Effect of aggregate shape on concrete behaviour under bending

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Abstract

The paper describes the effect of the aggregate shape on the behaviour of concrete beams under quasi-static three-point bending test. Concrete was modelled as a random heterogeneous three-phase material. The simulations were carried out with the FEM using a simple isotropic damage constitutive model enhanced by a characteristic length of micro-structure by means of a non-local theory.

Keywords: beams, damage, finite element methods, microstructures

1. Introduction

Cracks are a fundamental phenomenon in concrete materials [2], [4], [5]. They are always preceded by the formation of localized zones of a certain width. The width of localized zones is not negligible to cross-section dimensions of a concrete specimen and is large enough to cause significant stress redistribution in the structure [2]. This mechanism strongly depends upon a heterogeneous structure of materials over many different length scales, changing e.g. in concrete from the few nanometers (hydrated cement) to the millimeters (aggregate particles). To describe strain localization and other global properties in a plastic region, a material micro-structure has to be taken into account [2]-[5], [7]. In particular, the presence of aggregate is important since its volume fraction can be as high as 0.70-0.75 in concrete.

The intention of our calculations is to numerically analyse the effect of the aggregate shape on both strain localization and load-displacement curve for notched concrete beams under quasi-static three-point bending [8].

2. FE modeling

Two-dimensional numerical simulations of concrete beams subjected to quasi-static three-point bending were performed. The deformation was induced by prescribing a vertical displacement at the mid-point of the beam top. Two different concrete mixes were composed of ordinary Portland cement, water and sand (with a mean aggregate diameter d_{50}=0.5 mm mm and maximum aggregate diameter d_{max}=3.0 mm) or gravel (d_{50}=2.0 mm, d_{max}=8.0 mm). Concrete was modeled as a three-phase material composed of the cement matrix, aggregate and bond zones between the cement matrix and aggregate (Fig. 1). The aggregate particles were assumed as circles or angularly-shaped according to a grading curve (Fig. 2) Aggregate and bond zones had the highest and lowest stiffness, respectively. The aggregate density was ρ=30%, ρ=45% or ρ=60%.

The simulations were carried out with FEM using a simple isotropic continuum constitutive damage model (with a Rankine failure type criterion to define the equivalent strain measure and an exponential softening law) [6] enhanced by a characteristic length of micro-structure l_c by means of a non-local theory [1]. The model can realistically describe tensile failure [6], [9].

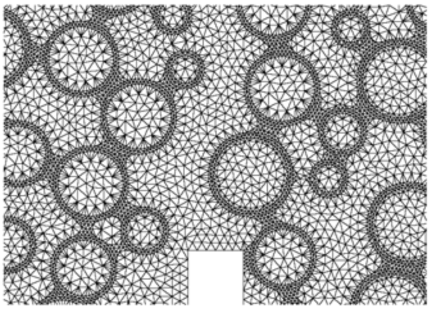

Figure 1: Three-phase concrete in neighbourhood of notch: aggregate of round shape, cement matrix and bond zones [8]

a) b)

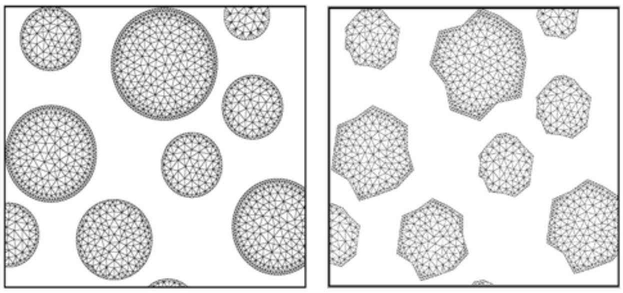

Figure 2: Shape of aggregate used in calculations: a) circular shape, b) angular shape (ρ=30%) [8]

3. FE results

The effect of the aggregate shape in a notched concrete beam (80×320 mm^2) of sand (d_{50}=0.5 mm and d_{max}=3 mm) is shown in Figs. 3 and 4 (l_c=1.5 mm). In turn, Fig. 5 shows the formation of a localized zone above the notch on the surface of a notched concrete beam using a non-invasive optical method called Digital Image Correlation [9]. The results with circular-shaped and angular-shaped aggregate were compared using the same stochastic distribution.

The beam strength is higher only by 10% for beams with angular-shape aggregate (Fig. 3). However, the shape of a localized zone and material softening are significantly affected by the aggregate shape (Figs. 3 and 4).

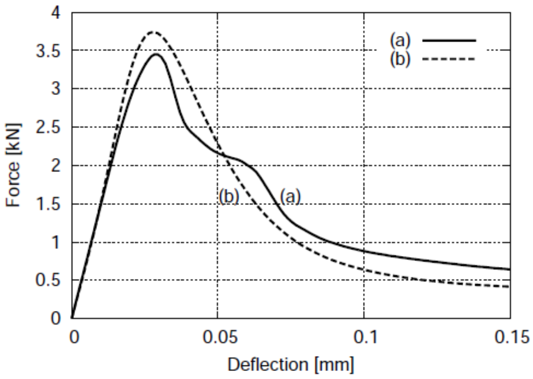

Figure 3: Calculated load-deflection diagram in sand concrete beam: a) circular aggregate shape, b) angular aggregate shape (ρ=45% and l_c=1.5 mm) [8]

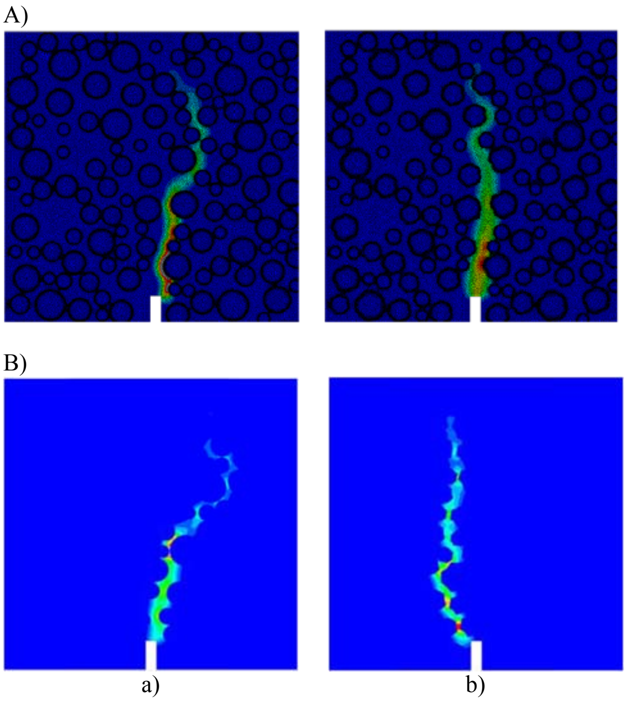

Figure 4: Calculated distribution of non-local strain measure in sand concrete above notch: A) ρ=45%, B) ρ=60%, a) circular aggregate shape, b) angular aggregate shape and l_c=1.5 mm) [8]

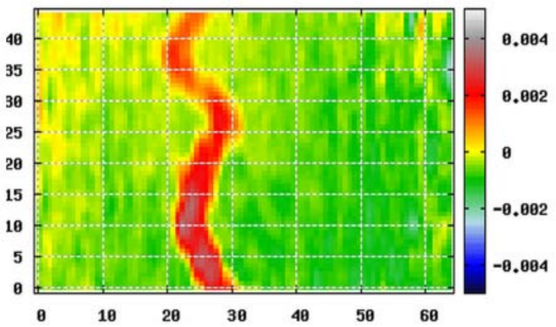

Figure 5: Formation of localized zone above notch in sand concrete beam from DIC [9]

A localized zone propagates in a cement matrix between aggregate grains and is strongly curved. The shape and width of a localized zone, w_c=(2-4)×l_c=3-6 mm (with l_c=1.5 mm), are in good accordance with the experimental value (Fig. 5) [9].

4. Conclusions

Our FE results at meso-scale of concrete beams under bending show a significant effect of the aggregate shape on the concrete behaviour.

Material micro-structure on meso-scale has to be taken into account in calculations of strain localization to obtain a proper shape.

The calculated strength, width and geometry of the localized zone are in a satisfactory agreement with experimental measurements when a characteristic length is about 1.5 mm.

The width of a localized zone above the notch increases with decreasing aggregate density from 2×l_c (ρ=60%) up to 4×l_c (ρ=30%).

Our further FE investigations will concern reinforced concrete beams.

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