Durability Performance of Recycled Coarse Aggregate As Partial Replacement of Coarse Aggregate in Concrete

Jajula.Bala Krishna[1], Yellinedi Madhavi[2], Bypaneni Krishna Chaitanya[3]

[1]PG student, Department of Civil Engineering, R.V.R & J.C College of Engineering (Autonomous), Guntur-522019, Andhra Pradesh, India
[2,3]Department of Civil Engineering, R.V.R & J.C College of Engineering (Autonomous), Guntur-522019, Andhra Pradesh, India.

Abstract:
This study explores the use of recycled coarse aggregates (RCA) in concrete, replacing natural coarse aggregates (NCA) at 12.5%, 25%, and 50% levels. Ordinary Portland Cement (OPC) was partially substituted with fly ash for sustainability. Concrete mixes were designed following IS 10262:2019, and a super plasticizer was added to maintain workability despite RCA's higher water absorption. Mechanical properties such as compressive strength, water absorption, sorptivity, pull-out strength, and rapid chloride penetration were tested. Results showed that upto 25% RCA improved compressive strength, water absorption, and chloride resistance. However, at 50% RCA, performance decreased due to higher porosity and weaker aggregates. The study highlights the potential of using RCA as a sustainable material in concrete, with optimal performance achieved with up to 25% replacement.

Keywords: super plasticizer, RCA, durability, sorptivity, sustainable concrete

1. Introduction

1.1 General

The construction industry is a major consumer of natural resources and energy significantly contributing to global carbon emissions [1-5]. Concrete, the most widely used construction material, heavily relies on non-renewable resources such as natural coarse aggregates (NCA) and Portland cement. The increasing demand for concrete has led to the depletion of natural aggregate reserves and a surge in construction and demolition waste generation. This dual challenge of resource scarcity and environmental degradation has intensified the search for sustainable alternatives [6-11]. Incorporating RCA in new concrete not only reduces the consumption of natural resources but also helps in managing construction and demolition waste. However, the use of RCA often raises concerns regarding the durability and mechanical performance of the resulting concrete, primarily due to the adhered mortar and higher porosity in RCA compared to natural aggregates. One effective approach to enhance the durability and workability of RCA concrete is the incorporation of super plasticizers. Super plasticizers are high-range water-reducing admixtures that improve the flow properties of concrete without increasing the water-to-cement ratio. This reduction in water content contributes to denser concrete microstructure and improved durability characteristics.

However, its effective integration into structural concrete requires careful consideration due to its differing properties from natural aggregates. RCA typically exhibits higher porosity, increased water absorption, and lower mechanical strength because of attached mortar and pre-existing micro cracks. These characteristics may negatively influence concrete & long-term durability—a vital factor in structural performance. To overcome these limitations, the incorporation of supplementary cementitious materials (SCMs) such as Ground Granulated Blast Furnace Slag (GGBS), silica fume, and nano-silica is explored. These SCMs refine the microstructure, densify the interfacial transition zone (ITZ), and improve resistance to moisture and chloride ingress. This study evaluates the durability performance of concrete with varying RCA levels (0%, 12.5%, 25%, and 50%) alongside different proportions of GGBS, silica fume, and nano-silica. By assessing both the physical properties of RCA and the results from durability tests, the research aims to identify optimal mix combinations that balance performance, sustainability, and practicality for structural applications.

1.2 Research Significance

The durability performance of concrete incorporating recycled coarse aggregate (RCA) is critical for promoting sustainable construction practices by enabling the reuse of construction and demolition waste. Super plasticizers, as advanced chemical admixtures, have the potential to mitigate these durability challenges by improving the workability and reducing the water-cement ratio, which leads to a denser and less permeable concrete matrix. Investigating the synergistic effect of RCA combined with super plasticizers is essential to understand how these materials influence key durability parameters. This research holds significance in guiding the development of durable, eco-friendly concrete mixes that meet modern construction standards and reduce environmental impact.

1.3 Aim and Objectives

The aim of this study is to evaluate the durability performance of concrete incorporating recycled coarse aggregate (RCA) and supplementary cementitious materials (SCMs). The objective is to determine optimal replacement levels that ensure structural suitability while enhancing sustainability.

2. Literature review

Yasumichi Koshiro et.al[12] Application of entire concrete waste reuse model to produce recycled aggregate, A concrete waste reuse model was developed to produce recycled aggregate class H concrete from demolished buildings. In a redevelopment project at Obayashi Technical Research Institute, a 24-year-old building was demolished, and its concrete waste was processed using a heat grinder system to create high-quality recycled aggregates. These materials were used in fair-faced concrete structures of a new building, while the fine powder by-product was repurposed for clay tiles. This model achieved complete recycling of concrete waste.Si-Min Jian, Bo Wu et.al[13] Compressive behavior of compound concrete containing demolished concrete lumps and recycled aggregate concrete,Reusing demolished concrete lumps (DCLs) and recycled coarse aggregates (RAs) together enhances total waste content in concrete. The compressive behavior of recycled lump/aggregate concrete (RLAC) was studied, along with its microstructure using mercury intrusion porosimetry and scanning electron microscopy. Results showed that RLAC can achieve over twice the waste content of RAC while maintaining satisfactory compressive strength up to 54.6% waste content. However, at a 100% RA replacement ratio, compressive strength decreases, and porosity in the fresh mortar surrounding DCLs increases significantly.B. Gonza´lez-Fonteboa et.al[14] Concretes with aggregates from demolition waste and silica fume Materials and mechanical properties,This study evaluates recycled aggregates in Spain through standard tests on density, absorption, and strength. Conventional and silica fume concretes were modified to create recycled versions with 50% recycled coarse aggregates. Physical and mechanical properties, including compressive strength and elasticity, were assessed. Results provide insights into the suitability of recycled concrete.Davood Mostofinejad et.al[15] Durability of concrete containing recycled concrete coarse and fine aggregates and milled waste glass in magnesium sulfate environment,Recycling demolished concrete helps address resource depletion in construction. This study tested concrete durability using recycled coarse (RCA) and fine aggregates (RFA) and milled waste glass (MWG) as partial replacements. Results showed reduced expansion and water absorption with RFA and improved sulfate resistance with MWG,increasing compressive strength by up to 53%. A durability loss index confirmed minimal sulfate impact with proper mix proportions.J. Vengadesh Marshall Raman et.al[16] Properties of concrete with dissimilar treated recycled coarse aggregate, To address natural aggregate scarcity, various treatments enhance recycled aggregate properties by removing adhered mortar. This study examines chemical, mechanical, thermal, and bio- based treatments, among others, to improve physical, mechanical, and durability properties. Results show all methods enhance recycled concrete performance, with some being eco-friendly and cost- effective.R.V. Silva et.al[17] Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production, Multiple-recycling of concrete helps reuse demolition waste sustainably. This study tested concrete durability using recycled coarse aggregates from up to three cycles. Results showed a decline in aggregate quality and durability with more cycles, though performance degradation slowed over time. However, full stabilization was not always achieved after three cycles.Amor Ben Fraj et.al[18] Concrete based on recycled aggregates – Recycling and environmental analysis, A case study of paris' region, Recycled concrete aggregates (RA) help reduce resource depletion but can lower concrete performance. This study assesses RAC's environmental impact in Paris, showing that high-grade RA requires less extra cement to maintain strength. RAC is more sustainable than natural aggregate concrete when transport distances exceed 50 km. High-grade RA improves most environmental factors except waste.Yunlong Yao et.al[19] Evolution of recycled concrete research: a data-driven scientometric review, Recycled aggregate concrete (RAC) is an eco-friendly material, with research on it growing rapidly since 2017. This study analyzes RAC publications from 2000–2023, highlighting trends in mechanical properties, durability, and innovative techniques. Key challenges include nanoparticle integration, biomineralization, and 3D printing. Advancements in these areas can enhance RAC's role in sustainable.

3. Materials and mix proportion

3.1 Materials

The materials used in this study include Ordinary Portland Cement (OPC) with a specific gravity of 3.15 and along with fly ash, which has a specific gravity of 2.15. Natural sand, conforming to Zone-II grading as per IS 383-1970, was used as fine aggregate and has a specific gravity of 2.37. For coarse aggregates, both natural coarse aggregate (NCA) and recycled coarse aggregate (RCA) were utilized, with particle sizes ranging from 10 mm to 20 mm. The NCA has an aggregate impact value of 15.74%, a specific gravity of 2.8, a bulk density of 1.46 g/cm^3, and a fineness modulus of 7.3. Meanwhile, the RCA has an aggregate impact value of 15.56%, a specific gravity of 2.7, a bulk density of 1.42 g/cm^3, and a fineness modulus of 7.238. The water absorption for NCA and RCA were 1.27% and 3.36%, respectively, indicating higher porosity in RCA. To improve the workability of the concrete mixes containing recycled aggregates, a polycarboxylate ether (PCE)-based super plasticizer was incorporated at an optimized dosage to maintain the desired slump and flow without affecting the mechanical properties.

Fig1. Recycled Coarse Aggregate

3.3 Mix design and proportions

The concrete mix was designed in a proportion of 1:1.44:2.40 following the guidelines of IS 10262:2019. In this study, natural coarse aggregate (NCA) was partially replaced with recycled coarse aggregate (RCA) at different levels. The control mix was prepared with 0% RCA and coarse aggregate was replaced at 12.5%, 25% and 50%, designated as RCA0%, RCA12.5%, RCA25% and RCA50% respectively. To enhance sustainability, ten percent of the cementitious binder was substituted with fly ash. Additionally, to mitigate the increased water absorption associated with RCA, a super plasticizer at 1% by weight of cement was added to improve workability without altering the water-cement ratio.

Table1. Details of the composition of mixes designed as per kg/cu.m

Sl.No	Mix id	Cement	Fly ash	FA	20 mm	12 mm	W	SP
1	RCA0%	355.5	39.5	645.7	748.33	498.89	169.85	3.95
2	RCA12.5%	355.5	39.5	645.7	654.78	436.52	169.85	3.95
3	RCA25%	355.5	39.5	645.7	561.24	374.16	169.85	3.95
4	RCA50%	355.5	39.5	645.7	374.16	249.44	169.85	3.95

4. Experimental Program

The performance of the concrete mixes was evaluated through various tests focusing on mechanical characteristics and durability. The recycled coarse aggregate was first tested for specific gravity, impact resistance, water absorption, bulk density, and particle size distribution. For concrete, tests included compressive strength, water absorption, sorptivity, Rapid Chloride Penetration Test (RCPT), and pull-out test. These tests were conducted in accordance with relevant IS codes and standard procedures to ensure accuracy and reliability of results.

5. Results and Discussion

5.1 Compressive strength test

The variation in compressive strength at 7 and 28 days is illustrated in fig5. The compressive strength of concrete mixes from table.2 shows a clear variation with different percentages of recycled coarse aggregate (RCA) replacement. At lower RCA contents of 12.5% and 25%, the compressive strength at 7 and 28 days is higher compared to the control mix without RCA, indicating that partial replacement can enhance strength possibly due to better packing and improved interfacial transition zones. However, when RCA content reaches 50%, the compressive strength significantly decreases at all curing ages, likely due to the higher porosity and weaker adhered mortar in the recycled aggregates, which reduce the overall concrete matrix strength. This trend highlights that moderate use of RCA can maintain or improve strength, but excessive replacement adversely affects the concrete's load-bearing capacity.

5.2 Water absorption capacity

From table.2 the control mix without RCA (0%) shows water absorption of 12.5%. When RCA is introduced at 12.5%, the water absorption decreases to 10.5%, indicating improved impermeability and a denser concrete matrix at this level. However, increasing the RCA content to 25% leads to a significant rise in water absorption to 16.5%, likely due to the higher porosity and absorption characteristics of recycled aggregates. At 50% RCA replacement, the water absorption slightly decreases to 13.5%, possibly influenced by changes in the mix design or compaction. These results as shown in figure.6 suggest that moderate RCA replacement can enhance the durability by reducing water absorption, but higher amounts may increase permeability and affect long-term performance.

Table 2.Test results

Mix (%)	Compression Strength (MPa)		Water Absorption (%)	Sorptivity (mm/s$^{0.5}$)	Pull Out Strength(MPa)		RCPT (Coulombs)
	7Days	28 Days	28 Days	28 Days	10 mm	20 mm	28 Days
RCA 0%	17.4	30.50	12.5	0.0783	6.80	2.03	1404
RCA12.5%	21.11	35.00	10.5	0.0602	6.00	1.85	1376
RCA 25%	20.4	34.00	16.5	0.0498	3.34	1.50	1244
RCA 50%	11.9	23.10	13.5	0.0530	3.61	1.89	1387

5.3 Sorptivity

The sorptivity values measured at 28 days are listed in table.2 variation is shown in fig.7 reveal that incorporating recycled coarse aggregate (RCA) influences the concrete's ability to absorb water through capillary action. The control mix (0% RCA) exhibits the highest sorptivity, indicating greater water absorption and potential vulnerability to moisture-related deterioration. Increasing RCA content reduces sorptivity, with the lowest value observed at 25% RCA, suggesting enhanced resistance to water ingress. Although there is a slight increase at 50% RCA, the sorptivity remains lower than the control mix. These results imply that moderate RCA replacement can improve the durability of concrete by reducing its capillary water absorption.

Fig 3.Pullout test

Fig4.Sorptivity test

5.4 Pull Out Test

Fig.8 represents the pull-out test results. The pullout test results from table.2 for the 20 mm reinforcement bars show a clear trend of decreasing bond strength with increasing RCA content up to 25%, where the pullout load drops from 2.03 kN (0% RCA) to 1.50 kN (25% RCA). This decline suggests that higher proportions of recycled coarse aggregate may weaken the bond between the concrete and the reinforcement, likely due to the increased porosity and lower strength of the recycled aggregate concrete. However, at 50% RCA, there is a slight increase in pullout load to 1.89 kN, which could be attributed to variability in the mix or testing conditions. Overall, the results indicate that moderate to high RCA replacement tends to reduce bond strength, but the relationship is not strictly linear.

5.5 Rapid chloride permeability test

From table.2 the control mix without RCA (RA0%) shows a charge passed of 1404 coulombs, indicating moderate permeability. Introducing RCA at 12.5% slightly reduces the charge to 1376 coulombs, suggesting a marginal improvement in resistance to chloride penetration. Interestingly, the mix with 25% RCA exhibits the lowest charge passed value of 1244 coulombs, reflecting better durability and reduced permeability. However, at 50% RCA replacement, the charge value increases again to 1387 coulombs, indicating a slight decline in chloride resistance. Overall, from fig.9, results suggest that moderate RCA content (around 25%) can enhance the concrete's resistance to chloride ion penetration, potentially improving its durability in aggressive environments.

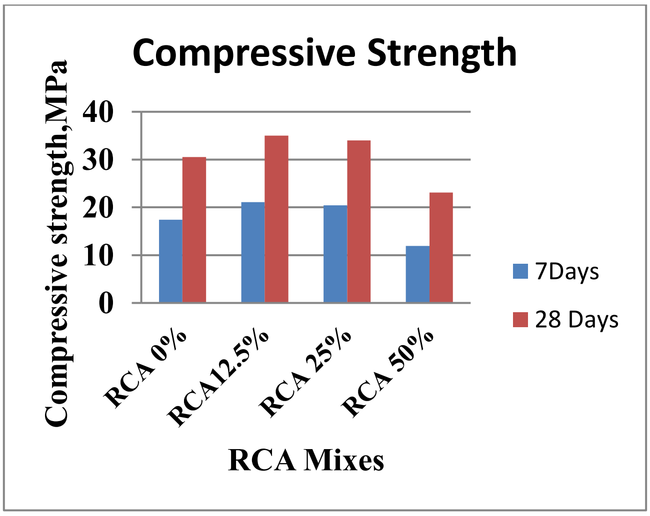

Fig5.Compressive Strength

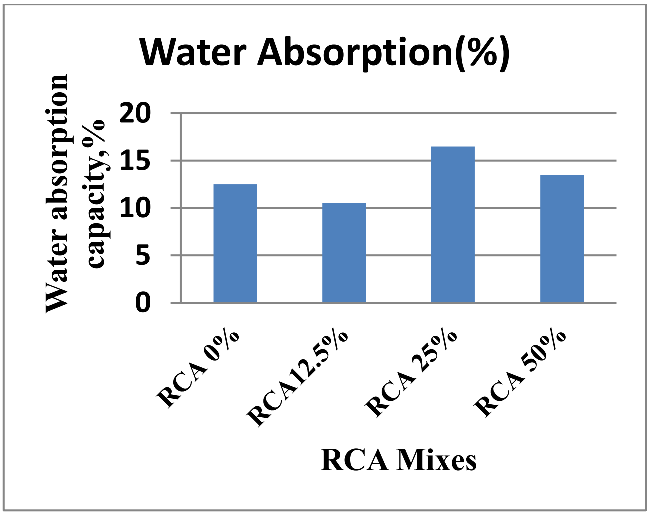

Fig6.Water absorption capacity

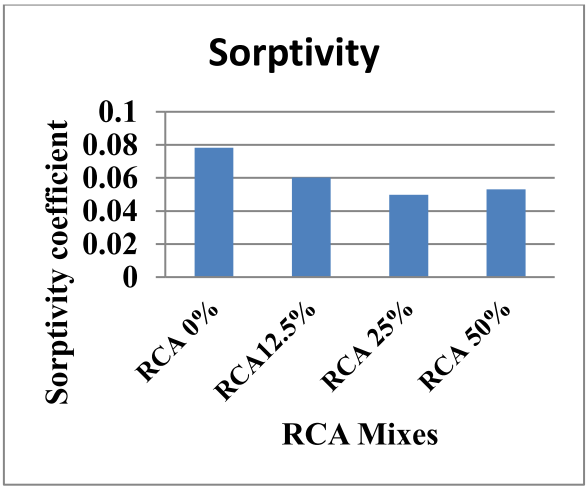

Fig7. Sorptivity

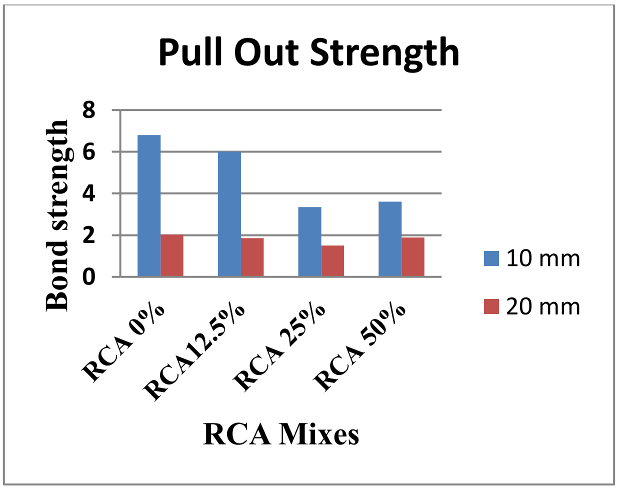

Fig8. Pull Out Test

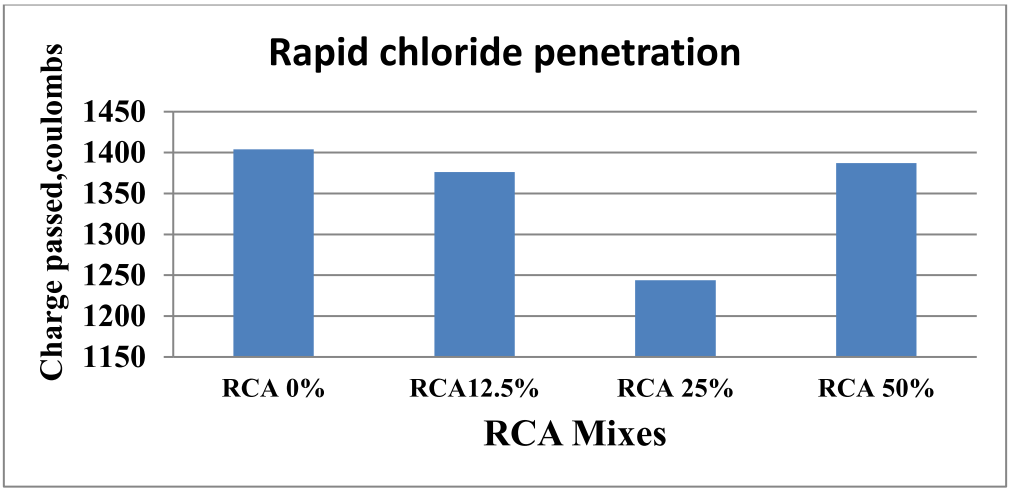

Fig9. RCPT test results

6. Conclusions

This study concluded that all mixes showed good workability due to super plasticizer use. However, the mix with 50% recycled coarse aggregate (RCA) had slightly lower workability because of the rough texture and higher water absorption of RCA. Replacing natural aggregate with 12.5% and 25% RCA improved compressive strength at 7 and 28 days compared to the control. But at 50% RCA, compressive strength dropped significantly because of higher porosity and weaker recycled aggregate quality. Water absorption decreased with 12.5% RCA, indicating a denser concrete. It increased significantly at 25% RCA due to porous recycled aggregates but slightly improved again at 50% RCA. The 25% RCA mix showed the lowest chloride ion penetration, meaning better durability. The control and 50% RCA mixes had higher permeability, indicating less resistance to chloride attack. Sorptivity (water absorption through capillary action) decreased as RCA increased to 25%, showing improved durability. It slightly increased at 50% RCA but remained better than the control mix. By using up to 12.5% RCA maintains good bond strength, showing minimal reduction compared to conventional concrete. Using up to 25% recycled coarse aggregate with super plasticizer improves concrete strength and durability.

References

1. Madhavi, Y & Supriya, Abburi & N, Venkata. (2022). Sustainable Use of Waste Wood Ash in Concrete. 2022. 10.9756/INT-JECSE/V14I2.730.
2. Chaitanya, B.K.; Sivakumar,I.; Madhavi, Y.; Cruze, D.; Venkatesh,C.; Naga Mahesh, Y.; Sri Durga, C.S.Microstructural and Residual Properties of Self-Compacting Concrete ContainingWaste Copper Slag as Fine Aggregate Exposed to Ambient and Elevated Temperatures. Infrastructures 2024, 9, 85.https://doi.org/10.3390/infrastructures9050085.
3. Narayana Rao, U. V., Kumar, N. V. S., Kavitha, C., Madhavi, Y., & Chowdary, P. S. (2024). Polycarboxylate Superplasticizers Used in Concrete: A review. International Journal of Experimental Research and Review, 38, 69–88. https://doi.org/10.52756/ijerr.2024.v38.007
4. Chaitanya, B.K.; Sivakumar, I. Experimental investigation on bond behaviour, durability and microstructural analysis of selfcompacting concrete using waste copper slag. J. Build. Rehabil. 2022, 7, 85.
5. Chaitanya, B.K.; Sivakumar, I. Flow-behaviour, microstructure, and strength properties of self-compacting concrete using wastecopper slag as fine aggregate. Innov. Infrastruct. Solut. 2022, 7, 18

1.

6. Chaitanya, B.K.; Sai Madupu, L.N.K.; Satyanarayana, S.V. Experimental Study on Fresh and Mechanical Properties of Crimpled Steel Fibers in Self Compacting Concrete. J. Polym. Compos. 2023, 11, S65–S75
7. KanthCh, L., Kumar, P.R., Chaitanya, B.K., Kumar, N.V.S., Thati, N.S.R.K., Kumar, N.S.V., Ravi, B., Rao, A.N. (2024). Prediction of mechanical and tensile properties of self-compacting concrete incorporating fly ash and waste copper slag by artificial neural network-ANN. Annales de Chimie - Science des Matériaux, Vol. 48, No. 5, pp. 655-665. https://doi.org/10.18280/acsm.480506
8. Sonali Sri Durga, C., Venkatesh, C., Priyanka, M., Krishna Chaitanya, B., Rao, B. N. M., &Rao, T. M. (2024). Synergistic effects of GGBFS addition and oven drying on the physical and mechanical properties of fly ash-based geopolymer aggregates. J Sustain Const Mater Technol, 9(2), 93–105.
9. Chaitanya, B.K.; Kumar, I.S. Effect of waste copper slag as a substitute in cement and concrete-a review. In IOP Conference Series: Earth and Environmental Science; IOP Publishing: Bristol, UK, 2022; Volume 982, p. 012029.
10. Krishna Chaitanya, B.; Sivakumar, I. Influence of waste copper slag on flexural strength properties of self-compacting concrete.Mater. Today Proc. 2021, 42, 671–676.
11. Venkatesh, C., Rao, T.M., Sujatha, T. et al. Synergistic integration of geopolymer coatings and concrete for enhanced corrosion protection: performance and economic assessment. J Infrastruct Preserv Resil 6, 21 (2025). https://doi.org/10.1186/s43065-025-00134-2
12. Yasumichi Koshiro, Kenichi Ichise,Application of entire concrete waste reuse model to produce recycled aggregate class H,Construction and Building Materials,Volume 67, Part C2014,Pages 308-314,ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2014.05.072
13. Si-Min Jian, Bo Wu,Compressive behavior of compound concrete containing demolished concrete lumps and recycled aggregate concrete,Construction and Building Materials,Volume 272,2021, 121624,ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2020.121624
14. B. González-Fonteboa and F. Martínez-Abella,“Concretes with aggregates from demolition waste and silica fume: Materials and mechanical properties,” *Building and Environment*, vol. 43, no. 4, pp. 429–437, Apr. 2008. https://doi.org/10.1016/j.buildenv.2007.01.008
15. Davood Mostofinejad, Seyed Mohammad Hosseini, Farzaneh Nosouhian, Togay Ozbakkaloglu, Bahareh Nader Tehrani,Durability of concrete containing recycled concrete coarse and fine aggregates and milled waste glass in magnesium sulfate environment,Journal of Building Engineering,Volume 29,2020,101182,ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2020.101182
16. J. V. M. Raman and V. Ramasamy, “Properties of concrete with dissimilar treated recycled coarse aggregate,” *Journal of Building Pathology and Rehabilitation*, vol. 9, no. 1, Apr. 2024.: https://doi.org/10.1007/s41024-024-00402-w
17. R.V. Silva, J. de Brito, R.K. Dhir, Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production, Construction and Building Materials, Volume 65, 2014, Pages 201-217, ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2014.04.117.

18. Amor Ben Fraj and Rafik Idir,"Concrete based on recycled aggregates – Recycling and environmental analysis: A case study of Paris' region,"*Construction and Building Materials*, vol. 157, pp. 952–964, 2017. https://doi.org/10.1016/j.conbuildmat.2017.09.059
19. Y. Yao and B. Hong,"Evolution of recycled concrete research: a data-driven scientometric review,"*Low-Carbon Materials and Green Construction*, vol. 2, art. 16, 2024, https://doi.org/10.1007/s44242-024-00047-5