Journal of Civil Engineering (IEB), 40 (2) (2012) 105-114

Journal of
Civil Engineering
IEB

Cyclic behaviour of reinforced cement concrete composite beam made with polypropylene fiber

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Received 8 October 2011

Abstract

The cyclic behaviour of polypropylene fiber reinforced concrete, plain concrete beams with and without reinforcement was conducted in this study. 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 tested under two point loads. Beams were tested under positive cyclic loading, and the results were evaluated with respect to strength, ductility, energy absorption capacity, and energy absorption and stiffness degradation. Test results indicate that the provision of polypropylene fiber in beam enhances the strength, ductility, energy absorption capacity and stiffness. Also 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, (cracking moment and ultimate moment), combining polypropylene fibers and reinforcement improved the behaviour of reinforced concrete beams and changed its failure mode.

Keywords: Polypropylene fibers, Cyclic load, Energy absorption capacity, Ductility, Flexural strength, Crack, Stiffness

Notation

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
I_g	=	moment of inertia of the section
y	=	position of neutral axis
d	=	effective depth of tension steel
b	=	width of the section
PCC	=	plain cement concrete
PFC	=	plain Fiber concrete
RCC	=	reinfoced cement concete
PPFRC	=	polypropylene fibers reinforced concrete

1. Introduction

The introduction of fibers was brought in as a solution to develop concrete in view of enhancing its flexural and tensile strength, which are a new form of binder that could combine Portland cement in the bonding with cement matrices. Fibers are most generally discontinuous, randomly distributed throughout the cements matrices. The term of 'Fiber reinforced concrete' (FRC) is made up with cement, various sizes of aggregates, which incorporate with discrete, discontinuous fibers. Fiber reinforced concrete (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 behaviour such as ductility, cracking control and impact resistance. Recent earthquakes in different parts of the world have revealed again the importance of design of reinforced concrete structures with high ductility. Conventional concrete looses its tensile resistance after the formation of multiple cracks. However, fiber concrete can sustain a portion of its resistance following cracking to resist more cycles of loading. For this reason they must be provided with adequate stiffness and strength to sustain the loads transmitted from beams. A study conducted on fibre reinforced normal strength concrete by Filiatrault et al. (1994) indicates that this material is an alternative to the confining reinforcement in the joint region. Besides these, there are a large number of investigations on the effect of addition of fibres on the strength and ductility of flexural members. The study conducted out by Oh (1992) indicates that ductility and ultimate resistance of flexural members are remarkably enhanced due to the addition of steel fibres. Also it was emphasised that the neglect of fibre contribution may considerably underestimate the flexural capacity of fibre reinforced concrete beams.Chuan Mein WONG(2004) was experienced in his research work it was found that different type 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 showed specimens with fibers that drastic increase in strength from specimens without fibers.

Peled et al.(2000) studied, in general, the improvement in the matrix behaviour varies according to the fiber type, volume ratio (Vf), 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, Laresen et al(1994), Malhotra et al,(1991) conducted research 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 PPF(polypropylene fibers) on the properties of concrete was studied by many researchers such as Hughes et al,(1977) Badr et al.(2001)the excellent control of cracking due to improvement in flexural toughness. Feldman et al.(1993) and Alhozaimy et al.(1996) is reported widely Impact resistance of PPFRC. However, the effect of PPF on other properties is not well documented. Some studies reported slight improvements in compressive, tensile and flexural strengths [Al-Tayyib et al.(1988) Badr et al.(2001)] while others [Alhozaimy et al.(1996)] showed either no effect or slight adverse effect on these properties due to the inclusion of polypropylene fibers.The difference between the results may be related to the difference in PPF parameters and matrix composition.All these studies are limited to the normal strength concrete, and the research in the area of cyclic behaviour of polypropylene fiber reinforced concrete, plain concrete beams with and without reinforcement is limited. In general, when fibres are added to concrete, tensile strain in the neighborhood of fibres improves significantly. In the case of PPFRC, since concrete is dense even at the microstructure level, tensile strain would be much higher than that of the conventional RCC. This will improve the cracking behaviour, ductility and energy absorption capacity of the composite. This is in addition to the durability aspect of conventional RCC. In order to tap the potential of PPFRC, the existing body of knowledge must be expanded. Hence, an attempt has been made to study the behaviour of PPFRC beam under the positive cyclic loading.

2. Experimental Program

2.1 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 type of polypropylene fiber was used in this study as shown in Table 1.The concrete mix proportions were chosen based on the results of trial mixes carried out to optimize the mix proportions and fiber content. Properties of coarse aggregate, fine aggregate, cement and slum values of concretes are given in Table 2. 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.

Table 1
Properties of Polypropylene Fiber

Properties	Fiber type(polypropylene)
Nominal Diameter	0.002mm
Nominal Diameter	coarse
Length (mm)	12
Specific gravity	0.90
Melting point	160 degree centigrade
Tensile strength	551MPa
Young’s Modulus	$3.45X10^3$ MPa
Ultimate Elongation	25%

2.2 Test beams

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 three minutes, to avoid clumping. Mixing was continued for another two minutes to achieve uniform distribution of the fiber. Workability of the fresh concrete was assessed using the slump test**.** 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 two150dia, 300mm height cylinders for compressive and split tensile strength. The beams and the cubes were cured in a room temperature environmental humidity until testing at 30 days. The properties of fine, coarse aggregates, cement and slump values are listed in Table 2.

2.3 Test procedure and measurements

The size of the test beams are 900mm length, 150mm breath and 150mm depth. The test beams were total length of 900 mm and an effective span length of 800 mm between supports. The dimensions and the reinforcement details for the test beams are shown in Figure 1, while Table 3 shows the properties of these beams. All beams were same dimensions and longitudinal and shear reinforcement, specimens were tested in a universal testing machine of 400 kN capacity. A constant load of 10 kN, which is about 10% of the capacity of the beam, was applied to the beam for holding the specimens in position and to simulate load. A hydraulic load was used to apply load at the top of the beam. A dial gauge with a least count of 0.02 mm was used to measure the beam tip displacements. The increment of loading was taken as 10 kN. The beam was loaded up to the first increment, then unloaded and reloaded to the next increment of load, and this pattern of loading was continued for each increment.

Table 2
Property details of fine, coarse aggregate and cement

Sl. 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 mins	≤ 30 min.
4	Final setting time	460 mins	≥ 600 min.
5	Slum values of P.C.C concrete		83mm
6	Slum values of R.C.C concrete		96mm
7	Slum values of F.R.C.C concrete		104mm

Table 3: 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	5.1	----	415	----	370	----	----
PFC-2	29.7		---		---		----	----
RCC-1	29.7		2T10		2T8		1φ8/180mm	0.35
RCC-2	29.7		2T10		2T8		1φ8/180mm	0.35
PPFRC-1	28.3		2T10		2T8		1φ8/180mm	0.35
PPFRC-2	28.3		2T10		2T8		1φ8/180mm	0.35

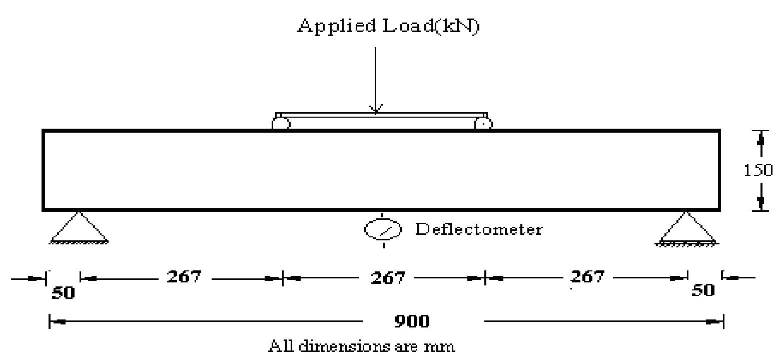


Fig. 1. Details of test beam

3. Results and Discussion

3.1 Cracking strength and Cracking patterns

Figure 2 shows 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 was approached the FRC beams developed new cracks between the primary cracks. The new cracks due to increased ductility. The extension of the cracks through the beam height was lower in case of PPFRC beams compared with RCC beams due to the action of the fibers that restrained the propagation of cracks.

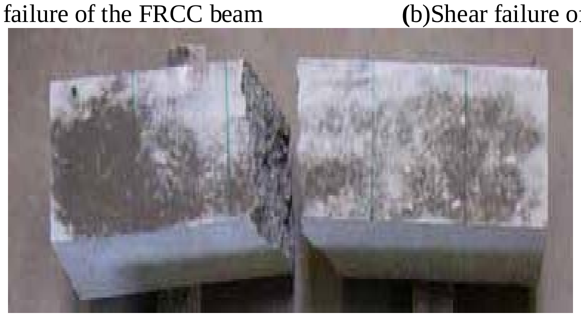
Table 4 shows the actual cracking moment for the tested beams. The presence of the polypropylene fibers (with volume ratio V_f= 0.35%) slightly reduced the flexural cracking resistance, this was observed in case of beams with or without reinforcement. This is because the volume ratio of polypropylene fibers 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 4
Cracking, Yield & 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

(a)Flexural failure of the FRCC beam

(b)Shear failure of RCC beam



(c) Failure of PCC beam

Fig. 2. Cracks Patterns for Test Beams

3.2 Load-deflection behaviour

Table 5 shows the deflection of the tested beams at the mid span at different load stages(Load and deflection in 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 5
Deflection at Different Load Levels

Beam Specimen	Deflection (mm)			max. Crack Width (mm)
	Cracking	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

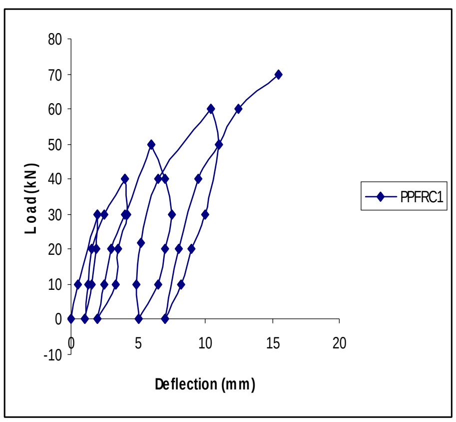


Fig. 3(a)load-deflection-PPFRC1

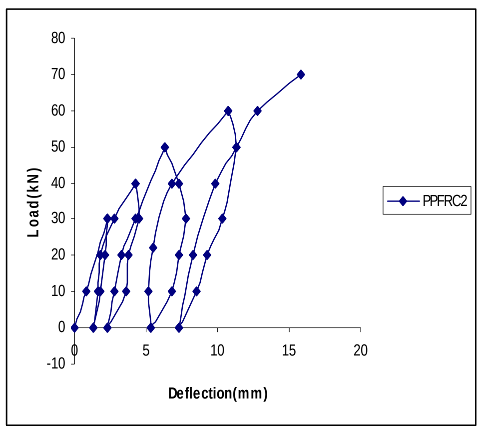


Fig. 3(b)load-deflection-PPFRC2

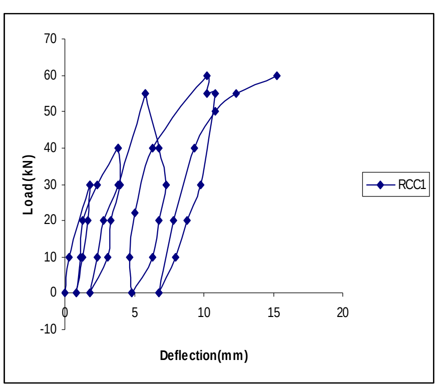


Fig. 3(c)load-deflection-RCC1

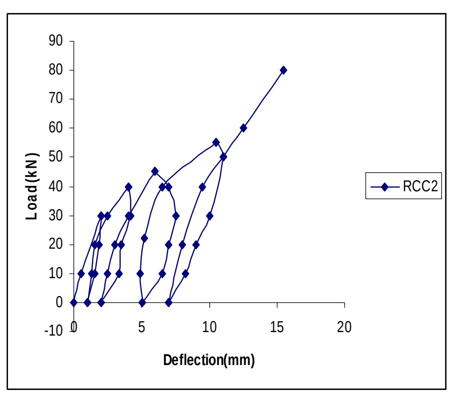


Fig. 3(d)load-deflection-RCC2

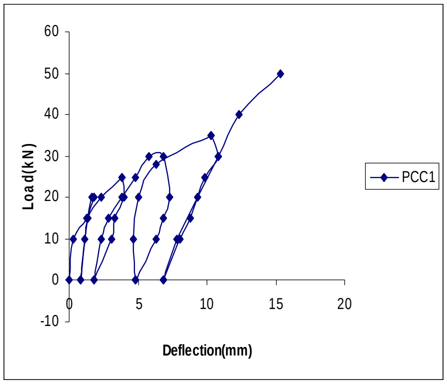


Fig. 3(e)load-deflection-PCC1

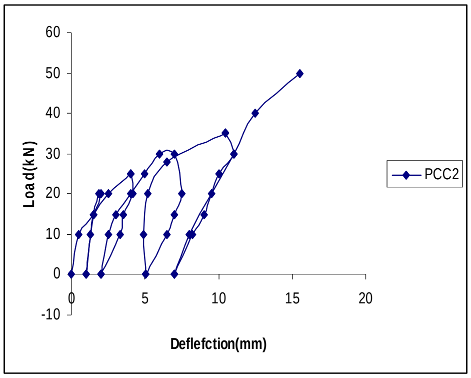


Fig. 3(f)load-deflection-PCC2

Fig. 3 Cyclic load-deflection

3.3 Energy Absorption Capacity

Area under the load-deflection curve represents the energy absorption capacity of the specimen. Due to inherent limitations of the test setup, load deflection could be traced only up to 80% of the post peak loading in the descending portion of the curve. Hence, the energy absorption capacity of specimens were calculated as the areas under the load deflection plots up to the each cycle curve peak load and under the descending portion up to 80% peak load and are given in Table 6. For PPFRC specimens with 0.35% fibres it is about 2.45 times than that of RCC without fibres.

Table 6
Energy Absorption Capacity, Stiffness degradation and ductility factor

Beam Specimen	Energy Absorption Capacity kN-mm	Stiffness Degradation kN/mm	Ductility factor
PFC-1	700	2.50	0.76
PFC-2	727	2.00	0.90
RCC-1	1600	4.50	1.29
RCC-2	1400	4.80	1.33
PPFRC-1	1750	4.80	1.44
PPFRC-2	1800	5.10	1.50

3.4 Flexural Ductility

The term ductility is defined as the ability of the material/member to sustain deformation beyond the elastic limit while maintaining the reasonable load carrying capacity until total failure. In reinforced concrete beam the deformation most suited for measurement of ductility is the curvature of the beam. As an alternative the deflection of the beams which is generally easier to measure, is used. When evaluating ductility, the most important parameter to be considered is the maximum deformation that the member can sustain prior to failure. The ductility factor can be expressed in dimensionless term "μ", as defined below

$$\mu = \frac{\Delta u}{\Delta y}, \tag{1}$$

where
Δu is the maximum deformation at failure and
Δy is the deformation when material or member yields.

The μ values given in Table 7 and are plotted against the corresponding tension steel ratio as shown in Figure 7. From the Figure 7 it is observed that the specimen with equal reinforcement ratio, the ductility capacity of specimen's increases in the fiber reinforced concrete beams when compared to conventional concrete and plain cement concrete specimens this is due the tensile property of fibers.

Table 7
Ductility factor

Beam Specimen	Yield deflection Δy	Ultimate deflection Δu	Ductility factor μ= Δu/ Δy
PFC-1	3.40	4.50	0.76
PFC-2	4.44	4.95	0.90
RCC-1	4.00	5.15	1.29
RCC-2	3.90	5.20	1.33
PPFRC-1	3.53	5.10	1.44
PPFRC-2	3.44	5.15	1.50

3.5 Stiffness degradation behaviour

The gradient of the load-deflection relationship is an indication of beam stiffness. It may be seen in Figure 3 that prior to cracking, the stiffness of the beams remained practically the same for the entire set of parameters and their ranges considered in this study. PPFRC beam, demonstrated slightly smaller post-cracking stiffness than the corresponding PCC beam. The post cracking stiffness has been found to decreases in PCC beam specimens and with an increase in the amount of tension reinforcement with PPFRC. The effect of the amount of compression reinforcement or the spacing of stirrups in the flexural zone has practically no influence on beam stiffness. The maximum (mid span) deflection,(δs) obtained experimentally at the assumed service load, are presented in Table 7. It ranges from about 2.00 mm to about 5.10.

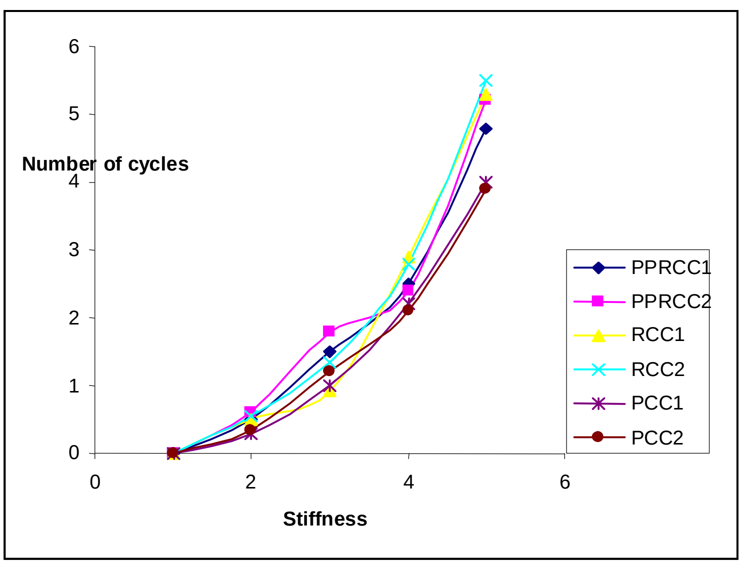


Fig. 4 Relationship between stiffness and number of cycles

3.6 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.

4. Conclusions

To study the effect of polypropylene fibers (PPF) on the seismic behaviour 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:

1. The inclusion of polypropylene fibers into plain and reinforced concrete beams reduced the crack propagation and steel tensile stress and significantly improved the ductility of the reinforced concrete beams which is essential for seismic force resisting structure. However, PPF had a negligible effect on the cracking moment and ultimate moment.

2. While the inclusion of polypropylene fibers had a minor effect on the beam stiffness before cracking, the rate of stiffness delay in the PPFRC beam after cracking was lower than that of the beams without fibers.

3. Ductility of the fiber reinforced concrete beam specimen is improved while the other conventional concrete beams.

4. Energy absorption capacity has improved considerably when fibre content increased which makes PPFRC highly suitable for seismic force resistant structures.

Acknowledgements
Author is a postdoctoral fellow, professor and H.O.D in Civil Engineering Department of Dr.M.G.R Universit. This research work is a Post Doctoral Research work of the author. Authors wish to express their gratitude and sincere appreciations to the President, Dr.M.G.R. Educational and Research Institute (Dr. M.G.R Deemed University), Chennai, Tamil Nadu, India for giving research fund assistance and full co-operation of this research. The authors are very grateful for the assistance rendered by the Civil Engineering Laboratory & Technical Staff and University students at various stages of this investigation.

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