Shear performance of polypropylene fiber reinforced high-strength self-compacting concrete beams

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Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.

Abstract

This paper consists of two parts. The first one looks for producing self-compacting polypropylene fibrous concrete (PFSCC) with reasonable passing, filling, and flow abilities and segregation resistance. Limestone powder with a particle size less than 75 μm was used to increase the fines fraction in the mix. The second part of this study deals with the effect of adding polypropylene fibers on the shear strength of self-compacted reinforced concrete beams. Eighteen beams were cast, each 1.8 m long, 150 mm wide, and with an overall depth of 200 mm. Four volume percentages of polypropylene fibers were used: 0, 0.1, 0.2, and 0.3 percent of the cementitious materials' weight. The test results showed that the polypropylene fibers have no serious adverse effect on the fresh properties, and this effect was reduced by using a plasticizer. Moreover, although the polypropylene fibers improved the tension properties of the hardened concrete, they don't have an impact on compression properties. The test results showed that the presence of polypropylene fibers increased the cracking shear stress and the shear strength, and this increase depends on the volume fraction of the fibers.

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Keywords: Shear performance; high-strength self-compacting concrete; polypropylene fiber.

1. Introduction

Numerous experimental and analytical studies on structure members have been reported [1][2][3][4]. Concrete is a material for building construction that is made from Portland cement, water, fine and coarse aggregates. Beside good compressive strength, the concrete material is very weak in tensile strength. To increase the tensile strength, usually the concrete was added by fiber materials. Fiber reinforced concrete (FRC), which was developed more than sixty years ago, is concrete reinforced with discrete short fibers with tensile strength, flexural strength, flexural toughness, cracking resistance, and strain capacity. Several researches have been conducted dealing with the impact of steel fibers on the shear strength of reinforced concrete beams [5][6][7]. Prediction equations for the shear strength of steel fiber reinforced concrete beams were proposed in some studies [8][9]. It was shown that steel fibers improve the mechanical properties of concrete, especially in the modulus of rupture and the splitting tensile strength [10]. However, steel fibers have disadvantages such as being easily corroded, higher weight, easily damaged mixer, magnetic interference, and higher price [11]. Therefore, another fiber material was developed and used in concrete such as steel fibers, glass fibers, carbon fibers, and polypropylene fibers. Investigation of fiber concrete using polypropylene fiber was already done by researchers [12][13][14]. It was shown that polypropylene can improve the tensile strength of concretes. Investigation on self-compacting concrete was comprehensively carried out several decades ago. However, study on self-compacting concrete using polypropylene is still rare. Therefore, a study on high-strength self-compacting concrete using polypropylene is still needed.

2. Experimental program

2.1. Materials

Main materials of concrete (Portland cement, water, aggregates) were taken from local sources. Table 1 shows the mix proportions used. Micro silica fume and superplasticizer were added to the concrete in the proportions of 10 and 1.5 percent of the Portland cement weight, respectively. Limestone powder passing sieve No. 200 (75 microns) was added in the proportion of fifty percent of the total weight of the cement in the concrete mixture. To decrease friction between the mix constituents and increase the flowability, the limestone powder was used to act as a filler. Finally, micro monofilament polypropylene fibers with four different proportions of the concrete weight, as presented in table 1, were used in this study. The length of the fibers was 12 mm, and the tensile strength of the fibers was about 350 MPa. The mix proportions were chosen to produce nominal cube compressive strengths of 80 and 90 MPa, as explained above.

Table 1. Mix proportions of concrete

Mix No.			Cement (kg)	Micro silica fume (kg)	Limestone powder (kg)	Water (l)	Superplasticizer (ml)	Polypropylene fibers	
	Gravel (kg)	Sand (kg)						percent	Weight (g)
1	717	717	470	47	262	192	7135	0.0	0
2								0.1	517
3								0.2	1034
4								0.3	1551
5	693	570	570	570	300	196	9945	0.0	0
6								0.1	627
7								0.2	1254
8								0.3	1881

2.2. Specimens Description

To get the properties of fresh self-compacting concrete, three types of properties were tested. The testing of fresh self-compacting concrete follows the EFNARC, and the properties to be tested were:

- Viscosity using T50 slump-flow test
- Passing ability using L-shape box
- Air-void stability in fresh self-compacting concretes

To get the compressive strength of high-strength self-compacting concrete, 24 cubic specimens with the size of (100 mm × 100 mm × 100 mm) were made. To get the tensile strength, 8 cylindrical specimens with the size of (150 mm×300 mm) were made. Sixteen beam specimens were cast and tested in this study.

Table 2. The results of fresh concrete tests

Mix No.	Passing ability	Viscosity	Filling ability	Compressive strength	Splitting tensile strength
	L-shape box (h2/h1)	T50 slump flow (s)	Slump flow (mm)	Cubic specimens	Cylindrical specimens
1	93%	4	635	82.3	8.8
2	92%	5	570	81.7	9.2
3	85%	6	550	80.3	9.6
4	81%	8	520	79.7	9.8
5	94%	5	660	90.7	9.5
6	91%	5	640	90.4	10.1
7	86%	6	590	89.9	10.6
8	83%	7	530	89.0	10.8

The results show that the compressive strength and the splitting tensile strength of self-compacting polypropylene fiber concrete were lower and higher than those of self-compacting non-fiber concrete, respectively. The decreasing compressive strength and the increasing splitting tensile strength of self-compacting polypropylene fiber concrete compared to self-compacting non-fiber concrete are shown in Table 2. The increasing splitting tensile strength of self-compacting polypropylene fiber concrete compared to self-compacting non-fiber concrete was higher for specimens with higher compressive strength. The increasing splitting tensile strength of self-compacting polypropylene fiber concrete was 11% and 14% for specimens with compressive strengths of 80 MPa and 90 MPa, respectively.

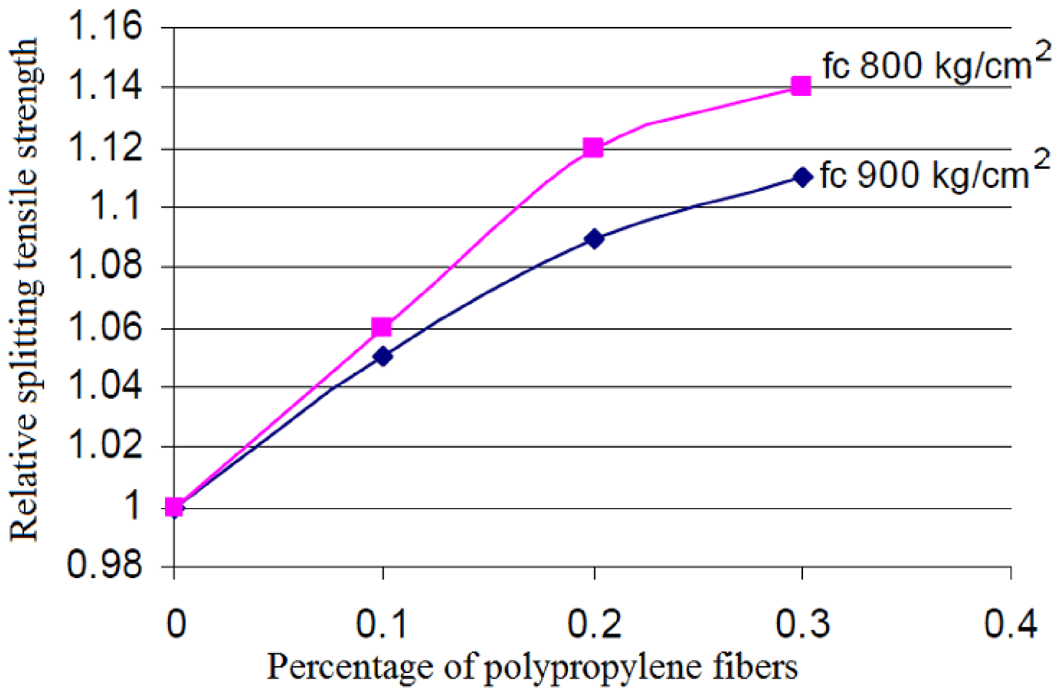

Figure 1. Relative splitting tensile strength curves

The main experimental program consisted of 8 beam types (two specimens for each type) with 2 types of concrete mixtures and 4 different percentages of polypropylene fibers (0.0, 0.1, 0.2, and 0.3 percent). All beams were 120 mm wide, 200 mm deep, and 1600 mm long. The beams were simply supported over a span of 1400 mm. The shear span to depth ratio (a/d) for specimens selected to be 2.8. Two reinforcements with a diameter of Ø10 mm were used for compressive reinforcement, and three reinforcements with a diameter of Ø16 mm were used for tensile reinforcement. The shear reinforcements, with a diameter of 6 mm and a spacing of 90 mm, were placed along the total span. The size and detailing of the beam specimens can be seen in Figure 2.

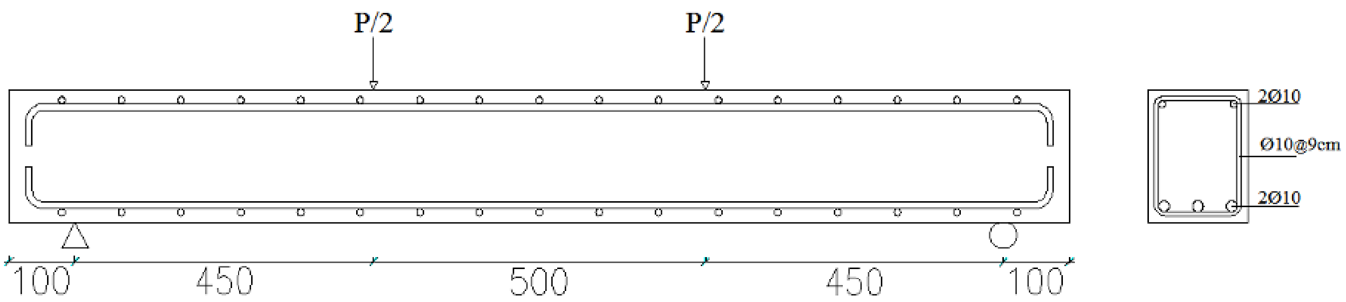

Figure 2. Beam dimensions and specifications

The applied load, mid-span deflection, and strains of vertical and horizontal stirrups in the constant shear force region were measured by instrumenting the test specimens. A load was applied by the actuator with a capacity of 50 kN through the transfer rigid beam, so the beam specimen was subjected to two-point loading as depicted in Figure 3. A linear variable differential transducer (LVDT) was used to measure the deflection of the specimen. The LVDT was placed at the middle of the specimen to measure the displacement in the vertical direction. Measured data of load and deflection were read through a computer-driven data acquisition system using a data logger. In addition, two strain gauges were placed on each side at position L/4 for linear displacement. The propagation of cracks was marked along the sides of the specimens. Cubic and cylindrical specimens were tested on the same day as the testing of the beams to determine the mean compressive and tensile strength of the concrete, respectively.

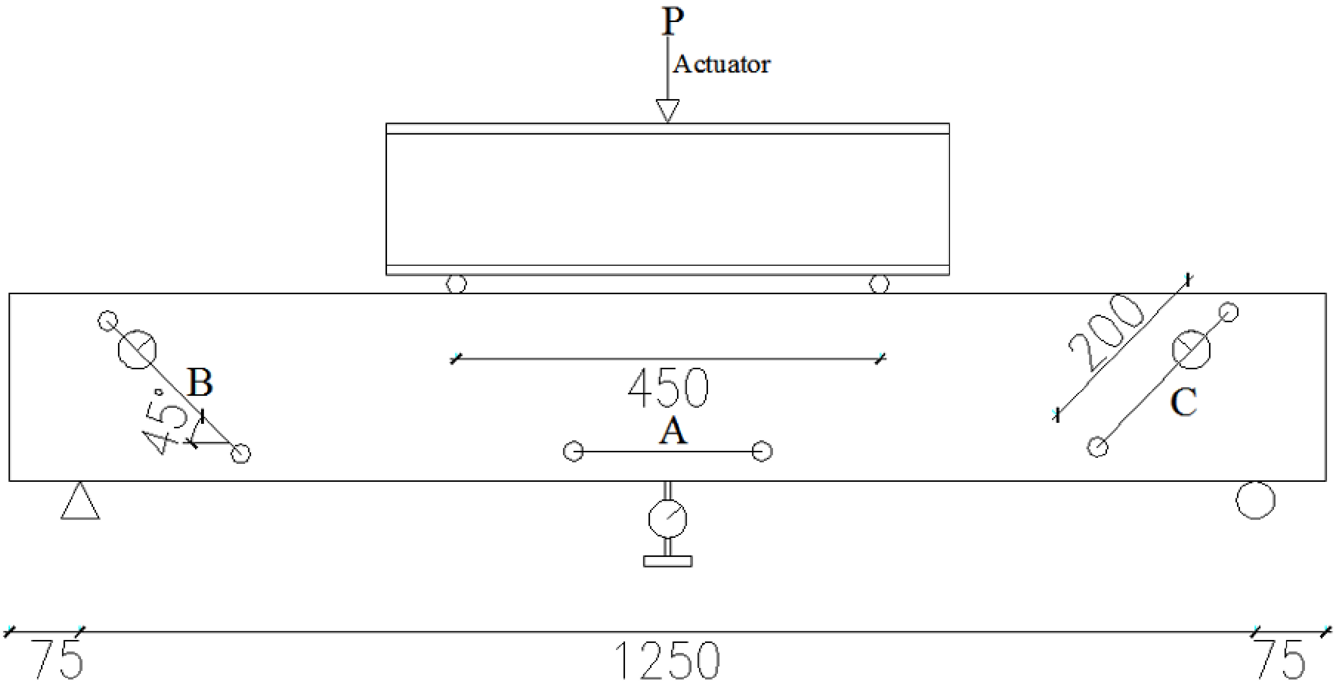

Figure 3. Deflection and strain gauge configurations

The load-carrying capacity-deflection curves of the beam specimens can be seen in Figures 4 and 5. Firstly, the curve of the load-carrying capacity-deflection relationship at lower loads is increasing linearly. Then, after initial cracks, the curve is increasing nonlinearly up to a value, after which the curve increases almost horizontally up to failure.

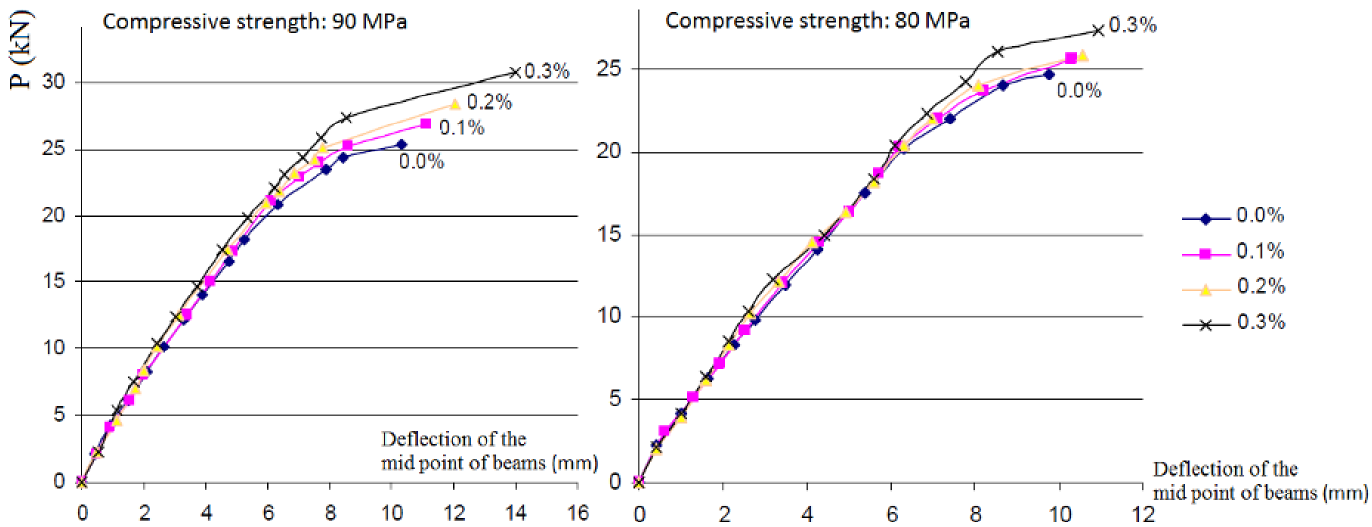

Figure 4. Comparison of deflection of the mid-point of beams with different amounts of fibers

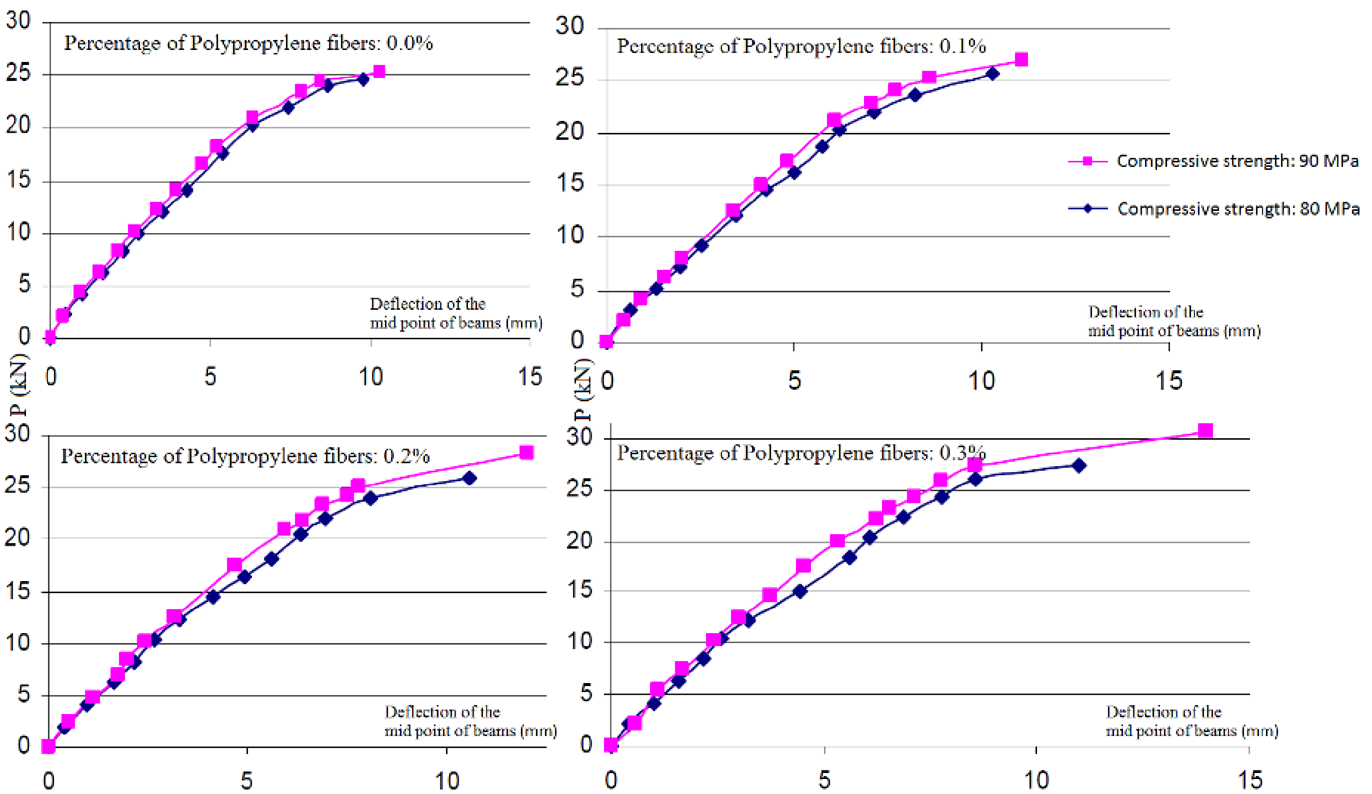

Figure 5. Comparison of deflection of the mid-point of beams with different specified compressive strengths

Toughness is the ability of a material to absorb energy and plastically deform without fracturing. Integrating the stress-strain curve determines the toughness of materials. While the percentage of polypropylene fibers was increased, the area under the load-strain curve was heightened too.

The maximum and relative deflection of the mid-point of the beam specimens is presented in table[3]. The maximum deflection of self-compacted reinforced concrete beams was increased from 5 to 36%. The increasing maximum deflection for beams with a specified compressive strength of concrete of 80 MPa was higher than those with 90 MPa.

Table 3. Maximum and Relative Deflection of Beams

Specimen No.	Specified Compressive Strength (MPa)	Percentage of Polypropylene Fibers	Maximum Deflection of Mid-Point (mm)	P_{max} (kN)	D_m/D_M
1	80	0.0	10.3	24.4	1.00
2	80	0.1	11.11	25.8	1.08
3	80	0.2	12.07	26.1	1.17
4	80	0.3	13.98	27.5	1.36
5	90	0.0	9.78	25.2	1.00
6	90	0.1	10.31	27.5	1.05
7	90	0.2	10.57	28.0	1.08
8	90	0.3	10.96	30.9	1.12

Several line charts for comparison of strain vs. load are presented, and curves for different amounts of fibers and specified compressive strength of concrete are compared. In the linear stage of the load-strain curves, tests show similar results for beams with the same specified compressive strength of concrete. But after initial cracks, curves grow to the nonlinear stage, and beams with more polypropylene fibers carry more load, which results in more strains.

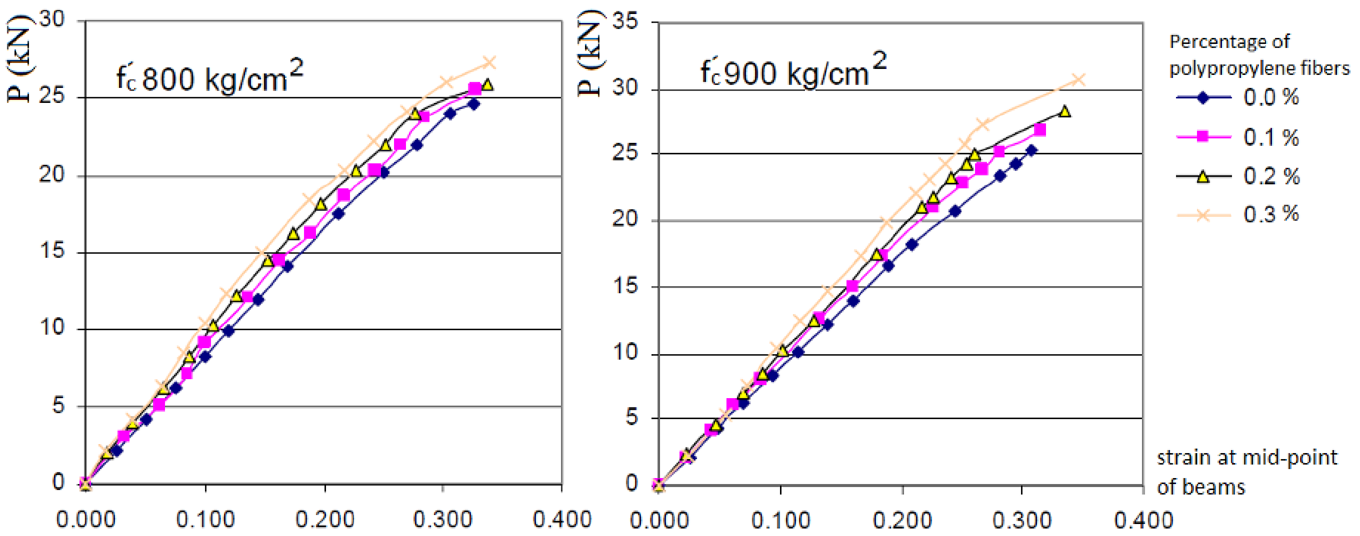

Figure 6. Comparison of flexural strain at the mid-point of beams

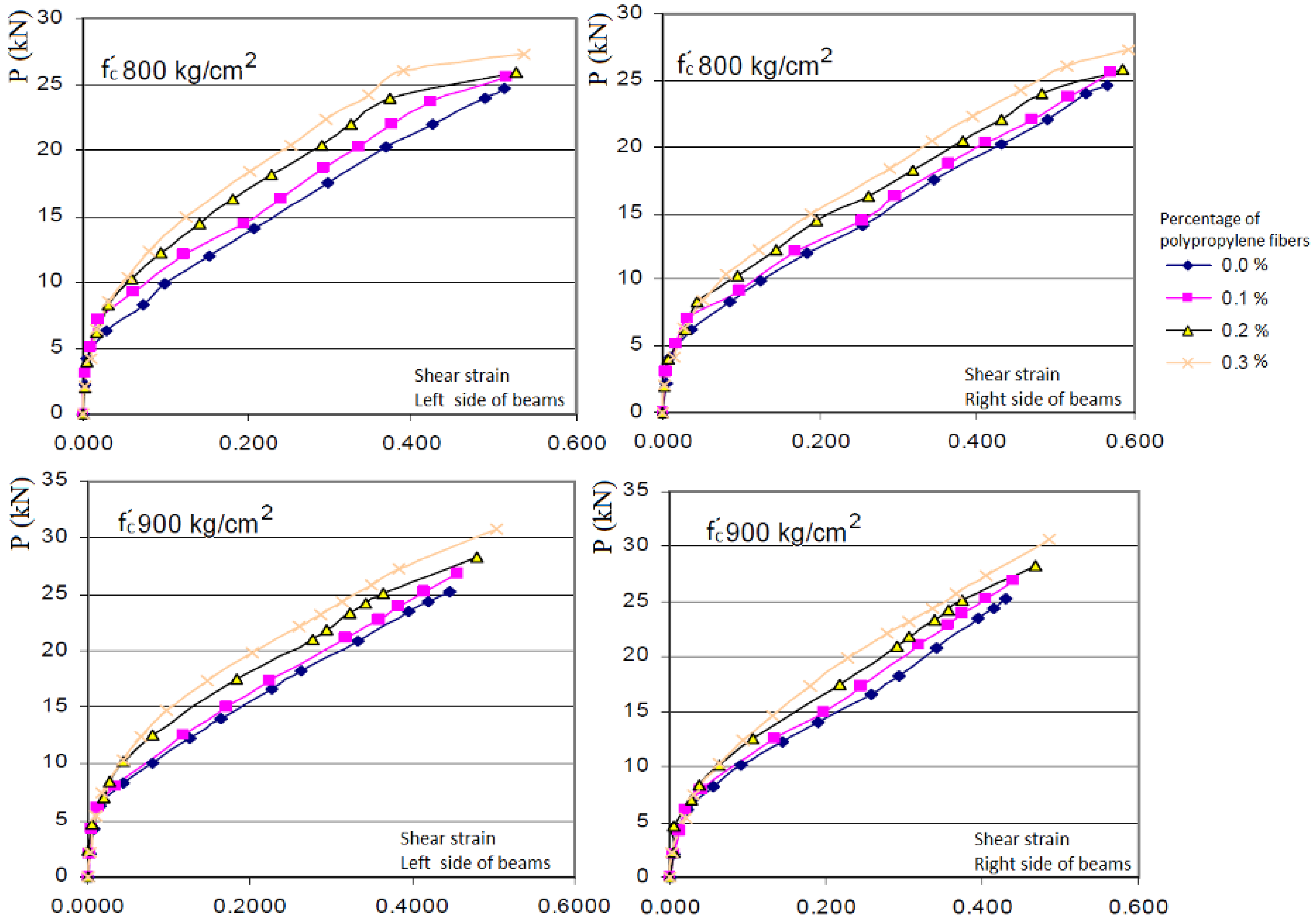

Figure 7. Comparison of shear strain on the right and left sides of beams

The shear strain of beams was compared and illustrated in figure 8. The shear strain for beams with higher compressive strength was significantly higher than for others.

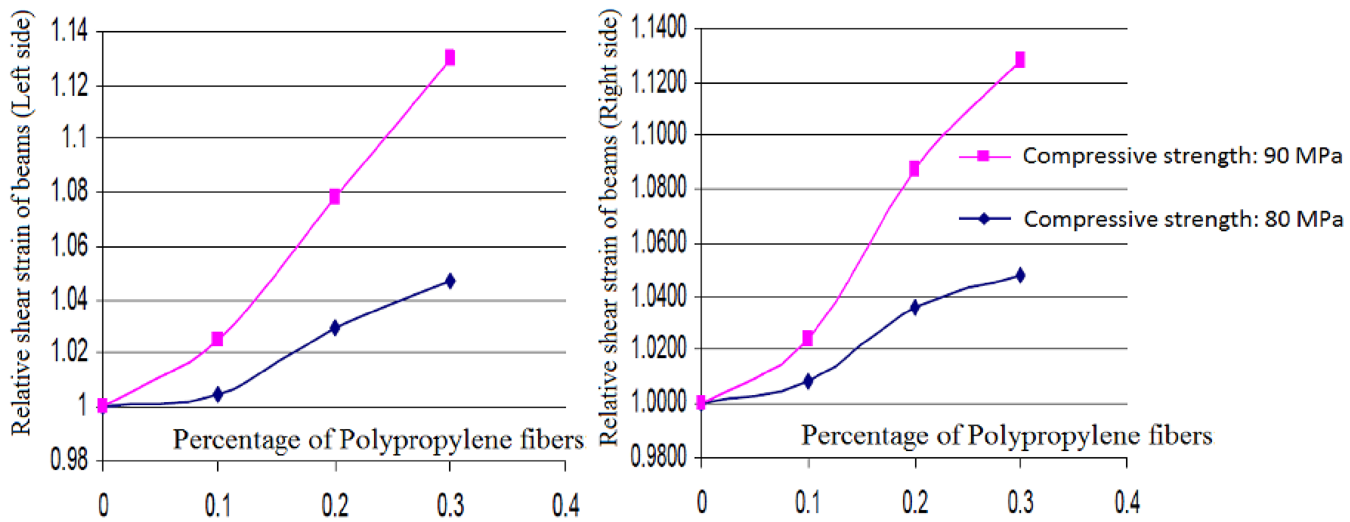

Figure 8. Relative shear strain of beams by percentage of polypropylene fibers

Figures 9 and 10 illustrate the appearance of cracks in specimens. Flexural cracks in the middle of beams appeared and grew by increasing load. Beams with polypropylene fibers have shorter flexural cracks. In addition, shear cracks appear inclined and longer in the beams with more polypropylene fibers. All beams fractured by shear stress.

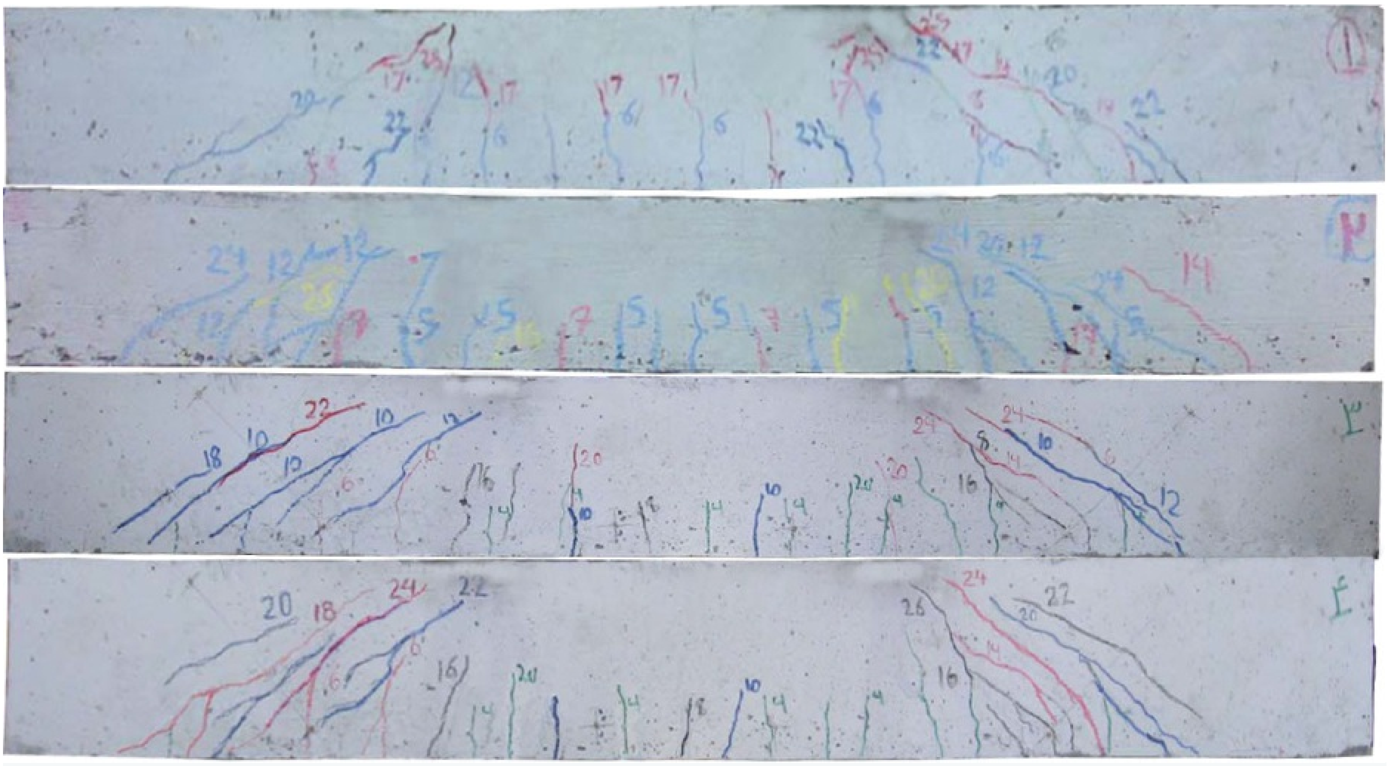

Figure 9. Appearance of cracks for the beams subjected to ultimate loads (f'_c=80 MPa)

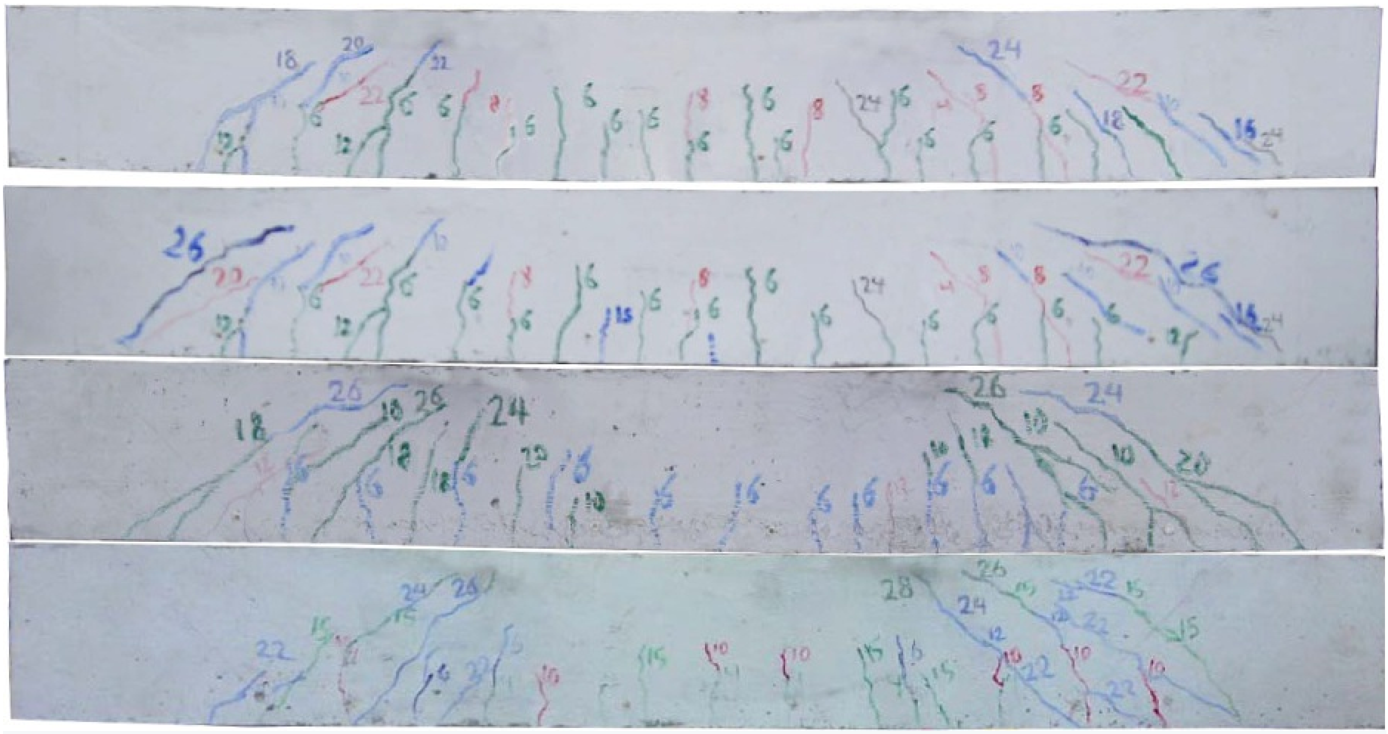

Figure 10. Appearance of cracks for the beams subjected to ultimate loads (f'_c=90 MPa)

3. Discussion and Conclusion

Based on the experimental program, the following conclusions can be drawn:

The compressive strength of self-compacting polypropylene fiber concrete was 2 to 3% lower than that of self-compacting non-fiber concrete. The decreasing compressive strength is reduced by increasing the specified compressive strength of concrete.

The splitting tensile strength of self-compacting polypropylene fiber concrete was 4 to 14% higher than that of self-compacting non-fiber concrete. The increase in polypropylene fiber percentage causes a higher splitting tensile strength.

The polypropylene fibers lead to an increase in the cracking shear stress of self-compacted reinforced concrete beams from 4 to 11%.

The polypropylene fibers increased the maximum deflection of self-compacted reinforced concrete beams from 5 to 36%. The increasing maximum deflection is heightened by reducing the specified compressive strength of concrete.

Flexural cracks in the beams with polypropylene fibers are shorter; on the other hand, shear cracks appear longer in the beams with more polypropylene fibers.

The linear stages of stress-strain curves related to beams with the same specified compressive strength of concrete are similar, but those curves grow more in the nonlinear stage for beams with more polypropylene fibers.

Beams with polypropylene fibers absorb more energy than beams without fibers.

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