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Effect of waste cement bag fibers on the mechanical strength of concrete

Comingstarful Marthong*

Department of Civil Engineering, National Institute of Technology Meghalaya, Shillong 793003, India

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Abstract. Polypropylene (PP) fibers for making fabric which is used for packing cement have a high strength and high tear resistance. Due to these excellent properties the present study investigates the effect of PP fibers on the mechanical strength of concrete. Mechanical strength parameters such as compressive strength, splitting tensile strength and flexural strength are evaluated. Structural integrity of concrete using Ultrasonic Pulse Velocity (UPV) was also studied. Concrete containing PP fibers in percentage of 0%, 0.15%, 0.25%, 0.5% and 0.75% was developed with a characteristic compressive strength of 25 MPa. Concrete cubes, cylinder and prismatic specimens were cast and tested. It was found that the UPV values recorded for all specimens were of the similar order. Test results indicated the used of PP fibers can significantly improve the flexural and splitting tensile strengths of concrete materials whereas it resulted a decreased in compressive strength. The relative increase in split tensile and flexural strength was optimum at a fiber dosage of 0.5% and a mild decreased were observed in 28 days compressive strength. The findings in this paper suggested that PP fibers deriving from these waste cement bags are a feasible fiber option for fiber-reinforced concrete productions.

Keywords: polypropylene fiber; waste cement bag; concrete properties; mechanical strength

1. Introduction

Although concrete offers many advantages regarding mechanical characteristics and economic aspects of the construction, the brittle behavior of the material remains a larger handicap for the seismic and other applications where flexible behaviour is essentially required. However, the development of fiber-reinforced concrete (FRC) has provided a technical basis for improving these deficiencies. Different types of discontinuous fibers such as steel, glass and polymeric fiber are commercially available. Fiber also has been in a continuous mat for production of thin sheet components (woven sack) used for packing goods and material. The woven sacks are highly demanded in various industries such as pharmaceuticals, fertilizers, sugar, polymers, agro, cement and others for packaging of goods in big quantities. The woven polypropylene is one kind of thermoplastic resin material that is produced by the polymerization of propylene. The woven sack used for packing cement is made from high density polypropylene fibers. According to IS 11652 (2000) the sack tube of 50 kg capacity is woven on a flat bed loom which effectively weaves two layers of fabrics (warp and weft). In order to prolong the shelf life of the packed products the

*Corresponding author, Ph.D., Associate Professor, E-mail: commarthong@nitm.ac.in

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polypropylene fibers for making fabric normally has a high strength, high tear resistance, resistant to acids and alkalis, high melting point and being coated with water repellant film.

The consumption of cement is increasing day by day due to increase in construction activities and the cement bags are producing in large quantities as a waste. It is considered to be too light and bulky for transport and recycle and recycling consume more resources than it would return. Therefore, it appears that recycling is not profitable from an ecological and economic point of view. Effort has been made to utilize these waste bags by filling it with soil and then used as a retaining wall or as an embankment in a temporary construction. However, as shown in Fig. 1, most of these bags have been disposed in an open area which may pollute the environment. It has been observed that the waste cement bag production and disposal has increased exponentially as time passes. Therefore, use of theses waste bags in any form would be benefitted not only in the prevention of the environmental pollution but also energy saving in the disposal.

2. Utilization of polypropylene fibers for concrete production

Concrete modification by fibers such as steel, glass and polymeric has been studied for the past four decades (Dodson 1989). Since then the use of these fibers has increased tremendously in construction of structures because addition of fibers in concrete improves the toughness, flexural strength, tensile strength and impact strength as well as failure mode of concrete. The polymeric fibers most frequently used as concrete reinforcements are nylon, aramid, polypropylene, polyethylene, polyester etc. Amply research has been carried to study the mechanical behavior of polypropylene fiber's concrete. The effect of polypropylene fibers on the properties of fresh and hardened lightweight self-compacting concrete was reported by Mazaheripour *et al*. (2011). They found that polypropylene fibers did not influence the compressive strength and elastic modulus but increased the flexural strength and splitting tensile strength by 14.4% and 10.7% respectively. Kakooei *et al*. (2012) studied the influence of different amount of polypropylene fibers (0 to 2 kg m^{-3}) on concrete fabricated with coral and siliceous aggregate by measuring the permeability, electrical resistivity and compressive strength. The samples with added polypropylene fibers of 1.5 kg m^{-3} showed better results in comparison with the others. Study by Lee *et al*. (2012) revealed that the use of hybrid fibers of polypropylene and nylon fibers improve the spalling protection of high-strength concrete subjected to fire. In the study conducted by Zhang and Zhao (2012) the mechanical strength and durability of concrete containing polypropylene fiber showed significant improvement. Parameters like flexural and splitting tensile strengths were significantly enhanced. On the durability aspect, the increased in the volume of fibers make the concrete to resist more

Fig. 1 Dumping of waste cement bag on the road side

freeze-thaw cycles. Shihada (2011) observed that the concrete containing polypropylene fibers upto 0.5% can significantly promote the residual compressive strength during the heating. López-Buendía *et al*. (2013) reported that modifications in the fiber surface led to an increase in the adhesion properties between the treated fibers and concrete and an improvement in the mechanical properties of the fibre-reinforced concrete composite as compared to the untreated concrete. Donkor and Obonyo (2015) used macro synthetic polypropylene fibers for improving the strength of compressed earth blocks. It was reported that the bending and ductility were improved by the addition of fibers. However, as observed by Aslani and Samali (2014) the addition of polypropylene in concrete reduces the flowability and passing ability but will increase viscosity and segregation resistance. The use of steel-polypropylene hybrid fiber has been extended to reinforce concrete (RC) column (Huang *et al*. 2015) and RC beam (Sahoo *et al*. 2015), slender wall (Ganesan *et al*. 2014). The experimental results showed that the presence of hybrid fibers in RC member had a positive influence on improving the seismic bearing capacity. Also, the formation of multiple cracks of smaller crack width indicated the better fiber bridging action of combined metallic and nonmetallic fibers. The combined effect of polypropylene fibers and silica fume to improve the durability of concrete has been carried out by Medina *et al*. (2015). It was reported that the addition of 0.1% polypropylene short fibers in concrete combined with 10% silica fume mitigated the early age cracking and significantly reduced water permeability and carbonation depth. Jun *et al*. (2016) use corrugated polypropylene fiber to evaluate the mechanical properties of lightweight aggregate concrete. They found that flexural strength, splitting tensile strength; flexural toughness and impact resistance were enhanced while no effect on compressive strength was observed. An optimal fiber content of 0.95% was recommended to enhance the mechanical properties of concrete. The use of natural fibers as a reinforcing composite material was investigated by Khelifa *et al*. (2016). In their study, alfa derived from vegetable fibers was used as a reinforcing material composite. They concluded that the use alfa fibers allow to obtain a concrete less expensive, more eco-friendly and better from the mechanical point of view than when using polypropylene fibers, which makes of alfa a good candidate to produce sustainable concrete and green buildings. The addition of 0.9% fiber leads to significant improvement in the overall structural behavior of the slabs and their resistance to impact loading (Al-Rousan *et al*. 2017).

The review of the past study demonstrated that mechanical properties of concrete were enhanced upon the inclusion of PP fibers and the fibers commercially available have been extensively used in all the studies except study conducted by Khelifa *et al*. (2016). It is worth mentioning that for a rough use of the cement bag the fabrics of the cement bags possess the properties such as high resistance to stress and cracking, high melting point, resistant to alkalis and acid and water proof with a laminated film. Therefore, with these excellent properties presented by the polypropylene fibers, it is anticipated that when mix with concrete helps in improving the mechanical strength and durability properties of fiber's concrete similar to those commercially manufactured PP fibers.

3. Experimental programs

Table 1 presented the experimental program and test parameters carried out in the present study. Concrete cubes of 150 × 150 mm, cylindrical of 100 mm diameter × 200 mm height and prismatic specimens of 100 × 100 × 500 mm with fiber dosage of 0%, 0.15%, 0.25%, 0.5% and 0.75% by weight were considered.

3.1 Materials

3.1.1 Cement and aggregates

Ordinary Portland Cement (OPC) of 53 grades conforming to IS: 12269 (1987) was considered. The maximum size of coarse aggregate was 12.5 mm. River sand was used as fine aggregate. Aggregates used have been tested as per relevant codes (IS: 2386 1963a and 1963b).

3.1.2 Polypropylene fibers

As per guideline of IS 11652 (2000), polypropylene (PP) fibers used for making fabric bag for packing cement are flat in shape and its density and thickness is ranging from 0.940 to 0.965 g/cm^3 and 2.5 mm respectively. Its melting point is about 170℃ and the average breaking loads of fabrics in both lengthwise and widthwise is about 850 N. PP fiber used in the present study is obtained by cutting the polypropylene cement bags (PPCB). The waste PPCB of 50 kg capacity was collected from the construction site which was 3 months old after used. The PPCB is in the form of polypropylene strips (fiber)/threads that have been woven in two directions (warp and weft) to create a light and strong support for heavy duty material. Since large quantity of short fibers is required for mixing with concrete, therefore manual separation of fibers from the two directions fabric is a difficult task. To ease the fiber's separation at first the dirt and dust presence in the PPCB was brushed and washed with water and then sun dried. After drying, a strip of 50 mm wide was cut along the width or length wise of the PPCB. The long strip of PPCB was further cut into a short length of 50 mm, which makes the two directions fabric a size of 50 mm × 50 mm. In the presence of aggregate the fibers from the two directions fabric will detach by itself during the mixing process. Fig. 2 shows the cutting process of fibers. To the best of the author's knowledge so far no experimental study has been conducted on incorporating PP fibers deriving from waste PPCB in a concrete mix. Therefore, the short discrete fiber (length to width ratio around 2) is considered herein for more even distribution in the concrete matrix, greater surface area and thus a better anchorage. The fiber dosages considered are 0.15%, 0.25%, 0.5% and 0.75% by weight of total concrete mixture.

3.2 Casting and curing of specimens

Concrete mix was designed for a characteristic cube compressive strength of 25 MPa which resulted in a target mean cube compressive strength of 31.6 MPa as per IS: 10262 (2009) code provisions. Water cement ratio (*w*/*c*) of 0.5 was considered. The proportioning and description of the concrete mixtures with fiber dosage are summarized in Table 2. The amount of PP fibers introduced was 0%, 0.15%, 0.25%, 0.5% and 0.75% by weight of a total concrete mixture. Corresponding to the fiber dosage, the specimens were named accordingly. The first two letters indicated the specimens' type such as concrete cube (Cu), cylindrical (Cy) and prismatic (Pr) while the third letter indicated the fiber dosages. According to test parameter three concrete specimens were cast in each mix. Concrete with no fiber dosage is treated as a reference specimen (CC), while with fiber dosage is designated as polypropylene fiber-reinforced concrete (FC). Reference concrete mixes were produced with 372 kg/m^3 of cement, 733 kg/m^3 of fine aggregate (FA), 1087 kg/m^3 of coarse aggregate (CA), for a water-cement ratio (w/c) of 0.5 and a compaction factor of 0.9. To achieve a better workability, 0.5% and 0.8% of superplasticizer by volume of water was used in mixing of 0.5% and 0.75% fiber concretes. A total of 15 cubes, cylindrical and prismatic

Fig. 2 Cutting process of PP fibers (a) PPCB; (b) Cutting of 50 mm strip; (c) Bunch of strips; (d) Fabric of 50 mm square size; (e) Mixing of small fabric with aggregate; (d) Discrete fiber formed after mixing

Fig. 3 Set of cast specimens

specimens each were casted. Fig. 3 presented one set of cast specimens. After 24 hours of casting the specimens were removed from the mould and were kept in water tank for 28 days curing period.

3.3 Testing methodology

Workability for fresh concrete was obtained by carrying out slump cone test as per IS: 1199 (1959). In accordance to IS: 516 (1959) the hardened concrete cubes and prismatic specimens were tested for compressive strength and flexural strength. In addition, split tensile strength was performed on cylindrical specimens as per IS: 5816 (1999). Test on hardened concrete were carried out in a hydraulic compression testing machine of capacity 1000 kN. To assess the homogeneity and integrity of concrete ultrasonic pulse velocity (UPV) test on CC and FC cubes was also performed. The ultrasonic test equipment supported a broad range of transducers that varied from 24 kHz to 500 kHz with an accuracy of 0.1 μs was used to measure the ultrasonic velocity according to IS: 13311(1992).

Table 1 Experimental program and test parameters

Sl. No.	Specimen mark	No of specimens	Characteristics	Test parameters
1	Cu/0	3	Concrete with 0% fiber	Compressive strength and Ultrasonic pulse velocity
	Cu/0.15	3	Concrete with 0.15% fiber	
	Cu/0.25	3	Concrete with 0.25% fiber	
	Cu/0.50	3	Concrete with 0.50% fiber	
	Cu/0.75	3	Concrete with 0.75% fiber	
2	Cy/0	3	Concrete with 0% fiber	Tensile strength and Ultrasonic pulse velocity
	Cy/0.15	3	Concrete with 0.15% fiber	
	Cy/0.25	3	Concrete with 0.25% fiber	
	Cy/0.50	3	Concrete with 0.50% fiber	
	Cy/0.75	3	Concrete with 0.75% fiber	
3	Pr/0	3	Concrete with 0% fiber	Flexural strength and Ultrasonic pulse velocity
	Pr/0.15	3	Concrete with 0.15% fiber	
	Pr/0.25	3	Concrete with 0.25% fiber	
	Pr/0.50	3	Concrete with 0.50% fiber	
	Pr/0.75	3	Concrete with 0.75% fiber	

4. Results and discussion

4.1 Workability and unit weight

Workability of fresh concrete and unit weight of hardened concretes of 5 mixes are shown in Table 3. It can be observed that for a constant *w/c* of 0.5, the slump of concrete varied from 50 mm (typical mixes with fibers) and 80 mm (mixes without fibers), which indicates a “low to medium” degree of workability (IS: 456 2000). Test results also show that the slump value decreases as the fiber dosage is increased. To achieve a better workability a superplasticizer of 0.5% and 0.8% by volume of water were added to the mix of FC/0.5 and FC/0.75 respectively. The unit weight of each concrete mix is also presented in Table 3. Due to light weight and lower density of PP fibers the unit weight of FC specimens show no significant difference as those of the CC mixes. Nevertheless, a decrease of 5% of unit weight was noted at a fiber dosage of 0.75%.

4.2 Tests on hardened concrete for strength

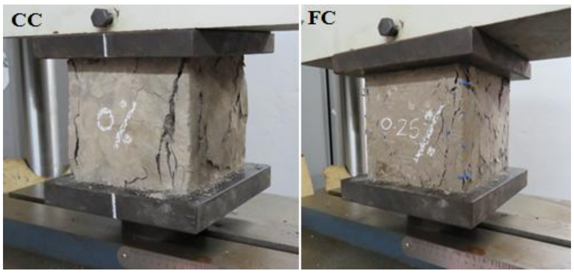
According to the test parameters given in Table 1, a total of 45 specimens were cast. All the specimens were tested at 28 days. Non-destructive test i.e., UPV was conducted first on the specimens. Afterwards, tests to evaluate compressive strength, split tensile strength and flexural strength were carried out. The details of each test are presented in the following section.

4.3 Compressive strength test

The compressive strength test was carried out in accordance to IS: 516 (1959). A total of 15 specimens of size 150 × 150 mm were tested. Tested specimens at 28 day are shown in Fig. 4(a) and the average compressive strength values (f_c^a) are given in Table 4. The addition of PP fiber increased the fragmentation resistance of FC specimens. This is also evident from the plot given in Fig. 4(b). Though, all FC specimens achieved the target compressive strength of 31.6 MPa nevertheless, the compressive strength were reduced with fibers additions and decreased in accordance to the fiber dosages. The relative reduction in compressive strength of FC mixes is also given in Table 4. It can be seen from the results that the compressive strength of FC are lower by about 3-21% as compared to the CC specimens. At a fiber dosage of 0.5% a decrease in compressive strength was 14%, while at 0.75% a higher jump of strength reduction about 21%. From this it can be concluded that fiber dosage upto 0.5% did not seem to jeopardize the compressive strength of FC specimens.

Table 2 Mix proportions and description of concrete mixtures

Sets	Specimen mark	Fiber dosage (%)	Concrete (kg/m^3)	Batch weight (kg/m^3)					
				Cement	FA	CA	Fiber	Water	Superplasticizer
1	Cu/0	-	2360	372	733	1087	-	168	-
	Cu/0.15	0.15	2360	372	733	1087	4	168	-
	Cu/0.25	0.25	2360	370	731	1085	6	168	-
	Cu/0.50	0.50	2360	368	729	1083	12	168	0.84
	Cu/0.75	0.75	2360	366	727	1081	18	168	1.34
2	Cy/0	-	2360	372	733	1087	-	168	-
	Cy/0.15	0.15	2360	372	733	1087	4	168	-
	Cy/0.25	0.25	2360	370	731	1085	6	168	-
	Cy/0.50	0.50	2360	368	729	1083	12	168	0.84
	Cy/0.75	0.75	2360	366	727	1081	18	168	1.34
3	Pr/0	-	2360	372	733	1087	-	168	-
	Pr/0.15	0.15	2360	372	733	1087	4	168	-
	Pr/0.25	0.25	2360	370	731	1085	6	168	-
	Pr/0.5	0.50	2360	368	729	1083	12	168	0.84
	Pr/0.75	0.75	2360	366	727	1081	18	168	1.34



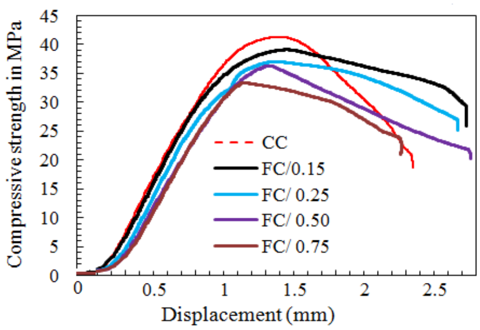


Fig. 4 Compressive strength test (a) Failure pattern; (b) Variation of strength with respect to fiber dosage

4.4 Splitting tensile strength test

In accordance to IS: 5816 (1999) the splitting tensile strength of the specimens was carried out. The condition of tested specimens is shown in Fig. 5(a). The CC specimens cracked and split out. Meanwhile all FC specimens exhibited cracking but did not fully separate. The even distribution of fibers inside the concrete matrix increased the cracking resistance. Splitting tensile strength values (f_{st}^{a}) are given in Table 4. The values also indicated that split tensile strength of FC specimens increase with increasing fiber dosage. The relative increases in split tensile strength of FC specimens are higher about 4-30% and maximum at fiber dosage of 0.5%. Further, the plot presented in Fig. 5(b) revealed that FC specimen's have improved tensile strength over the reference specimen and showed the ability to dissipate more energy.

4.5 Flexural strength test

The influences of PP fibers on the flexural strength were evaluated on concrete prismatic specimens of dimension 100 mm × 100 mm × 500 mm. The flexural strength was calculated using

Table 3 Slump value and unit weight of concrete

Mix code	Slump value (mm)	Unit weight (kg/m^3)
CC	80	2396
FC/0.15	78	2392
FC/0.25	77	2350
FC/0.50	60	2334
FC/0.75	50	2283

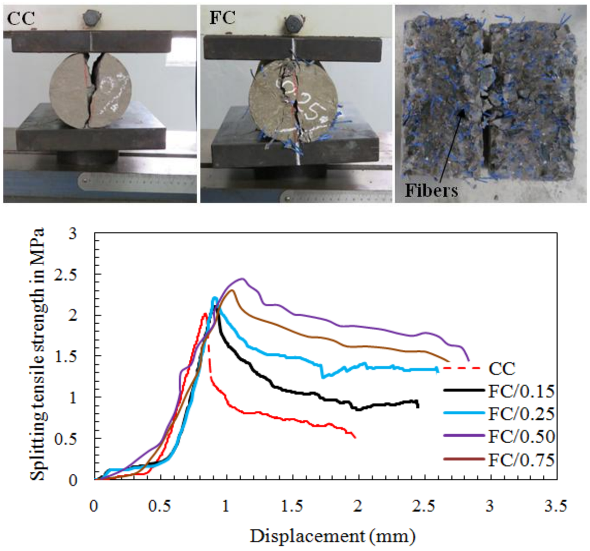


Fig. 5 Splitting tensile strength test (a) Failure pattern; (b) Variation of strength with respect to fiber dosage

the equation, $f_f = \frac{PL}{bd^2}$ (IS: 516 1959) where f_f a flexural strength in MPa, P is maximum flexural load in N; L, b and d are the supported length, width and failure point depth of the specimens in mm, respectively. The average flexural strength (f_f^a) and their relative increase are presented in Table 4. To prolong the shelf life of the packed products, woven fabric used for packing cement normally has high strength and tear resistance. Thus, it is expected that mixing PP fibers in concrete would provide an excellent resistance to stress and cracking. The results also show that mixing PP fiber in the concrete mix led to an increased in the flexural strength of about 1.4 times over the reference specimens. The percentage increased in flexural strength of concrete specimens due to the presence of fibers are 5%, 24%, 40% and 29% for FC/0.15, FC/0.25, FC/0.5 and FC/0.75 respectively. Test setup and the failed specimens are shown in Fig. 6(a). Due to the even distribution of fibers inside the concrete prism, all FC specimens presented a ductile behaviour when compared to the CC specimens. The flexural strength versus displacement shown in Fig. 6(b) also revealed that CC specimens failed suddenly and collapsed while FC specimens could sustain a higher displacement level. This shows that inclusion of PP fiber created an anchorage effect and prevents the crack propagation of the concrete specimens and thus improved the flexural strength. Nevertheless, higher fiber dosage more than 0.5% decreased the flexural strength.

4.6 Flexural toughness

Flexural toughness is considered as the amount of energy that concrete will sustain in flexure

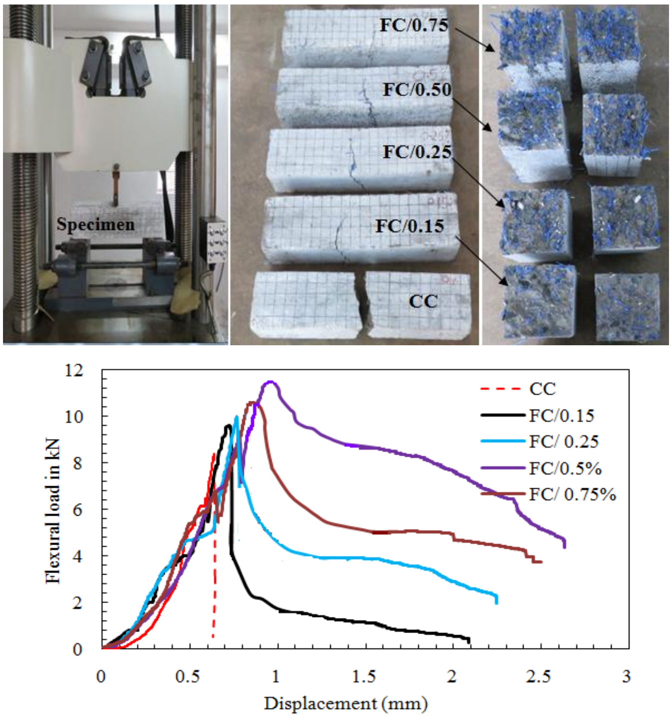


Fig. 6 Flexural strength test (a) test set-up, failure pattern and fiber distributions; (b) Variation of strength with respect to fiber dosage

Fig. 7 UPV test

Table 4 Mechanical properties of concrete mixtures

Mix code	Fiber dosage (%)	Compressive strength test		Tensile strength test		Flexural strength test		UPV test		Flexural toughness	
		f_c^a (MPa)	Relative reduction (%)	f_{st}^a (MPa)	Relative increase (%)	f_f^a (MPa)	Relative increase (%)	UPV (m/s)	Relative reduction (%)	E^a (kN-mm)	Relative increase (%)
CC	-	40.44	-	2.02	-	4.19	-	4360	-	3.55	-
FE/0.15	0.15	39.11	3.30	2.11	4.45	4.41	5.25	4273	2.0	4.78	34.650
FE/0.25	0.25	36.67	9.34	2.11	9.90	5.21	24.34	4153	4.75	10.57	197.75
FE/0.50	0.50	34.89	13.74	2.63	30.20	5.87	40.10	4061	6.86	20.23	469.86
FE/0.75	0.75	31.78	21.43	2.44	20.79	5.39	28.64	3916	10.18	16.34	360.28

before a failure occurs. Prismatic specimens as per IS: 516 (1959) was conducted to determine the energy absorption of FC specimens. The toughness index is defined as the area under the load versus displacement curve (Shannag and Ziyyad 2007) and the toughness values are shown in Table 4. Non-fiber-reinforced concrete has little or no energy absorbing capability. The toughness of FC specimens is, however 6, times higher than that of the non-fiber-reinforced concrete. Also, it can be observed from Fig. 6(b) that the areas in the load versus displacement curves of all FC specimens are bigger than that of the CC specimen. This shows that the presence of PP fibers in the concrete matrix improved the toughness when compared with non-fiber-reinforced concrete specimens and the toughness value starts decreasing with fiber dosage beyond 0.5%.

4.7 UPV test

To examine the condition inside the concrete specimens UPV test was conducted on both CC and FC specimens as shown in Fig. 7. The results obtained are presented in Table 4. All UPV values are in the range of 3.5 km/sec to 4.5 km/sec, which indicates the quality of concrete falls in the “good” scale as per quality assessment of IS: 13311 (1992). However, the UPV values of FC specimens are lower about 2-10% due to the lower specific gravity of PP fibers.

5. Conclusions

In this paper, the effect of mixing polypropylene fiber on the properties of fresh and hardened concretes was investigated. PP fibers were obtained by cutting the polypropylene waste cement bag of 50 kg capacity. Considering different fiber dosage five concrete mixes were prepared. Cubes, cylinder and prismatic specimens were prepared to evaluate the mechanical strength of fiber concretes. Based on the test results and the analyses the following conclusions can be drawn:

- For a *w*/*c* ratio of 0.5 the workability of PP fiber' concretes decreases as the dosage of fiber increased. The slump value is lower by 37.5% at 0.75% dosage.
- Due to the light weight and lower density of PP fibers the unit weight of FC specimens show no significant difference as those of the CC specimens.
- All FC specimens achieved the target compressive strength of 31.6 MPa. However, the compressive strength was reduced with fibers addition. The relative reduction in compressive strength of fiber concretes is lower about 3-21% and the fiber dosage upto 0.5% show a comparable compressive strength.
- The tensile strength of specimens was enhanced due to the addition of PP fibers. The even distribution of fibers inside the concrete matrix increased the cracking resistance. The relative increases in split tensile strength of FC specimens are higher about 4-30% and maximum at a fiber dosage of 0.5%.
- The mixing of fiber led to an increased in the flexural strength. The percentage increased is 5%, 24%, 40% and 29% for FC/0.15, FC/0.25, FC/0.5 and FC/0.75 respectively. This shows that the presence of fiber in the concrete matrix bridge the micro cracks and prevents the crack propagation and thus improved the flexural strength. The loads versus displacement curve also show a ductile behavior for which it could sustain a higher displacement level and thus improved the toughness. Nevertheless at higher fiber contents the toughness value starts decreasing.
- Due to fibers' lower density the inclusion of PP fibers results a slightly lower UPV value of about 2-10%. Nevertheless, 0.75% PP fibers content was capable of producing concrete with UPV values that fall within the "good" quality grading.
- The results obtained from the present study gave experimental evidence on the feasibility of using PP fibers deriving from the waste cement bag as a discrete reinforcement. As such no study could be found on using these fibers in production of better concrete so far, hence more studies needs to be conducted.

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