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Waste and Recycled Material in Concrete Technology

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Abstract: The increasing demand for sustainable and eco-friendly construction materials has led to the exploration of alternative materials in concrete production. This research investigates the performance of M50 grade concrete using industrial and agricultural waste materials—Fly Ash, Rice Husk Ash (RHA), and Coconut Shells (CS)—as partial replacements for cement and coarse aggregates. The increasing emphasis on sustainable construction has prompted researchers to explore the incorporation of industrial and agricultural waste materials into concrete. This study investigates the potential of using Fly Ash, Rice Husk Ash (RHA), and Coconut Shells (CS) as partial replacements in high-strength M50 grade concrete. The aim is to evaluate their influence on workability, strength, durability, and density, while reducing dependency on conventional materials. The project involves developing a standard M50 concrete mix and then partially replacing cement with Fly Ash and RHA, and coarse aggregates with Coconut Shells. Each mix was tested for fresh and hardened properties over different curing periods. The experimental work follows IS codes and standard testing protocols to ensure accuracy and consistency. The results indicate that these waste materials can effectively be used in concrete without compromising essential performance characteristics. Depending on the type and percentage of replacement, they also contribute to reduced material cost, improved environmental sustainability, and lower dead load in structural elements. The study underscores the feasibility of using waste-based concrete in both structural and non-structural applications.

Keywords: M50 Grade Concrete, Fly Ash, Rice Husk Ash (RHA), Coconut Shells (CS), Sustainable Construction, Waste Material Utilization, Partial Replacement, High-Strength Concrete, Workability, Compressive Strength, Durability, Eco-Friendly Materials, Agricultural Waste, Industrial Waste, Lightweight Concrete, etc.

I. INTRODUCTION

Concrete is basically made of aggregates, cementitious materials paste, which includes cementitious materials and water. Major problems to the local authority to identify the potential and recycling of waste products like Waste rubber tires which are expensive and decreases the number of landfills. The disposals of waste tires to landfill are legally banned in all the countries. The main purpose of study on waste rubber tyre in concrete for eco-friendly environment. Decomposition of waste rubber tyre which contains composed materials and it causes serious contamination for environment condition. Another process of decomposing is burning that can cause pollution in environment and the gases exhausted are harmful. Concrete recycling is the use of rubble from demolished concrete structures. Recycling is cheaper and more ecological than trucking rubble to a landfill. Crushed rubble can be used for road gravel, revetments, retaining walls, landscaping gravel, or raw material for new concrete. Large pieces can be used as bricks or slabs, or incorporated with new concrete into structures, a material called urbanite. Concrete is an excellent material with which to make long-lasting and energy-efficient buildings. However, even with good design, human needs change and potential waste will be generated.

The supply of social infrastructures such as roads, buildings, and bridges is an important aspect of India's future growth that must be maintained. Sustainable development necessitates addressing daily needs without jeopardizing the country's future. Adequate safeguards should be put in place in this manner to assure the availability of materials for future growth. Waste products such as fly ash, risers, and destroyed concrete have been a hazard for the well-being of species in recent years. In several regions, these materials have been examined, and various studies have looked employing them as an alternative. The pace of garbage creation is growing all across the globe. As a growing nation, India creates 62 million tonnes of trash every year, with the figure expected to rise to 165 million tonnes by 2030. Solid waste is classified into industrial, agricultural, and home waste. The majority of these waste items, such as fly ash, rises, and destroyed concrete, are quite valuable and recyclable. Materials produced via different techniques of changing discarded materials into new ones are referred to as recycled materials. Today, recycled materials are accessible for highway buildings all around the globe.

Most of materials are easily accessible in the form of trash and were in use at the time. Underutilized resources, of which zero to seventy percent are recyclable. Some of them, which are biodegradable, include compounds that are detrimental to the environment, whereas the vast majority are not. This has become a serious worry for everyone, and it is in line with the second trend of identifying possible resources from created solid waste. Some researchers devised methods for recycling these materials, which are widely accessible and suitable for highway building. This idea was considered in light of the fact that most roads, particularly in India, are in poor condition and the cost of standard building materials is too expensive. Aside from the high expense, widespread usage of recycled materials has become a possibility. Building utilizing both new and recycled materials is a sustainable technique. Concrete, formed from Portland cement, water, admixtures, and aggregates, is the most abundant of all man-made materials. Historically, if new compounds were developed or waste material was gathered in industries, they were used as a component of concrete. Examples include fly ash rises and destroyed concrete, among others. The universal desire to save resources and the environment will place a strong focus on the use of waste materials and byproducts. They have several remarkable technical qualities that make them acceptable for use in pavement construction, and their use will encourage waste reduction, a cleaner environment, cost reduction, and construction work, as well as as alternative construction material

II. MATERIAL

A. Fly Ash

Fly ash is a fine, powdery material generated as a byproduct during the combustion of pulverized coal in thermal power plants. Chemically, it mainly consists of silica (SiO_2), alumina (Al_2O_3), and iron oxides (Fe_2O_3), along with minor amounts of calcium, magnesium, potassium, and sulfur compounds. The physical appearance of fly ash varies from light grey to dark grey, depending on its source and composition.

Fly ash is classified as a pozzolanic material, which means it contains siliceous or siliceous and aluminous material that, in itself, possesses little or no cementitious value. However, when mixed with lime (calcium hydroxide) and water, it reacts chemically to form compounds with cementitious properties (like calcium silicate hydrate).

Two types of fly ash are produced:

- Class F Fly Ash: Low calcium content, typically derived from burning anthracite or bituminous coal. It offers excellent resistance to sulfate attack.
- Class C Fly Ash: High calcium content, often produced from lignite or sub-bituminous coal, and possesses self-cementing properties.

Fly ash offers multiple advantages:

- Improves workability and durability of concrete.
- Reduces the heat of hydration, making it suitable for mass concrete applications like dams.
- Enhances resistance to chemical attacks like sulfate and alkali-silica reaction (ASR).

Given India’s heavy reliance on coal for electricity, around 200 million tons of fly ash is produced annually. Proper utilization of fly ash is critical to prevent environmental issues such as air pollution, groundwater contamination, and land degradation.

Fig 1.1 - Fly Ash

1) Fly Ash Product Uses in India

In India, fly ash has found versatile applications:

- Fly Ash Bricks and Blocks: Fly ash bricks are lighter, have superior thermal insulation, uniform shape, and are less energy-intensive to produce compared to clay bricks.
- Portland Pozzolana Cement (PPC): About 15-35% of fly ash is blended into ordinary cement to produce PPC, improving workability and reducing the environmental footprint.
- Road Construction: Fly ash is used in building embankments, base layers, and soil stabilization to improve load-bearing capacity.
- Mine Filling: In abandoned and underground coal mines, fly ash slurry is used to fill voids, preventing land subsidence.
- Agriculture: When used in controlled quantities, fly ash improves soil aeration, water retention, and provides trace minerals.
- Land Reclamation: Low-lying or marshy lands are filled and stabilized using fly ash.
- The Indian government has mandated the use of fly ash within a 300 km radius of thermal power plants, boosting its market significantly.

Table 1.1.1 Fly ash generation and utilization in different countries

Sr. No.	Country	Annual ash production, MT	Ash utilization %
1	India	112	38
2	China	100	45
3	USA	75	65
4	Germany	40	85
5	UK	15	50
6	Australia	10	85
7	Canada	6	75
8	France	3	85
9	Denmark	2	100
10	Italy	2	100
11	Netherlands	2	100

2) Rice Husk

Rice husk is the hard protective layer that envelopes rice grains during their growth and is removed during milling. It constitutes about 20% of the weight of paddy and has a composition rich in organic compounds like lignin and cellulose.

When rice husk is burnt under controlled conditions, it produces Rice Husk Ash (RHA), which contains a very high percentage of amorphous silica (up to 85–95%). This amorphous silica makes RHA a highly reactive pozzolan, useful in concrete technology and construction.

Physical Characteristics:

Low density (~90–150 kg/m³)

High silica content

High insulating value

Fire resistance

Rice husk management is vital for agricultural sustainability, considering India produces about 120 million tons of rice annually, resulting in 24 million tons of rice husk waste.

Fig 1.2 - Rice Husk

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3) Rice Husk Usage in Materials in India

Construction Applications:
- Cement Replacement: RHA is used as a partial replacement (up to 20%) for Portland cement. It enhances concrete's compressive strength, impermeability, and resistance to chemical attacks like sulfates.
- Brick Manufacturing: RHA is mixed with lime and clay to produce lightweight, insulating, and fire-resistant bricks.
- Panels and Boards: RHA is added into wall panels, roofing sheets, and insulation boards for improved thermal performance.
- Soil Stabilization: Lime–RHA mixtures are employed to stabilize weak soils for rural roads, embankments, and foundations.

Energy Applications
- Bioenergy: Rice husk is used as a biomass fuel in gasifiers and power plants, contributing to renewable energy goals.
- Activated Carbon: High-quality activated carbon is manufactured from carbonized rice husk.

Fig 1.2.1 Rice Husk Usage

Table 1.2.2 Countries with major rice production

Country	Rice Production (in million tons)
China	205.21
India	104.80
Indonesia	71.29
Bangladesh	51.50
Vietnam	44.04

4) Coconut Shell

The coconut shell is the hard, stony endocarp surrounding the coconut seed. It is highly lignocellulosic in nature, containing about 30–35% lignin, which gives it strength and durability.

Physical properties:
- High compressive strength
- Low density (~500–600 kg/m³)
- Excellent thermal insulation
- High resistance to microbial attacks

In India, coconut production exceeds 21 million tons annually, resulting in enormous quantities of shells. Previously, much of this biomass went to waste or was used inefficiently.

Fig 1.3 Coconut Shell

5) Coconut Shell Usage in Concrete Technology in India

Coconut shells, when crushed into specific sizes, are increasingly used as coarse aggregates in the concrete industry.

Benefits:

- Produces lightweight concrete with a density of around 1800–1900 kg/m³ compared to conventional concrete (~2400 kg/m³).
- Provides better thermal insulation due to porous structure.
- Suitable for non-structural applications like partitions, flooring blocks, and architectural features.
- Reduces construction cost by utilizing agro-waste.
- Minimizes dead load, advantageous for multi-storey buildings and earthquake-resistant structures.

Performance Characteristics:

- Compressive strength of coconut shell concrete can reach 18–24 MPa, sufficient for non-load-bearing members.
- Good flexural strength and impact resistance.

Research by institutions like Anna University and IIT Madras highlights coconut shell concrete's promise in rural and low-cost housing initiatives.

III.METHODOLOGY

A. Mix Proportions

Mix proportions are the ratios of the ingredients used in concrete: cement, water, fine aggregates (sand), and coarse aggregates (gravel, crushed stone, etc.). The purpose of determining the correct mix proportions is to ensure that the concrete performs well for its intended purpose, considering both strength and durability requirements. This section delves into the detailed design of concrete mixes, the materials used, and the methodology followed for the mix proportions.

1) Concrete Mix Design Process

Concrete mix design is a systematic process used to determine the quantities of various ingredients that will make up a concrete mix of desired properties. The process begins with determining the strength requirements and continues with selecting appropriate materials and proportions. The aim is to achieve a concrete mix that meets the required performance criteria for a particular construction task, such as strength, workability, and durability.

The IS 10262:2009 code is typically followed for mix design, which provides detailed guidelines for determining proportions for various grades of concrete. This procedure takes into account local conditions, material properties, and workability considerations.

Steps in Concrete Mix Design

2) Determining the Target Compressive Strength

The first step in designing the concrete mix is to determine the target compressive strength. This is based on the required grade of concrete (e.g., M55), which is the strength the concrete should achieve at 28 days of curing. The characteristic strength is typically specified in MPa (Mega Pascals), and the target strength is calculated by adding a safety margin (typically 1.65 times the standard deviation) to this value.

For example:

- M55 grade concrete has a characteristic strength of 55 MPa.
- The target strength is calculated as:

TARGET STRENGTH = CHARACTERISTIC STRENGTH + SAFETY MARGIN

1) Choosing the Water-Cement Ratio

The water-cement ratio is one of the most important factors in determining the strength and durability of concrete. A lower water-cement ratio results in higher strength, while a higher ratio increases workability but reduces strength.

- The water-cement ratio is selected based on the desired strength and workability.
- For most ordinary mixes (such as M50), a ratio between 0.30 and 0.45 is typical.

2) Selecting the Type of Cement

The type of cement used affects the hydration process and, subsequently, the strength of the concrete. In this study, Ordinary Portland Cement (OPC) was used due to its consistent and reliable performance in construction. Other types of cements, like blended cements containing fly ash or slag, were also tested for their impact on concrete properties.

3) Choosing the Aggregates

Aggregates (both fine and coarse) make up a significant portion of the concrete mix and affect its strength, workability, and cost. The selection of aggregates includes considerations such as size, grading, and shape.

- COARSE AGGREGATES: These are particles larger than 4.75 mm, and they make up about 60-75% of the total volume of concrete. In this study, crushed stone aggregates were used, with sizes typically between 10 mm and 20 mm. Proper grading of coarse aggregates ensures that there are fewer voids in the mix, improving the density and strength of the concrete.
- FINE AGGREGATES: Sand, which has particle sizes less than 4.75 mm, is used as the fine aggregate. In this study, river sand was used due to its clean, rounded, and free-flowing nature. The properties of the fine aggregate, including its grading, play a significant role in the workability and strength of the concrete.

4) Incorporating Additives and Admixtures

Admixtures are materials added to the concrete mix to modify its properties. These can include plasticizers to improve workability, retarders to delay setting time, and accelerators to speed up curing. Superplasticizers were used in this study to improve the workability of the concrete without altering the water-cement ratio, ensuring that the concrete maintained a high strength while being easy to handle.

B. Mix Proportions For M50 Grades Of Concrete

1) M50 Grade Concrete

This grade is typically used for high-performance structures such as bridges, high-rise buildings, industrial floors, and prestressed concrete members. Unlike nominal mixes, M50 is a design mix, where the proportions are determined through laboratory trials to achieve high strength and durability. A typical water-cement ratio for M50 is around 0.30 to 0.35, ensuring very high strength while maintaining workability with the help of superplasticizers. The concrete is dense, durable, and resistant to environmental attacks.

C. MIX Design (M50 Grade)

1) MIX Design For Concrete using FLY ASH (FA)

MATERIALS USED:

- CEMENT: 280 KG/M³ (AFTER REPLACING 20% WITH FLY ASH)
- FLY ASH: 70 KG/M³ (REPLACING 20% OF CEMENT)
- FINE AGGREGATE: 650 KG/M³ (RIVER SAND, ZONE II)
- COARSE AGGREGATE (NATURAL): 825 KG/M³ (CRUSHED 20 MM GRADED)
- COARSE AGGREGATE (RECYCLED): 275 KG/M³ (RECYCLED AGGREGATES)
- WATER: 157.5 KG/M³ (WATER-CEMENT RATIO OF 0.45)

STEP 1: TARGET MEAN STRENGTH CALCULATION

For the target strength of 62 N/mm², the target mean strength calculation is as follows:

$fck(target)=fck+1.65\times\sigma$

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Where:

- fckf_ = Characteristic strength of concrete (50 N/mm²).
- σ = Standard deviation (assumed to be 5 N/mm² for this mix).

Thus, the target mean strength for this mix will be:

fck(target)=50+1.65×5=62.5 N/mm².

Step 2: Selection of Water-Cement Ratio

The maximum water-cement ratio is limited to 0.4 as per the given specifications. This ensures that the concrete mix has good workability and strength.

Given that the water-cement ratio is 0.45 based on the provided quantities, we'll proceed with this ratio and adjust the mix accordingly.

Step 3: Water Content Calculation

The water content is calculated as:

Water Content = Water-Cement Ratio × Cement Content

Water Content = 0.45×280=157.5kg/m³.

Step 4: Cementitious Material (Cement + Fly Ash)

The total cementitious material content is the sum of the OP Cement and Fly Ash:

Total Cementitious Material=280 kg/m³ (Cement)+70 kg/m³ (Fly Ash)=350 kg/m³

Step 5: Fine Aggregate and Coarse Aggregate Calculation

The fine and coarse aggregates are calculated using the bulk volume method.

Fine Aggregate:

The fine aggregate is taken as 650 kg/m³ based on the given data.

Coarse Aggregate (Natural + Recycled):

The total coarse aggregate content is calculated as:

Total Coarse Aggregate=825 kg/m³ (Natural)+275 kg/m³ (Recycled)=1100 kg/m³

The mix uses 100% of the recycled aggregates as part of the coarse aggregate to improve sustainability.

Step 6: Volume Calculation for Cementitious Materials

The volume of each material is calculated using the specific gravities of the materials.

Volume of Cement:

The volume of OP Cement is calculated as:

$$\text{Volume of Cement} = \frac{\text{Weight of Cement}}{\text{Specific Gravity of Cement} \times 1000} = \frac{280}{3.15 \times 1000} = 0.0892\,\text{m}^3.$$

Volume of Fly Ash:

The volume of **Fly Ash** is calculated as:

$$\text{Volume of Fly Ash} = \frac{\text{Weight of Fly Ash}}{\text{Specific Gravity of Fly Ash} \times 1000} = \frac{70}{2.25 \times 1000} = 0.0311\,\text{m}^3.$$

Volume of Water:

The volume of **Water** is calculated as:

$$\text{Volume of Water} = \frac{\text{Weight of Water}}{1000} = \frac{157.5}{1000} = 0.1575\,\text{m}^3.$$

Volume of Aggregates

The total volume of aggregates is the remainder after the volumes of the cementitious materials and water are subtracted from 1 m³.

Volume of Aggregates=1−(Volume of Cement+Volume of Fly Ash+Volume of Water)=1−(0.0892+0.0311+0.1575)=0.7222 m³.

The aggregates include both fine and coarse aggregates.

Volume of Coarse Aggregate:

The volume of **Coarse Aggregate** is calculated based on its specific gravity:

$$\text{Volume of Coarse Aggregate} = \frac{\text{Weight of Coarse Aggregate}}{\text{Specific Gravity of Coarse Aggregate} \times 1000} = \frac{1100}{2.6 \times 1000} = 0.4231\,\text{m}^3.$$

Volume of Fine Aggregate:

The volume of **Fine Aggregate** is calculated as:

$$\text{Volume of Fine Aggregate} = \frac{\text{Weight of Fine Aggregate}}{\text{Specific Gravity of Fine Aggregate} \times 1000} = \frac{650}{2.6 \times 1000} = 0.2500\,\text{m}^3.$$

Step 7: Final Mix Proportion Calculation
Now that we have the volumes, we can calculate the final mix proportion.

- Cement: 280 kg/m³
- Fly Ash: 70 kg/m³
- Water: 157.5 kg/m³
- Fine Aggregate: 650 kg/m³
- Coarse Aggregate (Natural + Recycled): 1100 kg/m³

Table 4.1 Comparison Plain Concrete vs Fly Ash Concrete

Material	Plain Concrete (kg/m³)	Fly Ash Concrete (kg/m³)
Water (free)	170	157.5
Cement (OPC)	430	280
Fly Ash	—	70
Fine Aggregate	707	650
Coarse Aggregate (Natural)	1060	825
Coarse Aggregate (Recycled)	—	275
Total Mix	2371	2375.5

2) Mix Design For Concrete Using Rice Husk Ash (RHA)

Design Requirements:

- Characteristic strength (fck) = 50 MPa
- Target strength (f'ck) = 62 MPa (fck + 1.65 × standard deviation, assuming SD = 7.3 MPa)
- Water-cement ratio (w/c) = 0.45
- Minimum Cementitious Content = 400 kg/m³
- Slump = 50 ±10 mm
- Rice Husk Ash Replacement = 20% of cementitious material

Materials Properties:

- Cement (OPC 53 Grade), Specific Gravity = 3.15
- Fine Aggregate (Zone II, River Sand), Specific Gravity = 2.6
- Coarse Aggregate (Natural + Recycled), Specific Gravity = 2.6
- Rice Husk Ash (RHA), Specific Gravity = 2.20
- Water, Specific Gravity = 1.0

Rice Husk Ash Concrete Mix Design

Step 1 Cementitious Material Calculation:

- Increase cementitious content by 12% (as done with Fly Ash)

Total cementitious material=1.12×430=482 kg/m³

Step 2 Cement and RHA Distribution:

- Cement (80%): 482×0.80=385.6 kg/m³
- Rice Husk Ash (20%): 482×0.20=96.4 kg/m³

Step 3 Water Content Adjustment:

- Water reduction for RHA concrete: assume about 5% reduction.

Water content=170×0.95=161.5 kg/m³

Step 4 Volume Calculations:

Table 3.3.2.1 Volume Calculations

Material	Quantity (kg/m³)	Specific Gravity	Volume (m³)
Cement	385.6	3.15	0.1224
Rice Husk Ash	96.4	2.20	0.0438
Water	161.5	1.0	0.1615
Air Content	—	—	0.0100
Total Volume (Materials)	—	—	0.3377

- Volume available for aggregates:1−0.3377=0.6623 m³

Step 5 Aggregate Calculations:

- Coarse Aggregate (Natural + Recycled):
  - Natural Coarse Aggregate = 825 kg/m³
  - Recycled Coarse Aggregate = 275 kg/m³
  - Combined = 1100 kg/m³
- Volume of Coarse Aggregate: 11002600=0.4231 m³
- Remaining Volume for Fine Aggregate: 0.6623−0.4231=0.2392 m³
- Fine Aggregate Quantity: 0.2392×2600=622 kg/m³

Comparison Table:

Table 3.3.2.1 Comparison Table

Materials	Plain Concrete (kg/m³)	Fly Ash Concrete (kg/m³)	Rice Husk Ash Concrete (kg/m³)
Water	170	162	161.5
OPC Cement	430	337	385.6
Fly Ash	—	145	—
Rice Husk Ash	—	—	96.4
Fine Aggregate	707	636	622
Coarse Aggregate	1060	1060	1100 (825+275)
Total	2371	2345	2365.5

3) Mix Design For Concrete Using Coconut Shells

Design Requirements:

- Characteristic strength (fck) = 50 MPa
- Target strength (f'ck) = 62 MPa
- Water-cement ratio (w/c) = 0.45
- Minimum Cementitious Content = 400 kg/m³
- Slump = 50 ±10 mm
- Coconut Shells replacing 25% of total coarse aggregates

Materials Properties:

- Cement (OPC 53 Grade), Specific Gravity = 3.15
- Fine Aggregate (Zone II River Sand), Specific Gravity = 2.6
- Natural Coarse Aggregate (20 mm Crushed), Specific Gravity = 2.6
- Coconut Shells (Crushed, 10-20 mm), Specific Gravity = 1.2
- Water, Specific Gravity = 1.0

Coconut Shell Concrete Mix Design

STEP 1 Cementitious Material Calculation:
No replacement in cementitious content here (only coarse aggregate is replaced).
Cement Content = 430 kg/m³
Water Content = 170 kg/m³

STEP 2 Volume Calculations for Ingredients:

Table 3.3.3.1 Volume Calculations for Ingredients

Material	Quantity (kg/m³)	Specific Gravity	Volume (m³)
Cement	430	3.15	0.1365
Water	170	1.0	0.1700
Air Content	—	—	0.0100
Total Volume (Materials)	—	—	0.3165

- Volume available for aggregates:
  1−0.3165=0.6835 m³

STEP 3 Aggregate Adjustments:

- Coarse Aggregates:
  - 75% Natural Coarse Aggregate
  - 25% Coconut Shells
- Volume Split:
  - Natural Coarse Aggregate (75%): 0.6835×0.75=0.5126 m³
  - Coconut Shells (25%):0.6835×0.25=0.1709 m³
- Mass of Aggregates:
  - Natural Coarse Aggregate: 0.5126×2600=1332.8 kg/m³
  - Coconut Shells: 0.1709×1200=205.08 kg/m³
- Fine Aggregate Volume:
  - No replacement in fine aggregate.
- Volume for Fine Aggregate:

0.6835−(0.5126+0.1709)=0 (All used by coarse aggregates)

- Therefore, Fine Aggregate remains at around 650–700 kg/m³ for maintaining workability.
- Use 650 kg/m³ fine aggregates.

Final Mix Design (kg/m³)

Material	Quantity (kg/m³)
Water (free)	170
OPC Cement	430
Fine Aggregate	650
Natural Coarse Aggregate	825
Coconut Shells	275
Total	2350

Comparison Table:

Materials	Plain Concrete (kg/m³)	Coconut Shell Concrete (kg/m³)
Water	170	170
OPC Cement	430	430
Fine Aggregate	707	650
Coarse Aggregate	1060	825
Coconut Shells	—	275
Superplasticizer	—	—
Total	2371	2350

TABLE 3.3.3.2 MIX DESIGN SUMMARY FOR M50 GRADE CONCRETE (TARGET STRENGTH = 62 MPA)

MIX TYPE	CEMENT (KG/M³)	SCM (KG/M³)	WATER (KG/M³)	FINE AGGREGATE (KG/M³)	COARSE AGGREGATE (KG/M³)	W/C RATIO
FLY ASH (30%)	337	145 (FLY ASH)	162	636	1060	0.34
RICE HUSK ASH (30%)	337	145 (RHA)	162	635	1060	0.34
COCONUT SHELL (25%)	355.6	—	160	650	825 (NATURAL) + 275 (CS)	0.45

IV. CONCLUSIONS

1) Plain m50 concrete exhibited the highest early and 28-day strength, serving as a reliable control benchmark.
2) Fly ash concrete (30% replacement) showed moderate early strength but surpassed the plain mix in long-term strength due to the extended pozzolanic reaction. it is highly recommended for mass concrete works where durability and reduced heat of hydration are desired.
3) Rice husk ash concrete also displayed similar trends to fly ash, with slightly reduced early strength and good long-term performance. its high silica content helps improve concrete density and resistance to chemical attacks.
4) Coconut shell concrete (25% coarse aggregate replacement) resulted in lower compressive strength across all curing durations. however, it remains suitable for non-structural applications where weight reduction and sustainability are more critical than strength.
5) Workability and water demand varied across the mixes. mixes with rha required more water due to the fine particle size, while fly ash improved workability.
6) Environmental impact: the use of industrial by-products like fly ash and agricultural waste like rice husk ash and coconut shells significantly reduces the carbon footprint, supports waste management, and encourages sustainable development in construction.

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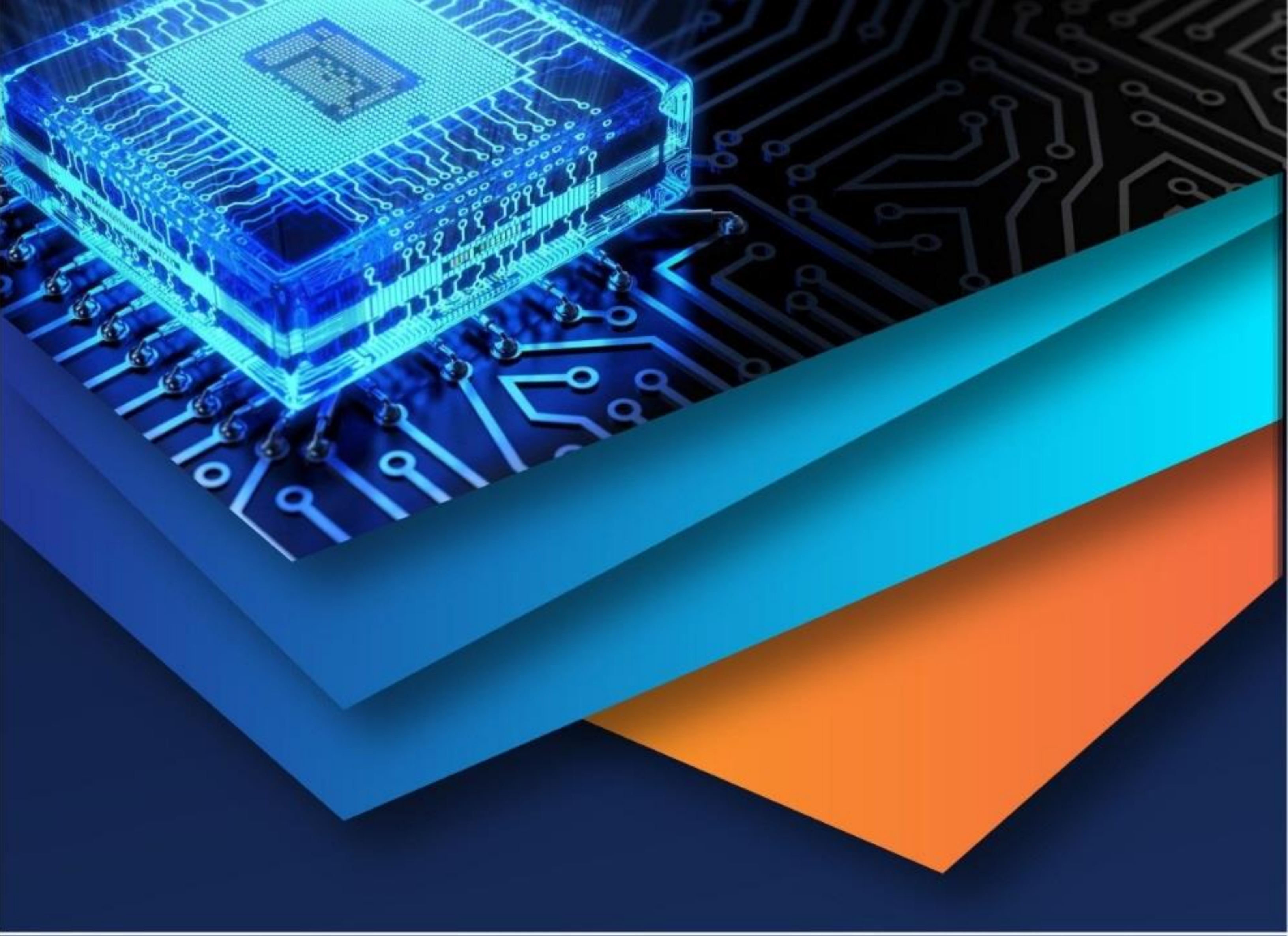

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