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Performance Evaluation of M40 Grade Concrete Using Recycled Coarse Aggregate and Plastic Granules as Sustainable Aggregate Replacements

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Abstract: The increasing demand for natural aggregates and the disposal of construction and demolition (C&D) waste and plastic waste have created significant environmental challenges. This study investigates the mechanical properties of M40 concrete by partially replacing natural coarse aggregate with recycled aggregate (RA) and fine aggregate with plastic granules (PG). Four concrete mixes were prepared: a control mix and three modified mixes containing 20% RA + 5% PG, 30% RA + 7% PG, and 40% RA + 9% PG. Fresh and hardened concrete properties were evaluated through slump, density, compressive strength, split tensile strength, and flexural strength tests. The results indicate that moderate replacement levels provide satisfactory strength while promoting sustainable construction and reducing environmental pollution.

Keywords: Recycled Aggregate, Plastic Granules, Sustainable Concrete, M40 Concrete, Mechanical Properties.

1. INTRODUCTION

Background: Concrete is the most extensively used construction material due to its excellent strength, durability, and versatility. The rapid growth of infrastructure and urbanization has considerably increased the demand for natural aggregates and river sand, leading to the depletion of these non-renewable resources. Simultaneously, the generation of construction and demolition (C&D) waste and plastic waste has increased significantly, creating serious environmental and waste management challenges. Sustainable construction practices encourage the reuse of these waste materials as alternative construction resources. Recycled aggregates obtained from demolished concrete and plastic granules recovered from waste plastics offer a promising solution to reduce environmental pollution while conserving natural resources. Therefore, the utilization of recycled aggregate and plastic granules in concrete has become an important area of research for developing sustainable and eco-friendly construction materials.

Problem Statement: The continuous extraction of natural aggregates for concrete production has resulted in resource depletion and environmental degradation. At the same time, enormous quantities of construction debris and plastic waste are disposed of in landfills, causing pollution and occupying valuable land. Although recycled aggregates and plastic waste have been studied individually, their combined use in concrete has not been investigated extensively. Furthermore, uncertainties regarding their influence on workability, density, compressive strength, tensile strength, and flexural strength limit their practical application. Therefore, there is a need to experimentally evaluate the combined effect of recycled aggregates and plastic granules in M40 concrete and identify suitable replacement levels that maintain acceptable engineering performance.

Need for Sustainable Concrete: The construction industry is one of the largest consumers of natural resources and also generates substantial quantities of waste materials. Sustainable concrete provides an effective solution by replacing conventional aggregates with recycled materials, thereby reducing environmental impacts and promoting resource conservation. The incorporation of recycled aggregates and plastic granules minimizes landfill disposal, reduces dependence on natural aggregates, and supports circular economy principles. In addition, sustainable concrete contributes to reducing construction costs, conserving energy, and promoting environmentally responsible infrastructure development. The present study has therefore been undertaken to investigate whether recycled aggregates and plastic granules can be successfully utilized in M40 concrete without significantly affecting its mechanical performance.

Research Gap: Several researchers have investigated recycled aggregate concrete and plastic-modified concrete independently and reported encouraging results. However, only a limited number of studies have examined the combined effect of recycled coarse aggregates and plastic granules as simultaneous replacements in M40 grade concrete. In

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addition, there is insufficient information regarding the optimum replacement levels that provide a balance between mechanical strength, workability, density, and sustainability. The lack of comprehensive experimental data under Indian conditions further highlights the need for this investigation. Therefore, this research focuses on evaluating the combined influence of recycled aggregates and plastic granules to identify suitable replacement percentages for practical structural and non-structural applications.

Objectives:

1. To investigate the effect of partial replacement of natural coarse aggregate with recycled aggregate and fine aggregate with plastic granules on the mechanical properties of M40 concrete.
2. To evaluate the workability, density, compressive strength, split tensile strength, and flexural strength of modified concrete at different replacement levels.
3. To compare the performance of recycled aggregate–plastic granule concrete with conventional M40 concrete.
4. To determine the optimum replacement level of recycled aggregate and plastic granules that provides the best balance between mechanical performance and sustainability.
5. To assess the feasibility of utilizing recycled aggregate and plastic granules as sustainable construction materials for structural and non-structural applications.
6. To promote sustainable concrete by reducing the consumption of natural aggregates and encouraging the utilization of construction and plastic waste.

2. MATERIALS USED

OPC 43 Grade Cement

Ordinary Portland Cement (OPC) 43 Grade was used as the binding material in this study. It provides good workability, adequate early and long-term strength, and complies with IS 8112:2013.

Important Properties:

1. Specific Gravity: 3.15
2. Standard Consistency: 30–32%
3. Initial Setting Time: ≥30 min
4. Final Setting Time: ≤600 min

River Sand (Zone II)

Natural river sand conforming to Zone II of IS 383:2016 was used as the fine aggregate. It provides good particle grading and improves concrete workability.

Important Properties:

1. Specific Gravity: 2.64
2. Fineness Modulus: 2.6–2.9
3. Water Absorption: 1–2%
4. Maximum Size: 4.75 mm

Natural Coarse Aggregate

Crushed angular stone of 20 mm maximum size was used as the conventional coarse aggregate to provide strength and durability.

Important Properties:

1. Maximum Size: 20 mm
2. Specific Gravity: 2.70
3. Water Absorption: 0.5–1.0%
4. Bulk Density: 1500–1700 kg/m^3

Recycled Aggregate (RA)

Recycled aggregate obtained from crushed concrete waste was used as a partial replacement for natural coarse aggregate to promote sustainable construction.

Important Properties:

1. Specific Gravity: **2.40-2.60**
2. Water Absorption: **3–6%**
3. Maximum Size: **20 mm**

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4. Higher porosity than natural aggregate

Plastic Granules (PG)
Plastic granules were used as a partial replacement for fine aggregate to utilize plastic waste and reduce environmental pollution.
Important Properties:
1. Specific Gravity: 0.90-0.95
2. Water Absorption: Negligible
3. Particle Size: 2–4 mm
4. Lightweight and non-biodegradable

Water
Clean potable water free from harmful impurities was used for concrete mixing and curing, as recommended by IS 456:2000.
Important Properties:
1. pH: 6.5–8.5
2. Clean and free from oils, acids, and organic matter
3. Suitable for mixing and curing concrete

FOSROC Conplast SP430 (Superplasticizer)
FOSROC Conplast SP430 is a high-range water-reducing superplasticizer used to improve workability without increasing the water–cement ratio.
Important Properties:
1. Specific Gravity: 1.12
2. Colour: Brown Liquid
3. Dosage: 0.5–2.0% by weight of cement
4. Water Reduction: Up to 20–25%
5. Chloride Content: Chloride-Free

3.EXPERIMENTAL METHODOLOGY

M40 Mix Design: The concrete mix was designed for M40 grade according to IS 10262:2019 to achieve the required compressive strength, workability, and durability. The mix proportions were determined based on the properties of cement, aggregates, water, and superplasticizer. Different replacement levels of recycled aggregate (RA) and plastic granules (PG) were incorporated while maintaining a suitable water–cement ratio. The control mix and modified mixes were prepared under identical laboratory conditions for comparison.

Mixes:
1. Control (0% RA + 0% PG)
2. 20% RA + 5% PG
3. 30% RA + 7% PG
4. 40% RA + 9% PG

Mix M1 (20% RA + 5% PG): In Mix M1, **20% of natural coarse aggregate** was replaced with recycled aggregate, while **5% of river sand** was replaced with plastic granules. This replacement level was selected to evaluate the initial influence of recycled materials on concrete performance. The mix was expected to maintain satisfactory workability and strength while reducing the consumption of natural resources. It also represented the most practical replacement level for sustainable concrete production.

Mix M2 (30% RA + 7% PG): Mix M2 contained **30% recycled aggregate** and **7% plastic granules** as partial replacements. This mix was prepared to study the effect of moderate replacement levels on the mechanical properties of concrete. The increase in recycled materials was expected to reduce density and workability slightly while still producing acceptable compressive, tensile, and flexural strengths. The performance was compared with both the control mix and Mix M1.
Mix M3 (40% RA + 9% PG) : Mix M3 was prepared with the highest replacement level, consisting of **40% recycled aggregate** and **9% plastic granules**. This mix was designed to evaluate the maximum utilization of waste materials in concrete. The effect of higher replacement percentages on workability, strength, and density was investigated. The results helped determine the practical limit for using recycled aggregate and plastic granules in structural concrete.

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Mixing : All materials were accurately weighed according to the mix design before mixing. Cement, fine aggregate, natural coarse aggregate, recycled aggregate, and plastic granules were first dry mixed until a uniform blend was obtained. Water mixed with **FOSROC Conplast SP430** superplasticizer was then added gradually while mixing continued. The concrete was thoroughly mixed until a homogeneous and workable mixture free from segregation was achieved.

Casting : The fresh concrete was poured into standard cube, cylinder, and beam moulds in three equal layers. Each layer was compacted using a vibrating table to eliminate air voids and ensure proper compaction. The top surface was finished smoothly using a steel trowel. After casting, the specimens were covered to prevent moisture loss and left undisturbed for **24 hours** before demoulding.

Curing : After demoulding, all specimens were immersed in a curing tank filled with clean potable water. The concrete specimens were cured for **7, 14, and 28 days** to ensure complete cement hydration and proper strength development. Adequate curing improved the durability and mechanical properties of concrete and provided consistent test results for all mixes.

Testing : After the specified curing periods, the specimens were tested according to relevant **Indian Standard (IS) codes**. The **slump test** evaluated the workability of fresh concrete, while **compressive strength, split tensile strength, and flexural strength tests** assessed the mechanical performance of hardened concrete. The test results were compared for all mixes to determine the influence of recycled aggregate and plastic granules and to identify the optimum replacement level for sustainable concrete.

Mix Design Table
Final quantities for 1 m³ for M40 Grade Concrete

Material	Quantity
Cement	416 kg
Water	158 kg
Superplasticizer	4.16 kg
Fine aggregate remaining	758.03 kg
Plastic granules	74.97 kg
Coarse aggregate remaining	712.80 kg
Recycled aggregate	475.20 kg

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Consolidated table for all replacement

Mix ID	Cement	Water	SP	Fine aggregate remaining	Plastic granules	Coarse aggregate remaining	Recycled aggregate
Control mix	416 kg	158 kg	4.16 kg	833.00 kg	0.00 kg	1188.00 kg	0.00 kg
20% RA + 5% PG	416 kg	158 kg	4.16 kg	791.35 kg	41.65 kg	950.40 kg	237.60 kg
30% RA + 7% PG	416 kg	158 kg	4.16 kg	774.69 kg	58.31 kg	831.60 kg	356.40 kg
40% RA + 9% PG	416 kg	158 kg	4.16 kg	758.03 kg	74.97 kg	712.80 kg	475.20 kg

Four concrete mixes were prepared.

Mix ID	Recycled Aggregate (%)	Plastic Granules (%)
Control (M1)	0	0
M2	20	5
M3	30	7
M4	40	10

4.TESTS CONDUCTED

Slump Test : The slump test was conducted to determine the workability and consistency of fresh concrete in accordance with IS 1199 (Part 2): 2018. A standard slump cone having a height of 300 mm, top diameter of 100 mm, and bottom diameter of 200 mm was placed on a rigid, non-absorbent surface. Fresh concrete was filled into the mould in three equal layers, and each layer was compacted with 25 strokes using a standard tamping rod. After filling, the cone was lifted vertically, allowing the concrete to subside freely. The difference between the original height of the cone and the height of the slumped concrete was measured as the slump value in millimetres (mm). The test was carried out immediately after mixing to evaluate the effect of recycled aggregate and plastic granules on concrete workability. The slump values were compared for all mixes to assess changes in consistency due to aggregate replacement. IS Code: IS 1199 (Part 2): 2018

Compressive Strength Test : The compressive strength test was conducted to determine the load-carrying capacity of concrete in accordance with IS 516 (Part 1): 2021. Cube specimens of 150 mm × 150 mm × 150 mm were cast, compacted, and cured in water for 7, 14, and 28 days. After curing, the specimens were tested in a Compression Testing Machine (CTM). The load was applied continuously at the specified loading rate until failure occurred, and the maximum load was recorded. The compressive strength was calculated using:

$fc=P/A$

where:
- fc= Compressive strength (N/mm²)
- P = Maximum failure load (N)
- A = Loaded area (22500 mm²)

The results indicated that compressive strength increased with curing age for all concrete mixes. However, increasing the replacement percentage of recycled aggregate and plastic granules caused a gradual reduction in strength because of the porous nature of recycled aggregate and the relatively weaker bond between plastic particles and cement paste. Among

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all mixes, the concrete containing 20% recycled aggregate and 5% plastic granules exhibited the best overall compressive strength while maintaining sustainable material utilization.IS Code: IS 516 (Part 1): 2021

Split Tensile Strength Test

The split tensile strength test was carried out in accordance with IS 5816:1999 to determine the tensile resistance of concrete. Cylindrical specimens of 150 mm diameter and 300 mm height were cured for 7, 14, and 28 days. During testing, each cylinder was placed horizontally between the compression platens of the testing machine, and the load was applied gradually until failure occurred along the vertical diameter. The split tensile strength was calculated using:

$fct=2P/\pi LD$

where:P = Failure load (N)
L = Length of cylinder (300 mm)
D = Diameter of cylinder (150 mm)

The test evaluates the tensile behaviour of concrete, which is important for assessing crack resistance. Experimental results showed that the split tensile strength followed a trend similar to compressive strength. Moderate replacement levels maintained satisfactory tensile performance, while higher percentages resulted in lower tensile strength due to weaker interfacial bonding between recycled aggregate, plastic granules, and cement paste.IS Code: IS 5816:1999

Flexural Strength Test

The flexural strength test was conducted to evaluate the bending resistance of concrete beams in accordance with IS 516 (Part 1): 2021. Beam specimens of 100 mm × 100 mm × 500 mm were cast and cured for 28 days before testing under a two-point loading arrangement in a flexural testing machine. The maximum load at failure was recorded, and the modulus of rupture was determined using:

$fr=PL/bd2$

where: fr = Flexural strength (N/mm²)
P = Failure load (N)
L = Span length (mm)
b = Beam width (mm)
d = Beam depth (mm)

The flexural strength results demonstrated that the bending capacity of concrete decreased gradually with increasing replacement levels of recycled aggregate and plastic granules. The reduction was mainly attributed to the weaker bond between plastic particles and cement paste and the higher porosity of recycled aggregates. Nevertheless, the mix containing 20% recycled aggregate and 5% plastic granules exhibited satisfactory flexural performance, indicating its suitability for sustainable structural applications.IS Code: IS 516 (Part 1): 2021

5. Comparison Between Conventional Concrete and Modified Concrete

Property	Conventional Concrete	Modified Concrete
Coarse Aggregate	Natural Aggregate	Recycled Aggregate (20–40%)
Fine Aggregate	Natural Sand	Plastic Granules (5–9%) + Sand
Workability	Higher	Slightly Lower
Density	Higher	Lower
Compressive Strength	Higher	Slightly Lower
Split Tensile Strength	Higher	Slightly Lower
Flexural Strength	Higher	Slightly Lower
Water Absorption	Lower	Slightly Higher
Sustainability	Low	High
Overall Performance	Excellent	Good (Optimum Replacement)

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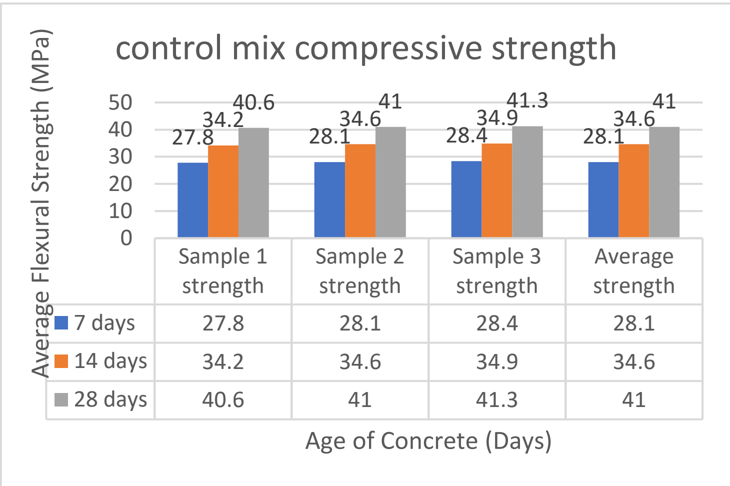
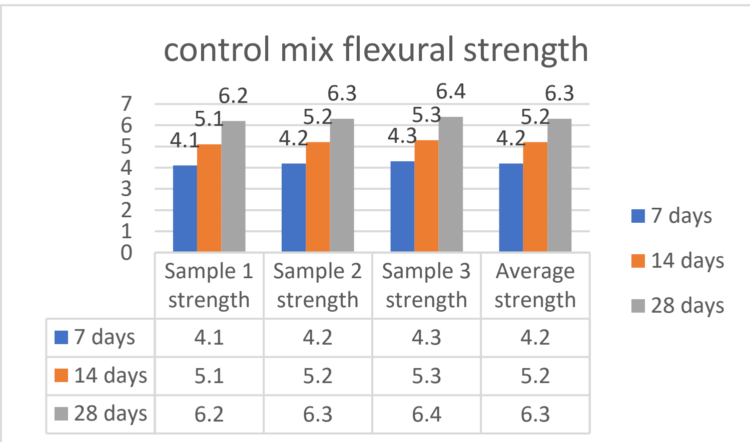
6.RESULTS AND DISCUSSION

Result for Control mix

Test type	Age	Sample 1 strength	Sample 1 load	Sample 2 strength	Sample 2 load	Sample 3 strength	Sample 3 load	Average strength	Average load
Cube	7 days	27.8	625.5	28.1	632.3	28.4	639.0	28.1	632.3
Cube	14 days	34.2	769.5	34.6	778.5	34.9	785.3	34.6	777.8
Cube	28 days	40.6	913.5	41.0	922.5	41.3	929.3	41.0	921.8
Cylinder	7 days	2.7	190.9	2.8	197.9	2.9	204.9	2.8	197.9
Cylinder	14 days	3.4	240.3	3.5	247.4	3.6	254.4	3.5	247.4
Cylinder	28 days	4.1	289.8	4.2	296.8	4.3	303.8	4.2	296.8
Beam	7 days	4.1	102.5	4.2	105.0	4.3	107.5	4.2	105.0
Beam	14 days	5.1	127.5	5.2	130.0	5.3	132.5	5.2	130.0
Beam	28 days	6.2	155.0	6.3	157.5	6.4	160.0	6.3	157.5



control mix compressive strength result



control mix split tensile test strength result

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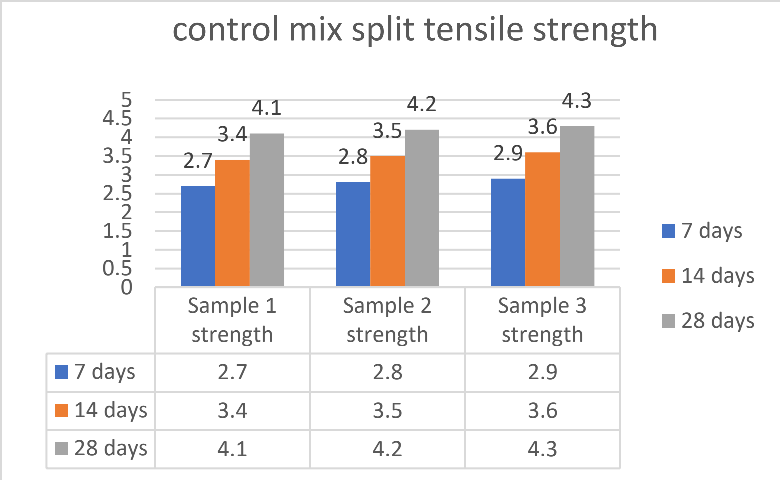
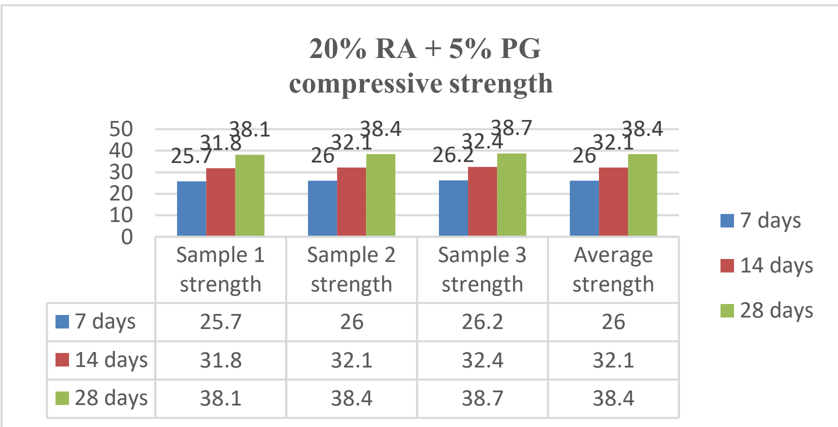


control mix flexural test result

20% RA + 5% PG

Test type	Age	Sample 1 strength	Sample 1 load	Sample 2 strength	Sample 2 load	Sample 3 strength	Sample 3 load	Average strength	Average load
Cube	7 days	25.7	578.3	26.0	585.0	26.2	589.5	26.0	584.3
Cube	14 days	31.8	715.5	32.1	722.3	32.4	729.0	32.1	722.3
Cube	28 days	38.1	857.3	38.4	864.0	38.7	870.8	38.4	864.0
Cylinder	7 days	2.5	176.7	2.6	183.8	2.7	190.9	2.6	183.8
Cylinder	14 days	3.1	219.1	3.2	226.2	3.3	233.2	3.2	226.2
Cylinder	28 days	3.8	268.6	3.9	275.7	4.0	282.8	3.9	275.7
Beam	7 days	3.8	95.0	3.9	97.5	4.0	100.0	3.9	97.5
Beam	14 days	4.7	117.5	4.8	120.0	4.9	122.5	4.8	120.0
Beam	28 days	5.7	142.5	5.8	145.0	5.9	147.5	5.8	145.0

20% RA + 5% PG replacement results



20% RA + 5% PG compressive strength

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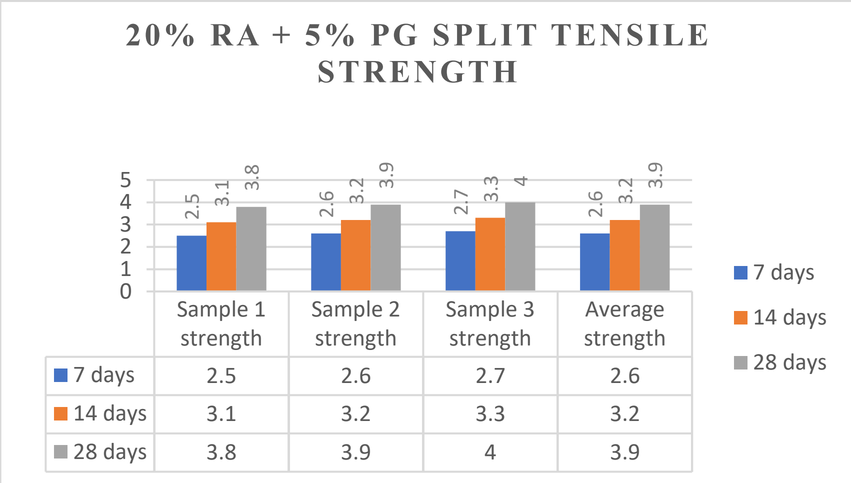
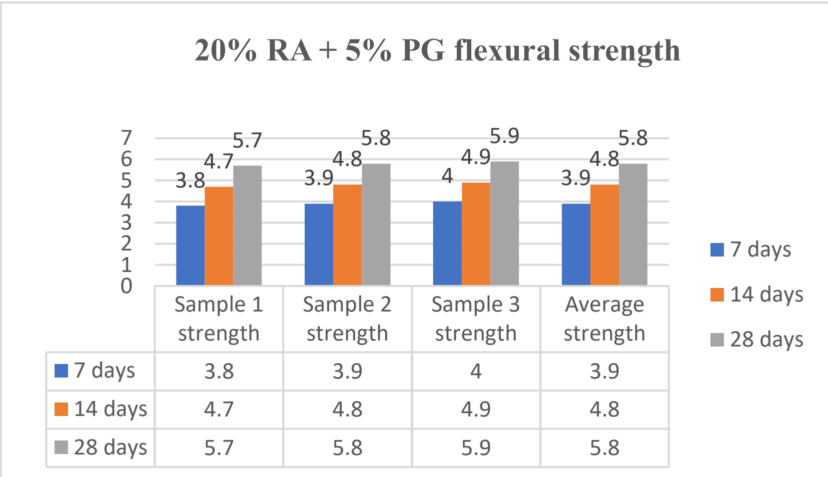


20% RA + 5% PG split tensile test strength



20% RA + 5% PG flexural test strength

7.ENVIRONMENTAL SIGNIFICANCE

The utilization of recycled aggregates (RA) and plastic granules (PG) in concrete offers an effective solution for sustainable construction by converting construction and demolition waste and plastic waste into valuable construction materials. Their incorporation reduces the demand for natural aggregates and river sand, thereby conserving non-renewable resources and minimizing environmental degradation caused by excessive mining. In addition, the reuse of waste materials decreases landfill disposal, lowers the carbon footprint associated with aggregate production and transportation, and supports circular economy principles. The study demonstrates that concrete containing controlled proportions of recycled aggregates and plastic granules can achieve satisfactory engineering performance while promoting resource conservation, waste minimization, and environmentally responsible construction practices.

8.RESULTS AND DISCUSSION

The experimental results showed that the workability and mechanical properties of concrete were influenced by the replacement of natural coarse aggregate with recycled aggregate (RA) and fine aggregate with plastic granules (PG). Workability decreased gradually with increasing replacement levels due to the higher water absorption of recycled aggregates. Concrete density also reduced because of the lightweight nature of plastic granules.

The compressive, split tensile, and flexural strengths increased with curing age for all mixes but showed a slight reduction as the percentage of RA and PG increased. Among the modified mixes, 20% recycled aggregate and 5% plastic granules

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exhibited the best overall performance, providing strength values close to those of conventional concrete. Higher replacement levels resulted in lower strength due to weaker bonding and increased porosity.

Overall, the study demonstrates that concrete incorporating recycled aggregates and plastic granules can be successfully used as a sustainable alternative to conventional concrete. The optimum replacement level of 20% RA and 5% PG offers a good balance between mechanical performance and environmental sustainability.

CONCLUSION

This study demonstrated that the partial replacement of natural coarse aggregates with recycled aggregates and fine aggregates with plastic granules is a feasible and sustainable approach for concrete production. Although higher replacement levels caused a slight reduction in workability and mechanical properties, all mixes achieved acceptable performance. The mix containing 20% recycled aggregate and 5% plastic granules showed the optimum balance between strength, workability, and sustainability, making it suitable for practical construction applications. The findings confirm that the use of recycled and plastic waste in concrete can reduce environmental impact while conserving natural resources and promoting sustainable construction

FUTURE SCOPE

Future research should focus on evaluating the **long-term durability** of concrete containing recycled aggregates and plastic granules under aggressive environmental conditions, including chloride attack, sulphate attack, freeze–thaw cycles, and carbonation. **Microstructural characterization** using techniques such as (Scanning Electron Microscopy) SEM, (X-ray Diffraction) XRD, and (Computed Tomography or X-ray Computed Tomography) CT scanning is recommended to better understand the interfacial bonding and failure mechanisms. Further studies can investigate **higher replacement percentages** in combination with supplementary cementitious materials (e.g., fly ash, GGBS, or silica fume) to enhance mechanical performance. In addition, **field-scale applications** and life-cycle assessment should be carried out to validate the practical feasibility, economic benefits, and environmental sustainability of this concrete for large-scale infrastructure projects.

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