Y. M. Lim, and J. Bolander*
Durability and Long Term Performance of Engineered Cementitious Composites	*M. Lepech and V. C. Li*
Durability on the Fracture Parameters of Crack-Repaired High Performance Fiber Reinforced Cementitious Composites	*Y. Kistutaka and M. Tamura*
Developing Fiber Applications in Structural Concrete	*J. Morton*
Time Dependent Response of ECC: Characterization and Modeling of Creep and Creep Fracture	*W. Boshoff and G. van Zijl*
Micromechanical Properties of Calcium Leached Engineered Cementitious Composites	*J. Němeček, P. Kabele, L. Kopecký, and Z. Bittnar*
Cracking Ductility and Durability Characteristics of HPFRCC with Various Mixture Proportions and Fibers	*B. H. Oh and K. J. Shin*
Properties of Polyvinyl Alcohol Fiber Reinforcing Materials for Cementitious Composites	*T. Horikoshi, A. Ogawa, T. Saito, and H. Hoshiro*
Influence of Surface Preparation on the Behavior of ECC/Concrete Layer Repair System Under Drying Shrinkage Conditions	*M. Li and V. C. Li*
Rapid Hardening PVA Fiber Reinforced Concrete	*G. Martinola, M. Bäuml, and D. Sommain*