Experimental and Numerical Research Programme for the Design and Optimization of Various Aspects of Concrete Behaviour

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1 Introduction

Concrete is the most widely applied construction material. The freedom of form as well as the relatively low cost of the material are among the most important reasons to select it as a construction material. The low cost argument is valid only if durability of the material is warranted over a longer time span, without need for excessive repairs. Often only the costs needed for construction are considered, and future expenses for maintenance and repair are neglected. Since this is the current state of affairs, it seems important to explore the limits of the material under various conditions and to investigate whether it is possible to extend lifetimes over current limits.

'Better', 'stronger', 'more durable' and a 'better understanding' of the family of materials called concrete are the key-words in the research programme that was initiated in 1997, and which now gradually start to come to the point where new results and insight are obtained. The programme is extensive in the sense that many aspects of concrete material behaviour are explored, i.e. from basic properties of cement and hydration processes to high strength concrete, and from more simple manufacturing methods to improved durability. The programme is a unique meeting place where several researchers from different fields of expertise interact, as will be explained in Section 2. Emphasis is on fundamental understanding, culminating in new practical applicable methods and materials.

2 Scope of the research programme

In order to come to a full understanding of the cement and concrete it is important to study the material at different levels of observation. The three-level approach, introduced by Wittmann (1982) has become a standardized approach for modelling cement and concrete. Normally three scale levels are distinguished in research on cementitious composites. At the micro-level the structure of (hardening) cement is recognized (μm-scale), at the meso-level the particle (aggregate)

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structure of the concrete (mm-scale), and at the macro-level the material is homogenized (m-scale). In order to explain behaviour at a given level of observation, the general approach is to descend one level in observational scale. For example, for engineering, concrete is modelled at the macro-level. Constitutive models in terms of stress and strain are used to describe the behaviour of the equivalent continuum. However, in order to explain why certain behaviour is as observed it is essential to consider the effects of material structure.

For example, looking to crack growth in concrete, at a macroscopic scale the crack is considered as a band where discontinuous deformations take place. At mesoscopic scale irregularities in the shape of the cracks caused by the particle structure of the concrete become visible, whereas at the microlevel even more detail can be recognized. Looking to moisture transport, the flow of fluid and vapour at the microlevel occurs through gel pores and capillary pores. In detailed consideration of these flow processes many physical mechanisms are operational. All together these processes determine the diffusivity of concrete. However, knowledge has not advanced far enough, to obtain a clear overview over all mechanisms, and to compute the diffusion coefficients from a material structure. Time is an important factor in diffusion processes of water and chlorides, both important for durability of concrete.

In the research programme it is tried to combine experimental and numerical techniques to elucidate the behaviour of concrete at various spatial and temporal scales. Fundamental research focuses on:
(1) the determination of the complex structure of hydrating cement (including the development in time), as well as the particle and/or fibre structure of concrete for different types of concrete like self-compacting-concrete and hybrid fibre reinforced concrete.
(2) observations of fracture processes and development of fracture mechanics models operating at different size scales, specifically in three-dimensions.
(3) observations of moisture flow phenomena at different size scales, but most importantly in the porous cement structure. In addition, ingress and transport of chloride ions, which may cause corrosion of rebars, are studied.

It should be mentioned that new techniques are needed in order to improve the knowledge of these materials. Therefore two often not recognized, but equally important aspects of the research are:
(4) development of new numerical simulation techniques for crack growth, microstructure development and moisture- and ion-transport.
(5) development of new experimental techniques to observe and visualize many of the aforementioned phenomena

In the programme 15 PhD students are active on these aspects. More specifically, the work is separated in five clusters of projects, namely,

- I hydration and microstructure of cement
- II fracture mechanics of concrete
- III new concretes
- IV durability

V moisture transport in porous materials

In the cluster I 'hydration and microstructure of cement' three PhD students are active. Xiong works on activation energy and microstructure, Guang's project deals with porosity in the cement microstructure and the relation to permeability, whereas Jankovic studies the effect of moisture flow on crack growth in the complex interface zone between cement and aggregate. All three projects are reported in this issue of HERON.
In cluster II 'fracture mechanics', Lilliu works on torsion experiments and simple lattice models for 3D crack propagation, whereas Wells project is focussed on the discontinuous modelling of two- and three-dimensional fracture. The latter aspect of the fracture research has been included in this issue. Pannachet and Askes work on an advanced discretization technique for combined continuum-discrete fracture.

In cluster III the emphasis is on new concretes. There exist many types of dedicated concretes nowadays such as self-compacting concrete (Takada/Pelova), self-compacting fibre concrete (Grünewald), fibre reinforced concrete (Kooiman) and hybrid fibre reinforced concrete (Sato/Markovic). Two contributions are included in this review, namely on self-compacting fibre concrete (Grünewald) and on hybrid fibre concrete (Markovich). The work of Kooiman was presented in an earlier issue of HERON (Vol. 45 No. 4).

Cluster IV deals with durability aspects of concrete and other porous building materials. Meijer's project focuses on computational modelling of chloride ion transport, whereas in two other projects by Goossens and Van der Wel attention is paid to several aspects of moisture transport in coated plaster. This special issue contains papers by Meijers and Goossens.

In cluster V collaboration is sought with the NMR-group at Eindhoven University of Technology, headed by Kopinga and Pel. In this group important new development of NMR equipment for measurement of moisture flow phenomena in porous building materials is developed.

3 Synergy

The above mentioned projects focus on many aspects of cement and concrete behaviour. Fracture, microstructure and transport are important fundamental aspects that can be recognized in several of the projects. Synergy between the different projects should develop, but it has appeared to be a lengthy process. Not only do the PhD students work on different topics, they work at different locations in The Netherlands. Moreover, they undergo a 'learning process', starting from almost 'zero' knowledge to expert status in their specific field of activity. Similarities in neighbouring projects are often only recognized after two or three years of study. Given the fact that each PhD project may last only four years, the time available for real interaction is very limited indeed. The technical meetings that are organized at regular intervals become more interesting when the projects mature. This pleas for a continuation of such meetings, also when the programme is finished, but where ideally PhD students in all stages of development are interacting.

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