Recycling of Domestic Plastic Waste Bags as Fine Aggregate in Concrete

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Abstract. Plastic has been used in many ways in modern life both in industry product as well as in domestic use. The waste generated by using plastic poses an enormous threat to the environment due to its non-degradable nature for a very long time. There has been a lot of effort to minimise plastic waste generation and reuse it. However, the plastic waste generation has been increased considerably in the past decade. This paper presents a potential use of plastic waste as fine aggregate in concrete. Experimental investigations were carried out to determine the strength characteristics of concrete by replacing fine aggregate with 10, 15, 20, and 25% of processed plastic waste. Tests were conducted on concrete specimens under tensile, compressive, and flexural loading conditions to understand its behaviour. Although there was a notable reduction in strength characteristics of the concrete specimens, the optimum strength was obtained at 15% sand replacement. The concrete mix prepared using plastic waste can be used for mass concreting and low load-bearing structures.

1. Introduction
A modern lifestyle, alongside the advancement of technology, has led to an increase in the amount of waste being generated. The various types of waste generated lead to disposal crisis. Humankind had generated 6.3 billion metric tons of plastic waste until the previous decade. Out of this, only 9% was recycled and 12% incinerated. The vast majority of 79% was thrown away. It is expected to generate four times more plastic waste over the next 30 years. If these trends continue 26 billion metric tons of plastic waste will be produced by 2050. Almost half of which will be dumped in landfills. Due to non-degradable nature of plastic, huge amount of waste would be accumulated in near future. Plastic takes more than 400 years to degrade, so most of it still exists in some form. Therefore, the management of such waste is one of the major environmental concerns worldwide [1].

In the past, several researchers have studied the possibility of recycling the plastic waste in various forms. The reuse of plastic waste helps in minimizing the environmental problem. With the scarcity of space for landfilling and cost associated, waste utilization has become an alternative to disposal [1]. Use of plastic waste as aggregate in concrete is considered as one of the possible options. The development of new construction material using recycled plastics is important to both the construction and the plastics recycling industries [2]. The use of plastic waste in concrete is economical and environment friendly. Several studies conducted to evaluate the properties of cement-composites containing various types of plastic waste as aggregate, filler or fiber [3-5]. Some researchers used glass, plastics, and demolished concrete to recycle in concrete [6]. Ground plastics and glass were used to replace the fine aggregates. The crushed concrete was used to replace coarse aggregates in concrete. The recycled materials partially substituted sand and coarse aggregates in concrete mixture. Studies were conducted to recycle waste...
polymeric materials as aggregate in concrete [7]. The efficiency of reusing plastic waste and plastic bags in concrete also investigated [8-13]. This paper presents an optimum content of plastic waste as a fine aggregate in concrete. The recycled plastic bags in concrete would reduce environmental pollution. One series of tests were conducted using sand and coarse aggregates for the concrete mix design of M25. Other tests were conducted by replacing sand with 10, 15, 20, and 25% of plastic waste by volume. The results were compared with the concrete prepared without adding any plastic waste as fine aggregate.

2. Materials and method

2.1. Cement
Cement is a crystalline compound of calcium silicates and other calcium compounds. Cement is used as a binder material, a substance that sets, hardens and binds other elements together. In the current investigation portland slag cement was used. The specific gravity of the cement used for this study was determined using Le Chatelier flask found to be 2.99. The specific gravity tests were repeated three times, and the average value is reported.

2.2. Coarse aggregate
Coarse aggregates are particles of sizes greater than 4.75 mm. Usually 9.5 to 37.5 mm diameter coarse aggregates are used in concrete mix design. Coarse aggregates can be obtained from primary, secondary, or recycled sources. In this study, crushed stones of size below 20 mm were used as coarse aggregates. The water absorption test conducted by weighing the aggregates soaked in water for 24 hours was found to be 1.2%. The specific gravity of the coarse aggregate was found out by weighing the certain quantity of coarse aggregate within a wire basket inside and outside the water. The specific gravity of coarse aggregates was found to be 2.84.

2.3. Fine aggregates
Fine aggregates consist of natural sand or crushed stone of particle sizes lower than 4.75 mm. Locally available river bed sand was used as primary fine aggregate in this study. The water absorption and specific gravity of the sand were found to be 1.5% and 2.71, respectively. Zone II sand was used in this study. One series of tests were conducted using sand as a fine aggregate. For all other tests sand was replaced with the plastic waste of 10, 15, 20 and 25% by volume.

2.3.1. Waste plastic as fine aggregate
Processed plastic waste bags were used in the concrete mix design. The specific gravity of waste plastic was determined using kerosene as it is lighter than water. The specific gravity of kerosene is 0.82. The specific gravity of plastic waste used in this study was found to be 0.95.

3. Process of plastic waste recycling
The various stages of processing to recycling plastic bags used in the current investigation are shown in figure 1. Plastic waste was collected from various sources and separated into several categories. The low-density plastic wastes were shredded into tiny pieces or flakes. The shredded plastic flakes were cleaned and compressed by applying heat to densify. The densified plastic wastes were formed into granules. The granules formed in this process were used in the current investigation.

4. Details of tests
Series of tests were conducted to determine compressive strength, tensile strength, flexural strength, bond stress and ultrasonic pulse velocity of concrete. Concrete mix were prepared replacing 10, 15, 20 and 25% by volume of fine aggregates by plastic waste. The mix design ratio of concrete used for the study was 1:1.4:2.5. The mix design was prepared for M25 grade of concrete. One series of tests was conducted without using plastic waste as fine aggregate. Compressive strength, ultrasonic pulse velocity, and pull out tests were carried out on cube specimens of 150 mm size each. The diameter of the reinforcement used during the pullout test was 16 mm. Tensile splitting tests were carried out on cylindrical specimens of height 300 mm and diameter 150 mm. Flexural strength tests were carried out on specimens of size 500 mm × 100 mm × 100 mm. In total, 54 tests were conducted. Three identical
specimens were cast at each condition and tests were conducted. The average values of the three tests are reported.

![Shredded plastic waste](image1)
![Compressed plastic waste](image2)
![Final granules/threads used in concrete](image3)

**Figure 1.** Various stages of plastic waste processing for recycle.

4.1. **Compressive strength test**
Compressive strength is the capacity of material or structure to withstand the load applied to it. It is measured using compressive strength testing machine. Cube or cylindrical samples are usually tested to determine the compressive strength of concrete. In this study, concrete cubes were cast using the design mix as per IS code guidelines [14]. For each mix, six cubes of dimension 150 mm × 150 mm × 150 mm were cast. After seven days of curing inside water bath, three cubes were tested to determine compressive strength using a universal compression testing machine. Similarly, another three cubes were tested after 28 days to determine its compressive load-carrying capacity.

4.2. **Tensile splitting test**
Concrete is very weak in tension due to its brittle nature. The tensile strength is one of the important properties of concrete. The tensile splitting test is usually carried out on cylindrical concrete specimens. The test was conducted using compressive strength testing machine. For each mix, six cylindrical specimens of 150 mm diameter and 300 mm length were prepared. After seven days of curing underwater, three specimens were tested, and the average strength was noted [15]. Other specimens were tested after 28 days of curing.

4.3. **Pull out test**
Pull out test measures the force required to pull out the reinforcement bar inserted into the concrete specimen. For each mix, three cubes of 150 mm × 150 mm × 150 mm were cast. For pullout test, 16 mm diameter reinforcement bars were used inside the concrete. The reinforcement were placed inside the
cubes up to about 10 mm from bottom. The bond stress was measured after 28 days of curing underwater [16].

4.4. Ultrasonic pulse velocity test

Ultrasonic pulse velocity (UPV) test is a non-destructive test to analyse the quality of concrete. The velocity of an ultrasonic pulse traveling through the concrete can indicate the strength and quality of concrete. An ultrasonic wave pulse was sent through concrete specimens and the time required to travel was noted. Higher pulse velocities indicate good quality and continuity of the material. Whereas, lower velocities may indicate concrete with voids or lesser density. In the current investigation, UPV tests were conducted after 28 days of curing [17].

4.5. Flexural strength test

Flexural strength test was conducted on hardened concrete. Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. Flexural strength tests were carried out [18] after seven days and 28 days of curing the specimens under water.

5. Results and discussion

The various tests conducted with and without plastic wastes were compared.

5.1. Effect of plastic waste as fine aggregate on compressive strength of concrete

Figure 2 presents the effect of plastic content on compressive strength of concrete after 7 and 28 days curing. The compressive strength was found to be constant after seven days curing for the sand replacement up to 15%. Beyond 15% replacement of sand by plastic waste, the compressive strength of the concrete was found to decrease. However, for the tests conducted after 28 days of curing, the compressive strength was found to decrease gradually. A change in the compressive strength of 30 and 35% was noted for 25% sand replacements after curing for 7 and 28 days, respectively. The plastic waste granules used in this investigation were found to be smoother and slippery. Therefore, the bonding between granules was weaker, resulting in lower compressive strength as compared to aggregates. Therefore, the concrete with a lower percentage of plastic as a fine aggregate can be used in large construction projects. High percentage of waste plastic can be used to replace sand for lighter structures where the total amount of load is lesser.

![Figure 2](image-url)  
Figure 2. Change in compressive strength due to addition of plastic as fine aggregate
5.2. Effect of plastic waste as fine aggregate on tensile strength of concrete
Figure 3 presents the change in tensile strength with various percentages of plastic waste used in concrete after 7 and 28 days curing. The crack propagation during the tensile test on the cylindrical concrete specimen is shown in figure 4. The variation in tensile splitting strength for various percentages of plastic waste used in concrete was not significant after 7 days curing. Any particular trend of change in flexural strength was not observed. However, the tensile splitting strength determined after 28 days curing was found to be constant up to 15% sand replacement. For a further increase in plastic waste content, the tensile splitting strength was found to decrease by about 18%. Hence, the concrete with up to 15% of plastic replacement can be used for various construction purposes.

![Figure 3](image1.png)

**Figure 3.** Variation in tensile strength due to addition of plastic waste as fine aggregate.

![Figure 4](image2.png)

**Figure 4.** Crack propagation during tensile splitting test in concrete cylinders.

5.3. Effect of plastic waste as fine aggregate on flexural strength of concrete
Flexural strength is one of the measures of tensile strength of concrete. The force required to resist the failure of an unreinforced concrete beam or slab by bending is determined. Figure 5 shows the crack propagation of the specimen after failure. The effect of plastic waste on flexural strength of concrete is shown in figure 6. After 7 days curing, the flexural strength decreased for 10% addition of plastic waste as compared to concrete without any plastic waste. Upon further increase in plastic content, the flexural strength was found to be constant. However, for 28 days curing the flexural strength was found to increase by 10% addition of plastic waste. At higher percentage of plastic content similar behaviour as observed for 7 days curing was found.

![Figure 5](image3.png)

![Figure 6](image4.png)
5.4. Effect of plastic waste as fine aggregate on pull out strength of concrete
Figure 7 presents the bond stresses measured from pull out tests with various percentages of plastic waste. There was no particular trend obtained from pull out test results. The maximum bond stress was obtained at 15% sand replacement by plastic waste.

5.5. Effect of plastic waste as fine aggregate on ultrasonic pulse velocity of concrete
The UPV is a non-destructive test to determine the strength of concrete. Figure 8 presents the variation of ultrasonic pulse velocity with different percentages of plastic waste. The UPV was found to decrease continuously with an increase in plastic content. Therefore, the strength of the concrete tested for the investigation would be decreased with higher percentages of plastic content. The results indicate that the rigidity of the material reduces.

6. Conclusions
Series of tests were conducted to determine the suitability of plastic waste bags as fine aggregates in concrete. Tests were conducted after curing the concrete specimens for 7 and 28 days. Based on the results obtained, following conclusions are drawn:

- The compressive strength of recycled plastic concrete was found to decrease with increase in plastic content. The surface of the plastic is smoother than sand, and hence the bonding between elements in the concrete mix is weaker.
The tensile strength was found to be constant up to 15% sand replacement after 28 days curing under water.

The bond stress was observed to be maximum at 15% replacement of sand replacement. The strength of the modified concrete mix with up to 15% addition of plastic waste as fine aggregate was noted to be within the permissible limit.

Therefore, 15% of sand can be replaced by plastic waste in concrete for light structures. The use of plastic waste in concrete would be helpful in reducing the environmental pollution. The concrete with plastic waste would be lighter as well as economically viable.

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