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APPLYING OF FRACTURE PARAMETERS DURING DEVELOPING OF SPECIAL FIBRE-REINFORCED COMPOSITES

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1.Introduction

Cement based composites present an important material in civil engineering. Moreover advanced forms of these composites (e.g. (U)HPC – (ultra)hight-performance concrete or fibre-reinforced concrete/cement based composites) are still more often used. Under loading this composites show so called quasi-brittle response/behaviour. When analysing the behaviour of such composites the fracture process zone should be taken into account. This zone, which arises ahead of the crack tip, provokes a typical nonlinear behaviour/mechanical response from the studied composites/structural members. The fracture mechanics parameters can be used to quantify the structural resistance against crack initiation and propagation (or the brittleness and toughness of the structural members), as well as for the comparison of the studied or developed composites (this case is shown in the presented paper) or the structural members of buildings. Simultaneously, they can be employed for the definition of the material models for simulations of the quasi-brittle behaviour of cement based composites/members (FEM models with implemented nonlinear fracture mechanics principles). Models can be used for parametric studies as well as for probability analyses, which plays an important role in the field of cement based composites as there can usually be a significant variability in the experimentally determined values of the fracture mechanics characteristics.

Two fracture parameters of studied composites are mentioned in the paper: (i) effective fracture toughness measured using the Effective Crack Model, which combines the linear elastic fracture mechanics and effective crack length approaches and (ii) fracture energy computed from the recorded load–deflection (see e.g. Fig. 4) diagrams according to the RILEM method (work-of-fracture) – values of these parameters are determined using records from the three-point bending test (Fig. 1), see e.g. (Karihaloo 1995, Bažant&Planas 1998, Keršner 2005, Veselý 2004, Stibor 2004, Řoutil 2012).

The paper presents a brief overview of selected results (mainly focused on the fracture parameters of the quasi-brittle fibre-reinforced composites) obtained within two research projects (FT-TA3/027 and CIVAK), which were solved in the cooperation between Institute of Structural Mechanics, Faculty of Civil Engineering, Brno University of Technology and Research Institute of Building Materials in Brno (VUSTAH). Obtained results were continuously published and discussed in the specialized conferences. Within the concluding remarks use of the fracture-mechanical parameters in the complex approach to the design and evaluation of quasi-brittle structures/structural members made of (advanced) cement based composites is presented.

2.Selected studies

Composites with PVA fibres

In this study specimens made of cement based composites with polyvinyl alcohol (PVA) fibres were investigated (Řoutil et al. 2010b). Specimens (40×40×200 mm) were prepared by the specialists of VUSTAH in two series – the first one with the length of fibres equal to 12 mm as the second one with the combinations of the fibres with two lengths, 6 and 12 mm. Also an influence of the degradation was investigated during the mentioned research. Some specimens of each set were stored in an aggressive environment (for 1, 7 or 14 cycles). All this aspects are hidden in the specimens marks used in Fig. 2, e.g. *PVA 6/12-14* means the composite with the combination of fibres with lengths 6 and 12 mm stored in the aggressive environment for 14 cycles. Three-point bending tests of notched specimens were performed in the laboratory of Department of Structural. Note that equipment Zwick/Roell Z 100 were used and the speed of the loading was 0,08 mm/min (Fig. 1).

Fig. 1 *Configuration of the three-point bending test*

Values of specific fracture energy (average values, standard deviations and coefficients of variation) are presented in Fig. 2. Note that this values are based on 12 (8) tests for each referenced (degraded) set of samples. Specimens *PVA 12* show higher values and smaller variability of specific fracture energy. Moreover these values increase for the specimens stored in the aggressive environment. This phenomenon could be caused by the continuing hydration of cement components in the first phases of simulated degradation, but is not in accordance with previous results from the research focused on another (glass-)fibre cement based composite (Keršner et al. 2007).

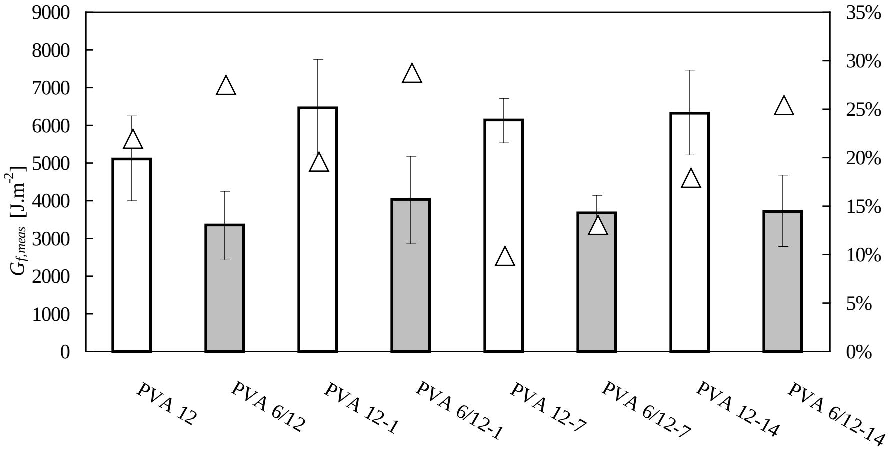

Fig. 2 *Values of specific fracture energy (average values, standard deviations and coefficients of variation (COV – signed by triangles)) of studied composites*

Extruded steel-fibre composite

The specimens made of steel fibre cement based composite (designed by the specialist of VUSTAH) were prepared from bulk material produced by extrusion technique (Fig. 3). The aim of this research was to verify the effect of the orientation of fibres in the material on values of mechanical/fracture parameter of the extruded composite (Řoutil et al. 2010a). For this purpose tested samples (22.5×19×200 mm) were prepared/cut by the specific way from the extruded profile, according to scheme in Fig. 4. Two sets of specimens signed as A and B were prepared, each consist of 9 samples. Subsequently they were tested (three-point bending test of notched specimens) and fracture parameters were determined using obtained load–deflection diagrams (Fig. 4). Values of fracture toughness as well as specific fracture energy (Fig. 5) confirm and quantify effect of the produce technology on the values of material parameters which change their values along the height of the extruded profile.

***Fig. 3** Equipments for the extrusion technique*

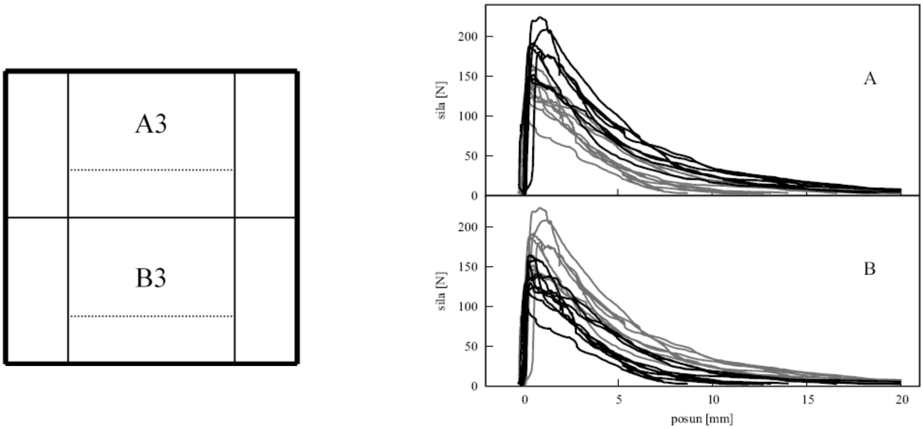

***Fig. 4** Scheme of preparation of tested samples from the extruded profile (left; dotted lines shows notches), corresponding load–deflection diagrams recorded during the three-point bending tests of notched specimens*

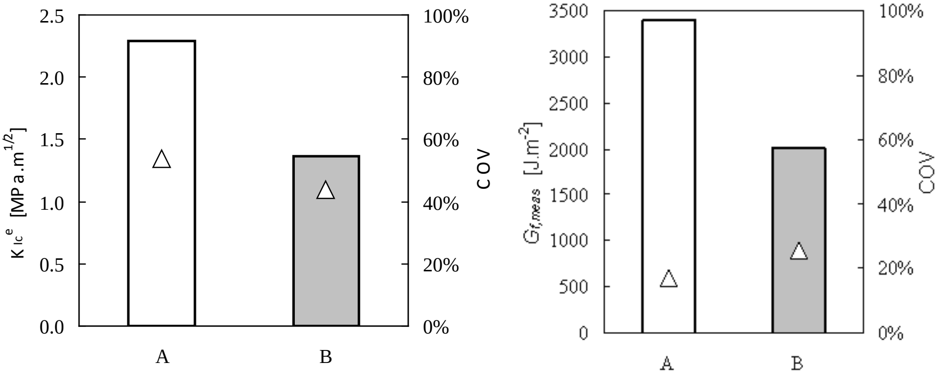

***Fig. 5** Values of effective fracture toughness (left) and specific fracture energy (right) of studied extruded composites, average values and coefficients of variation (COV – signed by triangles) are shown for the both parameters*

Composites with electro-conductive admixtures

Values of effective fracture toughness and specific fracture energy of seven types of special composites are presented and compared in this section (Řoutil et al. 2009). Described experiments were performed in order to compare the fracture-mechanical parameters values of composites for the special applications (Fig. 6) selected according to the electrical features (investigated simultaneously in a specialized laboratory) which were developed by VUSTAH and to recommend the composites suitable from the fracture-mechanical point of view for the next stages of the research. During these experiments (notched specimens with the size 50×10×250 mm, Fig. 6) some useful fracture-mechanical parameters of cement based composites were obtained. Note that together 13 types of composites were tested during the described research, each set consist of 15 specimens. Obtained values of effective fracture toughness and specific fracture energy for chosen studied composites are shown in Fig. 7.

***Fig. 6** Application of studied composite for the heating core of the structural member (left); configuration of the three-point bending test (right)*

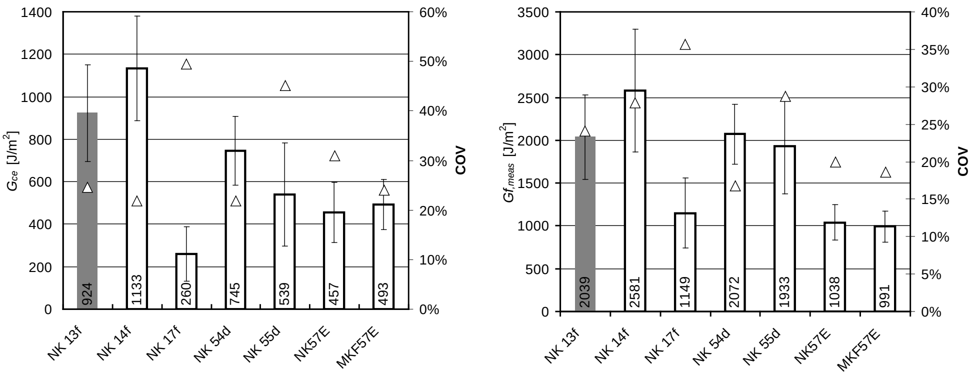

***Fig. 7** Values of effective fracture toughness (left) and specific fracture energy (right) of studied composites, average values, standard deviations and coefficients of variation (COV – signed by triangles) are shown for the both parameters*

Recommendation from the fracture-mechanical point of view was that composite NK 14f shows the highest values of effective fracture toughness as well as specific fracture energy. When we consider composites with a combination of two types of carbon particles (CR2 995 and carbon particles which seems to be more suitable from electrical features point of view), we can point out composite NK 54d. Details of the bath content can be found in (Řoutil et al. 2009). It seems that the suitable amount of carbon particles can improve the fracture-mechanical parameters, but on the other hand oversized amount of carbon particles leads to lower values of fracture-mechanical parameters.

3.Concluding remarks

The paper shows the use of the determined fracture parameters (effective fracture toughness and specific fracture energy) during the development of fibre reinforced cement based composites, where they were used for the recommendation of the composites suitable from the fracture-mechanical point of view for the next stages of the research.

All presented composites show a high value of fracture energy – these values are much higher than values of composites without fibres and present great advantage of these materials. Simultaneously we can observe quite high variability of studied fracture-mechanical parameters. It is necessary to take into account this phenomenon. Note that the structural design which takes into account the nonlinear fracture mechanics principles as well as probability aspects is still not common in civil engineering. This situation is noticeable especially in the case of quasi-brittle structures/structural members made typically of cement based composites. One possibility present the complex approach to the design and evaluation of quasi-brittle structures/structural members made of (advanced) cement based composites (Fig. 8), which presents object of interest of two research groups at the Institute of Structural Mechanics, Brno University of Technology (Keršner et al. 2007). The first one, under supervision of prof. Zbyněk Keršner, is focused on the nonlinear fracture mechanics, while the latter, around prof. Drahomír Novák, deals with the stochastic computational mechanics. As these subjects are topical also in the field of transport structures, there is a space for the closer cooperation between mentioned research teams and research teams from the Jan Perner Transport Faculty.

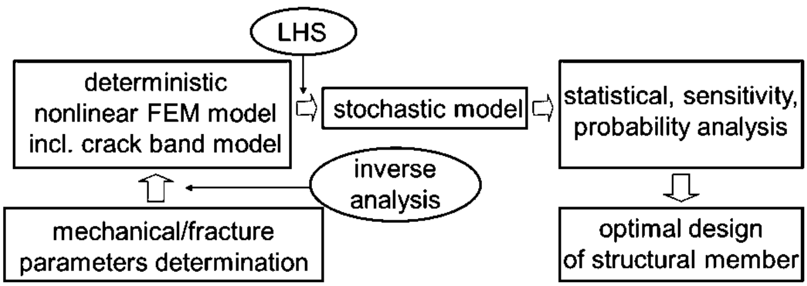

***Fig. 8** The scheme of the complex approach to the design and evaluation of quasi-brittle structures/structural members (LHS means Latin Hybercube Sampling)*

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Resumé

UPLATNĚNÍ LOMOVÝCH PARAMETRŮ PŘI VÝVOJI SPECIÁLNÍCH VLÁKNOVÝCH KOMPOZITŮ

Ladislav Řoutil, Zbyněk Keršner

Přehledový příspěvek nastiňuje využití stanovených lomově-mechanických parametrů při řešení dílčích problémů vývoje vláknokompozitů (hledání vhodného složení vláknokopozitu s elektrovodivou příměsí, kvantifikace vlivu výrobní technologie – extruze a vlivu degradace kompozitu) realizovaného ve spolupráci s Výzkumným ústavem stavebních hmot především při řešení projektu FT-TA3/027 – Multifunkční kompozity mimořádných vlastností na bázi anorganických nanosložek (2006–2010), příp. CIVAK – Centrum integrovaného výzkumu anorganických kompozitů (2006–2011). V závěru je představen přístup ke komplexnímu posouzení konstrukcí/konstrukčníh prvků z cementových kompozitů a tým zabývající se na STM FAST VUT v Brně dlouhodobě lomovou mechanikou kvazikřehkých kompozitů a je otevřena možnost budoucí spolupráce s pracovišti Dopravní fakulty Jana Pernera.