Foreword

It is an old and well known technique to reinforce brittle materials by ductile fibres in order to improve the stiffness, the cracking behaviour, the loading capacity and the impact resistance. The mechanical behaviour of such composites is generally known, but there are still some questions to be solved for a good estimation.

For instance has the distribution of the fibres in the matrix an essential influence on the mechanical behaviour, especially on the tensile strength and stiffness. The bond properties of the fibres in the matrix determines for a great deal the deformation and strength of a cracked element. Whether repeated loading affects the bond properties of the fibres around a crack is hardly known. But in general civil engineering structures repeated loading is just the normal case. While the analysis of a bar reinforced concrete beam is well established, simple models for beams jointly reinforced with reinforcing bars and steel fibres do not exist. In order to use fibre concrete in practice such simple models are prerequisite.

These and other questions have been treated in an investigation on fibre reinforced concrete and mortar which has strongly been stimulated by prof. dr. S. P. Shah from University of Illinois at Chicago Circle. In close co-operation with prof. dr. Y. M. de Haan of Delft University of Technology prof. Shah has set the starting-points and has defined the direction of this research project. During his stay at Delft as a visiting professor for Materials Science the final program of the investigation was discussed and layed out in general working meetings in which the divisions of Material Science and Concrete Structures of the Stevin Laboratory of the Department of Civil Engineering of Delft University of Technology participated.

The total program was divided into several parts in such a way that the materials properties were studied and investigated by the division of Materials Science, whereas the beam tests were carried out by the division of Concrete Structures.

Due to the special experience, the beams were manufactured by the laboratory of the Royal Dutch Military Academy (KMA) at Breda under the supervision of ing. A. H. Verhagen.

This investigation is thought to be a good example of an international cooperation project in order to stimulate more contact between international laboratories. It is hoped that the cooperative work can be continued.

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From the total program, three topics have been selected for this edition of HERON. Detail information is compiled in several Stevin reports which can be ordered from Delft University of Technology.

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The authors

FIBRE CONCRETE

Summary

This issue of HERON contains three topics selected from a joint research program of Delft University of Technology and University of Illinois at Chicago Circle.

In the first part it is shown that the macromechanical behaviour of mortar reinforced with short pieces of steel wires (commonly referred to as fibres) is predominantly governed by the micromechanics of the cementitious, interparticle pockets that contain a number of fibres and are under higher loads split up by one or more microcracks. The smallest structural element, i.e. a matrix element including a single fibre that bridges a crack, has been investigated separately by performing pull-out experiments.

Three types of fibres and four different matrix compositions have been encompassed in the macromechanical as well as the microscopical tension tests. Since integration towards a higher dimensional level requires knowledge of the structural morphology, the actual fibre dispersion characteristics have been studied also. Sections and projections of transverse elements (obtained by X-ray radiography) have been sampled for that purpose by image analysis techniques, such as feature (fibre section) counting and counting of intersections with a superimposed line grid. The occurrence of compaction-induced segregation as well as partial orientation effects is detected in this way.

It is theoretically established that the preferred direction of orientation of fibres intersecting a crack deviates considerably from the normal one. This may ask for a modification of the commonly adopted test set-up in pull-out testing.

Various mechanical properties are determined in the two test programs. A mutual comparison on the basis of a partially planar-oriented fibre structural model without segregation mostly reveals satisfactory agreement. The largest (paddled) fibres score relatively low in the macro test, though. This is possibly due to the size-induced high degree of fibre segregation.

Crack development data and stress-strain diagrams of sections along the specimen length show interesting features of structural behaviour under tensile loads, such as multiple cracking, crack growth and relaxation.

The second part of this issue deals with a simple model of a concrete beam which is reinforced by bars and fibres and which is loaded in pure bending. Three cases are considered: the linear elastic cracked stage, the non-linear elastic cracked stage, and the elastic plastic cracked stage. In all three cases it is assumed that the tensile stress is constant over the whole tensile zone of the cross-section whereas the contribution of the concrete in compression and of the rebars in tension depends upon the stress-strain behaviour of these materials. It turned out that the contribution of the fibres amounts to 100% of the uni-axial tensile strength for straight fibres and 85% for deformed fibres. No extra contribution of the tension stiffening effect of the concrete has been considered.

Bending tests under repeated loading are reported and analysed in the third part of this edition. Three steel fibre types and quantities have been used in reinforced con-

crete beams with rectangular cross-section. Deflections and surface strains have been measured during the fatigue tests up to a million cycles. It could be seen that the increase of the deflection and the crack width during repeated loading depend upon the stress level in the reinforcing bars. Beyond a certain stress level fatigue failure of the rebars occurred. Analysing the deflection results it turned out that the contribution of the fibres (tension stiffening effect included) diminishes during cyclic loading. Contribution and decrease during cyclic loading are strongly dependent on the amount of the bar reinforcement. It seems that deformed fibres behave better than straight ones.

In general it can be concluded that fibre reinforcement increases the number of cycles and diminishes the crack width, crack spacing, and deflection in cyclic loading. The beneficial influence is more distinct the smaller the bar reinforcement ratio and the higher the volume aspect ratio of the fibres.