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Identification of mechanical and fracture properties of self-compacting concrete beams with different types of steel fibres using inverse analysis

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HIGHLIGHTS

- Identified properties allows for the reproduction of experimental LD diagrams.
- Trend lines for the material parameters and steel fibers fraction dependence are introduced.
- 3D LD diagram for SFRC with respect to fiber content is presented.

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ABSTRACT

The application of self-compacting concrete has found wide use in practice. However, its application is often limited by lack of knowledge on material parameters gained from laboratory tests, which results in difficulties in the design of progressive building structures and buildings where non-linear finite element analysis should be used. The submitted paper presents results of identification of mechanical and fracture properties of selected self-compacting concrete beams applicable for non-linear finite element analyses. A procedure dealing with the determination of mechanical and fracture properties from an extensive series of tests on notched beams is also presented. The studied material is a high-performance concrete reinforced with two types and three volume ratios of steel fibres. An inverse analysis in combination with a multi-criterial analysis is used for evaluation of fracture-mechanical characteristics.

1. Introduction

Composite materials based on a combination of short, randomly distributed fibres and concrete has shown a wide range of applicability because of its enhanced mechanical parameters compared to plain concrete [1,2]. The enhanced properties are tensile mechanical parameters, ductility and energy absorption capacity under impact [3,4]. Steel fiber reinforced concrete (SFRC) is commonly used in structural engineering e.g. in road pavements, lining or slabs. However, current wider structural applicability of the discussed composite material is limited by lack of knowledge and recommendations for advanced design using computer programmes considering non-linear analysis. Therefore, it is necessary to have a knowledge of several mechanical properties or to be able to identify the properties of interest.

The properties are often not available and include tensile strength, testing of which is very demanding and sensitive [5]. Usually, there is also a large scatter in the measured values, and it is a significant challenge to take this fact into account in the calculation, particularly in connection with determination of Young's modulus, tensile strength, fracture energy [6] and other parameters [7]. Because of this fact, in the present investigation the flexural tensile tests presented in [8] were used as a base for the numerical simulations.

The work [8] deals with flexural behaviour of self-compacting concrete reinforced with steel fibres (SFR-SCC). Self-compacting concrete is a kind of a new cement-based material, which simplifies the processing technology of concrete on construction sites and also enables the production of complex structural shapes [9]. The main difference in comparison to a commonly used concrete is in the use of the type of aggregate, the amount of cement and plasticizers. Otherwise, however, typical brittleness of concrete

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remains. These include low tensile strength of concrete and poor resistance to cracking. For these reasons, self-compacting concrete, as any other concrete, can be supplemented with fibres [10,11]. The addition of fibres significantly improves the tensile strength of concrete, and the behaviour of concrete in the post-crack regime. The effectiveness of fibres in the brittle matrix depends on its material, geometry (longitudinal and cross-sectional shape), length, volume and the position/orientation of the fibres [12,13], which can be verified using methods presented in [14]. It should be mentioned, that the best improvements of mechanical parameters can be obtained using a combination of different fibres [15].

To investigate the SFR-SCC in a wide range of mentioned parameters, the investigation with two types of steel fibres (straight, hooked) and three volume ratio (0.5%, 1.0%, 1.5%) were tested according to [16,17] in [8]. The paper provides a detailed description of the experiments and evaluation of laboratory tests within the standards for steel fibre reinforced concrete, considering a linear relationship between mechanical properties and volume of steel fibres according to different type of fibres. However such data for advanced non-linear computations are not sufficient.

As a result, the design using linear, even though finite element method-based [18] models is often not optimal and cost-effective, or does not give information related to residual post peak carrying capacity. The right selection of approach to calculate important structures is especially important in cases of advanced non-linear and sensitivity analyses [19]. The amount of information required varies especially with regard to the chosen constitutive model of concrete. The important and basic information shall include, in particular, the knowledge of the stress-strain relationship for tension, strength of concrete in tension and compression, as well as fracture-mechanical properties [20]. With this information it is then possible to perform advanced analysis and optimized design that respects the actual behaviour of the structure. The new applications of fibres include their use in combination with self-compacting, high-strength concrete or high-quality types of concrete [21]. Support for such applications was provided in experimental research [8].

For a proper design of structures (based on non-linear computational analysis) which takes into account the actual behaviour of steel fibre reinforced concrete it is typical to start with the concrete-based constitutive models. There are a number of approaches in this area. For example, one can name elasto-plastic models [22,23], models based on fracture mechanics [20] and damage mechanics, or combined models. Especially fracture mechanics have been paid considerable attention both from the theoretical and experimental research point of view. [23] lists concrete constitutive models used for numerical modelling of typical tests of concrete elements as well as their mutual comparison.

The subject of research is particularly the issue of determining fracture parameters [24,25], tensile strength [26,27] and other material properties [28–35]. Methods for determination of some of the properties are already standardized in some states [36].

There are also a number of design approaches or recommendations specialized directly for steel fibre reinforced concrete. In these cases, however, it is often a specific procedure for specific design cases and situations [37]. What they all have in common is that their important input is the knowledge of relationship (dependence) between deformation and (tensile) stress across the discontinuity. This is often expressed, in the case of cracks, in the form of crack opening law (traction-separation law, or cohesive law). Other parameters include concrete tensile strength and fracture energy. Another piece of important information is the strength in uniaxial or biaxial compression and modulus of elasticity. Characteristics of concrete in compression are, as opposed to tension,

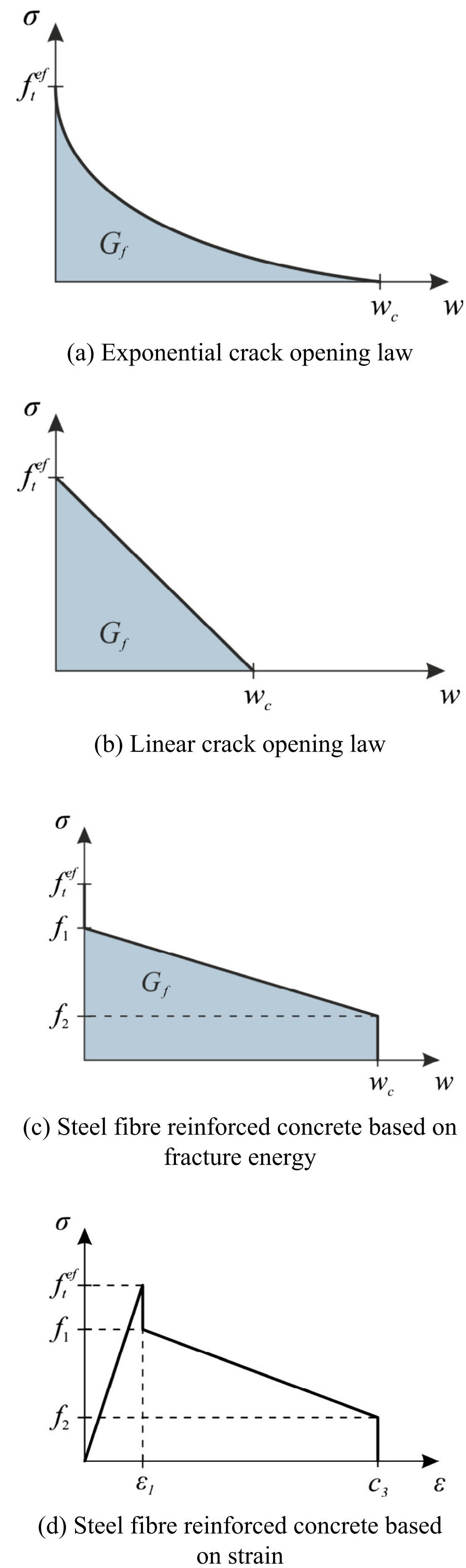

Fig. 1. dependences between the crack .opening/cracking strain and the tensile stress along the process zone (exponential, triangular, fibre steel reinforced concrete)