

Development of Eco-Friendly Concrete Composites Using Recycled Concrete Aggregates and Green Cement

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Abstract—The construction industry's increasing demand for sustainable practices has led to the exploration of alternative materials to reduce environmental impact. This study investigates the feasibility of using Recycled Concrete Aggregates (RCA) as partial and full replacements for Natural Coarse Aggregates (NCA) in the production of green concrete. Five concrete mixes were designed with varying RCA replacement levels (0%, 25%, 50%, 75%, and 100%) while maintaining a constant binder content comprising cement, fly ash, and ground granulated blast furnace slag (GGBFS). The performance of these mixes was evaluated through tests for initial and final setting time, workability (slump), compressive strength, splitting tensile strength, flexural strength, water absorption, and Rapid Chloride Penetration Test (RCPT). The results indicated that while the incorporation of RCA led to a slight reduction in workability and mechanical strengths, mixes with up to 50% RCA replacement retained satisfactory performance in both strength and durability parameters. The increased water absorption and chloride permeability at higher RCA contents were attributed to the porous nature and adhered mortar on the RCA surface. However, the setting times remained within acceptable limits across all mixes. The study demonstrates that RCA can effectively replace NCA in structural-grade concrete up to 50% without significant loss in performance, promoting environmental sustainability through resource conservation and waste utilization. The findings encourage further development of green concrete technologies using recycled materials to support a circular economy in the construction sector.

Index Terms—Green concrete; Fly ash; GGBFS; Recycled aggregates; Mechanical properties; Durability.

Concrete is the most widely used construction material in the world due to its versatility, strength, and durability. However, its extensive use has led to significant environmental concerns, primarily stemming from the production of Portland cement—the primary binding material in concrete. Cement manufacturing contributes nearly 7–8% of global carbon dioxide (CO₂) emissions due to the calcination of limestone and the energy-intensive nature of the process [1,2]. Additionally, the growing demand for natural aggregates, such as sand and crushed stone, is placing immense pressure on limited natural resources. This situation necessitates an urgent shift toward sustainable alternatives in concrete production that can reduce carbon emissions and promote circular economy principles [2-5].

One such approach gaining widespread attention is the use of Recycled Concrete Aggregates (RCA) derived from construction and demolition waste. RCA is obtained by crushing existing concrete structures after they have reached the end of their service life. These recycled aggregates can partially or completely replace natural coarse aggregates in new concrete mixes, significantly reducing the demand for virgin materials and landfill space [6]. RCA not only helps in waste management but also lowers the environmental footprint of concrete by reducing the extraction and processing of raw materials. However, the use of RCA poses certain challenges, such as variable quality, lower density, and higher water absorption, which may affect the performance of concrete unless properly addressed

I. INTRODUCTION

through mix design optimization and the incorporation of suitable binder systems [7,8].

In parallel with the adoption of RCA, the development of green cement alternatives—such as blended cements containing fly ash, slag, silica fume, or alkali-activated binders—has emerged as another promising avenue to achieve sustainability in concrete construction. Green cements aim to reduce the clinker content in concrete, which directly cuts down CO₂ emissions and energy consumption [9]. These alternative cements also often improve long-term durability and chemical resistance. When combined with RCA, green cements offer a synergistic approach to producing concrete that is not only environmentally responsible but also structurally competent [10].

The concept of green concrete composites involves integrating multiple sustainable materials, such as RCA and green binders, into a cohesive concrete system that fulfills both structural performance and environmental sustainability criteria [11,12]. These composites are especially relevant in the current global context where infrastructure development must align with low-carbon strategies and resource conservation goals. Researchers and engineers are increasingly focusing on the life cycle performance of such concrete, examining not just mechanical strength but also durability characteristics, thermal behavior, shrinkage, and microstructural properties [13-15].

Despite the potential benefits, incorporating RCA in concrete still faces practical challenges. The old adhered mortar on RCA particles increases porosity, reduces strength, and increases water demand. Therefore, using a modified binder system, such as green cement, can help mitigate these issues by improving the bond between aggregates and paste, refining the microstructure, and enhancing durability. Additionally, the mechanical performance of green concrete composites with RCA must be carefully evaluated through comprehensive laboratory testing to ensure compliance with structural and durability requirements [16,17].

However, recent developments in structural design increasingly favor the use of RCA as a partial or full replacement for NCA, driven by several critical factors. The production and use of RCA contribute significantly to sustainable construction practices by diverting concrete waste from landfills and

promoting recycling [18]. This approach not only supports environmental conservation but also addresses the growing scarcity of natural aggregates, reducing the reliance on quarrying operations and helping preserve finite natural resources. While the cost implications of RCA production and processing may present challenges, the environmental and material conservation benefits have led to a surge in interest and adoption within the construction sector. Nevertheless, there remains a notable gap in comprehensive data concerning the long-term performance, durability, and sustainability of RCA-based concrete [19]. This lack of information poses a challenge to wider implementation and highlights the need for continued research to ensure reliable and environmentally responsible applications of RCA in modern structural designs [20].

II. RESEARCH SIGNIFICANCE

In this study, an effort has been made to explore the feasibility and performance characteristics of green cement-based concrete composites incorporating various percentages of recycled concrete aggregates. The objective is to develop a sustainable concrete system that minimizes environmental impact without compromising structural performance. The study involves the use of blended green cement, specifically containing supplementary cementitious materials (SCMs) such as fly ash and GGBFS (Ground Granulated Blast Furnace Slag), combined with RCA to produce eco-efficient concrete.

The concrete mixes were designed with varying proportions of RCA as a replacement for natural coarse aggregates (0%, 25%, 50%, 75%, and 100%) to assess the influence on workability, compressive strength, tensile strength, flexural strength, and water absorption. All mixes used a consistent green binder system to maintain uniformity in the matrix and to isolate the effects of RCA on the performance parameters. The fresh and hardened properties of the concrete were evaluated using standard test procedures under ambient curing conditions.

III. TEST MATERIALS

The materials used in this study were selected with a focus on sustainability and compliance with relevant standards to produce green cement-based concrete

composites incorporating RCA. The binder system consisted of Portland Pozzolana Cement (PPC), supplemented with industrial by-products such as Class F fly ash and GGBFS. These SCMs helped reduce the clinker content, thereby lowering carbon emissions while enhancing long-term strength and durability through the formation of additional C-S-H gel. The PPC used conformed to IS 1489 (Part 1): 2015, and the fly ash and GGBFS were sourced from local power and steel industries, respectively.

RCA was obtained by crushing waste concrete from a demolition site. After processing and sieving, the RCA was used to replace NCA at varying levels (0%, 25%, 50%, 75%, and 100%). RCA exhibited lower specific gravity (2.45) and higher water absorption (4.8%) compared to NCA due to the adhered mortar and porous surface texture. Despite slightly inferior mechanical properties like aggregate crushing and impact values compared to NCA, RCA was suitable for structural-grade concrete when properly graded and pre-wetted.

NCA, used in the control mix and as part of the replacement strategy, consisted of crushed granite aggregates with good angularity and mechanical strength. Their specific gravity was 2.68 with low water absorption (1.2%) and better crushing and impact resistance compared to RCA. Fine aggregates used in all mixes consisted of river sand conforming to Zone II grading per IS 383:2016. The sand had a specific gravity of 2.64 and a fineness modulus of 2.65, and was clean, well-graded, and devoid of harmful substances.

Potable water was used for both mixing and curing purposes, complying with IS 456:2000 specifications. The quality of water ensured that no adverse chemical reactions would affect hydration or durability. All materials were tested and used according to the mix design to ensure that the RCA-based green concrete composites performed optimally in terms of both strength and sustainability.

Table 1: Mix proportioning of green concrete

Mix ID	Cement	Fly Ash	GGBFS	Fine Aggregate	NCA	RCA	Water
M0	250	50	50	650	1220	0	180
M1	250	50	50	650	915	305	180
M2	250	50	50	650	610	610	180
M3	250	50	50	650	305	915	180
M4	250	50	50	650	0	1220	180

The mix proportioning for green concrete in this study involved five different mixes, M0 to M4, where RCA was incorporated as partial to full replacements for NCA. Each mix was designed to evaluate the effect of RCA on the fresh and hardened properties of green concrete. The binder system across all mixes consisted of 250 kg of cement, 50 kg of fly ash, and 50 kg of GGBFS, maintaining a total binder content of 350 kg per cubic meter. This blended cementitious matrix aimed to enhance the sustainability of the concrete while ensuring strength and durability.

Fine aggregate, in the form of natural river sand, was maintained constant at 650 kg/m³ for all mixes to isolate the effects of varying coarse aggregate compositions. In Mix M0 (control), 1220 kg/m³ of NCA was used without any RCA. Subsequently, in Mixes M1 to M4, RCA replaced NCA at 25%, 50%, 75%, and 100%, respectively, by mass. Thus, Mix

M1 used 915 kg of NCA and 305 kg of RCA, while M2 had equal parts NCA and RCA (610 kg each), M3 had 305 kg of NCA and 915 kg of RCA, and Mix M4 used 1220 kg of RCA alone with no natural aggregates.

The water content was held constant at 180 kg/m³ for all mixes to maintain a consistent water-to-binder ratio and to allow proper hydration and workability. This standardization across mixes facilitated an accurate comparison of the mechanical and durability properties of the resulting concrete, thereby allowing for an effective evaluation of RCA's influence on green cement-based concrete composites.

All raw materials, including cement, fly ash, GGBFS, fine aggregate (river sand), NCA, and RCA, were collected per IS codes and stored in dry conditions. The RCA was sourced from demolished concrete structures, cleaned manually to remove impurities

such as wood, metals, and dust, and then crushed using a jaw crusher to obtain the desired size (typically 20 mm and down). The RCA was sieved and washed to remove adhered dust and mortar particles and was pre-soaked for 24 hours prior to mixing to compensate for its high water absorption capacity.

Based on the designed mix proportions (M0 to M4), individual materials were weighed precisely using a digital weighing scale. The binder content was consistent in all mixes, comprising 250 kg of cement, 50 kg of fly ash, and 50 kg of GGBFS per m³ of concrete. Fine aggregate was measured at 650 kg/m³, while the coarse aggregate proportion varied in terms of NCA and RCA combinations. Water content was maintained at 180 kg/m³ for all mixes to ensure uniform water-to-binder ratios.

Concrete mixing was performed using a pan-type mechanical mixer. Initially, all dry ingredients (cement, fly ash, GGBFS, sand, and both types of aggregates) were thoroughly dry-mixed for 2–3 minutes to achieve uniformity. Following this, about 70–80% of the mixing water was added gradually and the materials were wet-mixed for another 2–3 minutes. The remaining water was added during final mixing to achieve the desired workability. For mixes with higher RCA content (M3 and M4), extra attention was paid during mixing to prevent balling and to ensure proper blending of RCA with other constituents.

After mixing, the fresh concrete was immediately tested for slump to assess workability. Then, the concrete was poured into molds of required sizes for various tests: 150 mm cubes for compressive strength, 150 mm diameter × 300 mm cylinders for split tensile strength, 100 × 100 × 500 mm prisms for flexural strength, and 100 mm cubes for water absorption. The concrete in each mold was compacted using a vibrating table to eliminate air voids and achieve maximum density.

After casting, all specimens were covered with plastic sheets and left in the laboratory for 24 hours for initial setting. After demolding, the specimens were transferred into a curing tank filled with potable water and kept at ambient temperature (27±2°C) for the specified curing periods (7 and 28 days). Proper curing was essential, especially for mixes containing RCA, to enhance hydration and strength development.

IV. TEST METHODS

The initial and final setting times of the binder system (cement, fly ash, GGBFS) were determined using the Vicat apparatus as per IS: 4031 Part 5. A standard consistency paste was prepared and placed in the Vicat mold. The initial setting time was recorded as the time taken for the needle to penetrate 33–35 mm from the top of the mold, while the final setting time was marked when the needle failed to make a visible impression. These tests help assess the working time and early setting behavior of the blended cement matrix [21].

Workability of fresh concrete was assessed using the slump cone test as per IS: 1199. A standard slump cone (300 mm height, 200 mm bottom diameter, 100 mm top diameter) was filled with fresh concrete in three layers, each tamped 25 times with a standard tamping rod. The cone was lifted vertically, and the slump value (difference between the height of the cone and the displaced concrete) was measured [22]. Workability variations with different RCA contents were analyzed using these results.

Compressive strength was tested on 150 mm concrete cubes after curing periods of 7 and 28 days. The specimens were loaded using a compression testing machine (CTM) at a uniform rate of 140 kg/cm²/min until failure. The ultimate load was recorded, and the compressive strength was calculated using the formula:

$$F = \frac{P}{A}$$

Where, P = ultimate load

A = cross-sectional area

This test assesses the primary load-bearing capacity of the concrete.

The splitting tensile strength test was conducted on cylindrical specimens (150 mm diameter × 300 mm height) using a CTM. The specimen was placed horizontally, and the load was applied along the vertical diameter until failure. This test indirectly evaluates the tensile strength of concrete, which is critical in understanding cracking and fracture resistance under tension.

Flexural strength was tested using beam specimens (100 × 100 × 500 mm) under a two-point loading system. The test setup ensured symmetrical loading, and the maximum load was recorded at failure. The modulus of rupture was calculated using the formula:

$$F = (P \times L) / (b \times d^2)$$

Where, P = load,

L = span length,

b = width, and

d = depth of beam.

This test helps evaluate the concrete’s ability to resist bending.

Water absorption was determined on 100 mm cube specimens. The specimens were oven-dried at 105°C until constant weight was achieved (W1), then immersed in water for 48 hours and weighed again (W2). The water absorption (%) was calculated as:

$$\text{Water absorption (\%)} = [(W2 - W1) / W1] \times 100.$$

This test evaluates the porosity and permeability of concrete, which directly affects its durability.

The RCPT was performed on 100 mm diameter × 50 mm thick disc specimens. The specimens were vacuum-saturated, then placed between two chambers: one filled with sodium chloride solution and the other with sodium hydroxide solution. A 60 V DC voltage was applied across the specimen for 6 hours, and the total charge passed in coulombs was recorded. Lower charge values indicate better resistance to chloride ion penetration and higher durability. This test is crucial in evaluating the long-term resistance of concrete to chloride-induced corrosion.

V. RESULTS AND DISCUSSION

5.1 Initial and final setting time

The setting time is a crucial property that affects the workability and handling of fresh concrete. In the current study, Mix M0, containing 100% natural coarse aggregates (NCA), exhibited the shortest initial setting time of 25 minutes and a final setting time of 560 minutes. As the proportion of RCA increased from Mix M1 to M4, a gradual increase in initial setting time was observed, with the maximum of 30 minutes in Mixes M2 and M3. Final setting times also showed a slight increase, ranging from 580 to 585 minutes, with the highest values noted in M1 and M3.

The increase in setting times with higher RCA content can be attributed to the porous nature and residual hydration products present in RCA. These characteristics slow down the early hydration reaction due to increased water demand and delayed availability of free water for cementitious reactions.

Moreover, the finer particles and residual adhered mortar in RCA may also impact the paste consistency and affect the initial stiffening behavior [23,24].

However, the variations in setting times across the mixes were not drastic, indicating that RCA can be used in green concrete without significantly compromising setting characteristics. All mixes met acceptable limits for practical applications. The results suggest that up to 100% RCA replacement (M4) is feasible from a setting time perspective, with only a marginal increase in setting periods.

Table 2: Initial and final setting times of different mixes

Mix ID	Initial Setting Time (min)	Final Setting Time (min)
M0	25	560
M1	27	585
M2	30	580
M3	30	585
M4	29	582

5.2 Workability

The slump value for the control mix (M0), containing 100% NCA, was observed to be 85 mm, indicating a medium workability suitable for normal concrete construction. As RCA content increased from M1 to M4, a slight but consistent decrease in slump was recorded, with the lowest value of 78 mm observed in M4, which incorporated 100% RCA.

This trend reflects the high water absorption capacity and angular particle shape of RCA, both of which tend to reduce workability. The adhered old mortar on RCA surfaces increases the surface area and roughness, demanding more water to achieve the same level of fluidity. Additionally, the presence of micro-cracks and increased porosity in RCA contributes to internal water demand, which is not available for lubricating the mix, thereby reducing slump [25].

Despite the reduction in slump, all mixes exhibited acceptable workability, with only a marginal difference (7 mm) between M0 and M4. This suggests that concrete containing RCA, even up to 100% replacement, can maintain a satisfactory level of workability without the use of additional water or plasticizers, provided proper mix design considerations are applied.

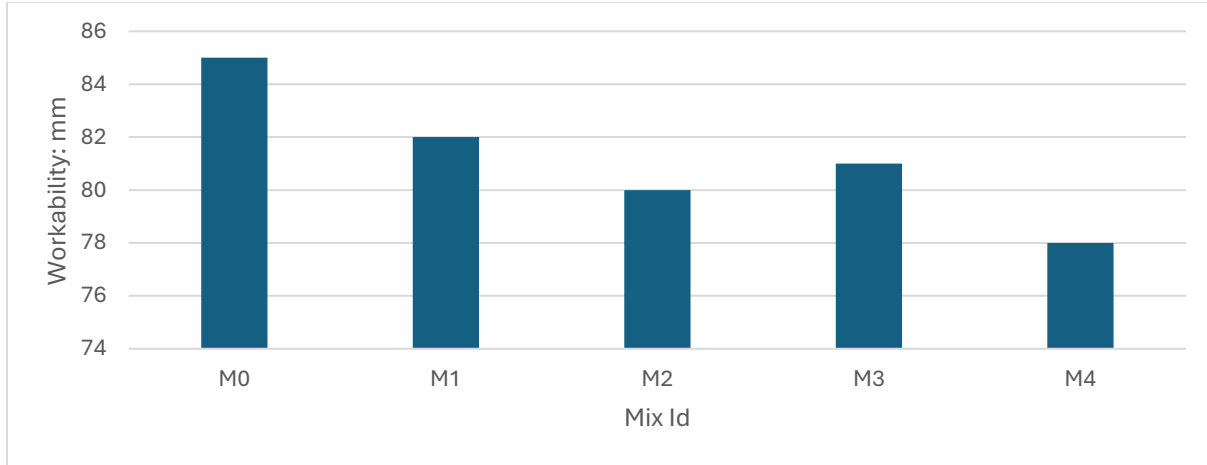


Figure 1: Workability of green concrete samples

5.3 Compressive strength

Compressive strength is a fundamental property reflecting the load-carrying capacity of concrete. In the present study, the compressive strength values for different mixes showed a gradual reduction as the RCA content increased. The control mix M0, containing 100% NCA, exhibited the highest compressive strength due to better interlocking and lesser porosity. However, as RCA content increased in M1 to M4, a decreasing trend in strength was

noted. This can be attributed to the weaker old mortar adhered to RCA, higher porosity, and micro-cracks inherent in recycled aggregates, which negatively impact the bond between the aggregate and cement paste [26]. Despite the decline, the compressive strength values for all mixes remained within acceptable structural grade limits, indicating that RCA can be effectively used in structural concrete with proper mix design and quality control.

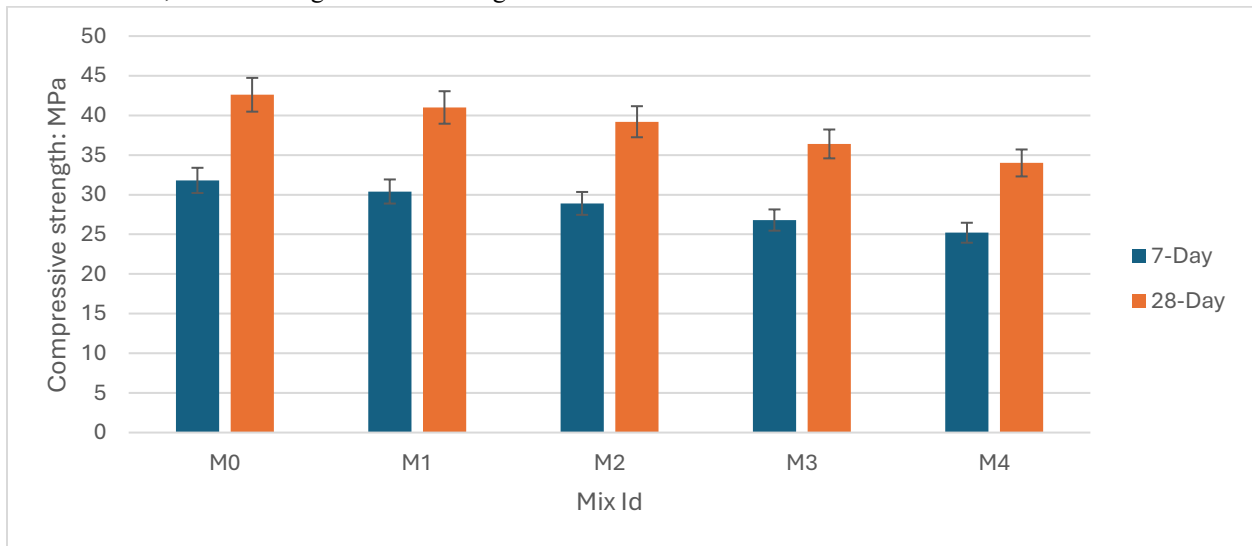


Figure 2: Compressive strength of green concrete samples

5.4 Splitting tensile strength

The splitting tensile strength also followed a decreasing trend with increased RCA substitution. The control mix (M0) exhibited the highest tensile strength due to the better integrity and cohesion provided by natural aggregates. RCA mixes (M1 to

M4) showed reduced tensile capacity, primarily due to the weaker aggregate-paste interface and higher water absorption of RCA, which disrupts the internal hydration and reduces bond strength. The interfacial transition zone (ITZ) around recycled aggregates tends to be more porous and less dense compared to

NCA, contributing to early crack initiation under tensile loading [27,28]. However, the reductions were modest and consistent, and the values for M1 and M2

(with 25–50% RCA) were still comparable to the control mix, making partial RCA replacement viable.

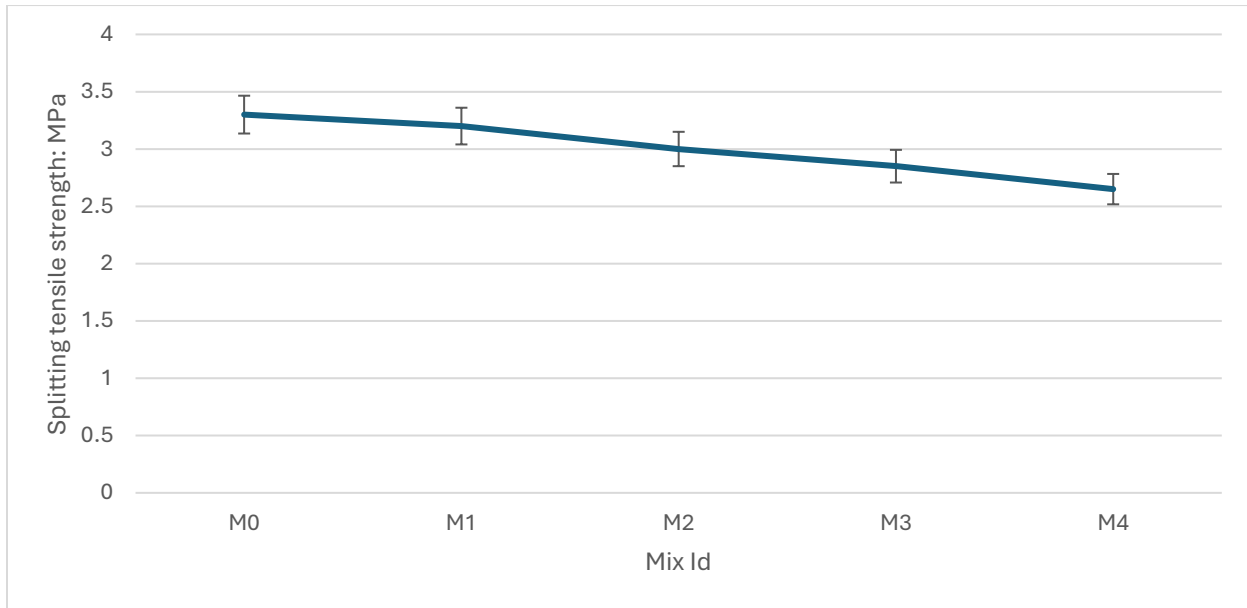


Figure 3: Splitting tensile strength of green concrete samples

5.5 Flexural strength

Flexural strength results revealed a pattern similar to compressive and tensile strengths. Mix M0 had the highest flexural strength, while strength decreased progressively in mixes M1 through M4. Flexural strength is highly sensitive to the quality of aggregates and their bond with the cementitious matrix. The presence of micro-cracks and old adhered

mortar in RCA leads to stress concentrations under bending loads, thereby reducing flexural capacity. Nonetheless, mixes with partial RCA (up to 50%) retained satisfactory flexural behavior, suggesting that moderate RCA replacement does not significantly compromise bending performance, especially when the fine aggregate matrix remains consistent and good compaction is achieved [29].

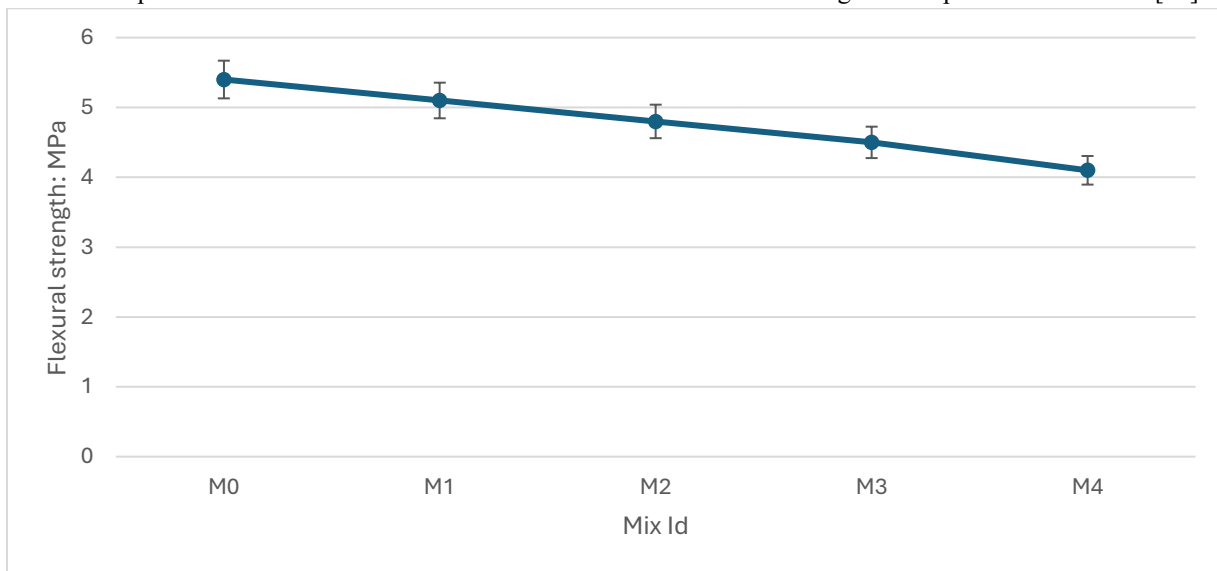


Figure 4: Flexural strength of green concrete samples

5.6 Water absorption

Water absorption is a measure of the porosity and durability of concrete. The results showed a steady increase in water absorption with the rise in RCA content. M0 recorded the lowest water absorption, while M4, with 100% RCA, showed the highest. This increase is primarily due to the porous nature of RCA, which includes residual mortar, voids, and cracks that contribute to higher permeability.

Increased absorption affects durability by making concrete more susceptible to ingress of harmful agents like chlorides and sulfates [30,31]. The data suggests that high RCA content should be limited in durability-critical structures, unless additional measures such as surface densifiers, low water-cement ratio, or supplementary cementitious materials (SCMs) are adopted.

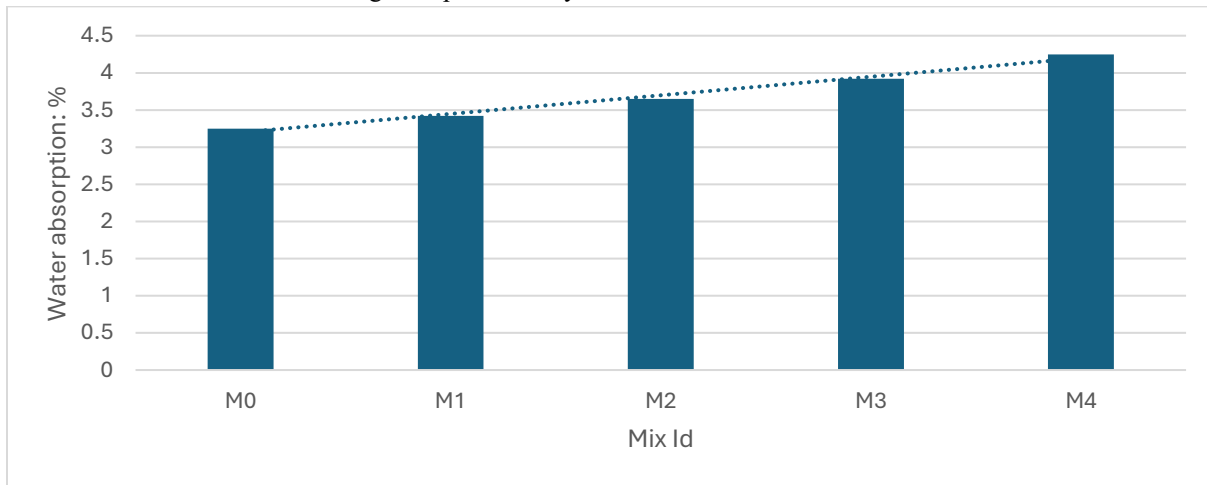


Figure 5: Water absorption of green concrete mix samples

5.7 RCPT

RCPT values increased with higher RCA replacement, indicating higher charge passed, and hence lower resistance to chloride ion penetration. The control mix M0 showed the lowest RCPT value, demonstrating superior impermeability. As RCA content increased, permeability worsened due to the open pore structure and weak ITZ associated with recycled aggregates. This is a critical durability

concern, especially for structures exposed to marine or deicing environments. However, the RCPT values for mixes M1 and M2 were still within moderate ranges, suggesting that partial use of RCA (up to 50%) can be acceptable for exposure conditions with moderate chloride risk. For aggressive environments, concrete with high RCA content should be modified using pozzolanic materials (e.g., fly ash, GGBS) or surface sealers to improve chloride resistance.

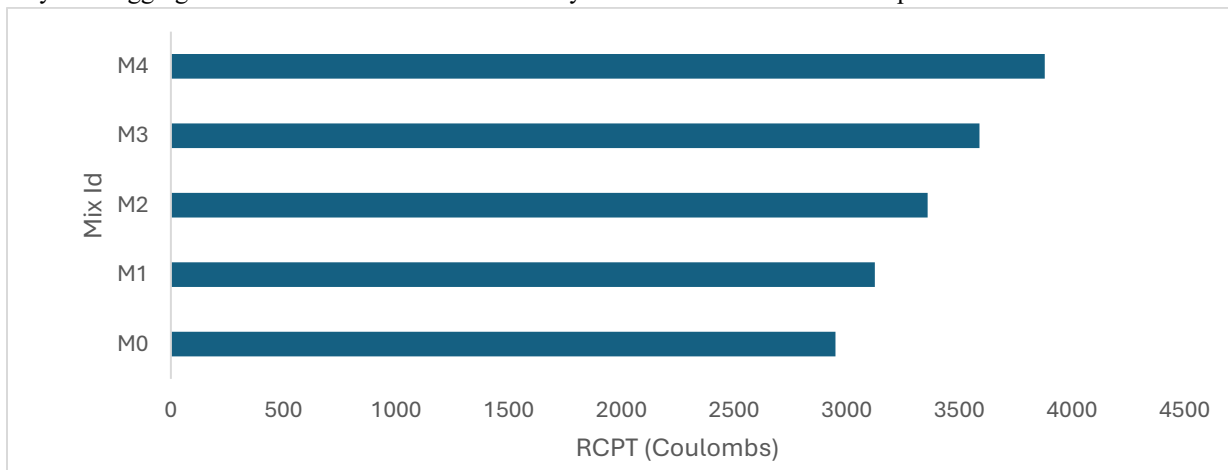


Figure 5: RCPT of green concrete mix samples

VI. CONCLUSIONS

Based on the comprehensive experimental investigation of green concrete incorporating RCA, several key conclusions can be drawn. The study indicates that partial replacement of NCA with RCA in concrete is technically feasible and environmentally beneficial. Strength characteristics such as compressive strength, splitting tensile strength, and flexural strength showed a marginal decrease as RCA content increased. However, up to 50% RCA replacement (Mixes M1 and M2) retained acceptable structural performance, suggesting that RCA can be used effectively without severely compromising mechanical integrity.

Workability, as measured by slump values, showed a slight reduction with higher RCA content, primarily due to the higher water absorption and irregular texture of recycled aggregates. Initial and final setting times slightly increased with RCA content but remained within the permissible limits, indicating that the use of RCA does not adversely affect the setting behavior of cement paste.

In terms of durability, water absorption and RCPT values increased with higher RCA percentages, highlighting the influence of the porous nature and residual mortar content in RCA. Mix M4 (100% RCA) showed the highest permeability and absorption, indicating a potential vulnerability to chloride ingress and moisture-related deterioration. Nevertheless, moderate RCA replacement levels (up to 50%) offered a reasonable balance between strength and durability.

The use of RCA in green concrete is a promising sustainable solution, particularly when the replacement is limited to 50% or below. This approach supports waste reduction, conservation of natural resources, and the promotion of the circular economy in construction. Further enhancements in durability can be achieved by combining RCA with supplementary cementitious materials like fly ash and GGBFS.

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DECLARATIONS

The authors declared that there is no conflict of interest statement to publish this paper.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

- [1] Tam, V.W.Y.; Soomro, M.; Evangelista, A.C.J. A review of recycled aggregate in concrete applications (2000–2017). *Constr. Build. Mater.* 2018, 172, 272–292.
- [2] Bektas, F.; Wang, K.; Ceylan, H. Effects of crushed clay brick aggregate on mortar durability. *Constr. Build. Mater.* 2009, 23, 1909–1914.
- [3] Zachariah, J.P.; Sarkar, P.P.; Debnath, B.; Pal, M. Effect of polypropylene fibres on bituminous concrete with brick as aggregate. *Constr. Build. Mater.* 2018, 168, 867–876.
- [4] Zachariah, J.P.; Sarkar, P.P.; Pal, M. A study on the moisture damage and rutting resistance of polypropylene modified bituminous mixes with crushed brick aggregate wastes. *Constr. Build. Mater.* 2021, 269, 121357.
- [5] Prasad, D.; Singh, B.; Suman, S.K. Utilization of recycled concrete aggregate in bituminous mixtures: A comprehensive review. *Constr. Build. Mater.* 2022, 326, 126859.
- [6] Ram, V.G.; Kishore, K.C.; Kalidindi, S.N. Environmental benefits of construction and demolition debris recycling: Evidence from an Indian case study using life cycle assessment. *J. Clean. Prod.* 2020, 255, 120258.
- [7] Singh, S.; Ransinchung, G.D.; Monu, K. Sustainable lean concrete mixes containing wastes originating from roads and industries. *Constr. Build. Mater.* 2019, 209, 619–630.
- [8] Mazumder, A.R.; Kabir, A.; Yazdani, N. Performance of Overburnt Distorted Bricks as Aggregates in Pavement Works. *J. Mater. Civ. Eng.* 2006, 18, 777–785.
- [9] Sarkar, D.; Pal, M.; Sarkar, A.K.; Mishra, U. Evaluation of the Properties of Bituminous Concrete Prepared from Brick-Stone Mix Aggregate. *Adv. Mater. Sci. Eng.* 2016, 2016, 2761038.

- [10] Etxeberria, M.; Mari, A.; Vázquez, E. Recycled aggregate concrete as structural material. *Mater. Struct.* 2006, 40, 529–541.
- [11] Singh, S.; Ransinchung, G.; Monu, K.; Kumar, P. Laboratory investigation of RAP aggregates for dry lean concrete mixes. *Constr. Build. Mater.* 2018, 166, 808–816
- [12] Prasad, D.; Pandey, A.; Kumar, B. Sustainable production of recycled concrete aggregates by lime treatment and mechanical abrasion for M40 grade concrete. *Constr. Build. Mater.* 2021, 268, 121119.
- [13] Yunchao, T.; Zheng, C.; Wanhui, F.; Yumei, N.; Cong, L.; Jieming, C. Combined effects of nano-silica and silica fume on the mechanical behavior of recycled aggregate concrete. *Nanotechnol. Rev.* 2021, 10, 819–838.
- [14] Salehi, S.; Arashpour, M.; Kodikara, J.; Guppy, R. Sustainable pavement construction: A systematic literature review of environmental and economic analysis of recycled materials. *J. Clean. Prod.* 2021, 313, 127936.
- [15] Mohammed, T.U.; Hasnat, A.; Awal, M.A.; Bosunia, S.Z. Recycling of Brick Aggregate Concrete as Coarse Aggregate. *J. Mater. Civ. Eng.* 2015, 27, B4014005.
- [16] Zhu, X.; Chen, X.; Shen, N.; Tian, H.; Fan, X.; Lu, J. Mechanical properties of pervious concrete with recycled aggregate. *Comput. Concr.* 2018, 21, 623–635.
- [17] Toghroli, A.; Shariati, M.; Sajedi, F.; Ibrahim, Z.; Koting, S.; Mohamad, E.T.; Khorami, M. A review on pavement porous concrete using recycled waste materials. *Smart Struct. Syst.* 2018, 22, 433–440.
- [18] Debnath, B.; Sarkar, P.P. Pervious concrete as an alternative pavement strategy: A state-of-the-art review. *Int. J. Pavement Eng.* 2018, 21, 1516–1531.
- [19] Mullaney, J.; Lucke, T. Practical Review of Pervious Pavement Designs. *Clean-Soil Air Water* 2013, 42, 111–124.
- [20] Guo, H.; Shi, C.; Guan, X.; Zhu, J.; Ding, Y.; Ling, T.-C.; Zhang, H.; Wang, Y. Durability of recycled aggregate concrete—A review. *Cem. Concr. Compos.* 2018, 89, 251–259.
- [21] Etxeberria, M.; Vázquez, E.; Mari, A.; Barra, M. Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. *Cem. Concr. Res.* 2007, 37, 735–742.
- [22] Debnath, B.; Sarkar, P.P. Clogging in Pervious Concrete Pavement Made with Non-conventional Aggregates: Performance Evaluation and Rehabilitation Technique. *Arab. J. Sci. Eng.* 2021, 46, 10381–10396.
- [23] Imran, H.; Akib, S.; Karim, M.R. Permeable pavement and stormwater management systems: A review. *Environ. Technol.* 2013, 34, 2649–2656.
- [24] Chen, J.; Chu, R.; Wang, H.; Zhang, L.; Chen, X.; Du, Y. Alleviating urban heat island effect using high-conductivity permeable concrete pavement. *J. Clean. Prod.* 2019, 237, 117722.
- [25] Chandrappa, A.K.; Biligiri, K.P. Pervious concrete as a sustainable pavement material—Research findings and future prospects: A state-of-the-art review. *Constr. Build. Mater.* 2016, 111, 262–274.
- [26] Debnath, B.; Sarkar, P.P. Prediction and model development for fatigue performance of pervious concrete made with over burnt brick aggregate. *Mater. Struct.* 2020, 53, 86.
- [27] Zaetang, Y.; Wongsas, A.; Sata, V.; Chindaprasirt, P. Use of lightweight aggregates in pervious concrete. *Constr. Build. Mater.* 2013, 48, 585–591.
- [28] Aliabdo, A.A.; Elmoaty, A.E.M.A.; Fawzy, A.M. Experimental investigation on permeability indices and strength of modified pervious concrete with recycled concrete aggregate. *Constr. Build. Mater.* 2018, 193, 105–127.
- [29] Sartipi, M.; Sartipi, F. Stormwater retention using pervious concrete pavement: Great Western Sydney case study. *Case Stud. Constr. Mater.* 2019, 11, e00274.
- [30] Khankhaje, E.; Rafieizonooz, M.; Salim, M.R.; Khan, R.; Mirza, J.; Siong, H.C. Salmiati Sustainable clean pervious concrete pavement production incorporating palm oil fuel ash as cement replacement. *J. Clean. Prod.* 2018, 172, 1476–1485.
- [31] Debnath, B.; Sarkar, P.P. Permeability prediction and pore structure feature of pervious concrete using brick as aggregate. *Constr. Build. Mater.* 2019, 213, 643–651.