# Optimizing Mix Design of Concrete using Recycled Plastic Aggregates

**FINAL YEAR PROJECT UG-2020**


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**2024**

This is to certify that the Final Year Project

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Has been accepted towards the requirements

for the award of undergraduate degree.

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# Abstract

This abstract investigates the capability of RPAs in enhancing sustainability within the construction industry. It initiates by highlighting the environmental implications posed by traditional construction materials and spotlights the benefits of using RPAs, including reduction in waste, energy conservation, and carbon -dioxide emissions reduction. The mechanical properties of RPAs are evaluated, emphasizing their conformance to various construction applications such as concrete, asphalt, and road base layers.

Moreover, it magnifies the economic feasibility of incorporating RPAs into construction projects, considering factors like material availability, production costs, and market demand. The potential problems and limitations related with RPAs, such as durability issues and standardization issues, are also elaborated alongside ongoing research work aimed at addressing these issues.

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# LIST OF ACRONYMS

| | |
|---|---|
| RPA | Recycled Plastic Aggregates |
| HDPE | High Density Polyethylene |
| PVC | Polyvinyl Chloride |
| STS | Splitting Tensile Strength |
| CS | Compressive Strength |
| LCA | Life Cycle Assessment |
| SDGs | Sustainable Development Goals |
| UNDP | United Nations Development Program |
| RIC | Resin Identification Code |
| 2D | Two Dimensional |
| 3D | Three Dimensional |

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# Chapter 1: Introduction

## *Section 1.1 : Background*

Concrete is widely used construction material throughout world from many years. It possesses excellent mechanical and physical properties which makes it extensively usable. Some key features include versatility, adaptability, strength, thermal insulation and freeze-thaw cycles. Concrete structures are very resilient to natural disasters and environmental impacts. Also, their life cycle is very good. The materials used for concrete construction are easily available.

Concrete is mixture of cement, water, sand and coarse aggregates. Coarse aggregates constitute about 60 to 70 % of concrete. Aggregate properties are very much reflection of properties of concrete.

While aggregate production is important for construction industry and the development of infrastructure, it has certain demerits. Some of demerits are listed below:

Aggregates production is detrimental for habitat. Quarrying activities on site destroy natural features affecting visual aesthetics. This creates problems for local flora and fauna.

About 3 billion tons of materials are used annually for construction [1]. Excessive use of natural resources may diminish them. Also, quarrying activities affect water table of surrounding ecosystem.

During crushing of aggregates, a lot of noise is produced. Also, dust generated during grinding contribute to air pollution.

A lot of energy is required for production of aggregates and their transportation. This causes increase in carbon footprint. The extraction of these materials accounts for 7% of global total energy consumption [2]. The transportation of these materials is responsible for 40% of total energy consumption by industry.

Waste products generated during aggregate production require proper disposal management system posing challenges to sustainability.

Keeping in consideration above factors, the need of hour is that we should find substitute of natural aggregates. Different studies were conducted to find feasible material for replacement through sustainable practices.

Plastic, due to its non-biodegradable characteristics is of major concern for scientists and environmentalists. There is dire need to discover avenues for its consumption. Earlier practices such as landfill and incineration are threat for humanity. Concrete is widely used construction material with annual production of about 11.5 billion tons in 2014 [3]. So, recycled plastic aggregates in concrete meet concerns regarding safe disposal.

In last 50 years, growth of world plastic industry has increased from 15 to 322 million metric tons [4]. Less than 30 percent of this is recycled [5].

According to a report by the United Nations Development Program (UNDP), Pakistan produces about 20 million tons of solid waste every year, of which about

5 to 10 percent is plastic. Moreover, a study conducted by the Worldwide Fund for Nature (WWF) in 2018 revealed that Pakistan is one of the top 10 countries in the world for plastic pollution, with an estimated 90 percent of plastic waste not properly disposed of.

The use of plastic aggregates in construction has several advantages. Some of them are given below:

Plastic having low density (1.44 -1.48 g/cm^3) is excellent for lightweight aggregates. This is useful where weight is critical factor such as tall buildings as it reduces dead load. This also improves seismic response of building as less base shear generated due to less weight. Also, transportation and handling of materials becomes easier.

Plastic has good thermal insulation properties. So, it is advantageous in regions with where energy conservation and comfort is required e.g. residential and commercial buildings.

By using plastic aggregates, workability of construction is increased during mixing and placement due to light weight. This causes an improvement in flow of concrete. Consequently, cost of labor and construction is reduced.

Utilizing plastic as lightweight aggregate provides effective solution for recycling plastic waste. This generates circular economy by giving new life to plastic.

## *Section 1.2: Problem Statement*

Aggregates form about 60-70% of concrete. The construction industry dependence on natural aggregates in concrete production opens new avenues for exploration into alternatives like lightweight plastic aggregates. The plastic aggregates have many benefits such lowering burden on natural resources, environment friendly solutions and favorable mechanical properties.

Moreover, the economic aspect during construction is of major concern. The use of conventional heavy weight aggregates cost much to steel cost. However, use of plastic aggregates lowers deadload. Consequently, steel cost is also reduced.

Also, dumping of large amount of waste plastic is not possible and it poses serious challenges. The use of conventional methods like incineration are not environment-friendly. So, utilization of plastic in concrete solves this problem.

Construction industry contributes to carbon footprint globally for aggregates production. But use of plastic aggregates is environment friendly. These factors justify use of lightweight aggregates in concrete.

### *Section 1.3: Objectives*

- Development of lightweight plastic aggregates from PPRC waste by incineration process and carrying out complete testing of the manufactured aggregates by following ACI guidelines.
- Development of Concrete specimens incorporating plastic aggregates and finding their mechanical, durability and workability characteristics by extensive testing.
- Carrying out a thorough cost feasibility analysis of multi-story building using concrete with manufactured plastic aggregates.
- Carrying out a comprehensive Life Cycle Analysis of developed optimized mix, focusing on environmental impacts, sustainability, and Carbon footprint.

## *Section 1.4: Scope and Limitations*

One of the demerits of using RAP in concrete is reduction in mechanical strength as compared to conventional concrete if we go to high replacements.

RAP affects durability in terms of freeze-thaw cycle, chemical resistance and compatibility.

Ensuring consistent quality of RAP is difficult due to different plastic types and processing methods.

Intrusion of plastic aggregates in concrete can affect workability, flowability and mixing process.

## *Section 1.5: Thesis Structure*

This document is divided into five chapters:

1. Started with providing the background of the study area, problem statement, listing the research objectives, defining its scope and limitations in Chapter 1.

2. Chapter 2 provides an in depth and complete literature review. The chapter also outlines research gaps in this field.

3. Chapter three demonstrates the research methodology framework that was followed to execute the project.

4. Chapter four entails the results of the project and provides brief details on the outcomes.

5. Finally, chapter five constitutes the life cycle analysis and analyze environmental impacts.

# Chapter 2: Literature Review

## *Section 2.1: Recycled Plastic Aggregates*

As discussed already, aggregates form about 60 to 70% of concrete. So, concrete properties are dominated by aggregates. These impart soundness and hardness to concrete. Conventionally, natural aggregates are used for this purpose. But due to certain environmental factors and depletion of natural resources, there is intensive research to find an alternative that meet modern avenues of sustainability and construction. For this replacement, the best option is to use recycled material that follows 3R strategy on one hand and meets other structural demands on other hands.

Based on literature review, plastic was found to serve as alternate to natural aggregates. Commercial production of plastic that was started around 1950's has increased by leaps and bounds. At present growth rate it is estimated to be doubled in next 20 years. According to Plastics Europe Market Research Group, Global plastic production was 368 million metric ton in 2019 with indicators showing continuous growth. Such immense production of plastic has led to increase in plastic waste production which is figured 300 million tons annually. The main issue lies in heart of fact that very minor amount of this plastic is recycled. In 2015, only 9% of this waste was recycled. Rest of waste because of its non-biodegradable nature poses many serious problems. Conventional methods of landfilling and incineration emit huge amount of carbon dioxide in atmosphere. Recycling of plastic waste to produce new materials like concrete appears to be efficient solution due to environmental advantages.

The use of recycled plastic aggregates (RPA) in concrete mix design is an ongoing field of research with significant implications for sustainable construction practices. This literature review aims to briefly analyze the technical aspects of optimizing concrete mixtures with RPA, examining the material properties, optimization strategies, environmental impact, challenges, and future research directions.

Not all the plastic is found equally. It has variety of types based on material and characteristics. In 1988, the society of plastic industry formulated the Resin Identification Code (RIC) which divided plastic into different categories.

### *PET*

It is made up of polyethylene terephthalate. It is mostly used for food and drinking purposes. It is the most recycled plastic worldwide and has positive track records.

### *HDPE*

HDPE stands for High Density Polyethylene. It is mostly used for grocery bags, agricultural pipes etc. It is stronger and thicker compared to PET and has good resilient properties and can bear heat of about 120˚C.

### *PVC*

PVC plastic is widely used plastic in building construction for doors & windows work and pipes etc. It is replacing traditional construction materials like wood, glass and concrete etc.

### *LDPE*

LDPE stands for Light Density Polyethylene. It usually comes in thinner and flexible forms. It finds its applications in manufacturing of plastic bags and is usually avoided to be recycled.

These were various plastic types which can be recycled. However, the recycling process depends on demands and needs of the product to be designed.

## *Section 2.2: Production of RPA*

The composition of plastic aggregates consists of two constituents. One is binder and other is filler. Binder material is any type of plastic. These are added to improve adhesion and cohesion between particles thus improving strength whereas filler may be any river sand, fly ash and brick powder etc. Purpose of filler is to impart toughness and reducing ductile response of aggregates. However, selected material should be such that it is inert and does not react chemically with concrete.

The production of plastic aggregates is one of major concerns. We have to go through a number of steps which are discussed briefly here.

Firstly, raw material is collected which exists in different forms like plastic bags, bottles and plastic jars etc. It is washed to remove clay and silt impurities because dust present affects the interfacial transition zone of concrete resulting in reduced strength of concrete. This is evident from microscopic analysis of concrete. These impurities are removed by water followed by air drying.

After this, plastic is tormented and shredded into small pieces. Shredding processes ensure uniformity and particle size control of pieces. The main purpose of shredding is to break plastic into pieces so that they can be easily handled. The shredders typically consist of rotating hammers or blades that have cutting properties.

Next, this plastic is screened through to remove major impurities like iron and leather as these may affect further processing of aggregates.

Once screening is done, plastic is sent to mills for heating where it is melted. It may also be mixed with suitable materials like fly ash, river sand and brick powder to enhance mechanical properties. The filler provides soundness to aggregates. Also, texture of aggregates is improved which results in better bonding with concrete at ITZ. The kiln is heated to about 200˚ C. The melted material is sent to water coolers where the melted material is solidified to rocks. The cooling can involve air cooling, water quenching and controlled chamber cooling.

The solidified matter can then be crushed by mechanical mixers to get a variety of gradation of aggregates. Quality control measures ensure that we have gained aggregates of specific standard and size. The resulting product can then be packed and is ready for use.

## ***Section 2.3: Properties of RPA***

Properties of concrete are dominated by aggregates. In this section, we will evaluate the effect of using recycled plastic aggregates instead of natural aggregates. The intrusion of RPA causes reduction in compressive strength. The happens due to weaker bond at interfacial transition zone. The contact area between aggregates and concrete lacks adhesion properties resulting in strength loss. If natural aggregates are replaced totally, there is reduction in compressive strength from 40 to 60%. Due to this reason, natural aggregates are replaced partially. Tests are conducted at different replacements e.g. 10,20,30,40 and 50%. After 50% replacement, there is major loss of strength as indicated by rapid dropdown in curve. In same manner, flexural strength is also reduced. This problem is addressed by partial replacement to 30%. Also, where higher strength is required, we can use steel fiber reinforcement to boast flexural strength. Moreover, splitting tensile strength is an important parameter of concrete strength. It is ability of concrete to withstand the tensile forces. The manipulation of plastic aggregates cause reduction in splitting tensile strength with increase in replacement %.

The thermal properties were increased due to use of plastic aggregates. Researches show that thermal conductivity was seven times better as compared to concrete composed of natural aggregates. As we know that buildings consume large amount of energy, however, due to increase in thermal insulation, there was significant reduction in building cost. The thermal stability of aggregates influences their ability to endure cracking or dimension changes.

The water absorption and vapor transport increase due to use of plastic aggregates. This happened due to increase in openings in concrete. Also, mechanical properties of concrete are affected due to shape and grading of plastic aggregates. For dense gradation including particles of varying sizes, there is better packing of particles.

Concrete beyond its strength should also meet standards of workability and compatibility. Workability is the ease with which concrete can be poured and handled. Test results show that with increase in plastic amount, the workability is increased due to smooth surface texture of aggregates up to a certain limit. After that, it starts to decrease. This is likely due to non-absorbent property of aggregates. As water remains in mix leads to greater flexibility, workability is decreased.

Recycled plastic aggregates need to withstand weathering effects like freeze-thaw cycles. If water absorption of plastic aggregates is more, then during winter season water compares 7% more volume as compared to that in liquid state. Proper production and treatment can only ensure good quality aggregates.

Plastic aggregates should demonstrate resistance to chemical degradation. They should be chemically inert and don't react with concrete, acids and alkalis. The choice of plastic type affects resistance property of aggregates to chemicals. Other influencing factors include processing methods and surface treatments.

## *Section 2.4: Environmental Impact Assessment*

Environmental impact assessment of recycled plastic aggregates is prescribed in terms of life cycle analysis, resource conservation, and carbon footprint. LCA is a comprehensive and detailed method used to assess the environmental impacts associated with a product, process, or material throughout its entire life cycle, from raw material extraction to disposal or recycling.

When comparing recycled plastic aggregates with conventional aggregates (such as natural stone, gravel, or sand), several environmental factors are typically considered.

LCA evaluates the energy inputs required for aggregate production, transportation, processing, and end-use applications. Recycled plastic aggregates may require less energy compared to extracting, crushing, and processing traditional aggregates.

LCA assesses various emissions, including greenhouse gas emissions, air pollutants, and water pollutants. The production of recycled plastic aggregates may result in lower emissions of CO2 and other pollutants compared to conventional aggregates, especially if the recycling process is energy-efficient and reduces the need for materials.

LCA considers the depletion of natural resources such as fossil fuels, minerals, and water. Using recycled plastic aggregates can reduce the demand for virgin materials, contributing to resource conservation.

LCA analyzes waste generation throughout the life cycle, including waste from production, processing, and end-of-life disposal. Recycling plastic waste into aggregates helps divert waste from landfills, reducing the environmental burden of waste management.

In conclusion, assessing the environmental impact of recycled plastic aggregates involves evaluating their life cycle, resource conservation benefits, and carbon footprint. Proper recycling practices, energy efficiency, waste reduction, and sustainable management practices contribute to the environmental sustainability of using recycled plastic aggregates in various applications.

## *Section 2.5: Applications of RPA*

RPA finds its applications in various domains of construction validating its use. Its versatility makes it applicable in different conditions. Some of them are discussed here:

Several case studies have explained the suitability of RPA in road construction. These studies have shown that incorporating plastic aggregates in asphalt mixes can enhance the performance of pavements in terms of durability, resistance to cracking, and reduction in rutting. Projects such as the Plastic Road initiative in the Netherlands and various road construction projects in India, Malaysia, and the United States have successfully utilized recycled plastic aggregates in asphalt pavements. These projects have highlighted the benefits of using plastic aggregates, including longer pavement lifespan, reduced maintenance costs, and enhanced sustainability by recycling plastic waste.

Recycled plastic aggregates have been employed in landscaping and green infrastructure projects to create permeable pavements, retaining walls, and decorative elements. Studies have shown that plastic aggregates can enhance water drainage, reduce soil erosion, and contribute to sustainable urban design. Green spaces, parks, and urban redevelopment projects in cities like Singapore, Vancouver, and London have utilized recycled plastic aggregates in landscaping applications. These projects showcase the aesthetic appeal, functionality, and environmental benefits of using plastic aggregates in outdoor environments.

Initiatives such as plastic recycling plants, waste-to-energy facilities, and circular economy programs in regions like Europe, Japan, and Australia have integrated recycled plastic aggregates into sustainable waste management strategies. These projects contribute to the circularity of plastic materials, where waste is transformed into valuable resources for construction and infrastructure.

These projects showcase the potential of plastic aggregates to improve material performance, reduce environmental impacts, and support sustainable development goals related to waste management, resource conservation, and infrastructure resilience.

# Chapter 3: Research Methodology

## *Section 3.1: Material Characterization*

In this chapter, methodology of research is explained. After doing literature review, we go for production of aggregates. Our aggregates constitute Binder and Filler. The processing of these two materials involves several steps. First of all, we wash waste plastic. Impurities are removed e.g. dust. Afterwards, plastic is crushed and mixed with filler material. Once we get homogenized mixture, it is subjected to heat. Until plastic is liquidized, heating is continued. After that, it is allowed to cool till solidifying. The hardened product is then shredded into pieces. We can get gradation as desired.

## *Section 3.2: Testing of Aggregates & Concrete*

Testing is done so that our material conforms to specific standards. In first phase, aggregates are tested. Several tests like Los Angles Abrasion test, toughness test, fineness modulus test are performed. Once aggregates are validated through testing, next step is to cast concrete samples. We use different replacement ratios. Based on this, we find optimum replacement. Tests like workability, compressive strength, flexural strength and STS are performed.

## *Section 3.3: Optimization of concrete mix*

Our major concentration is on optimizing the mix design of concrete by using RAP, with aim to increase the sustainability and performance of concrete.

The research design used is experimental, as it allows us to vary input variables such as % of plastic aggregates. This approach is opted to accurately evaluate the impact of varying mix proportions on concrete properties.

The materials used in our testing included of recycled plastic aggregates collected from wastes, Ordinary Portland cement, fine aggregates and water. The waste plastic was processed carefully to remove impurities and graded suitably for use in concrete mixtures.

Our experimental procedure involves preparing concrete mixes with varying proportions of plastic aggregates while keeping other variables such as curing conditions and aggregate size constant. The concrete samples are casted and cured using ASTM standards to ensure consistency in testing. We performed a number of tests, including compressive strength, tensile strength, workability (using slump tests) to assess the performance of each concrete mix.

Analysis of data was done using conventional methods to analyze the results obtained from testing. The results are compared with control sample. We make contrast of the properties of concrete specimens with different plastic aggregate contents to identify varying trends and patterns. At last, we came up with the optimal mix proportions that led to improved concrete properties including workability while minimizing environmental impact.

In conclusion, our research methodology entailed a systematic method to optimize the mix design of concrete using recycled plastic aggregates. The results gained through experiments offer practical applications for industry.

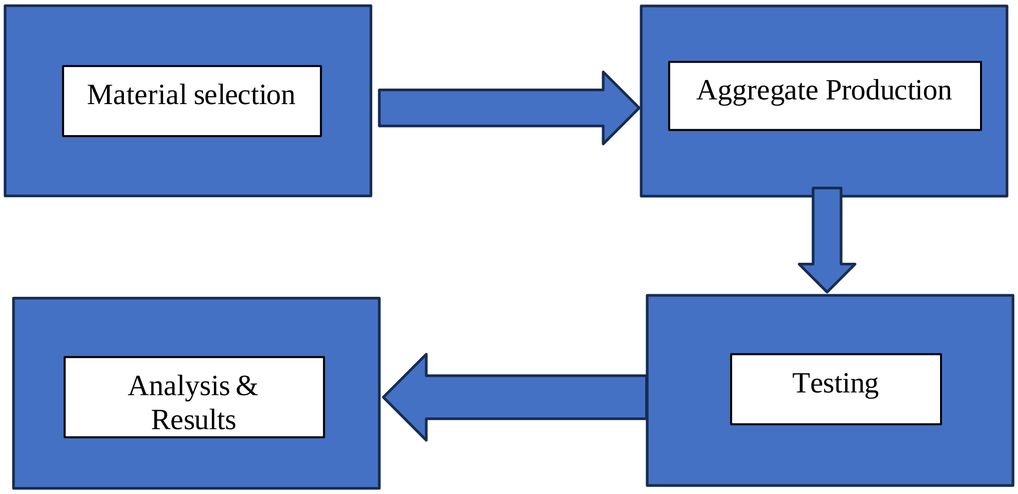


Figure 1 showing Research Methodology

# Chapter 4: Results and Discussion

## *Section 4.1: Mechanical Properties*

### *Section 4.1.1: Compressive Strength*

Compressive Strength is a key mechanical property of structural concrete which describes the ability of the concrete to withstand and carry structural loads. Cylindrical molds were used to cast 12 samples, including control sample. In the first phase,7-day compressive strength was found out in accordance with ASTM C-39 and in the second phase 28 days compressive strength was found for the specimens. Fig 2 shows the results

| SPECIMEN | 7-Day Compressive Strength(psi) | 28-Day Compressive Strength(psi) |
|---|---|---|
| Control Sample | 2205.45 | 3516.00 |
| 10% Replacement | 2069.15 | 3182.75 |
| 20% Replacement | 1956.05 | 3010.2 |
| 30% Replacement | 1674.75 | 2595.5 |
| 40% Replacement | 1129.55 | 1721.15 |
| 50% Replacement | 230.55 | 1218.00 |

7 days Compressive strength of the control sample was found as 2205.45psi, while concrete with 10%, 20%, 30%, 40%, and 50% PCA revealed compressive strengths of 2069.15psi, 1956.05psi,1674.75psi.1129.55psi, and 230.55psi. There was a reduction of 24.06% up till 30 percent replacement, but there was an overall drop of 89.54% between 0 and 50% percent, with the steepest drop coming from 30% to 50% replacement.

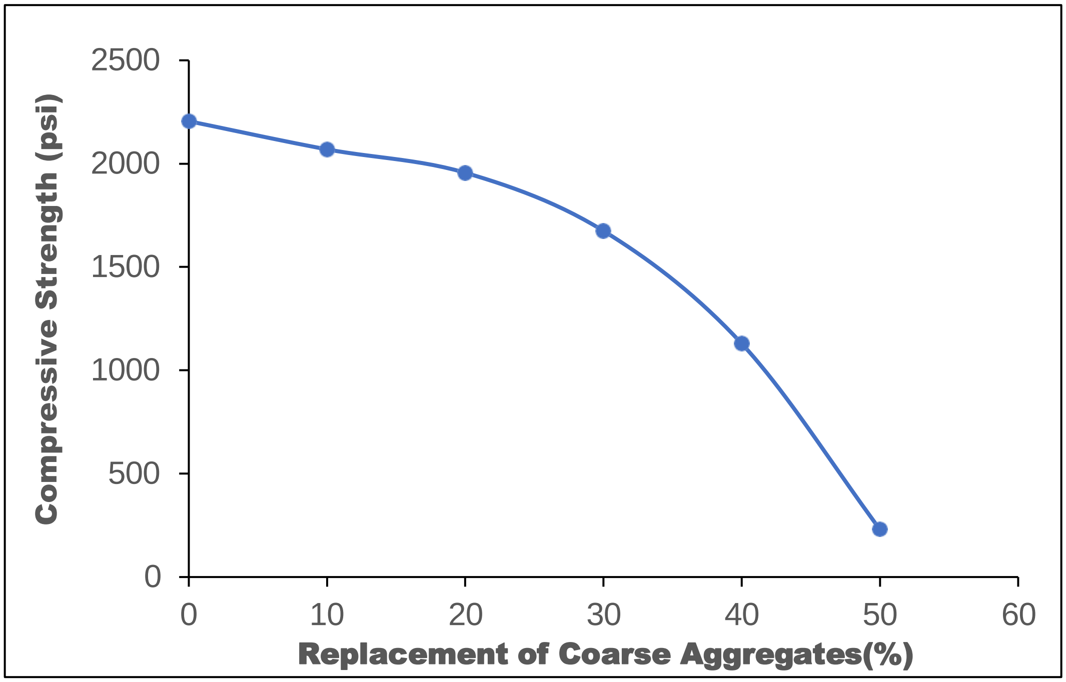



Figure 2 showing compressive strength at 7 days

A similar trend is observed in the 28 days compressive strength results, 28 days Compressive strength of the control sample was found as 3516psi, while concrete with 10%, 20%, 30%, 40%, and 50% PCA revealed compressive strengths of 3182.75psi, 3010.2psi,2595.5psi.1721.15psi and 1218psi. However, the overall decrease observed from 0 to 50 percent interval Is 64.16% which is lower than that observed in the case of 7 Day Compressive strength.

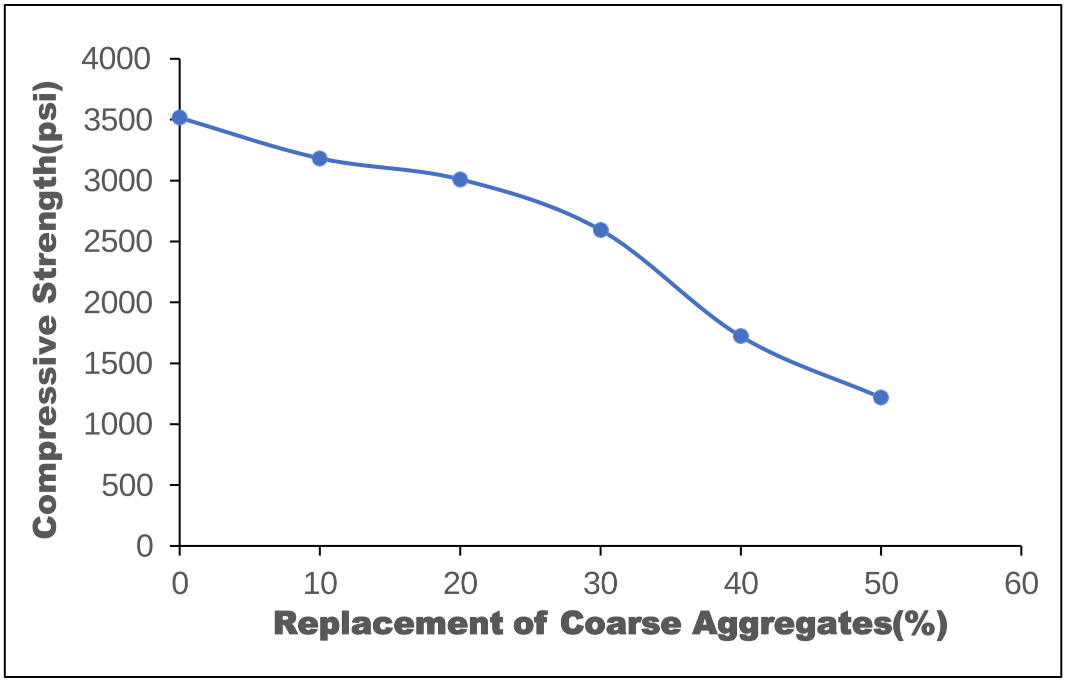



Figure 3 showing Compressive Strength at 28 days

The results clearly show that a significant drop in compression strength is evident as the PA replacement with CA increases. The results, however, also indicate, that the compressive strengths of the specimen with 40% and 50% replacement fall below the minimum compressive strength requirement of Structural concrete as specified by ACI -318 which is 2500psi, and so these two % replacements are not advisable. This can be justified by the weak bond formation between the PA and rest of the concrete components. Also, the smooth texture of the PPRC aggregate causes weak adhesion with the cement paste, thus causing reduced compressive strength. The non uniformity of the concrete matrix in the case of PA concrete, allows the failure cracks to travel rapidly and more irregularly, leading to lower compressive strengths.

### *Section 4.1.2: Split Tensile Strength*

Tensile Strength is that property of concrete which allows it to resist cracking and withstand tensile stresses as concrete is weak in tension. It is important to evaluate the tensile strength of concrete before applying the structural loads. The STS test Is carried out in which when tensile loads are applied to cylindrical specimens of concrete, tensile stresses develop and the maximum load at failure then indicates the STS of the specimen.

Cylindrical specimens of 100mm diameter and 200mm height were prepared. Testing was done at both 7 day and 28 days samples, the maximum loads and strengths at failure were noted and the tensile strength was calculated based on the formula

TS= $\frac{2P}{\pi LD}$

The results were found as following:

| Specimen | 7-Day STS (psi) | 28-Day STS (psi) |
|---|---|---|
| Control sample | 285.65 | 506.05 |
| 10% Replacement | 258.1 | 430.65 |
| 20% Replacement | 194.3 | 392.95 |
| 30% Replacement | 181.25 | 371.2 |
| 40% Replacement | 124.7 | 314.65 |
| 50% Replacement | 85.55 | 250.85 |

STS results for the 7 days samples show a decreasing trend as the replacement % of PA is increasing. The highest value is recorded for the control sample as 285.65psi, and the values decrease progressively from there on. A total decrease of 70% is observed between the replacement % of 0 to 50%.As the figure indicates, there are two parts of the graph where steeper decline. In the value of STS was noted, between 10 and 20% replacement, a decrease of 24.7% was observed, with a relatively slower decline between 20% and 30% replacement, the decline is steeper again between 30% and 40% replacement with a value of 31.2%, both of these two portions combine to contribute to about 80% of the total decline, which indicates that 20% and 40% were the critical replacement percentages.

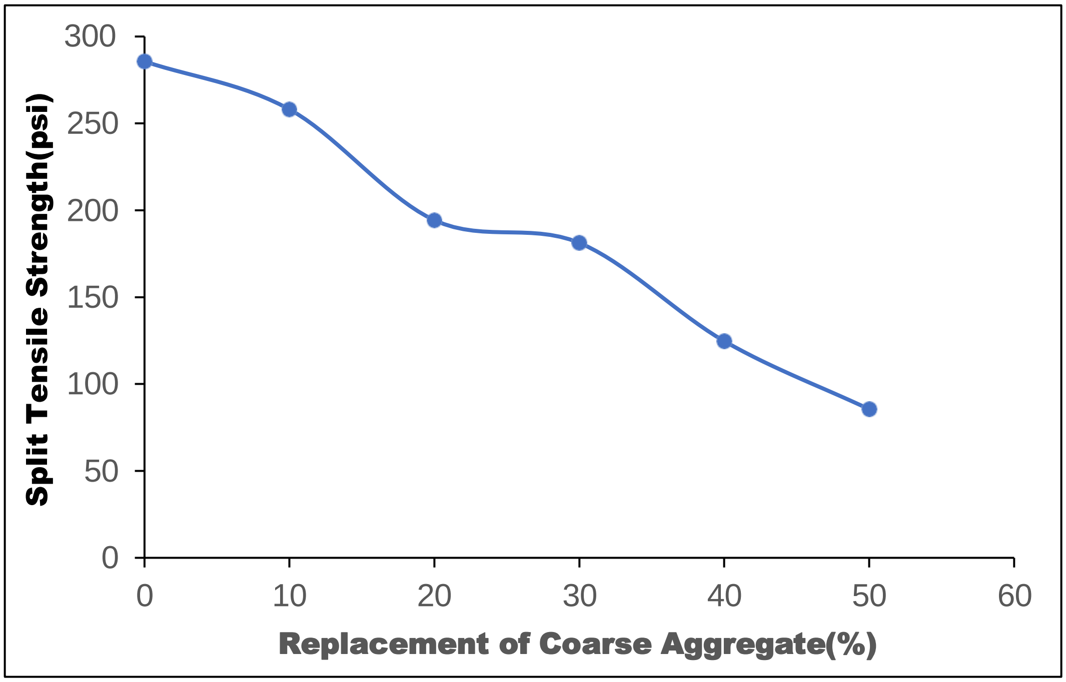



Figure 4 showing STS at 7 days

For 28 days samples, the figure indicates, the control sample's STS came out to be 506.05 psi. On 10%, 20%, 30%, 40%, and 50% replacement of NCA with PCA, the STS values were 430.65psi,392.95psi,371.2psi,314.65psi, and 250.85psi respectively. A decrease of 50.3% was observed in the STS from control mix to 50% replacement. The minimum reduction in STS was 14.9%, observed at 10% replacement. The overall decline in the 28 days strength is lower than the 7 days results which showed an overall decrease of 70%

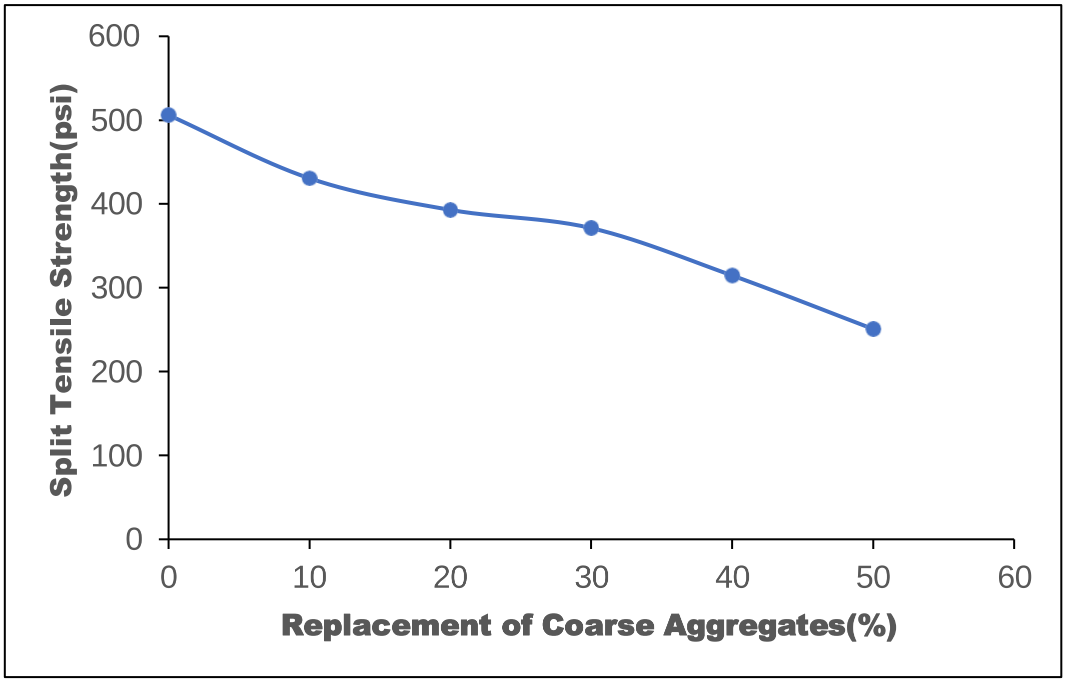



Figure 5 showing STS at 28 days

It is evident from the tests results for both 7days and 28 days, that increasing the replacement percentage decreased the STS in a near linear manner. The smooth surface texture of the PCA and weak adhesion between the PCA and cement paste results in a weak bond, and a high stress zone leading to more abrupt failure and hence lower strength

### *Section 4.1.3: Flexural Strength*

Flexural strength or Modulus of Rupture is measure of maximum stress concrete can withstand while being flexed before rupture. When concrete is used for the construction of structural members like slab and beams, they experience flexural stresses, which makes it pertinent to have a suitable flexural strength in order to ensure structural integrity and safety. ASTM C-78 was applied by simple beam in third point loading to determine flexural strength of concrete. Standard beams are first prepared in accordance with ACI recommendations, then third point loading is applied to the specimen at a rate of 1MPA/min. loading is applied till failure and the flexural strength is found from the formula, by using the maximum load at failure

$$FS=\frac{PL}{bd^2}$$

Testing was done at both 7day and 28 days samples, the maximum loads and strengths at failure were noted and the tensile strength was calculated. The results are shown as below

| Specimen | 7-days (psi) | 28-days (psi) |
|---|---|---|
| Control Sample | 624.95 | 1100.55 |
| 10% Replacement | 510.4 | 990.35 |
| 20% Replacement | 456.75 | 885.95 |
| 30% Replacement | 414.7 | 791.7 |
| 40% Replacement | 361.05 | 735.15 |
| 50% Replacement | 311.75 | 698.9 |

As the figure indicates for 7-Day flexure strength, as the value of % replacement is increased much like STS and CS, the flexural strength of the concrete beams goes on decreasing. The graph follows an almost linear trend with a negative slope, implying a clear inverse relationship between % replacement and Flexure Strength. However, unlike the STS and CS, results, these results do not indicate a very significant decline in FS, from 0 to 50 % replacement, an overall decline of 50.1% was observed which is quite low compared to Cs results which showed a 89.54% and STS results which showed a 70% overall decline at 7 day strengths, respectively. Still however the Flexural strength reduced by over a half.

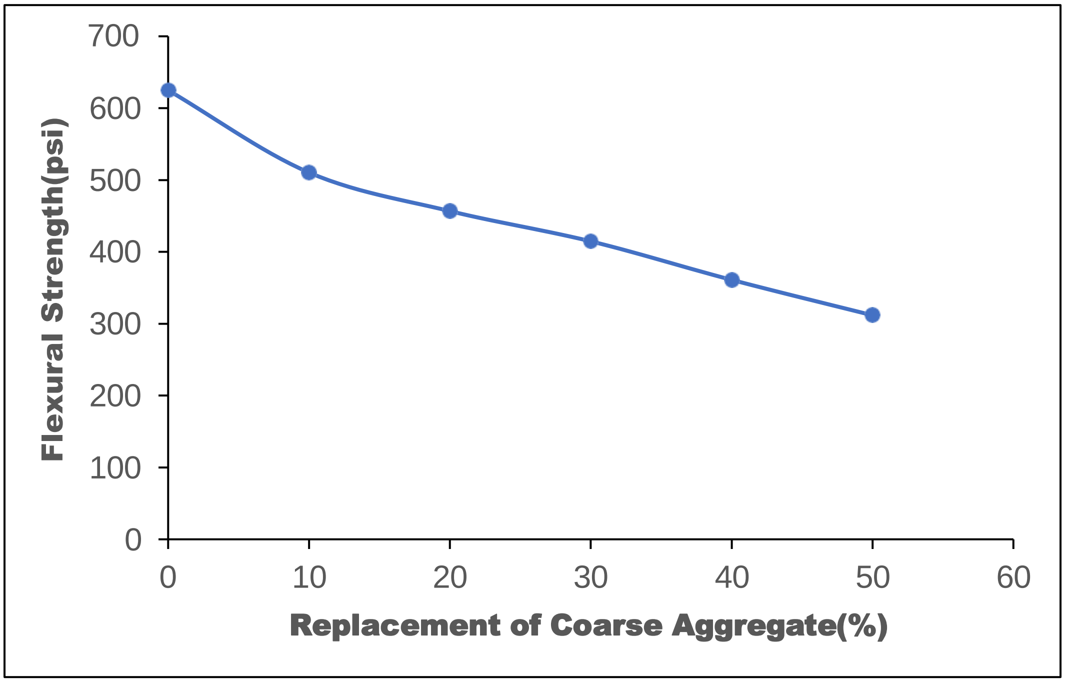



Figure 6 showing FS at 7 days

As evident from the results of the figure, the control sample's FS at 28 Days was 1100.55psi. At 10%, 20%, 30%, 40%, and 50% replacement of NCA with PCA, the FS values were 990.35psi,885.95psi,791.7psi,735.15psi and 698.9psi respectively. An overall decline of 36.4% was observed at the 50% replacement of PA, This drop is considerably lower than the drops observed for CS, STS which were 64.16% and 50.3% respectively.

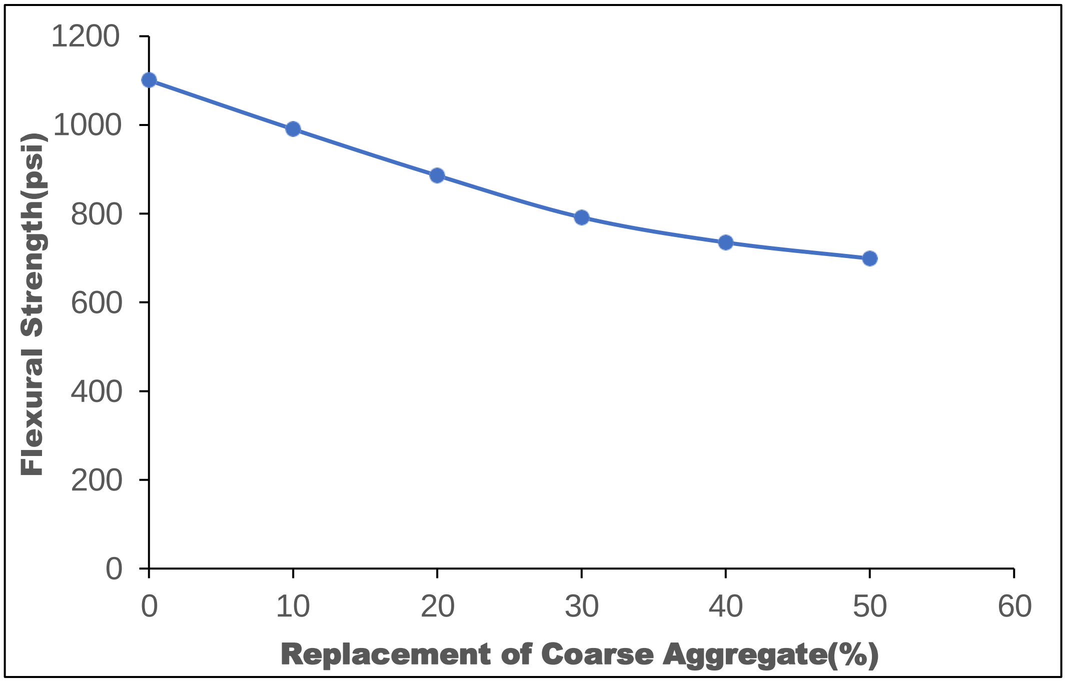



Figure 7 showing FS at 28 days

The results show an almost identical pattern for both 7-day and 28day flexural strengths, both of them decrease in near linear pattern, however the decline observed is significantly lower compared to the declines observed in Compressive Strengths and STS. The decrease in FS in RCPA can be attributed to the lower strength and water repellant property of RCPA which causes a barrier between PCA and cement paste and resulting in decreased bond strength. Plastic aggregates often have lower density than traditional aggregates, which can lead to variations in the density and porosity of the concrete mixture. Higher porosity can result in decreased strength and durability of the concrete due to increased permeability and reduced interlocking of particles.

## *Section 4.2: Durability Properties*

### *Section 4.2.1: Ultra Sonic Pulse Velocity*

The UPV test is carried out to determine the consistency, uniformity and quality of the concrete specimen. It also assesses the imperfections and compactness like cracks and voids inside a concrete sample. UPV value has a direct relationship with concrete density, i.e., the denser the concrete, the higher will be its UPV value. The PUNDIT (Portable Ultrasonic Non-Destructive Digital Indicating Test) was carried out. By placing the ultrasonic transducer probe on surface of the concrete and applying coupling agent, gel, the time taken for the ultrasonic pulse to travel through the concrete and reflect back to the transducer was recorded. This time measurement was used to calculate the ultrasonic pulse velocity using the following formula;

$$\text{Velocity}=\frac{\text{Distance}}{\text{Time}}$$

The following results were found

| SPECIMEN | Ultrasonic Pulse Velocity(km/s) |
|---|---|
| Control Sample | 4.238 |
| 10% Replacement | 4.171 |
| 20% Replacement | 4.089 |
| 30% Replacement | 4.016 |
| 40% Replacement | 3.907 |
| 50% Replacement | 3.718 |

UPV range of 3.5-4.5km/s indicates a concrete specimen with good quality, consistency and compactness. All of the specimens ranging from the control sample to 50% replacement have UPV values within the range of 3.5-4.5km/s, this indicates that all the specimens are of a reasonable and satisfactory quality and the induction of PA has not compromised the quality of the concrete specimens. be of good quality if its UPV value lies in the range of 3.66–4.57 km/s (i.e., 3660–4575 m/s). Figure8 shows the UPV values of RPAC containing different percentages of PA. The results show that with the increase of PA replacement in concrete the UPV value deceased in almost a linear trend. From replacement increasing from 10% to 50% replacement the UPV decreased, with reference to the control sample, by 1.58%,3.50%,5.24%,7.80% and 12.26% respectively.

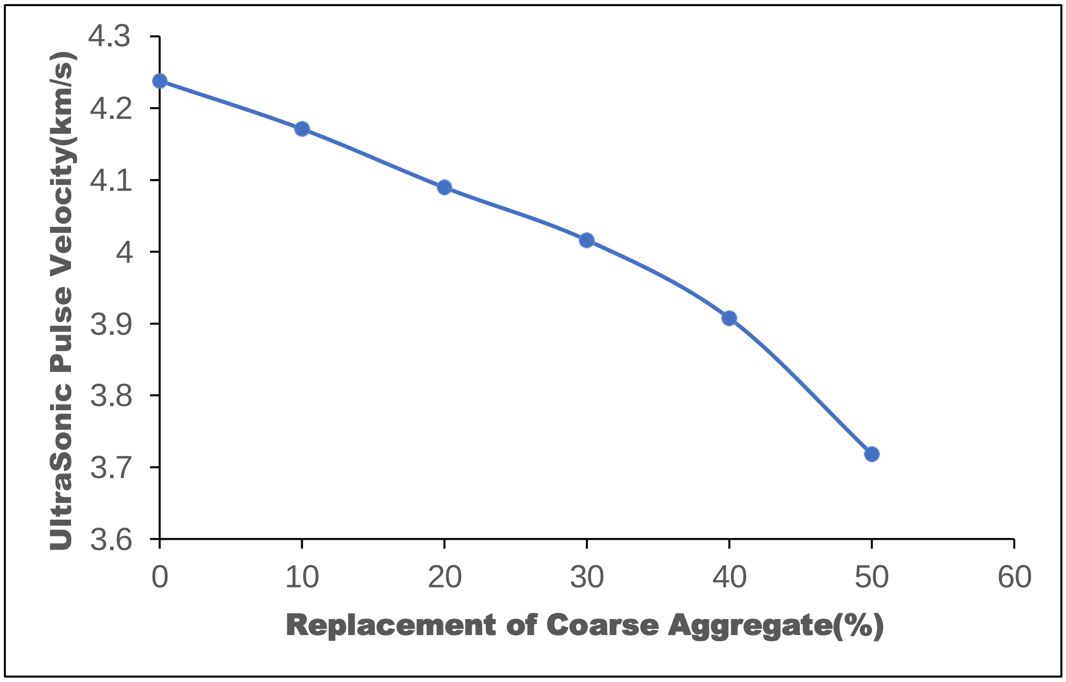



Figure 8 showing Ultra-sonic Pulse Velocity

The results for the test indicate the presence of greater air void content in concrete containing PCA was considered to be the reason for UPV reduction. In addition, the UPV value also depends on the elastic properties and volumetric concentration of the various concrete constituents, hence reducing the UPV value when PCA is utilized instead of natural aggregates. In present study, the results reveal that the UPV values for all the specimens lie in the range from 3.5 to 4.5 km/s; therefore, it is concluded that up to 50% substitution of PA can be utilized without significantly affecting the quality of concrete.

## *Section 4.3: Workability*

### *Section 4.3.1: Slump Test*

Workability refers to the ease with which concrete can be mixed, placed, and finished without sacrificing its desired properties. A well-balanced mix ensures that concrete can be easily handled and molded while maintaining its structural integrity. For RPAC, the slump test was carried out in accordance with the guidelines of ASTM C143 to determine the workability. Fig 9 shows the results of slump values of various mixes prepared in orders of increasing orders of percentage replacement of CA with RPA.

| Specimen | SLUMP(MM) |
|---|---|
| Control Sample | 41.8 |
| 10% replacement | 43.7 |
| 20% replacement | 59.4 |
| 30% replacement | 79.1 |
| 40% replacement | 85.5 |
| 50% replacement | 106.7 |

At 10%, 20%, 30%, 40%, and 50% replacement of NCA with PCA, the slump values were 43.7mm,59.4mm,79.1mm,85.5mm, and 106.7mm, respectively. With the control sample having a slump of 41.8mm, a total increase of 155.2% was observed from 0 to 50% replacement, the Fig indicates this trend and it can be observed that the slump increases almost in a linear pattern.

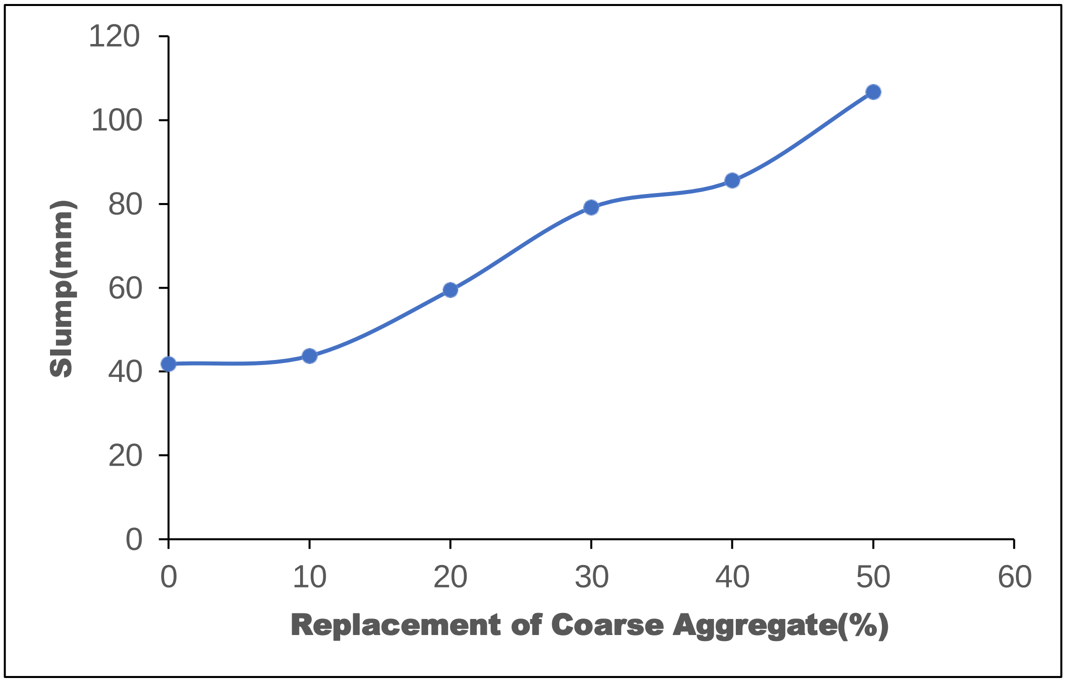


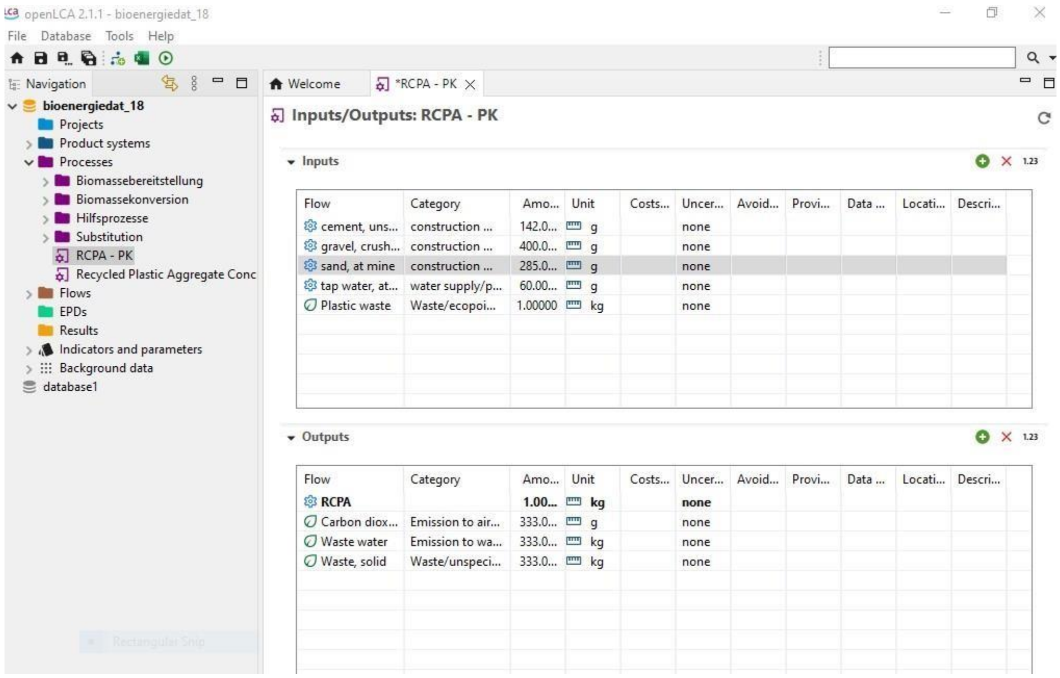

Figure 9 showing Slump Value

The results reveal a non-uniform general increase in the workability, with increasing orders of replacement. This is likely due to the nonabsorbent property of PPRC aggregates, which allows most of the mix water to remain in the mix, leading to a greater flexibility and reducing the friction between the aggregate particles. Plastic aggregates are lightweight and generally have a smoother surface compared to traditional coarse aggregates like gravel or crushed stone. This smoothness reduces friction and improves the ease with which the concrete mix can be handled and manipulated during construction.

# Chapter 5: Life Cycle Analysis

The conducted life cycle analysis (LCA) of concrete integrating recycled plastic aggregates instead of natural coarse aggregates has offered a profound understanding of its environmental impact, encompassing various critical factors. Scrutinizing every phase from inception to disposal, this study delved into the intricate dynamics shaping sustainability. Through comprehensive inventory analysis, data on material inputs and outputs were meticulously collected and scrutinized. The evaluation extended to a diverse range of environmental concerns, including abiotic depletion, freshwater aquatic ecotoxicity, global warming potential, human toxicity, photochemical oxidation, and terrestrial ecotoxicity. This examination revealed the multifaceted dimensions of the concrete's ecological footprint, shedding light on its implications across different ecosystems and human health domains.

The findings of this study resonate profoundly in the realm of sustainable construction, offering invaluable insights into the complexities of material choices and their wider implications. By quantifying the environmental trade-offs associated with incorporating recycled plastic aggregates, this research paves the way for informed decision-making in the construction industry. Armed with this knowledge, stakeholders can navigate towards more conscientious practices, balancing structural integrity with environmental responsibility.


openLCA 2.1.1 - bioenergiedat_18
File
Database
Tools
Help
Navigation
bioenergiedat_18
Projects
Product systems
Processes
Biomassebereitstellung
Biomassekonversion
Hilfsprozesse
Substitution
RCPA - PK
Recycled Plastic Aggregate Conc
Flows
EPDs
Results
Indicators and parameters
Background data
database1
Welcome
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Inputs/Outputs: RCPA - PK
Inputs
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Uncer...
Avoid...
Provi...
Data ...
Locati...
Descri...
cement, uns...
construction ...
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gravel, crush...
construction ...
400.0...
g
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sand, at mine
construction ...
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water supply/p...
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g
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Plastic waste
Waste/ecopoi...
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kg
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Outputs
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kg
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Carbon diox...
Emission to air...
333.0...
g
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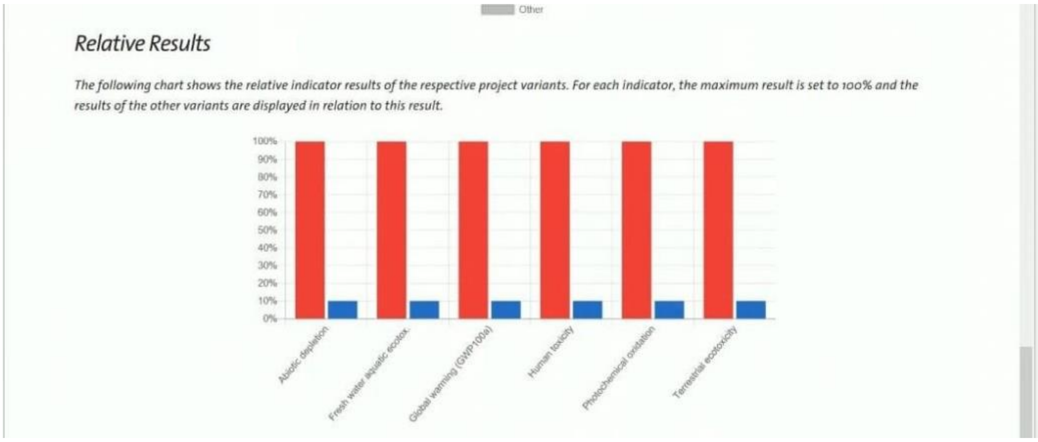
Waste water
Emission to wa...
333.0...
kg
none
Waste, solid
Waste/unspeci...
333.0...
kg
none


bioenergiedat_18
Projects
Product systems
Processes
Biomassebereitstellung
Biomassekonversion
Hilfsprozesse
Substitution
RCPA - PK
Recycled Plastic Aggregate Conc
Flows
EPDs
Results
Indicators and parameters
Background data
database1
RCPA - PK
>> input flows
cement, unspecified, at plant 1.42E2 g
gravel, crushed, at mine 4.00E2 g
polyethylene, HDPE, granula... 1.72E2 g
sand, at mine 2.85E2 g
tap water, at user 6.00E1 g
output flows >>
RCPA 1.00 kg




**LCIA Results**

▾ **LCIA Results**

| Impact category | Result | Reference unit |
|---|---|---|
| Human toxicity - HTP inf | 47.06869 | kg 1,4-dichlorobenzene eq. |
| Terrestrial ecotoxicity - TETP inf | 0.04185 | kg 1,4-dichlorobenzene eq. |
| Eutrophication - generic | 0.10822 | kg PO4--- eq. |
| Depletion of abiotic resources - elements, ultimate reserves | 0.00168 | kg antimony eq. |
| Ozone layer depletion - ODP steady state | 1.29002E-5 | kg CFC-11 eq. |
| Freshwater aquatic ecotoxicity - FAETP inf | 0.70725 | kg 1,4-dichlorobenzene eq. |
| Marine aquatic ecotoxicity - MAETP inf | 6.72060E4 | kg 1,4-dichlorobenzene eq. |
| Depletion of abiotic resources - fossil fuels | 2914.44507 | MJ |
| Acidification potential - average Europe | 1.19881 | kg SO2 eq. |
| Photochemical oxidation - high Nox | 0.07597 | kg ethylene eq. |
| Climate change - GWP100 | 277.76924 | kg CO2 eq. |

# Chapter 6: Structural Analysis of Building

An arbitrary structural was taken and its response was evaluated to analyze performance of RPAC. The site location of the structure was Islamabad. In analysis of structure only beam, column and slab elements were evaluated. Following analysis, RPAC structure was compared with normal concrete structure evaluate difference internal forces generated. The structure was subjected to gravity and seismic load in accordance with ASCE-7-22.

Material properties of RPAC and normal concrete are as follows:

TYPE: RPAC Concrete

Weight per unit Volume: 121.4 Ib/ft$^3$

Modulus of Elasticity (E): 2422121.38 Ib/in$^2$

Coefficient of Thermal Expansion (A): 0.0000055

Shear Modulus (G) 1009217.25: Ib/in$^2$

Compressive Strength (fc'): 3010.98 Ib/in$^2$

TYPE: Normal Concrete

Weight per unit Volume: 150 Ib/ft$^3$

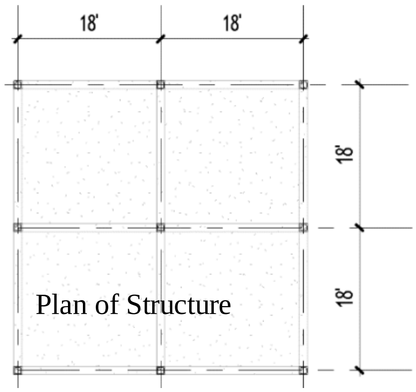
Modulus of Elasticity (E): 3604996.5Ib/in$^2$

Coefficient of Thermal Expansion (A): 0.0000055

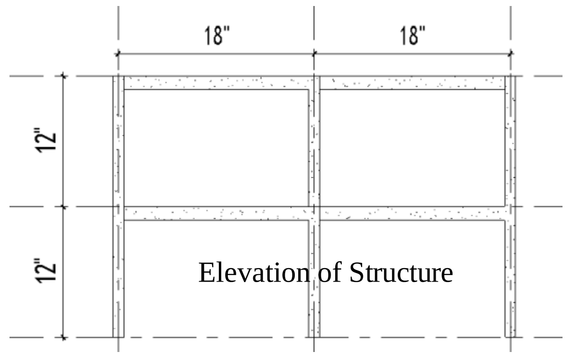
Shear Modulus (G) 1009217.25: Ib/in$^2$

Compressive Strength (fc'): 4000

Symmetrical structure was taken which had 2 bays with total width and length equal to 36ft. The structure was taken as 2 story concrete frame structure, with story height being equal to 12ft. Framing system was considered as special moment resisting frame structure. The structure consisted of 9 columns equally and symmetrically spaced, categorized into 3 types internal column, Edge column, and finally corner column. Similarly, beam was 12 in total, categorized in 2 types, edge beam and interior beams. The following figures shows the plan and elevations views of structure.




Plan of Structure




Elevation of Structure

The structure was subjected to loading combination compromising of dead load, live load as well as seismic loads. The loading combination was taken according to ASCE-7-22 and ACI-318-19. The loading combination used in analysis of structure later in design are as follows.

1) 1.4 D
2) 1.2D+1.6L
3) 1.3D+1L+1EQ
4) 1.3D+1L-1EQ
5) 0.8D+1EQ
6) 0.8D-1EQ

The structure was subjected to both dead and lives loads in accordance with ASCE-7-22. The dead load only being self-weight of concrete taken as 150psf while 2 types of lives load were applied, which are as follows.

1) Residential 30psf
2) Roof Live load 20psf

Residential live 2 was applied at story 1 of the structure while Roof live load of 20psf was applied at story 2 since story 2 was considered as inaccessible.

The structure was subjected to seismic loads, spectral accelerations of Maximum considered earthquake (MCE) level having 2% probability of exceedance in 50 years with return period of 2475 years were taken from BCP-2021 were as follows:

1) 0.2 Sec Spectral Acceleration Ss: 1.302
2) 1 Sec Spectral Acceleration S1: 0.381

Equivalent Lateral Force (ELF) procedure was used to analyze response of structure against seismic loads. The site class was taken as B (Rocks) with shear velocity profile between 3000ft/sec to 5000ft/sec. The site coefficients were taken from ASCE-7-22 which are as follows

1. Site Coefficient Fa= 0.9
2. Site Coefficient, Fv = 0.8

The spectral Accelerations Ss S1 were multiplied with site coefficients and a factor of 2/3 to calculate

SDs and SD1 which are of design basis earthquake (DBE) level having 10% probability of exceedance in 50 years with return period of 475 are as follows:

1. SMs = $\frac{2}{3} * Fa * Ss = 0.7812$
2. SM1 = $\frac{2}{3} * Fv * S1 = 0.2032$

The structure was considered as risk category 2 and seismic design category D. Other factors used in ELF procedure are as follows:

1) Response Modification (R) = 8
2) System Overstrength (Ω) = 3
3) Deflection Amplification (Cd) = 5.5
4) Importance Factor (I) = 1

Response modification factor is used to account for the ductile members in structure. Base shear coefficient Cs is related inversely to R. System Overstrength factor used to account for brittle elements of structure. This factor is directly related to base shear coefficient Cs. Deflection amplification factor is used to account for amplified deflection of structure during shaking of structure in earthquake event. Importance factor is depended risk category of structure which is classified according to type of structure and its occupancy

The base shear is by the following equation $V = Cs * W$

Cs is seismic response coefficient which is determined in accordance to ASCE 12.8.1.1. W is the effective seismic weight which is considered as dead load along with 25% of live load.

The seismic response coefficient Cs is calculated by the following equation $Cs = \frac{SDs}{R/I}$

The maximum value of permissible is as follows

1. $Cs = \frac{SD1}{T(\frac{R}{I})}$
2. $Cs = \frac{SD1 * T_L}{T^2(\frac{R}{I})}$

The structural time period is calculated from structural stiffness and dynamic properties. The approximate fundamental period is calculated from

$T = C_t * h_n^x$ Ct = 0.016 and X =0.9.

X = 0.9

Also, for structures less than 12 stories with floor height more than 10 ft the following equation calculated structural time period.

$T = 0.1N$ N is number of stories.

The minimum value permissible for $C_s$ is as follows

1. $Cs = 0.44 * I * SD_s$

2. $Cs = \frac{0.5S_1}{R/I}$ $S_1 > 0.1g$.

The following tables compare the internal forces generated in RPAC concrete structure with those generated in normal concrete structure along with percentage difference.

| Story | Location | Shear Force (kips) | | | Bending Moments (kips-ft) | | | Axial Force kips | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | RPAC | Normal | Difference | RPAC | Normal | Difference | RPAC | Normal | Difference |
| Story 1 | Corner Column | 3.5 | 5.1 | 31.4 | 22.9 | 32.1 | 28.7 | 23 | 29.1 | 21.0 |
| | Edge Column | 3.9 | 5.0 | 22.0 | 24.4 | 31.8 | 23.3 | 39.3 | 48.3 | 18.6 |
| | Interior Column | 3.7 | 4.7 | 21.3 | 23.7 | 30.4 | 22.0 | 64.8 | 76.2 | 15.0 |
| Story 2 | Corner Column | 3.1 | 3.8 | 18.4 | 16.6 | 26.5 | 37.4 | 10.6 | 13.4 | 20.9 |
| | Edge | 3.9 | 4.9 | 20.4 | 19.4 | 24.9 | 22.1 | 19.1 | 23.4 | 18.4 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Column | | | | | | | | | |
| | Interior Column | 2.9 | 3.9 | 25.6 | 16.6 | 21.2 | 21.7 | 33.1 | 38.9 | 14.9 |

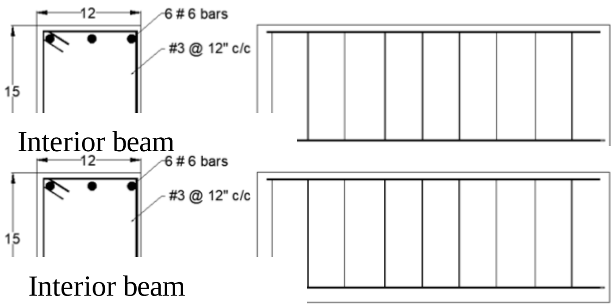
| Story | Location | Shear Force (Kips) | | | Pos Bending Moments (Kips-ft) | | | Neg Bending Moments (Kips-ft) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | RPAC | Normal | Difference | RPAC | Normal | Difference | RPAC | Normal | Difference |
| Story 1 | Edge Beam | 4.5 | 5.6 | 19.6 | 9.9 | 12.1 | 18.2 | 25.1 | 34.1 | 25.8 |
| | Interior Beam | 6.5 | 7.9 | 17.7 | 14.8 | 17.7 | 16.4 | 27.8 | 36.8 | 24.5 |
| Story 2 | Edge Beam | 4.7 | 5.6 | 16.1 | 11.1 | 13.6 | 18.4 | 13.7 | 16.9 | 18.9 |
| | Interior Beam | 6.4 | 7.5 | 14.7 | 16.8 | 20 | 16.0 | 20.2 | 24.3 | 16.9 |

Furthermore, statistical analysis revealed that percentage reduction in column elements had mean value (μ) of 23 and standard deviation (σ) of 5.6 while beam elements mean value (μ) was 16 with standard deviation (σ) of 7.7

The following table compares the internal forces generated in slab elements and difference in required area of steel.

| Story | Location | Pos Bending Moments (Kips-ft) | Neg Bending Moments (Kips-ft) | Area of Steel Required |
|---|---|---|---|---|
| Story 1 | RCPA Slab | 1.072 | 1.185 | 0.13 |
| | Concrete Slab | 1.369 | 4.135 | 0.18 |
| | Difference % | 21.7 | 71.3 | 27.8 |
| Story 2 | RCPA Slab | 0.858 | 0.948 | 0.13 |
| | Concrete Slab | 1.164 | 3.597 | 0.16 |
| | Difference % | 26.3 | 73.6 | 16.0 |

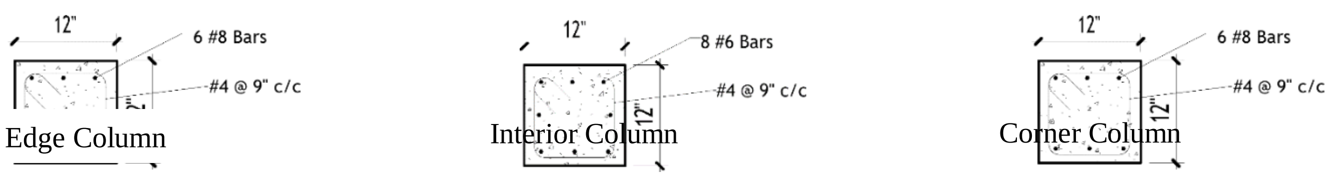
After analysis of structure design was carried out to determine required cross-sections and steel reinforcement which will be used further in detail cost estimation. The design of beams conformed according to seismic provisions of ACI. Both the beams were designed on minimum flexural reinforcement. The width of beam was kept 12inches, which is minimum width of beam according to seismic provisions. The depth of beam was kept 15inches to avoid squared section which is inefficient. Due to large cross-sectional area no additional torsional reinforcement. The following figure shows the cross-sections interior and edge beams respectively.



Interior beam

Interior beam

The design of columns was also quite similar. The cross-section of all 3 types of columns were same which was 12inches by 12inches with effective concrete cover of 2.5inches. The shear reinforcement of all 3 types of columns were kept same due to similar shear stresses. The main reinforcement of edge column and corner column were same, however interior column had relatively more reinforcement due to more axial load. The following figure shows reinforcement of columns.



Edge Column

Interior Column

Corner Column

# Chapter 7: Cost Benefit Analysis

The use of recycled plastic as a partial replacement of coarse aggregate in concrete offers significant economic benefits. This section provides a detailed cost estimation and economic analysis of this innovative approach. For this study we use 25 ft x 50 ft simple house with ground plus two stories (G+2).

The cost of recycled plastic used in this study was estimated to be Rs. 15/kg, which is substantially lower than the cost of virgin aggregate materials (Rs. 135/cft). The cost of processing and transporting recycled plastic was not considered in this study, as it is assumed to be negligible.

The replacement ratio of recycled plastic to coarse aggregate was 30% by weight. Based on this ratio, the estimated cost savings for using recycled plastic as a partial replacement of coarse aggregate in concrete is:

- Material cost savings: Rs. 15/kg (cost of recycled plastic) x 30% replacement ratio = Rs. 4.5/kg of concrete
- Waste management cost savings: Rs. 30/kg (cost savings from reduced waste management) x 30% replacement ratio = Rs. 9/kg of concrete

Total estimated cost savings: Rs. 13.5/kg of concrete

Concrete Mix Design and Cost Savings per Cubic Foot

For a typical concrete mix design with a weight of 150 lb/cft (approximately 68 kg/cft), the estimated cost savings would be:

- Rs. 13.5/kg x 68 kg/cft = Rs. 918/cft

This represents a significant cost savings of approximately 6.8% compared to traditional concrete mix designs.

The use of recycled plastic as a partial replacement of coarse aggregate in concrete offers a win-win situation, reducing both material costs and waste management costs. The estimated cost savings of Rs. 918/cft can lead to significant economic benefits for construction projects, particularly large-scale infrastructure developments.

A sensitivity analysis was conducted to assess the impact of varying costs of recycled plastic and replacement ratios on the estimated cost savings. The results show that:

- A 10% increase in the cost of recycled plastic reduces the estimated cost savings by 12%.
- A 10% decrease in the replacement ratio reduces the estimated cost savings by 15%.

| Sr # | Description | Unit | Quantity | | Rate | Amount | |
|---|---|---|---|---|---|---|---|
| | | | Controlled | Plastic | | Controlled | Plastic |
| 1 | Cement | Bag | 856.81 | 639.75 | 1300 | 1,113,853 | 831,675 |
| 2 | Fine Aggregate | Tonne | 42.84 | 31.98 | 3700 | 158,508 | 118,326 |
| 3 | Coarse Aggregate | Tonne | 85.68 | 44.78 | 6480 | 555,206.40 | 290,174.40 |
| 4 | Plastic Aggregate | Tonne | 0 | 19.19 | 15000 | 0 | 287,850 |
| | | | | | Sum | 1,827,567.40 | 1,528,025.40 |
| | | | | | Saving / Difference | **2,999,542** | |
| | | | | | Percentage | **16.39%** | |

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