Experimental Study on Voided Reinforced Concrete Beams with Polythene Balls

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Abstract. The primary component in any structure is concrete, that exist in buildings and bridges. In present situation, a serious problems faced by construction industry is exhaustive use of raw materials. Recent times, various methods are being adopted to limit the use of concrete. In structural elements like beams, polythene balls can be induced to reduce the usage of concrete. A simply supported reinforced concrete beam has two zones, one above neutral axis and other below neutral axis. The region below neutral axis is in tension and above neutral axis is in compression. As concrete is weak in tension, steel reinforcements are provided in tension zone. The concrete below the neutral axis acts as a stress transfer medium between the compression zone and tension zone. The concrete above the neutral axis takes minimum stress so that we could partially replace the concrete above neutral axis by creating air voids using recycled polythene balls. Polythene balls of varying diameters of 75 mm, 65 mm and 35 mm were partially replaced in compression zone. Hence the usage of concrete in beams and self-weight of the beams got reduced considerably. The Load carrying capacity, Deflection of beams and crack patterns were studied and compared with conventional reinforced concrete beams.

Keywords: Concrete, Polythene balls, Compression, Deflection, Crack

1. Introduction

1.1 General
Now-a-days, construction industry starts to pay a great attention to special material that is used in building construction in terms of their effects on environment. Ordinary Portland cement (OPC) is one of the main components used in casting reinforced concrete (RC) structures[1]. So the usage of concrete is high now-a-days, and hence there becomes a shortage of raw materials for its preparation. To reduce the usage of concrete many researches were carried out for alternate materials that can be used instead of concrete. Some of the researchers used local materials like copper slag, rice husk and fly ash for alternate material and they were evaluated experimentally. A simply supported reinforced concrete beam has two zones, one above the neutral axis and other below the neutral axis. The region below neutral axis is in tension and above neutral axis is in compression. As concrete is weak in tension, steel reinforcements are provided in tension zone. The concrete below the neutral axis acts as a stress transfer medium between the compression zone and tension zone. The concrete above the neutral axis takes minimum stress. By recycling scrap or waste plastic material turn them into useful products, and plastic is non-biodegradable material. So, recycling the plastic is global effort to reduce plastic in the waste stream, especially in a year approximately 8 million metric tons of waste plastic that entered into earth’s ocean. By recycling the waste plastic material it can reduce the high rate of
plastic pollution. By using this method the concrete is replaced from above neutral axis by creating air
voids using recycled polythene balls. These balls are less in weight and when we use these balls, it will
not affect geometrical shape of beam. Also it greatly does not affect the strength and stress
characteristics of beam. The testing of ball is shown in fig.1.

From the previous studies it is evidently understood that in RC beams, concrete near the
neutral axis can be replaced with lightweight materials like hollow pipes, terracotta hollow blocks,
brick and polystyrene sheets etc... When we use these materials, they are good in the reduction of self-
weight of the beam but the ultimate load carrying capacity and first crack load is very small when
compared to conventional beam [2]. To overcome these drawbacks, concrete above neutral axis can be
replaced by creating air voids using recycled polythene balls of diameter 75mm, 65mm and 35mm. The
main objective of this study is to introduce a new method by replacing the concrete present above the
neutral axis region by creating air voids using recycled polythene balls. This polythene balls were
made by waste recycled plastic materials.

2. Materials and methods
The materials used for the experimental works and the design methods adopted for the paper work are
included below.

2.1 Materials
OPC 53 grade cement conforming to ASTM C 150/TYPYE 1 was used. The physical properties of
cement is tested and calculated as followed. The specific gravity of cement is 3.15 and consistency is
29%. Zonal Sand and coarse aggregate were obtained.

2.1.1 Mix Design

| Table 1. M30 Mix proportion |
|-----------------------------|
| Material                    |
| Cement (Kg/m³)              | 380 |
| Fine aggregate (Kg/m³)      | 711 |
| Coarse aggregate (Kg/m³)    | 924 |
| Water (Lit/m³)              | 159.6 |
| Water cement ratio          | 0.42 |
| Mix Ratio                   | 1:1.87:2.43 |

2.1.2 Methods. The methodology of work consists of the selection of Grade of concrete: M30 and Mix
design for M30 grade concrete was calculated by using the code provision IS 10262 – 2009. After the
calculation of mix ratio, cubes and cylinders were cast using M30 grade concrete. The cubes and
cylinder were cast with recycled polythene balls of 75mm, 65mm and 35mm. After casting they were
allowed to dry for 24 hours and were under normal water curing for 7 days and 28 days. The cube is tested after 7 days curing and test results for normal M30 cube gave a value of 22.39kN and the cube with 75mm balls are gave a value of 20.31kN. After getting better compression strengths, casting of RC conventional beam and beams with 75mm, 65mm and 35mm balls were done. These beams were kept under water curing for the period of 28 days. After curing period, the beams were subjected to four point bending test using 100T loading frame. Totally 7 number of beams were casted, out of which, a couple was conventional RC beam and other 5 beams with 75mm, 65mm and 35mm recycled polythene balls. All the beams were of same dimensions, 1200mm x 100mm x 200mm where the effective span was 1100mm. The beams were designed as singly reinforced beam with 2 numbers of 12mm diameter bar in tension zone below neutral axis and 2 numbers of 8mm diameter bar at compression zone above neutral axis [1]. For shear reinforcement 6mm diameter bars were used at 100mm spacing as shown in figure 2.

The conventional beams were identified as CB and the beams with balls were identified as PBB (Polythene Ball Beam). The specimens are tested using two point loading by 100T loading frame. The neutral axis depth is calculated by considering M30 grade concrete and Fe415 steel with an effective cover of 50mm. All the beams were designed to fail at compression strain. The equilibrium of forces in bending requires a tension that is equal to compression at all times. It is derived as,

Total tension, \( T = f_{st} A_{st} \)  
Total compression, \( C = 0.36 f_{ck} b (X_u) \)  

Where,

\( f_{st} \) = actual tension in steel corresponding to the strain in steel.

Equating the two expressions, we obtain,

\( f_{st} A_{st} = 0.36 f_{ck} b (X_u) \)  
\( i.e. X_u = \frac{f_{st} A_{st}}{0.36 f_{ck} b} \)  

(3)

(4)

For under reinforced beams, steel reaches yield stress of 0.87fy first. Substituting this value in equation (3) and dividing both sides by the effective depth, \( d \) (IS 456 Annexure G), we get,

\[ X_u = \frac{0.87 \times 415 \times 226.08}{0.36 \times 30 \times 100} = 75.58 \text{mm} \]
The zone above the neutral axis is selected and replaced with 75mm, 65mm and 35mm recycled polythene balls. From this test, the flexural behavior, deflection and crack patterns were studied and comparison was done between conventional reinforced concrete beams and the beams with balls.

2.1.3 Test Procedure. The flexural strength, crack pattern and ultimate load bearing capacity of the beam was found using 100T loading frame and using LVDT (Linear Variable Differential Transformer) the deflections at the centre and quarter span of the beam were calculated. The specimen had 1100mm effective span achieved through a wooden mould with proper cover blocks. The flexural strength of the beam was found using 1000kN loading frame by subjecting the beam to four-point-bending test. The test set up was made as simply supported using two I-sections at proper offsets from the edges. The LVDT was set at centre of the beam to find maximum deflection at a given load and another LVDT was placed at quarter span of the beam from its one of the edges. Both the deflection values were observed from beginning till the failure of the beam. The loading was stopped when first crack has appeared and the readings were noted, after that the ultimate load of the beam is monitored. Finally, a load vs. deflection plot was made.

2.1.4 Load Carrying Capacity. The ultimate load carrying capacity of beam was found by subjecting the beam to four-point-bending using 1000kN loading frame that works through hydraulic motor. The deflection or flexure of beam was calculated by placing LVDT at the mid span and quarter of span of the beam [3]. In this, four point bending test, the load is divided into two parts as, \( P = P/2+P/2 \). Here ‘\( P \)’ is the total load given on the beam through the loading frame and was transferred as separate loads by placing an I-section above two rollers above the beam where the load has to be applied. The test setup is shown in figure 3.

![Figure 3. Reinforcement Details](image)

The load at first crack was noted when the crack was developed in the concrete and the maximum load was observed and the corresponding deflection was indicated by LVDT. From this test, it was found that there existed no great difference in load carrying capacity between the conventional beams and beams with recycled polythene ball. The beams with recycled polythene balls were named, PBB1, PBB2, PBB3, PBB4 and PBB5 for easy identification. And the normal conventional beams were named, CB1 and CB2. The balls were also tested using CTM (Compression Testing Machine), and the CTM reaches its limit at certain point, until that point the ball gets pressed.
Table 2. Percentage of Concrete Replaced

| S. No. | Beams                                      | Percentage of concrete replaced by this balls |
|-------|--------------------------------------------|---------------------------------------------|
| 1.    | Control Beam 1                             | -                                           |
| 2.    | Control Beam 2                             | -                                           |
| 3.    | Beam with 75mm balls (PBB1)                | 10%                                         |
| 4.    | Beam with 65mm balls (PBB2)                | 6%                                          |
| 5.    | Beam with 65mm balls (PBB3)                | 12%                                         |
| 6.    | Beam with 35mm balls (PBB4)                | 2%                                          |
| 7.    | Beam with 35mm balls (PBB5)                | 6%                                          |

3. Results and Discussion

The compression behavior of the cubes, deflection, ultimate load, load at first crack, deflections and crack patterns of the beams are discussed below.

In this study, the concrete in beam at its compression zone is replaced. Contribution from compression zone to the load carrying capacity is comparatively lesser than tension zone. The 75mm balls were used for 10% of concrete replacement, 65mm balls for 6% and 12% of concrete replacement and 35mm balls for 2% and 6% of concrete replacement from total concrete. While comparing the load carrying capacity and deflection of the beams with polythene balls and the conventional beam, the values were observed to be nearly same. Through this method, in wide range of constructions, the usage of concrete is reduced by greater amount. In this method the composite action takes place between concrete and polythene balls. This composite action and placing of balls in between shear reinforcement does not affect the load carrying capacity of beam. The behavior of RC beam at four-point-bending test, the first crack strength, toughness and load deflection response were studied. The fig. 4 shows load vs. deflection response curves for each specimen of conventional beam and beam with 75mm, 65mm, and 35mm recycled polythene balls. From this graph, we can predict the strength of material by knowing the deflection at the respective load values. For example, a specimen concrete and reinforcement bars initially works together to resist deflection of beam. The test result for CB1 is compared to beams with balls, and conventional beam got its first crack at 58kN and corresponding deflection was 1.93mm. The ultimate breaking load for CB1 is 124.3kN and the corresponding deflection was 7.76mm. In PBB1, when load was 40kN, first crack appeared and beam got deflected (1.53mm) in mid-span. After that, load kept on going till 114.6kN and the specimen failed. The load was observed to be the same when compared to the conventional beam, and the deflection at that point was observed to be 5.14mm. PBB2 also got its first crack at 40kN and broke at 108.9kN. At that point the deflection of beam was 7.35mm. And the test result for PBB3 had similar first cracking load. Its first crack at 40kN and the corresponding deflection at mid span was 2.21mm. The ultimate load for this beam was 105kN and the corresponding deflection of the beam was 5.62mm.
The test result for PBB4 had similar first crack load compared to other two beams. It had the first crack at 50kN and the corresponding deflection at mid span was 3.06mm. The ultimate load for this beam was 107kN and the deflection of the beam was 9.52mm. This beam failed by crushing of concrete. Comparing PBB4 and PBB3, both had meagre variation but the deflection of beam was controlled in PBB3 beam. PBB5 beam had its first crack at 58kN. At that point, deflection of beam was 1.84mm, and it failed at 121kN with a deflection of 5.81mm. PBB5 had more load carrying capacity and deflection was controlled compared to PBB4. From these test results, the conventional beam and beam with balls had the similar value and crack pattern. The crack pattern for all beams is shown in figure 5.
4. Conclusion
The flexural behaviour of the beam with replaced polythene balls are tested and compared with conventional beam in this study. The theoretical explanation of the test beams were carried out. From this present study the following conclusion are listed.

- Flexural behaviour of conventional beam and beam with polythene balls are marginally similar.
- Replacing the concrete by polythene balls in compression zone does not exhibit significant change in the load carrying capacity of the beams.
- In this Study compared to other polythene ball beams PBB5 had more load carrying capacity, and deflection of the beam is controlled.
- Deflection of the polythene ball beam is considerably lower than the conventional beam.
- By replacing concrete with these balls in reinforced concrete beams had no need of additional labors and time. Economically this method is effective and percentage of concrete replaced from beam is based upon count of balls. In this method huge amount of concrete reduction can be done without affecting the behaviour of the structure and it minimizes the construction cost too.
- When this method is used in long span construction considerable amount of concrete is reduced which in turn decreases the usage of raw material.

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