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THE BEHAVIOR OF PFRC BEAMS WITH AND WITHOUT WEB REINFORCEMENT

Mehdi Ozturk
Yildiz Technical University

Riza Secer Orkun Keskin
Yildiz Technical University

Guray Arslan
Yildiz Technical University

Abstract: Numerous researches have focused on the contribution of steel fibers to the shear and flexural behavior of reinforced concrete (RC) beams without web reinforcement. While it has been shown that the addition of steel fibers makes concrete tougher and more ductile, there exists a relatively limited amount of studies concerning the shear behavior of polypropylene fiber reinforced concrete (PFRC) beams. For this purpose, an experimental program was carried out for investigating the shear behavior of PFRC beams. This paper presents the test results of PFRC beams with and without web reinforcement. It is shown that the use of polypropylene fibers improved the shear capacities of RC beams. However, the additional shear resistance provided by polypropylene fibers was not sufficient to overcome the shear demand and change the failure mode from shear to flexure.

Keywords: Reinforced concrete, beam, polypropylene fiber, web reinforcement

Introduction

Previous studies have shown that adding steel fibers to concrete increases tensile strength, post-cracking toughness, and ductility of concrete (ACI 544, 1997; Susetyo, Gauvreau & Vecchio, 2011). While a substantial amount of researches has focused on the shear behavior of steel fiber reinforced concrete (SFRC) beams (Batson Jenkins & Spatney, 1972; Mansur, Ong & Paramasivam, 1986; Lim, Paramasivam & Lee, 1987; Narayanan & Darwish, 1987; Li, Ward & Hamza, 1992; Swamy, Jones, & Chiam, 1993; Noghabai, 2000; Kwak, Eberhard, Kim & Kim, 2002; Dupont & Vandewalle, 2003; Cucchiara, La Mendola & Papia, 2004; Parra-Montesinos, Wight, Dinh, Libbrecht & Padilla, 2006; Ding, You & Jalali, 2011; Shoaib, Lubell & Bindiganavile, 2014; Sahoo, Maran & Kumar, 2015; Shaoo, Bhagat & Reddy, 2016; Biolzi & Cattaneo, 2017), there exists a relatively limited amount of studies concerning the shear behavior of PFRC beams (Li et al., 1992; Noghabai 2000; Majdzadeh, Soleimani & Banthia, 2006; Altoubat, Yazdanbakhsh & Rieder, 2009; Conforti, Minelli, Tinini & Plizzari, 2015; Sahoo et al., 2015).

With the aim of expanding the researches involving PFRC beams, an experimental study was carried out (Arslan, Keskin & Ozturk, 2017; Arslan & Keskin, 2017). This paper presents four beams with and without web reinforcement tested to investigate the influence of polypropylene fibers on the shear behavior. The beams with a shear span-to-effective depth ratio (a/d) ratio of 2.5 and fiber contents (V_f) of 0% and 1% by volume were tested under a concentrated load at mid-span. The addition of polypropylene fibers enhanced both the shear strength and ductility of beams, but it was not able to change the failure mode from shear to flexure.

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*Corresponding author: Mehdi Ozturk-E-mail: mehdioztrk@gmail.com

Experimental Program

Test Specimens

A combination of letters and numbers is used for specimen labels. “B” followed by the shear span-to-effective depth ratio to indicate all test specimens in this research; “S” followed by the spacing of web reinforcement (*s*) and “P” followed by the volume fraction of polypropylene fibers. For example, a beam having a shear span-to-effective depth ratio of 2.5 with a volume fraction of fibers equal to 1.0% and a web reinforcement spacing of 15 cm is labeled as B2.5S15P1.0. The specimens labelled as B2.5R and B2.5S15R are the reference beams that do not contain any fibers.

The concrete mix proportions for all beams are given in Table 1. The properties of test specimens are given in Table 2, where ρ is the tensile reinforcement ratio, ρ' is the compressive reinforcement ratio, ρ_w is the web reinforcement ratio and f_c is the concrete compressive strength.

Table 1. Mix proportions of concrete

Material	**Proportions (kg/m^3)**
0-1 mm naturel sand	350
0–3 mm crushed sand	530
5-12 mm crushed stone	1010
Cement CEMI 42.5R	300
Water	164
Superplasticizer	3

All beams have the same cross-section of 150 mm by 240 mm with an effective depth of 210 mm and are 1400 mm long. The shear span-to-effective depth ratios of all beams are 2.5. The geometrical properties and reinforcement arrangements of test specimens are shown in Figure 1. Deformed bars with diameters of 16 mm and 12 mm were used as the tensile and compressive reinforcement, respectively. Two-legged vertical stirrups with a diameter of 8 mm were used as the web reinforcement. The yield strength of reinforcing bars is given in Table 3.

Table 2. Properties of test specimens

Beam	***a/d***	**ρ (%)**	**ρ’ (%)**	**ρ_w (%)**	**f_c (MPa)**	**V_f (%)**	***s*(cm)**
B2.5R	2.5	1.28	---	---	26.50	---	---
B2.5P1.0	2.5	1.28	---	---	27.00	1.0	---
B2.5S15R	2.5	1.28	0.72	0.45	26.50	---	15
B2.5S15P1.0	2.5	1.28	0.72	0.45	27.00	1.0	15

Polypropylene fibers (Polymacro PM 39) with a length of 39 mm and cross-sectional dimensions of 0.93 mm by 0.50 mm were used. The fibers, classified as tall-crimped, are monofilaments with converging wave shape to a sharp corner. The ultimate strength and elasticity modulus of polypropylene fibers are reported as approximately 470 MPa in traction and 3.6 GPa, respectively, by the manufacturer.

Table 3. Yield strength of reinforcing bars

Reinforcing Bar	**Average Yield Strength (MPa)**
8 mm	486
12 mm	358
16 mm	492

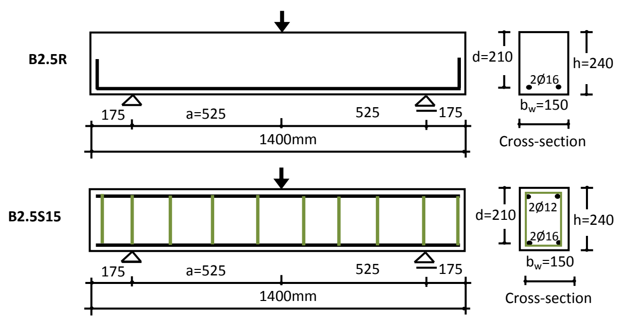

Figure 1. Geometry and reinforcement arrangement of beams

Testing and Instrumentation

The beams were loaded at mid-span with a static loading rate of 30 μm/s by using a displacement-controlled loading machine (Figure 2). The applied load and the deflections at various locations were recorded at pre-determined time intervals via a computer-aided data acquisition system. Potentiometric displacement transducers were used for recording the net deflections. The beams were loaded until either failure or the load dropped below approximately 80% of its peak value.

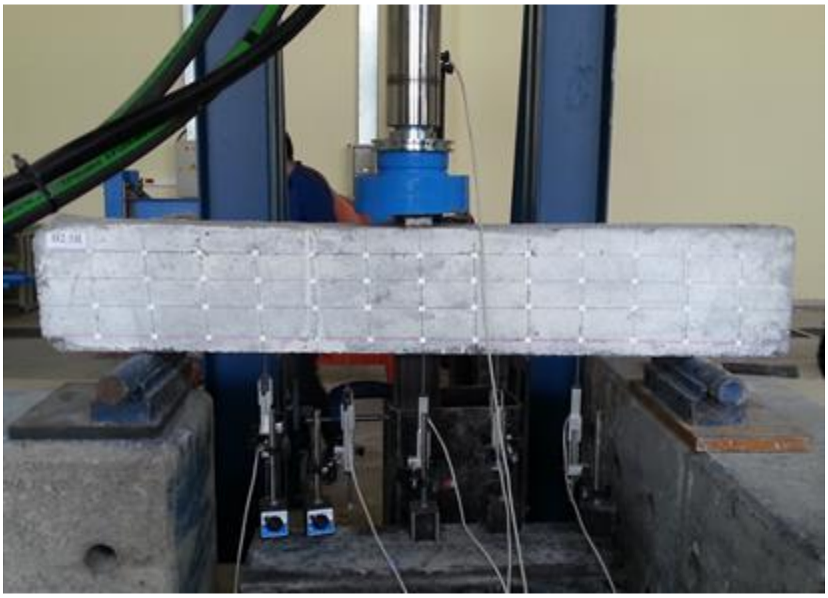

Figure 2. Test setup

Results and Findings

The crack patterns of tested beams are shown in Figure 3-6. At the early stages of loading, fine vertical cracks were observed around the mid-span of all beams as expected. As the load was increased, new flexural cracks appeared away from the mid-span area. Some of these cracks were gradually inclined towards the loading point with further increases in the applied loads and the applied load reached its maximum value with the formation of first diagonal crack. The loads carried by the beams without web reinforcement decreased rapidly and the beams failed in shear. The beams with web reinforcement failed after the formation of two or more significant diagonal cracks exhibiting shear-compression failures.

Figure 3. Crack pattern of B2.5R

Figure 4. Crack pattern of B2.5P1.0

Experimental results are summarized in Table 4, where P_{co} and δ_{co} are the maximum load and the mid-span deflection at the maximum load, respectively, P_u and δ_u are the ultimate load and mid-span deflection, respectively, and the dissipated energy is the area under the load-deflection curve, which is plotted for each beam in Figure 7.

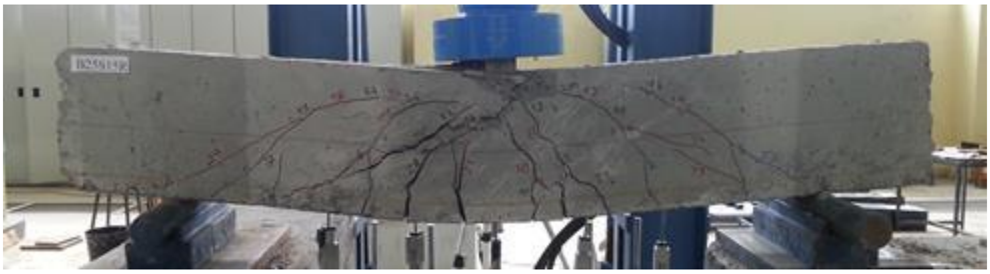

Figure 5. Crack pattern of B2.5S15R

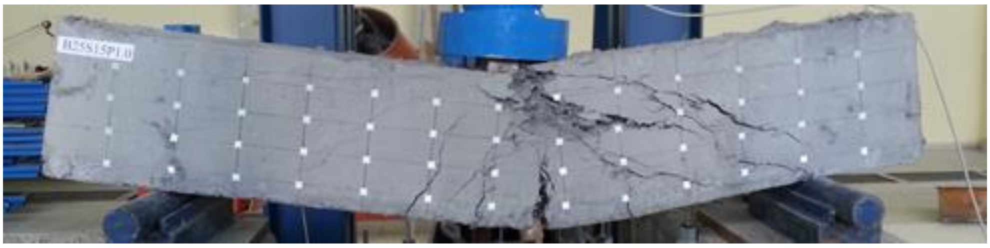

Figure 6. Crack pattern of B2.5S15P1.0

Table 4. Experimental results

Beam	P_{co} **(kN)**	P_u **(kN)**	δ_{co} **(mm)**	δ_u **(mm)**	δ_u / δ_{co}	***Dissipated Energy* (kNm)**
B2.5R	70.91	56.73	2.16	2.61	1.20	0.1155
B2.5P1.0	95.83	76.67	3.76	5.76	1.53	0.3940
B2.5S15R	119.03	96.44	25.42	43.42	1.71	4.8005
B2.5S15P1.0	147.26	118.02	10.79	64.03	5.93	8.5874

The use of polypropylene fibers in the amount of 1.0% by volume improved the shear capacities of RC beams significantly. The load carrying capacities of RC beams without and with web reinforcement were increased by 35% and 24%, respectively. While the load carrying capacity of beam with web reinforcement is 1.68 times the capacity of beam without web reinforcement in the absence of polypropylene fibers, the ratio of capacities is 1.54 for PFRC beams. It is observed in Figure 7 that the initial stiffness of all beams are approximately the same.

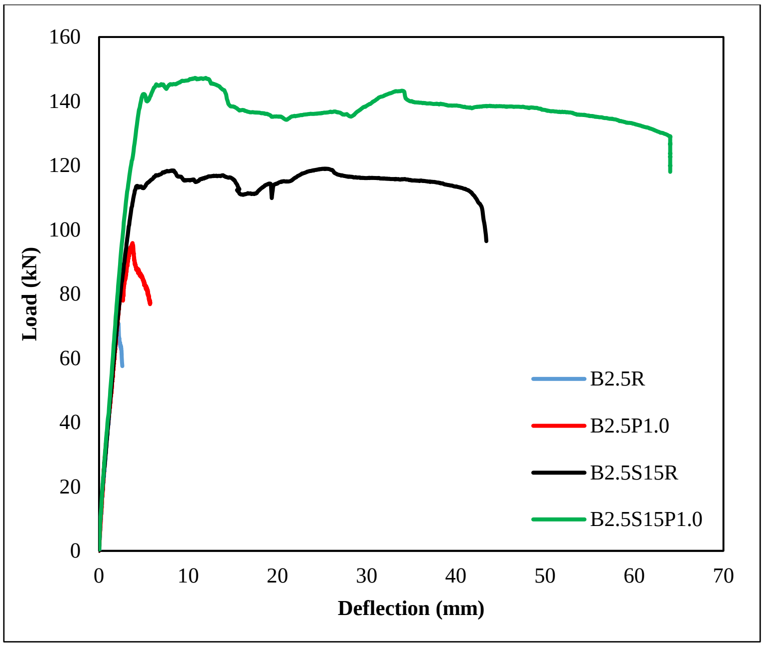

Figure 7. Load deflection curves

The use of polypropylene fibers enhanced the ductility of RC beams besides their shear capacities. The energies dissipated by the beams without and with web reinforcement were increased 3.41 and 1.79 times, respectively, by the addition of polypropylene fibers. The energy dissipated by RC beam with web reinforcement is 41.6 times the energy dissipated by RC beam without web reinforcement, whereas the ratio of dissipated energies is 21.8 for PFRC beams. Even though the use of polypropylene fibers promoted the shear strength and ductility of RC beams, it was not sufficient to overcome the shear demand and change the failure mode from shear to flexure.

Conclusion

The following conclusions are drawn based on the experiments of PFRC beams.

- The use of polypropylene fibers increased the shear capacities of RC beams significantly. The percent increase in the capacity is larger for the beam without web reinforcement.
- The percent increase in the shear capacity due to the presence of web reinforcement in the form of vertical stirrups is larger in the absence of polypropylene fibers.
- The initial stiffness of all beams tested in this study are approximately the same.
- The use of polypropylene fibers increased the ductility of RC beams. The percent increase in the dissipated energy is larger for the beam without web reinforcement.
- The percent increase in the dissipated energy due to the presence of web reinforcement in the form of vertical stirrups is larger in the absence of polypropylene fibers.
- Despite the improvements in the shear strength and ductility of RC beams, the use of polypropylene fibers was not able to change the failure mode from shear to flexure.

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