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Durability and Bonding Characteristics of Plastic Aggregate Concrete

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Abstract: *This study is intended to explore the durability and bonding characteristics of recycled plastic aggregate in concrete. Durability of concrete is an important factor. The present investigation focused on the effects of sulphuric acid, hydrochloric acid and sodium sulphate on the resultant concrete. From the test, sulphate attack, acid attack and chloride attack on concrete were measured. The obtained results supported the use of high density polyethylene aggregate for partial replacement of natural aggregate. Bonding of plastic aggregate in concrete is also an important parameter to be measured. Bonding of plastic aggregate concrete was tested and studied with the help of pullout apparatus.*
Keywords: *Acid attack, Bonding, Chloride attack, Durability, Plastic Aggregate, Pullout, Sulphate attack*

I. Introduction

Aggregates used in construction are the most mined materials in the world. Modern blasting techniques increased the number of quarries at places wherever competent bedrock deposits are available. Also construction demand at places where neither stone, nor sand and gravel are available is usually satisfied by shipping in aggregate by rail, barge or truck.

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 need of non-renewable aggregate has become a challenge. The future seems to be in dark for the construction sector. Researches are being conducted using alternative for aggregate 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 can be considered as a 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 can be utilized to prepare aggregates.

II. Plastic Aggregate

After a review of various research studies, high density polyethylene (HDPE) was selected for the study 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 resistant to chemical actions and cheaper 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 (polyethylene), allowing a wider range of use. The properties of HDPE are:

- Excellent resistance 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 resistance
- Impact and wear resistance
- 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 (Fig 1).

Fig 1 Extruder and Extrusion of Plastic

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 2).

Fig 2 Plastic Aggregate

III. Objectives

Study (i.e. [1]) revealed that the optimum percentage replacement of natural coarse aggregate using plastic aggregate was 30%. This study thus compares the properties of natural coarse aggregate concrete with 30% plastic aggregate 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 durability of mix in which natural aggregate is 30% replaced by plastic aggregate.
- To study the bonding characteristics of mix in which 30% natural aggregate is replaced by plastic aggregate.

IV. 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, natural aggregate and plastic aggregate to determine its properties.
- Casting of cubes with control mix using natural aggregate.
- Casting of cubes for 30 percentage replacement (optimum percentage replacement) of natural aggregate by plastic aggregate.
- Durability against sulphuric acid, hydrochloric acid and sodium sulphate were studied.
- The bonding characteristics of the mix were studied.

V. Materials Used

The properties of materials used in the study were determined by conducting necessary test as per IS specifications and are tabulated subsequently.

Table 1 Properties of Cement

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

Table 2 Properties of Fine Aggregate

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

Table 3 Properties of Coarse Aggregate

Fineness Modulus	5.09%
Nominal Size	20 mm
Specific Gravity	2.745
Water Absorption	0.05 %

Table 4 Properties of Plastic Aggregate

Fineness Modulus	5.63
Nominal Size	20 mm
Specific Gravity	0.94

Chemicals like sulphuric acid, hydrochloric acid and sodium sulphate anhydrous were used to carry out chemical curing. The chemicals were manufactured by NICE Chemicals Pvt. Ltd.

VI. Control Mix

Mix design was performed as per IS: 10262 – 2009 (i.e. [12]) to obtain M20 mix (TABLE 5). For making a mix with plastic aggregate, the amount of plastic was calculated using the specific gravity of plastic.

Table 5 Mix Proportion – Control Mix

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

The mix is designated as CM for the control mix and 30P for the mix containing plastic aggregate. A total of three specimens were casted for each test and the average of the results were considered.

Table 6 Total Specimens Casted

Specimen	Tests Conducted	Dimension	Total Number
Cube	Durability	150 mm x 150 mm x 150 mm	18
Cube	Pullout	150 mm x 150 mm x 150 mm	6

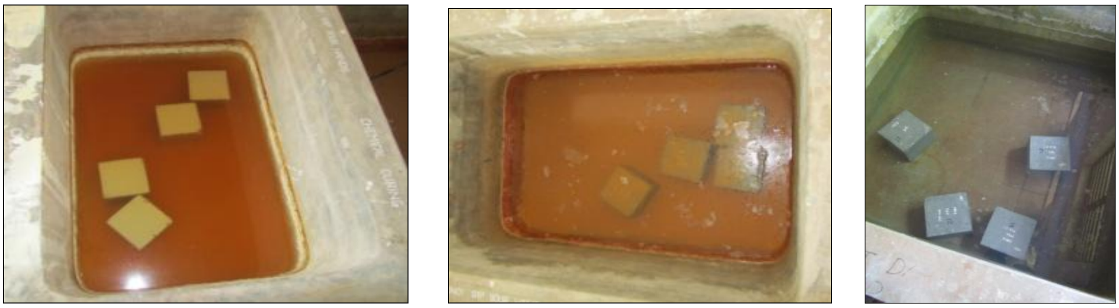
Fig 3 Casting and Curing of Specimens

VIII. Experimental Procedure

1.1 Determination of Resistance of Concrete to Chemical Attack

Durability of concrete against sulphuric acid, hydrochloric acid and sodium sulphate was checked. Cubes of 150 mm x 150 mm x 150 mm were casted for CM and for the mix with a replacement of 30% of natural aggregate by plastic aggregate. The cubes were cured for a period of 7 days. After 7 day water curing, the specimens were kept in atmosphere for 2 days for constant weight. Subsequently the respective specimens were weighed and immersed in 2% sulphuric acid solution, hydrochloric acid solution and sodium sulphate solution respectively for 90 days (Fig 4). After 90 days, the specimens were taken out, washed and kept in atmosphere for 2 days for constant weight.

The effect of chemical attack was estimated by taking the change of mass into consideration. The reductions in compressive strength of the specimens when they were immersed in chemical solution were also determined.



Sulphuric Acid Curing   Hydrochloric Acid Curing   Sodium Sulphate Curing

Fig 4 Chemical Curing

9.2 Determination of Bonding Stress of Concrete

Bonding of the concrete was checked using pullout test. Cube of 150 mm x 150 mm x 150 mm were casted with a pullout attachment in it. The cylindrical attachment had an inner diameter of 4 cm, outer diameter of 6 cm and a height of 10 cm (Fig 5).

Cylindrical Attachment   Cube for Pullout Test

Fig 5 Cube Casted with Pullout Attachment

IX. Test Results And Discussions

1.2 Sulphuric Acid Attack on Concrete

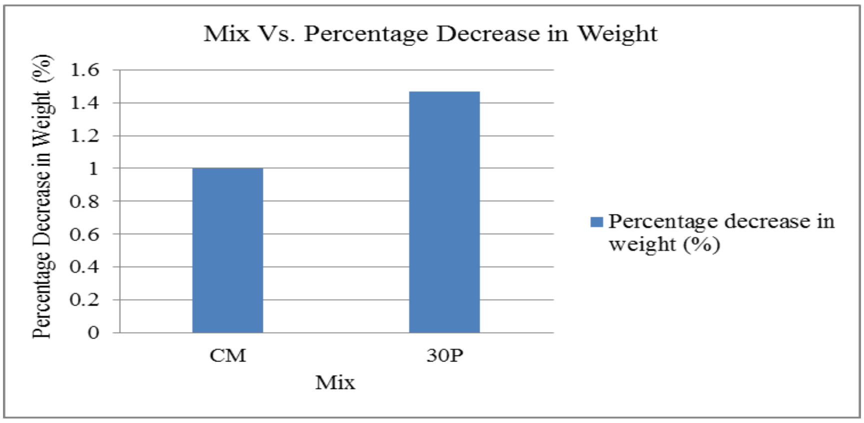


Fig 6 Percentage Decrease in Weight of Cubes after H_2SO_4 Curing

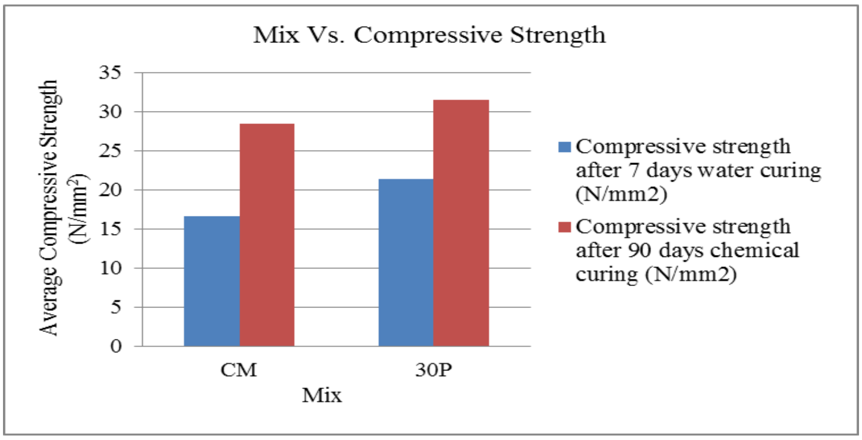


Fig 7 Variation in Compressive Strength of Cubes after H_2SO_4 Curing

When compared, significant differences in weight losses (Fig 6) were not observed for both the mixes after 90 days sulphuric acid curing. Mix using plastic aggregate showed more decrease in compressive strength after H_2SO_4 curing when compared with control mix using natural aggregate (Fig 7). Sulphate corrodes aggregate making the concrete surface rough. Sulphate attack was indicated by a characteristic whitish appearance (Fig 8).

Fig 8 Whitish Appearance on Specimens after Sulphuric Acid Curing

10.2 Hydrochloric Acid Attack on Concrete

Percentage decrese in weight loss (Fig 9) of specimen after 90 days hydrochloric acid curing was 1.46% and 0.5% for CM and 30P respectively.Variation in compressive strength (Fig 10) shows that concrete is highly resistance to chloride attack on replacement of natural aggregate with plastic aggregate. The strength differed by 3.1%.

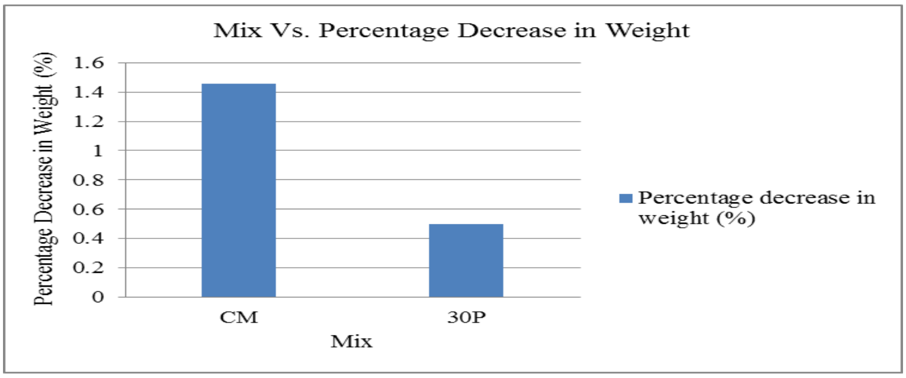


Fig 9 Percentage Decrease in Weight of Cubes after HCl Curing

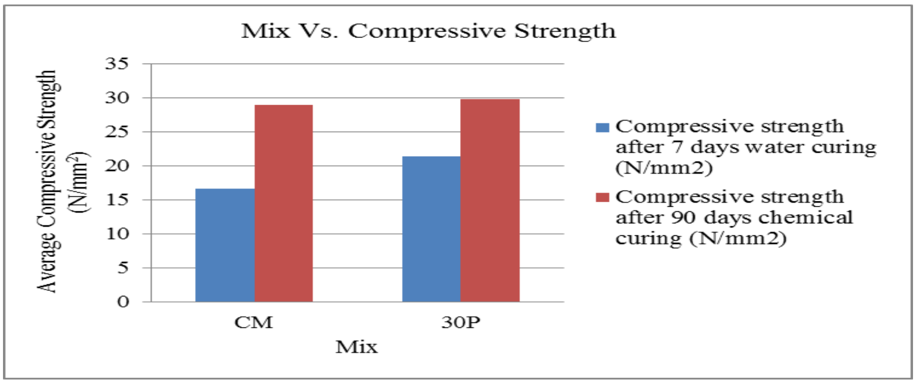


Fig 10 Variation in Compressive Strength of Cubes after HCl Curing

10.3 Sodium Sulphate Attack on Concrete

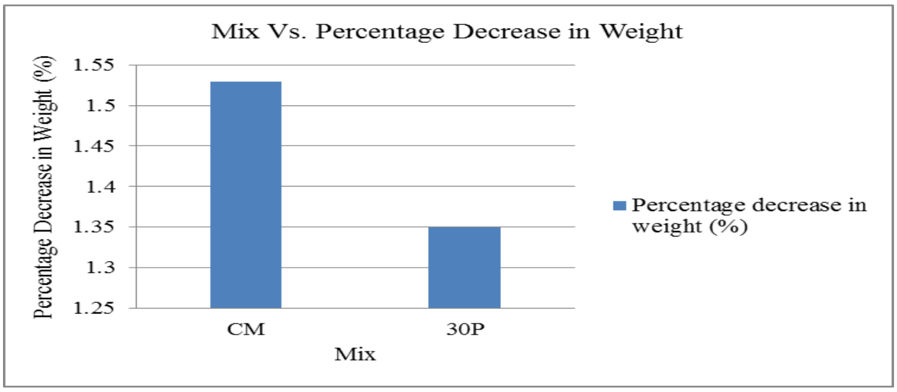


Fig 11 Percentage Decrease in Weight of Cubes after Na_2SO_4 Curing

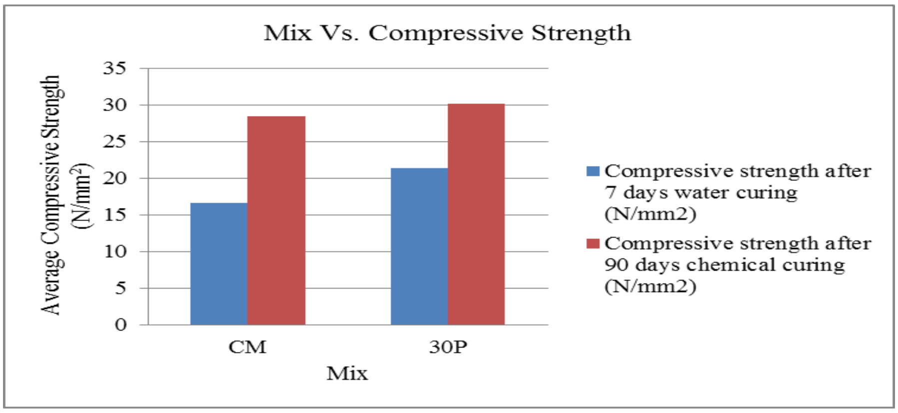


Fig 12 Variation in Compressive Strength of Cube after Na_2SO_4 Curing

When compared, significant differences in weight losses (Fig 11) were not observed for both the mixes after 90 days sodium sulphate curing. Mix using plastic aggregate showed lesser decrease in compressive strength after H_2SO_4 curing when compared with control mix using natural aggregate (Fig 12). Concrete surface was found to be rough and a white colour appeared on the surface of concrete which indicates sulphate attack **(**Fig 13).

Fig 13 Whitish Appearance on Specimens after Sulphuric Acid Curing

10.4 Bonding Stress

The bonding stress of CM was found to be 0.4 N/mm^2 and that of 30P was 0.44 N/mm^2. This indicates that the bonding of plastic aggregate is almost the same to that of natural aggregate.

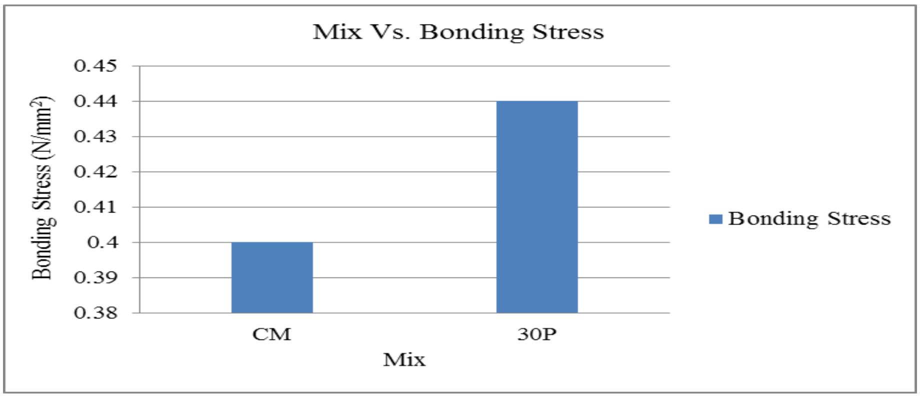


Fig 17 Variation in Bonding Stress

X. 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 durability and bonding 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.
- After 90 days sulphuric acid curing (2% solution), the percentage decrease in weight of the mix containing plastic aggregate was found to be 1.4% and that of control mix was 1%.
- Compressive strength (after sulphuric acid curing) increased by 11% for a mix with 30% replacement of natural aggregate by plastic aggregate when compared to control mix.
- After 90 days hydrochloric acid curing, the percentage decrease in weight of the control mix was 1.46% whereas that of the mix containing plastic aggregate was 0.5%
- After hydrochloric acid curing, there was an improvement in compressive strength by 3% for the mix with 30% plastic aggregate when compared to control mix.
- After 90 days sodium sulphate curing (2% solution), the percentage decrease in the weight of the mix containing plastic aggregate was 1.35% and that of control mix was 1.53%.
- Compressive strength increased by 7% for the mix with 30% replacement of natural aggregate by plastic aggregate when compared to control mix; after sodium sulphate curing.
- Results indicated that bonding stress was almost the same for both the mixes. The mix control mix had a bonding stress of 0.4 N/mm^2 whereas the mix containing plastic aggregate had a bonding stress of 0.44 N/mm^2

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