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Experimental Study of Fiber Reinforced Concrete Beams

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Abstract:
Shear strength of fiber reinforced concrete beams was studied in this research project. Three types of fibers were examined: hooked-end steel fiber, crimped-steel fiber, and crimped-monofilament polypropylene fibers. The experimental program included five beam specimens. Two of the beams were control specimens in which one was reinforced with minimum shear reinforcement according to ACI 318, while the other one did not have any shear reinforcement.

Each one of the other three specimens was reinforced with one of the above mentioned fibers by 1% volumetric ratio. In addition to the beam specimens, three prisms were also made for each type fiber to determine their toughness. The aim of this research was to investigate the following questions for medium-high concrete strength 1) to evaluate the effectiveness of each type of fibers on the shear strength, 2) to investigate the shear strength, toughness, crack patterns and near ultimate load crack width of each beam, and 3) to determine if using 1% volumetric ratio of fibers as shear reinforcement in beams would provide adequate strength and stiffness properties comparable to reinforcing steel used as minimum shear reinforcement.

The results showed that all three types of fibers increased the shear capacity of the beam specimens more than the beam reinforced with minimum shear reinforcement. Moreover, some of the fibers used could shift the type of failure from a pure shear failure to a combined flexural-shear or pure flexural failure.

1: Introduction:

1.1.Historical Background and Development of Fibers:

Historically, much effort has been spent improving the behavior of concrete structures. Flexural, compressive, shear strength, ductility, and other properties have been the focus of many researchers who have tested concretes with added steel and other materials to improve the behavior of concrete. The concept of adding fibers to improve brittle material behavior is ancient. For example, Mesopotamians used straw to reinforce sunbaked bricks. This ancient technology is still used to improve concrete characteristics.

1.2. Potential Uses of Fiber Reinforced Concrete FRC:

Steel fiber is used to improve the mechanical properties of concrete, especially the post-cracking tensile resistant. Moreover, it has recently been used as an alternative engineering material instead of steel bars/steel stirrups in short-span concrete slabs. Steel fibers reinforced concrete (SFRC) construction is more economical than conventional construction. In addition to cost reduction, SFRC has other beneficial properties such as higher stiffness, higher ductility, lightweight, low repair costs, and better post-cracking and dynamic behavior.

1.3. Motivation for the Research:

The guidelines that deal with SFRC is “Design Consideration for Steel Fiber Reinforced Concrete” (ACI Committee 544, 2009). It contains test results and equations to predict shear strength. This provision does not have any design equations for two possible reasons.

First, the most available research has been done with older types of fibers such as chopped-straight wire. These types of fibers do not enhance concrete characteristics as much as modern fibers.

1.4. Objective and Scope of the Research:

The objective of this research was to investigate the following aspects of fiber reinforced beams made of medium-high concrete capacity. 1) to evaluate the effectiveness of each type of fibers (hooked-end steel fibers, crimped-steel fibers and polypropylene fibers) on the shear strength of beams, 2) to investigate the shear strength, toughness, crack patterns and near ultimate load crack width of each beam, and 3) to determine if using 1% volumetric ratio of fibers as shear reinforcement in beams would provide adequate strength and stiffness properties comparable to reinforcing steel used as minimum shear reinforcement.

2: Literature Review:

2.1. Mechanical Properties of SFRC:

2.1.1.Bond Behavior of Steel Fiber Reinforced Concrete:

As it mentioned before, the utilization of fibers to enhance the characteristics of brittle material is very old. In the early 1960s [1], steel fiber was introduced as a new a version of fiber. Straight fiber was the first type of that fiber. The bond of that fiber depended on the friction between the concrete and fiber. Consequently, a rectangular section with higher aspect ratio was more efficient.

3: Experimental Program:

3.1. Introduction:

As mentioned in chapters 1 and 2, fibers are used to enhance both plastic and harden concrete characteristics. The experimental program of this research provides further understanding of using steel fiber, hybrid steel and fibrillated polypropylene fiber, and hybrid monofilament and fibrillated polypropylene fiber to enhance concrete characteristics.

The experimental program aimed to answer the following questions:

(1)What are the shear strength, cracks patterns, cracks width, and flexural toughness of fiber reinforced concrete?
(2)How do these results change if the fiber type is changed?
(3) Can 1% fiber be used to substitute minimum shear reinforcement as specified by ACI Committee 318 for RC beams?

The concrete strength for the experimental beams was selected as a “medium-high” capacity of 6000 psi. This capacity was selected in order to reflect the expected capacities of the future concretes, possibly in the next one or two decades. The experimental program involved designing, manufacturing, and testing about one-third scale simply supported beam specimens subjected to two concentrated symmetrical loads. In addition, a fiber bond test, a trial mix test, cylinder tests, and a rebar test were conducted

3.2. Beam Specimens:

The experimental program consisted of five beam specimens of the same size. Each specimen had a different shear resisting system. The first three specimens were reinforced with 1% volumetric ratio of hooked-end steel, crimped-steel and crimped-monofilament polypropylene. The fourth specimen was reinforced with minimum shear steel reinforcement specified by ACI 318 [41]. The last one did not have shear steel reinforcement or fiber. Table 3-1 shows the detail of these specimens. The system used to identify the specimens was based on two parts. The first part of the specimen name refers to its number in the sequence. The second part refers to the shear resisting system that was used such as HS which refers to hooked-end steel fiber.

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Beams(*)	ρ	Fiber type	Shear resisting system	Vf	Targeted f'c
B1-MS	2.42%	No fiber	Conventional Minimum Steel reinforcement	0%	6000
B2-HS	2.42%	Novocon 1050	Hooked-end Steel fiber	1.0%	6000
B3-CS	2.42%	Novomesh 850**	Crimped-Steel fiber	1.0%	6000
B4-CPP	2.42%	Novomesh 950**	Crimped monofilament Polypropylene fiber	1.0%	6000
B5-NS	2.42%	No fiber	No Shear	Zero	6000

3.4. Varied Parameters:

3.4.1. Fiber Types:

There are three types of fibers used in this experimental program. These fibers are manufactured by Propex. The first type of fiber is Novocon 1050, which is hooked-end steel fiber. The second type is Novomesh 850. This type is a hybrid of two fibers, which are crimped-steel fibers and fibrillated-polypropylene fiber. The last one is Novomesh 950. Similar to the previous one, this type is also is a hybrid fiber of two types. However, both of them are made of polypropylene. These fibers are monofilament fibers of sinusoidal deformations and fibrillated polypropylene fibers. All these fibers can be seen in figure 3-3. In addition, their properties are listed in table 3-5, where aspect ratio is the approximate ratio of length to diameter.

Table 3-5 Type and Characteristics of the used fibers:

Fiber type	Diameter	Length	Aspect ratio
Novocon 1050	0.039 in (1.0 mm)	2 in (50 mm)	50
Novomesh 850 (*)	-	1.5 in (38 mm)	34
Novomesh 950(*)	0.033 in (0.83 mm)	1.8 in (45 mm)	55

* Only crimped steel fiber and monofilament polypropylene fiber were used.

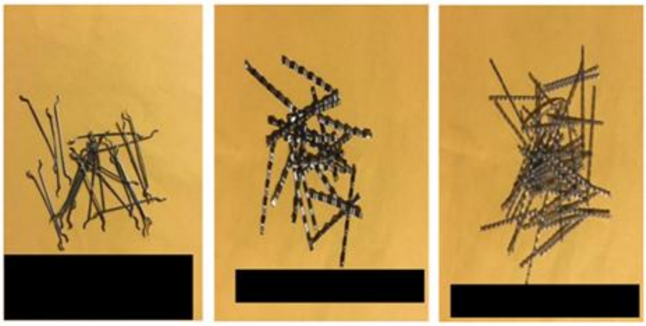

Figure 3-3 Fibers used in the experimental program

3.5. Fabrication of Reinforcement Cages and Formwork:

Reinforcement cages were constructed at Portland State University "Hoophouse" Lab. First, they were cut to the required length.

Figure 3-4 Steel fabrication and form work

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3.6. Proportioning, Mixing and Curing of FRC:

The amounts of cement, fine aggregate and coarse aggregate, were determined depending on the targeted compressive strength using trial mixes. However, the required amount of each type of fibers was determined depending on the specific gravity, which was determined in the lab or provided by a producer. Table 3-6 shows the specific gravity and the amount of fiber used one cubic foot.

Table 3-6 Proportion of mixed fibers:

Fiber type	Specific gravity	Amount in lb for every ft^3
Novocon 1050	7.84	5.1
Novomesh 850*	7.84	5.1
Novomesh 950*	0.91	0.6

3.7. Instrumentation and Testing:

3.7.1.Steel Tensile Test:

The Instron, a direct tensile stress machine housed in the Department of Mechanical and Materials Lab at Portland State University was used to determine the tensile capacity of steel. This machine is shown in figure 3-5. The strain was determined using two methods. The first one used strain gages fixed on the rebar. The second used a "laser extensometer". The second method was done by fixing two reflectors on the surface of the steel rebar. The laser extensometer determined the length of the rebar surrounded by the two reflectors. After applying the load, the laser extensometer recoded the length increase. From knowing the original length and increment in the length, strain can be determined.

Figure 3-5 Direct tensile testing machine "Instorn"

4: Result of the Experimental Program

4.1. Introduction:

This chapter is divided into two main parts. The first part focuses on the mechanical properties and behavior of the fiber reinforced concrete, which are compressive, tensile, toughness, and modules of elasticity. The second part provides a detailed analysis of the fiber reinforced concrete beams. Each is discussed separately to describe the behavior of the reinforced concrete beams by reviewing load versus deflection relationship, crack width, crack pattern, shear strength, and failure mode.

4.2. Mechanical Properties of Fiber Reinforced Concrete

4.2.1. Compressive Strength of Fiber Reinforced Concrete

At least two cylindrical specimens were tested on the same day of the beam testing, which was twenty-eight days after casting. For beams reinforced with fibers, another two specimens were tested using ACCU-TEK 250 digital series compression tester following ASTM [44]. In addition, there were two cylinders used to determine the stress-strain diagram for plain and fiber reinforced concrete. Therefore, for each beam specimen there were at least five cylindrical specimens that were tested.

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Beam	Beam Type	f'c (psi)										Modulus of Elasticity (ksi)
		Plain Concrete					Fiber reinforced concrete					
		C1	C2	C3	C4	Ave	C1	C2	C3	C4	Ave	
B1-MS	Min. renf.	7253	7188	7188	7700	7332	-	-	-	-	-	4320
B2-HS	Hook steel	7253	7188	7188	7700	7332	5823	6781	6374	7000	6495	5332
B3-CS	Crimp steel	5805	6400	-	-	6102	5399	5753	6155	5723	5758	4180
B4-CPP	Crimp PPl	6441	6981	-	-	6711	6649	6833	7046	7127	6914	4356
B5-NS	No reinf.	6441	6981	-	-	6711	-	-	-	-	-	-

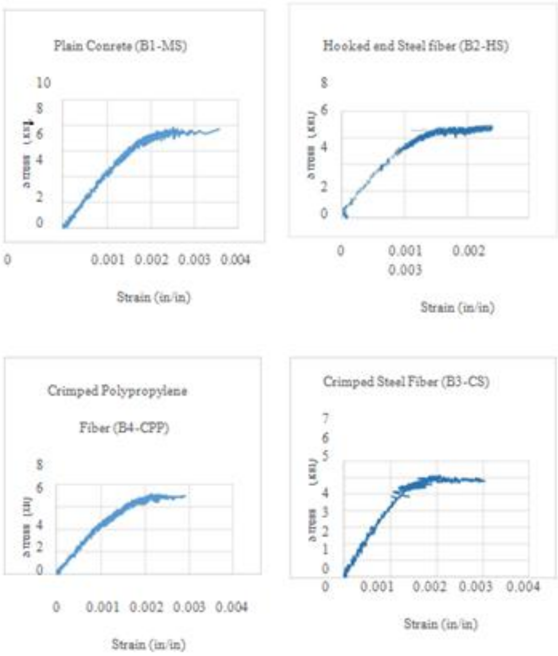

Figure 4-1 Stress-Strain curves

Figure 4-2 Cylinders failure pattern

Beam	Fiber type	C1 (psi)	C2 (psi)	Average splitting strength (psi)
B1-TD	No Fiber	597	553	575
B2-HS	Hooked end steel fiber	605	581	593
B3-CS	Crimped steel fiber	557	542	550
B4-CPP	Crimped polypropylene	572	587	580

Figure 4-4 Splitting test

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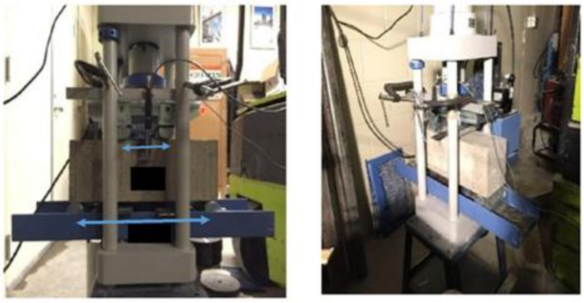

Figure 4-5 Flexural test setup

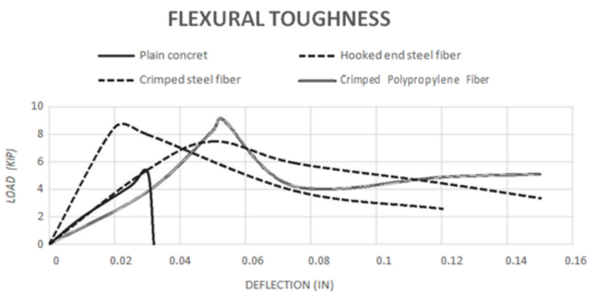

Figure 4-8 Comparison of the average flexural toughness index for the three used fiber.

Figure 4-9 Failure stages of plain concrete

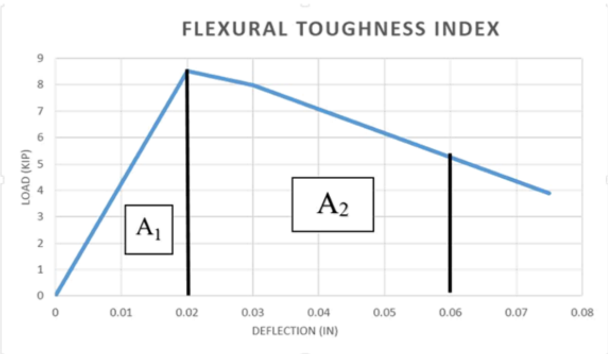

Figure 4-10 Areas used to determine flexural toughness

5: Summary, Conclusions and Recommendations for Further Research:

5.1. Summary:

The experimental program consisted of five approximately one-third scale beam specimens. Three specimens were reinforced with hooked-end steel, crimped-steel and crimped-monofilament polypropylene fibers. The other two were control beam specimens. One was reinforced with steel wire stirrups placed at maximum spacing specified by ACI 318. The other control beam did not have any shear reinforcement. These beams had a moderate slenderness ratio of effective shear span-to-depth ratio of 3.6. The concrete compressive strength varied from 5758 psi to 7332 psi. In order to avoid flexural failure and ensure a shear failure, a longitudinal reinforcement ratio of 2.42% was selected. In addition to the beam specimens, twelve prisms measuring 6” x 6” x 18” were made to determine flexural strength and flexural toughness of each type of fiber. The effect of fibers on the compressive strength of concrete were determined by testing standard 6”x12” cylinders. The effect of fibers on the tensile strength of concrete were determined by testing eight cylinders, 6” x 12”, using the splitting tensile test. The aim of this research was to compare the effect of the fiber on the compressive strength, tensile strength, crack pattern, flexural strength, and the flexural toughness of FRC. Moreover, the effect of the type of fiber on the shear strength was studied. Finally, this research investigated the possibility replacing minimum shear reinforcement specified by ACI 318 by a 1% volumetric amount of fiber.

5.2. Conclusions:

1- Using 1% of the crimped-polypropylene fiber increased the pre-cracking flexural strength by bridging the micro-cracks. However, this effect diminished in the case of crimped-steel fiber and vanished for hooked-end steel fiber.

2- Using a 1% volumetric ratio of the hooked-end steel fiber greatly enhanced the post-cracking characteristics or flexural toughness.

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This effect was slightly decreased when crimped-steel fiber used. However, in the case of crimped-polypropylene fiber, flexural toughness was greatly decreased.

3- For the beam specimens, all three types of fibers increased the number of cracks, especially in case of the steel fibers. Beams reinforced with steel fibers developed more cracks than the controls beams, which points to a better stress redistribution.

4- The results showed that the three types of the fibers could increase the shear strength of the beams more than the one reinforced with traditional shear reinforcement based on minimum reinforcement specified in the ACI 318. All three types of the fiber showed an increase in the shear strength up to 5.0√ ′

5- Both types of steel fibers enhanced the ductility of the beam beyond the ductility of the beam with minimum shear reinforcement. Therefore, it is observed that a 1% volumetric ratio of steel fiber is able to replace minimum traditional shear reinforcement.

5.3. Recommendations for Further Research:

Fiber industry is a developing industryand a variety of types of fiberare being introduced such as arched-hooked end steel fibers. These newer types of fiber should be investigated. Another promising field of study is using hybrid fibers. Hybrid fiber can be obtained by mixing fibers made of different materials such as mixing steel fiber with polypropylene fiber to enhance both fresh and hardened concrete characteristics. Another form of hybrid fiber is mixing fibers of different size or shape.

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