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Fracture Mechanics Parameters of Fine Grained Concrete with Polypropylene Fibres

Marta Kosior-Kazberuk[a,*], Piotr Berkowski[b]

[a]*Bialystok University of Technology, Wiejska 45A, 15-351 Bialystok, Poland*
[b]*Wrocław University of Science and Technology, Wyb. Wyspiańskiego 27, 50-370 Wrocław, Poland*

Abstract

Fracture mechanics is widely used to analyze the material behaviour in a structure. The paper reports the results of an experimental programme focused on the effect of various synthetic fibres on the fracture properties of concrete investigated in Mode I conditions. The changes in concrete properties were analysed on the basis of the critical stress intensity factor K_{Ic}, the critical value of crack tip opening displacement ($CTOD_c$) and the fracture energy G_F. The addition of the synthetic fibres had a slight effect on the strength properties of concrete but, at the same time, it had a significant influence on the fracture mechanics parameters by the modification of pre-cracking and particularly post-cracking behaviour of the concrete. Results of measuring the toughness and energy-absorption characteristics showed that the specimens reinforced with synthetic fibres acquired a great ductile behaviour and energy absorption capacity, compared to ordinary concrete specimens.

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Keywords: concrete, polypropylene fibre, fracture mechanics parameters, ductility;

1. Introduction

Fibre reinforced concrete has gained increasing significance over the past years, both in research and construction industry. The addition of fibres makes the cementitious material more isotropic and transforms it from a brittle to a quasi-brittle material. The real benefits of adding fibres to concrete become evident at the stage of post-cracking. Before that, the most of fibre types had a limited effect on the concrete mechanical properties [1].

* Corresponding author. Tel.: +48 85 746 96 00
E-mail address: m.kosior@pb.edu.pl

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However, the full potential of fibre reinforced concrete is still not fully exploited in practice [2]. The fracture mechanics, as one of the most significant field of science, is widely used to analyze the material behaviour in a structure [3, 4, 5]. The relation between microstructure evolution and macroscopic response is crucial in the design and modelling of heterogeneous materials. Applications of fracture mechanics to concrete structures can provide a rational basis for both service performance and failure analysis and can lead to a better understanding of the design methods.

The most of the experiments relate to concrete reinforced with steel fibres and very few represent the research on composites with other kinds of fibres, i.e. synthetic fibres, which can present the series of advantages. With low modulus of elasticity, high strength, excellent ductility, excellent durability and low price, synthetic fibres can be used in cement-based materials to improve the ductility and fracture properties of the matrix [6, 7]. In addition, in the recent years, important efforts have been devoted to development of new types of synthetic fibres [8, 9]. At present, there is little information available in literature about the fracture properties of modified polypropylene macro fibre reinforced composites. Therefore, the aim of the experimental study was the analysis of the effect of various kinds of polypropylene fibres on the fracture mechanics parameters and post-cracking behaviour of fine grained cement concrete.

2. Experimental programme

2.1. Materials and specimen's preparation

Three types of synthetic fibres were used. Two of them were smooth surface, straight, flexible fibres with a diameter of 0.05 mm and different length: type A (50 mm) and type B (25 mm). The third type (C) of dispersed reinforcement was a structural, extruded fibre with a length of 50 mm and a cross section of size 0.8×1.4 mm. Specially treated surface of the type C fibre should create a multi-directional bond between the fibre and the cement matrix. The fibres were added as a replacement of adequate portion of an aggregate at three volume fractions 0.3%, 0.6% and 0.9%, which range the dosage suggested by the producer. The cement (CEM I 42,5 R) content in concretes tested was constant – 360 kg/m^3. The river sand, fraction 0-2 mm, and the natural aggregate with maximum diameter of 4 mm, were used. The cement content, fine aggregate content and water to cement ratio of 0.40 were also kept constant in all mixes. The maximum size of the aggregate was limited to reduce its influence on fracture properties.

The modified polycarboxylate based super-plasticizer was used to minimize fibre clumping and enhance fibre dispersion in the concrete. For each fibre-dosage combination the notched beams of size 100×100×400 mm were prepared for fracture parameters determination. Every series was composed of four replicates. The initial saw-cut notch with a depth a_0 equal to 30 mm and a width of 3 mm was located in the mid-span place. The geometry of the specimen is presented in Fig. 1a. Moreover, the beams (100×100×400 mm) for flexural strength and cubes (100×100×100 mm) for the compressive strength test were also cast. After demoulding all the specimens were cured in water at the temperature of 20±2^{o}C till they were tested.

2.2. Test methods

The fracture parameters such as the critical stress intensity factor K_{Ic} and the critical tip opening displacement CTOD$_c$ were determined using procedure given by RILEM TC 89-FMT [10]. The fracture parameters were assessed in a three-point bend test on beams with initial notches (Fig. 1a). The testing machine (MTS 322) with closed-loop servo control was used to achieve a stable failure of the specimens. The crack mouth opening displacement (CMOD), measured using the clip gauge at the centre of the notch, was a feedback signal (Fig. 1b). The cycles of loading and unloading were repeated four times, and then the specimen was loaded up to failure.

The load-CMOD relationships were used for K_{Ic} and CTOD$_c$ determination. The fracture energy G_F was assessed according to a procedure given by RILEM TC 50-FMT [11]. The fracture energy was defined as the area under the load-deflection curve per unit fractured surface area.

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