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Experimental investigation of effect of waste PET fibres on the impact behaviour of PET fibre reinforced concrete

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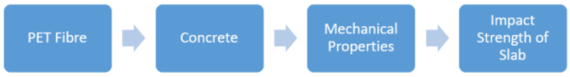
Graphical abstract



Experimental Investigation of Effect of Waste PET fibres on the Impact Behaviour of PET Fibre Reinforced Concrete

Abstract

Concrete, being the construction material that is extensively employed, possesses various limitations despite its adaptability in building projects. It exhibits weakness when subjected to tension, has restricted ductility, and offers minimal resistance against cracking. Concrete is widely used in construction due to its high strength. The aim of this study is to conduct experimental research on the utilization of PET fibre as a construction material in concrete, which is technically sound and environmentally safe. The use of PET fibre in various engineering applications can solve the problem of disposal of plastic waste. PET fibre can be used in concrete to improve its ductile parameters. PET wires of 50 mm in length and 3 mm in width are used in this work. The tests conducted on M30 grade concrete included assessments of its strength in compression, strength in split tensile, strength in flexure, and resistance to impact. The percentages of addition were 0 %, 0.25 % and 0.5 % volume of fibre. The impact properties of PET fibre concrete were studied. Test results showed that there is improvement in compressive strength, split tensile strength, flexural strength and a significant increase in impact resistance of concrete after the addition of PET fibres.

Keywords: PET fibre, Concrete grade, Mechanical properties, Tensile Strength, Impact Strength

1. Introduction

In the latest decades, there has been an increasing acknowledgement of environmental concerns, particularly in relation to waste management. With the continuous increase in solid waste generation and limited landfill space, the practice of recycling and utilizing waste materials has emerged as viable alternatives to traditional waste disposal methods [Foti 2011]. Consequently, numerous studies have been conducted to explore innovative approaches to give new purpose to various types of waste.

The excessive use of plastics results in the generation of substantial quantities of plastic waste worldwide [Fraternali *et al.* 2011]. The disposal of discarded polythene and plastics poses an increasingly significant challenge in waste management. These non-biodegradable wastes persist in the environment after being discarded [Irwan *et al.* 2013]. Incineration, which is a common method for treating plastics, can release toxic gases into the environment, posing potential risks to human health.

Plastics have become a major concern due to their extensive use in everyday life and their non-biodegradable nature. The annual consumption of plastics has witnessed a dramatic rise, necessitating an urgent solution to address this problem [Irwan *et al.* 2013]. As a result, there has been extensive research into the reuse of discarded plastics, with a focus on investigating potential applications in concrete production using post-consumer and recycled plastic [Kim *et al.* 2010]. This approach aims to achieve both economic and environmental benefits.

In recent decades, research efforts have been focused on concrete reinforcements made from polymeric materials, specifically emphasizing the reutilization of waste materials [Choi *et al.* 2009]. This approach aims to combine the benefits of improved concrete performance with the advantages derived from effectively utilizing substantial amounts of waste that would otherwise be directed towards problematic solutions such as landfilling, incineration, or recycling, which still present unresolved issues.

PET (polyethylene terephthalate) is a prominent component among plastic wastes. It is a thermoplastic polymer resin extensively utilized in various applications, including synthetic fibres, food and beverage containers, and more [da Silva Magalhãesand and Fernandes 2015]. PET exhibits favourable mechanical properties, making it suitable for structural purposes, such as reinforcing concrete.

Notably, PET surpasses concrete in terms of tensile strength, enabling it to serve as a substitute for steel reinforcement bars in concrete structures [Afroz *et al.* 2013; Mello *et al.* 2014]. This substitution is made possible by the strong adherence between PET and concrete, which contributes to

PET fibres exhibit a notable high pull-out strength and demonstrate a ductile behavior [Nibudey *et al.* 2013]. A significant advantage of PET is its durability, a crucial concern in concrete applications. The corrosion of steel bars, resulting from various factors, is a primary factor contributing to concrete deterioration [Ochi *et al.* 2007]. Therefore, PET has the potential to mitigate this issue and improve the durability of reinforced concrete

There has been a lack of extensive research focusing on the impact resistance of concrete when subjected to dynamic loads, including impact loads [Kim *et al.* 2010]. At present, there is a lack of established regulations or standardized guidelines that specifically govern the conduct of impact tests on concrete. The primary goal of this study is to evaluate the impact strength of concrete incorporating PET fibres at various fractions. Mohammed [Mohammed and Karim 2023] conducted studies pertaining to the mechanical characteristics and impact strength of high-strength concrete that contained PET waste fibre. Concrete was mixed with varying lengths of PET fibres (10 mm, 20 mm, and 40 mm) at volumes of 0.50, 0.75, 1.00, 1.25, and 1.50 %. Depending on the fibre length and fraction volume, striking results were recorded against the impact strength property, showing improvements of up to 833 %. Anas [Anas *et al.* 2023] looked into the impact response prediction of a square reinforced concrete slab with normal strength that was enhanced with mild steel, C-FRP laminates, and C-FRP strips under a falling-weight load. The nonlinear elastic and inelastic behaviours, stiffness deterioration, and loading rate influence on concrete are beggaring the Concrete Damage Plasticity model. It is discovered that the applied strengthening procedures change the mode of failure and enhance the slab's response in terms of displacement and damage severity.

2. Materials and methodology

2.1. Materials

Ordinary Portland Cement (OPC) of 53 Grade having specific gravity of 3.05 and fineness modulus of 6 was used for the entire investigation. Normal potable water was used for the experimental investigations and curing purpose. Locally available manufactured M-sand passing through 4.75 mm sieve and retained on 600 µm sieve, conforming to Zone II as per IS:383-1970 was used as fine aggregate. Specific gravity and fineness modulus of fine aggregates was found to be 2.55 and 2.59 respectively. 20 mm angular coarse aggregates having specific gravity of 2.66 and fineness modulus of 7.2 was used in the study.

The PET strips were acquired through manual cutting of bottles, resulting in a thickness of 0.1 mm. These bottles had a corrugated surface, which is anticipated to enhance the adhesion of PET with concrete. During the hand cutting process, the neck of the bottles was removed. The PET fibres are shredded to a size having length 30 mm and width 5 mm [Karthikeyan and Vennila 2018]. The plastic fibre used were having specific gravity 1.34 and water absorption 0.10%.

2.2. Mix design

The mix proportion for M30 grade is designed using IS 10262 – 2009. Materials required for 1 cubic meter of concrete is shown in Table 1. The fibres are added in the proportion of 0 %, 0.25 % and 0.50 % of volume for all cube, cylinder, prism and slab specimens [Karthikeyan and Vennila 2018]. The mix was stopped at 0.5 % as the addition of fibres in higher percentages will lead to improper bonding and strength reduction.

Table 1. Mix design

Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m 3)	Coarse aggregate (kg/m 3)
191	426.7	705.5	1103.5
0.45	1	1.65	2.59

3. Mechanical properties of concrete

3.1. Compressive strength

Three cubes in each mix were casted and tested using Universal Testing Machine (UTM) and the test setup is in Figure 1. The compressive strength of the cube specimens, on average, fabricated with different proportions of PET fibres, is displayed in Table 2.

Figure 1. Compression Test

Table 2. Compressive Strength

% of Fibre	28 days Average Compressive Strength (N/mm^2)
0	32.5
0.25	33.1
0.5	33.7

The results indicate that the compressive strength of the concrete specimens exhibited a noticeable increase up to a fibre content of 0.5%. Specifically, at this fibre content level, there was a significant enhancement of 3.70% in compressive strength compared to conventional concrete.

3.2. Split tensile strength

Three cylinders in each mix were casted and tested using Universal Testing Machine (UTM) and the test setup is in Figure 2. The split tensile strength of the cylinder specimens, on average, fabricated with different proportions of PET fibres, is displayed in Table 3.

Based on the aforementioned results, it was observed that the split tensile strength of the concrete specimens exhibited a noticeable increase up to a fibre content of 0.5%. There was a significant enhancement of 18% in split tensile strength compared to conventional concrete.

Figure 2. Split Tensile Test

Table 3. Split tensile strength

% of fibre	Average 28 days Split tensile strength (N/mm^2)
0	3.1
0.25	3.32
0.5	3.64

3.3. Flexural strength

The results of the prisms tested using a Flexural Testing Machine (FTM) and the test setup is presented in Figure 3. The flexural strength of the prism specimens, obtained on average, is displayed in Table 4.

Figure 3. Flexural strength test

Table 4. Flexural strength of prism

% of fibre	Flexural strength (Average) N/mm^2 (28 days)
0	2.8
0.25	3.7
0.5	4.12

Based on the above-mentioned results, it was observed that the flexural strength of the concrete specimens exhibited a noticeable increase up to a fibre content of 0.5%. There was a significant enhancement of 47.14% in flexural strength compared to normal concrete.

4. Impact strength

Research on the impact resistance of concrete under dynamic loads has been relatively scarce currently, there is a lack of established regulations or standardized guidelines specifically addressing the conduction of impact tests on concrete.

In situations involving punching failure and plate perforation, further increases in impact energy, the behavior of the slab is minimally affected by variations in drop height or mass, indicating that these factors do not significantly influence the slab's performance. It is crucial to recognize that the choice of concrete directly impacts the strength of the slab.

4.1. Test setup

The testing program involves subjecting the prepared specimens to dynamic impact loads to assess the strength of concrete reinforced with PET fibres. The experimental setup used for the impact test of slabs is shown in Figure 4.

The setup, sponsored by India Chapter of American Concrete Institute (ICACI) consists of a steel frame which supports a pendulum weight of 8 kg a top and bottom frame which can hold a slab specimen of dimension 600 mm x 600 mm. The suspended weight can be dropped from a height of 1.5 m. The weight collides with the slab specimen, applying a sudden impact force at its centre. This collision typically results in the destruction of the specimen, but the energy transfer between the weight and specimen is utilized to determine the fracture mechanics and impact resistance of the material.

$$\text{Energy absorbed} = \text{No. of blows} \times \text{height} \times \text{load}$$

Figure 4. Impact Test Setup

The objective is to compare this behavior with that of reinforced concrete without PET fibres. To achieve this objective, three slabs measuring 600 mm × 600 mm × 60 mm have been prepared. Three slabs of each mix are made of reinforced concrete, with the addition of PET fibres at different levels. Another three slabs are made of reinforced concrete without the inclusion of PET fibres.

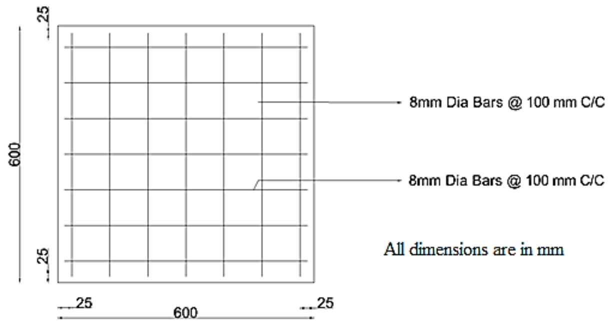


Figure 5. Reinforcement Detailing of Slab

4.2. Behaviour of PET fibre RCC slabs

The experiment involves conducting an impact resistance test on a concrete slab that contains PET Fibre. The slab has a cross-section measuring 600 mm x 600 mm x 60 mm. The reinforcement provided on both sides of slabs were of 8 mm diameter placed at a spacing of 100 mm.

The purpose of the impact test is to observe how the material behaves when subjected to a sudden and intense shock load, causing immediate deformation, fracture, or complete rupture of the specimen.

Figure 6. Slab with PET fibres

4.3. Impact test results

The impact tests were conducted on both conventional concrete and PET fibre-reinforced concrete using the optimal content, and the results are presented in the table below.

Table 5. Impact strength of slab

Specimen	No. of blows (average)	
	First crack	Failure
PET (0 %)	3	33
PET (0.25 %)	4	36
PET (0.5 %)	6	40

Standard concrete slabs proved brittle, succumbing to cracks as early as the third blow and complete failure by the 33rd. However, the introduction of PET fibers dramatically transformed their resilience. When 0.25% addition of PET fibers postponed cracking to the fourth blow and final breakdown to the thirty sixth blow. This effect amplified with 0.5% PET fibers, where cracks held off until the sixth blow and ultimate failure did not occur until the fortieth impact. These results convincingly reveal that PET fibers act as a shield, significantly increasing both the impact resistance and ductility of concrete slabs. This enhanced toughness enables them to withstand significantly more punishment before succumbing to damage, making them ideal for applications where robustness and longevity are paramount.

Based on the aforementioned results, it was observed that the impact strength of the concrete specimens exhibited a noticeable increase up to fibre content of 0.5%. There was a significant enhancement of 25% in impact strength compared to normal concrete.

The introduction of PET fibers into concrete has demonstrated a notable enhancement in the material's impact strength. The inclusion of PET fibers enables the concrete to effectively absorb and disperse greater amounts of energy upon impact, leading to heightened resilience against sudden loads or forces. This augmented capacity for energy absorption equips the concrete to withstand impacts more effectively, reducing the likelihood of cracking or fracturing. Notably, the observed ductile failure mode indicates that the concrete displays improved toughness, allowing it to undergo more deformation before reaching failure points. These positive attributes, encompassing heightened impact strength, enhanced energy absorption, and increased ductility, position PET fiber-reinforced concrete as a promising material for applications where the ability to withstand impact forces is paramount. The collective improvements underscore the potential of PET fiber-reinforced concrete to offer durability and reliability in scenarios where resistance to impact is a critical factor. The high impact resistance of PET fiber-included slabs makes them well-suited for a variety of applications where durability and the ability to withstand impact forces are essential. Industrial floorings, commercial complex floorings, warehouses and distribution centers, parking areas are some of the common cases where these kind of slabs can be useful.

Table 6. Energy absorption capacity of slabs

Specimen	Energy absorbed (kN mm)
PET (0 %)	3765
0.25 % PET	4235
0.5 % PET	4705

Figure 7. Impact Resistance Test (Formation of Cracks)

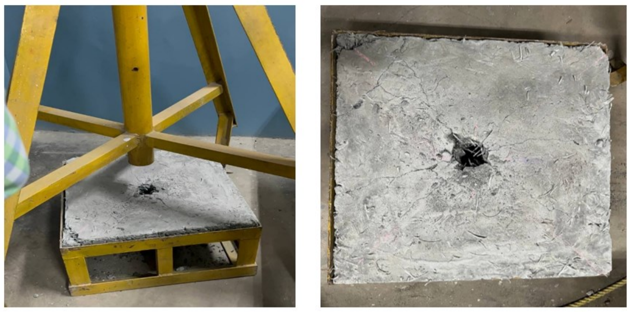


Figure 8. Impact Resistance Test (Failure Mode of Slabs with PET fibres)

5. Conclusion

The experimental investigation involving the use of PET wires as fibres in concrete led to several notable conclusions. The key findings are summarised below:

1. Compressive Strength: In comparison to conventional concrete, the addition of 0.5% PET fibre content resulted in a notable increase in compressive strength of 3.70%.

2. Split Tensile Strength: The inclusion of PET fibres led to a significant 17.6% increase in split tensile strength. This improvement suggests that PET fibres enhance the resistance of concrete to tensile stresses.

3. Flexural Strength: The flexural test showed a substantial 47.14% increase in flexural strength when PET fibres were added. This implies that the fibres contribute to the concrete's ability to withstand bending and flexural loads.

4. Optimum Fibre Content: The optimal strength was observed at a 0.5% fibre content for all the mentioned strength properties. Beyond this point, the mechanical properties of the concrete started to decrease with increasing fibre content.

5. Impact Strength: The inclusion of PET fibres in concrete led to an increase in impact strength. The energy absorption capacity of the concrete increased significantly, and failure was observed to be more ductile, indicating improved toughness and resistance to impact forces.

Overall, the experimental investigation highlights the potential of PET fibres as a low-cost material for improving the mechanical properties of concrete. It not only helps address solid waste problems and environmental pollution but also offers a new avenue for construction materials with enhanced strength and impact resistance.

References

Afroz M., Jobaer M. and Mahmudul Hasan M. (2013). Performance of plain PET fibers to enhance the mechanical behavior of concrete under tension and shear, International Journal of Science, Engineering and Technology Research, **2(9)**, 1668–1672.

Anas S.M., Alam M. and Tahzeeb R. (2023). Impact response prediction of square RC slab of normal strength concrete strengthened with (1) laminates of (i) mild-steel and (ii) C-FRP, and (2) strips of C-FRP under falling-weight load, Materials Today: Proceedings, **87**, 9–19.

Choi Y.W., Moon D.J., Kim Y.J. and Lachemi M. (2009). Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles, Construction and Building Materials, **23(8)**, 2829–2835.

Choi Y.W., Moon D.J., Kim Y.J. and Lachemi M. (2009). Characteristics of mortar and concrete containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles, Construction and Building Materials, **23(8)**, 2829–2835.

da Silva Magalhãesand M. and Fernandes M.S.V. (2015). Bending behaviour of recycled PET fiber reinforced cement-based composite, International Journal of Engineering and Technology, **7(4)**, 282.

Foti D. (2011). Preliminary analysis of concrete reinforced with waste bottles PET fibers. Construction and building materials, **25(4)**, 1906–1915.

Foti D. (2013). Use of recycled waste pet bottles fibers for the reinforcement of concrete, Composite Structures, **96**, 396–404.

Fraternali F., Ciancia V., Chechile R., Rizzano G., Feo L. and Incarnato L. (2011). Experimental study of the thermo-mechanical properties of recycled PET fiber-reinforced concrete, Composite structures, **93(9)**, 2368–2374.

Fraternali F., Farina I., Polzone C., Pagliuca E. and Feo L. (2013). On the use of R-PET strips for the reinforcement of cement mortars, Composites Part B: Engineering, **46**, 207–210.

Frigione M. (2010). Recycling of PET bottles as fine aggregate in concrete, Waste management, **30(6)**, 1101–1106.

Irwan J.M., Asyraf R.M., Othman N., Koh K.H., Annas M.M.K. and Faisal S.K. (2013). The mechanical properties of PET fiber reinforced concrete from recycled bottle wastes, Advanced Materials Research, **795**, 347–351.

Irwan J.M., Faisal S.K., Othman N., Wan I.M.H., Asyraf R.M. and Annas M.M.K. (2013). Performance of concrete using light waste PET fibre, Advanced Materials Research, **795**, 352–355.

IS: 2386-1963, "Indian standards code of practice for methods of test for Aggregate for concrete", Bureau of Indian Standard Institution, New Delhi.

IS: 383-1970, "Indian standards specification for coarse and fine aggregates from natural sources for concrete", Bureau of Indian Standards, New Delhi.

Karthikeyan S & Vennila G, (2018). Study on utilization of waste plastic fibres as a construction entity, Ecology, Environment and Conservation, **24**, 1720–1725.

Kim S.B., Yi N.H., Kim H.Y., Kim J.H. J. and Song Y.C. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete, Cement and concrete composites, **32(3)**, 232–240.

Kim S.B., Yi N.H., Kim H.Y., Kim J.H.J. and Song Y.C. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete, Cement and concrete composites, **32(3)**, 232–240.

Mello E., Ribellato C. and Mohamedelhassan E. (2014). Improving concrete properties with fibers addition, International Journal of Civil and Environmental Engineering, **8(3)**, 249–254.

Mohammed A.A. and Karim S.H. (2023). Impact strength and mechanical properties of high strength concrete containing PET waste fiber, Journal of Building Engineering, **68**, 106195.

Nibudey R.N., Nagarnaik P.B., Parbat D.K. and Pande A.M. (2013). Strength and fracture properties of post consumed waste plastic fiber reinforced concrete, Int. J. Civ. Struct. Environ. Infrastruct. Eng. Res. Dev, **3(2)**, 9–16.

Ochi T., Okubo S. and Fukui K. (2007). Development of recycled PET fiber and its application as concrete-reinforcing fiber, Cement and Concrete Composites, **29(6)**, 448–455.