National Conference with International Participation

ENGINEERING MECHANICS 2008

Svratka, Czech Republic, May 12 – 15, 2008

INFLUENCE OF NOTCH SHAPE AND WIDTH ON LOAD-DEFLECTION DIAGRAM/FRACTURE PARAMETERS OF CEMENT BASED COMPOSITE

L. Řoutil[*], V. Veselý [**]

Summary: *Values of fracture parameters of quasi-brittle building materials are usually determined from results of tests performed on notched testing specimens. The paper focuses on the influence of the notch width and the notch tip shape on the quasi-brittle behavior of the specimen during the fracture test. The influence is investigated via numerical simulations of the three-point bending tests of notched beams and its significance is expressed through values of fracture parameters calculated from the simulated testing records. Also the influence of FE mesh arrangement is monitored.*

1. Introduction

An important task for the material engineers who deal with (advanced) quasi-brittle cement based composites behavior – both experimentally and numerically – presents the fracture parameters determination. Usually these parameters are calculated from experimentally obtained dates (load–deflection diagram) using fracture-mechanical principles with the presumption, that the stress concentrator, by which the testing specimen is usually provided, is a crack (Karihaloo, 1995; Shah et al., 1995). In fact it is impossible to fulfill this condition. Specimens used in fracture experiments contain a notch which is often more than one millimeter thick, even in its tip. In our case it is usually made by a diamond saw or rarely by a water ray.

2. Methodological and conceptual approach

The paper deals with the influence of the notch shape and width on the load–deflection diagram and consequently on the fracture parameters of cement based composite (work of fracture/fracture energy, critical effective crack length, fracture toughness…) evaluated from it. This influence is investigated numerically using FEM model (Červenka et al., 2005) of three point bending test of specimen with central notch and a special program developed for evaluation of fracture parameters from the test records (StiCrack – Stibor, 2004). Also the influence of FE mesh size and shape (especially in the cracking area) is monitored. The paper

[*] Ing. Ladislav Řoutil: Institute of Structural Mechanics, Brno University of Technology, Veveří 331/95; 602 00 Brno; tel.: +420 541 147 370, fax: +420 541 240 994; e-mail: routil.l@fce.vutbr.cz

[**] Ing. Václav Veselý, Ph. D.: Institute of Structural Mechanics, Brno University of Technology, Veveří 331/95; 602 00 Brno; tel.: +420 541 147 362, fax: +420 541 240 994; e-mail: vesely.v1@fce.vutbr.cz

contributes to other studies carried out recently (Seitl et al., 2007; Klusák et al., 2007; Frantík, 2007; Veselý et al., 2008).

Numerical experiment

The study is performed on a specimen with nominal dimensions $W \times B \times L$ equal to $100 \times 100 \times 400$ mm with span $S = 300$ mm. Four notch shapes (Fig. 1) and several notch widths for each shape are used for the study. The notch in the case a) represents a theoretical crack of zero width; other configurations approximate the real situation in experiments.

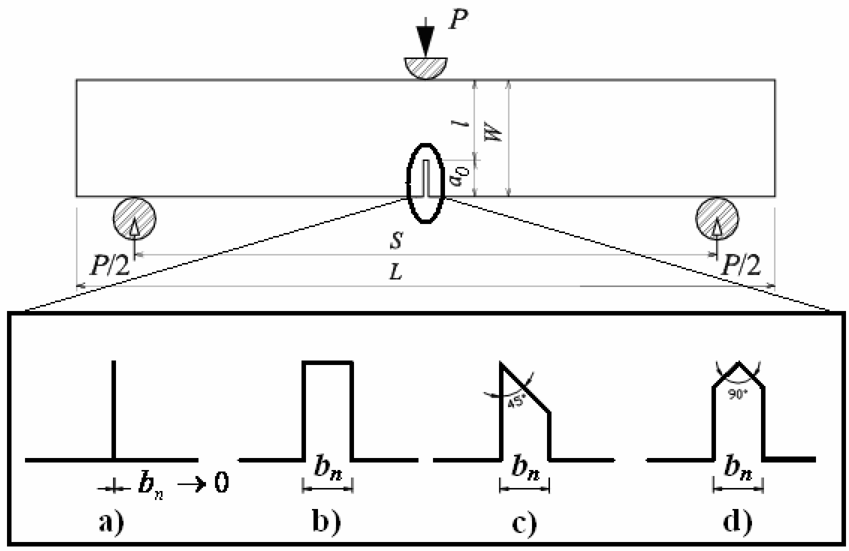


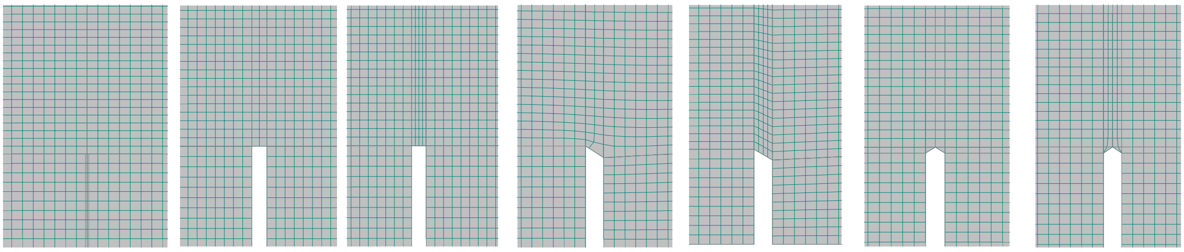
Fig. 1: Configuration of simulated experiment – three point bending test of notched beam and four investigated stress concentrator shapes (a–d)

FE mesh in performed analyses is created according to two different approaches:

- The first employs the mesh generator abilities, implemented in the used computational program, which allow the user to cover quadrilateral regions of the FE model by exactly defined mesh of quadrilateral elements (by means of specification of number of elements along the lines of the region). Such a way several variants of models in cases b), c) and d) are created (cuts of the part around the notch tip are depicted in Fig. 2). In this case area above the notch is formed by one or two (in case of notch d) macroelements. Then the line – a boundary of a macroelement – corresponds to the notch width is divided in parts (n) which form a basis for FE mesh. Also the influence of FE mesh smoothing is monitored, but this influence is not described in the paper.
- The second utilizes the ability to mesh selected parts of the model by a mesh of defined uniform finite element size. In the central part of the modeled beams this ability was employed within a separate region to create a mesh with element size $e = \{1, 2, 4\}$ mm (Fig. 3). Considerably more rough mesh was created out of the region where the number of finite elements along the specimen depth was set to 8.

  The FE mesh in the central region was created with regard to avoid mesh shape symmetry in the ligament, especially for the models with crack. The crack tip was therefore shifted of 1/2 of the finite element size sideways from the axis of symmetry to enable the crack to propagate within an element band which passes the ligament approximately in the axis of symmetry. Another variant (crack v2) was prepared using the same philosophy, but differing from the first variant somewhat in the shape of the stress concentrator. In this variant actually a very narrow V-notch with the notch mouth opening close to zero was modeled. The third variant (crack v3) introduces a symmetrical crack without the above-mentioned avoiding of the mesh symmetry in the ligament.

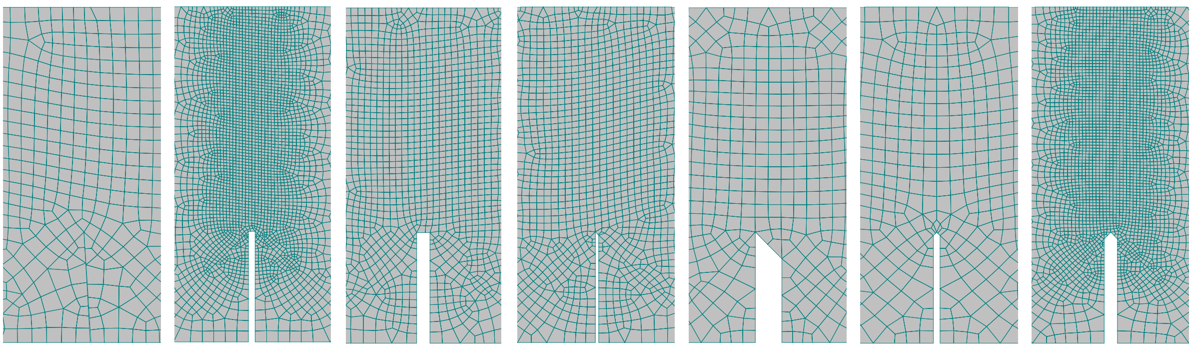
a) b) c) d)



$b_n = 0$ mm	$b_n = 4$ mm	$b_n = 4$ mm	$b_n = 4$ mm	$b_n = 4$ mm	$b_n = 4$ mm	$b_n = 4$ mm
	$n = 2$	$n = 4$	$n = 2$	$n = 4$	$n = 2$	$n = 4$

Fig. 2: Variants of FE mesh near the stress concentrator tip – arrangement I

a) b) c) d)



$b_n = 0$ mm	$b_n = 2$ mm	$b_n = 4$ mm	$b_n = 1$ mm	$b_n = 8$ mm	$b_n = 2$ mm	$b_n = 4$ mm
$e = 4$ mm	$e = 1$ mm	$e = 2$ mm	$e = 2$ mm	$e = 4$ mm	$e = 4$ mm	$e = 1$ mm

Fig. 3: Variants of FE mesh near the stress concentrator tip – arrangement II

Results and discussion

Chosen results of the numerical study are graphically presented in this section. In Figs. 4 and 5 load–deflection diagrams from models in both FE mesh arrangement are shown. More details to load–deflection diagrams from models with first FE mesh arrangement can be found also in Řoutil et al., 2008. Selected examples of the influence of the notch width on the crack propagation (crack pattern) are shown in Fig. 6 and 7.

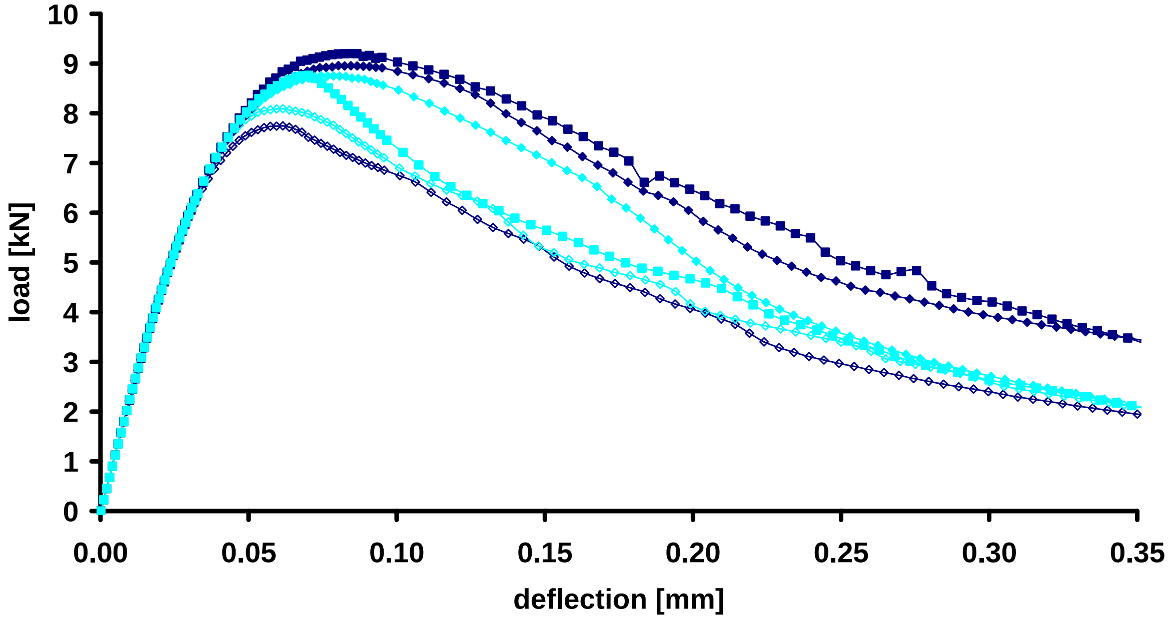


Fig. 4: Chosen load–deflection diagrams from models with first FE mesh arrangement; notch b) – notch width 1 mm (blue empty diamond), 2 mm (green empty diamond), 4 mm (fine mesh (n = 4) – full green diamond, FE mesh with n = 2 – full green square), 7 mm (fine mesh (n = 5) – full blue diamond, FE mesh with n = 4 – full green square)

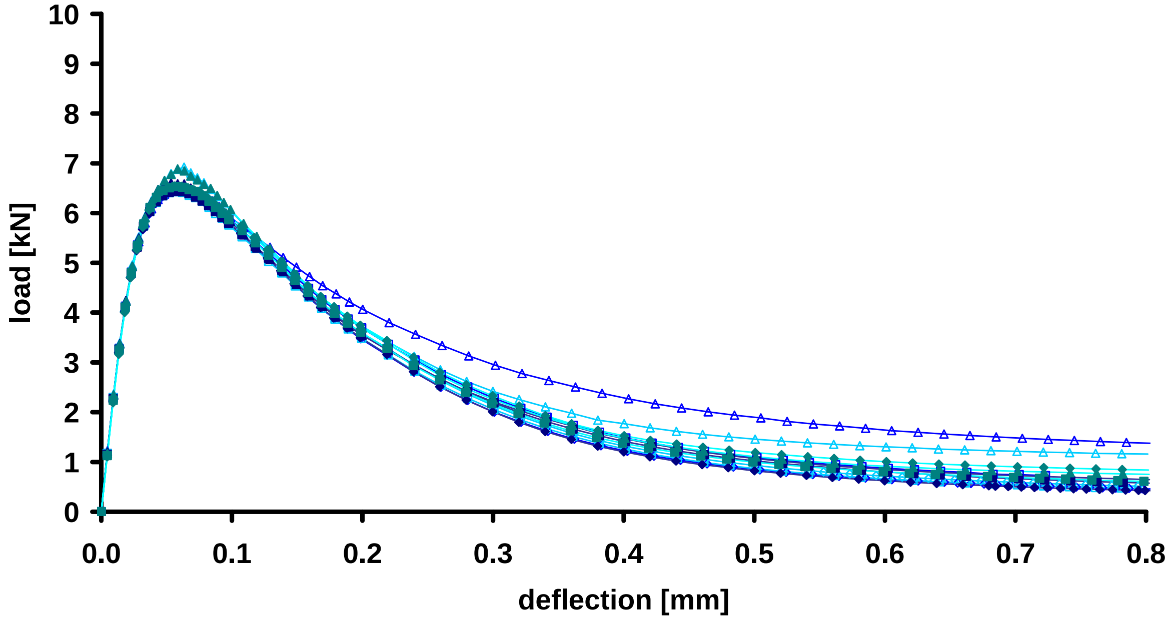


Fig. 5: Chosen load–deflection diagrams from models with second FE mesh arrangement; notch b) – notch width 1 mm (FE mesh with e = 1mm – blue empty diamond, FE mesh with e = 2mm – blue empty square, FE mesh with e = 4mm – blue empty triangle), 2 mm (green empty signs), 4 mm (blue full signs), 8 mm (green full signs)

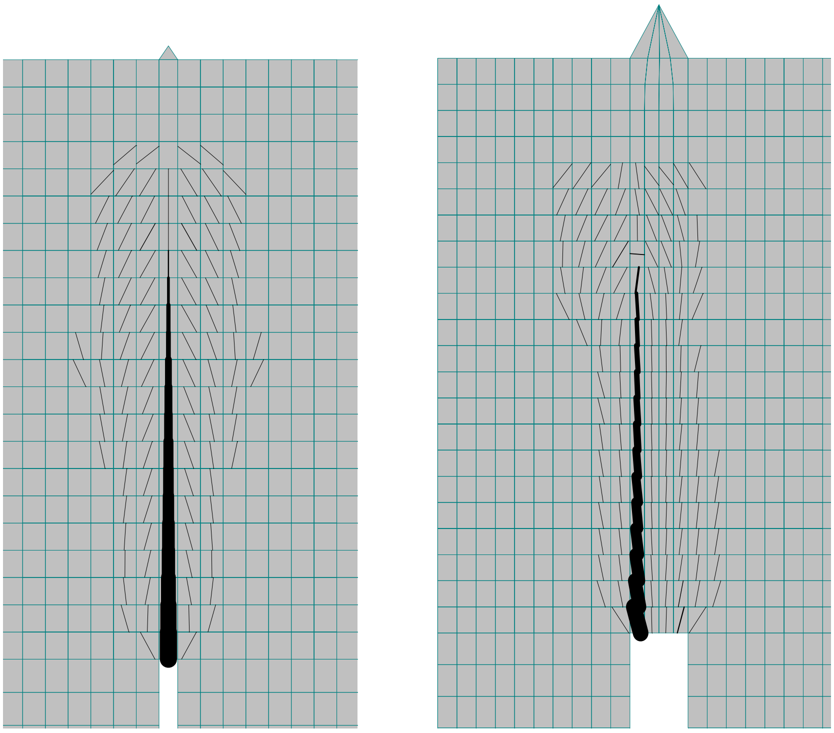


Fig. 6: FE mesh arrangement I, notch b) – influence of notch width on crack pattern; left – notch width 2 mm, right – notch width 7 mm; value of monitored deflection in both cases is equal to 0.16 mm

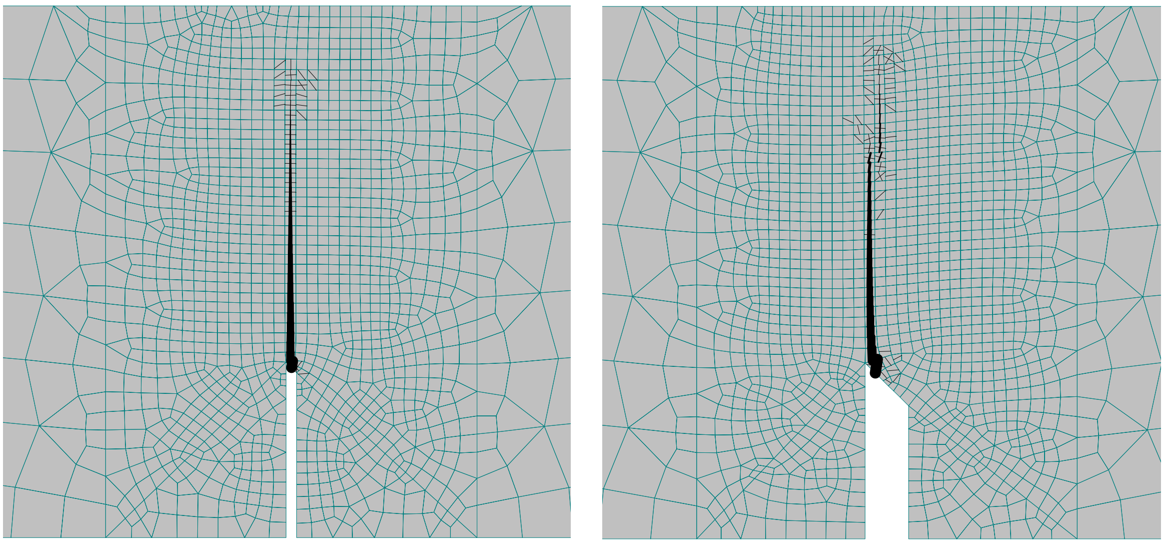


Fig. 7: FE mesh arrangement II (*e* =2), notch c) – influence of notch width on crack pattern; left – notch width 2 mm, right – notch width 8 mm; value of monitored deflection in both cases is equal to 0.16 mm

Fracture parameters calculated from obtained load–deflection diagrams (Karihaloo, 1995; Rilem, 1985; Stibor, 2004) are presented in following graphs. Figs. 8, 9, 10, and 11 show the dependences of fracture energy, fracture energy 1, effective fracture toughness, and effective crack extension, respectively, on the notch width and notch tip shape for the FE mesh arrangement I. Note that fracture energy signed by number 1 means fracture energy determined using the area under the first part of load–deflection diagram (until the peak, see Stibor, 2004). The dependences for the mesh arrangement II is displayed in Figs. 12–15.

Significant scatter of the calculated fracture parameter values can be apparently seen in the graphs. The scatter is considerably higher for the simulations with model meshed using the first approach. Obtained results also show that the influences of the notch shape and the FE mesh arrangement on the fracture mechanical parameters are more significant than the effect of the notch width. The basis for this effect can be observed in the crack pattern and load–deflection diagrams obtained from simulations.

Moderate increase of all studied fracture parameters with the increase of the notch width can be observed for meshing type I; hardly noticeable increase of only the effective fracture toughness and effective crack extension with the increase of the notch width is evident in the case of mesh arrangement II. In the next steps obtained results/trends, i.e. the influence of notch and mesh parameters on fracture parameters from simulations, will be quantified using mathematical tools.

3. Conclusions

The performed numerical study indicates that the width of the stress concentrator created in the test specimen have no considerable influence on the load–deflection diagrams recorded during fracture tests on specimens made of quasi-brittle materials and, therefore, also on fracture parameters of nonlinear fracture models applied within the test results processing. This influence is noticeable when dealing with the shape of the notch. However, due to observed significant mesh size/shape sensitivity on the simulated load–deflection diagrams some doubts about the value of this conclusion are legitimate. It is expected, that the investigated influence would be more pronounced in case of quasi-brittle materials with shorter internal length than the concrete assumed in this study.

It was also shown that the influence of FE mesh arrangement and size is important and should be taken in the account when creating and evaluating numerical models of quasi-brittle structures/structural members.

Acknowledgement

This outcome has been achieved with the financial support of the Ministry of Education, Youth and Sports, project No. 1M0579 within the CIDEAS research centre. In this undertaking, theoretical results gained in the project of the Grant Agency of the Czech Republic No. 103/07/1276 were partially exploited.

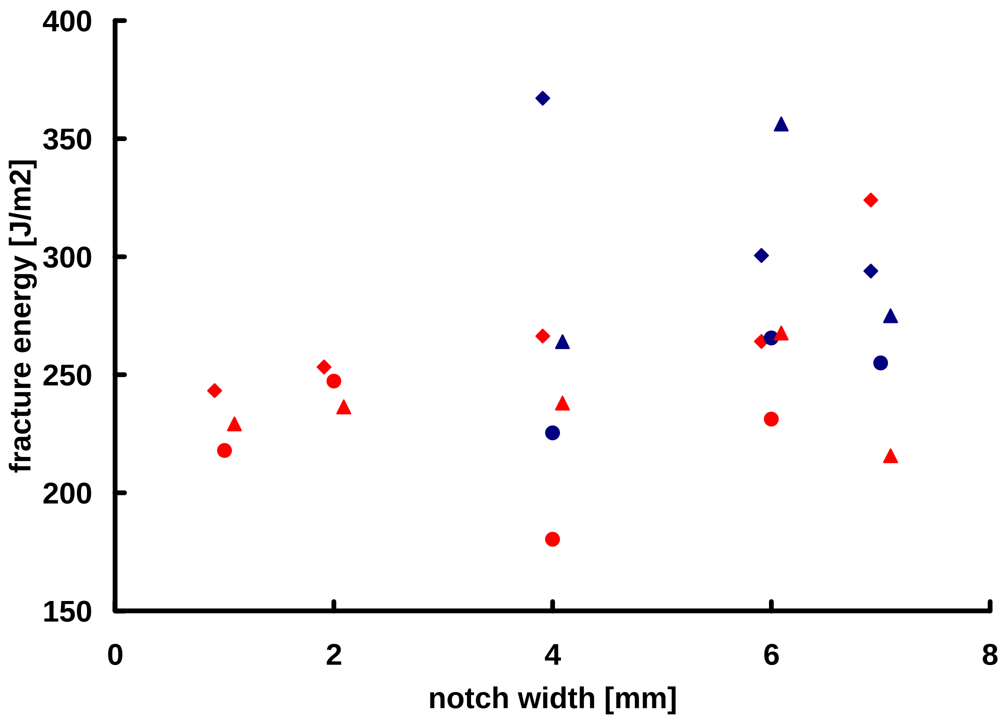


Fig. 8: Values of fracture energy – FE mesh configuration I; notch b) – diamond, notch c) – circle, notch d) – triangle, red color – "fine" mesh, blue color – "rough" mesh

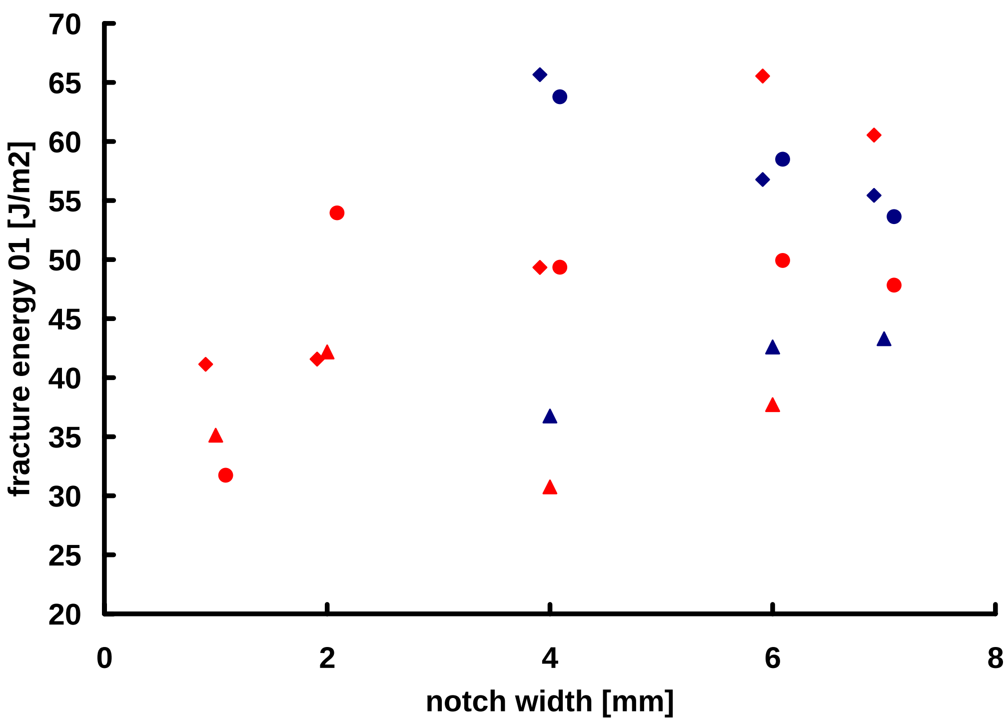


Fig. 9: Values of fracture energy 01 – FE mesh configuration I

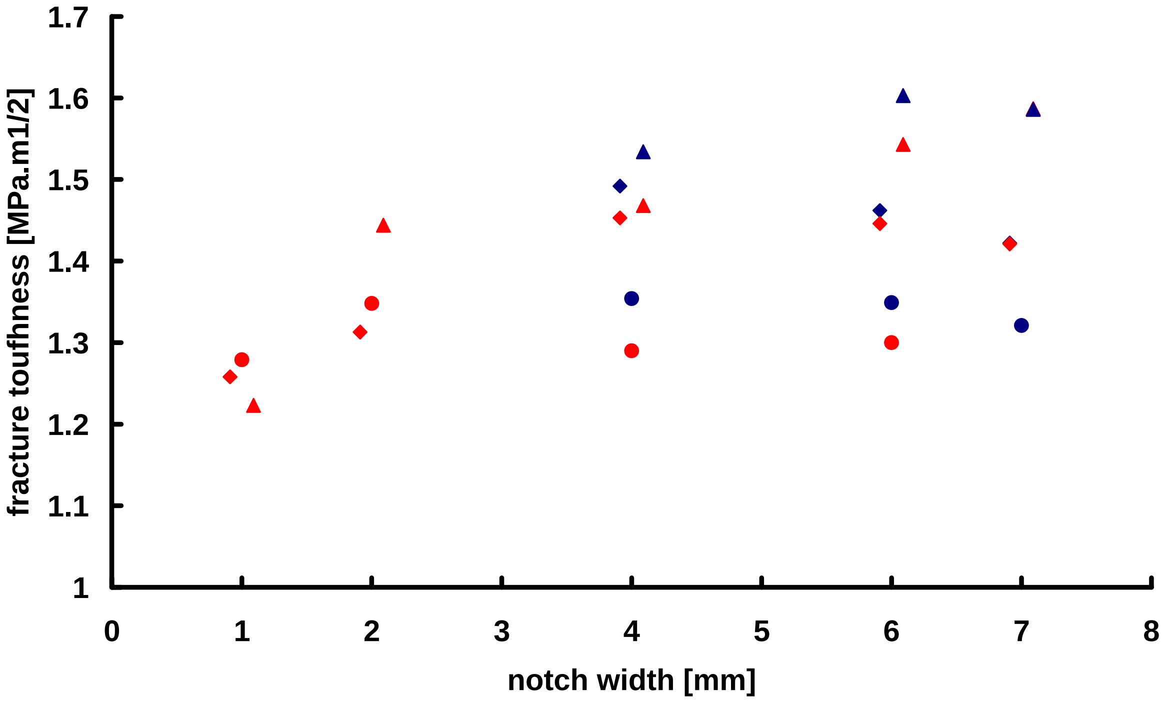


Fig. 10: Values of fracture toughness – FE mesh configuration I

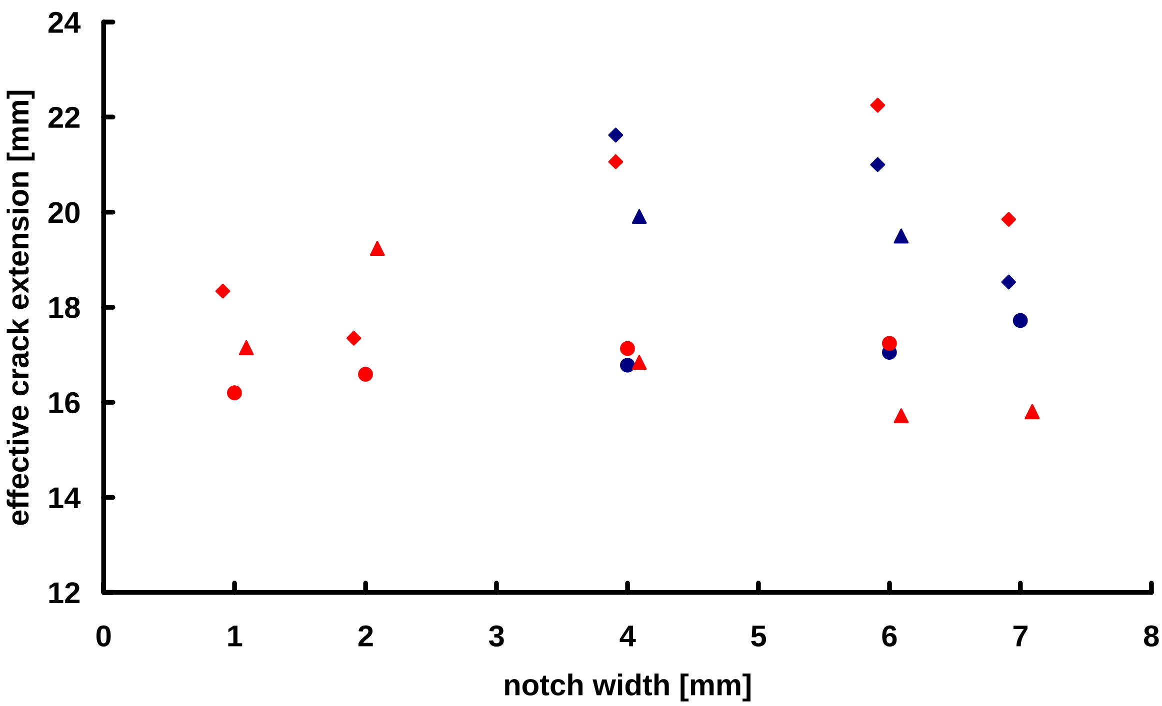


Fig. 11: Values of effective crack extension – FE mesh configuration I

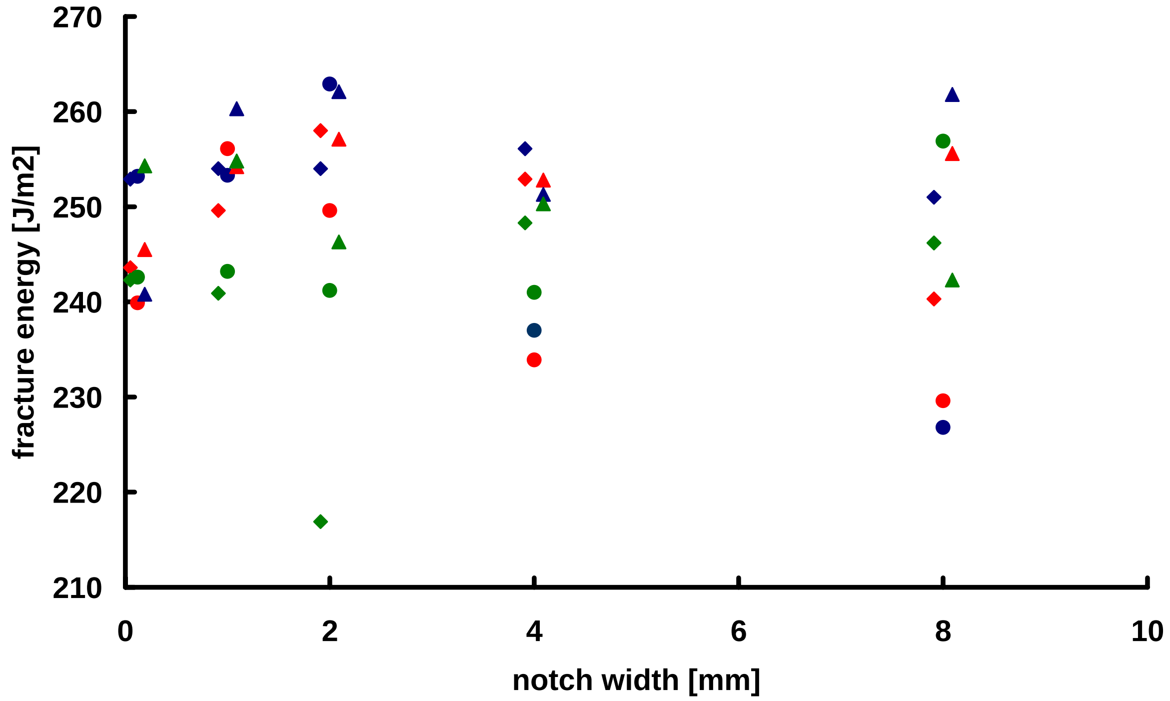


Fig. 12: Values of fracture energy – FE mesh configuration II; notch b) or crack – diamond, notch c) or crack v2) – circle, notch d) or crack v3) – triangle, red color – mesh with *e* = 1mm, blue color – mesh with *e* = 2mm, green color – mesh with *e* = 4mm

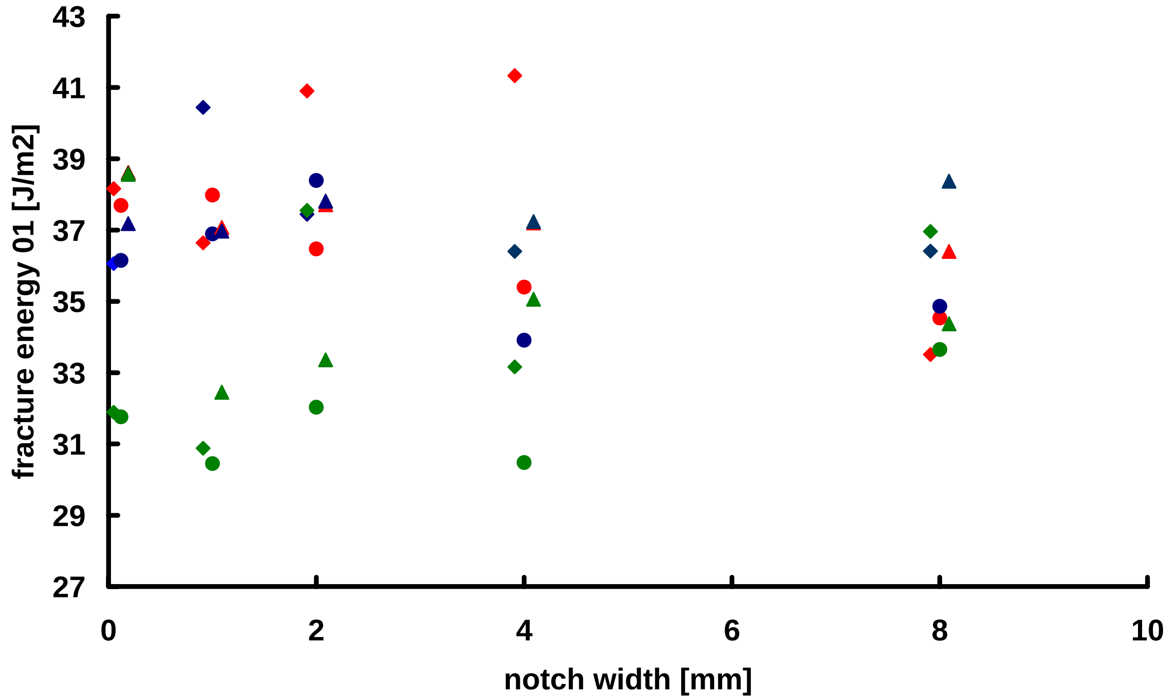


Fig. 13: Values of fracture energy 01 – FE mesh configuration II

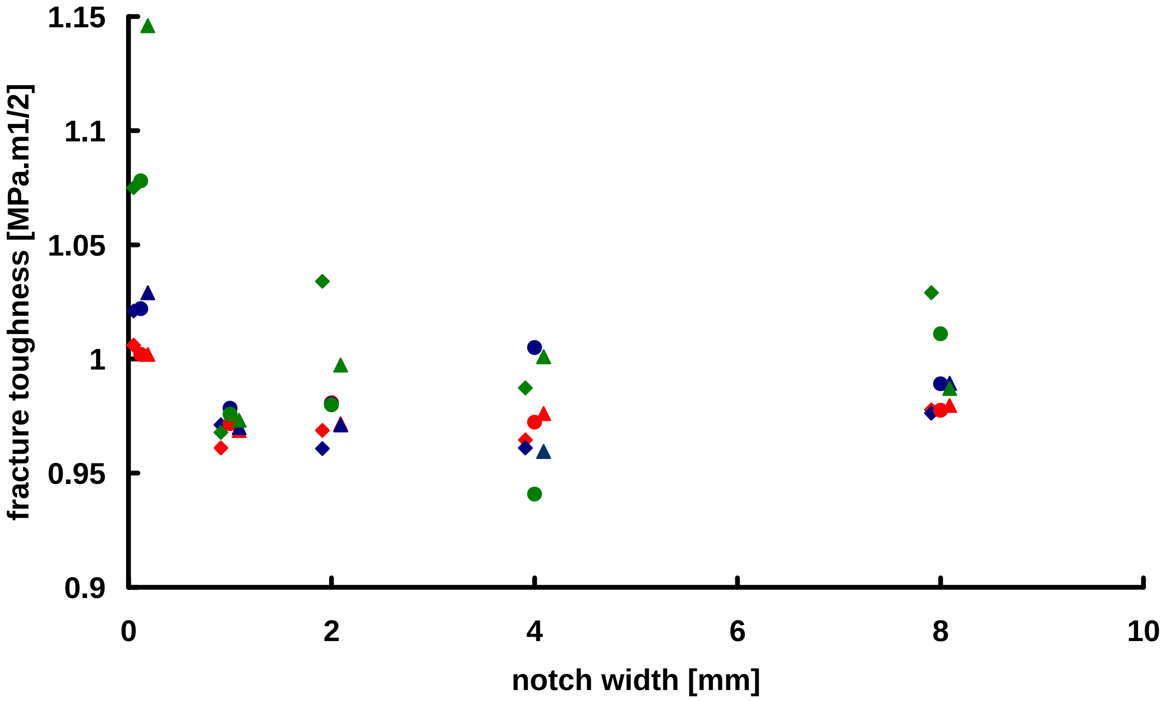


Fig. 14: Values of fracture toughness – FE mesh configuration II

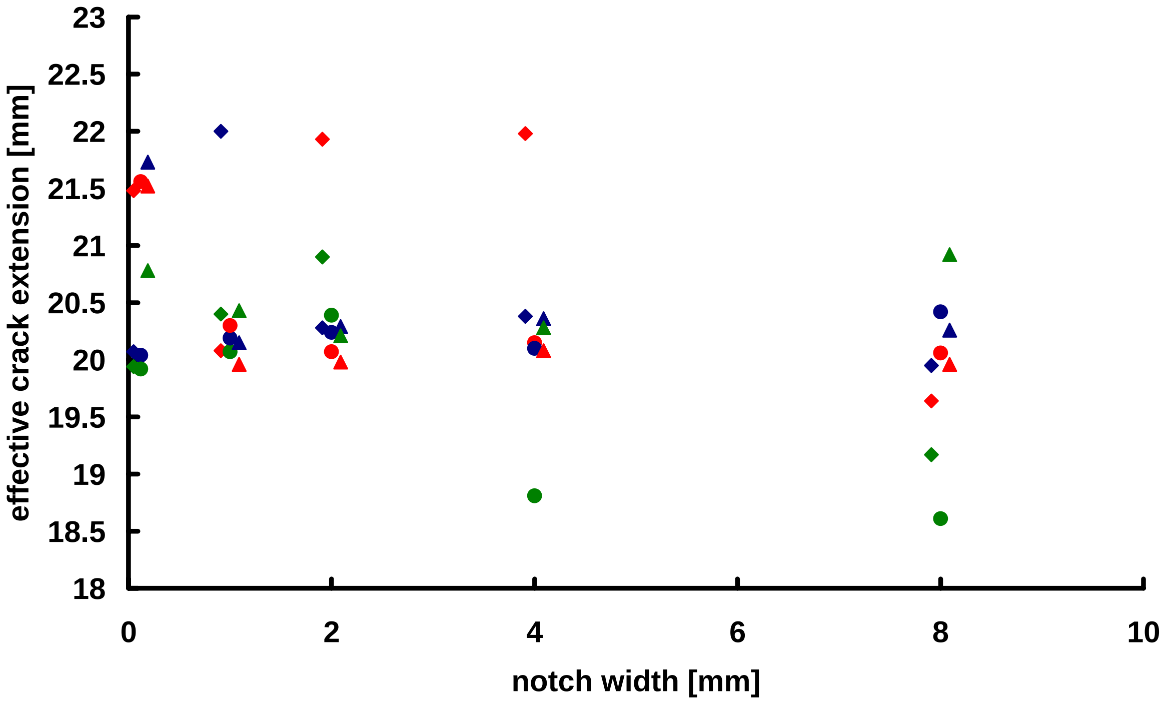


Fig. 15: Values of effective crack extension – FE mesh configuration II

References

Červenka, V. et al. (2005) *ATENA Documentation.* Cervenka Consulting, Prague.

Frantík, P., Keršner, Z., Klusák, J. & Seitl, S. (2007) Fracture toughness of quasi-brittle specimens using three-point bending test: Correction with respect to notch width. In: *Proc. Experiment 2007* (J. Melcher & M. Karmazínová eds), Faculty of CE of Brno University of Technology, Brno, pp. 77–80 (in Czech).

Karihaloo, B.L. (1995) *Fracture Mechanics of Concrete*. Longman Scientific & Technical, New York.

Klusák, J., Knésl, Z. & Náhlík, L. (2007) Crack initiation criteria for singular stress concentrations, Part II: Stability of sharp and bi-material notches. *Engineering mechanics* 14, **6.**

RILEM Committee FMT 50 (1985) Determination of the fracture energy of mortar and concrete by means of three-point bend test on notched beams. *Mater. Struct*., 18: 285–290

Řoutil, L., Veselý, V., Keršner, Z. (2008) Influence of notch width on load-deflection diagram of three point bended quasi-brittle specimen: Numerical study. In: *Proc. of Modelling in Mechanics*, Technical University of Ostrava, Ostrava, pp. 15-16 + 4pp (in Czech).

Seitl, S., Klusák, J. & Keršner, Z. (2007) Influence of notch width on crack propagation for various specimens for three point bending test. *Materials Engineering*, Vol. 14, No. 3, 213–219.

Shah, S. P., Swartz, S. E., Ouyang, C. (1995) *Fracture mechanics of structural concrete: aplications of fracture mechanics to concrete, rock, and other quasi-brittle materials*. John Wiley & Sons, Inc., New York.

Stibor, M. (2004) Fracture parameters of concrete and their determination. *Ph.D. Thesis*, ISM FCE BUT Brno (in Czech).

Veselý, V., Keršner, Z., Seitl, S., Klusák, J. (2008) Influence of notch width on fracture response of bended concrete specimens. In: *Proc. of Engineering Mechanics 2008*.