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Performance of Light-Weight Concrete with Plastic Aggregate

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ABSTRACT
This study is intended to explore the suitability of recycled plastics (high density polyethylene) as coarse aggregate in concrete by conducting various tests like workability by slump test, compressive strength of cube and cylinder, splitting tensile strength test of cylinder, flexural strength of R.C.C as well as P.CC. beams to determine the properties and behaviour in concrete. Effect of replacement of coarse aggregate with various percentages (0% to 40%) of plastic aggregate on behaviour of concrete was experimentally investigated and the optimum replacement of coarse aggregate was found out. The results showed that the addition of plastic aggregate to the concrete mixture improved the properties of the resultant mix.
Keywords **–** High density polyethylene, Optimum replacement, Plastic aggregate, Recycled Plastic, Strength

I. INTRODUCTION

Indian construction industry today is amongst the five largest in the world. The demand for new construction is ever increasing with the rise in population. Hence the non-renewable aggregate supply has emerged as a problem in India. With the shortage as seen today, the future seems to be in dark for the construction sector. Seeking aggregates for concrete, new materials have been used in the construction field. Focusing on the environment and safeguarding natural resources, new waste materials have been used in the construction industry. In India, due to growing population the quantity of solid waste is increasing rapidly. Among the solid waste materials, plastics represent 8% by weight of the total solid wastes. These non-biodegradable plastic materials will finally end up as earth fill.

For solving the disposal of large amount of plastic materials and to meet the increasing need for aggregates, reuse of plastic in concrete is considered as the most feasible application. Plastic aggregates will not be crushed as easily as natural aggregate since plastic are polymers made up of long string molecules consisting of carbon atoms bonded with other atoms such as hydrogen, nitrogen, oxygen, fluorine. They develop a crystalline structure which is strong, hard and more resistant to chemical penetration and degradation. Hence it will be a boon to the construction industry if plastic is utilized to prepare aggregates rather than recycling it repeatedly. The present work is aimed at studying the strength of concrete with partial replacement of natural aggregate by plastic aggregate.

II. OBJECTIVES

The primary objective of this study is to evaluate the possibility of using plastic aggregate as coarse aggregate in concrete. Specific objectives of this work include:

- To prepare plastic aggregate of 20mm size.
- To determine the properties of plastic aggregate.
- To conduct a comparative study of plastic aggregate and natural aggregate.
- To study the effect of replacing natural aggregate with plastic aggregate on workability, compressive strength, splitting tensile strength and flexural strength of concrete.
- To study the effect of replacing natural aggregate with plastic aggregate on weight of concrete.
- To find the optimum replacement of natural aggregate using plastic aggregate.

III. METHODOLOGY

The successive steps that were followed to complete the study were as follows:

- Collection of high density polyethylene (HDPE) materials.
- Preparation of recycled plastic aggregate.
- Various tests were conducted on cement, fine aggregate and coarse aggregate to determine its physical properties
  a. Test on Cement: Specific gravity, standard consistency, initial and final setting time, compressive strength of mortar cube.
  b. Test on aggregates: Specific gravity, sieve analysis.
- Mix design of M20 grade concrete.
- Cubes, cylinders and beams were casted with control mix using natural aggregate.

- Cubes, cylinders and beams were casted for varying percentage replacement (5, 10, 15, 20, 25, 30, 35, and 40) of natural aggregate by plastic aggregate.
- Workability, compressive strength, splitting tensile strength and flexural strength tests of concrete were conducted.
- Optimum percentage of plastic aggregate that can be replaced in concrete was determined.

IV. MAKING OF PLASTIC AGGREGATE

After a review of various research studies, high density polyethylene (HDPE) was selected as a substitute for natural aggregate. HDPE is the largest of the three polyethylenes by volume of consumption. HDPE is prepared from ethylene by a catalytic process. It is also harder, more opaque and can withstand higher temperature. They are impact and wear resistant and can have very high elongation before breaking when compared to other materials. They are chemical resistant and cheap too. It has a very linear structure with only a few short side branches and hence leading to higher density range as well as more crystalline structure. These properties give HDPE its higher strength compared to the other PEs, allowing a wider range of use. The properties of HDPE are:

- Excellent resistant (no attack) to dilute and concentrated acids, alcohols and bases.
- Melting point:130^{o}C - 180^{o}C
- Specific Gravity: 0.95
- Water absorption: 0.001% - 0.010%
- Chemical resistant
- Impact and wear resistant
- Can withstand high temperature

The plastic aggregates were prepared from recycled HDPE sheets. Generally the plastic recycling can be completed through 5 steps: Sorting, shredding, washing and extruding. The various steps involved in recycling and making of plastic are described below.

Sorting the plastic: Once the recyclable plastic materials were collected, the first stage of recycling began by sorting out the plastic material of different types. Plastic recycling is a complex process compared to other recycling process because of the different types of plastic that exists. Mixed plastic cannot be used as it is poor in quality. Therefore it's essential to sort out plastic materials. HDPE is thus sorted out. (Fig 1)

Fig 1 Sorting of Plastic

Shredding the plastic: The plastic materials were then prepared for melting by cutting them into small pieces. The plastic items are fed into a machine which has set of blades that slice through the material and break the plastic into tiny bits (Fig 2).

Fig 2 Shredding and Shredded HDPE Materials

Washing shredded plastic: All residues of products contained in the plastic items and various other contaminants are removed. A particular wash solution consisting of an alkaline, cationic detergent and water are used to effectively get rid of all the contaminants on the plastic (Fig 3).

Fig 3 Washing of Shredded Plastic

Extruding: This is the final stage in the recycling process. The cleaned and chipped pieces of plastic are melted down and put through a machine called extruder. After the plastic is melted and compressed, it is channelled into the metering section. Here, the plastic undergoes pressurized pumping, while the root diameter of the screw and the flight size remain constant (Fig 4)

Fig 4 Extruder and Extrusion of Plastic

Plastic aggregate: These melted plastics were allowed to fall on a rough surface through the die. Plastic sheets of 20mm thick were made out of these recycled materials. Undulations were made on the surface of the sheets. These sheets were then cut into aggregates of 20mm size (Fig 5).

Fig 5 Making and Cutting of Plastic Sheets into Aggregate

V. MATERIALS USED

Material testing were conducted as per IS specifications.

5.1 Cement

Cement was tested as per IS: 1489 (Part 1) – 1991 (i.e. [7])**.**

Table 1 Properties of Cement

Brand	Shankar Cement; Portland Pozzolana Cement - 43 grade
Standard Consistency	32%
Initial Setting Time	190 min
Final Setting Time	365 min
Specific Gravity	2.965
Mortar Cube Strength	43 N/mm^2

5.2 Fine Aggregate

Fine aggregate was tested as per IS: 2386 (Part 1 and 3) - 1963 (i.e.[8]) and IS: 383 - 1970 (i.e.[9])**.**

Table 2 Properties of Fine Aggregate

Fineness Modulus	4.129
Zone	I
Specific Gravity	2.697
Water Absorption	0.2 %

5.3 Coarse Aggregate

Coarse aggregate was tested as per IS: 2386 (Part 1and 3) – 1963 (i.e.[8]) and IS: 383 – 1970 (i.e.[9])**.**

Table 3 Properties of Coarse Aggregate

Fineness Modulus	3.21
Nominal Size	12 mm
Specific Gravity	2.748
Water Absorption	0.15

5.4 Plastic Aggregate

Plastic aggregate was tested as per IS: 2386 (Part 1and 3) – 1963 (i.e.[8]) and IS: 383 – 1970 (i.e.[9])**.**

Table 4 Properties of Plastic Aggregate

Fineness Modulus	5.63
Nominal Size	20 mm
Specific Gravity	0.94

5.5 Water

Water used for mixing and curing was clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that are deleterious to concrete or steel.

VI. CONTROL MIX

Mix design was performed as per IS: 10262 – 2009 (i.e.,[10]) to obtain M20 mix. For making a mix with plastic aggregate, the amount of plastic was calculated using the specific gravity of plastic.

Table 5 Mix Proportion

Material	Cement	Fine Aggregate	Coarse Aggregate	Water
Weight (kg/m^3)	383.16	733.584	1119.96	191.58
Ratio	1	1.914	2.922	0.5

VII. CASTING OF SPECIMENS

Specimens were casted for varying percentage replacement of 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% of natural aggregate with plastic aggregate.

Table 6 Mix Designation

% Replacement of aggregate with plastic	**Mix**
5	5P
10	10P
15	15P
20	20P
25	25P
30	30P
35	35P
40	40P

The total number of specimens casted (Fig 6) for the study are listed in TABLE 7

Table 7 Total Number of Specimens Casted

Specimen	Dimension	Total No.
Cube	150 mm x 150 mm x 150 mm	93
Cylinder	150 mm diameter, 300 mm height	162
Beam	100 mm x 100 mm x 500 mm	162

Fig 6 Casted Specimens

VIII. Test Results And Discussions

8.1 Workability by Slump Test

With the introduction of plastic in concrete the slump value increases (Fig 7); i.e. the workability of concrete increases. This is due to the influence of surface texture and water absorption of the aggregates on workability.

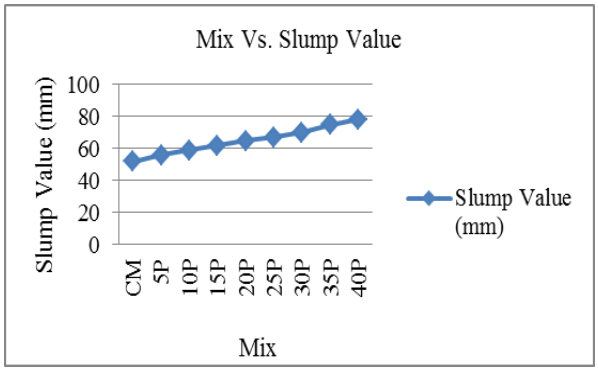

Fig 7 Variation in Slump Value

8.2 Compressive Strength of Concrete Cubes

Fig 8 shows that on addition of plastic aggregate there was a gradual increase in 7 day, 14 day and 28 day compressive strength of cube. An increase in strength was observed till 30% replacement of natural aggregate with plastic aggregate and on further replacement strength was found to be decreasing.

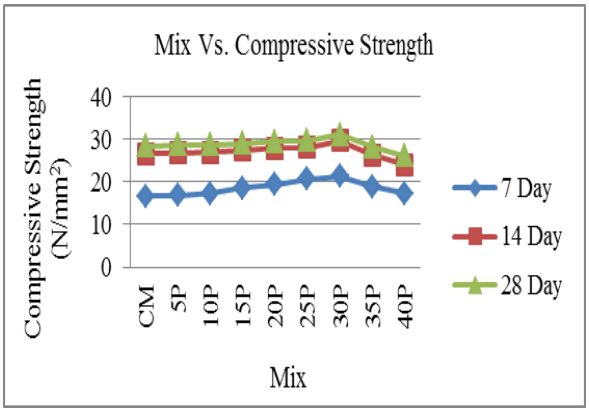

Fig 8 Variation in Compressive Strength of Concrete Cubes for Various Mix

8.3 Compressive Strength of Concrete Cylinders

It is seen 7 day, 14 day and 28 day compressive strength of cylinder increased gradually with the replacement of natural aggregate with plastic aggregate in concrete (Fig 9). Compressive strength increased till 30% replacement of natural aggregate with plastic aggregate and on further replacement a decrease in the strength was noted.

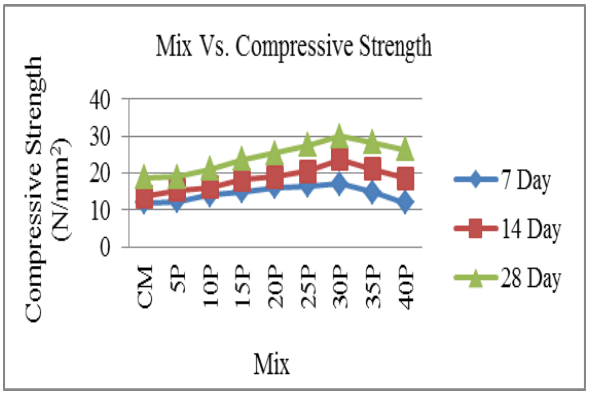

Fig 9 Variation in Compressive Strength of Concrete Cylinders for Various Mix

8.4 Splitting Tensile Strength of Concrete Cylinders

An increasing trend in splitting tensile strength of concrete was observed till 30% replacement of natural aggregate with plastic aggregate. After 30P a decrease in strength was observed.

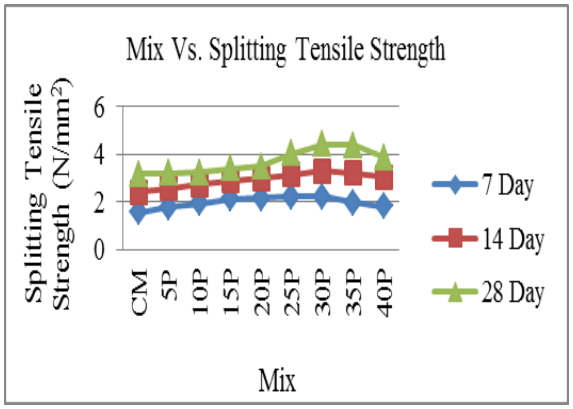

Fig 10. Variation in Splitting Tensile Strength of Cylinders for Various Mix

8.4 Flexural Strength of P.C.C Beams

Flexural strength increased with the increase in plastic content in concrete. Replacement of natural aggregate with plastic aggregate tends to make concrete ductile and hence increases the ability of concrete to significantly deform before failure.

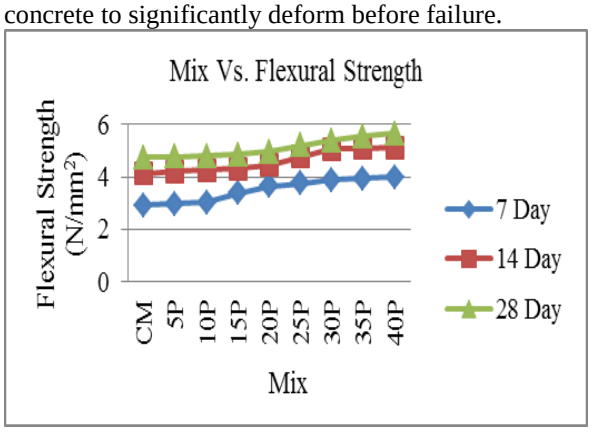

Fig 11. Variation in Flexural Strength of P.C.C Beam for Various Mix

8.5 Breaking Load of R.C.C Beams

Breaking load increased with the increase in plastic content in concrete. Replacement of natural aggregate with plastic aggregate tends to make concrete ductile and hence increases the ability of concrete to significantly deform before failure.

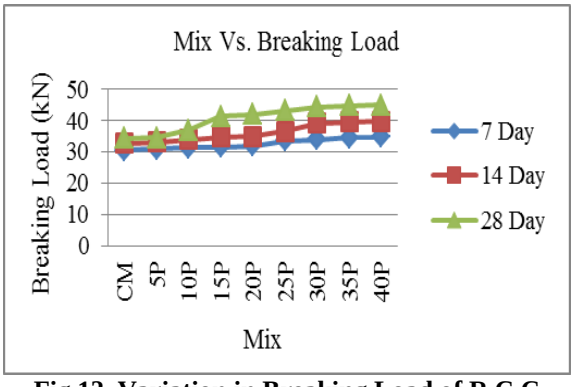

Fig 12. Variation in Breaking Load of R.C.C Beam for Various Mix

8.6 Cube Weight

A decreasing trend was observed in the case of cube weight (Fig 13). Plastic being a light weight material tends to decrease the weight of the resultant concrete.

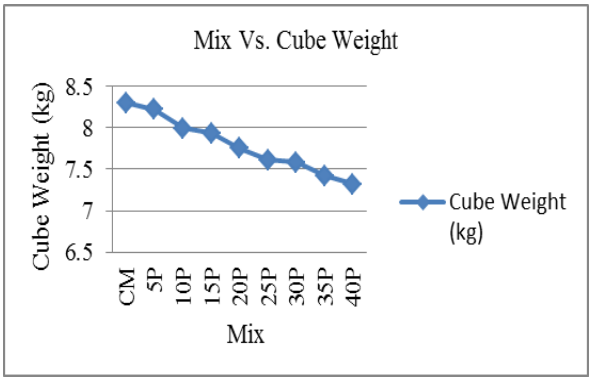

Fig 13. Variation in Unit Weight of Cube for Various Mix

IX. CONCLUSION

A study was conducted to investigate the possibility of making plastic aggregate and using the aggregate made from plastic as a substitute for natural coarse aggregate in concrete. The present work is aimed at studying the strength and workability of concrete with partial replacement of natural aggregate by plastic aggregate. The study can be concluded as follows:

- Plastic aggregate is a lightweight material with specific gravity 0.94.
- The workability of concrete increased by 50% for a mix containing 40% plastic aggregate.
- Compressive strength and splitting tensile strength of concrete increased till 30% replacement of natural aggregate with plastic aggregate and on further replacement they tend to decrease but not below the target mean strength.
- Compressive strength increased by 9.4% and splitting tensile strength by 39% for a mix with 30 % replacement of natural aggregate by plastic aggregate when compared to control mix.
- Flexural strength of PCC beam and breaking load of RCC beam increased till 40% replacement. There was an improvement of 20% and 31% strength respectively.
- The optimum percentage replacement of natural coarse aggregate using plastic aggregate was obtained as 30%

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