EFFECT OF AGGREGATE SHAPE ON CONCRETE FRACTURE DURING COMPRESSION AND BENDING IN DEM CALCULATIONS

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1. Introduction

Fracture is a main phenomenon in concrete materials. It is an extremely complex process since it consists main cracks with various branches, complementary cracks and micro-cracks [1], [2]. The concrete materials have very complicated heterogeneous structures over many different length scales, changing from the few nanometres (hydrated cement) to the millimetres (aggregate). The experiments and numerical simulations evidently show that the concrete fracture behaviour depends on micro-structure (e.g. aggregate volume, aggregate size, aggregate roughness aggregate stiffness, particle size distribution curve, mortar volume and macro-porosity). In order to realistically describe the concrete fracture behaviour, its micro-structure should be taken into account, at least at the meso-scale. In the paper we used the discrete element method (DEM), which allowed us to directly simulate micro-structure and to comprehensively study local mechanisms of the initiation, growth and formation of cracks which affected the macroscopic concrete behaviour [3], [4]. In the future the DEM calculations may replace laboratory tests to investigate the influence of the concrete meso-structure on the concrete macro-behaviour (that is reasonable in economic sense). The disadvantages are: an enormous computational cost and a difficult calibration procedure due to the lack of the corresponding experimental measurements.

2. DEM calculations

The main objective of this paper is to estimate the effect of aggregate shape on a fracture process in concrete under compression and bending. The calculations were performed with the three-dimensional spherical discrete element model YADE, which was developed at University of Grenoble [5]. This 3D spherical discrete element method takes advantage of the so-called soft-particle approach (i.e. the model allows for particle deformation which is modelled as an overlap of particles). During the simulations, particles may overlap that can be interpreted as a local contact deformation. A linear normal contact model under compression was used. The interaction force vector representing the action between two spherical discrete elements in contact was decomposed into a normal and tangential vector, respectively. The normal forces acting on spheres were modelled by an elastic law with cohesion. Concrete was depicted as a four-phase composite materials including aggregate, cement matrix, interfacial transitional zones (ITZs) and macro-voids. The presence of ITZs was necessary to faithfully reproduce the crack shape in concrete The numerical concrete micro-structure was based on real concrete specimens under uniaxial compression and 3-point bending obtained from 3D images by means of a non-destructive technique - *x*-ray micro-tomography using the micro-tomograph Skyscan 117 [6]. We performed the DEM calculations with aggregate simulated as: a) real aggregate in the form of sphere clusters in 2D analyses (Fig.1), b) spheres in 2D analyses and c) spheres in 3D analyses. The 2D and 3D spheres had a similar circular cross-sectional area as the area of the 2D particle clusters. The process of micro- and macro-cracking was studied in detail. The macroscopic stress-strain curves and shapes of cracks were directly compared with the laboratory test outcomes. In addition, the evolution of contact forces, displacement fluctuations and strained regions was presented at the aggregate level.

The aggregate shape extremely strongly affected the shape and length of discrete macro-cracks. The cracks were shorter in length and more straight with round aggregate. The width of macro-cracks was similar. %).

The macro-cracks were always curved due to a stochastic distribution of aggregate with ITZs. They were created by bridging the interfacial micro-cracks. They possessed many small branches. The single micro-cracks also occurred far beyond the macro-cracks. The external vertical forces were transmitted via a network of contact forces which formed force chains of a different intensity. The compressive normal contact forces (connected to the tangential contact forces) developed also along the macro-crack due to aggregate inter-locking. The displacement fluctuations might be used for the prediction of cracks.

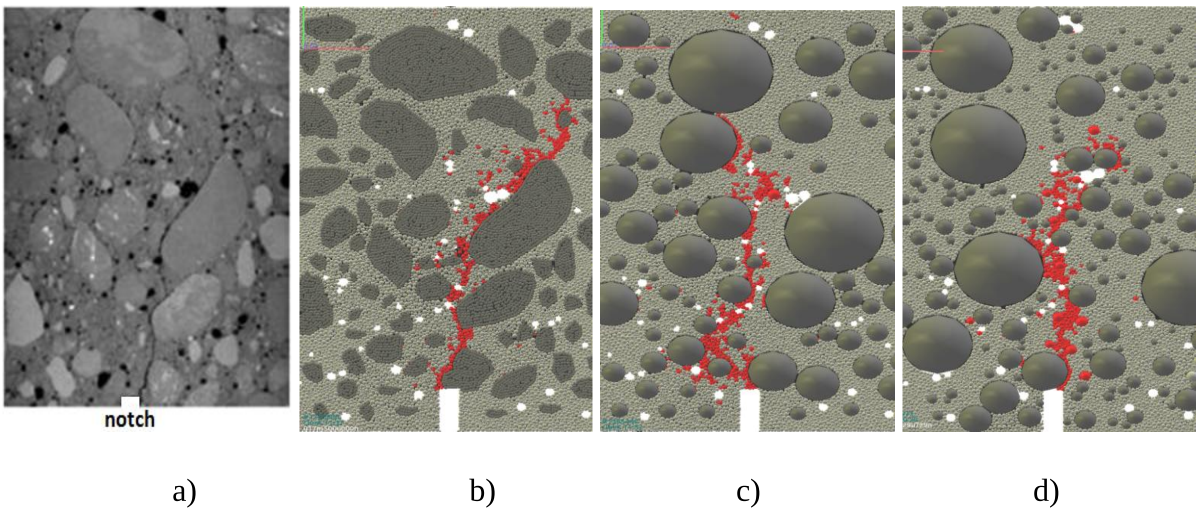

Figure 1: Final crack trajectory in concrete beam above notch after 3-point bending test: a) μCT-image at depth of 3 mm from beam face side and b) DEM with real non-regularly-shaped aggregate [6], c) DEM with real aggregate described by spheres and d) DEM with random aggregate described by spheres (red colour denotes elements with broken contacts, dark grey denotes aggregate, light grey denotes cement matrix and white colour denotes macro-voids)

3. References

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