PROBABILISTIC STUDY ON CRACKING EVOLUTION AND FRACTURE ENERGY CHANGE OF STEEL FIBER-REINFORCED CONCRETE

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1. Introduction

The fracture mechanics defines concrete as a quasi-brittle material. Concrete cracking process is a common problem, because a period to the first micro-cracks may occur even before it is loaded. This is due to the loss of moisture from the concrete. The production method, admixtures, porosity, hardening conditions, maximum aggregate size, etc., as well as its inherent disadvantages are the main reasons that the process of cracks formation in concrete and their subsequent growth up to failure is complex. The use of fracture mechanics helps to better understand this process. The results of fracture energy (G_f) in the three-point bending test of steel-fiber reinforced high-strength concrete (SFRHSC) beams with notches and tensile strength (f_{ct}, f_l) were presented by Bywalski et al. [1]. They recorded two relationships, i.e. force-displacement (F- δ) and crack tip opening displacement (CTOD). On the basis of data captured, the parameters f_{ct}, f_l and G_f were estimated as a function of the fiber reinforcement coefficient.

On the other hand, the probabilistic fracture mechanics (PFM) is becoming more and more popular for realistic assessment of the fracture response and reliability of structures. However, the application of stochastic nonlinear computational mechanics to real world applications faces a major impediment as detailed information is lacking on the stochastic properties of the material parameters related to the problem. The process of the stochastic fracture-mechanical parameters determination is presented in [2] for C25/30 concrete together with stochastic models. The experimental procedure consisted of specimens compression, three-point bending tests of notched beams and splitting the wedges on the notched specimens. The inverse analyzes based on an artificial neural network were performed in order to identify material parameters. A quantitative influence of the freshly mixed concrete consistency on its mechanical cracking was determined. Moreover, the temporal development of fracture-mechanical parameters and their variability were investigated. Neha et al. [3] were used Two Parameter Weibull Distribution for the statistical analysis of the fracture energy of plain concrete and concrete reinforced by natural fibers. Weibull reliability curves show fracture energy at each reliability level. This enables the fracture energy to be selected for a given concrete mix in order to ensure reliability and a safety limit. This method can be applied in analyzing the scattered experimental results.

2. Materials and Methods

Concrete mixture of 380 kg/m^3 cement by 0.44 w/c ratio was prepared. Fraction of river sand of 0 – 2 mm and natural gravel fraction of 2 – 8 mm were used. Aggregates were kept at laboratory air-dry condition. The sand point was established to be SP=37% and used 12% sand and 88% gravel what allowed for the aggregate grading curves fit between the boundary curves. Superplasticizer Atlas Duruflow PE-220 and VMA admixture Atlas Duruflow VM-500 were used according to

PN-EN 934-2. A regular tap water was applied as the mixing water. Steel fibers of 0.8 mm diameter and 40 mm length were used.

The specimens for the basic test were produced in horizontally placed molds with dimensions of 500x500x50 mm. Based on the experience presented in the works [4, 5], it was decided to form the specimens horizontally, which enables better compaction and homogeneity of the mixture than in the case of vertical forms. The specimens were formed and compacted in two layers. In order to minimize segregation of the mixture and the separation of milk on the upper surface, the F2 consistency was chosen. It enabled the correct concentration of simple-shaped specimens, and VMA application. The specimens of 500x200x50 mm were cut out of the boards 20 days after forming, approximately, using a laboratory saw, and a notch of 10 mm high and 4 mm wide was manufactured in the middle of the longest wall.

Specimens for the compressive strength and bending tensile strength determination (beams with dimensions 500x100x100 mm) were also produced. After taking them out of the molds, they were stored together with the boards/beams in the air-dry laboratory conditions t = 20°C ± 2°C, RH = 50% ± 10%. Tests were carried out after 134 days of their production. The compressive strength tests were conducted on 100 mm cubic specimens after either 28 or 134 days of hardening. The tests were carried out in accordance with PN-EN 12390-3 by using a ToniTechnik instrument of 3000 kN compression force capacity. The flexural strength tests were conducted on the beams with dimensions of 500x100x100 mm after 134 days of hardening. The tests were carried out in accordance with PN-EN 12390-5 by using a Matest instrument of 300 kN compression force capacity. The rate of loading was maintained at 0.5 MPa/s for compressive strength tests and at 0.05 MPa/s for tensile splitting strength tests.

3. Conclusions

The paper presents the results of analysis concerning an evolution of the fracture process developing in the fibro-concrete specimens subjected to several types of mechanical tests. The results elaborated in the form of probability distributions and force - CMOD curves enabled to check suitability of the stochastic constitutive models with special emphasis of taking into account the random nature of the parameters describing the material tested and the analysis of cross-correlation of these parameters.

4. References

[1] C. Bywalski, M. Kaźmierowski, M. Kamiński, M. Drzazga, (2020), Material Analysis of Steel Fibre Reinforced High-Strength Concrete in Terms of Flexural Behaviour. Experimental and Numerical Investigation, *Materials*, 13, (7), 163.

[2] T. Zimmermann, A. Strauss, D. Lehký, D. Novák, Z. Keršne, (2014), Stochastic fracture-mechanical characteristics of concrete based on experiments and inverse analysis, *Construction and Building Materials*, Volume 73, 30 December, 535-543.

[3] P. Neha Asrani, G. Murali, J. Arthika, K. Karthikeyan, M.K. Haridharan, (2019), Probabilistic Fracture Energy Assessment of Natural Fibre Reinforced Concrete by Two Parameter Weibull Distribution International, *Journal of Engineering & Technology*, 7 (3.12), 407-410.

[4] C.G. Hoover, Z. Bažant, J. Vorel, R. Wendner, M. Hubler, (2013), Comprehensive concrete fracture tests: Description and results. *Engineering Fracture Mechanics,* 114, 92, 103, doi:10.1016/j.engfracmech.2013.08.007.

[5] C.G. Hoover, Z. Bažant, (2013), Comprehensive concrete fracture tests: Size effects of Types 1 & 2, crack length effect and postpeak. *Engineering Fracture Mechanics* 110, 281-289, doi:10.1016/j.engfracmech.2013.08.008.