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MODIFIED COMPACT TENSION TEST: THE INFLUENCE OF THE STEEL BARS POSITION

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Abstract: *Testing and analysis of fatigue behavior of homogeneous materials, such as concrete or other cement based composites, are one major problem being studied in this scientific field. In this contribution, adaptation of the compact tension test, well known its use in the testing of metallic materials, is pursued for crack propagation rate measurement on cement based composites using cylindrical specimens. In particular, the influence of the steel bars position on the fracture parameters is studied in the modified compact tension test. The numerical study is performed by ATENA 2D. The results are compared by Load-COD diagrams and the variation of the fracture parameters values is discussed.*

Keywords: Modified compact tension test, Concrete, Fracture parameters of concrete, FEM.

1. Introduction

The fatigue behavior of quasi-brittle materials is still a fairly unexplored scientific field. Several different setups for the experimental testing of cement based materials are available for fracture mechanics purposes, such as the three or four point bending test (RILEM, 1991), or the recently postulated wedge-splitting test (Brühwiller & Wittmann, 1990) for determination of the fracture-mechanics parameters of quasi-brittle materials (Karihaloo, 1995). Such configurations can be adopted for determining experimentally the fatigue resistance of the constructions under cyclic loads.

To obtain the adequate parameters, the specimens can simply be extracted from the real construction as a drill core without or with a small amount of reinforcement, and subsequently cut into several small cylindrical specimens. Though this specimen shape is suitable for cylindrical wedge-splitting static tests, the test setup is unfortunately unsuitable for a cyclic load since the test configuration is relatively complicated and the use of the wedge equipment is involved for repeated load, although preparation of the test specimens is very easy. The CT specimen (compact tension specimen) is well known from fatigue testing on metallic materials and after a convenient modification (see Fig. 1b) can be properly engaged for compact tension tests. A hole is drilled perpendicular to the specimen notch, through which two steel bars of 8 or 10 mm diameter are introduced and fixed by hart epoxy resin. Once the resin is hardened, the steel bars are gripped by their ends into the load machine and loaded under cyclic load.

In this paper, a numerical study of the influence of the steel bars position on the results of the modified compact tension test is performed by means of the finite element method (FEM) software ATENA 2D (Červenka Consulting, 2005). Three different positions of the steel bars are considered, which are marked as *W* (see Fig. 1) where *W* is the distance from the load axis to the opposite side of the specimen.

2. Numerical Model

According to the ASTM Standard E-399-06 (2006) recommendations for CT specimens, a ratio $D/W \approx 1.25$ between the load position parameter (W) and specimen diameter (D) was used, whereas by

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Kim et al. (2009) this ratio was *D/W ≈ 1.35 W*.

In Fig. 1 two possibilities are shown for creation of the modified compact tension test for cement based composites, although the shape of the specimen in Fig. 1a) was already used in the previous literature (Kim et al., 2009, Xu & Reinhardt, 1999).

Three sizes of parameter W are considered in this contribution: 100, 110 and 120 mm. For numerical study, configuration with steel bars gripped into the specimen (positions of steel bars see Fig. 1b) is modeled. For all positions of steel bars, the relative starting crack lengths α were 0.1; 0.15; 0.2; 0.3; 0.4 and 0.5. The symbol a in equation (1) indicates the starting notch length (notch thickness is around 3 mm) measured from the load axis. All these values are summarized in Tab. 1.

$$\alpha = \frac{a}{W} \tag{1}$$

Tab. 1: All considered dimensions for model of compact tension test.

***W* [mm]**	***α* [-]**	**0.1**	**0.15**	**0.2**	**0.25**	**0.3**	**0.4**	**0.5**
100	***a* [mm]**	10	15	20	25	30	40	50
110	***a* [mm]**	11	16.5	22	27.5	33	44	55
120	***a* [mm]**	12	18	24	30	36	48	60

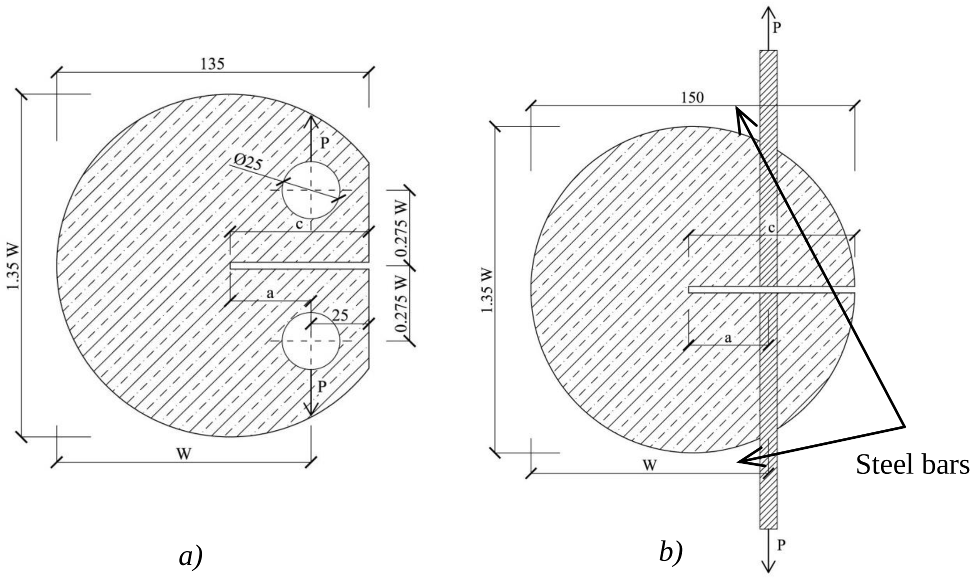

Fig. 1: Specimen for compact tension test: a) Standard one for metal materials (based on Knésl & Bednář, 1998); b) Modified specimen for cement based composites.

3. Numerical Calculation

The finite element software ATENA 2D was performed for calculation. The thickness of the specimens was in all cases equal to 100 mm. This value is relatively small, so the models were subjected under plane stress. For that occasion the concrete parts were modeled by the material model called SBETA and for modeling steel bars the material Plane stress elastic isotropic was used. Model SBETA is the material model recommended by software developers for modeling of concrete in ATENA 2D. The input values for both materials are summarized in Tab. 2.

For all models, the same finite element mesh with densification around starting crack (notch) to 0.1 mm was used, see Fig. 2. The basic element size for the model was 2 mm. In Fig. 2a), the model of the cylindrical specimen with diameter $D = 150$ mm, the position of the steel bars $W = 120$ mm and relative crack length $\alpha = 0.1$ is shown. Fig. 2b) shows a cylindrical specimen with the same diameter ($D = 150$ mm), but the position of the steel bars is $W = 100$ mm and relative crack length $\alpha = 0.5$.

Tab. 2: Input parameters of concrete and steel for ATENA 2D.

	Cube strength f_c [MPa]	**Tensile strength f_t [MPa]**	**Young's modulus E [GPa]**	**Density ρ [kg/m^3]**
Concrete	30	2.317	30.32	2300
Steel	-	-	210	7850

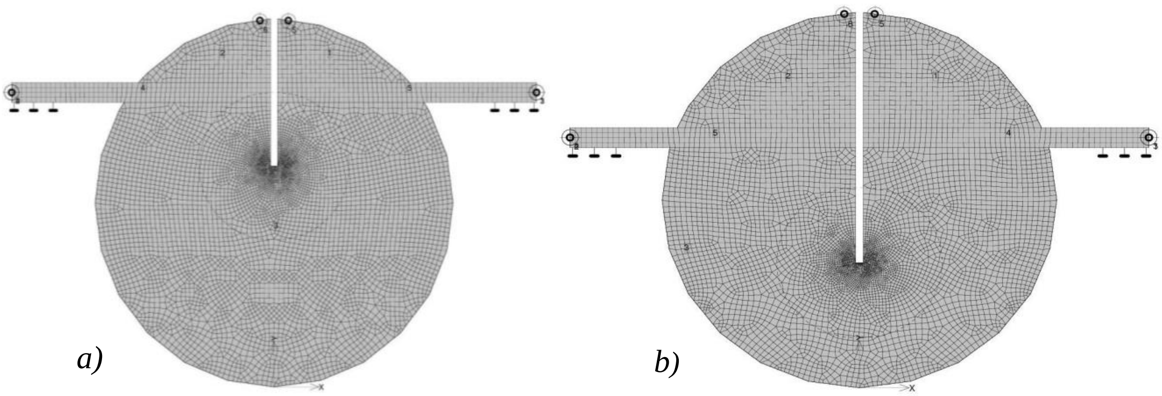

Fig. 2: Finite element mesh (2 mm with densification to 0.1 mm) and boundary conditions: a) D = 150 mm, W = 120 mm, α = 0.1; b) D = 150 mm, W = 100 mm, α = 0.5.

4. Results and Discussion

The obtained numerical results are performed by Load-COD (Load – Crack Opening Displacement) diagram. For better visualization, selected Load-COD curves for relative notch length α = 0.1; 0.25 and 0.5 are shown in Fig. 3. Loading curves for α = 0.1 are marked by black lines, for α = 0.25 are marked by double black lines and for α = 0.5 gray lines were used.

In elastic parts of the loading curves in the diagram, the values are similar and trends of the decreasing parts are relatively parallel. There are two influences caught in Fig. 3. The first one is the influence of the starting relative crack length α and the second one is the influence of the steel bars position W according to the values of fracture energy calculated from loading curves in Fig. 3. The obtained values of fracture energy are not the final ones and are shown in Fig. 4.

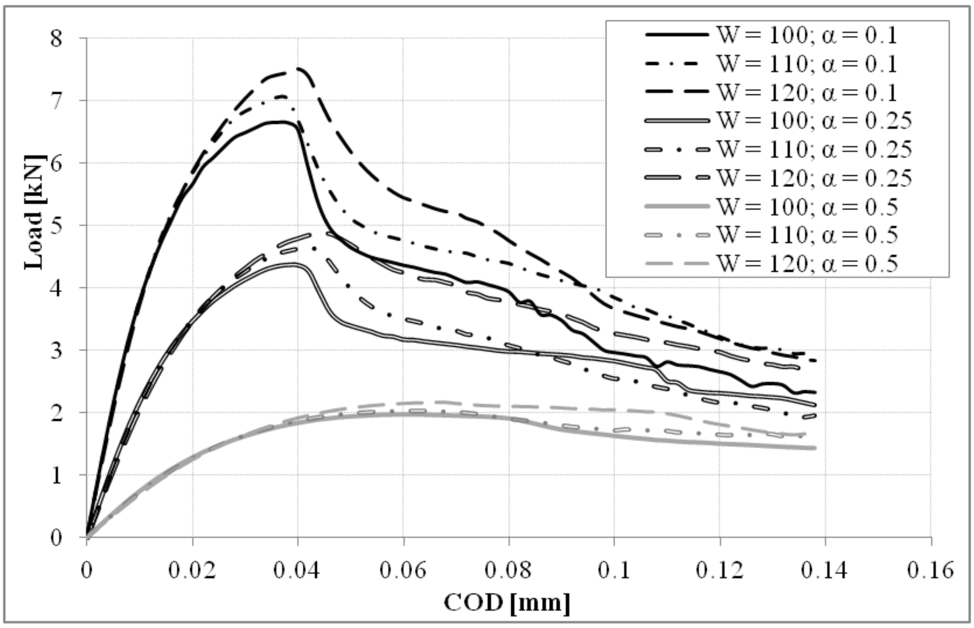

Fig. 3: Loading diagrams of selected CT configurations.

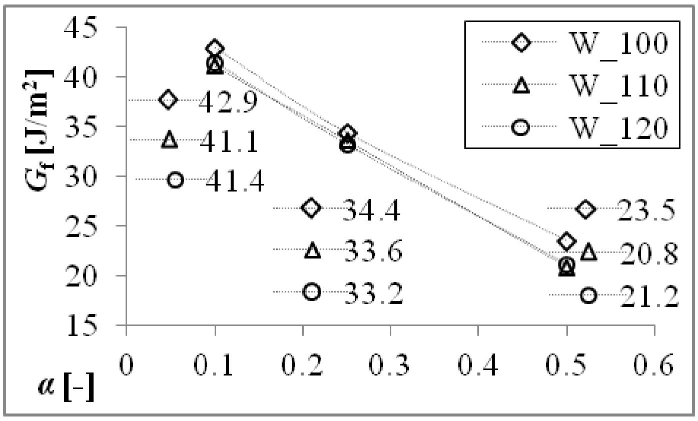

Fig. 4: Values of fracture energy obtained from the loading curves.

5. Conclusions

This contribution presents a part of the investigation of the compact tension test modification for use on cement based composites. The influence of the steel bars position was investigated. The results were presented and compared by loading diagrams and a diagram of the fracture energy values dependent on relative crack/notch length. The following conclusions can be drawn:

The values of maximum load are dependent on the position of the steel bars. A lower position means lower resistance to fatal damage. On the other hand, all three mentioned position of steel bars can be used in future investigations.

According to this numerical study preparation of an initial relative crack/notch length between 0.1 and 0.3. is recommended.

According to these values the results are independent of the steel bars position *W*, otherwise the position of the steel bars has an influence on the resistance of the specimens to fatal damage.

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