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# An Experimental Study on the Axial Behavior of Recycled Plastic Aggregate Concrete Columns

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**ABSTRACT.** *Plastic production and the resultant plastic waste is increasingly challenging due to population growth and urbanization. This study focuses on plastic reuse as an aggregate in concrete to explore the recycling avenue in the construction industry. In addition, the work focused on the mechanical properties of eco-friendly concrete that uses plastic waste as a partial substitution for coarse aggregate. From this method the negative impact of plastic waste on the environment not only reduced, but it also helps avoid exploitation of natural resources for natural aggregate production. Several past works have explored the use of plastic as an aggregate in concrete; however, most works were focussed on the material level behavior. In this study, compressive behaviour of reinforced concrete columns consisting of recycled plastic aggregate concrete and exposed to axial loads is investigated. This paper provides the axial loading test results of 5 columns consisting of Recycled Plastic Aggregate Concrete (RPAC). The replacement rate in the M40 grade concrete is kept at 12%. Compressive performance of RPAC columns such as strain, failure mode, reinforcement along longitudinal direction and ties spacing are analysed. The results clearly show the potential of recycled plastic aggregates for use in columns with structural performance equivalent to that of conventional aggregate concrete.*

**Keywords:** Recycled Plastic Aggregate Concrete (RPAC), Reinforced Concrete Columns, Green Concrete, Sustainability, Replacement Ratio, Compressive Strength

## 1. INTRODUCTION

Rising popularity of different plastic products is among the primary barriers to environmental preservation. Use of plastics generates a lot of waste which degrades slowly and hence is bad for the environment. Every type of plastic is eventually discarded, requiring vast quantities of space for storage, and prohibiting simultaneous full recycling [1]. Globally, some 6.5 Bn metric tonnes of unwanted plastic garbage and cast-off rubber are generated annually. The environment is seriously threatened by the disposal of these polymers because of their protracted decomposition times [2]. Reusing garbage is crucial from a variety of angles because it minimises environmental pollution, encourages energy recycling and conservation during production, and supports the sustainability and conservation of natural resources that are non-renewable [3]. Utilizing plastic waste in the manufacturing of goods is a green method to lessen the quantity of waste that is disposed of in landfills [4]. Recently, incorporation of plastic aggregate in concrete has become a popular research area [5]. Recycled plastic aggregate concrete emphasizes on the two most important advantages i.e., recycling of plastic, which reduces the adverse effect of plastic on environment and saving of natural resources. In order to use recycled plastic aggregate concrete in real structures, experimental work is required on the structural performance of columns composed of recycled plastic aggregate concrete. Concrete is the most frequently used material for construction all over the world. The key reasons for the widespread usage of concrete are its compressive strength, durability, and its ability to be formed in shape which are desired. Most of the volume in concrete is made up of coarse aggregate. Natural aggregates are currently in short supply in many nations throughout the world, forcing them to rely on imports to meet their needs [6]. Rapid urbanisation and development have prompted the construction of extensive infrastructure, which has in turn increased the use of natural rock resources, severely degrading the environment, and increasing environmental pollution. Therefore, it is crucial to place an emphasis on raw material preservation [7, 8]. To this end, recent initiatives have been undertaken to partially replace natural aggregates with electronic waste (E-waste) plastic aggregate [9-13]. As a result, research into the creation of various alternatives for natural aggregates in concrete is picking up steam. Previous studies have discussed the usage of different plastics as substitutes for fine and coarse aggregate in concrete. However, few studies have been published on the use of plastic waste as a substitute for fine or coarse aggregate in concrete, reviewing the structural performance of resulting concrete in reinforced concrete structural members. Therefore, the current study emphases on the axial behaviour of reinforced concrete columns comprising manufactured plastic coarse aggregate as a partial replacement for natural coarse aggregate. For this purpose, recycled plastic aggregate with a replacement ratio of 0% and 12% was used instead of the coarse aggregate.

## 2. LITERATURE REVIEW

Several experimental works have been conducted on the axial behaviour of recycled aggregate concrete columns, but little is understood about the axial behaviour of plastic aggregate concrete columns. In a study, coarse aggregate of conventional concrete was replaced with recycled plastic coarse aggregate up to 30% by volume. It was observed that concrete compressive strength reduces with the increase of percentage of recycled aggregate. But its split tensile strength increases up to 17% at 20% replacement [13]. In another study, it was seen that using 20% (by volume) replacement reduced the strength but the mechanical properties were enhanced with the inclusion of steel fibers, polypropylene fibers, and silica fume [14]. Hence, it is concluded that plastic concrete can be used for structural elements by adding some additional constituents to it. In another work increase in the workability of concrete is observed by adding Recycled plastic coarse aggregate while reduction in compressive strength is observed by increasing the percentage of recycled plastic [15]. In another work, the samples that contained 25% (by volume) of recycled waste as an aggregate, and 5% of nano graphite platelets NGPs (by weight of cement) was proved effective in increasing compressive strength by 13.56% [10]. Columns with size 400x400x200 mm with w/c of 0.43 and replacement percentage of 0, 30, 60 & 100 with recycled aggregates from demolition waste, resulting in reinforced recycled aggregate concrete columns (RRAC) with different replacement ratios has similar or considerably lower structural performance to reinforced natural aggregate concrete columns (RNAC) showing the practicality of recycled concrete aggregate for structural applications [16].

From the previous studies, it has been concluded that relatively less work is performed on structural members i.e., columns with RPAC. In a study it was observed that column with 150x200x1400 mm size and the replacement percentage of 0, 50, and 70 with recycled aggregate from demolition construction blocks, resulting in the decrease in compressive strength when the replacement percentage went beyond 50% [21]. RPAC compressive behaviour can be measured at the material level with conventional specimens (such as prisms or cylinders) or on a structural component level with full-sized columns.

## 3. EXPERIMENTAL WORK

Past works utilized recycled plastic as coarse aggregate replacement by up to 20% and concluded that if the proportion of recycled aggregate is over 20%, the strength starts to decline [10,11]. Hence, up to 12% of plastic aggregate replacement has been used in the current study. The columns are cast with the designed reinforcement to check how well recycled plastic aggregates behave after they are exposed to axial loading. The cross-section of the column is 200 mm x 200 mm x 800 mm. Columns were cast using ties with #2@5", 6" and 7" c/c spacing and longitudinal reinforcement of 4#4 and 4#3 as variables, along with 12% recycled plastic aggregate as shown in Table 1. The specimens were cast and cured for 28-day period. Mix ratio of 1:1.41:2.41 is used along with w/c ratio of 0.43 and the quantities are shown in Table 2. Compressive performance of concrete such as strain, failure mode, reinforcement along longitudinal direction and ties spacing of RPAC columns are analysed. To Explore the axial performance of recycled plastic aggregate concrete columns, the samples are tested in a universal testing machine (UTM) having 5000 KN capacity with a displacement control rate of 0.5mm/min. Columns are placed in UTM with both ends capped with steel plates after that strain gauges were attached. After preparation of this assembly, axial load was applied on the columns.

**Table -1:** Design parameters of members

| Member | Concrete Strength | Replacement Ratio [%] | Longitudinal Reinforcement | Stirrup |
|---|---|---|---|---|
| RCC-1 | M40 | 0 | 4#4 | #2@6" c/c |
| RPACC-1 | M40 | 12 | 4#4 | #2@6" c/c |
| RPACC-2 | M40 | 12 | 4#3 | #2@6" c/c |
| RPACC-3 | M40 | 12 | 4#4 | #2@5" c/c |
| RPACC-4 | M40 | 12 | 4#4 | #2@7" c/c |

**Table -2**: Quantities of concrete constituents

| Replacement Ratio [%] | Cement [Kg/m$^3$] | Natural Coarse Aggregate [Kg/m$^3$] | Recycled Plastic Coarse Aggregate [Kg/m$^3$] | Fine Aggregate [Kg/m$^3$] | Water [Kg/m$^3$] |
|---|---|---|---|---|---|
| 0 | 493 | 1300 | 0 | 969 | 212 |

| | | | | | |
|---|---|---|---|---|---|
| 12 | 493 | 1144 | 156 | 969 | 212 |

## 3.1 Constituents

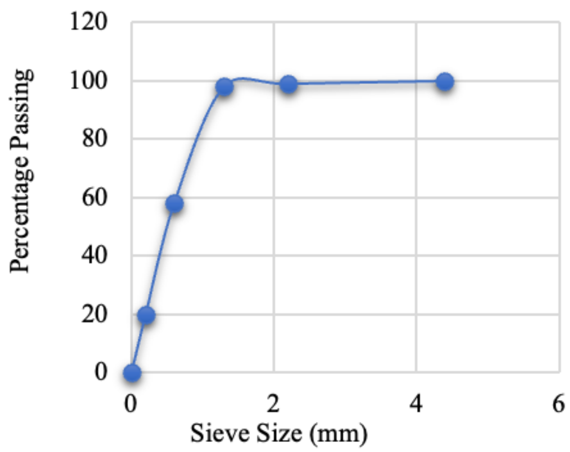
Coarse aggregates from Margallah quarry were used in this investigation with a maximum size of 20mm. The maximum size of the Lawrancepur riverbed sand used as fine aggregates is 4.75mm. The bulk of the materials used to make the plastic aggregates are TV, LCD, computer monitor, keyboard, and other scraps. Ordinary Portland cement (OPC) Type-I, meeting the guidelines as per ASTM C-150 was utilized as a binder. Table 3 indicates different characteristic of Type-1 cement. Plastic aggregate in processed form with a maximum size of 20 mm was purchased for the current investigation from the local market. In Fig. 1, gradation curves for both fine and coarse aggregates are displayed. All ingredients are combined with potable water. Table 4 lists the characteristics of fine aggregates, natural coarse aggregates, and plastic coarse aggregates. Fig. 2 shows the plastic coarse aggregates used in the current study.

**Table -3**: Properties of OPC

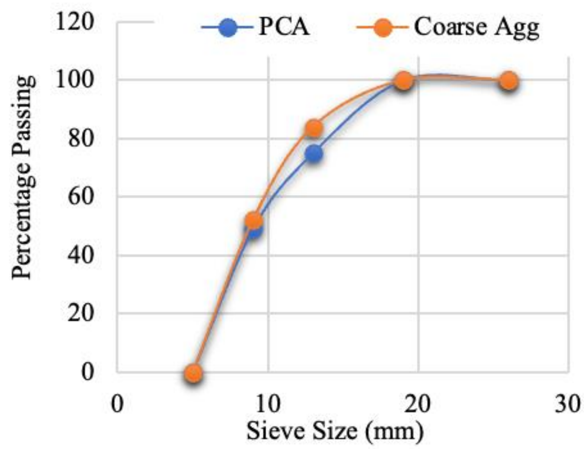
| Chemical composition | Content (%) |
|---|---|
| CaO | 63.58 |
| $SiO_2$ | 21.9 |
| $Al_2o_3$ | 5.1 |
| $Fe_2O_3$ | 4.1 |
| MgO | 2.56 |
| SO3 | 2.74 |
| Na2O | 0.23 |
| K2O | 0.88 |
| Ignition loss | 0.63 |

**Table -4**: Properties of aggregates

| Property | Natural Coarse Aggregate (NCA) | Plastic Coarse Aggregate (PCA) | Fine Aggregate |
|---|---|---|---|
| Min aggregate size (mm) | 4.75 | 4.75 | - |
| Specific Gravity | 2.62 | 1.05 | 2.65 |
| SSD water Absorption (%) | 1.08 | 0 | 0.5 |
| Color | Dark | Black, Brown | Dark |
| Shape | Angular | Angular | - |
| Aggregate impact value (%) | 25.3 | 8.2 | Nil |
| Aggregate Crushing value | 27.2 | 1.28 | Nil |
| Fineness Modulus | Nil | Nil | 2.23 |
| Bulk Density (lb/$ft^3$) | 93.5 | 29.95 | 100 |




(a)




(b)

**Fig -1**: a) Gradation curve for sand b) NCA and PCA

### 3.2 Preparation of concrete and curing

First, the coarse aggregate is added in the mixer, then afterward sand and then cement were added. Materials were mixed dry in a mixer for 1.5-3 minutes. After the dry ingredients were properly mixed, water was gradually added while the machine was running. After adding water, the concrete was mixed in the drum for at least two minutes. After that, workability of the concrete is checked before pouring it into the moulds, and the process is repeated to complete the material for a specific number of moulds or specimens. While placing concrete in mould, each layer was compacted with the rods by tamping. After 24 hours column moulds were demoulded, and the specimen were cured for 28 days.

**Fig -2**: Plastic aggregate

## 4. RESULTS AND DISCUSSION

### 4.1 Compressive strength

The range of values of compressive strength for different column specimens is represented in Fig. 3. Control mix compressive strength is 2635 Psi while the sample with 12% recycled plastic aggregate (RPA) showed compressive strength of 2273 Psi. Furthermore, it is observed that column specimen having longitudinal reinforcement 4#3 with 12% RPA showed more compressive strength as compared to the column with 4#4 longitudinal reinforcement & 12 % RPA. It is also seen that while decreasing stirrups spacing compressive strength of specimens increased. According to earlier research, compressive strength reduction can be credited to the aquaphobic quality of plastic aggregate as well as the weak connection between plastic aggregate and cement matrix [17]. Plastic aggregates don't often absorb the water, leaving the cement matrix with excess water. The aggregates develop a film over the additional water, weakening the bond between both the aggregates and the cement matrix. [18] SEM images in past studies revealed obvious cracks between the cement matrix and the plastics aggregates, as well as a liquid layer surrounding the particles. As per [19], the loss of strength properties is primarily caused by improper bonding between plastic granules & cement paste. Compressive strength reduction is affected by the type of plastic used, and the size, and shape of both types of aggregate. Prior study indicates compressive Concrete strength can be reduced by up to 46% if plastic is substituted by up to 30% [20]. However, the results show that the maximum strength reduction for RPACC-4 was 23% while a minimum reduction of 8.2% was observed for RPACC-2.

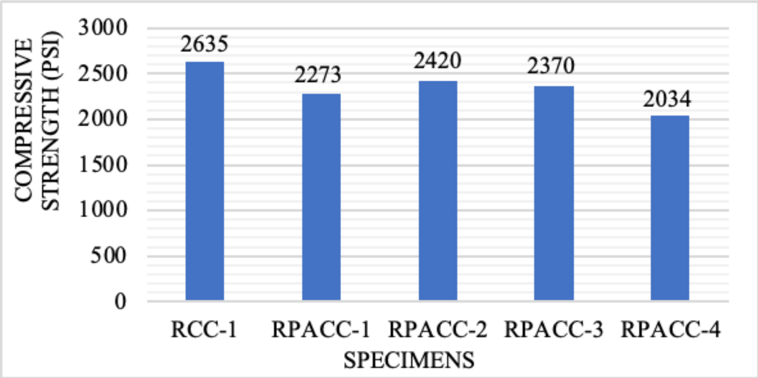



**Fig -3:** Compressive strength of all column specimen

### 4.2 Load verses displacement relationship

Fig. 4 shows the load vs displacement relationship. As the axial compressive load increases, the curve is almost linear without any crack appearing up to the yielding of longitudinal reinforcement, a point reached where the steel yield and concrete start cracking. It is also observed that column with less stirrups spacing showed a consist decrease after ultimate load point, while the other sample where stirrup spacing is increased showed a more ductile behaviour as compared to the other samples. Stirrups spacing is found to affect the initial stiffness considerably.

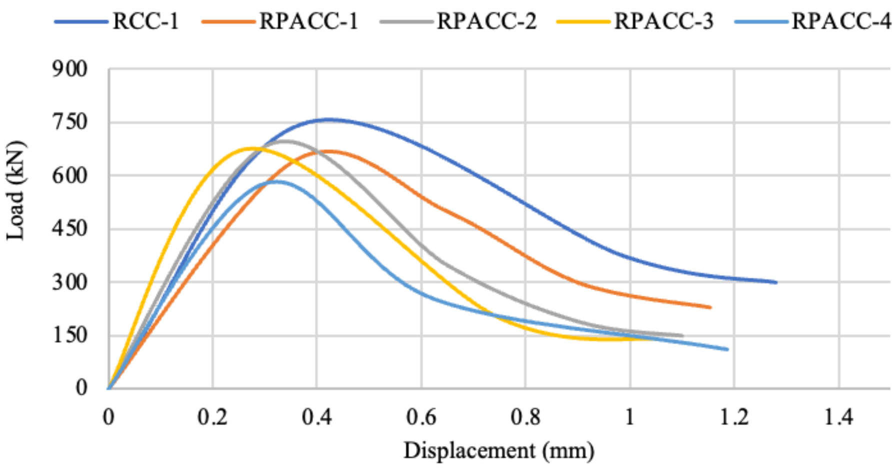



**Fig -4**: Load vs Displacement Curves

### 4.3 Workability

Results of slump tests for various percentages of Plastic waste aggregate can be seen in Fig. 5. Concrete workability including plastic waste increased significantly with increase in percentage of plastic waste. Plastic waste concrete workability increased by 41.3% at 12% replacement of natural coarse aggregate. This increase in slump value is due to water adsorption property of plastic aggregate, resulting in the availability of more free water in the cement matrix. Increasing pattern of workability was also reflected in past studies [21,22]

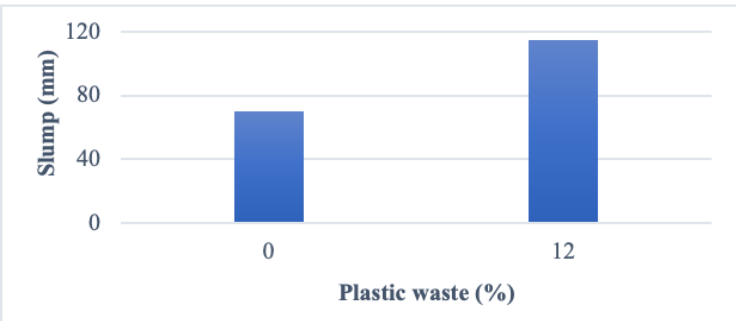



**Fig -5**: Slump Values

## 4.4 Cracking and failure modes

As shown in Fig. 6, as the axial stress increased, small cracks which are vertical began to appear at the end of the column. As the stress increased further, the width of the crack increased and extended slowly toward the centre of the column. When the column is close to the failure, vertical cracks increased, and a large splitting crack finally appeared longitudinally along the column until the column failure. The longitudinal reinforcement was exposed during the testing, due to spalling of concrete cover. The shear failure of most columns was similar in behaviour. Buckling of steel at the bottom of the columns was also noticed. It is also observed that columns with 12% recycled plastic showed cone like cracks shape but if we start increasing the ties spacing columns moves toward shear failure and by reducing ties spacing diagonal cracks occur and buckling phenomena was also observed.

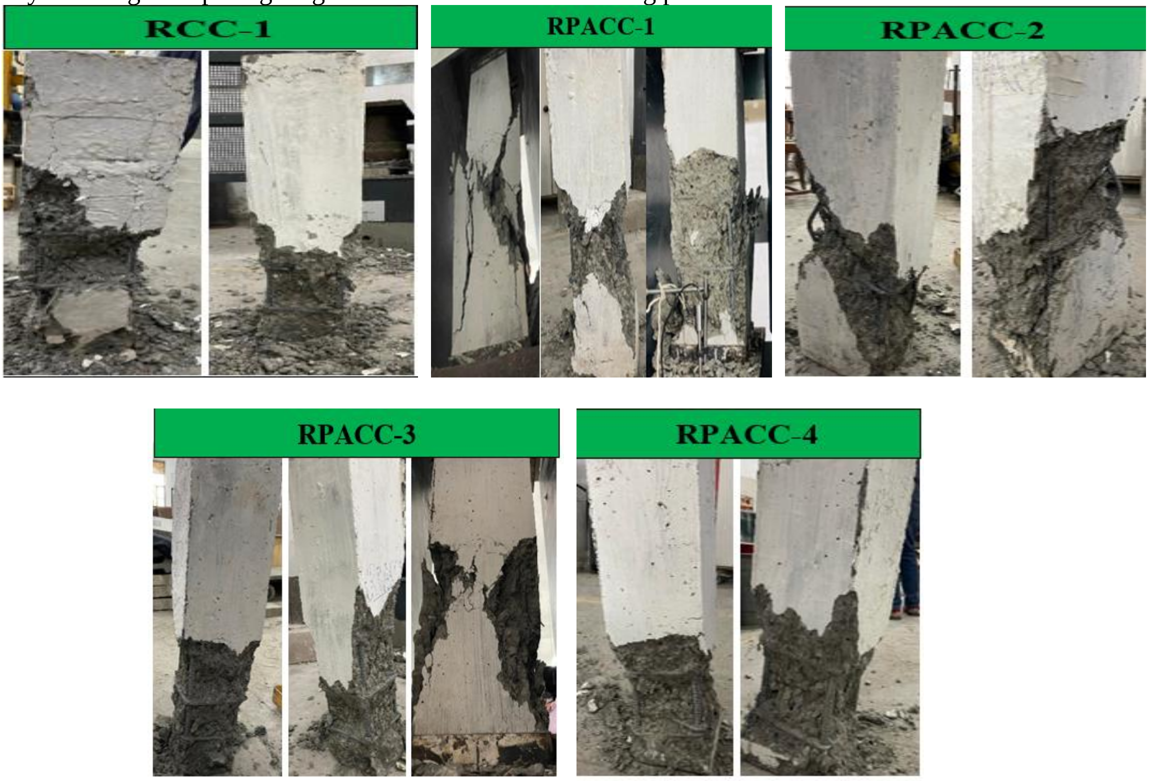



**Fig -6**: Failure pattern of all column specimen

The current study is limited to constant use of replacement ratio of recycled plastic aggregate which is 12%. Furthermore, axial loading is also one of the limitations along with the variations in the stirrup spacing and longitudinal reinforcement.

## 5. CONCLUSIONS AND RECOMMENDATIONS

In this paper compressive behaviour of reinforced concrete columns containing partial substitution of natural coarse aggregate with recycled plastic aggregate is investigated. Experimental investigation produced the following results:

- Incorporation of plastic aggregates with 12% replacement ratio reduced concrete compressive strength due to the aquaphobic nature of recycled plastic aggregates resulting in poor bonding between cement matrix and PCA; however, the reduction is within manageable range and the columns can be used for structural applications.
- Spacing of the stirrups had the maximum effect of reduction of compressive strength while the longitudinal reinforcement ratio shows a relatively lower effect on strength of the columns.
- The failure patterns of columns with and without plastic aggregates is found to be similar in nature.
- Recycled plastic waste coarse aggregates are much lighter in weight as compared to natural coarse aggregate. They have density about 1.04 which leads to the production of lightweight concrete.

Future works need to focus on improving the compressive strength of RPAC columns by the addition of different admixtures like fly ash and nano graphite particles. Furthermore, durability properties also need to be focused. Research should also be focused on replacing both fine and coarse aggregate with different replacement ratios.

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