Experimental Study on Mechanical Properties of Concrete Using Plastics as Fiber (PP) and Partial Replacement of Fine Aggregate (PET)

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Abstract. Worldwide research has been conducted concerning the use of Fiber and PET (Poly Ethylene Teraphthalate) in the area of strengthening of the reinforced concrete members. The PET bottles are the remaining from the storage of cold beverages or drinks or even water. On the other side ultra-high strength with high performance becomes the need of the hour in order to make the structure durable, sensitive to the environment and even economical sometimes. Composite material has been developing these days to satisfy the construction industry by producing concrete which are more flexible and durable. Disposing plastics in any form is the big challenge to the producers and users of plastic. Producing eco-friendly plastics have not reached its height in today's scenario. Here is an attempt to dispose the same effectively by incorporating it in to the concrete as effective component. Crushed PET bottles have found its way in concrete when replaced for fine and coarse aggregates by its improvised strength. PET bottles ad fine aggregate and polypropylene fiber to enhance the tensile property of concrete has been made a try with M35 grade concrete in order to make it effective light weight and efficient concrete. The mechanical properties have been assessed and the performance of the concrete has been evaluated in this study.

1. Introduction

Plastic irrespective of its any kind would take several years commonly (20-30 years) for decomposition [17]. Many attempts has been made and under research for finding effective methods of disposal of plastics [1]. Polymers like polypropylene and polyethylene terephthalate are the commonly used for manufacturing plastic products [3]. Production of plastics being uncontrolled in today's era even after banning its usage, and there is a need to find the effective disposal method. One effective method identified is the usage of waste plastic in construction materials [2]. Hence, is an attempt to replace the construction materials like fine aggregates by means of waste plastics especially the available abundant plastics like polypropylene and polyethylene terephthalate [15]. Some plastic of some type will usually take several years (20-30 years) for decomposition. Many attempts to find effective methods of disposing of plastics have been made and are under research.[4] Polymers such as polypropylene and terephthalate polyethylene are the most widely used in plastic goods. In today's era, plastics production is uncontrolled even after its use has been banned; the effective method of disposal has to be found. One effective method identified is the use of waste plastics in building materials.[13].
Therefore, an attempt is made to replace building materials such as fine aggregates with waste plastics, particularly the abundant plastics available such as polypropylene and polyethylene terephthalate. The objectives of the project are

- To investigate the material properties made up of concrete,
- To study concrete resistance parameters using plastic waste and fibres.
- To identify the optimum content of the plastic waste (PET) along with fiber (PP) to be added to concrete.

2. Literature review

Addition of 0.3%, 0.6% and 0.9%, volume of polypropylene increase the splitting tensile strength of concrete by 15.1%, 7.8% and 5.6% respectively [16]. Water absorption increased with increasing in dosage of polypropylene fiber, the failure mode of concrete matrix depended on the fiber dosage and failure mode of PFRC was bulging in transverse direction.[18] Compressive strength enhanced up to 5% to 10% substitution of the fine aggregate with PET bottles waste and it is diminished for 15% and 20% replacements.[20] The flexural and split tensile strength were observed to be improved up to 10% addition of the fine aggregate with PET bottle aggregate and it is diminished for 15% and 20% replacements. The mixture containing PET particles would have more porous structure which causes reduction in ultrasonic pulse velocity.[14] Thus PET concrete can be used as a proper sound absorbent structural material. Recycling of plastic waste with river sand reduces its negative environmental impact of river sand quarries, reduces the depletion of natural resources. The inclusion of fibers content increases the flow properties of concrete. The density was also affected but made concrete slightly lighter weight.[7]

![Table: 1 Ingredients](image)

### Table: 1 Ingredients

| S.No | Ingredients Used      | Type of Ingredient                                      |
|------|-----------------------|---------------------------------------------------------|
| 1.   | Cement                | Ordinary Portland Cement 53 grade (OPC)                |
| 2.   | Fine aggregate        | M sand, Polyethylene Terephthalate (Recycled Plastic)  |
| 3.   | Coarse aggregate      | Gravel or crushed stone                                |
| 4.   | Fiber                 | Polypropylene Fiber (Aspect ratio 200)                 |
| 5.   | Water                 | Ordinary potable water                                  |
| 6.   | Admixture             | Silica Fume                                             |

2.1 Polypropylene Fibres

Polypropylene fibers are the synthetic fiber produced by the petroleum by-product and used in concrete and mortar to overcome concrete deficiencies.
Figure 1: Polypropylene Fiber

Table 2: Water Absorption of Ingredients

| Material               | Water absorption in % after 24hrs |
|------------------------|----------------------------------|
| Polypropylene fibers   | 0.3                              |
| Poly Ethylene Terephthalate | 0.1                          |
| Fine Aggregate        | 1.2                              |
| Coarse Aggregate      | 1.38                             |

Table 3: Properties of Poly Ethylene Terephthalate

| Properties                                      | Values         |
|------------------------------------------------|----------------|
| Density (gm/cm$^3$)                            | 1.3 - 1.4      |
| Coefficient of thermal expansion ($\times10^{-6}$K$^{-1}$) | 20 - 80        |
| Lower limit of working temperature ($^\circ$C)  | -40 to -60     |
| Upper limit of working temperature ($^\circ$C)  | 115 - 170      |

Table 4: Physical Characteristics of Polypropylene Fiber

| Property         | Value |
|------------------|-------|
| Length (mm)      | 12    |
| Diameter (mm)    | 0.034 |
| Youngs Modulus (MPa) | 2800   |
| Melting point ($^\circ$C) | 160    |
| Burning point ($^\circ$C) | 590    |

3. Results and Discussion
3.1 Compressive Strength

The 15 cm x 15 cm x 15 cm cubes were tested for compressive strength. The cubes tested have been cured under normal room temperature in ordinary drinking water for 28 days as per IS 516:1959 Method of Tests for Strength of Concrete as per Bureau of Indian standards, New Delhi, India. For the combination of trail mixes, three cubes were tested using compression testing machine at the age of 28 days of curing as shown in Figure 2 and the test results are shown in Tables 4 and 5. The compressive strength test results shows an increase for M3P30, ie, mix 3 with PET proportion as 30%. Later the strength starts to decrease for the further mix ratios.
Figure: 2 Compressive Strength Test Setup

Table 5 Results of PET & Fiber Concrete under Compression

| Mix Designation | Load (kN) | Compressive Strength @ 28 days (MPa) |
|-----------------|-----------|-------------------------------------|
| M0P0            | 700.2     | 31.12                               |
| M1P10           | 666.22    | 29.61                               |
| M2P20           | 652.05    | 28.98                               |
| M3P30           | 667.35    | 29.66                               |
| M4P40           | 617.17    | 27.43                               |

Table: 6 Test results of Silica fume Concrete

| Mix Designation | Load (kN) | Compressive Strength @ 28 days (MPa) |
|-----------------|-----------|-------------------------------------|
| M0P0S15         | 702.38    | 31.217                              |
| M1P10S15        | 699.52    | 31.09                               |
| M2P20S15        | 701.28    | 31.168                              |
| M3P30S15        | 702.47    | 31.221                              |
| M4P40S15        | 701.78    | 31.19                               |

Figure: 3 Compressive Strength at 28 days
The percentage of strength increase for various mixes starting from control mix (M0P0) to mix 4 with PET 40% (M4P40) against the control mix along with 15% of silica fume (M0P0S15) to mix 4 with PET 40% and silica fume 15% (M4P40S15) has been shown in the following table.

Table 7 Percentage of Strength increased

| Mix Designation       | % of Strength Increased |
|-----------------------|-------------------------|
| M0P0 - M0P0S15        | 0.31%                   |
| M1P10 - M1P10S15      | 5%                      |
| M2P20 - M2P20S15      | 7.55%                   |
| M3P30 - M3P30S15      | 5.26%                   |
| M4P40 - M4P40S15      | 13.71%                  |

3.2 Split Tensile Strength

Indirect tensile strength or Split tensile strength tests has been tested on cylindrical specimens of size 150 mm diameter and 300 mm length by curing it for 28 days in ordinary potable water using the compression testing machine as shown in Figure 4 and the test results are shown in Table 8 & 9.

\[ F_t = \frac{2P}{(3.14 \times (DL))} \]  

Where,
- \( F_t \) - Split tensile strength of the specimen in (MPa)
- \( P \) - Maximum load applied to the specimen (N)
- \( D \) - Diameter of the specimen (mm)
- \( L \) - Length of the specimen (mm)

Table 8 Strength results of PET & Fiber Concrete under Tension

| Mix Designation | Load (kN) | Tensile Strength @ 28 days (MPa) |
|-----------------|-----------|----------------------------------|
| M0P0            | 269.88    | 3.82                             |
| M1P10           | 193.58    | 2.74                             |
| M2P20           | 170.97    | 2.42                             |
| M3P30           | 149.07    | 2.11                             |
| M4P40           | 139.89    | 1.98                             |

As like that of compressive strength, the split tensile strength value increases for M1P10 and shows further decrease in the values which is represented in table 8.
Table 9 Test results of Silica Fume Concrete

| Mix Designation | Load (kN) | Tensile Strength @ 28 days (MPa) |
|-----------------|-----------|----------------------------------|
| M0P0S15         | 272.71    | 3.86                             |
| M1P10S15        | 198.52    | 2.81                             |
| M2P20S15        | 176.77    | 2.502                            |
| M3P30S15        | 154.72    | 2.19                             |
| M4P40S15        | 141.37    | 2.001                            |

Figure: 5 Split Tensile Strength Results

Table 10 Percentage of Strength Increase

| Mix Designation      | % of Strength Increase |
|----------------------|------------------------|
| M0P0 - M0P0S15       | 1.05%                  |
| M1P10 - M1P10S15     | 3%                     |
| M2P20 - M2P20S15     | 3.39%                  |
| M3P30 - M3P30S15     | 3.79%                  |
| M4P40 - M4P40S15     | 1.06%                  |

3.3 Flexural Strength

Concrete prisms of size 100mm x 100mm x 500 mm has been used to determine the flexural strength of concrete being weak in tension. The test set up includes central point loading or called third point loading. The specimens are placed as shown in figure 6 in the testing machine which is of reliable type and has sufficient capacity to test. The results found are represented in the Tables 11 & 12.

Flexural strength = \( \frac{P \times L}{B \times D^2} \)  \hspace{1cm} (2)

Where,
P - Load applied to the specimen (KN)
L - Length of the specimen (mm)
B - Breadth of the specimen (mm)
D - Depth of the specimen (mm)
Similarly the percentage increase for the designated mixes has been shown in the table 13. The increase in percentage was found to be high was Mix 1 with PET 10% and silica fume content 15%. Whereas further it starts to decrease gradually and deliberately for Mix 2 and 3 respectively with a percentage of 16.68% and 2.38%.
Table: 13 Percentage of Strength Increase

| Mix Designation | % of Strength Increase |
|-----------------|------------------------|
| M0P0 - M0P0S15  | 0.71%                  |
| M1P10 - M1P10S15| 18%                    |
| M2P20 - M2P20S15| 16.68%                 |
| M3P30 - M3P30S15| 2.38%                  |
| M4P40 - M4P40S15| 5.87%                  |

4. Conclusion

1. Comparing the compressive strength test results of conventional concrete, fiber induced concrete and silica fume concrete, it was evident that the compressive strength increases to 31.221 MPa for silica fume concrete whereas the test results of conventional and fiber concrete are found to be 31.12 and 29.66 MPa respectively.

2. Similarly the split tensile strength of adding PET as fine aggregate and PPA as fiber in concrete shows the indirect tensile strength of 2.74 MPa and 3.82 MPa respectively whereas the silica fume as admixture in concrete increases the strength to 3.86 MPa. The reason behind the strength improvement is all because of densified silica fume which fills the minute pores of concrete and makes the concrete denser.

3. The flexural strength of PET concrete and fiber added concrete are 4.97 MPa and 5.49 MPa whereas for silica fume added concrete it was 5.529 MPa. It shows that the concrete added with admixtures would increase the flexural strength which in turn improves the overall property of the concrete.

4. At the outset Silica Fume added concrete along with fibers proves to be in more need for improving the mechanical properties of concrete and thus making the concrete to be highly stable and durable. Hence the waste plastics along with the admixtures can be used effectively in concrete in order to produce efficient and economical concrete.

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