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Case study

Experimental investigation and identification of single and multiple cracks in synthetic fiber concrete beams

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The tensile behavior of fiber-reinforced concrete is recognized as being superior to that of ordinary concrete, and since serviceability is a primary concern in existing design specifications, it is important to evaluate its post-cracking performance. This research experimentally identified and investigated cracks in concrete beams reinforced with synthetic fibers. Concrete beams with and without longitudinal reinforcement were studied in order to assess both single and multiple cracking scenarios. Synthetic fiber volume fractions of 0.5% and 1% were used to prepare the specimens, and the results were compared with those of concrete beams with no synthetic fibers. Six unreinforced beams and six reinforced beams with flexural behavior were tested. The digital image correlation (DIC) method was utilized to record the width, spacing, number, and locations of the cracks for all the specimens during the displacement control-type loading. The results indicated that using 1% synthetic fiber increased the failure load of the reinforced concrete beams and improved the serviceability by reducing the number of cracks and the width of the cracks. When the cracks opened significantly, the beams with 1% fiber dosage were able to carry higher loads due to the bridging action of the fibers at the crack locations.

1. Introduction

Various types of fibers such as steel, glass, polymer, synthetic, etc. are commonly used in girders, slabs, and infrastructures [1,2]. They strengthen concrete tensile behavior and have a slight effect on its compressive strength [3–8]. Fiber-reinforced concrete (FRC) contains short discrete fibers that are uniformly distributed and randomly oriented [9], and increase its structural integrity. Its many advantages include improving structural strength, reducing the number of steel reinforcements, and improving the freeze-thaw resistance [10]. Its behavior is dependent on the type, dosage, density, distribution, and orientation of the fiber(s), making it necessary to investigate each case independently.

A harsh environment significantly decreases the functionality of reinforced concrete (R.C.) structures. Corrosion of steel reinforcements is one of the main threats to infrastructures such as pipeline, bridges, etc., and a crack opening elevates the risk of corrosion in reinforcements. Therefore, another benefit of FRC is the enhanced probability of controlling the crack opening in order to maintain structures in serviceable conditions. The existing design standards, such as ACI318-14 [11],

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propose a limitation for the crack spacing. Section 24.3.2 in the ACI-318-14 correlates the crack spacing with strain in the longitudinal rebar and configuration of the rebar.

Many studies have been conducted on crack measurements since 1968. Gergely and Lutz [12] performed a statistical investigation on a large number of crack-width measurements. Their study included 612 observations of bottom cracks and 315 observations of side cracks in reinforced concrete beams. Based on their study, a formula was developed which became the design formula of ACI 318-83 [13]. To improve the correlation between experimental data and existing formulas, Oh and Kang [14] conducted tests on a series of 747 data points on reinforced concrete beams under pure flexure. Along with the development of equations for crack-width measurement, Frosch [15] investigated the effects of different thicknesses of a steel cover, using the existing test data to modify the previous formula. Colotti and Spadea [4] proposed a crack-width model based on the softened truss theory. The crack width of reinforced concrete elements under combined axial, flexural, and shear can be predicted by this model. A uniformly loaded panel with a combination of normal and shear forces was considered, and the average principal tensile strain was predicted, using the compatibility and equilibrium equations. The model was verified by using the existing test results. Considering the effects of bond between longitudinal rebar and concrete, Gupta and Maestrini [16], Wu et al. [17], Muhamad et al. [18] and Sturm et al. [19] performed an explicit integration on the stress distribution in the bond of steel and concrete. They also suggested different tension stiffening curves for reinforced concrete elements.

The advent of various types of fibers in concrete technology called for a comprehensive investigation of the characteristics of cracks in fiber-reinforced concrete. Vandewalle [3] tested five full-scale steel fiber- reinforced concrete (SFRC) beams with conventional longitudinal reinforcement and different types and ratios of steel fibers. Based on the results, he proposed modifications of the crack width and crack spacing formulas. Deluce and Vecchio [5] performed several experimental uniaxial tensile tests to investigate the cracking behavior of structural concrete components reinforced with steel fibers, and they found that the presence of conventional reinforcement significantly changed the cracking behavior of the SFRC. Deluce et al. [6] proposed a model to calculate the crack spacing and crack width of SFRC members containing conventional reinforcement. The results of this model were compared with 17 plain reinforced concrete and 53 conventionally reinforced SFRC specimens subjected to uniaxial tension. The model was found to be accurate, both for crack spacing and crack width measurement. The uniaxial behavior of fiber-reinforced concrete with longitudinal reinforcement was investigated by Moreno et al. [20], Tiberti et al. [21] and Visintin et al. [22]. The distribution of cracks as well as the amount of crack width found to be highly affected by the presence of fibers in reinforced concrete members.

Synthetic fibers were introduced to the concrete industry in the past decade, and an experimental study of the shear and flexural behavior of synthetic fiber-reinforced concrete (SYN-FRC) with different volume fractions was performed by Mostafazadeh and Abolmaali [8]. Their results revealed that the application of synthetic fibers in concrete improves its toughness and its shear and flexural strength. Synthetic fiber products rapidly entered the infrastructure industry. Park et al. [23] proposed a new class of concrete pipes, using synthetic fibers. Compared to traditional steel cage pipes, the SYN-FRC pipes have greater flexibility, thinner walls, and require fewer reinforcements, showing that synthetic fibers can increase the shear capacity of the pipes and delay the shear failure mode so that the load-carrying capacity of the pipes is increased, even with reduced steel reinforcement.

The issue of long-term serviceability of SYN-FRC infrastructures requires an investigation of the impact of the volume of synthetic fibers on crack openings. Therefore, this study compares the cracking behavior of reinforced and unreinforced concrete beams when the volume fraction of the synthetic fibers varies. This research presents an experimental investigation of crack initiation and its propagation in specifically synthetic fiber reinforced concrete beams. Also, the effects of presence of longitudinal reinforcement on the crack identification was studied in this research. Two experimental phases were performed. The first phase included testing a series of FRC beams without longitudinal steel reinforcements and stirrups with two different fiber dosages. In this phase, the tested beams experienced single cracking. The crack measurement was recorded for all of the case studies by using the digital image correlation (DIC) method. Six reinforced concrete (R.C.) beams with flexural behavior were studied in the second phase to investigate beams with multiple cracks. The results of the testing

Table 1
Characteristics of tested specimens.

Phase No.	V_f %	Specimen	Size (mm)	Reinforcement
I	0.5	UB1-0.5F	152×152×507	N/A
		UB2-0.5F		
		UB3-0.5F		
	1.0	UB1-1.0F		
		UB2-1.0F		
		UB3-1.0F		
II	0.0	B1-0.0F	152×229×1144	$\rho_s = 0.005$
		B2-0.0F		2 #3 top
	0.5	B1-0.5F		2 #3 bottom
		B2-0.5F		No stirrups
	0.5	B1-1.0F		
		B2-1.0F		