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Experimental Study on Compressive and Tensile Strength of Plain Concrete With Polyethylene Terephthalate (PET) Powder

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ABSTRACT. This study examines the compressive strength and split tensile strength of concrete with polyethylene terephthalate (PET) powder as a partial replacement for sand in varying proportions. PET is a polymer commonly used in the food packaging industry, including cold drink and water bottles, and is considered a waste material. In this research, PET powder derived from recycled plastic bottles collected by a recycling plant in Itahari, Nepal, was utilized. Concrete specimens incorporating PET powder at proportions of 3.8%, 4.0%, and 4.2% by weight of sand were cast and tested for strength development at 7, 21, and 28 days. Cube and cylinder specimens were prepared using a water-to-cement ratio of 0.5. Results indicated that the inclusion of PET powder enhanced early-age compressive strength. At 7 days, concrete mixes with 3.8%, 4.0%, and 4.2% PET exhibited compressive strength increases of 26.44%, 40.53%, and 12.43%, respectively, over the M20 control mix, indicating accelerated early strength gain. However, all PET-modified mixes showed lower compressive strengths compared to the control mix at 21 and 28 days, with the reduction becoming more significant at higher PET concentrations. Notably, at 28 days, the mix with 4.2% PET showed a decrease in compressive strength of over 31.06% relative to the control mix. In contrast, split tensile strength increased consistently across all curing periods. The 4.0% PET mix achieved a 35.86% increase at 7 days, while the 3.8% PET mix showed the highest increase of 62.84% at 21 days. At 28 days, the 4.0% PET mix again showed the highest improvement, with a 45.35% increase in split tensile strength. These findings suggest that while a higher PET content may negatively impact long-term compressive strength, optimal PET incorporation can substantially enhance split tensile capacity, crack resistance, and ductility. Overall, the study demonstrates the sustainable utility of PET waste as a partial sand replacement in concrete, improving specific mechanical properties and promoting environmental sustainability. The results further confirm that compressive and tensile strengths tend to decrease with increasing PET content beyond optimal levels.

Keywords: Compressive strength, PET powder, Partial Replacement, Split tensile strength.

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1. Introduction

Despite its apparently insignificant nature, sand is an essential component of our existence. It is the main component used to build contemporary cities. Sand and gravel are combined to create the concrete required to build office buildings, shopping centers and residential complexes, as well as the pavement used to build highways that connect them. Sand that has melted is used to make the glass in all windows, windscreens, and smartphone screens. Additionally, almost every piece of electronic equipment in your home, including the silicon chips found in our phones and laptops, is composed of sand [1]. The last 20 years have seen the production of half of all polymers ever produced. From 2.3 million tons in 1950 to 448 million tons in 2015, production grew at an exponential rate. By 2050, production is predicted to double. Approximately eight million tons of plastic debris from coastal countries end up in the oceans each year. It would be the same as filling five garbage bags with trash on every foot of the world's shoreline. Additives are often employed in plastics to increase their strength, flexibility, and durability. However, if a product ends up as litter, several of these chemicals can prolong its life; according to some forecasts, it will take at least 400 years for it to decompose [2]. According to studies, concrete's compressive strength decreases when recovered waste plastic is used in place of natural particles. For instance, the strength was reduced by 50% when PVC granules were used in place of up to 50% of the sand. Three primary causes contribute to the reduction in strength: increased air content, weakened cement paste-plastic aggregate binding, and decreased plastic aggregate strength and stiffness. Concrete is further weakened by the increased porosity in the interfacial transition zone caused by the low water absorption of plastic particles. The study shows that discarded plastic can be included into concrete to lessen trash going to landfills and possibly enhance the material's mechanical qualities. Waste plastic can be used to replace up to 10% of cement, fine, and coarse aggregates in concrete without changing the concrete's consistency or chemical composition, thereby providing a sustainable approach to resource use and waste management [3].

According to the slump test, batches containing recycled PET fibers had a slump of 472 mm, whereas control samples had a 22% higher slump. Higher dosages and ratios improved slump, probably because the fibers were more flexible, but the fiber dose and aspect ratio had little effect. Comparing 100 $\times$ 200 mm concrete cylinders to control samples, compressive testing revealed that adding recycled PET fiber had little impact on the final compressive strength. The stress-strain curves for varying fiber doses and dimensions, however, show that the addition of PET fibers improved the concrete's compressive toughness [4]. Higher replacement percentages lead to higher energy absorption; the reference specimens have the lowest absorption. At a replacement rate of 12.5%, the maximum energy absorption takes place, meaning it's 108.28% higher than the reference. Energy absorption is 50% greater than that of the reference specimens at a replacement rate of 5% [5]. Our initiative to partially substitute sand in building with waste PET plastic tackles a number of significant resource and environmental issues. Recycling PET plastic trash could lessen its environmental impact and encourage more sustainable waste management techniques. PET plastic waste is an important component of pollution and landfill accumulation. Important natural resources can also be maintained by substituting natural sand, whose mining destroys ecosystems and depletes riverbeds. In keeping with international initiatives to promote the use of waste materials, this strategy promotes sustainable development methods by providing an environmentally friendly substitute for traditional building materials. Incorporating recycled plastic trash into concrete has become a viable way to improve material performance and reduce environmental issues.

The potential of waste polyethylene terephthalate (PET) and other plastic derivatives as aggregates, fibers, and reinforcements in concrete has been investigated in a number of research. Utilizing recycled PET [6] examined the time-temperature characteristics of polymer concrete, proving its feasibility for use in building applications. Similar to this, [7] investigated how plastic particles affected the durability and mechanical strength of concrete. The valorization of post-consumer waste plastic and PET bottle aggregates was the subject of studies by [8] and [9], respectively. The results showed encouraging results in terms of workability, density decrease, and impact resistance. Furthermore, [10] investigated the incorporation of certain waste components into concrete mixtures, indicating that plastic trash enhances sustainability in the building industry. Additionally, studies have shown that polymer-modified concrete reinforced with waste plastic fibers can increase durability and flexural strength [11]. Furthermore, studies by [12] and [13] examined how concrete compositions could be made tougher and more ductile by substituting scrap tire rubber and textile fibers, respectively, for conventional particles. The usage of fiber-reinforced polymer (FRP) encased rubberized concrete and the effects of recycling PET bottles in building materials were the subjects of other investigations, including those conducted by [14] and [15]. A thorough analysis of recycled plastic in concrete was presented by [16] confirming its viability for use in large-scale building. The mechanical characteristics of recycled PET fiber-reinforced mortar and concrete were further investigated by [17] and [18], respectively, and the results showed notable increases in structural integrity. Recent developments by [19] and [20] showed potential uses in load-bearing structures by successfully integrating plastic waste into fiber-reinforced concrete beams. The addition of waste plastic fibers to reinforced concrete beams has been shown to improve its ductility and shear strength [21]. Furthermore, research by [22] on the substitution of PET waste for fine aggregates demonstrated that it may be used to create lightweight and eco-friendly concrete composites. The mechanical behavior of PET-modified concrete was evaluated in other noteworthy research by [23] and [24], which showed how well it improved impact resistance and decreased shrinkage cracks. The performance of plastic-modified concrete is assessed using standardized testing techniques which guarantee adherence to industry standards. The use of recycled plastics in concrete offers a practical substitute for conventional materials, supporting the circular economy concepts and lowering dependency on non-renewable resources in light of the growing concerns over environmental sustainability and waste management.

The consequence of powdered PET on the microstructure, particle-cement bonding, and overall performance of concrete in contrast with shredded PET is one of the research gaps in our project. The long-term impact on characteristics including permeability, freeze-thaw resistance, and chemical attacks, as well as durability tests under various conditions in the environment require consideration. Additionally, the cost-effectiveness and adaptability of utilizing powdered PET are frequently disregarded, as are the environmental effects determined by lifecycle assessments. Investigating hybrid replacement using distinct industrial byproducts alongside particular uses for sustainable or lightweight building could also provide meaningful information and close knowledge gaps.

The study looks into using Polyethylene Terephthalate Waste Powder (PWP) in mortars as a partial substitute for sand. It finds that while higher PWP percentages reduce density and mechanical qualities, 5% PWP improves workability and strength. By increasing compressive strength and ductility, the ideal 5% PWP provides an environmentally beneficial way to control waste in building materials. It is advised to conduct more durability research [25]. The study investigates the utilization of waste Polyethylene Terephthalate (PET) in concrete by substituting 3%, 6%, and 9% PET by weight for fine particles. According to the study, adding PET to concrete weakens it, but a 3% PET component provides the optimal strength-to-sustainability ratio. Concrete's density barely changed, yet using 3.52% PET resulted in a 0.47% cost reduction. According to their results, PET aids in waste management and marginally lowers expenses, but if utilized in excess of what is necessary, strength is compromised. For real-world applications, the study suggests more research on maximizing PET content, environmental impact, and durability [26]. To lessen plastic waste and enhance material qualities, the study looks into replacing some of the sand in concrete with PET bottle fibers. PET fibers in concrete mixtures containing 1%–5% demonstrated the maximum flexural strength at 2.5% and the best compressive strength at 2%. Strength declined beyond these percentages.

According to the findings, replacing up to 2.5% of the PET fiber in concrete increases its strength and provides a sustainable way to reduce waste and improve material quality. Research on additives may be necessary to further improve performance [27]. For two main reasons, the percentages of 3.8%, 4%, and 4.2% were chosen to partially replace sand with plastic. The values were selected to examine performance just below (3.8%) and above (4.2%) this criterion since research showed that a 4% replacement is a commonly used and successful benchmark. This allowed for sensitivity analysis close to the predetermined range. Second, utilizing larger percentages was not feasible due to material availability limitations, therefore these small changes were both useful and scientifically significant for the study.

The objective of this study is to evaluate and compare the compressive and tensile strength between ordinary M20 grade plain concrete and PET mixed concrete. The scope of this study is comparison of compressive and tensile strength of plain concrete of M20 grade and concrete mixed with PET powder. Compressive strength and Tensile strength of plain concrete and PET mixed concrete comparison study has been studied for M20 grade of concrete only. The results and outputs may vary for other grades of concrete. The study is conducted using 3.8%, 4% and 4.2% PET replacement of fine aggregate. The fineness modulus analysis of natural sand and PET pouches were not conducted. Only one specimen per mix was evaluated for tensile strength. To guarantee statistical validity, future research should strive for a minimum of three specimens per test circumstances.

2. Methodology

This experiment investigates the effects of partially replacing fine aggregates in concrete with varying percentages of polyethylene terephthalate (PET) waste, which has been cut, shredded, and powdered by machinery. The optimal weight percentage of PET waste is determined by comparing concrete samples with different PET contents against reference samples containing only fine aggregates. The concrete mix used is a nominal M20 mix (1:1.5:3) with a water-to-cement ratio of 0.5, following Indian Standards. This water-to-cement ratio ensures adequate hydration, and the mixture meets the standard parameters

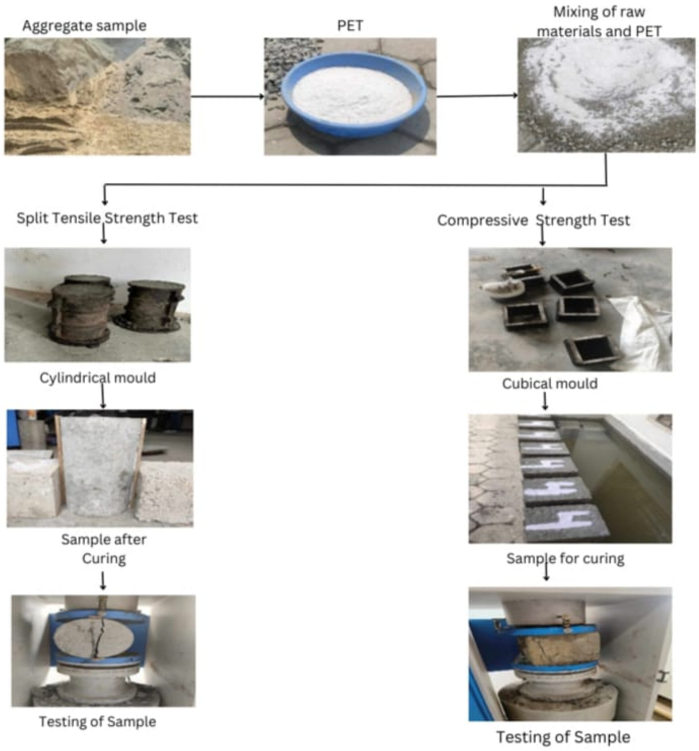

FIGURE 1. Chart showing Methodology.

for M20 concrete. Good quality potable water was used throughout the experiment. Fine and coarse aggregates were sourced with proper gradation and purity, and Ordinary Portland Cement (OPC) grade 43 was employed.

Concrete samples were prepared by replacing fine aggregates with PET powder at percentages of 0%, 3.8%, 4%, and 4.2% by weight. The materials were first dry-mixed to ensure uniform distribution of constituents. Water was then gradually added during mixing to prevent segregation and lump formation. Destructive strength tests, including compressive strength and split tensile strength tests, were conducted on the samples. Three specimens from each mix were tested at 7, 21, and 28 days to failure to determine their ultimate compressive strength. All tests were performed according to the relevant Indian Standard procedures. The methodology for this study is shown in Figure 1.

2.1. **Materials.**

2.1.1. *Cement.* In this study, ordinary Portland cement of grade 43 is utilized. In accordance with Indian Standard (IS) Code: 8112-1989, the cement's physical properties and chemical components are met. The cement utilized during the experiment was purchased from the commercial market, which guarantees that it satisfies standard quality and consistency requirements. The commercially available cement is widely used in a variety of construction applications, making it perfect for implementing real-world conditions in the experimental setup.

2.1.2. *Coarse Aggregates.* The coarse aggregates used in this study are crushed natural stones with a maximum size of 20 mm, while the fine aggregates consist of natural sand with a maximum size of 4.75 mm. The grading and specifications for the fine aggregates conform to the Indian Standard Specification IS 383:2016. The aggregates were procured directly from the quarry, ensuring high quality and providing cost advantages. These aggregates exhibit suitable shapes, robust durability, and consistent particle sizes that contribute to superior bonding within the concrete matrix. Additionally, the controlled particle size distribution and moisture content of the aggregates enhance the overall performance of the concrete. Testing of key properties such as grading and absorption was carried out to optimize their application in the construction process.

2.1.3. *Fine Aggregates.* It was clean and free from any types of dust, clay, and chemicals. PET is added to the reference mixture in three different percentages (3.8%, 4%, and 4.2%) by weight of sand as a partial replacement.

2.1.4. *Pet.* In this investigation, PET bottles of various sizes were collected from nearby recycling plants and processed into a fine powder. The polyethylene terephthalate (PET) particles underwent sieve analysis to determine their suitability for use in concrete. Specifically, the powdered PET was sourced from a recycling facility in Itahari, Nepal, where plastic waste bottles are collected, shredded, and powdered. This recycled PET was incorporated into the concrete mix as a partial replacement for fine aggregate to evaluate its potential as a sustainable building material. Besides promoting reuse of plastic waste and supporting environmental sustainability, this approach provides valuable insight into how PET influences the durability and strength characteristics of concrete. The PET powder used was clean and free from contaminants such as dust, clay, and chemicals. The application of recycled PET in this experiment aims to develop innovative methods for utilizing waste plastic in construction, thereby improving both material efficiency and environmental performance.

FIGURE 2. Shredding Machine for Powdered PET.

FIGURE 3. PET Powder.

2.2. **Mixture Proportions.** In this study, a nominal mix for M20 concrete (1:1.5:3) was used. The water-to-cement ratio was maintained at 0.5.

TABLE 1. Material Quantities for Casting Specimens

Cement (kg)	Sand (kg)	Aggregate (kg)	Water (L)	PET (%)
6.41	10.21	22.05	3.21	3.8
6.41	10.19	22.05	3.21	4.0
6.41	10.17	22.05	3.21	4.2

2.3. **Preparation of the Test Specimens.** Prior to use, the fine and coarse aggregates are cleaned and washed. Before casting, all cube and cylinder molds are prepared, cleaned, and lubricated. To partially replace sand, the PET waste particles are first processed and combined according to the weight percentages mentioned above. The aggregates, including gravel and PET waste substitutes, are mixed in a mixer. Cement is then added to the concrete mixture. Finally, water is gradually added while mixing continuously for at least two minutes.

TABLE 2. Variation in Specimen Types Prepared

S.N	Specimen Type	Set 1	Set 2	Set 3	Total Specimens
1	Cube	12	12	12	36
2	Cylinder	4	4	4	12
	Total Number of Specimens Prepared				48

Figure 4. Specimen Casted.

2.4. **Laboratory Tests.** Compressive strength tests were conducted using a compression testing machine with a capacity of 2000 kN, following the guidelines specified in IS 516:1959. For each substitution ratio, 36 concrete cubes measuring 150 × 150 × 150 mm were cast to evaluate compressive strength at curing ages of 7, 21, and 28 days. Similarly, split tensile strength tests were performed using the same 2000 kN capacity compression testing machine in accordance with IS 5816:1999. For this test, twelve cylindrical specimens measuring 150 mm in diameter and 300 mm in height were prepared—four specimens for each curing age.

Figure 5. Preparation of Compression Test Specimens.

FIGURE 6. Failure Modes of Specimens.

3. Results and Discussions

3.1. **Compressive Strength.** Concrete specimens were tested to assess their capacity to withstand axial loads applied uniformly along their length. This test is critical for evaluating the suitability of concrete for structural applications, as it provides essential data regarding the material's overall strength and durability. When compared to the standard M20 mix, the addition of PET demonstrated a significant influence on compressive strength. Mixes containing 3.80% and 4.00% PET exhibited notable increases in compressive strength at 7 days by 26.44% and 40.53%, respectively, indicating enhanced early-age performance. However, all PET-modified mixes displayed lower compressive strengths than the control M20 mix at 28 days, with the reduction becoming more pronounced as the PET content increased. These results suggest that while PET addition can improve early strength, excessive PET content may negatively impact long-term compressive strength.

TABLE 3. Variations of 7-days Compressive Strength

S.N	% Addition of PET	Failure Load (kN)	Compressive Strength (MPa)	Avg. Compressive Strength (MPa)	% Change in Compressive Strength
1	0%	292.5	13.00		
		289.8	12.88	12.97	–
		293.2	13.03		
2	3.80%	332.7	14.79		
		392.2	17.43	16.40	26.44
		382.1	16.98		
3	4%	396.9	17.64		
		468.2	20.81	18.23	40.53
		365.2	16.23		
4	4.20%	338.8	15.06		
		316.3	14.06	14.58	12.43
		329.2	14.63		

At 21 days, compressive strength for all PET-modified mixes was also lower than that of the control mix, with decreases of 5.54%, 11.19%, and 38.31% observed for the 3.80%,

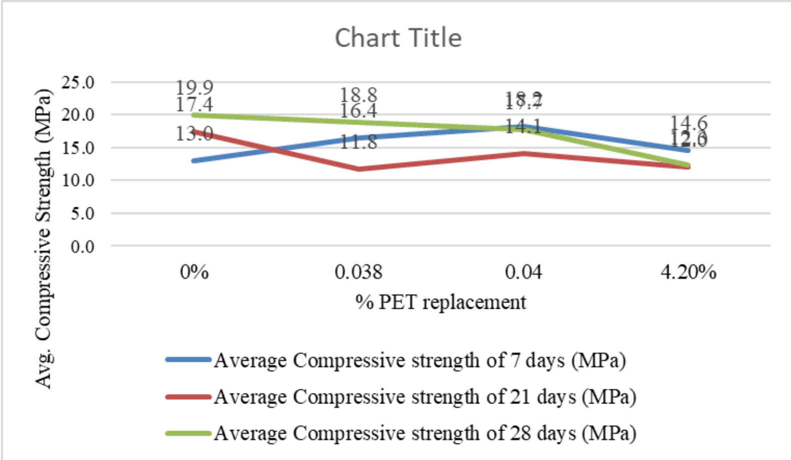

FIGURE 7. Compressive Strength Test of Samples Obtained After Curing for Respective Days.

TABLE 4. Variation of 21 Days Compressive Strength

S.N	% Addition of PET	Failure Load (kN)	Compressive Strength (MPa)	Avg. Compressive Strength(MPa)	% Change in Compressive Strength
1	0%	391.8	17.41		
		394.4	17.53	17.42	–
		389.9	17.33		
2	3.80%	306.5	13.62		
		211.1	9.38	11.78	-32.37
		277.8	12.35		
3	4%	335.7	14.92		
		335.6	14.92	14.07	-19.24
		278.5	12.38		
4	4.20%	277.3	12.32		
		245.4	10.91	12.01	-31.06
		288.1	12.80		

TABLE 5. Variations of 28 Days Compressive Strength

S.N	% Addition of PET	Failure Load (kN)	Compressive Strength(MPa)	Avg. Compressive Strength (MPa)	% Change in Compressive Strength
1	0%	449.2	19.96		
		447.9	19.91	19.89	–
		445.7	19.81		
2	3.80%	423.9	18.84		
		417.3	18.55	18.79	-5.54
		427.2	18.99		
3	4%	396.5	17.62		
		404.3	17.97	17.67	-11.19
		391.8	17.41		
4	4.20%	274.2	12.19		
		283.3	12.59	12.27	-38.31
		270.9	12.04		

4.00%, and 4.20% PET mixes, respectively. Despite the early strength gains observed at 7 days, these findings indicate that PET incorporation adversely affects medium-term strength development. None of the PET-containing mixes attained the target M20 compressive strength of 20 MPa at 28 days. Strength reductions of approximately 32.37%, 19.24%, and 31.06% were recorded for the 3.80%, 4.00%, and 4.20% PET mixes, respectively. This trend confirms that although PET can enhance early-age strength, higher replacement levels significantly impair compressive strength over extended curing periods. Overall, the results indicate that PET waste can effectively improve both compressive and tensile strengths of concrete when used in optimal amounts. The ideal dosage varies by strength parameter, with 3.80% PET being optimal for tensile strength and 4.00% PET for early-age compressive strength. This variation suggests that while PET contributes to densification and crack resistance at moderate levels, it may act as an inert filler beyond a certain threshold, adversely affecting load distribution. These experimental findings support the sustainable reuse of PET plastic waste as a partial sand replacement, promoting environmental conservation while enhancing specific concrete properties. The strength development of the different concrete mixes over time is illustrated in Figure **??**.

3.2. **Split Tensile Strength.** Here, 12 cylindrical specimens were tested for their tensile strength. The highest split tensile strength was found to be 2.87 MPa with a 4% partial replacement of sand by PET plastic finer powder after 28 days of curing.The split tensile strength of various concrete mixes is shown in Figure 9 as it varies over 7, 21, and 28 days. When compared to the M20 control mix, the 7-day split tensile strength data show that the use of PET enhances early-age tensile performance. The mixes containing 3.80% and 4% PET showed the greatest improvement, with increases of 21.01% and 35.86%, respectively. A moderate 13.09% increase was seen even at 4.20% PET. PET has a beneficial influence on early-age tensile capacity, as seen by the control mix (0% PET).

Table 6. Variation of 7-Days Split Tensile Strength

S.N	% Addition of PET	Failure Load (kN)	Split Tensile Strength of 7 days (MPa)	% Change in Tensile Strength
1	0	90.9	1.29	–
2	3.8	110	1.56	21.01
3	4	123.5	1.75	35.86
4	4.2	102.8	1.45	13.09

Figure 8. Split Tensile Strength Test Specimens.

Split tensile strength at 21 days was considerably higher with PET incorporation than with the M20 objective of 1.74 MPa. The 3.80% PET concrete mix showed the greatest improvement at 62.84%, followed by 4.20% PET concrete mix (43.36%) and 4% PET concrete mix (24.61%). The target value was somewhat exceeded by the control mix. This demonstrates that, particularly at moderate contents, PET replacement improves medium-term tensile performance. With increases ranging from 23% to 44%, all PET-modified mixes performed better than the M20 tensile target of 1.98 MPa after 28 days.

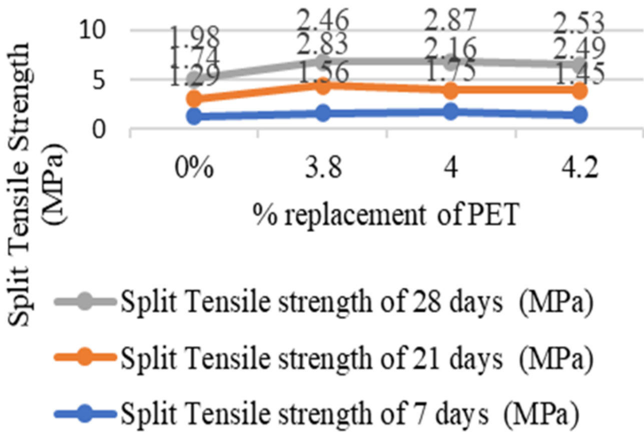

FIGURE 9. Comparison of Split Tensile Test Result.

The largest split tensile strength increase of 45.35% was attained by the 4% PET concrete mix, which was closely followed by the 4.20% PET concrete mix by 27.97% and 3.80% PET concrete mix by 24.32%. When applied in the right quantity, PET addition can improve long-term tensile capability, as demonstrated by the control mix.

TABLE 7. Variation of 21 Days Split Tensile Strength

S.N	% Addition of PET	Failure Load (kN)	Split Tensile Strength of 21 days (MPa)	% Change in Tensile Strength
1	0	122.7	1.74	–
2	3.8	199.8	2.83	62.84
3	4	152.9	2.16	24.61
4	4.2	175.9	2.49	43.36

TABLE 8. Variation of 28 Days Split Tensile Strength

S.N	% Addition of PET	Failure Load (kN)	Split Tensile Strength of 28 days (MPa)	% Change in Tensile Strength
1	0	139.8	1.98	–
2	3.8	173.8	2.46	24.32
3	4	203.2	2.87	45.35
4	4.2	178.9	2.53	27.97

The results of our examination correspond with an assortment of sources. Our usage of PET powder effectively addresses the requirement for sand substitutes, as highlighted by studies such as Beiser (2019). Similar to our findings at 3.8% replacement, research by Khajuria & Sharma and Khandelwal also revealed workability difficulties and strength benefits at optimal PET replacement levels. The ideal range indicated by Ahmed & Raju (2013) and OpenAI (2024) is 2–5%, which is quite comparable to our 3.8% outcome. According to research like Kumar & Kumar (2013) and Karthikeyan et al. (2019), our data aligns with the findings that lower PET replacement levels increase strength but higher amounts decrease it. The findings we found coincide with Meza et al. (2021) and Dawood et al. (2021), who further support the idea that PET waste enhances mechanical qualities and encourages sustainability.

4. Conclusion

This study demonstrates that PET powder from waste plastic bottles can be used to partially replace fine aggregate in concrete, providing a sustainable solution to environmental issues. PET in concrete promotes sustainable building practices by lowering dependency on natural resources and decreasing the amount of plastic waste that ends up in landfills. Future studies should examine performance in a range of environmental settings, long-term durability, and the possibility of large-scale implementation from an economic standpoint. The results of this study support sustainable development objectives by opening the door for creative and environmentally conscious solutions in the building sector.

Our research on using eliminated polyethylene terephthalate (PET) plastic to partially replace sand contains a number of gaps. First, little research has been done on the subject, especially within Nepal, and there is a lack of information about local aggregates, waste disposal methods, and environmental effects. The long-term environmental consequences of PET in building, including its effects on animals, water, and soil, are not widely understood. Furthermore, the financial viability and sustainability of substantial PET use have not been fully investigated, and further research is required in order to maximize the percentage of PET in different materials for construction.

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