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Incorporating recycled PET fibres for concrete Cylindrical Culverts

Rathnayaka R.M.M.P, Malshan W.V.D, De Silva Sudhira and De Silva Subashi

Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Galle, Sri Lanka
E-Mail: madushanpri@gmail.com, TP: +94779991335

Abstract: Fiber reinforced concrete is one of the prominent solutions for many problems that concrete had from its early stage. Polyethylene terephthalate (PET) fiber is a sustainable solution for fiber reinforced concrete since it makes fiber material an eco-friendly material. It's a well-known fact that steel reinforced concrete is vulnerable to corrosion. It is accelerated in the water conveying elements such as concrete pipes. So usage of PET fibers as a replacement material for steel reinforcement cage in reinforced concrete pipe element would definitely have a long life. At the initial stage concrete cubes were casted with different fiber compositions for water cement ratio of 0.3 and 0.45.From that it has observed that 2% of PET fiber would give the optimum result for concrete having 0.3 water cement ratio. Three sets of specimens (plain concrete, Reinforced concrete and PET fiber concrete) were subjected to three-edge-bearing test. It was identified that PET fiber reinforced concrete is the most applicable method for production of concrete pipes. Because manufacturing of the cage form of the conventional reinforcement bars adjusted for concrete pipes requires special bending, welding, and placement machinery, and also it is time-consuming. PET fibres of standard sizes, on the other hand, can be added to the pan-mixer of any concrete plant as if they were another aggregate or mineral admixture. Without any extra process modification, PET-fibre concrete can be produced and cast in the moulds similar to the ordinary plain concrete. Therefore it can be declared that PET-fibre concrete pipes seem to be an economical alternative to the classically-reinforced-concrete pipes.
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Keywords: Recycled PET, PET Fiber reinforced concrete, cylindrical culverts, three edge bearing test

1. Introduction

Fiber reinforced concrete has become a prominent solution for the drawbacks of ordinary concrete. Pavement laying, shotcrete tunnel linings, blast resistant concrete, overlays, and application to mine construction have proven the above statement (Ochi T, Okubo S & Fukui K, 2007).

Polyethylene terephthalate (PET) analysed in present study belongs to the polyester group. Due to rapid development in the technology the use of PET materials has been increased. Among that PET bottles used for beverage containers has become a major issue. This will eventually become an environmental pollutant (Kim et al, 2010).Use of recycled PET fiber in fiber reinforced concrete would provide a sustainable solution for the environment pollution.

One of the application of fiber reinforced concrete can be identified as the casting of cylindrical pipes. Casting of the pipes using reinforced cage with concrete is the current practise. There are many advantages of using steel fiber reinforced concrete over the ordinary steel reinforcement pipe. Manufacturing of the cage form of the conventional reinforcement bars adjusted for concrete pipes requires special bending, welding, and placement machinery, and it is time consuming. Steel fibres of standard sizes, on the other hand, can be added to the pan-mixer of any concrete plant as if they were another aggregate or mineral admixture. Without any extra process modification, steel-fibre concrete can be produced and cast in the moulds similar to the ordinary plain concrete. Therefore, steel-fibre concrete pipes seem to be an economical alternative to the classically-reinforced-concrete pipes. But there is a significant drawback in steel fiber reinforced concrete cylindrical pipes. These pipes are used to convey liquid such as water and waste water. Therefore in the process of conveying liquid through these pipes steel or fiber could be exposed to the moisture. As a result of that steel fiber will be corroded and durability of the pipe would reduce. To overcome that problem PET fiber reinforced concrete is used in this study. As the first stage of the study different mix proportions were checked in order to identify the best mix proportion for the application.

Fraternali (2011) conducted an experiment in order to determine the compressive strength of FRC and identified that it has an improvement in the compressive strength over the normal concrete. And also it has been identified that compressive strength was increased with the increment of PET fiber diameter. Short PET fibers give more compressive strength than the long PET fibers. Despite of Fraternalis findings, Kim (2010) observed that there was a reduction of compressive strength by 1~10% as the volumetric fiber percentage increase form 0% to 1% with 0.25 increments. Marthong (2015) also identified that there is a reduction of compressive strength as the volumetric fiber percentage increases beyond 0.5%. Additionally, it was declared that compressive strength also varies with the geometry and the dimensions of fibers. Ochi (2006) conducted uniaxial compression test and identified that compressive strength of PET FRC was increased with the fiber content and this was valid up to 1% of fiber. While compressive strength was decreased with the increment of fiber content. Similar to the Ochi's findings Sandaruwani (2012) identified that compressive strength of PET FRC is increasing with the fiber content and this is valid up to 1% of fiber then the compressive strength is decreasing with the increment of fiber content.

According to the Marthong's (2015) findings, it was found that that the inclusion of PET fiber above 1.0% decreases the tensile strength. The inclusion of PET fiber improved the tensile property and showed the ability in absorbing energy in the post-cracking state due to the bridging action imparted by the fibers during cracking. But Sandaruwani (2012) identified that fiber content can be increased up to 2% with an improvement in the tensile strength. After that the tensile strength will reduce as the fiber content increase beyond 2%.

Haktanir (2007) conducted a research to identify the performance of fiber reinforced concrete as a material for concrete pipes. Steel fibers were used at dosages of 25kg/m^3 and 40 kg/m^3. In this study, three concrete pipes were casted using plain concrete, reinforced concrete and fiber reinforced concrete. The common type of Dramix RC80/60-BN steel fibres were used for one set of samples. Smaller type of steel fibres, ZP-308 was also used for another set of samples. The total length and cross-sectional diameter of RC80/60-BN and ZP-308 are 60 mm and 0.75 mm, and 30 mm and 0.75 mm, respectively.

Concrete pipes of 500mm inner diameter were casted. Concrete were poured in to steel mould which rests on a strongly vibrating platform. Three cylindrical samples of 150x300 mm were used to determine the compressive strength of the concrete.

Plain concrete pipes were casted using grade 35 concrete. Wall thickness of the pipe was 65 mm.For the reinforced concrete pipes, 7 mm reinforcement bars were used at 75 mm intervals.

Table 01: Test results (Haktanir (2007))

Pipe	Average ultimate load(KN)	Crack length (mm)	Crack width (mm)
Plain concrete	64.5	550	1.5
Reinforced concrete	110.6	217	0.22
ZP-308 25kg/m3	105.3	117	0.1
ZP-308 40kg/m3	112.3	93	0.03
RC80/60-BN 25kg/m3	117.4	85	0.02
RC80/60-BN 40kg/m3	120.8	53	0.02

Three edge bearing test was perfumed to each cylinder and results are shown in the Table 01.It can be identify that there is an improvement in fiber reinforced concrete over plain concrete and steel reinforced concrete.

The objectives of this present study were : to investigate the appropriate mix proportions and resultant variations in strength characteristics of fiber reinforced concrete made with re-cycled PET fibers and to investigate the mechanical and durability characteristics of fiber reinforced concrete made with shorter-cycled PET fibres and study its practical application in construction industry.

2. Methodology

2.1 Specimens for mix proportion identification

Re-cycled PET fibers obtained from Beira Group, Horana, Sri Lanka was introduced in to the concrete mix. PET fibber was added on the volume basis, and it would not replace any material in the concrete. Each PET fiber addition was done for two water cement ratios of 0.3 and 0.45 samples preparation as shown in Table 2. Fibers were added in 0%, 1%, 2%, and 3% of total volume to check the performance of the concrete mix.

Table 02: PET sample preparation

Sample	PET fiber diameter (mm)	PET fiber length (mm)	Water cement ratio	PET fiber percentage (%)
C0				0
C1	0.7	50±0.5	0.3	1
C2				2
C3				3
D1				0
D2	0.7	50±0.5	0.45	1
D3				2
D4				3

2.1.1 Experimental procedure

Compressive strength of concrete was tested using 150x150x150 mm. Cubes were casted according to BS 1881 -108 (1988) and cured until the test day as described in BS1881-111(1988). Concrete is mixed based on the mix design in accordance with BS 5328. In order to achieve a workable mix admixture Rheobuild 1000 is added to the concrete mix as a high-range water-reducing admixture

Slump was evaluated for each set of specimen on the day of mixing before casting the cubes (BS 1881 102). These test specimens were crushed on 3rd. 7th 14th 21st and 28th day form they are casted as shown in Figure 2.1. Compressive strength was measured in accordance with BS 1881 115(1988) and BS 1881 116(1988)

(a) (b)

Figure 2.1: Testing of specimens; (a) Compressive strength test, (b) Split tensile strength test.

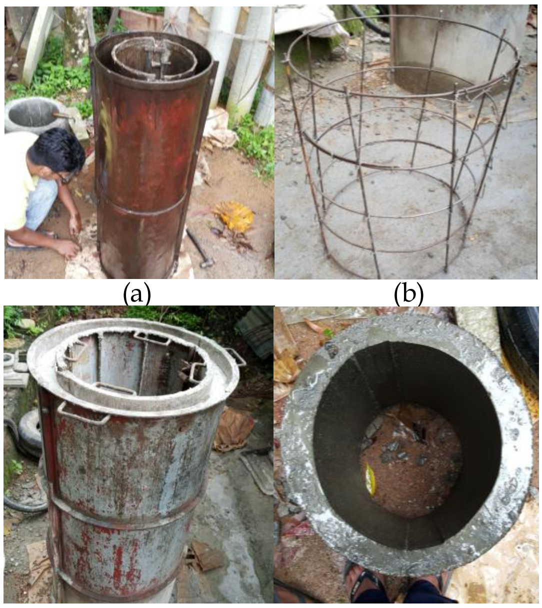
Cylindrical specimens of 150x300 mm were casted to test tensile strength of concrete. Tensile strength was evaluated by split tensile test as shown in the Figure 2.1 (a).

2.2 Cylindrical specimen casting

Using the results of the above study it was identified that for water cement ratio of 0.3 and 2% of PET fiber would give the optimum results for both compressive strength, slump and tensile strength.

Table 03: Composition of cylindrical culvert

Specimen	Steel reinforcement	PET fibers (Total volume)
Plain concrete	non	non
Reinforced concrete	6mm mild steel at 120mm c/c spacing	non
Fiber reinforced concrete	non	2% PET



(a) (b) (c) (d)

Figure 2.2: Casting procedure of cylindrical culverts; (a) Assembling of the mould. (b) Steel reinforcement cage, (c) Concreting, (d) Curing

Testing of Cylindrical culverts was performed in accordance with concrete pipe and portal culvert handbook. According to the standard specified in the manual, three edge bearing test was performed as shown in the Figure 2.3. Then the proof load was obtained and then ultimate load that the pipe can sustain was calculated. According to the handbook proof load is the line load that a pipe can sustain without the development of cracks of width exceeding 0.25 mm or more over a distance exceeding 300 mm in a two or three edge beading test. Then the ultimate load obtained by multiplying the proof load by 1.5.

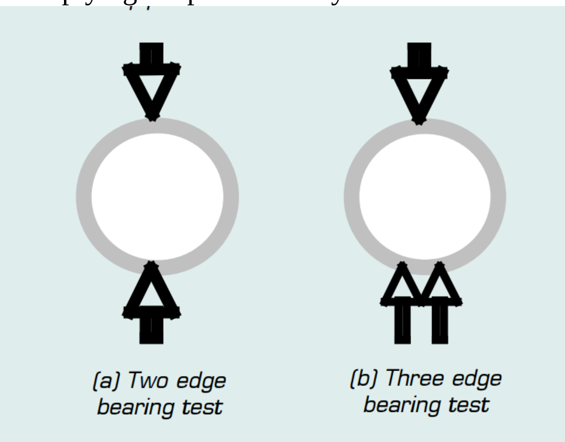


Figure 2.3: Two edge and three edge bearing tests

4. Results and Discussion

4.1 Variation of compressive strength with PET fiber content

For water cement ratio of 0.45 there is a significant reduction in the compressive strength compared to the control specimen as shown in the Table 4.1. Variation of 28 days compressive strength with the fiber percentage is shown in the Figure 4.1(a).

Table 4.1: Reduction of compressive strength with PET fiber percentage for w/c ratio of 0.45

PET fiber percentage (%)	Compressive strength reduction (%)
1	42.35
2	42.14
3	37.61

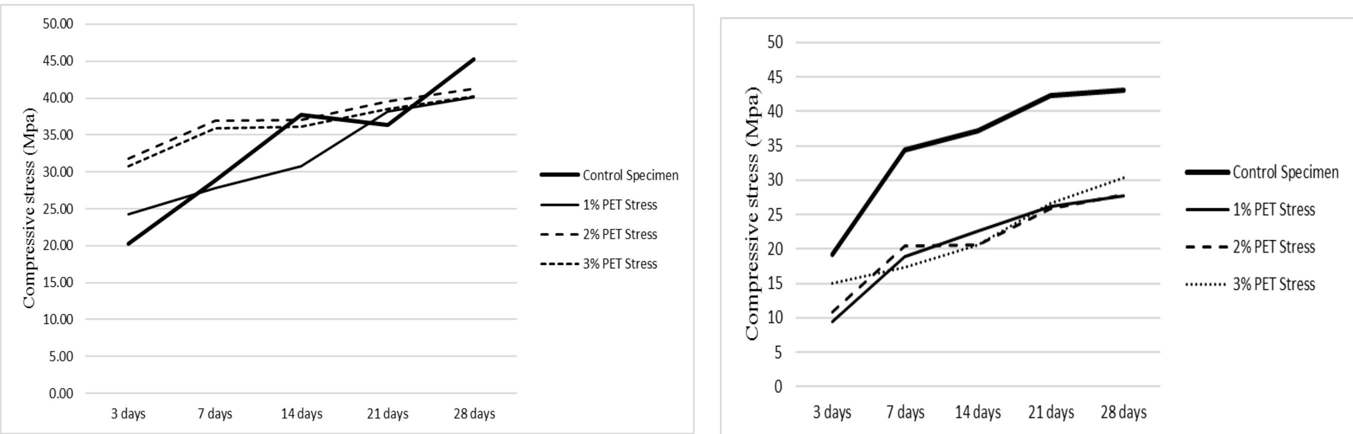
But for a water comet ratio of 0.3 the variation of compressive strength with the PET fiber percentage is less significant compared to the water cement ratio of 0.45. The variation of strength is shown in the Table 4.2. Variation of 28 days compressive strength with the PET fiber content is shown in the Figure 4.1(b).

Table 4.2: Reduction of compressive strength with fiber percentage for 0.3 W/C ratio

PET fiber percentage (%)	Compressive Strength reduction (%)
1	11.29
2	8.92
3	11.12

4.2 Variation of tensile strength with PET fiber content

Even though there is a reduction in the compressive strength, it can be observed that there is an improvement in the tensile strength of PET fiber concrete for both water cement ratios of 0.3 and 0.45. In the Figure 4.2 it indicates how the improvement of tensile strength compared to the control specimen.



(a)

(b)

Figure 4.1 Variation of compressive strength; (a) Water cement ratio 0.45, (b) Water cement ratio 0.3

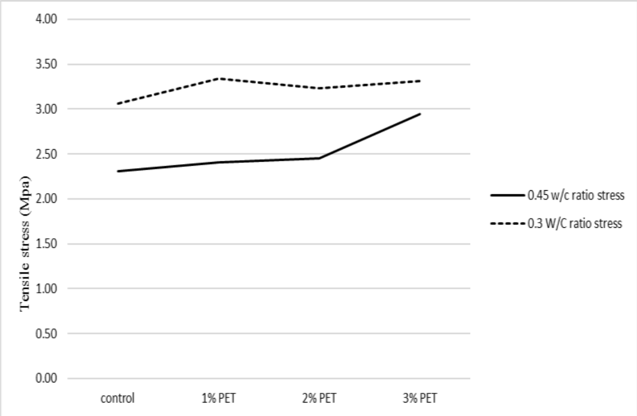


Figure 4.2: Variation of tensile strength for water cement ratio of 0.3 and 0.45 of 0.45 and 0.3
Variation of tensile strength

4.3 Variation of slump of concrete with PET fiber content

Slump value of the concrete with a water cement ratio of 0.45 is higher than the concrete with water cement ratio 0.3. As the fiber is added to the concrete, slump value of the concrete starts to reduce. The variation of the slump values with the PET fiber content is shown in the Figure 4.3.

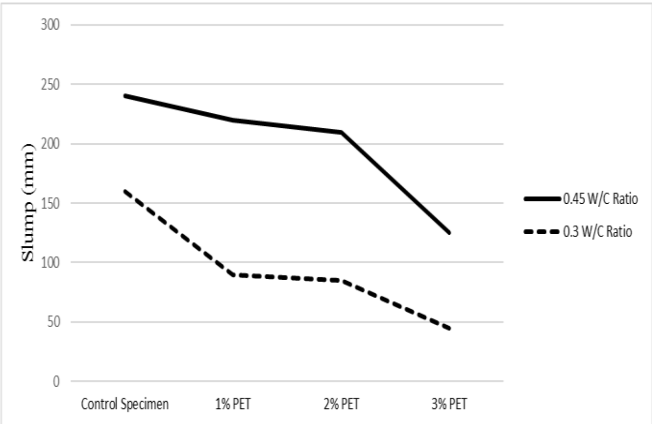
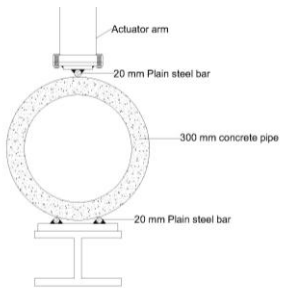


Figure 4.3: Variation of slump for water cement ratio of 0.45 and 0.3

4.3 Bearing load test results for concrete culverts



Reinforced concrete cylinder shows an improvement in ultimate load over the plain concrete. But it was identified PET fiber concrete performs well in bearing test comparing to the steel reinforced concrete and plain concrete. Also a significant reduction in the crack length and width was observed in the PET fiber reinforced cylinder.

Table 4.4 Test results of cylindrical specimens

	Plain concrete	Reinforced concrete	Fiber reinforced concrete
Ultimate load (kN/m)	15.1	32.00	30.04
Crest displacement(mm)	1.54	5.74	3.72
Lateral displacement(mm)	1.44	2.19	1.76
Crack width (W) (mm)	0.25<W	0.12<W<0.15	W<0.05

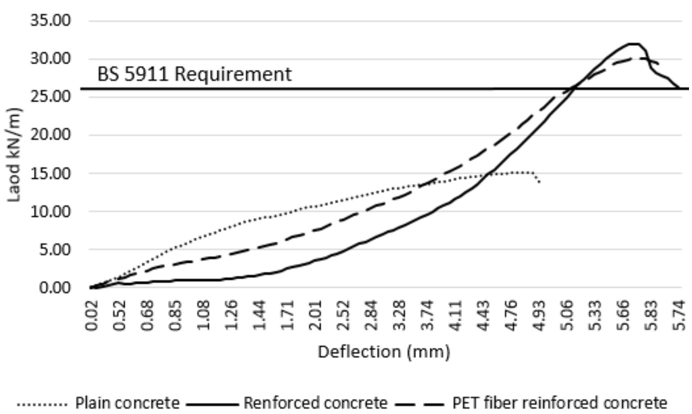


Figure 4.4: Three edge bearing test

Figure 4.4 Comparison of test results with BS 5911 part 100 standards

5. Conclusions

For water cement ratio of 0.3 and 0.45, the workability of fresh concrete decreases with the addition of PET fiber. However, geometry of PET fibers has a small effect on the workability of concrete. But in the case of 3% of PET with water cement ratio of 0.3 achieved a less workable mix.

Significant reduction of compressive strength in PET fiber reinforced concrete was observed for water cement ratio of 0.45. But in the case of 0.3 water cement ratio there is a slight reduction in 28 day compressive strength, but increases in the tensile strength clearly observed. The inclusion of PET fiber improved the tensile property and showed the ability in absorbing energy in the post-cracking state due to the bridging action imparted by the fibers during cracking. Therefore, use of PET fiber concrete in the production of cylindrical culvert is one of the good applications. Further studies will continue to check whether quality of these applications and other mechanical properties in re-cycled PET fibers.

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