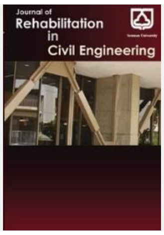

Journal of Rehabilitation in Civil Engineering

Journal homepage: https://civiljournal.semnan.ac.ir/

Flexural Behavior of Non-Biodegradable Plastic PET Bottles as a Part of Reinforcement in Beams

Raj Mohan Packieya Eswari [1,*]; Kumar Sherjin [2]; Kumar Thiruvasagam [2]; Sivakumar Nandha Kumar [2]

1. Assistant Professor, Department of Civil Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu, India
2. UG Student, Department of Civil Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu, India
Corresponding author: *packieyaeswarir@mepcoeng.ac.in*

ARTICLE INFO

Article history:
Received: 07 October 2024
Revised: 25 November 2024
Accepted: 15 January 2025

Keywords:
Polyethylene terephthalate;
Plastic strip;
Flexural strength test;
Beams;
Conventional concrete.

ABSTRACT

Bottles made with polyethylene terephthalate (PET) will never biodegrade. These are banned due to their adverse effect on the environment. The prohibition of plastic extends to items like plastic cups, plates, and packaging, in addition to plastic bags. At this juncture, Recycling or reusing plastic waste is crucial to protect the environment. Hence, it is decided to reuse the PET bottles in this research work. In this research, it is decided to reuse the PET bottles by cutting them into 20 mm wide strips and wrapping them around the steel bar in such a way that both behave monolithically as a part of the reinforcement in the reinforced concrete element. It is proposed to do an experimental investigation by conducting a flexural test on the beams. Cast using a single plastic strip wrapped partially around the 8 mm diameter steel bar located in the tension zone and also using a double wrap partially around the 8 mm diameter steel bar located in the tension zone. The findings are to be compared with the conventional concrete beam and the PET-wrapped beam has gone under nearly 18% higher deflection than the conventional beam. And, also the double-strip wrapped beam undergoes deflection of up to 5% higher than the single-wrapped beam under the same load.

E-ISSN: 2345-4423

How to cite this article:
Packieya Eswari, R. M., Sherjin, K., Thiruvasagam, K. and Nandha Kumar, S. (2026). Flexural Behavior of Non-Biodegradable Plastic PET Bottles as a Part of Reinforcement in Beams. Journal of Rehabilitation in Civil Engineering, 14(1), 2181 https://doi.org/10.22075/jrce.2025.35530.2181

1. Introduction

One million plastic bottles (PET) are purchased worldwide every minute of the day. An individual uses 156 plastic bottles annually on average. Even worse, each year the world's oceans receive 8 million tons of plastic waste, and 90% of plastic bottles are never recycled before ending up in landfills across the globe.[1] All around the world, 300 million tons of plastic trash are created annually. Plastic bottles, if not properly discarded in landfills, can pollute our oceans, damage the ecosystem, and cause harm or death to marine creatures. By the year 2050, environmental scientists foresee a scenario where the amount of plastic in the oceans surpasses the number of fish.

Reinforcement is typically required for any structural element designed to bear a heavy load, especially slabs, footings, columns, and foundations. Without reinforcement, these parts could eventually suffer from structural compromise or complete failure. Although steel reinforcing increases the strength of concrete, exposure to moisture and other external elements can cause corrosion. Protective techniques are used during construction to reduce this risk, such as epoxy coating and the use of steel rebar that is resistant to corrosion [2].

There is a plethora of options available for concrete reinforcing [3]. Now-a-days, FRP bars are used to enhance the ductile nature of the concrete specimen [4][5]. The thermal coefficients of steel and concrete are comparable, despite the fact that steel has some qualities that make it a better option than other materials [6][7]. Additionally, since it won't float over the concrete, no special tie-up is required while placing the concrete. It is a superior option to other materials since it is easier to fabricate, recyclable, and bends more easily on site without negatively affecting the section [8].

The author discussed utilizing recycled PET fiber in four different types of specimens of concrete beams. steel rods without steel rod reinforcement, reinforcement with PET material, and a combination of PET and steel reinforcement [9]. The first kind of concrete beams is manufactured without any reinforcement; the second type is made with PET hollow bars that have an external diameter of 24 mm and an interior diameter of 22.8 mm; the third and fourth types are made with a combination of steel and PET in the tension zone for reinforcement. The author discovered that the flexural strength of every type increased [10]. Experimental Investigation of Using PET Wastes as Tension Bars in Reinforced Concrete Beams [11]. The author focuses on exploring the feasibility of reusing PET waste by shaping it into plastic semi-bars for use as tension bars in simply supported reinforced concrete beams [12]. The test findings indicated that most of the plastic semi-bars did not pass, except for one instance where a deformed steel bar and a divided PET bottle layer were utilized. This resulted in a 3.03% increase in ultimate failure load and the deflection of the beam samples increased by 213.83% compared to the reference samples. The reason for the decrease in the ultimate load of beams with PET semi-bars is the lack of proper bonding between the PET bars along the adjacent concrete, resulting in the PET bars becoming empty spaces or areas of low strength within the beam's profile [13].

The behavior of concrete beams reinforced with bars made from recycled PET bottle waste is analyzed, with PET bars placed in the tension zone as a substitute for traditional steel reinforcement [14]. In addition, the material is pre-loaded before casting using a specialized tool to ensure a smooth texture and minimize elongation. The outcomes are remarkable and unparalleled, with models featuring rods reaching a failure load of up to 25% compared to those with steel bars.

The author studied the “Strength behavior of reinforced concrete beams using recycled PET waste as synthetic fibers” and aims to assess the mechanical characteristics of reinforced concrete incorporating polyethylene terephthalate waste fibers [13]. Five combinations of NC (Normal Concrete) with a water-to-cement ratio of 0.41 were tested to analyze the impact of waste on the behavior of reinforced concrete beams. The study of reinforced concrete beams involved analyzing load-deflection behavior, examining cracks, calculating ductility indices, and assessing stiffness. Experiments on reinforced concrete beams indicated a slight reduction in the ultimate failure load and secant stiffness of the specimens. However, there was a significant enhancement in the ductility performance of all beams, particularly the hybrid beam, along with an increase in the initial stiffness [15][16].

The author analyzed the possibility of using waste PET Plastic Strips to enhance the flexural capacity of concrete beams and the findings indicated that adding plastic strips can enhance the load capacity and resistance of concrete beams more than those without reinforcement [17]. Structural behavior of reinforced concrete beams containing recycled polyethylene terephthalate and sugarcane bagasse ash [18]. The results indicate that beams manufactured with 5% SCBA (Sugarcane Bagasse Ash) and 10% RPET (Recycled Polyethylene Terephthalate) have a flexural capacity that is 11% lower than that of conventional beams [19]. Nevertheless, the SCBA-RPET beams showed a shear capacity that exceeded that of the conventional beams by 17.38%. The crack patterns in the SCBA-RPET (Sugarcane bagasse ash added Recycled Polyethylene Terephthalate) beams and conventional beams are alike and can be compared in both shear and flexural strength tests. The behavior of concrete beams reinforced with PET bottles presents a study on structural performance and waste bars Polyethylene terephthalate (PET) bottle waste bars are used as reinforcement in concrete beams, placed in the same position as steel bars in the tension zone [15][17]. In addition, the material is pre-loaded before casting using a specialized tool to ensure a smooth texture and minimize elongation [3],[20]. The outcomes are remarkable and unparalleled, with models featuring rods reaching a failure load of up to 25% compared to those with steel bars.

So this experimental work is being conducted to explore the potential of incorporating waste plastic strips into the primary reinforcement steel bars to enhance the corrosion resistance and enhance the flexural strength of concrete beams. The primary goal of this study is to effectively utilize the waste PET bottle strip as a part of reinforcement and to analyze it’s flexural behavior.

2. Materials

The investigation involves using 53-grade Portland Pozzolana cement found in the nearby market. Testing of the cement was conducted at various ratios as per IS: 4031 – 1988 and it was discovered to fulfill the different criteria of IS: 12269 – 1987. Specific gravity was measured as 3.20 and fineness was recorded at 3200 cm^2/gm. Crushed angular granite was used as the coarse aggregate from a nearby area. The density was 2.71, the thinness percentage was 4.58, and the elongation ratio was 3.96 Crushed angular granite from a nearby area was used as the coarse aggregate. The density was 2.71, the thinness percentage was 4.58, and the elongation ratio was 3.96.

2.1. PET Plastic Strip

Plastic strips were 20 mm wide, 0.8 mm thick, and transparent in color. The elongation of them ranged between 10–15%, with variation in strength when the applied force is exerted of 40–50 kg/mm^2. The tensile strength capacity of the PET strip was analyzed in the Tensile testing machine as shown in Figure 1. The tensile strength of the 20 mm strip was found to be 80 MPa and the maximum elongation of the strip was found to be 13.5 %.

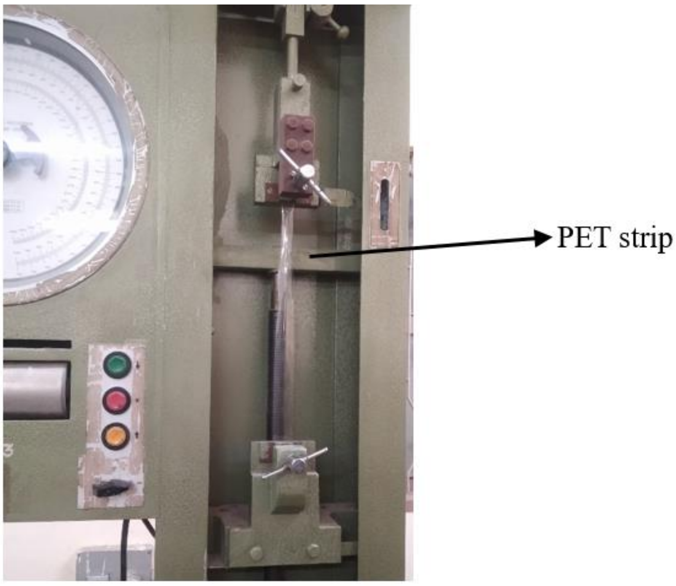

Fig. 1 Tensile strength test setup for PET strip.

3. Experimental Investigation

To conduct a successful investigation, it is necessary to carry out several tests and analyze the trend of the results before drawing any conclusions. To have reliable results from the tests, proper experimental set-up and testing procedures are required. The equipment used for testing should have the right range, and care should be exercised in selecting load conditions, rate of loading, etc., which will have an enormous impact on the durability of the concrete to be tested. Table 1 shows the details of the test specimens to be studied for this research. Figure 2 displays the specific design of the specimen.

Table 1. Details of the test specimen.

S.No	Designation of specimens	Specimens Details	Dimension of the beam specimens(mm)
1	CC	Conventional concrete Beam	100 X 200 X 1200
2	PSC	PET Strip Singly wrapped Concrete Beam	100 X 200 X 1200
3	PDC	PET Strip Doubly wrapped Concrete Beam	100 X 200 X 1200

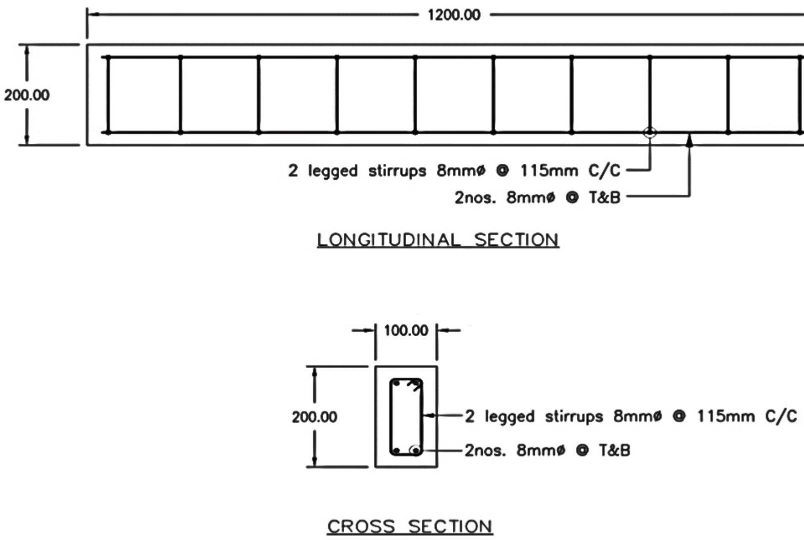

Fig. 2 Detailing of the Beam.

4. Preparation Of Test Specimens

4.1. Wrapping of PET bottle strips around the reinforcement

The plastic PET bottles were cut into strips, and the strips were wrapped around the tension reinforcement at the bottom of the beam as shown in Figure 3. The surface of the rod was cleaned and coated with primer, and then the stripes of the plastic PET bottles were wrapped around it and tied firmly. The strips were partially wrapped around the steel rebar to prevent the extent of corrosion by avoiding the direct contact with the moisture. Even it will not affect the bonding between the concrete, since the longitudinal rebars are tightly wound with the stirrups and thus the stirrups will take of the bonding between the concrete. Plastic stirrups rely heavily on mechanical interlock and friction because their surface does not naturally bond with concrete as effectively as steel. Surface modification techniques, such as roughening or applying special coatings, can enhance this bond [17],[21],[22],[23]. Additionally, in some cases, hybrid reinforcement (plastic and steel) may be used to combine the benefits of both materials for optimal performance. However, the wide spread of plastics in our lives, necessitates the recycling and reuse of these materials in research studies and civil engineering applications. So, in this research work, in order to maintain the integrity of bonding between plastic strip and the concrete, binding wires were used to tie the rod and the plastic strip at a regular interval of 4 – 5 cm along the length of the longitudinal reinforcement and this serves as a formation of roughening surface on the plastic strip and helps to attain the bonding with concrete.

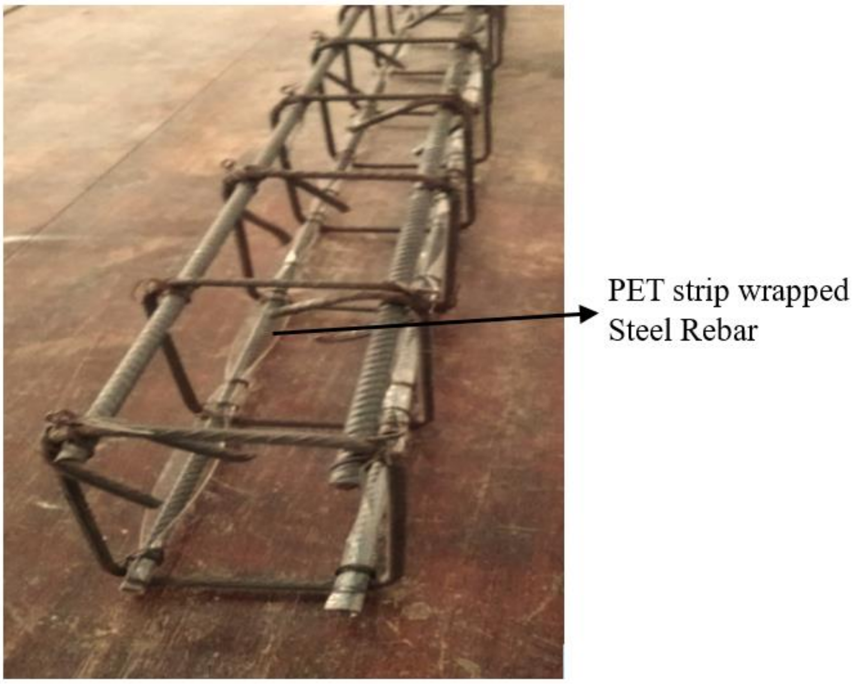

Fig. 3 Wrapping PET Strip on the Reinforcement.

4.2. Casting and curing

The materials were mixed in dry conditions over a non-porous, smooth surface. Then the required water content was added, and the concrete was thoroughly mixed by manual means. The inner surface of the mold was greased, and the mixed wet concrete was placed in three layers with enough compactions. The concrete samples were taken out of the molds 24 hours after being cast and were then placed in water for 28 days for curing. The curing condition requirements for beams wrapped with PET plastic strips from ordinary concrete. The cement phase achieves optimal strength when exposed to wet conditions like water immersion and high humidity, while the fiber phase develops strength best in dry conditions.

4.3. Surface preparation

The concrete needs to be completely finished curing, without any chemical substances for treating illnesses, oils or mold release agents, and must be entirely dried and devoid of any dust when applied. The concrete beam must be repaired using cement mortar—surface imperfections on concrete need to be repaired. Adjacent concrete surface levels must not vary by more than 1 mm. Concrete surface protrusions consist of small projections, grouting lines, and other similar features. It must be ground flattened. Gaps in the concrete surface, like the concrete joint, need to be filled. Curved edges should have a minimum radius of 10 mm. A greater radius leads to improved preparation. The internal sharp angle needs to be smoothed out.

4.4. Flexural test setup

Measuring the strength of concrete under tension directly presents challenges. A beam test was done to measure the concrete's flexural strength as depicted in figure 4. The modulus of rupture is determined by the size of the beam and the way it is being loaded [24]–[26]. Four-point flexural tests were performed to assess the structural element's ability to withstand flexural loads. Figure 5 depicts the arrangement of the load for the traditional four-point bending test.

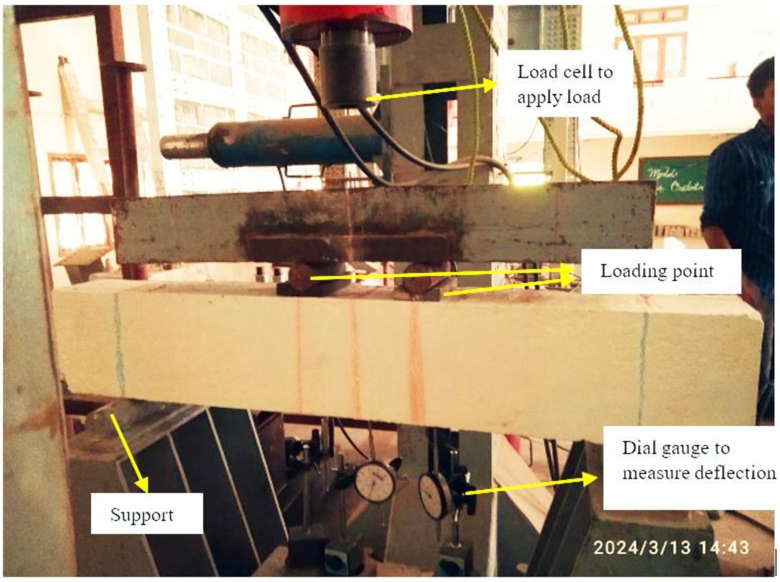

Fig. 4 Preparation and Positioning of Specimens.

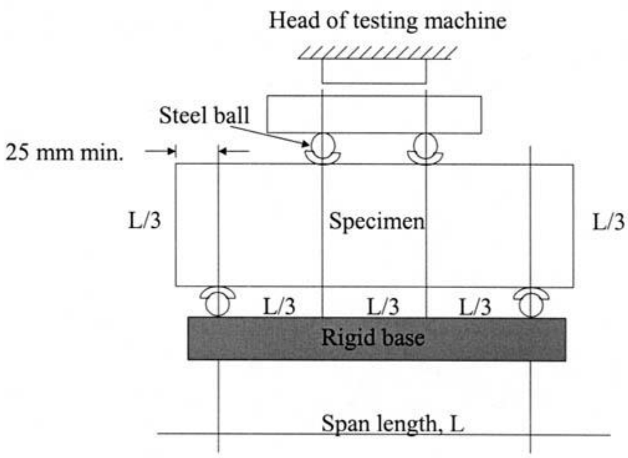

Fig. 5 Flexural test setup.

Test specimens, which had been submerged in water, were removed and immediately tested while they were still wet. The supporting and loading rollers' bearing surfaces were cleaned. The samples were cured for 28 days and then tested in the Flexural testing machine to measure their flexibility. Afterward, the specimens were positioned in the device in a way that the force was exerted on the top layer. The alignment of the specimen's axis with the loading device's axis in a meticulous manner. The load was applied and the bending in the center of the Beam was noted. The initial crack was noted on the specimens. This was continued till the failure of the beam and the maximum load on the specimen was noted. This procedure was carried out for specimens B1(CC), B2(PSC) and specimens B3(PDC). The flexural strength of specimens B2 and B3 is compared with that of the flexural strength of B1.

5. Results And Discussions

The primary objective of this investigation was to find out the suitability of PET Strips wrapped rebar in reinforced concrete beams under bending. The flexural test was performed on six numbers of casted beam specimens and their results are discussed below.

5.1. Effect of wrapping in the initial cracking of the beam

The pattern of cracks in the beam specimens that were tested is displayed in Figure 6. The first crack of the conventional beam initiates under the load of 25 kN, whereas the initial cracking load of PET strips wrapped rebar goes a little higher than the conventional beam. The initial cracking load of single and double-strip-wrapped beams is 30 kN and 35 kN respectively. The increase in the initial cracking load is mainly due to the yielding of PET strips when combined with the steel rebar. This increase mainly contributes towards a safer environment which leads to a reduction in life loss due to unforeseen incidents. Thus, the usage of environmental waste also helps in providing a safer environment and also leads to sustainability. This research work provides an idea of utilizing the waste plastics, especially thrown-away bottles, successively in the concrete and such an idea also helps in the reduction of environmental pollution and thus saves our environment.

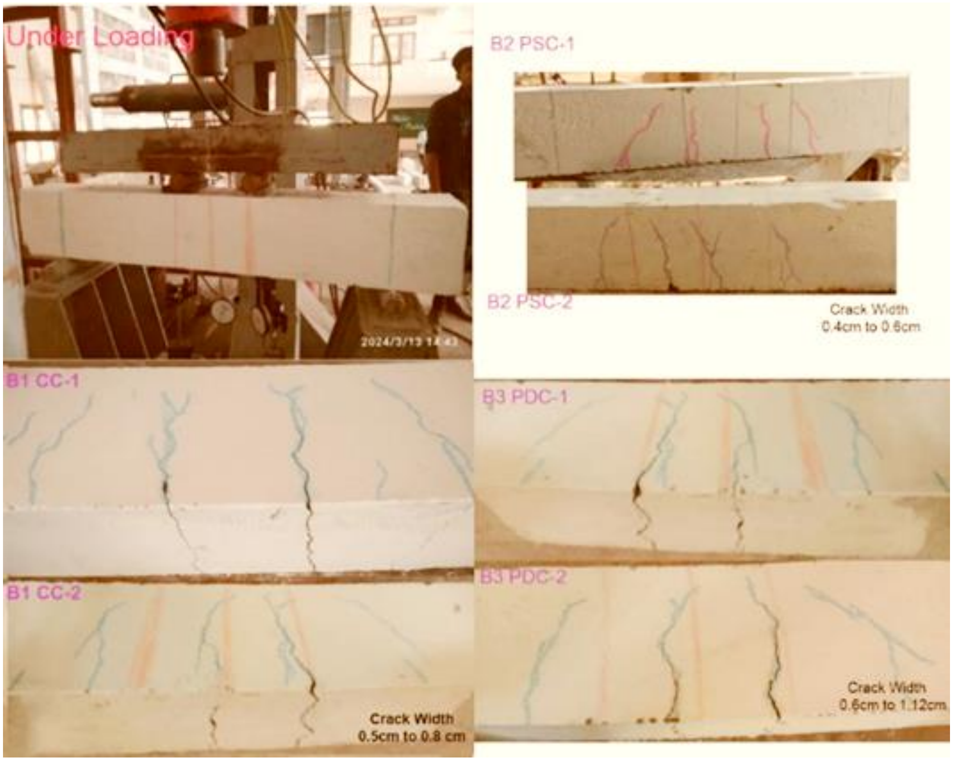

Fig. 6 Crack pattern of the test specimens.

The singly reinforced beam projects a smaller crack width of around 33% lesser than the conventional rebar beam, and this is widely due to the elongation behavior of PET strips along with the steel reinforcement. Whereas the doubly reinforced beam possesses a larger value of crack width due to the slippage that occurs between the PET strips i.e., the loss of friction between the two strips.

5.2. Effect of wrapping in the ultimate load capacity of the beam

The ultimate load capacity of the beam is defined as the highest amount of load that can be supported before it fails or breaks [13], [17], [27]. From Figure 7, it is inferred that the ultimate load decreased when the reinforcement was doubly wrapped around with the PET strips. The reason behind this is due to the presence of an antifriction element like plastic, hinders the beam's capacity to carry loads, since the plastic fails first due to yielding and this behaviour hinders the steel rebar from taking up the additional load. As the failure load of the doubly wrapped beam is lesser than the conventional beam, the wrapped beam will undergo more deflection for the same load compared to the conventional beam. The maximum load-carrying capacity of the singly wrapped beam is around 2 – 4% higher than the conventional beam and hence it shows a wider influence in the deflection of the beam. At the same time, the singly wrapped beam undergoes a maximum strain than the conventional beam and hence shows strain hardening behaviour. So, the singly wrapped rebar can be effectively utilized as a part of reinforcement in the beam, since it has a very low deflection with a maximum ultimate load [28],[29].

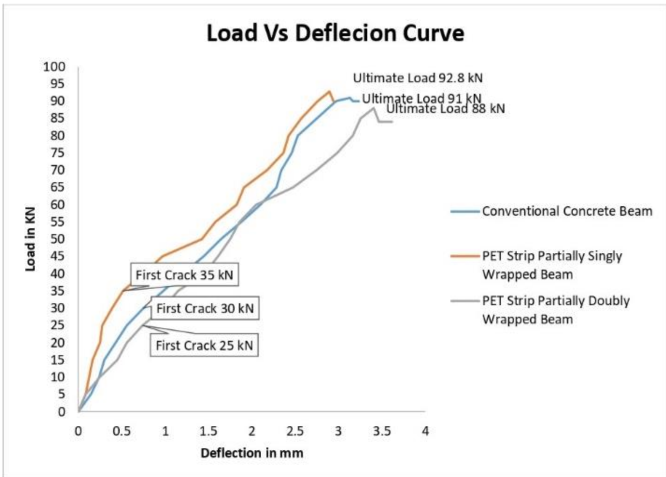

Fig. 7 Load vs Deflection relation for all beams.

Table 2 Comparative Results.

Details of specimen (Beam)	Maximum Bending Stress (N/mm^2)	Flexural Rigidity ($N\ mm^2$)	Modulus of Rupture (N)
CC Beam	40.95	7.52×10^{11}	16.58×10^{6}
PSC Beam	41.75	8.30×10^{11}	16.91×10^{6}
PDC Beam	39.59	6.69×10^{11}	16.03×10^{6}

5.3. Effect of wrapping in the beam characteristics

The modulus of rupture for the doubly wrapped rebar shows a slighter decrease than the conventional and singly wrapped beam and was tabulated in Table 2. The reason why the PDC beam failed is due to the air gaps between the two neighboring layers being able to smoothly slide over each other when they bend, as they have a slippery surface [30]–[32]. Due to less friction between the adjacent layers of PET strips, the bond gets broken and this yields a lower bending stress and modulus of rupture. The singly wrapped beam has a flexural rigidity of 10% higher than the conventional beam, and the enhancement in the flexural rigidity is widely due to the maximum deflection that can be withstood by the singly wrapped beam. The maximum bending stress result infers that the singly reinforced beam has a maximum bending stress of 41.75 MPa compared to the conventional beam of 40.95 MPa. This meager increase in the bending stress indicates the ability of the PET strips to take upon additional deflection upon loading. However, the doubly wrapped beam shows fewer characteristic parameters and can be widely enhanced by the application of suitable binding elements between the layers of the PET strips.

On average, two 1-liter PET bottles can be used for the production of the wrapped bar of 1 meter in length. In the current scenario, around 156 plastic bottles have been disposed of by an individual every day. For the construction of the RC building around tonnes of steel reinforcements had been used. Taking this into account, the proposed idea will be the most suitable one to reduce the landfill of PET bottles.

6. Conclusion

The investigation led to the following conclusions.

- Waste PET bottle Strips can be successfully used in the tension zone of reinforced concrete beams to partially wrap around steel bars in single and double layers. The capacity for carrying a load of the PSC beam is higher than that of conventional concrete beams and PDC beams. This may lead to an increase in the initial construction cost/labor charges while preparing on the site or on a local small scale. But this can be minimized by producing on a large scale by considering the long-term durability of the RC structures. This may be an effective method of reusing waste without dumping it in the yards and will compensate for the cost of production of wrapped bars.
- The PSC beam has a maximum bending stress of 2% greater than the conventional concrete beam, while the PDC beam has a maximum bending stress of 3.3% lower.
- Stiffness is directly related to flexural rigidity. A reduction in flexural strength indicates a decrease in rigidity. According to the results, the flexural rigidity of the PSC beam is 10.5% higher than that of the conventional concrete beam, and the flexural rigidity of the PDC beam is 11% less than that of the conventional concrete beam.
- The PSC beam showed higher ductility and greater deflection capacity when compared to conventional and PDC beams. PET strip-wrapped beams will also have a good bonding nature between the rebar and the concrete. The bonding will be taken care of by the stirrups and the tie rods provided around the PET-wrapped steel reinforcements.
- Every beam develops a flexural crack in the tension zone at mid-span which grows until the beam reaches its ultimate load. However, PSC beams exhibit less deflection than conventional and PDC beams, and shear cracks form at the support when they reach their maximum load.
- The PDC beam ruptures at a faster rate due to the presence of air gaps between the two neighboring layers and this being able to smoothly slide over each other when they bend, as they have a slippery surface.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contribution

Packieya Eswari Raj Mohan: Conceptualization, validation, writing-reviewing and editing, supervision.

Sherjin Kumar: Methodology, result analysis, software tools, writing-original draft.

Thiruvasagam Kumar: conceptualization, writing-reviewing, and editing.

Nandha Kumar Sivakumar: reviewing the draft, and methodology.

Abbreviations

PSC : PET Strip Singly wrapped Concrete Beam

PDC : PET Strip Doubly wrapped Concrete Beam

PET : Polyethylene Terephthalate

FRP : Fiber Reinforced Polymer

RC : Reinforced Concrete

CC : Conventional Concrete

References

[1] M. A. T. Mustafa, I. Hanafi, R. Mahmoud, and B. A. Tayeh, “Effect of partial replacement of sand by plastic waste on impact resistance of concrete: experiment and simulation,” Structures, vol. 20, no. April, pp. 519–526, 2019, doi: 10.1016/j.istruc.2019.06.008.

[2] A. Kumbasaroglu and E. Korkmaz, “Effect of Longitudinal Circular Hollows on the Flexural Strength of Reinforced Concrete Beams,” KSCE J. Civ. Eng., vol. 28, no. 1, pp. 275–287, 2024, doi: 10.1007/s12205-023-0424-2.

[3] M. C. Sundarraja and G. G. Prabhu, “Flexural behaviour of CFST members strengthened using CFRP composites,” Steel Compos. Struct., vol. 15, no. 6, pp. 623–643, 2013, doi: 10.12989/scs.2013.15.6.623.

[4] M. M. Shirmardi and M. R. Mohammadizadeh, “Numerical Study on the Flexural Behaviour of Concrete Beams Reinforced by GFRP Bars,” J. Rehabil. Civ. Eng., vol. 7, no. 4, pp. 88–99, 2019, doi: 10.22075/JRCE.2018.14701.1268.

[5] S. Moazzenchi and A. V. Oskouei, “A Comparative Experimental Study on the Flexural Behavior of Geopolymer Concrete Beams Reinforced with FRP Bars,” J. Rehabil. Civ. Eng., vol. 11, no. 1, pp. 21–42, 2023, doi: 10.22075/JRCE.2022.25157.1569.

[6] K. Turk, C. Kina, and E. Oztekin, “Effect of macro and micro fiber volume on the flexural performance of hybrid fiber reinforced SCC,” Adv. Concr. Constr., vol. 10, no. 3, pp. 257–269, 2020, doi: 10.12989/acc.2020.10.3.257.

[7] M. K. Al-Kamal, “Nominal flexural strength of high-strength concrete beams,” Adv. Concr. Constr., vol. 7, no. 1, pp. 1–9, 2019, doi: 10.12989/acc.2019.7.1.001.

[8] H. Du, X. Hu, D. Shi, and W. Xue, “Flexural Performance of Composite Beams Using High-Strength Steel and High-Strength Concrete,” Int. J. Steel Struct., vol. 22, no. 1, pp. 27–41, 2022, doi: 10.1007/s13296-021-00558-y.

[9] W. : Www, M. L. Anoop Kumar, I. V Ramana Reddy, and C. Sasidhar, "International Journal of Emerging Technology and Advanced Engineering Experimental Investigations on The Flexural Strength of PET Reinforced Concrete," 2008.

[10] M. K. Talukder and M. N. Haque, "Experimental investigation of flexural capacity and deflection of low strength RCC beam strengthened with flexural steels and steel shear key," Asian J. Civ. Eng., vol. 24, no. 1, pp. 29–56, 2023, doi: 10.1007/s42107-022-00484-2.

[11] D. Y. Yoo and Y. S. Yoon, "A Review on Structural Behavior, Design, and Application of Ultra-High-Performance Fiber-Reinforced Concrete," Int. J. Concr. Struct. Mater., vol. 10, no. 2, pp. 125–142, Jun. 2016, doi: 10.1007/S40069-016-0143-X.

[12] A. O. Dawood and H. M. Adnan, "Experimental Investigation of Using PET Wastes as Tension Bars in Reinforced Concrete Beams," J. Univ. Babylon Eng. Sci., vol. 27, no. 1, pp. 247–261, 2019, doi: 10.29196/jubes.v27i1.1993.

[13] H. M. Adnan and A. O. Dawood, "Strength behavior of reinforced concrete beam using re-cycle of PET wastes as synthetic fibers," Case Stud. Constr. Mater., vol. 13, p. e00367, 2020, doi: 10.1016/j.cscm.2020.e00367.

[14] R. S. Falih, A. O. Dawood, and H. Al-Khazraji, "Structural behaviour of concrete beams reinforced with polyethylene terephthalate (PET) bottles wastes bars," IOP Conf. Ser. Mater. Sci. Eng., vol. 928, no. 2, 2020, doi: 10.1088/1757-899X/928/2/022033.

[15] M. Alshannag, M. Alshmalani, A. Alsaif, and M. Higazey, "Flexural performance of high-strength lightweight concrete beams made with hybrid fibers," Case Stud. Constr. Mater., vol. 18, p. e01861, Jul. 2023, doi: 10.1016/J.CSCM.2023.E01861.

[16] A. A. Mohammed and A. A. F. Rahim, "Experimental behavior and analysis of high strength concrete beams reinforced with PET waste fiber," Constr. Build. Mater., vol. 244, p. 118350, May 2020, doi: 10.1016/J.CONBUILDMAT.2020.118350.

[17] W. A. Abdullah, H. U. Ahmed, Y. M. Alshkane, D. B. Rahman, A. O. Ali, and S. S. Abubakr, "The possibility of using waste PET plastic strip to enhance the flexural capacity of concrete beams," J. Eng. Res., vol. 9, 2021, doi: 10.36909/jer.v9iICRIE.11649.

[18] C. Daniel, R. O. Onchiri, and B. O. Omondi, "Structural behaviour of reinforced concrete beams containing recycled polyethylene terephthalate and sugarcane bagasse ash," Appl. Eng. Sci., vol. 18, no. January, p. 100178, 2024, doi: 10.1016/j.apples.2024.100178.

[19] Y. L. Bai, W. Q. Niu, W. J. Xie, and W. Y. Gao, "Flexural behavior of reinforced concrete beams strengthened with hybrid carbon-PET FRP laminates," Constr. Build. Mater., vol. 411, p. 134372, Jan. 2024, doi: 10.1016/J.CONBUILDMAT.2023.134372.

[20] W. Mansour and S. Fayed, "Flexural rigidity and ductility of RC beams reinforced with steel and recycled plastic fibers," Steel Compos. Struct., vol. 41, no. 3, pp. 317–334, 2021, doi: 10.12989/scs.2021.41.3.317.

[21] A. Al-Shwaiter, H. Awang, and M. A. Khalaf, "Performance of sustainable lightweight foam concrete prepared using palm oil fuel ash as a sand replacement," Constr. Build. Mater., vol. 322, Mar. 2022, doi: 10.1016/j.conbuildmat.2022.126482.

[22] N. A. Abdulla, "Using the artificial neural network to predict the axial strength and strain of concrete-filled plastic tube," J. Soft Comput. Civ. Eng., vol. 4, no. 2, pp. 62–84, 2020, doi: 10.22115/SCCE.2020.225161.1198.

[23] N. Abduljabar Abdulla, "Strength models for uPVC-confined concrete," Constr. Build. Mater., vol. 310, no. October, p. 125070, 2021, doi: 10.1016/j.conbuildmat.2021.125070.

[24] A. A. Mohammed, I. I. Mohammed, and S. A. Mohammed, "Some properties of concrete with plastic aggregate derived from shredded PVC sheets," Constr. Build. Mater., vol. 201, pp. 232–245, 2019, doi: 10.1016/j.conbuildmat.2018.12.145.

[25] A. A. Mohammed, M. A. Muhammad, and B. K. Mohammed, "Effect of PET waste fiber addition on flexural behavior of concrete beams reinforced with GFRP bars," Case Stud. Constr. Mater., vol. 19, p. e02564, Dec. 2023, doi: 10.1016/J.CSCM.2023.E02564.

[26] J. Pablo Ojeda, "A meta-analysis on the use of plastic waste as fibers and aggregates in concrete composites," Constr. Build. Mater., vol. 295, p. 123420, 2021, doi: 10.1016/j.conbuildmat.2021.123420.

[27] H. M. Adnan and A. O. Dawood, "Strength behavior of reinforced concrete beam using re-cycle of PET wastes as synthetic fibers," Case Stud. Constr. Mater., vol. 13, p. e00367, Dec. 2020, doi: 10.1016/J.CSCM.2020.E00367.

[28] J. M. C. Ongpeng et al., "Strengthening rectangular columns using recycled PET bottle strips," Eng. Sci. Technol. an Int. J., vol. 24, no. 2, pp. 405–413, 2021, doi: 10.1016/j.jestch.2020.07.006.

[29] Y. Lattif and O. Hamdy, "An experimental investigation of the flexural strengthening of preloaded self-compacted RC beams using CFRP sheets and laminates composites," Adv. Concr. Constr., vol. 13, no. 4, pp. 307–313, 2022, doi: 10.12989/acc.2022.13.4.307.

[30] N. Ganesan, P. Bindurania, and P. V. Indirab, "Flexural strengthening of RCC beams using FRPs and ferrocement-A comparative study," Adv. Concr. Constr., vol. 10, no. 1, pp. 35–48, 2020, doi: 10.12989/acc.2020.10.1.035.

[31] A. Shiuly, T. Hazra, D. Sau, and D. Maji, "Performance and optimisation study of waste plastic aggregate based sustainable concrete – A machine learning approach," Clean. Waste Syst., vol. 2, no. April, p. 100014, 2022, doi: 10.1016/j.clwas.2022.100014.

[32] F. K. Alqahtani, G. Ghataora, M. I. Khan, and S. Dirar, "Novel lightweight concrete containing manufactured plastic aggregate," Constr. Build. Mater., vol. 148, pp. 386–397, 2017, doi: 10.1016/j.conbuildmat.2017.05.011.

[33] K. Ullah, M. Irshad Qureshi, A. Ahmad, and Z. Ullah, "Substitution potential of plastic fine aggregate in concrete for sustainable production," Structures, vol. 35, no. January 2021, pp. 622–637, 2022, doi: 10.1016/j.istruc.2021.11.003.