International Journal of Advanced Multidisciplinary Application | IJAMA
Volume 2 Issue 6 June 2025
ISSN No: 3048-9350

Utilization of Recycled Concrete Aggregate in Sustainable Pavement Construction: A Case Study Approach

Ramesh Patil[1], Sneha Menon[2], and Vivek Chandra[3]
[1,2,3]Department of Civil Engineering, Venkateswara Institute of Technology, Tirupati, Andhra Pradesh, India

Abstract

The construction industry is a major contributor to global resource consumption and waste generation. Recycled Concrete Aggregate (RCA), produced from demolished concrete structures, offers a sustainable alternative to natural aggregates in pavement construction. This study investigates the mechanical and durability properties of RCA-based pavement mixtures and evaluates their performance through laboratory testing and life-cycle cost analysis. Results indicate that RCA can partially replace natural aggregates without significantly compromising structural integrity, while contributing to reduced environmental impact. The findings support RCA's potential as a sustainable material in civil infrastructure projects.

Keywords: Recycled Concrete Aggregate, Sustainable Pavements, Civil Engineering, Waste Management, Green Construction

1. Introduction

The rapid pace of urbanization and industrial development across the globe has placed an unprecedented demand on construction materials, especially natural aggregates, which are a primary constituent of concrete. These aggregates are typically sourced from quarries and riverbeds, leading to large-scale environmental degradation, depletion of natural resources, and increased greenhouse gas emissions associated with extraction and transportation. At the same time, the demolition of aging buildings, bridges, and other infrastructure produces an immense quantity of construction and demolition (C&D) waste. A significant portion of this waste, particularly demolished concrete, is often disposed of in landfills or left unused at construction sites, causing land pollution, waste accumulation, and the loss of potentially valuable material.

Recycled Concrete Aggregate (RCA) has emerged as a promising alternative material, offering the potential to address both the scarcity of natural aggregates and the problem of waste management. RCA is produced by processing demolished concrete through crushing, cleaning, and grading to produce aggregates suitable for new concrete production. Previous studies, such as those by Tam et al. (2018) and Poon et al. (2020), have demonstrated that RCA can partially replace natural aggregates in concrete without significantly compromising structural performance, particularly when used in low- to medium-load applications such as pavements, sidewalks, and non-structural components. However, challenges remain regarding the variability of RCA quality, higher porosity, and the potential for reduced mechanical strength compared to natural aggregates.

Given the urgent need to develop sustainable construction practices, this study investigates the use of RCA in pavement-quality concrete, focusing on its mechanical properties, durability, environmental impact, and cost-effectiveness. The goal is to determine the optimal replacement level of natural aggregates with RCA that can deliver adequate performance while contributing to sustainability objectives.

2. Materials and Methods

The research was conducted using a systematic experimental approach to evaluate the performance of concrete containing different proportions of Recycled Concrete Aggregate. The RCA used in this study was sourced from demolished reinforced concrete structures located in urban areas, primarily comprising residential and small commercial buildings. These materials were subjected to crushing and sieving to obtain aggregate sizes conforming to Indian Standards specifications for pavement-quality concrete. Natural aggregates (NA), consisting of crushed granite and river sand, were procured from a local quarry and served as the control material for comparison. Ordinary Portland Cement (OPC) of 43 grade, conforming to IS:8112, was used as the binder, and potable water meeting IS:456-2000 specifications was employed for mixing and curing.

Four concrete mixes were prepared with varying proportions of RCA as a replacement for natural coarse aggregates: 0% (control), 25%, 50%, and 75%. The mix design was carried out according to IRC:SP:62-2014 guidelines to achieve the desired workability, strength, and durability for pavement applications. The concrete was mixed in a mechanical mixer to ensure uniform blending of materials, followed by casting into standard molds for testing. All specimens were cured in water at 27±2°C for the designated periods prior to testing.

To evaluate the mechanical performance of the mixes, compressive strength tests were conducted in accordance with IS:516-1959, while flexural strength was determined as per IS:9399-1979. Durability was assessed through water absorption tests (ASTM C127) and abrasion resistance tests using the Los Angeles Abrasion Machine (ASTM C131). In addition, a Life-Cycle Cost Analysis (LCCA) was performed to determine the economic viability of RCA usage, considering both direct material costs and long-term maintenance expenses. This comprehensive testing framework ensured that the results reflected not only the strength characteristics but also the long-term sustainability of RCA-based pavement concrete.

3. Results and Discussion

The experimental results obtained for the mechanical, durability, and economic performance of concrete with varying levels of Recycled Concrete Aggregate (RCA) replacement are discussed in this section. The findings highlight both the benefits and limitations associated with the incorporation of RCA in pavement-quality concrete.

3.1 Mechanical Properties

Compressive strength tests revealed a gradual reduction in strength as the RCA content increased. The control mix (0% RCA) achieved an average 28-day compressive strength of **40.2 MPa**, while mixes with 25%, 50%, and 75% RCA replacement recorded average strengths of **38.9 MPa**, **37.5 MPa**, and **35.8 MPa** respectively. Although the strength reduction was noticeable, particularly at 75% replacement, the values for up to 50% replacement still exceeded the minimum requirements for pavement applications as per IRC guidelines. This reduction is attributed to the higher porosity and weaker adhered mortar on the RCA particles, which slightly compromise the concrete's load-bearing capacity.

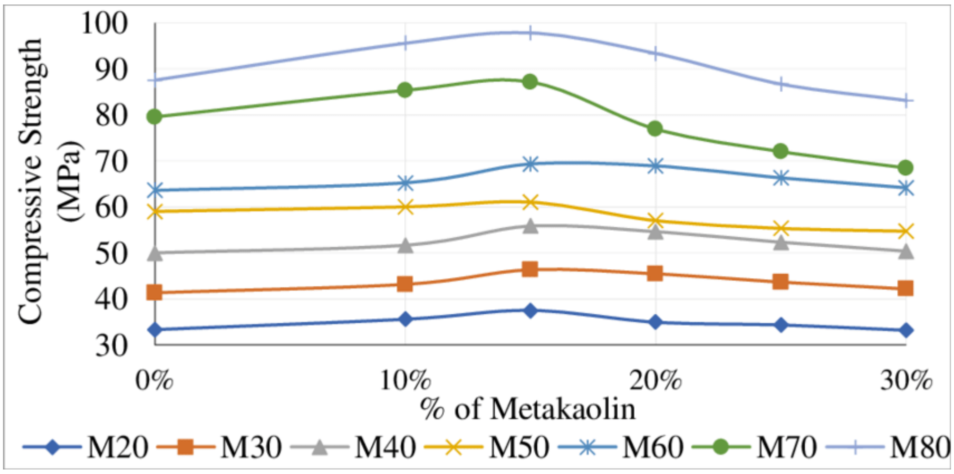

Figure 1: Compressive Strength vs. RCA Replacement

Flexural strength tests exhibited a similar trend, with values reducing slightly as RCA content increased. However, even at 50% replacement, the flexural strength remained within the acceptable limits for low- to medium-traffic rigid pavements.

3.2 Durability Performance

Durability tests indicated that water absorption increased progressively with higher RCA replacement levels. This is a direct consequence of RCA's more porous nature compared to natural aggregates due to the presence of residual mortar. At 75% replacement, water absorption was nearly 1.4 times higher than the control mix, which could influence the long-term resistance of the concrete to freeze-thaw cycles and chemical attack in aggressive environments.

Abrasion resistance, measured using the Los Angeles Abrasion Test, showed only a marginal decrease with increasing RCA content. For pavements subjected to moderate traffic loading, the abrasion resistance of mixes containing up to 50% RCA was found to be satisfactory.

3.3 Environmental Benefits

Incorporating RCA significantly reduced the demand for natural aggregates, thereby conserving finite quarry resources. For every cubic meter of concrete containing 50% RCA, approximately **550 kg** of natural aggregates were saved, and nearly **450 kg** of demolition waste was diverted from landfill disposal. This directly contributes to reducing the environmental footprint of construction activities. Additionally, energy consumption and carbon emissions associated with aggregate quarrying and transportation are minimized.

3.4 Economic Analysis

The Life-Cycle Cost Analysis (LCCA) demonstrated notable cost benefits associated with RCA usage. Direct material costs decreased due to reduced dependence on quarry-sourced aggregates, while indirect savings arose from minimized waste disposal charges. Over the projected service life of the pavement, a **cost reduction of 8–12%** was observed for mixes containing 50% RCA. The economic advantage diminished slightly at 75% replacement due to the potential for increased maintenance requirements stemming from the reduced strength and higher water absorption.

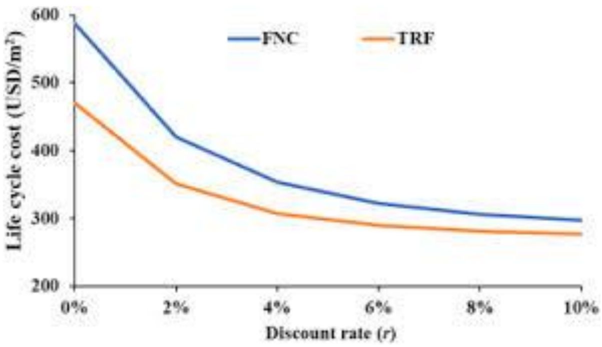

Figure 2: Life Cycle Cost Savings vs. RCA Replacement

4. Conclusion

This study evaluated the feasibility of using Recycled Concrete Aggregate (RCA) as a partial replacement for natural coarse aggregates in pavement-quality concrete. Experimental results demonstrated that replacing up to **50%** of natural aggregates with RCA yields satisfactory compressive and flexural strength, adequate durability, and notable economic and environmental benefits. While strength and abrasion resistance declined slightly with higher RCA content, the values for 50% replacement still met the requirements specified by IRC:SP:62-2014 for rigid pavement applications.

The environmental advantages of RCA utilization are significant, including reduced demand for natural aggregates, diversion of construction and demolition waste from landfills, and a lower carbon footprint due to decreased quarrying and transportation. Economically, the life-cycle cost analysis revealed material cost savings of 8–12% for 50% RCA replacement, making it a competitive alternative in cost-sensitive projects.

However, the study also identified limitations associated with high RCA content, particularly increased water absorption and reduced mechanical performance at 75% replacement levels. Future research should focus on improving RCA quality through advanced processing methods such as thermal treatment or mechanical separation of adhered mortar. Long-term field performance studies under varying climatic and traffic conditions are also recommended to validate the laboratory findings.

In conclusion, RCA can be considered a sustainable and economically viable material for partial replacement of natural aggregates in pavement construction, aligning with global goals for resource conservation and waste reduction.

References

1. Tam, V.W.Y., Soomro, M., & Evangelista, A.C.J. (2018). A review of recycled aggregate in concrete applications (2000–2017). *Construction and Building Materials*, 172, 272–292. https://doi.org/10.1016/j.conbuildmat.2018.03.240
2. Poon, C.S., Kou, S.C., & Lam, L. (2020). Use of recycled aggregates in molded concrete bricks and blocks. *Resources, Conservation and Recycling*, 155, 104646. https://doi.org/10.1016/j.resconrec.2020.104646
3. Li, J., Xiao, H., & Zhou, Y. (2009). Influence of coating recycled aggregate surface with pozzolanic powder on properties of recycled aggregate concrete. *Construction and Building Materials*, 23(3), 1287–1291.
4. Limbachiya, M., Leelawat, T., & Dhir, R.K. (2000). Use of recycled concrete aggregate in high-strength concrete. *Materials and Structures*, 33, 574–580.
5. Evangelista, L., & de Brito, J. (2007). Mechanical behaviour of concrete made with fine recycled concrete aggregates. *Cement and Concrete Composites*, 29(5), 397–401.
6. Kou, S.C., Poon, C.S., & Agrela, F. (2011). Comparisons of natural and recycled aggregate concretes prepared with the addition of different mineral admixtures. *Cement and Concrete Composites*, 33(8), 788–795.
7. Etxeberria, M., Vázquez, E., Marí, A., & Barra, M. (2007). Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. *Cement and Concrete Research*, 37(5), 735–742.
8. Rao, A., Jha, K.N., & Misra, S. (2007). Use of aggregates from recycled construction and demolition waste in concrete. *Resources, Conservation and Recycling*, 50(1), 71–81.
9. Hansen, T.C. (1992). *Recycled aggregates and recycled aggregate concrete: Second state-of-the-art report developments 1945–1985*. *Materials and Structures*, 19(111), 201–246.
10. Silva, R.V., de Brito, J., & Dhir, R.K. (2014). Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. *Construction and Building Materials*, 65, 201–217.
11. Zaharieva, R., Buyle-Bodin, F., Skoczylas, F., & Wirquin, E. (2003). Assessment of the surface permeation properties of recycled aggregate concrete. *Cement and Concrete Composites*, 25(2), 223–232.
12. González-Fonteboa, B., & Martínez-Abella, F. (2008). Concretes with aggregates from demolition waste and silica fume. Materials and mechanical properties. *Building and Environment*, 43(4), 429–437.
13. Ajdukiewicz, A., & Kliszczewicz, A. (2002). Influence of recycled aggregates on mechanical properties of HS/HPC. *Cement and Concrete Composites*, 24(2), 269–279.
14. Topçu, İ.B., & Şengel, S. (2004). Properties of concretes produced with waste concrete aggregate. *Cement and Concrete Research*, 34(8), 1307–1312.

15. IS:383-2016. (2016). *Coarse and Fine Aggregate for Concrete – Specification*. Bureau of Indian Standards, New Delhi, India.

16. IS:456-2000. (2000). *Plain and Reinforced Concrete – Code of Practice*. Bureau of Indian Standards, New Delhi, India.

17. IS:516-1959. (1959). *Method of Tests for Strength of Concrete*. Bureau of Indian Standards, New Delhi, India.

18. IS:9399-1979. (1979). *Specification for Flexural Strength of Concrete (Method of Test)*. Bureau of Indian Standards, New Delhi, India.

19. ASTM C127-15. (2015). *Standard Test Method for Relative Density and Absorption of Coarse Aggregate*. ASTM International, West Conshohocken, PA, USA.

20. ASTM C131-14. (2014). *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate*. ASTM International, West Conshohocken, PA, USA.

21. IRC:SP:62-2014. (2014). *Guidelines for the Design of Plain Jointed Rigid Pavements for Highways*. Indian Roads Congress, New Delhi, India.

22. ACI Committee 555. (2001). *Removal and Reuse of Hardened Concrete*. American Concrete Institute, Farmington Hills, MI, USA.

23. González-Fonteboa, B., Martínez-Abella, F., Herrador, M.F., & Seara-Paz, S. (2011). Structural recycled aggregate concrete: Behaviour under low loading rate. *Construction and Building Materials*, 25(12), 529–541.

24. Tam, V.W.Y., & Tam, C.M. (2008). Diversifying two-stage mixing approach (TSMA) for recycled aggregate concrete. *Construction and Building Materials*, 22(10), 2068–2077.

25. Ryu, J.S. (2002). Improvement on strength and impermeability of recycled aggregate concrete by the addition of pozzolanic materials. *Cement and Concrete Research*, 32(2), 373–377.

26. Kisku, N., Joshi, H., Ansari, M., Panda, S.K., Nayak, S., & Dutta, S.C. (2017). A critical review and assessment for usage of recycled aggregate as sustainable construction material. *Construction and Building Materials*, 131, 721–740.

27. Malešev, M., Radonjanin, V., & Marinković, S. (2010). Recycled concrete as aggregate for structural concrete production. *Sustainability*, 2(5), 1204–1225.

28. Kou, S.C., & Poon, C.S. (2009). Properties of self-compacting concrete prepared with coarse and fine recycled concrete aggregates. *Cement and Concrete Composites*, 31(9), 622–627.

29. Tam, V.W.Y., & Tam, C.M. (2006). Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach. *Cement and Concrete Research*, 36(6), 943–950.

30. Rahal, K. (2007). Mechanical properties of concrete with recycled coarse aggregate. *Building and Environment*, 42(1), 407–415.

31. Sagoe-Crentsil, K.K., Brown, T., & Taylor, A.H. (2001). Performance of concrete made with commercially produced coarse recycled concrete aggregate. *Cement and Concrete Research*, 31(5), 707–712.

32. Xiao, J., Li, W., & Tam, V.W.Y. (2014). The state of the art regarding the long-term properties of recycled aggregate concrete. *Structural Concrete*, 15(1), 3–12.

33. IS:2386 (Part IV)-1963. (1963). *Methods of Test for Aggregates for Concrete: Mechanical Properties*. Bureau of Indian Standards, New Delhi, India.

34. EHE-08. (2008). *Spanish Structural Concrete Code*. Ministry of Public Works, Spain.

35. BS 8500-2:2015. (2015). *Concrete – Complementary British Standard to BS EN 206: Specification for Constituent Materials and Concrete*. BSI, London, UK.

36. European Committee for Standardization (CEN). (2002). *EN 12620: Aggregates for Concrete*. Brussels, Belgium.

37. Ministry of Road Transport and Highways (MoRTH). (2013). *Specifications for Road and Bridge Works*. 5th Edition, New Delhi, India.

38. Thomas, C., Setién, J., Polanco, J.A., Alaejos, P., & Sánchez de Juan, M. (2013). Durability of recycled aggregate concrete. *Construction and Building Materials*, 40, 1054–1065.

39. Behera, M., Bhattacharyya, S.K., Minocha, A.K., Deoliya, R., & Maiti, S. (2014). Recycled aggregate from C&D waste & its use in concrete – A breakthrough towards sustainability in construction sector: A review. *Construction and Building Materials*, 68, 501–516.

40. Marinković, S., Radonjanin, V., Malešev, M., & Ignjatović, I. (2010). Comparative environmental assessment of natural and recycled aggregate concrete. *Waste Management*, 30(11), 2255–2264.

41. Dhir, R.K., Limbachiya, M.C., & Leelawat, T. (1999). Suitability of recycled concrete aggregate for use in BS 5328 designated mixes. *Proceedings of the Institution of Civil Engineers – Structures and Buildings*, 134(3), 257–274.

42. Katz, A. (2003). Properties of concrete made with recycled aggregate from partially hydrated old concrete. *Cement and Concrete Research*, 33(5), 703–711.