

EFFECT OF RECYCLED PET PLASTIC ON THE PROPERTIES OF CONCRETE

Sirwan Kamal Jalal¹, Salim T. Yousif², Ahmed Mohammed Ahmed¹

¹Department of Civil and Environmental Engineering, University of Zakho, Iraq

²Civil Engineering Department, Nawroz University, KRG, Iraq

Corresponding author: ahmed.hadi@uoz.edu.krd

Received 21 March 2026 Received in Revised form 11 April 2026 Accepted 15 April 2026

Available Online 17 April 2026

ABSTRACT

This study investigates the use of waste polyethylene terephthalate (PET) plastic bottles as reinforcement in M25 grade concrete to develop environmentally and economically sustainable construction materials. PET waste was incorporated into the concrete mix at percentages of 1.5% and 3%. This material was selected due to its wide availability, low cost, and its potential to reduce environmental pollution caused by improper plastic waste disposal. Experimental tests were conducted to evaluate the workability, bulk density, and compressive strength of the concrete mixtures. The results showed that increasing the PET content reduced the workability of concrete, as the slump value decreased from 86 mm for the control mix to 72 mm and 29 mm for mixes containing 1.5% and 3% PET, respectively. The bulk density also showed a slight reduction with increasing PET content due to the lower density of PET compared to natural aggregates. The compressive strength results indicated that adding 1.5% PET slightly improved the strength of concrete, reaching 20.12 MPa at 7 days and 26.1 MPa at 28 days, compared to the control mix. However, increasing the PET content to 3% led to a reduction in compressive strength. The findings suggest that a small percentage of PET can be effectively used in concrete to support sustainable construction while maintaining acceptable mechanical performance.

Keywords: PET, plastic waste, compressive strength, workability, bulk density, recycled plastic aggregate.

1. INTRODUCTION

Concrete is one of the most commonly used construction materials worldwide because it is versatile, durable, widely available, and relatively inexpensive. It is a composite material made mainly of cement, water, fine aggregates, and coarse aggregates. When cement reacts with water through hydration, it forms a hardened matrix that binds the aggregates together, creating a strong material capable of withstanding high compressive forces. For these reasons, concrete plays a fundamental role in modern infrastructure [1].

Different types of concrete have been developed to satisfy various engineering needs. Conventional concrete is used in general construction such as buildings, roads, and bridges [2]. Reinforced concrete includes steel bars to improve tensile strength and control cracking. High-performance concrete offers enhanced strength and durability, while lightweight concrete uses low-density materials to reduce the overall weight of structures [3].

Concrete is applied in both structural and non-structural elements, including foundations, columns, beams, slabs, retaining walls, dams, tunnels, and transportation systems. Its ability to be molded into different shapes makes it highly suitable for structural

and architectural purposes [4]. However, despite its many advantages, conventional concrete has some limitations, including low tensile strength, brittleness, and a tendency to crack. These challenges have encouraged researchers to develop new materials and additives to improve their overall performance [5].

An emerging method to enhance concrete performance while reducing environmental impact is the use of recycled plastics and tire waste [6]. PET is widely used in bottles, packaging, and fibers, but its slow degradation has created serious environmental problems. Recycling PET into construction materials offers a sustainable solution to reduce plastic waste. In construction, recycled PET can be used as aggregates, fillers, or fibers. PET fibers, in particular, show good potential as reinforcement in concrete. When added to the mix, they help improve strength, control cracking, increase ductility, and enhance energy absorption [7]. The performance of PET fiber-reinforced concrete depends on the bond between fibers and the cement matrix. PET fibers act as crack bridges, slowing crack growth and improving toughness. They also reduce shrinkage and increase impact resistance. However, their effectiveness depends on factors like size, shape, amount, and proper distribution, as too much fiber can reduce workability [8].

While conventional concrete has high compressive strength but low tensile strength, PET fibers offer advantages such as low weight, high flexibility, corrosion resistance, and durability. Although less stiff than steel, PET fibers improve crack resistance and ductility, resulting in a more balanced and sustainable composite material.

This study aims to investigate an eco-friendly and cost-effective method to improve concrete by using recycled plastic bottle fibers. It also aims to reduce environmental pollution and evaluate the feasibility of producing fiber-reinforced concrete. The study examines fresh and hardened concrete properties, including workability, density, compressive strength, and potential use as reinforcement.

1.1 Problem Statement

The rapid increase in plastic consumption, especially polyethylene terephthalate (PET), has led to serious environmental challenges due to its non-biodegradable nature. Large amounts of PET waste accumulate in landfills and natural environments, while traditional disposal methods such as landfilling and incineration are not sustainable and contribute to pollution and environmental degradation. Therefore, finding effective and eco-friendly reuse solutions for plastic waste has become essential. At the same time, conventional concrete, although widely used, has limitations such as low tensile strength, brittleness, and susceptibility to cracking, which affect durability and increase maintenance costs. Fiber reinforcement has been used to improve concrete performance, but materials like steel and commercial synthetic fibers can be costly and less sustainable.

The use of recycled PET fibers in concrete presents a promising solution to both environmental and engineering problems. It can improve mechanical properties, control cracking, and enhance durability while reducing plastic waste. However, the behavior of PET fibers in concrete is not yet fully understood. In particular, the effect of fiber size on workability, bonding, and strength remains unclear. Therefore, further investigation is needed to determine the optimal fiber size and improve the practical use of recycled plastic fibers in concrete.

1.2 Previous Studies

The construction industry consumes large amounts of natural resources and generates significant waste, which has encouraged researchers to explore sustainable materials for construction. One promising approach is the reuse of plastic waste, particularly polyethylene terephthalate (PET), in concrete. Incorporating recycled plastic fibers in concrete not only helps reduce plastic pollution but may also enhance certain mechanical and durability properties.

Several studies have investigated the performance of concrete containing recycled PET materials. Early research by Al-Manaseer and Dalal (1997) reported that plastic particles could reduce concrete density and improve ductility, although compressive strength slightly decreased with higher plastic content [9]. Similarly, Frigione (2010) observed that recycled PET fibers reduced workability but improved tensile and flexural strengths of concrete [10].

Other researchers focused on identifying optimal fiber content. Saikia and Brito (2014) suggested that small amounts of PET fibers (0.5–1.5% by volume) can improve crack resistance and post-cracking behavior without significantly affecting compressive strength [11]. Siddique et al. (2008) also reported that PET fibers performed better than other plastic wastes in enhancing flexural performance due to their high tensile strength and durability [12].

More recent studies confirm these findings. Abdulateef et al. (2024) found that adding 1–3% recycled plastic fibers improved compressive, tensile, and flexural strengths, with 2% providing the best balance between strength and workability [13]. Huynh et al. (2023) reported that recycled plastic fibers improved durability and reduced drying shrinkage [14], while Bui et al. (2018) showed that PET fibers enhanced the mechanical behavior and durability of recycled aggregate concrete [15]. Additional studies by Foti (2013) [16] and Kim et al. (2010) [8] highlighted the strong bonding and crack-bridging capacity of PET fibers, which can improve ductility and delay crack formation in reinforced concrete.

Overall, previous research indicates that recycled PET fibers can be successfully incorporated into concrete to enhance crack resistance, ductility, and durability while contributing to plastic waste reduction. However, the effectiveness of PET fibers depends on factors such as fiber size, shape, and percentage in the mixture. Therefore, further studies are needed to determine optimal proportions and mixing methods. Based on this need, the present study evaluates the influence of PET fiber contents of 1%, 3%, and 5% on the fresh and hardened properties of concrete, including slump, density, compressive strength, split tensile strength, and flexural strength.

2. MATERIALS AND METHODS

2.1 Materials

All materials used in this study were obtained locally from the Duhok city market and tested according to ASTM standards to ensure their suitability for concrete production. The main materials included cement, fine aggregate, coarse aggregate, water, and recycled PET fibers from plastic bottles.

2.1.1 Cement

Type I Ordinary Portland Cement (OPC) was used as the binding material in this study due to its availability and suitability for general construction. The cement complies with ASTM C150 requirements for Portland cement [17]. The physical and chemical properties of the cement were evaluated through laboratory testing to ensure compliance with the ASTM standards. All tests confirmed that the cement used in this research is suitable for use in concrete and meets the standard requirements. A summary of the tested cement properties is presented in Table 1, confirming that the material is acceptable for structural applications in accordance with ASTM guidelines.

2.1.2 Fine Aggregate

Natural sand obtained from the local market in Duhok was used as fine aggregate. The sand was clean, well-graded, and free from harmful materials such as clay and organic impurities. Laboratory tests, including sieve analysis (ASTM C136) [18] and specific gravity (ASTM C128) [19], confirmed its suitability for concrete production as presented in Table 2.

2.1.3 Coarse Aggregate

Locally sourced crushed gravel was used as coarse aggregate. The aggregate was angular, clean, and free from dust and other impurities that could affect bonding with cement paste. Its physical properties

were tested according to ASTM standards to ensure compatibility with the concrete mix design. To verify the quality and suitability of the coarse aggregate, several tests were conducted per ASTM standards. Its physical properties, as shown in Table 3, confirm its compatibility with the mix design and its ability to contribute positively to the mechanical properties of the concrete.

2.1.4 Recycled Plastic Fibers

Recycled plastic fibers were produced by cutting waste PET water bottles into thin strips. These fibers were selected because of their high tensile strength, durability, and resistance to environmental degradation. Using PET fibers not only improves the ductility and crack resistance of concrete but also contributes to reducing plastic waste. Their mechanical and thermal properties, including tensile strength, melting point, elongation at break, and fiber dimensions, were evaluated to determine their effectiveness as reinforcement in concrete. The PET thermal and mechanical properties were tested and summarized in Table 4. These properties include tensile strength, melting point, elongation at break, and fiber dimensions, which are critical in assessing their performance when used as reinforcement in concrete.

Table 1 Properties of Used Cement

No.	Property	Value	Unit
1	Fineness	404	-
2	Consistency	35	Mm
3	Specific Gravity	3.03	-
4	Initial Setting Time	180	Minute
5	Final Setting Time	230	Minute
6	Soundness	3	Mm
7	Compressive Strength (2 days)	26.2	MPa
8	Compressive Strength (7 days)	42.5	MPa
9	Compressive Strength (28 days)	47.6	MPa

Table 2 Properties of Fine Aggregate

No.	Property	Value	Unit
1	Bulk Specific Gravity (Dry)	2.552	-
2	Bulk Specific Gravity (SSD)	2.586	-
3	Apparent Specific Gravity	2.642	-
4	Water Absorption	1.4	%
5	Fineness Modulus	2.807	-

Table 3 Properties of Coarse Aggregate

No.	Property	Value	Unit
1	Bulk Specific Gravity (Dry)	2.634	-
2	Bulk Specific Gravity (SSD)	2.556	-
3	Apparent Specific Gravity	2.690	-
4	Water Absorption	0.8	%
5	Density	1707	kg/m ³
6	Maximum Aggregate Size	19	mm

Table 4 Thermal and Mechanical Properties of Recycled PET Fibers

Property	Value	Unit	Test Standard
Fiber Length	30	Mm	-
Fiber Width	3	Mm	-
Tensile Strength	250 – 350	MPa	ASTM D638
Elongation at Break	50 – 80	%	ASTM D638
Density	1.38	g/cm ³	ASTM D792
Melting Point	250 – 260	°C	ASTM D3418
Water Absorption	Negligible	-	ASTM D570
Appearance	Transparent to White	-	Visual Observation

2.1.5 Water

Water is an essential component of concrete, affecting cement hydration, strength development, setting time, and durability. In this study, tap water from Duhok city was used for mixing and curing. The water is potable and meets ASTM C1602 requirements, with acceptable levels of chlorides, sulfates, and alkalis [20]. It was also confirmed to be free from harmful substances that could affect cement hydration. The use of clean water ensures consistent concrete quality and proper curing performance.

2.2 Sample Preparation

2.2.1 Recycled Plastic Fibers (PET) Preparation

In this study, recycled PET fibers were produced from used water bottles for use as concrete reinforcement. The bottles were first collected, ensuring uniformity by selecting the same brand to maintain consistent material properties. They were then thoroughly washed and dried to remove dust, labels, and any residues that could affect bonding or durability. After preparation, the bottles were cut into thin longitudinal strips measuring approximately 30 mm × 3 mm. The strips were shaped to form a corrugated surface, which

improves mechanical interlocking with the cement matrix and enhances bond strength.

2.2.2 Mix Design

An M25 grade concrete mix was used in this study, designed according to the American Concrete Institute (ACI) method. This method is commonly used to achieve the required compressive strength while ensuring suitable workability, durability, and cost-effectiveness. The mix proportions were selected based on the target strength, aggregate properties, and the specified water–cement ratio. The detailed mix proportions for M25 concrete are presented in Table 5. Table 6 presents the quantities of materials required for casting six concrete cubes with different PET fiber contents (1.5% and 3%). It can be observed that the amounts of cement, water, fine aggregate, coarse aggregate, and HRWRA admixture remain constant for both mixes, ensuring a consistent M25 mix design. The only variation of recycled PET fibers, which increases from 0.24 kg for 1.5% to 0.48 kg for 3%. This variation allows for a direct comparison of the effect of increasing PET fiber content on the properties of concrete while keeping all other parameters unchanged.

Table 5 Mix Proportions for M25 Grade Concrete

Material	Quantity (kg/m ³)
Cement	400
Water	200
Fine Aggregate (Sand)	650
Coarse Aggregate (Gravel)	1182
Recycled PET Fibers (1.5% replacement of gravel)	18
HRWRA Admixture (2% of cement)	8

Table 6 Mix Proportions of Concrete Materials for 12 Cubes PET

Material	Quantity for 1 m ³ (kg)	6 Cubes (1.5% PET) (kg)	6 Cubes (3% PET) (kg)
Cement	400	5.40	5.40
Water	200	2.70	2.70
Fine Aggregate (Sand)	650	8.78	8.78
Coarse Aggregate (Gravel)	1182	15.95	15.95
Recycled PET Fibers	—	0.24 (1.5%)	0.48 (3%)
HRWRA Admixture	8	0.11	0.11

2.2.3 Mixing and Curing Method

All materials were accurately weighed before mixing to ensure consistency of the concrete batches. A dry mixing process was first carried out by combining coarse aggregate, fine aggregate, cement, and recycled PET fibers for about 4–5 minutes to achieve uniform distribution, especially to prevent fiber clumping. After that, the HRWRA admixture was mixed with water, and the solution was gradually added to the dry mix until a homogeneous and workable concrete was obtained.

Cube molds (15 × 15 × 15 cm) were then prepared and lightly oiled to facilitate demolding. The fresh concrete was placed in three equal layers, and each layer was compacted using a standard steel tamping rod (16 mm diameter) with 36 strokes per layer to remove air voids and ensure proper consolidation. After casting, the surface was leveled and the molds were covered for 24 hours to prevent moisture loss and reduce early shrinkage.

After 24 hours, the specimens were demolded and placed in a water curing tank for continuous hydration. Curing was carried out using clean water until testing ages of 7 and 28 days to evaluate early and long-term compressive strength development.

2.3 Experimental Tests

2.3.1 Bulk Density Test

The bulk density test was conducted to evaluate the effect of recycled PET fibers on concrete density. After curing, each cube specimen was weighed using a digital balance. The cube volume was calculated based on its dimensions (15 × 15 × 15 cm), giving 0.003375 m³. Density was then determined using the equation $d=m/v$ where d is density (kg/m³), m is mass (kg), and v is volume (m³).

2.3.2 Slump Test

The slump test was carried out according to ASTM C143 to determine the workability of fresh concrete and assess the influence of PET fibers and HRWRA [21]. Fresh concrete was placed in a slump cone in three equal layers, each compacted 25 times using a standard steel rod. After leveling the top surface, the

cone was lifted vertically, and the slump was measured as the difference between the cone height and the highest point of the slumped concrete, recorded in millimeters (mm). This test evaluates the flowability and consistency of the mix.

2.3.3 Compressive Strength Test

Compressive strength was tested following ASTM C39 using cube specimens (150 × 150 × 150 mm). After curing, specimens were removed from the water tank, surface-dried, and placed centrally in a compression testing machine. Load was applied gradually until failure, and the maximum load was recorded [22]. Compressive strength was calculated using $f_c=P/A$, where f_c is compressive strength (MPa), P is maximum load (N), and A is loaded area (mm²).

3. RESULT AND DISCUSSION

3.1 Bulk Density

Bulk density is an important property of concrete that indicates the mass of concrete per unit volume and reflects the compactness of the material. It is influenced by the type of materials used in the mix and the presence of additives or waste materials. In this study, waste polyethylene terephthalate (PET) was incorporated into M25 concrete at different percentages (0%, 1.5%, and 3%) to evaluate its effect on the bulk density of concrete at curing ages of 7 and 28 days. The experimental results are presented in Figure 1 and Figure 2.

As shown in Figure 1, the bulk density results at 7 days indicate that the control mix (M25 with 0% PET) achieved the highest density of 2394 kg/m³. When PET was added to the concrete mixture, the bulk density slightly decreased. The mix containing 1.5% PET recorded a density of 2371 kg/m³, while the mix with 3% PET showed the lowest value of 2338 kg/m³. A similar pattern was observed at 28 days, as illustrated in Figure 2. The control mix showed a density of 2386 kg/m³, while the mixes with 1.5% PET and 3% PET recorded 2368 kg/m³ and 2342 kg/m³, respectively. These results demonstrate that increasing the PET content in the concrete mixture leads to a gradual reduction in bulk density at both curing ages.

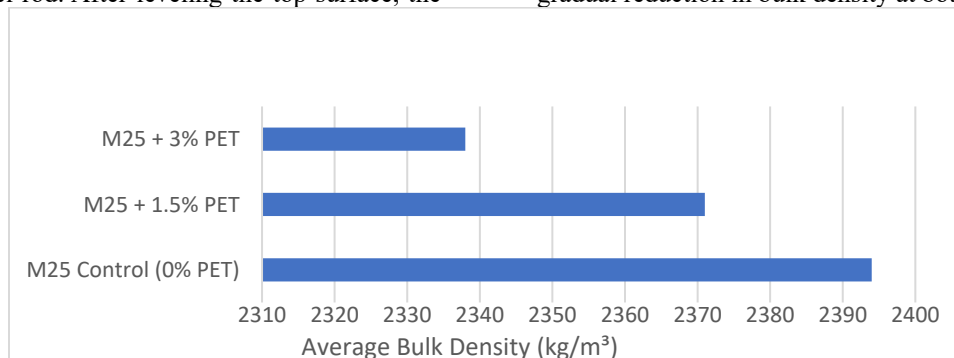


Figure 1 Bulk Density of PET of 7 days

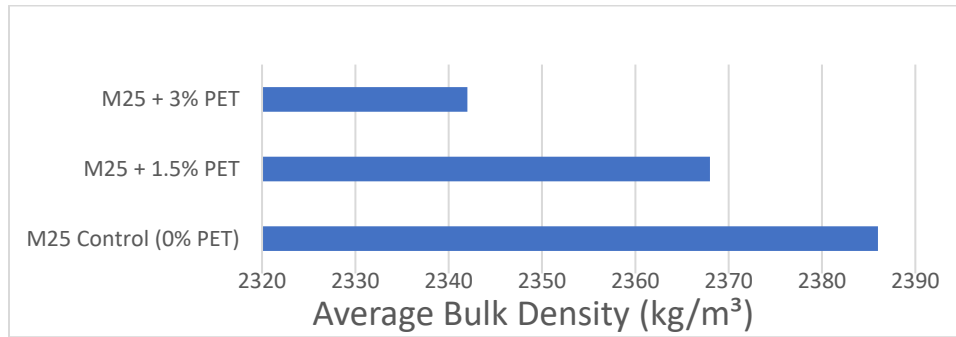


Figure 2 Bulk Density of PET of 28 days

The decrease in bulk density can be explained by the physical characteristics of PET material. PET has a lower density compared to conventional natural aggregates used in concrete. Therefore, when PET is incorporated into the mix, it partially replaces heavier materials, resulting in a lighter concrete matrix. Additionally, PET particles may reduce the compactness of the mixture and introduce small internal voids, which can further lower the overall density. This suggests that the use of PET waste can produce slightly lighter concrete while also contributing to sustainable waste recycling and environmental protection.

3.2 Slump Test

The slump test was conducted to evaluate the workability of fresh concrete mixtures with different percentages of PET. Workability is an important

property that determines the ease of mixing, placing, and compacting concrete without segregation. In this study, PET waste was incorporated into M25 concrete at percentages of 0%, 1.5%, and 3% to observe its influence on the slump value. The results of the slump test are presented in Figure 3.

As shown in Figure 3, the control mix (M25 with 0% PET) achieved the highest slump value of 86 mm, indicating good workability of the fresh concrete. When 1.5% PET was added to the mixture, the slump value decreased to 72 mm, showing a moderate reduction in workability. A significant decrease was observed when the PET content increased to 3%, where the slump value dropped sharply to 29 mm. This result indicates that increasing the PET content in the concrete mixture greatly reduces the workability of fresh concrete.

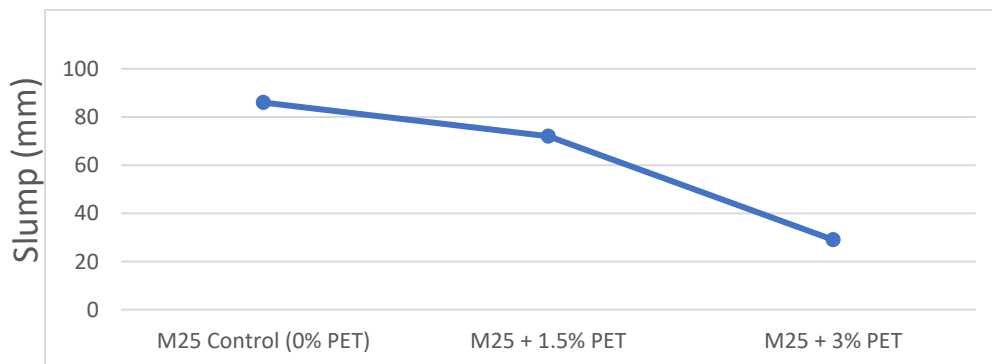


Figure 3 Result of Slump of PET FRC

The reduction in slump can be attributed to the physical characteristics of PET particles. PET pieces generally have irregular shapes and rough edges, which increase internal friction within the concrete mix and restrict the movement of particles. In addition, PET has a lower density and weaker bonding with cement paste compared to natural aggregates, which reduces the cohesiveness and flowability of the mix. As the PET percentage increases, the mixture becomes stiffer and requires more water to maintain the same workability; however, since the water–cement ratio

remains constant, the slump value decreases significantly.

3.3 Compressive Strength

Compressive strength is one of the most important mechanical properties of concrete as it indicates the ability of the material to resist compressive loads. In this study, the compressive strength of M25 concrete containing different percentages of PET (0%, 1.5%, and 3%) was tested at curing ages of 7 days and 28 days. The experimental results are presented in Figure 4 and Figure 5.

The results for 7 days, shown in Figure 4, indicate that the compressive strength increased slightly with the addition of 1.5% PET and then decreased at higher PET content. The control mix (M25 with 0% PET) achieved a compressive strength of 19.2 MPa. When 1.5% PET was incorporated into the mix, the strength increased to 20.12 MPa, indicating a small improvement in early-age strength. However, when the PET content increased to 3%, the compressive strength decreased to 17.86 MPa, which is lower than the control mix.

A similar trend was observed for the 28-day compressive strength, as shown in Figure 5. The

control mix reached a compressive strength of 25.8 MPa, while the mix containing 1.5% PET slightly increased to 26.1 MPa, representing the highest value among the tested mixes. However, when the PET content was increased to 3%, the compressive strength decreased compared with the other mixes. The initial increase in strength at 1.5% PET may be attributed to the better distribution of PET particles within the concrete matrix, which can help improve internal structure and crack resistance. On the other hand, excessive PET content (3%) may reduce the bonding between the cement paste and aggregates and introduce additional voids in the concrete matrix, leading to

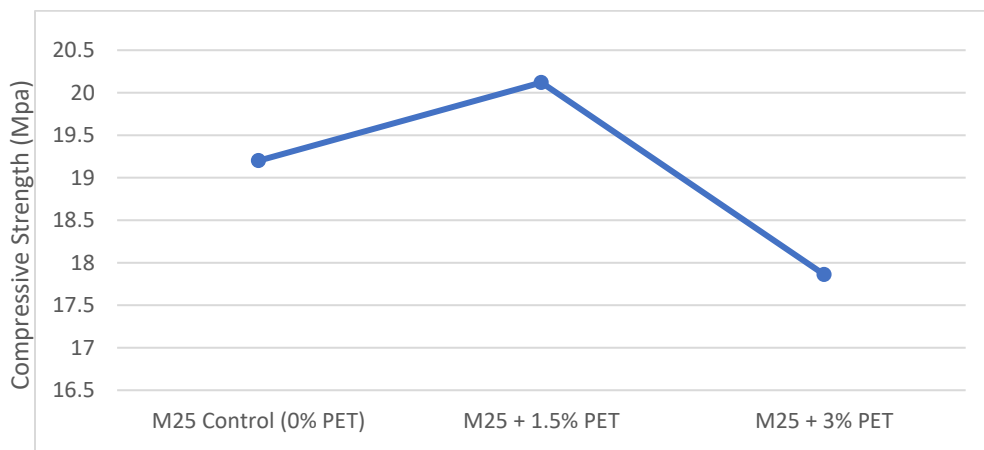


Figure 4 Compressive Strength of PET FRC at 7 Days

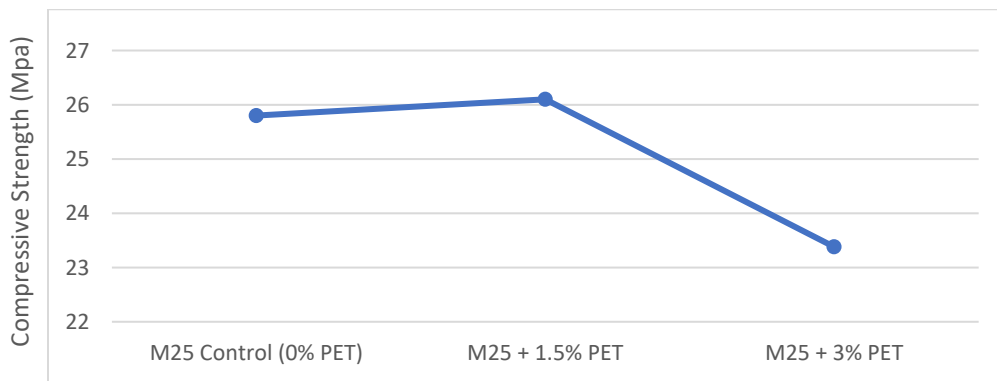


Figure 5 Compressive Strength of PET FRC at 28 Days

4. CONCLUSION

This study investigated the use of waste PET plastic bottles as reinforcement in M25 concrete to develop a more sustainable and environmentally friendly construction material. PET was incorporated into the concrete mix at proportions of 1.5% and 3% to evaluate its effect on workability, bulk density, and

compressive strength. The experimental results showed that the addition of PET reduced the workability of concrete, as the slump value decreased with increasing PET content. Similarly, the bulk density slightly decreased due to the lower density of PET compared with natural aggregates, producing a lighter concrete mixture.

The compressive strength results indicated that the inclusion of 1.5% PET slightly improved the compressive strength at both 7 and 28 days compared with the control mix. However, increasing the PET content to 3% resulted in a reduction in strength. Based on the findings, it can be concluded that a small percentage of PET waste, particularly around 1.5%, can be effectively used in concrete without significantly compromising its mechanical properties. The use of PET in concrete can contribute to reducing plastic waste and promoting sustainable and cost-effective construction materials.

REFERENCES

- Al-Luhybi, A. S., & Qader, D. N. (2021). Mechanical properties of concrete with recycled plastic waste. *Civ Environ Eng*, 17(2), 629-643.
- Qaidi, S., Al-Kamaki, Y. S., Al-Mahaidi, R., Mohammed, A. S., Ahmed, H. U., Zaid, O., ... & Bennetts, I. (2022). Investigation of the effectiveness of CFRP strengthening of concrete made with recycled waste PET fine plastic aggregate. *PloS one*, 17(7), e0269664.
- Alnahas, J., Lakhout, A., Alnchiwati, M., Albalawi, M., Elrazzaz, A., Alanzi, N., ... & Hijry, H. M. (2025). Enhancing the Properties of Concrete with the Incorporation of Recycled Polypropylene Plastic. *Buildings*, 15(7), 1055.
- Huynh, T. P., Le, T. H. M., & Ngan, N. V. C. (2023). An experimental evaluation of the performance of concrete reinforced with recycled fibers made from waste plastic bottles. *Results in Engineering*, 18, 101205.
- Bui, N. K., Satomi, T., & Takahashi, H. (2018). Recycling woven plastic sack waste and PET bottle waste as fiber in recycled aggregate concrete: An experimental study. *Waste management*, 78, 79-93.
- Artoshi, I. M. K., Abdulateef, L. A., Farman, I. H., & Ahmed, A. M. (2024). Efficiency and Durability Assessment of Soil Stabilization using Waste Tire Shreds. *Engineering, Technology & Applied Science Research*, 14(1), 13012-13016.
- Ochi, T., Okubo, S., & Fukui, K. (2007). Development of recycled PET fiber and its application as concrete-reinforcing fiber. *Cement and Concrete Composites*, 29(6), 448-455.
- Kim, S. B., Yi, N. H., Kim, H. Y., Kim, J. H. J., & Song, Y. C. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete. *Cement and concrete composites*, 32(3), 232-240.
- Al-Manaseer, A. A., & Dalal, T. R. (1997). Concrete containing plastic aggregates. *Concrete International*, 19(8), 47-52.
- Frigione, M. (2010). Recycling of PET bottles as fine aggregate in concrete. *Waste Management*, 30(6), 1101-1106.
- Saikia, N., & de Brito, J. (2014). Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate. *Construction and Building Materials*, 52, 236-244. <https://doi.org/10.1016/j.conbuildmat.2013.11.049>
- Siddique, R., Khatib, J., & Kaur, I. (2008). Use of recycled plastic in concrete: A review. *Waste Management*, 28(10), 1835-1852.
- Abdulateef, L. A., Hassan, S. H., & Ahmed, A. M. (2024). Exploring the Mechanical Behavior of Concrete enhanced with Fibers derived from recycled Plastic Bottles. *Engineering, Technology & Applied Science Research*, 14(2), 13481-13486.
- Huynh, T. P., Le, T. H. M., & Ngan, N. V. C. (2023). An experimental evaluation of the performance of concrete reinforced with recycled fibers made from waste plastic bottles. *Results in Engineering*, 18, 101205.
- Bui, N. K., Satomi, T., & Takahashi, H. (2018). Recycling woven plastic sack waste and PET bottle waste as fiber in recycled aggregate concrete: An experimental study. *Waste management*, 78, 79-93.
- Foti, D. (2013). Use of recycled waste pet bottles fibers for the reinforcement of concrete. *Composite Structures*, 96, 396-404.
- ASTM International. (2023). ASTM C150/C150M – Standard Specification for Portland Cement. West Conshohocken, PA: ASTM International.
- ASTM C136/C136M – Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.
- ASTM C128 – Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate.
- ASTM International. (2023). ASTM C1602/C1602M – Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.
- ASTM C143/C143M – Standard Test Method for Slump of Hydraulic-Cement Concrete.
- ASTM International. (2023). ASTM C39/C39M – Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.