CRACKING BEHAVIOUR RESULTING FROM A CORRODING BAR IN CONCRETE

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This paper deals with the cracking behaviour of selected cement-based composites due to corrosion process of steel bar embedded in the interior of the material. This problem has been approached experimentally in a two-dimensional (2-D) set up, using strain and clip gauges for recording surface deformations. In addition, acoustic emission was recorded to more completely assesses the details of the damage evolution process. Specimens of plain and fibre reinforced mortars and concretes were subjected to internal deformations by pushing a conically shaped steel element through a similarly shaped hole in the specimen. Tests have clearly revealed that three different stages of damage could be distinguished. The obtained results has also shown the significant role played by material composition itself.

INTRODUCTION

The structural loosening process of cementitious composites can be considered reflecting certain loading regimes operative under specified circumstances. Particularly, the traditional approach, of investigating material degradation under exterior influences, is not representative for stress-strain situation occurring under common service conditions. As an example, the problem of linear steel elements in concrete which increase radially in size with time can be considered. This phenomenon is met with tendons at early prestressing. It is also encountered under fire conditions, or in case of corrosion of the steel bars reinforcing concrete.

Among others, the corrosion effect could be considered as a problem of an expanding steel bar embedded in concrete. This provokes unfavourable tensile stresses in tangential direction around the lineal element and inevitably leads to concrete cracking. According to Hoff (1) it could be assumed that the durability resistance could be seriously reduced once cracks open more than

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about 0.2 mm. Thus, the delaying of crack formation and of their further development appear as a basic problems.

As a reference the situation of a corroding bar in the bottom corner of a reinforced concrete (RC) beam can be considered. For a theoretical analysis the bar is assumed being concentrically embedded in a concrete cylinder of infinite length, so that a 2-D solutions can be formulated. Such situation can be simplified to the so called "ring element", presented in Figure 1.

The mechanical behaviour of concrete stressed internally by expanding steel bar was analytically discussed by Stroeven (2). Some quantitative information and results of preliminary tests and 2-D non-linear elastic computer simulation (DIANA System), pertaining to early prestressing of tendons in concrete, were presented by Dantuma and den Uijl (3). Interesting aspects of this phenomenon has been also discussed by Moczko and Stroeven (4).

Presented paper reports a part of the test results obtained hitherto within the Polish-Dutch joint research project on: "Bond and Crack Development in Cementitious Composites", focused on the evaluation of the structural loosening processes in cement-based composites due to an expanding steel bar.

EXPERIMENTAL DETAILS

The tests were executed in the Stevin Laboratory of the Faculty of Civil Engineering, Delft University of Technology. They have been carried out on 128 days old specimens coded as "C" (Concrete), "M" (Mortar), "FC" (Steel Fibre Concrete) and "FM" (Steel Fibre Mortar). The particular mixtures were designed on the basis of constant cement and water quantities (resulting in a w/c of 0.5), and on a constant aggregate (eventually also encompassing the fibres) to cement ratio in volumetric terms. Portland cement type "A", satisfying the Netherlands Standard NEN 3550, was employed. Further use was made of a good quality river aggregate with a maximum grain size of 8 mm and 1.5% by volume of plain steel fibres with a length of 12.5 and a diameter of 0.4 mm, respectively.

The main element of the testing set up was constituted by a steel cone which is pushed with a constant rate of displacement through a similarly shaped hole in a concrete specimen. An example of a test specimen, provided with the measuring system is shown in Figure 2. The rate of applied cone displacement, amounting to 7.5 μm per second, was controlled by two LVDT's. Simultaneously, the surface strains were measured by strain gauges. The width of the leading crack was registered by clip gauges. The acoustic emission response has been monitored additionally. The friction between all contact zones was eliminated by polishing and greasing all adjoining surfaces with vaseline. Independently, compressive and tensile splitting strengths were determined using standard cubes.

RESULTS AND DISCUSSION

The results obtained have shown that the evolution of damage in composites, stressed internally by an expanding steel bar, can be generally classified into three main regions, schematically given in Figure 3. The first stage of loading (Elastic Range) the stress -strain situation is in accordance with elastic analysis. The DP (Discontinuity Point) forms the end of this stage. Further increase of the stress concentration around the expanding steel bar inevitably leads to microcracking, so that the material is gradually loosing its integrity. This intermediate stage, defined as Cracking Range, can be separated in one in which crack formations is stable and one - roughly starting at ultimate load-bearing capacity - in which crack propagation is taking place in an instable manner. The unstable crack propagation manifests itself by sudden acoustic emission discharges, which are associated with a considerable drop in the load-displacement curve. This stage finds its terminus once a single macrocrack starts accumulating all deformational energy; it is the Crack Open Point (COP). Starting from the COP basically only the opening of the so called "leading" macrocrack is observed. Finally, this process causes the material to lose its section continuity.

For further analysis the observed damage evolution process has been schematized according to Figure 3. Using accepted notations the experimental data has been processed and the proper parameters of global evaluation are proposed. For example, Table 1 shows some values of these parameters obtained for representative specimens selected from considered composites. Analysing the obtained results it can be found that the post-peak range reveals the predominant influence of fibres on the cracking behaviour of cementitious composites. It is also worth of notice that most promising parameter of evaluation seems to be DCI (Degree of Cracking Instability) expressed as the relationship between the total AE counts recorded over the post-peak cracking range and the external energy provoking this phenomenon.

TABLE 1 - Values of Global Evaluation Parameters obtained for selected specimens

Specimen Code	F_u (N)	β (%)	$\Delta\delta_1$ (μm)	E (N·mm)	DCI $\left[\frac{counts}{N \cdot mm}\right]$
M 1826	4000	77	1.1	217	50
FM 1824	4010	27	1.5	451	13
FC 1822	5380	38	2.7	633	20
C 1821	5760	77	0.6	280	125

CONCLUSIONS

- It has been found that three domains can be distinguished in the mechanical behaviour of cementitious composites stressed internally by expanding steel bar.

- It has been revealed that in the post-peak range even small amounts of steel fibres could considerably improve toughness of concrete by controlling crack development and significantly delay the process of losing its structural integrity.

- The DCI (Degree of Cracking Instability) appears as the most relevant parameter for evaluation of cracking behaviour of cement-based composites.

SYMBOLS USED

DP - Discontinuity Point; notion describing the end of elastic stage

BOP - Bend Over Point; notion which is usually attributed to the end of ascending branch of load-displacement relationship

COP - Crack Opening Point; notion referring to the stage in which the process of crack opening of the "leading" macrocrack is initiated

CRP - Critical Crack Opening Point; notion describing the stage in which the width of the "leading" macrocrack reaches its critical value, presumably 0.2 mm

δ_D, δ_U, δ_{CO}, δ_{CR} - bar expansion at discontinuity, ultimate, crack opening, resp. critical loads (μm)

F_D - load at DP, corresponding with the limit of elasticity (N)

F_u - ultimate load; load corresponding with BOP (N)

F_{co} - load corresponding with the onset of crack opening stage (N)

F_{cr} - critical load; load corresponding with the critical width of the leading crack, assumed to as 0.2 mm (N)

$\Delta\delta_1$ - bar expansion increment between BOP and COP (μm)

E - energy dissipated over post-peak cracking range ($N \cdot mm$)

$\sum AE$ - total acoustic emission counts over post-peak cracking range (counts)

$DCI = \sum AE/E$ - Degree of Cracking Instability $\left[\frac{counts}{N \cdot mm}\right]$

$\beta = \left[1 - F_{cr}/F_u\right] \cdot 100\%$ - relative post-peak load drop (%)

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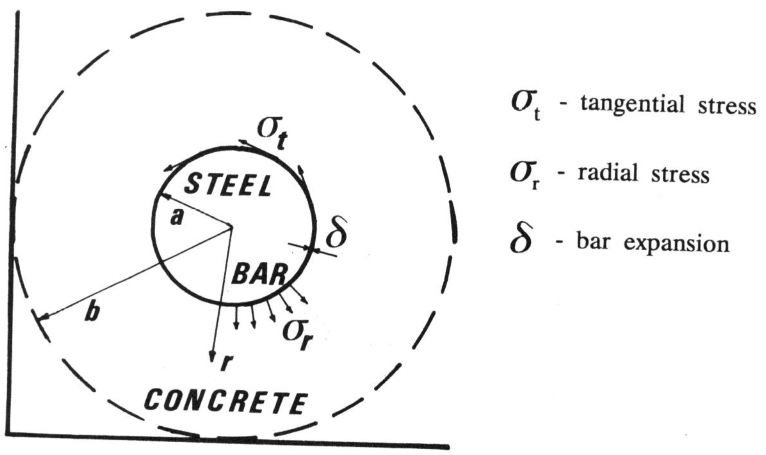

Figure 1 Stress-strain situation around expanding steel bar

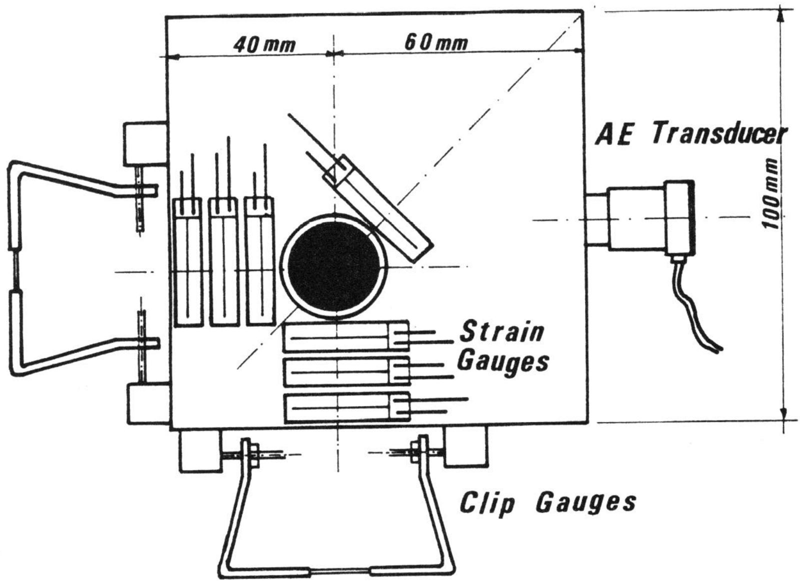

Figure 2 View of test specimen and measuring system

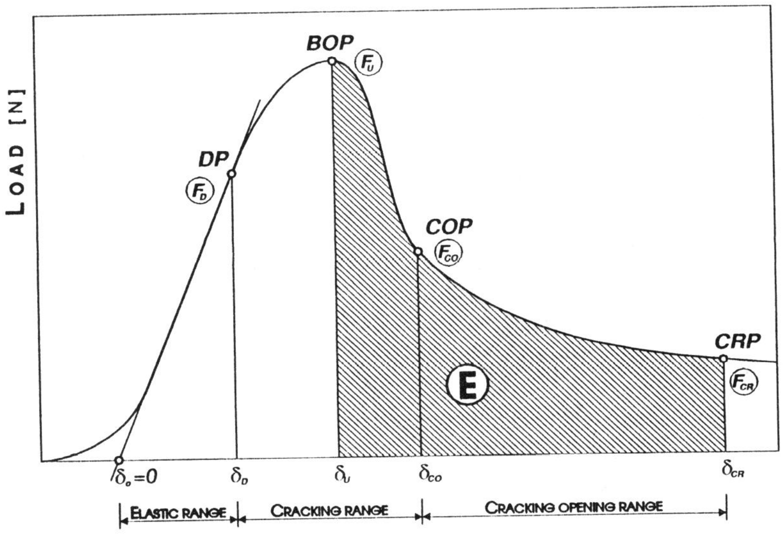

Figure 3 Idealization of the damage evolution process in tested concrete composites