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Ultimate Moment Capacity of Polypropylene Fibers Reinforced Concrete Beams

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ABSTRACT

The flexural behavior of polypropylene fiber reinforced concrete, plain concrete beams with and without reinforcement was investigated. The reinforcement, volume ratio of polypropylene fiber and surface type of polypropylene fiber kept constant for all the beams. All beams had the same dimensions and tested under two point loads. The results showed that polypropylene fibers were effective in reducing the crack width and crack propagation. The results also showed that while polypropylene fibers had only slight effect on the beam stiffness, combining polypropylene fibers, and reinforcement improved the behavior of reinforced concrete beams and changed its failure mode. Also from the results it was observed that introduction of polypropylene fiber significantly improves the cracking behavior. However, only marginal improvement was observed in the case of ultimate load.

Keywords: *Polypropylene fibers, reinforced concrete beams, plain concrete beams, flexural strength, crack*

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INTRODUCTION

Concrete is acknowledged to be a relatively brittle material when subjected to normal stresses and impact loads, where tensile strength is only approximately one tenth of its compressive strength. Due to these characteristics, concrete member is not able support such loads and stresses that usually take place in the majority of concrete beams and slabs. The introduction of fibers was brought in as a solution to develop concrete in view of enhancing its flexural tensile strength, which are a new form of binder that could combine Portland cement in the bonding with cement matrices. The term of "Fiber Reinforced concrete" (FRC) is made with cement, various sizes of aggregates, which incorporates with discrete, discontinuous fibers. FRC is an ordinary concrete with randomly distributed short fibers. The main role of the fiber is to bridge the cracks in the matrix and prevent them from extending. Hence, help to improve the concrete post-cracking behavior such as ductility, cracking control, and impact resistance.

Wong [1] in his research work it was found that different types and geometry of fibers influence the mechanical properties of concrete in a different manner. As to create a cost efficient fiber reinforced structure, these changes on fibers are vital to the design and construction. In flexural and indirect tensile test on specimens with fibers showed that drastic increase in strength over specimens without fibers. Peled et al. [2] studied, in general, the improvement in the matrix behavior which varies according to the fiber type, volume ratio (V_f), aspect ratio (lf/df), matrix composition, and maximum aggregate size. Common fibers added to structural concrete are either metallic such as steel or synthetic polymeric such as polypropylene and nylon. Among the polymeric fibers research conducted by Laresen and Khanchel [3], Malhotra et al. [4] on polypropylene is the most widely used in concrete due to its good resistance to acids and alkalis in addition to the cheapness of the raw material compared (on the volume basis) with steel fibers and other alternatives. The effect of polypropylene fibers (PPFs) on the properties of concrete was studied by many researchers the excellent control of cracking due to improvement in flexural toughness and impact resistance of polypropylene FRC (PPFRC) is well known and reported widely in Refs. [5–7]. However, the effect of PPF on other properties is not well documented. Al-Tayyib et al. [8] and Badr et al. [6] studies reported slight improvements in compressive, tensile, and flexural strengths while others Alhozaimy et al. [5] showed either no effect or slight adverse effect on these properties due to the inclusion of PPFs. Ganesan et al. [9] conducted an experimental programme compare the behavior of high performance concrete (HPC) and steel fiber reinforced high performance concrete (SFRHPC) flexural members under two point loading. Results indicate that introduction of steel fibers significantly improves the cracking behavior in terms of significant increase in first crack load and the formation of large number of finer cracks. However, only marginal improvement was observed in the case of ultimate load.

EXPERIMENTAL PROGRAM

Materials

The concrete was produced using ordinary Portland cement conforming to IS 456: (2000). The nominal maximum size of the coarse aggregate was 10-mm. The fine aggregate of zone II and coarse aggregate complied with IS: 383-(1970). The types of PPF was used in this study are shown in Figure 1. The properties of polyproplylane filler are presented in Table I.

Properties	Fiber type (polypropylene)
Nominal diameter	0.002 mm
Nominal diameter	Coarse
Length (mm)	12
Specific gravity	0.90
Melting point	160°C
Tensile strength	551 MPa
Young’s modulus	3.45×10^3 MPa
Ultimate elongation	25%

Table I Properties of Polypropylene Fiber.

Mixing and Preparation of Beams

The concrete mix proportions were chosen based on the results of trial mixes carried out to optimize the mix proportions and fiber content. The optimization of the of PPFRC basic mix proportions was based on combined properties including workability, compressive strength, flexural strength, and flexural toughness. Properties of coarse aggregate, fine aggregate, cement, and slump values of concretes are given in Table II. The nominal water to cement ratio was 0.50. However, the actual water content varied according to the fiber content to maintain comparable workability as measured from the slump test according to IS 10262-(1982).

A conventional rotary concrete mixer was used. The dry coarse aggregate, cement, and sand were first mixed for about one minute before adding half of the mixing water. The fibers were added slowly to the running mixer, after 3 min, to avoid clumping. Types of fibers are shown in Figure 1. Mixing was continued for another 2 min to achieve uniform distribution of the fiber. Workability of the fresh concrete was assessed using the slump test. The slump values are given in Table II. After casting, the concrete was compacted using a vibrating table. From each mix, a beam section was cast in addition to three 150 mm cubes and two 150 dia and 300 mm height cylinders for the evaluation of compressive and split tensile strength. The results of tested specimens are shown in Table IV. The beams and the cubes were cured in a room temperature environmental humidity until testing at 30 days.

Fig. 1 Types of Fibers.

Test Procedure and Measurements

The size of the test beams are 900 mm length, 150 mm breath, and 150 mm depth. The test beams were of total length of 900 mm and an effective span length of 800 mm between supports. The dimensions for the test beams are shown in Figure 2, while Table III shows the properties of these beams. All beams were of same dimensions and longitudinal reinforcement, loaded by two point load up to failure using a 400 kN Universal Testing Machine (UTM) shown in Figure 3. The initiation of the cracks was detected using a magnifying lenses. Deflection of the beams during test at the mid-span and under the concentrated loads was measured using deflectometers

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Table II Property Details of Fine, Coarse Aggregate, and Cement.

S. No	Property	Experimental values	
Properties of fine aggregate			
1	Fineness modulus	2.96	
2	Specific gravity	2.4	
Properties of coarse aggregate			
1	Fineness modulus	4.16	
2	Specific gravity	2.8	
Test on cement			
Sl. no	Property	Experimental values	Limiting values (as per code)
1	Specific gravity	3.15	--
2	Normal consistency	33%	--
3	Initial setting time	40 min	≤30 min
4	Final setting time	460 min	≥600 min
5	Slump values of P.C.C concrete		83 mm
6	Slump values of R.C.C concrete		96 mm
7	Slump values of F.R.C.C concrete		104 mm

Table III Properties of Test Beams.

Beam specimen	f_{ck} (MPa)	f_{ctr} (Mpa)	Ast	f_y (MPa)	Asc	f_y (MPa)	Stirrups	V_f (%)
PFC-1	29.7		----		----		----	----
PFC-2	29.7		----		----		----	----
RCC-1	29.7	5.1	**2T10**	415	2T8	370	1φ8/180 mm	0.35
RCC-2	29.7		**2T10**		2T8		1φ8/180 mm	0.35
PPFRC-1	28.3		**2T10**		2T8		1φ8/180 mm	0.35
PPFRC-2	28.3		**2T10**		2T8		1φ8/180 mm	0.35

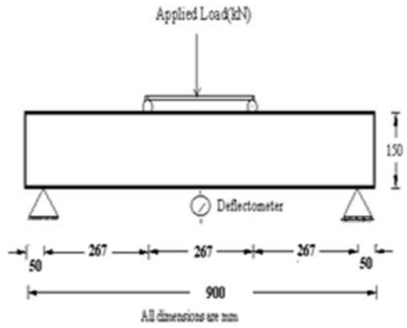


Fig. 2 Details of Test Beams.

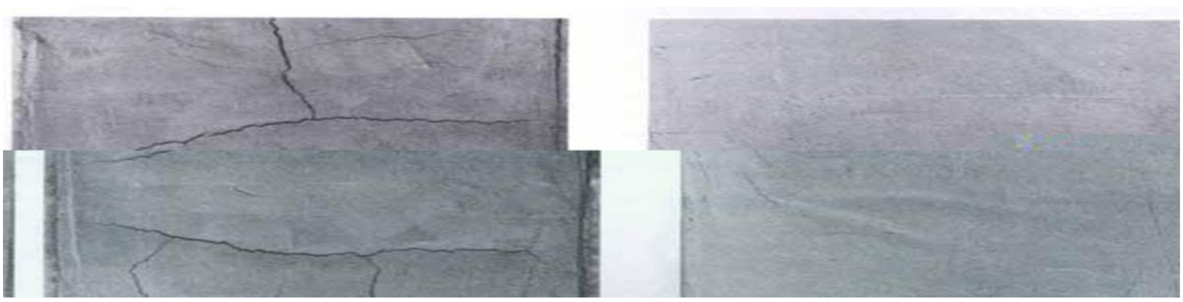
Fig. 3 Experimental Setup.

RESULTS AND DISCUSSION

Cracking Patterns and Cracking Strength

Figures 4 and 5 show the cracks patterns at failure for the tested beams. The crack patterns for beams without reinforcement or beams with reinforcement were nearly similar. As failure approached the FRC beams developed new cracks between the primary cracks. The extension of the cracks through the beam height was lower in case of PPFRC beams compared with reinforced cement concrete (RCC) beams due to the action of the fibers that restrained the propagation of cracks. The effect of fibers on the crack height was significant in case of the beam without reinforcement and less significant when reinforcement was used. The crack extension depends on several factors such as concrete tensile strength, beam stiffness, bond strength between concrete and fiber. At ultimate load, fiber beam without reinforcement [plain cement concrete (PCC)] and reinforcement with fibers failed in flexure while the others failed in shear. Also, the presence of fibers in reinforced concrete beams prevented extensive damage of concrete in the compression zone, thus helping the beam to be intact after the maximum load was reached. From Figure 4 it can be understood that there is cracking in RCC beam but in PPFRC beam cracking control was observed, control of cracking gives improvement in flexural resistance of PPFRC.

Fig. 4 Crack Patterns for Test Beam.



(a) Without Fiber-reinforced (b) With Fiber-reinforced

Fig. 5 Comparison of Cracks (a) With and (b) Without Fiber Reinforced.

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Table IV shows the actual cracking moment for the tested beams. The presence of the PPFs (with volume ratio $V_f = 0.35\%$) slightly reduced the flexural cracking resistance, this was observed in case of beams with or without reinforcement. This is because the volume ratio of PPFs reduced the mix workability and a higher (water/cement) ratio was required to obtain the required workability, which results in lower concrete strength, and hence, lower flexural tensile strength.

Table IV Cracking, Yield, and Ultimate Moments of Tested Beams.

Beam specimen	M_{cr} (kN m)	M_y (kN m)	M_{ult} (kN m)	Mode of failure
PFC-1	1.90	3.35	4.50	Shear
PFC-2	1.85	3.40	4.65	Shear
RCC-1	1.75	3.35	5.00	Shear
RCC-2	1.92	3.50	5.20	Flexure
PPFRC-1	1.95	3.77	5.10	Flexure
PPFRC-2	1.98	3.80	5.15	Flexure

Load-deflection Behavior

Table V shows the deflection of the tested beams at the mid span at different load stages load and deflection at the cracked, yield, and ultimate stages. Beams without fibers (RCC1 and RCC2) show higher flexural rigidity before cracking. After cracking, its rigidity dropped to about 57% relative to that before cracking, due to the rapid progress of cracks through the section height. For FRC beams, the slope of load-deflection relation in the uncracked stage was less than that of RCC beam. However, after cracking the drop was smaller than that of RCC beams.

Table V Deflection at Different Load Levels.

Beam specimen	Deflection (mm)			Max. crack width
	Cracking (mm)	Yield	Ultimate	
PFC-1	1.0	6.0	9.00	3.75
PFC-2	2.0	4.0	7.00	4.10
RCC-1	2.5	3.0	6.75	3.10
RCC-2	2.5	2.5	7.00	3.25
PPFRC-1	2.7	3.0	7.50	3.00
PPFRC-2	2.0	2.0	8.00	2.30

As shown in Figure 6 the relation between load and deflection of beams without reinforcement (PCC1 and PCC2) show two stages, and while the failure of both beams were due to shear, the deflection at ultimate of beam PPFRC2 was higher than that of RCC1 and RCC2 (about 14% higher). This gave an adequate warning before failure. In case of beams with reinforcement and fibers, the relation between load and deflection shows three stages (Figure 6). Before cracking the difference between the load-deflection relation was negligible. At yield, beam PPFRC2 had the least deflection while at ultimate it had the maximum deflection among the tested beams.

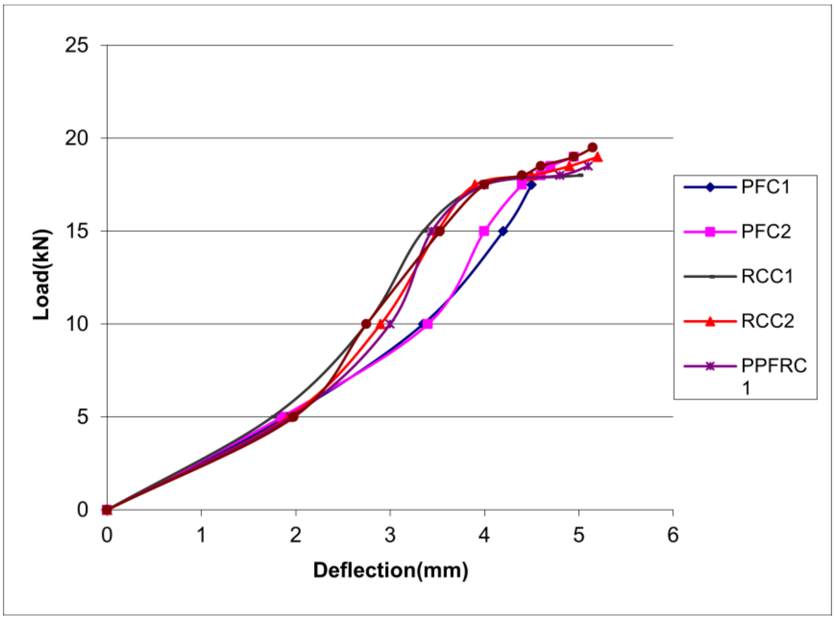

Fig. 6 Relation Between Load and Deflection of Beams.

Ultimate Flexural Strength

In this study, all beams without fibers failed in shear, while those with both fibers and with reinforcement failed in flexure. While in the case of beams with reinforcement, the addition of fiber slightly increased its ultimate flexural strength, (the increase in the flexural strength ranged between 1 and 2%). Although the results for ultimate bending are not conclusive since flexural strength was not exhausted in the beam without fibers, it can be stated that the effect of fibers on the ultimate flexural strength was negligible. However, the inclusion of fiber increased the shear strength and changed the failure pattern of the beam with reinforcement from shear failure to flexure failure. In case of the beams without reinforcement, there was an improvement in the ultimate load by about 19% due to the inclusion of fibers.

CONCLUSIONS

To study the effect of PPFs on the flexural behavior of reinforced concrete beams with or without reinforcement, six full scale beams with the same dimensions with fiber parameters were loaded up to failure. Based on the test results the following conclusions were obtained:

(i) The inclusion of PPFs into plain and reinforced concrete beams reduced the crack propagation and steel tensile stress. However, PPF had a negligible effect on the cracking moment and ultimate moment.
(ii) Due to the contribution of fiber in shear strength, there is a significant improvement in the flexural strength of beams failed in shear. However, this improvement was negligible in beam failed in flexure.

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NOMENCLATURE

Ast area of tensile steel
Asc area of compressive steel
fy yield strength of tensile
fcu compressive strength of concrete cubes
fctr compressive strength of concrete fibers
PCC Plain cement concrete
PFC Plain Fiber concrete
RCC Reinforced cement concrete
PPFRC polypropylene fibers reinforced con crete

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