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The relation between fiber orientation and tensile behavior in an Ultra High Performance Fiber Reinforced Cementitious Composites (UHPFRCC)

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ABSTRACT

In this study, the effect of the fiber orientation distribution on the tensile behavior of Ultra High Performance Fiber Reinforced Cementitious Composites (UHPFRCC) was investigated. The tensile behavior was explored separately in two stages; pre-cracking and post-cracking tensile behaviors. Pre-cracking tensile behavior is expressed using the mechanism of elastic shear transfer between the matrix and the fiber in the composites. Post-cracking tensile behavior was expressed as the combined behavior of the resistance by the fibers and the matrix, considering a probability density distribution for the fiber orientation distribution across crack surface and a pullout model of steel fiber. The effect of the fiber orientation distribution was found to be very small on pre-cracking behavior, but to be significant on post-cracking behavior of UHPFRCC. The predicted results were compared with the experimental results, and the comparison presented satisfactory agreement.

1. Introduction

Ultra High Performance Fiber Reinforced Cementitious Composites (UHPFRCC) dealt with in this study shows very high strength, self compacting ability, and high toughness. It does not contain coarse aggregates and develops compressive strength exceeding 150 MPa with improved toughness through mixing of 2 vol.% of steel fibers that are 13 mm long and 0.2 mm in diameter.

In general, the most important advantage of adopting Fiber Reinforced Concrete (FRC) is the increase of tensile strength and enhancement of toughness. In other words, fibers in FRC resist against crack propagation with the help of stress transfer from the matrix to the fibers. FRC thus exhibits strain hardening behavior after first cracking as well as improvement in energy absorption capacity and toughness.

In UHPFRCC, a steel-fiber reinforced cementitious composite, it is therefore clear that the improvement in tensile properties is achieved by adding steel fibers. In order to understand its tensile properties and the performance of structures using the composites clearly, research on the effect of fiber reinforcement should be first conducted.

To date, most researches on the effect of fiber reinforcement have been mainly focused on the effects of geometric shape, type, and volume fraction of fiber [1–9]. Although there have been also numerous studies regarding the effect of fiber distribution [10–14], they mostly were devoted to the correlation at a macro-structural level between fiber distribution characteristics (e.g. a coefficient to represent the average dispersion or orientation of fibers throughout the composites) and tensile properties (e.g. tensile strength or toughness). Few studies have adopted a systematic approach from a microscopic to macroscopic view; that is, from the bond behavior of individual fiber distributed in the composites to the tensile behavior of a fiber reinforced composite and its structural performance. While some researchers have focused on the systematic approach with special interest in the fiber orientation distribution [15,16], the approaches were limited to analytical studies with the assumption of an idealized fiber distribution. They did not consider the actual fiber distribution, which is affected by diverse factors such as placing method, form shape, and fiber geometry.

Meanwhile, recent researches on FRC unveiled that the rheology of the FRC mix plays an important role in fiber orientation and thus its mechanical performance [17–19]. Many researchers are getting more interest on the effect. In an effort to obtain better performance with better fiber orientation distribution, there has been a simple attempt to induce fiber alignment by extrusion forming process [20]. In another way, there have been efforts to investigate the variation of fiber orientation distribution with different fabrication processes and quantitatively estimate its effect on the mechanical performance, especially tensile behavior [21–23]. Wuest et al. [24] proposed a meso-mechanical model to predict the UHPFRCC tensile hardening response considering the effect of realistic fiber orientation distribution on it.

This study was intended to investigate the effect of the fiber orientation distribution on the tensile behavior of UHPFRCC, considering the pullout behavior of each fiber in the composites and the actual fiber

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