Research Journal of Applied Sciences, Engineering and Technology 6(14): 2662-2667, 2013
DOI:10.19026/rjaset.6.3755
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: February 11, 2013 Accepted: March 11, 2013 Published: August 10, 2013

Research Article

Reinforcing Efficiency of Crimped Profile of Polypropylene Fibres on the Cementitious Matrix

V.M. Sounthararajan, S. Thirumurugan and A. Sivakumar
Structural Engineering Division, SMBS, VIT University, Vellore, Tamil Nadu, India

Abstract: Fibre reinforcement in concrete is an effective solution for improving tensile properties of concrete. Different types of fibres such as steel, polypropylene, glass and polyester were commonly used in concrete. In the present study, the effect of adding crimped polypropylene fibres on the improvement in the compressive properties of hardened concrete was studied. Crimped polypropylene fibres with different levels of reinforcements index was investigated systematically with designed concrete mixtures consisting of various fibres dosages of 0.1 to 0.5% by volume of concrete. The effect of crimped profile of polypropylene fibres on the improvement in failure properties of concrete in compression and flexural tension were evaluated. Test results showed that polypropylene fibres showed higher fracture energy absorption and exhibited a marginal improvement in strength index and sudden failure is prevented resulting in multiple splitting cracks. The ultrasonic pulse velocity test results were also found to be consistent and exhibited a good integrity for all CPFRC concrete specimens. A maximum compressive strength was noted at an optimum dosage of 3.0% of CPFRC specimens with a strength value of 24.67 and 34.92 MPa at 7 and 28 days respectively.

Keywords: Crimped polypropylene, fracture, superplasticizer, ultrasonic pulse velocity

INTRODUCTION

Fibre addition in concrete is one of the promising technology for improving the load resistance of concrete composite in tension and to make it homogeneous. Discrete and randomly distributed fibres in concrete have high reinforcing efficiency and improve the matrix strength of concrete. Both high modulus and low modulus fibres had been typically used in concrete over decades and drawn specific attention for improving the composite properties. Failure of plain concrete is sudden and catastrophic and the brittle failure is suspended with the fibre addition. Toughness and ductility of plain concrete are the two vital requirements for important structural applications of high importance. Steel fibres and polypropylene fibres have been widely used in this aspect for improving the composite ductility. However the low modulus fibres proven to exhibit high failure strain rate compared to high modulus fibres due to large failure strain at rupture. Fibre pullout is commonly observed in the case of high strength fibre; whereas fibre rupture occurs with large deformation after post elastic stage in polypropylene fibre concrete.

The raw material of polypropylene is derived from monomeric C_3H_6 which is purely hydrocarbon (Alhozaimy *et al*., 1996). Its mode of polymerization, its high molecular weight and the way it is processed into fibres combine to give polypropylene fibres very useful properties (Qiana and Stroeven, 2000). Chemical inertness makes the fibres resistant to most chemicals and the concrete constituents will have no effect on the fibre either. The hydrophobic surface not being wet by cement paste helps to prevent chopped fibres from balling effect during mixing like other fibres. The orientation of the fibres leaves the film weak in the lateral direction which facilitates fibrillations (Chunxiang and Piet, 2000). The fibrillated polypropylene fibres were been traditionally used to improve the composite performance and the fibre increases the pull out load. Further, the maximum load and stress transfer could also be achieved by twisting fibres. Initial cracks due to defects and stress cracking play an important role as they change concrete structures into permeable elements and consequently with a high risk of corrosion (Noumowe, 2005). Cracks not only reduce the quality of concrete and make it aesthetically unacceptable but also make structures out of service and affects its long term serviceability (Ali and Masoud, 2009). Therefore, it is important to reduce the crack width and this can be achieved by adding fibres in concrete. Thus addition of fibres in cement concrete matrix bridges these micro-cracks and restrains them from further opening (Mahmoud and

Corresponding Author: V.M. Sounthararajan, Structural Engineering Division, SMBS, VIT University, Vellore, Tamil Nadu, India

Afroughsabet, 2012). In order to achieve more deflection in the beam, additional forces and energies are required to pull out or fracture the fibres. This process, apart from preserving the integrity of concrete, improves the load-carrying capacity of structural member beyond cracking. This improvement creates a long post-peak descending portion in the load deflection curve (Lanzoni *et al*., 2012). Reinforcing steel bars in concrete have the same beneficial effect because they act as long continuous fibres. Short discontinuous fibres have the advantage, however, of being uniformly mixed and dispersed throughout the concrete (Tara *et al*., 2012). Polypropylene fibres reduce the plastic shrinkage crack area due to their flexibility and ability to conform to form. The addition of 0.1% by volume of fibres is found to be effective in reducing the extent of cracking by a factor of 5-10 (Kiachehr and Omid, 2013). The extent of crack reduction is proportional to the fibre content in the concrete. FRC mixes usually contain a high mortar volume as compared to conventional concrete mixes and the aspect ratio for the fibres are restricted between 100 and 200 since fibres which are too long tend to "ball" in the mix and create workability problems. Fibre added in concrete gets randomly distributed in the concrete; however, placing of concrete should be in such a manner that the fibres become aligned in the direction of applied stress which will result in even greater tensile and flexural strength (Huijun *et al*., 2013). Chemical admixtures are added to fibre-reinforced concrete mixes primarily to increase the workability of the mix. Air-entraining agents and water-reducing admixtures are usually added to mixes with a fine aggregate content of 50% or more superplasticizer, when added to fibre-reinforced concrete with lower water to cement ratios and improve the strength, volumetric stability and handling characteristics of the wet mix. The performance and influence of the polypropylene fibres in the fresh and hardened concrete is dependent on the efficiency of dispersion. It is known that fibre addition in concrete shows a marginal improvement on the compressive strength since failure is other than fracture in which case the effect of fibre is not realized during compression (Sivakumar and Manu, 2007a). However, the improvement in flexural tensile strength shows a good improvement with the increase in volume fraction of fibre. The failure behavior of high-strength concretes is controlled with the fibre addition and failure occurs gradually and results in high energy absorption. The reduction in shrinkage due to the presence of fibres is anticipated as the fibres do not exhibit any shrinkage, thus reducing overall shrinkage of the mix. In addition the fibres have a role in retaining the water in the concrete mix upto a certain limit which helps to delay the shrinkage (Sivakumar and Manu, 2007b). Therefore addition of fibres to the concrete mixes is always advantageous in reducing shrinkage deformation. The present study is restricted to study the reinforcing efficiency of polypropylene fibres in a brittle concrete and to evaluate the relative performance levels in compression and flexural tension.

Table 1: Properties of PP fibres used in the study

Material	Polypropylene
Appearance	Crimped white fibre
Relative density	0.91
Length	48 mm
l/d ratio	80
Thickness	0.6 mm
Width	1.1 mm
Tensile strength	450 MPa
Failure strain	15%

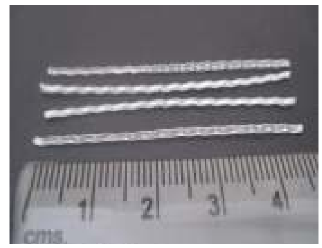

Fig. 1: Snap shot of crimped polypropylene fibres

EXPERIMENTAL INVESTIGATION

The details of materials used in the present experimental investigation are as follows.

Cement: Ordinary Portland cement of 53 grade having 28 days compressive strength of 48.7 MPa, satisfying the requirements of IS: 12269-1987. The specific gravity of cement was found to be 3.16.

Fine aggregates: River sand obtained from locally available source passing through 4.75 mm IS sieve, conforming to grading zone-II of IS: 383-1978 was used with fineness modulus of 2.57, a specific gravity of 2.71 and water absorption of 0.67% at 24 h.

Coarse aggregates: Machine crushed well graded angular blue granite stone with 12.5 mm maximum size, conforming to IS: 383-1978 was used. The specific gravity was found to be 2.75, fineness modulus of 7.2 and water absorption is 0.62 % at 24 h.

Chemical admixture: Polycarboxylate ether based super-plasticizer condensate as HRWR admixture was used and specific gravity of 1.18.

Polypropylene fibres: Crimped polypropylene fibres imported from Korea was used in the present study and the various properties of the material are given in Table 1 and the snap shot of the fibre is given in Fig. 1.

Conceptual concrete mixture proportions and casting of specimens: The concrete mixture proportions used in the study are provided in Table 2. A

Table 2: Various mix proportions

	Kg/m^3							
Mix Id	Cement	Fine aggregate	Coarse aggregate	SP dosage	PP fibre	Water	F/C ratio	w/c ratio
M1	470	659	1082	23	2.4	188	0.6	0.4
M2	470	659	1082	23	4.8	188	0.6	0.4
M3	470	659	1082	23	7.2	188	0.6	0.4
M4	470	659	1082	23	9.6	188	0.6	0.4
M5	470	659	1082	23	12.0	188	0.6	0.4
M6	470	659	1082	23	14.4	188	0.6	0.4

Fig. 2: Test set up for flexural strength of CPFRC specimens

Fig. 3: CPFRC specimens kept for curing

total of 6 different concrete mixtures were proportioned based on the water to cement ratio (w/c) 0.4 and fine to coarse aggregate ratio (F/C) 0.6. The concrete mixtures were mixed using a 30 L capacity of container with tilting drum type mixer and specimens were casted using steel mould, the standard cube 100 X 100 X 100 mm moulds and cylinders (100 mm diameter X 200 mm height) and size of beam mould 100 X 100 X 500. The experimental test set up for flexural strength is shown in Fig. 2. The fresh concrete mixtures in moulds were compacted using table vibrator and the sspecimens were demoulded after 24 h after casting and water cured at 27±3°C until the age of testing at 7 and 28 days as shown in Fig. 3.

EXPERIMENTAL TEST RESULTS AND DISCUSSION

Effect of polypropylene fibres on compressive strength: The increase in the percentage of polypropylene fibre addition showed a marginal improvement in the compressive strength compared to reference concrete (Table 3). The strength of various concrete mixes containing different dosage level of fibres for different curing days was plotted in Fig. 4 to 6. It can be concluded that addition of 0.3% V_f of PP

Table 3: Compressive strength for various percentages of fibres at different mixture proportions

		Compressive strength (N/mm^2)	
Mix Id	PP fibre (%)	7 days	28 days
M1	0	21.72	32.43
M2	0.1	22.21	32.67
M3	0.2	23.56	34.12
M4	0.3	24.67	34.98
M5	0.4	20.18	30.12
M6	0.5	18.46	27.15

Fig. 4: Splitting failure of CPFRC in compression

Fig. 5: Bulging failure mode of CPFRC specimens at peak load

Fig. 6: Multiple cracking mode of CPFRC specimens after post peak load

Table 4: Split tensile strength for various percentages of fibres for different mixture proportions

Mix Id	PP fibre (%)	Split tensile strength (N/mm^2) 7 days	28 days
M1	0	2.27	3.39
M2	0.1	2.30	3.42
M3	0.2	2.46	3.50
M4	0.3	2.58	3.65
M5	0.4	2.11	3.15
M6	0.5	1.93	2.84

Table 5: Flexural strength test results of concrete at different volume fractions

Mix Id	PP fibres volume fraction (%)	Flexural strength (N/mm^2) 7 days	28 days
M1	0	3.12	5.04
M2	0.1	3.90	5.83
M3	0.2	4.46	6.56
M4	0.3	4.83	7.92
M5	0.4	4.06	5.98
M6	0.5	2.95	4.34

Table 6: Ultrasonic pulse velocity for various mix proportions of concrete

Mix Id	Ultrasonic pulse velocity (m/sec) 1 day	3 days	7 days	28 days
M1	3400	3520	3870	4230
M2	3530	3690	4250	4600
M3	3670	3810	4460	4630
M4	3540	3610	4320	4570
M5	3620	3730	4080	4340
M6	3620	3680	3930	4130

fibres showed an increase in compressive strength upto 13.58 and 7.86% at 7 and 28 days and the compressive strength was found to be 24.67 and 34.98 MPa, respectively. With the further increase in PP fibre dosage the strength was found to be decreased compared to reference concrete due to defects arising internally as a result of loss in workability. This can be concluded that optimum fibre addition upto 0.3% V_f can result in good fibre dispersion as well as improving the fibre reinforcement index.

Effect of polypropylene fibres on split tensile strength: The tensile resistance of concrete was determined indirectly by split tensile strength test. The test results for various mixes (M1 to M6) on cylindrical specimens at the ages of 7 and 28 days in the compression testing machine is given in Table 4 and shown graphically in Fig. 7. The average split tensile strength achieved at 7 and 28 days for reference mix is 2.29 and 3.39 MPa and an addition of 0.3% of polypropylene fibres showed an improvement upto 11.15% (2.58 MPa) at 7 days and 7.76% (3.65 MPa). However, with the higher dosage of PP fibres i.e., for mixes M5 and M6 showed a slight reduction in the split tensile strength compared to reference concrete.

Effect of polypropylene fibres on flexural strength: The flexural strength results are provided in the Table 5 and shown graphically in Fig. 8. It was observed that a

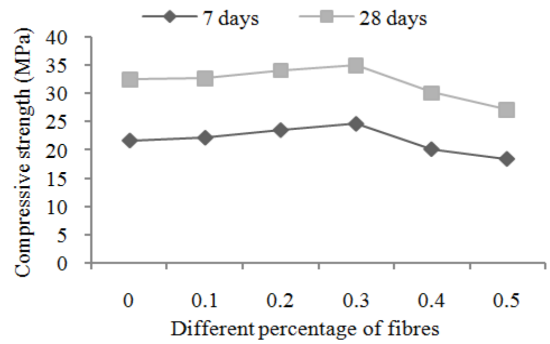

Fig. 7: Compressive strength for different CPFRC concretes

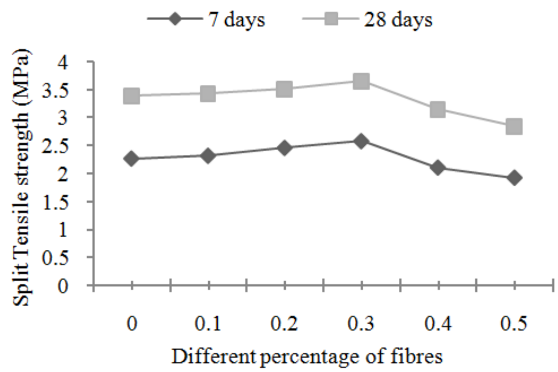

Fig. 8: Split tensile strength for various CPFRC concretes at 7 and 28 days

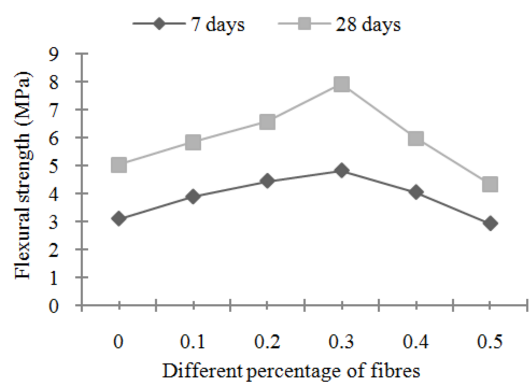

Fig. 9: Flexural strength for various CPFRC concretes at 7 and 28 days

maximum strength of 3.12 MPa at 7 days and 5.04 MPa at 28 days was seen for reference concrete; whereas with the fibre addition at 0.3 V_f the strength was around 4.83 MPa at 7 days and 7.92 MPa at 28 days. The test results on the flexural strength showed a similar trend that upto 0.3% of fibre volume the enhancement of flexural properties was noticed. Fibre addition beyond the optimum fibre volume of 0.3% V_f resulted in decreasing trend. This can be substantiated that addition of fibres beyond the required reinforcement index may reduce the contribution of interfacial bond strength

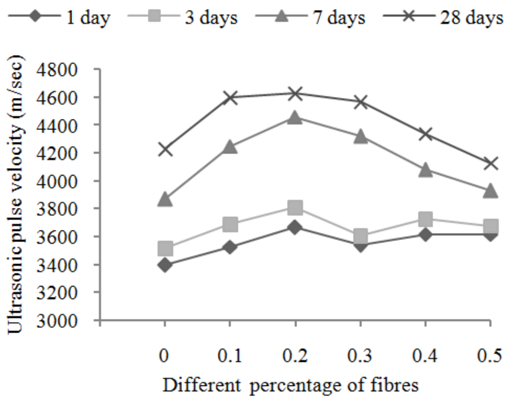

Fig. 10: Ultrasonic pulse velocity for various CPFRC concretes specimens

provided by matrix and can result in poor stress redistribution. A matrix reinforced with optimum fibres can envisage efficient stress transfer mechanism upon reaching maximum fibre stress and this result in composite energy absorbing capacity. Also, the failure strain of PP fibres (15%) had shown a good improvement in the post peak straining of concrete and results in high toughness. In this investigation, optimum percentage of fibre addition contributed for the strength enhancement of concrete which leads to the improvement on the hardened properties of concrete.

Ultrasonic pulse velocity: Test results on ultrasonic pulse velocity showed that there was a good increase in pulse velocity and satisfies the Indian standard [IS 13311]. The UPV values for different mix proportions for different curing days are presented in Table 6 and the values are plotted as shown in Fig. 9. The UPV values of CPFRC specimens were found to be in the range of 3400 to 4650 m/sec for different curing days of various concrete mixture proportions. These values indicated a good relationship between compressive strength and ultrasonic pulse velocity (Fig. 10). A good prediction of the strength based on the UPV values can be drawn from the relationship and can be ideal estimate for estimating the quality of concrete. The test results also provided a useful estimate for assessing the quality of concrete with the polypropylene fibre addition and for checking the integrity.

CONCLUSION

Based on the experimental investigation the following conclusions are drawn within the limitations of the test results:

- The performance characteristics of polypropylene fibres were dependent on the optimum fibre dosage upto 0.3% since fibre addition resulted in loss in workability.
- Unconditional failure of plain concrete specimens was restricted with volumetric bulging due to presence of PP fibres and gradual release of fracture energy was anticipated.
- The maximum increase in compressive strength was observed to be around 7.86% with the use of polypropylene fibres compared to the reference concrete.
- The maximum increase in split tensile strength was around 7.67% with the use of polypropylene fibres compared to the reference concrete.
- The maximum increase in flexural strength was found to be around 57.14% and the role of polypropylene fibres in delaying the crack formation were realized.
- The ultrasonic pulse velocity test results also confirmed that the quality and integrity of concrete was not affected with PP fibre addition.

REFERENCES

Alhozaimy, A.M., P. Soroushian and F. Mirza, 1996. Mechanical properties of polypropylene fibre reinforced concrete and the effects of pozzolanic materials. Cement Concrete Comp., 18: 85-92.

Ali, B. and G. Masoud, 2009. Comparison of compressive and splitting tensile strength of high-strength concrete with and without polypropylene fibres heated to high temperatures. Fire Safety J., 44: 1015-1022.

Chunxiang, Q. and S. Piet, 2000. Fracture properties of concrete reinforced with steel-polypropylene hybrid fibres. Cement Concrete Comp., 22: 343-351.

Huijun, W., Z. Jing and W. Zhongchang, 2013. Study on micro-structure and durability of fibre concrete. Res. J. Appl. Sci. Eng. Technol., 5(2): 659-664.

Kiachehr, B. and F. Omid, 2013. The effects of pozzolanic binders and polypropylene fibres on durability of SCC to magnesium sulfate attack. Constr. Build. Mater., 38: 64-71.

Lanzoni, L., A. Nobili and A.M. Tarantino, 2012. Performance evaluation of a polypropylene-based draw-wired fibre for concrete structures. Constr. Build. Mater., 28: 798-806.

Mahmoud, N. and V. Afroughsabet, 2012. The long-term compressive strength and durability properties of silica fume fibre-reinforced concrete. Mater. Sci. Eng., 531: 107-111.

Noumowe, A., 2005. Mechanical properties and microstructure of high strength concrete containing polypropylene fibres exposed to temperatures up to 200°C. Cement Concrete Res., 35: 2192-2198.

Tara, R., K. Behnam, S. Mohammad and S. Abdollah, 2012. Statistical and experimental analysis on the behavior of fibre reinforced concretes subjected to drop weight test. Constr. Build. Mater., 37: 360-369.

Qiana, C.X. and P. Stroeven, 2000. Development of hybrid polypropylene-steel fibre-reinforced concrete. Cement Concrete Res., 30: 63-69.

Sivakumar, A. and S. Manu, 2007a. Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibres. Cement Concrete Comp., 29(8): 603-608.

Sivakumar, A. and S. Manu, 2007b. A quantitative study on the plastic shrinkage cracking in high strength hybrid fibre reinforced concrete. Cement Concrete Comp., 29(7): 575-581.