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Effect of fibre length on the fracture energy of UHPFRC

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Abstract

Ultra-high-performance fibre-reinforced concrete (UHPFRC) is an advanced cementitious composite with enhanced mechanical and durability properties that outperforms conventionally used concretes in many ways. Such a material with certain properties and specifications is well suited for energy absorption facade panels and key elements of building structures that may be exposed to impacts or blast loads. It can be stated that the resistance of civil infrastructure is strongly related to the energy absorption capacity of concrete, which is the main material property that benefits from fibre reinforcement.

The aim of this study is to investigate the fracture energy of the UHPFRC with various fibre aspect ratios. Different behaviour of UHPFRC in terms of fracture energy can be expected for various aspect ratios of fibres, as the fibres are the key component of the UHPFRC that result in enhanced energy absorption and dissipation capacity. The aspect ratios (length-to-diameter) of fibres used in this study ranged from 50:1 to 108:1. It was verified experimentally that the fracture energy increases as the aspect ratio increases. In addition, it was found that the dependence of the fracture energy on the aspect ratio of the fibres tends to follow a linear trend. The results provided in the present study can serve as valuable information for verifying material models, and also for design purposes.

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Keywords: UHPFRC; flexural loading; fracture energy; steel fibres; aspect ratio

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1. Introduction

This paper investigates behavior of ultra-high-performance fiber-reinforced concrete (UHPFRC) with various fiber aspect (length-to-diameter) ratios in the framework of the effective fracture energy. Ultra-high-performance fibre-reinforced concrete can be classified as an advanced cementitious composite with enhanced mechanical and durability properties that outperforms conventionally used concretes in many ways. UHPFRC is typically characterized by compressive strengths that are in excess of 150 MPa to approximately 250 MPa and uniaxial tensile strengths that are ranging from 7 MPa to 15 MPa [1–3]. Many researchers confirmed that such a material with certain properties and specifications is well suited for energy absorption facade panels and key elements of building structures that may be exposed to impacts [4–6] or blast loads [7–10]. The energy absorption capacity of the UHPFRC is the main material property that benefits from fibre reinforcement. Herein, various aspect ratios of the fibres have been studied in order to find the best performing fibre geometry.

UHPFRC can be characterized as a composite containing large volume of steel fibers, low water-binder ratio, high microsilica and cement content and absence of coarse aggregate i.e. larger than 4 mm. It has outstanding material characteristics such as self-consolidating workability, very high mechanical properties and low permeability which results in excellent environmental resistance. In addition, these materials also exhibit strain hardening under tension which results in enhanced energy absorption capacity. The aim of this paper is to describe how the aspect ratio of the fibers influences the fracture energy of UHPFRC while keeping the fiber volume fraction constant.

2. Sample preparation

The UHPFRC investigated in this study was mixed in conventional mixers. UHPFRC used in this study was a self-consolidating concrete with fast strength development which does not require heat curing or special mixing techniques. The mixture contained a high volume of cement and silica fume, and the water-to-cement ratio was 0.22 (Table 1). The high-strength steel micro-fibres used in this study were straight and smooth, with a tensile strength of 2800 MPa as specified by the manufacturer. High tensile strength of the fibres was chosen in order to achieve the pull-out failure mode. The pull-out failure mode is a much more energy-consuming than the fibre failure mode [11]. Straight fibres also provided a good trade-off between the workability and the mechanical properties of the resulting UHPFRC mixture [1].

When mixing UHPFRC, it is very important to achieve good workability, particle distribution and packing density. In comparison to normal strength concrete, UHPFRC contains more constituents and finer particles. Several researchers recommend mixing all fine dry particles first, before adding water and superplasticizer [2,3,12]. They do so because small particles tend to agglomerate and it is easier to break these chunks when the particles are dry. The specific mixing procedure looked as follows: As the first step both types of aggregates and silica fume were mixed for five minutes. As the second step cement and silica powder were mixed for another five minutes. At the end of the procedure water and superplasticizer were added. The addition of superplasticizer was gradual. The mixture became fully workable after another 5 minutes. Fibres were added gradually into the flowable mixture, to avoid chunk formation, during the last 5 minutes of mixing. The shear action of the fibres helped to destroy any remaining agglomerates in the mixture, thus improving workability. The total mixing time was 20 minutes. A food-type mixer with a capacity of 25 l was used to prepare the samples.

Table 1. Composition of the UHPFRC

Cement CEM I 52,5R	kg/m^3	800	proportions by weight	1
Silica fume (Microsilica)		200		0.25
Silica powder		200		0.25
Water		176		0.22
Superplasticizer		39.0		0.049
Fine sand 0.1/0.6 mm		336		0.42
Fine sand 0.3/0.8 mm		640		0.8
Straight steel fibres		160		0.2