Effect of PET bottle pieces and waste wrapper fibers on concrete compressive strength

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Abstract. In this study, the main goal was to look into the effect on concrete's compressive strength by the addition of used PET bottle pieces & wrapper strips collected from waste generated on railway stations. To achieve the target compressive strength for M50 grade concrete, strips were cut from waste wrappers and shredded polyethylene terephthalate (PET) pieces from PET bottles were used. Waste wrapper strips were cut down in three different aspect ratios and four different proportions, along with differing proportions of shredded PET bottle pieces. After 28 days of curing, compressive strength was determined and it is observed that the compressive strength of concrete was decreased by the inclusion of wrapper strips &PET bottle pieces in different ways. Mix ID M4 i.e. 5 x 30 mm, 7.5 gm wrapper &50 gm PET bottle pieces offer better performance relative to the other Mix IDs as compared to the control mix at 28 days. Therefore, 5 X 30 mm size strips of wrappers along with 50gm of PET bottle pieces are the best mix for the compressive strength of concrete compared with other mixes. In the case of proportioning different sizes of shredded wrappers used along with PET bottle pieces, improved results are obtained relative to all other Mix IDs as relative with the 28-day control mix. Multiple size strip of (PET) wrapper with a mixture of (5 x 20 mm, 2.5 gm), (5 x 30 mm, 3 gm), (5 x 40 mm, 2 gm), and 25 gm of broken bits of PET bottles is the better combination for concrete compressive strength than any other combination.

Keywords: Concrete, Polyethylene terephthalate (PET), Compressive strength, Fiber, Shredded plastic wrappers

1. Introduction
Concrete is a simulated substance in the building industry, used widely and comprehensively. In terms of the consumption of different usable resources on earth after water, it is ranked second. The justification for such a large use lies in the fact that it has high compression strength. Usage also leads to the simple availability and extended life of the ingredients. Concrete has certain bitter qualities, such as lower impact resistance, poor tensile and flexural strength, etc. It forced the researchers to find an alternative material for other construction materials such as cement, sand, fine and coarse aggregate to be used.

Plastic is an extraordinary human invention that has become important that inseparable part of the life of a common man. The disposal of different current varieties of plastics in existence has long been a core topic of human interest. The amount of polymeric waste in the form of polyethylene terephthalate (PET) bottles and snack wrappers is growing increasingly due to everyday life use. The annual intake of PET bottles accounts for more than 3, 00,000 million units. Plastics are one of such
products that are littering the oceans and environment. Since the 1950s, 9 billion tonnes of plastic have been made, according to a CNBC report. In this, only 9% of the plastic waste generated ended up being recycled, and another 12% was incinerated, the remainder 79% built up in landfills or ended up in the atmosphere elsewhere. Every year, we now manufacture almost 300 million tonnes of plastic, half of which is for single use. Per year, over 8 million tonnes of waste were poured into our oceans. According to the 2014-15 CPCB survey, India produced 51.4 million tonnes of solid waste, of which 91 percent was collected. 27 percent of the collected waste was recycled and the remaining 73 percent was disposed of at landfill sites. We discovered that about 2500 to 5000 units of bottles are collected every day from the station platforms and surroundings during our visit to Ahmedabad railway station. Our survey at Surat railway station also showed that Surat Municipal Corporation is disposing of a giant collection of around 1 tonne of plastic waste inclusive of PET bottles & waste wrappers from the railway station alone.

Polyethylene terephthalate (PET) belongs to the polyester family, which is specifically suitable for packaging food and liquids. It is growing exponentially in usage in the world, because of its immense usage, it has created a troubling challenge to the disposal of solid waste, as the plastic is non-biodegradable because needs a massive landfilling for its disposal. In contrast to its production, the recycling potential in the world is very limited. Since PET waste is not biodegradable, for hundreds of years it will exist in nature. The PET properties that have made its use more appealing in concrete are chemically inert, corrosion-resistant, light in weight. Researchers have expressed considerable concern about environmental sustainability and the re-use of non-biodegradable (PET) waste. Previous analysis experiments have demonstrated very specifically that PET waste is capable of enhancing different concrete criteria, and is a much safer choice than sending it to landfill.

The main purpose of this study is to improve the compressive strength of concrete by the use of plastic waste collected from railway stations and reuse it again as an additive in concrete works in railways. Strips cut from snack wrappers and polyethylene terephthalate (PET) pieces shredded from PET bottles have been used to achieve the target compressive strength for M50 grade concrete. In three different aspect ratios and four different proportions, wrapper strips were used, along with different proportions of PET bottle pieces.

2. Literature Review
To study the influence of PET fiber in concrete, the experimental work of various researchers was widely reviewed. Vadivel and Doddurani [1] experimented with a different percent of PET fiber and fruitful results were obtained in PFRC affecting mechanical properties as compared to standard concrete. The PET fibers were added in 1, 2, and 3 percent, and the experimental findings prove 3% of fiber inclusion produces a 12.5% improvement in compressive strength while there was an improvement of 9% in tensile strength and 8.12% in flexure strength. It was suggested that PET fibers behaved as crack arresters, thereby preventing shrinkage cracks, raising this property with the addition of PET fiber quantity. The mechanical activity of fiber reinforced concrete under stress and shear was studied by Afroz et al. [2]. In different percentages, such as 0.0%, 0.40%, 0.46%, and 0.52% as volume fractions, polyethylene terephthalate (PET Bottle) synthetic fibers of 40 mm long, 1.5 mm width, and 0.6 mm thickness was applied to the concrete. Test findings after 28 days of curing indicate that tensile strength and shear strength, relative to plain concrete, improved maximal values by about 25% and 70% with the addition of 0.52% and 0.46%, respectively. The findings reflect the fact that when fiber volume fraction was optimum, macro synthetic fiber reinforcement improved the shear strength. The decline above this proportion may be due to the poor bonding of the concrete matrix to fiber. Another study using waste PET fiber has been done by Hassan [3] on using PET fibers of 1, 2, and 3 cm varying lengths and mixed to the concrete by volume of the overall mixture at 0.5 and 1%, and engineering properties like workability, compressive, tensile, and flexural and abrasion resistance, and elastic modulus were studied. The study findings revealed that the compressive, flexural, and tensile strength of PET fiber reinforced mixtures is weaker than the control mixture. Asha and Resmi [4] optimized the effects of using excess PET bottles straight and crimped fibers. Cubes, beams, and
PET fibers with three different aspect ratios were applied from varying 0% to 1.5%. After the standard healing process, the slump test, compressive, ultimate tensile strength, and flexural strength checks were carried out on the concrete. From the experimental findings, it concludes that incorporating fiber material impacts concrete flow properties. The use of post-consumer waste PET bottles as fiber reinforcement was explored through this research. With the addition of plastic fibers in concrete, significant changes in strength are noted. Since decreases in strength were detected, the optimal strength was achieved at 1 percent of fiber content for all kinds of strengths there. The inclusion of (PET) fiber has been shown to have altered the action from brittle to ductile. It can be inferred from this experimental investigation that the PET bottles tend to be a low-cost material that can help address the issues of solid waste and reduce environmental contamination. In the cement composite, Marzouk [5] pioneered the use of consumed plastic bottle waste as a sand substitute. As partial and full replacements for sand in concrete composites, polyethylene terephthalate (PET) bottles were used. Sand volume fractions ranging from 2% to 100% have been supplemented by the same volume of granulated plastic and different sizes of PET aggregates. They concluded that the compressive strength of composites and plastic bottles shredded into small PET particles can be efficiently used as sand-substitution aggregates in concrete by substituting sand at a level below 50% by volume with granulated PET, the upper granular limit being equal to 5 mm. Ochi et al. [6] researched the production and use of recycled PET fiber as a concrete-reinforcing. A process that can be used to manufacture PET fiber from post-consumer PET bottles has been identified. Its alkali resistance was the topic of concern in the production of PET fiber; however, no issues were experienced when using the fibers in regular concrete. A process for shaping short fibers from waste PET bottles was developed by Kim et al. [7]. For fiber volume fractions of 0.5%, 0.75%, and 1.0%, the recycled PET fiber reinforced concrete was contrasted with polypropylene fiber reinforced concrete. The findings show that the compressive strength and elastic modulus decreased at a higher fraction of the fiber volume. In the PET fiber reinforced concrete specimens, however, cracking due to drying shrinkage was slower relative to standard concrete. The ultimate strength and relative ductility of PET fiber in reinforced cement concrete beams were considerably greater concerning structural member efficiency than those of companion species without fiber reinforcement. To improve the ductility of the concrete, Foti [8] played with the idea of using polyethylene terephthalate (PET) fibers. By literally cutting from waste plastic bottles, the fibers were collected. Improvements were recorded in the ductility of the concrete. The advantages of using post-consumption waste PET bottles in fiber form in concrete were optimized by Nibudey et al. [9]. Plastic bottles of excess mineral water are manually shredded into fibers during ingestion. Concrete was applied to the varying amounts (0% to 3%) of waste plastic fibers for two aspect ratios. Workability (slump, compaction factor), compression, split tension, and flexural measurements have been performed and the findings have been contrasted with ordinary concrete. Improvement in the mechanical properties of concrete was found at 1% fiber inclusion. Hadithi et al. [10] used plastic waste PET fibres to produce self-compacting concrete (SCC) with an aspect ratio of 28 and different volumetric fractions (0.25%, 0.5%, 0.75%, 1%, 1.25%, 1.5%, 1.75% and 2%). Experiments have shown that compressive and flexural strength is improved by the use of PET fibers in SCC. The behavior of SCC slabs under impact loading was also analyzed, and a sustainable increase in the impact of load resistance and energy absorption ability of slabs containing PET fibers was observed.

3. Materials and methods
In this experimental study, concrete mixes were formed using ordinary Portland cement conforming to IS 269:2015 [11] and crushed coarse aggregates (gravel) of 10 mm and 20 mm scale, fine local river aggregates of Zone-II consistent with IS 383:2016 [12]. As shredded pieces of waste PET bottles retained on a 4.75 mm sieve were used, and as seen in Table-1, wrappers in the form of strips were shredded in different dimensions having different aspect ratios. In the proportion of single and multiple size wrapper strips along with broken pieces of PET bottle were mixed to the concrete as per
Tables 1 & 2. The M50 grade concrete was formulated as per IS 1026:2009 [13] using different proportions of materials for the design mix, as shown in Table-3. The specimens were cast according to the test specifications defined by the standard Civil Engineering Code of practices. The casting of cube prototypes was carried out in separate groups composed of traditional concrete with different amounts of PET fibers for concrete grade M50. The purpose of casting the specimens was to test and evaluate the effect of PET fibers on concrete compressive strength.

| Table 1 | Proportion of broken pieces of PET bottle and Single Size Plastic (PET) Wrappers |
|---------|--------------------------------------------------------------------------------|
| Mix ID  | Broken pieces of PET Bottle | Plastic (PET) Wrappers Dimension / Weight |
| Control Mix | - | - |
| M1 | 25gm | 5 X 20mm / 7.5gm |
| M2 | 50gm | 5 X 20mm / 7.5gm |
| M3 | 25gm | 5 X 30mm / 7.5gm |
| M4 | 50gm | 5 X 30mm / 7.5gm |
| M5 | 25gm | 5 X 40mm / 7.5gm |
| M6 | 50gm | 5 X 40mm / 7.5gm |

| Table 2 | Proportion of broken pieces of PET bottle and Multiple Size Plastic (PET) Wrappers |
|---------|--------------------------------------------------------------------------------|
| Mix ID  | Broken pieces of PET Bottle | Plastic (PET) Wrappers |
| Control Mix | - | - |
| M7 | 50gm | 2gm | 2.5gm | 3gm |
| M8 | 2.5gm | 3gm | 2gm | 2.5gm |
| M9 | 3gm | 2gm | 2.5gm | 3gm |
| M10 | 25gm | 2gm | 2.5gm | 3gm |
| M11 | 25gm | 2.5gm | 3gm | 2gm |
| M12 | 25gm | 3gm | 2gm | 2.5gm |

| Table 3 | Details of Control Concrete Mix Design in kg/m³ |
|---------|-----------------------------------------------|
| Material | Cement | Water | Sand | Coarse Aggregate |
|          |       |       |      | 10mm | 20mm |
|          | 469   | 178   | 362  | 211  | 494  |

4. Result and discussion
PET concrete specimens of varying proportions of broken pieces of the PET bottle and shredded plastic (PET) wrappers were manufactured to examine the compressive strength. The size of the sample was 150 X 150 mm concrete cubes cast using concrete grade M50. The cubes were manually vibrated by the use of a vibrator during the casting period. The specimens were removed from the molds within 24 hours and subjected to water curing for 7, 14, and 28 days. To achieve the compressive strength of concrete, the compressive strength test was performed on curated concrete cubes. At the rate of 5.2 kN/s, the load was applied before the specimen failed. By dividing the maximum compressive load by the cross-sectional area of the cube specimen, the compressive strength was then calculated [14].

| Table 4 | Average Compressive Strength of Concrete Mix in MPa |
|---------|---------------------------------------------------|
| Mix ID  | Control Mix | M1 | M2 | M3 | M4 | M5 | M6 |
| After 7 days | 36.31 | 27.84 | 26.43 | 29.82 | 30.71 | 30.1 | 31.46 |
| After 14 days | 50.52 | 32.82 | 30.9 | 42.43 | 41.43 | 38.93 | 40.69 |
| After 28 days | 59.57 | 38.74 | 37.71 | 43.28 | 47.14 | 41.12 | 45.35 |
Table 5 Average Compressive Strength of Concrete Mix in MPa

| Mix ID | Control Mix | M7  | M8  | M9  | M10 | M11 | M12 |
|-------|-------------|-----|-----|-----|-----|-----|-----|
| After 7 days | 36.31 | 24.83 | 25.43 | 24.63 | 26.84 | 28.97 | 27.69 |
| After 14 days  | 50.52 | 34.27 | 32.83 | 31.28 | 37.95 | 38.53 | 36.67 |
| After 28 days  | 59.57 | 36.55 | 37.68 | 34.63 | 41.44 | 44.78 | 39.97 |

Figure 1. Average compressive strength of concrete mix with a selected amount of broken pieces of PET bottles and Single Size Plastic (PET) Wrappers

Figure 2. Average compressive strength of concrete mix with a selected amount of broken pieces of PET bottles and Multiple Size Plastic (PET) Wrappers

Tables 4 and 5 show the effects of compressive strength experiments performed on control mix and PET concrete specimens with varying proportions of broken pieces of PET bottles and shredded plastic (PET) wrappers, and Figure 1 and Figure 2 are both graphically depicted. The finding reveals that, in contrast to the control combination, there is a drop in compressive strength in all PET fiber
combination IDs. It is observed that there is a marginal reduction in compressive strength (approx. 20%) for Mix ID M4 relative to all other Mix IDs as we used single size shredded plastic (PET) wrappers along with broken bits of PET bottle, compared to control mixes at 28 days. It is also noted that when shredded plastic (PET) wrappers are used in multiple sizes along with broken pieces of PET bottle Mix ID 11, compared to the control mix, the compressive strength (approx. 25%) is minimally reduced.

5. Conclusion
From the study, it is concluded that in all PET fiber mixture IDs, there is a reduction in compressive strength in comparison to the control mixture. Single size shredded plastic (PET) wrappers along with broken PET bottle pieces; Mix ID M4 offers better performance as compared to all other Mix IDs at 28 days as compared to the control mix. Thus, the best combination for the compressive strength of concrete is single size strip (PET) wrappers 5 X 30 mm along with 50gm of broken pieces of PET bottles. In the case of varying sizes of shredded plastic (PET) wrappers used along with broken pieces of PET bottles, Mix ID 11 gives better results are obtained relative to all other Mix IDs as compared to the 28-day control mix. Multiple size strip (PET) wrapper with a mixture of scale (5 x 20 mm, 2.5 gm), (5 x 30 mm, 3 gm), (5 x 40 mm, 2 gm) and 25 gm of broken pieces of PET bottles is the better combination for concrete compressive strength than any other combination.

Another part of the study shows that if 50gm PET bottle pieces are assumed to be replaced in a concrete cube, roughly 148kg of PET bottle pieces i.e. about 15000 bottles will be used per 1m³ of concrete, which directly impacts the recycling solid waste or landfill problem. In the same way, if we considered the 7.5gm wrapper strips are replaced in the concrete cube, it is feasible to minimize approximately 2.2kg of wrappers, i.e. 500 empty wrappers per 1m³ of concrete. Therefore, a sustainable solution can be provided if a reduction in compressive strength gain is hindered by additives such as silica fume and metakaolin.

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