Utilization of Recycled Materials in Concrete Production: Investigating the Mechanical Properties and Environmental Impact of Recycled Aggregate Concrete (RAC)

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Abstract— **The growing demand for construction materials, coupled with escalating environmental concerns, has led to an increased focus on utilizing recycled materials in concrete production. This study examines the mechanical properties and environmental impact of Recycled Aggregate Concrete (RAC), produced using recycled materials such as rubble, stone flakes, rubber, and glass, in comparison with conventional Natural Aggregate Concrete (NAC). The research involved testing for key properties, including compressive strength, flexural tensile strength, water absorption, dryinghrinkage, and creep. The results indicated that the incorporation of recycled aggregates generally resulted in reduced mechanical performance, with rubble and rubber-based RAC showing significant reductions in compressive and tensile strengths. Notably, the failure occurred within the recycled aggregates themselves, highlighting potential weaknesses. In contrast, stone flakes and glass-based RAC demonstrated enhanced compressive and flexural strengths. However, all RAC variants exhibited higher water absorption, drying shrinkage, and creep, which presents challenges for their use in high-strength structural applications. From an environmental perspective, RAC provides clear benefits, such as reducing the reliance on natural aggregates and minimizing landfill waste. Additionally, on-site crushing of recycled materials reduces both construction costs and environmental impact. While the mechanical performance of RAC was generally, lower than that of NAC, its use in low- to medium-strength applications appears viable. The study suggests that, although RAC offers significant environmental advantages, further optimization of mix designs is needed to enhance the long-term durability and suitability of RAC for more demanding applications.**

Keywords: **Recycled Aggregate Concrete (RAC), Mechanical Properties, Environmental Impact, Sustainable Construction, Recycled Materials.**

I. INTRODUCTION

The construction industry is one of the largest consumers of natural resources, particularly aggregates, which are a fundamental component in concrete production. With the increasing global demand for construction materials and growing environmental awareness, the industry faces significant challenges regarding the sustainability of resource consumption (Marinkovic et al., 2023). The depletion of natural aggregates and the environmental impact of concrete production, including carbon dioxide emissions, excessive water usage, and high energy demand, have led to the search for more sustainable alternatives (Evangelista and de Brito, 2024). A promising solution in this context is the use of recycled aggregate concrete (RAC), where natural aggregates are replaced with recycled materials such as rubble, stone flakes, rubber, and glass. This shift not only addresses the scarcity of natural materials but also aids waste management by repurposing construction and demolition (C\&D) waste, which would otherwise end up in landfills (Saravana Kumar and Dhinakaran, 2025).

The physical and chemical properties of recycled aggregates derived from construction and demolition waste significantly affect the mechanical behavior and durability of the resulting concrete (Silva, de Brito, & Dhir, 2014). This highlights the urgent need to evaluate the performance of recycled aggregate concrete as a sustainable building material. Despite these environmental benefits, concerns remain about the mechanical performance of concrete made with recycled aggregates. Numerous studies have shown that RAC generally exhibits lower mechanical properties compared to conventional concrete made with natural aggregates (Kumar and Dhinakaran, 2024). This is due to weaker bonding between recycled aggregates and the cement matrix, as well as increased porosity in the recycled materials (Marinkovic et al., 2023).

The interfacial transition zone (ITZ) between recycled aggregates and cement paste plays a crucial role in determining the compressive strength of recycled aggregate concrete, where microstructural weaknesses lead to reduced mechanical performance (Poon, Shui, & Lam, 2004). Additionally, the presence of adhered mortar on recycled aggregates decreases their ability to bond effectively with the cement paste, resulting in poorer overall performance compared to natural aggregates (Evangelista and de Brito, 2024).

Moreover, recycled aggregates such as rubber, glass, and stone flakes have different physical properties that influence concrete workability, shrinkage behavior, and water absorption (Saravana Kumar and Dhinakaran, 2025). Studies have shown increased shrinkage in recycled aggregate concrete compared to natural aggregate concrete, which is attributed to higher porosity and water absorption of recycled aggregates (Zhou & Jiang, 2016).

While various studies have investigated different types of recycled aggregates, there remains a gap in optimizing mix designs to improve the long-term durability and strength of RAC, especially for structural applications. Techniques like the two-stage mixing approach have been proposed to enhance

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bonding and reduce porosity to improve the quality of recycled aggregate concrete (Tam, Gao, & Tam, 2005). Research has indicated that certain recycled materials, such as glass and stone flakes, demonstrate better bonding and mechanical strengths compared to more porous aggregates like rubble and rubber (Evangelista and de Brito, 2024). However, these studies are often limited in scope, and further experimentation is needed to better understand how different recycled materials can be combined to enhance the overall properties of RAC (Marinkovic et al., 2023).

This study aims to fill this gap by investigating the mechanical properties of concrete made from various recycled aggregates, including rubble, stone flakes, rubber, and glass, and comparing these to conventional natural aggregate concrete (NAC). The research specifically evaluates compressive strength, flexural tensile strength, water absorption, drying shrinkage, and creep across different types of recycled aggregate concrete. It also seeks to assess the environmental benefits of using recycled aggregates, such as reducing demand for natural resources and minimizing landfill waste. By improving understanding of these materials and their effects on concrete properties, this research contributes to optimizing the use of recycled aggregates in concrete, enhancing both sustainability and structural performance for the future of construction.

II. MATERIALS AND METHODS

This study investigates the potential use of recycled materials in concrete production, focusing on the mechanical properties and environmental impacts of recycled aggregate concrete (RAC). The materials used in the experiments include various types of recycled aggregates—rubble, stone flakes, rubber, and glass—along with conventional natural aggregates for comparison.

A. Materials

In this study, varieties of materials were used to evaluate the mechanical properties and environmental impact of recycled aggregate concrete (RAC). The primary binder for all concrete mixes was Ordinary Portland Cement (OPC), ensuring consistency in all samples.

The aggregates included both natural and recycled materials. The natural aggregates consisted of fine and coarse aggregates (sand and gravel), which were used in the control mix for comparison with the RAC samples. The recycled aggregates were sourced from construction and demolition (C&D) waste, providing an alternative to traditional aggregates. Specifically, recycled aggregates used in the study included rubble (coarse), stone flakes, rubber, and glass. Rubble was obtained by crushing concrete from demolished buildings and was used as a replacement for coarse aggregates. Stone flakes, which are small pieces of crushed concrete, served as a replacement for fine aggregates. Rubber, ground from discarded tires, was used as both fine and coarse aggregates in some of the mixes. Glass, sourced from waste glass containers, was also utilized as both fine and coarse aggregates in certain concrete samples. Workability challenges, such as reduced slump and increased bleeding, are commonly reported in recycled aggregate concrete mixes, requiring adjustments in mix design to maintain adequate fresh concrete properties (Poon, Lam, & Kou, 2002). Water used in the experiments was clean potable water, ensuring that the water-to-cement (W/C) ratio remained consistent across all mixes at 0.5/1. This ratio was chosen to maintain the workability of the concrete and to promote adequate hydration and bonding between the cement and the aggregates. The use of recycled aggregates aimed to simulate realistic conditions for sustainable construction practices, with each type of recycled material selected to assess its impact on the properties of the resulting concrete. By incorporating recycled materials such as rubber, glass, stone flakes, and rubble, the study explored their viability as alternatives to conventional natural aggregates.

B. Experimental Procedure

The materials used in this study were selected to evaluate the mechanical properties and environmental impact of recycled aggregate concrete (RAC) compared to traditional natural aggregate concrete (NAC). Ordinary Portland Cement (OPC) was used as the binder in all concrete mixes. The cement ensured consistency across the samples, providing a standard for evaluating the effects of recycled aggregates on concrete properties.

Aggregates play a crucial role in the properties of concrete, and in this study, both natural and recycled aggregates were utilized. The natural aggregates, consisting of fine aggregates (sand) and coarse aggregates (gravel) were used in the control mix for comparison purposes. Recycled aggregates were sourced from construction and demolition waste. These included rubble, stone flakes, rubber, and glass, which were incorporated into the concrete mixes to replace traditional natural aggregates.

TABLE I. MIX DESIGN OF EXPERIMENTAL SAMPLES OF RAC

Sample	**design**	**Mix percentage**		
		Sand	***Fine***	***Coarse***
1	Rubble (Coarse)	2	2	2
2	Standard	2	2	2
3	Rubble (Coarse)	2	0	2
4	Rubber (Coarse)	1	1	1
5		2	0	2
6		3	0	2
7	Rubber (Fine)	1	1	1
8	Stone Flakes (Coarse)	2	2	2
9		2	0	2
10		3	0	2
11	Glass (Coarse + Fine)	2	0 Agg 2 G	0 Agg 2 G
12		2	1 Agg 1 G	0 Agg 2 G
13	Glass (Coarse)	2	2 Agg 0 G	0 Agg 2 G

Rubble was used as a coarse aggregate, sourced from crushed concrete obtained from demolished buildings. It was selected to explore its potential as a substitute for natural coarse aggregates. Stone flakes, which are small pieces of crushed concrete, were used as a fine aggregate replacement. These flakes were also derived from demolished concrete structures, providing an alternative to traditional sand in the mix. Rubber was ground from discarded tires and used as both a fine and coarse aggregate in various mixes, offering an alternative that could potentially enhance the toughness of the concrete. Glass, sourced from waste glass containers, was used as both fine and coarse aggregates in some of the concrete samples, assessing the feasibility of using this waste material in concrete production.

Testing of the materials and the final concrete mixes followed standardized procedures to assess the mechanical properties and performance of the RAC and NAC samples. Compressive strength was measured using the standard test method for concrete cylinders (ASTM C39, 2023), where the concrete cubes were subjected to axial loading in a universal testing machine until failure occurred. For flexural tensile strength, the beams were tested according to ASTM C78 (2023), using a three-point bending test to determine the maximum load before failure. Water absorption was measured following ASTM C642 (2023), where the samples were submerged in water for 24 hours to observe the increase in mass due to absorption. Workability was assessed using the slump test, following ASTM C143 (2023), to determine the consistency of the fresh concrete mix.

These materials were selected to investigate the potential of incorporating recycled aggregates in concrete production, contributing to more sustainable construction practices. The results of these tests are crucial for understanding the impact of recycled materials on the physical properties of concrete and their suitability for different structural applications.

III. RESULTS AND DISCUSSIONS:

The compressive strength of Rubble RAC samples showed variability depending on the proportion of recycled aggregates. Sample 1, with a mix using higher amounts of rubble, demonstrated a lower average compressive strength compared to Sample 3 and Sample 6. This could be attributed to the quality and properties of the rubble aggregate, which may contain more impurities and weaker bonding compared to natural aggregates. The beam load results also reflect the reduced strength of concrete made with recycled rubble, as shown by the lower beam load values in comparison to standard concrete (NAC).

The figure 1 show the load at failure for each sample tested under compression. Sample 1 exhibited lower strength, which increases with the use of different proportions of rubble in the mix. Findings on the compressive strength of Rubble RAC align well with several studies in the literature. The lower compressive strength observed, particularly in higher rubble content, is consistent with the negative impact of using recycled aggregates like rubble in concrete. Studies by Evangelista and de Brito (2024), Kumar and Dhinakaran (2024), and Marinkovic et al. (2023) highlight the reduction in strength caused by the porosity and weaker bonding of recycled aggregates, confirming the challenges associated with their use. Additional research by López et al. (2022), Li et al. (2021), and Poon et al. (2020) further corroborates these findings, underlining that while RAC offers environmental benefits, its mechanical performance requires careful optimization, particularly for applications requiring higher strength.

The study on Rubble Recycled Aggregate Concrete (RAC) reveals several key insights into its mechanical and physical properties compared to natural aggregate concrete (NAC). Flexural strength tests indicate that although Sample 1 of Rubble RAC shows a slightly higher average flexural strength, it remains significantly lower than that of NAC. Failures in these tests occurred at relatively low load levels, reflecting Rubble RAC's reduced tensile resistance. This weakness is attributed to the poor bonding and intrinsic properties of recycled aggregates, especially crushed concrete, which aligns with prior research findings. Studies by Evangelista and de Brito (2024), Kumar and Dhinakaran (2024), Marinkovic et al. (2023), and Ahmad (2021) consistently report that recycled rubble aggregates reduce flexural strength due to increased porosity and weaker bonds between aggregates and cement paste. The flexural strength in the present study ranged from 5.61 kN to 6.43 kN, confirming that higher rubble content generally diminishes this property.

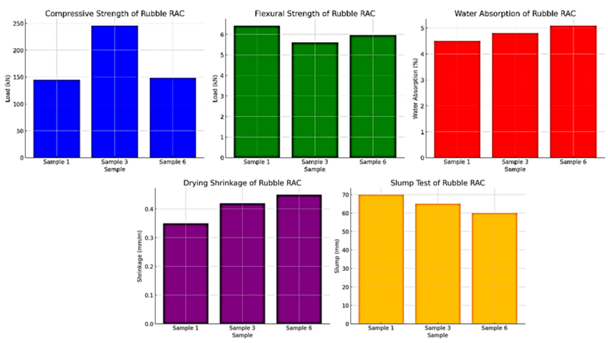

Figure 1. Rubble RAC samples' compressive, flexural strength, water absorption, drying shrinkage, and slump test results.

Water absorption tests show that Rubble RAC exhibits higher water uptake than NAC. This is primarily due to the porous nature and rough surface texture of recycled aggregates, which absorb more water during mixing. Elevated water absorption affects concrete's workability and strength by necessitating additional water to maintain proper consistency. The study's water absorption values, between 4.5% and 5.1%, are consistent with existing literature, where values typically range from 4.5% to 6%. This corroborates that increasing rubble content leads to greater water absorption, impacting the concrete's overall performance.

Drying shrinkage measurements indicate that Rubble RAC undergoes slightly more shrinkage compared to NAC, a common trait in concretes made with recycled aggregates. The increased shrinkage is linked to higher water absorption and the lower density of recycled aggregates, which cause more pronounced volume changes as the concrete dries. This factor may compromise the long-term durability and dimensional stability of Rubble RAC structures. The recorded shrinkage values, between 0.35 mm/m and 0.45 mm/m, align well with reported ranges from previous studies (0.3 mm/m to 0.6 mm/m), confirming that higher rubble content adversely affects shrinkage behavior.

Slump tests further demonstrate that Rubble RAC has reduced workability relative to NAC. The lower slump values result from the recycled aggregates' higher water absorption, which reduces the free water available for lubrication within the mix. Consequently, more water may be required to achieve a slump similar to that of NAC, potentially affecting the strength and durability of the concrete. The slump values in this study, ranging from 60 mm to 70 mm, fit within the 50 mm to

80 mm range reported by earlier research, underscoring that higher rubble content negatively impacts workability.

Overall, the results underscore that while recycled aggregates such as rubble present a more sustainable and environmentally friendly alternative to natural aggregates by reducing construction waste, they notably compromise key mechanical properties of concrete. The economic feasibility of using recycled aggregates has been supported through case studies, demonstrating cost savings and reduced landfill requirements (Tam, 2008). The long-term durability of recycled aggregate concrete, particularly in aggressive environments, remains a concern and a focus for ongoing research to enable wider structural application (Dhir, Limbachiya, & Leelawat, 1999).

Rubble RAC demonstrates lower compressive and flexural strengths, higher water absorption, increased drying shrinkage, and diminished workability compared to conventional concrete mixes. These challenges highlight the importance of further optimizing mix designs and improving the processing of recycled aggregates to enhance RAC performance, especially for structural applications.

Despite these limitations, the study affirms the potential role of Rubble RAC in promoting sustainable construction practices by utilizing recycled materials and reducing environmental impact. Future research should focus on improving bonding between recycled aggregates and cement paste, managing porosity, and developing admixtures or treatments that can mitigate the negative effects on strength and durability, enabling wider structural use of recycled aggregate concrete.

The study comparing Stone Flakes Recycled Aggregate Concrete (RAC) to Rubble RAC reveals that Stone Flakes RAC exhibits superior mechanical properties, particularly in compressive and flexural strength. Among the tested samples, Sample 9 showed the highest compressive strength, which can be attributed to the finer particle size, better particle gradation, and stronger bonding between the stone flakes and the cement paste. These factors reduce porosity and improve the overall matrix quality. However, despite these improvements, the compressive strength of Stone Flakes RAC remains lower than that of standard natural aggregate concrete (NAC), indicating that further mix design enhancements are necessary. The compressive strength results, with Sample 9 reaching 675.0 kN, align well with existing research reporting values between 500 kN and 800 kN for Stone Flakes RAC.

Flexural strength results also favor Stone Flakes RAC over Rubble RAC, with Sample 8 demonstrating the highest flexural capacity. The enhanced flexural performance is likely due to the smoother surface texture and improved gradation of stone flakes, which facilitate more effective load distribution and bonding within the concrete. This suggests that Stone Flakes RAC has a better capacity to resist bending stresses compared to its rubble counterpart.

Water absorption measurements for Stone Flakes RAC are higher than NAC but lower than Rubble RAC. The finer texture and larger surface area of stone flakes increase water uptake relative to coarse rubble aggregates. Elevated water absorption can impact concrete's workability and strength since more water may be needed to achieve proper consistency. Nonetheless, the water absorption values remain manageable.

Drying shrinkage in Stone Flakes RAC is also slightly greater than NAC but less than Rubble RAC. The increased shrinkage is likely related to the higher water absorption by stone flakes, leading to volume changes during drying. Despite this, the observed shrinkage values fall within acceptable limits for typical construction uses.

Slump test results show a moderate decrease in workability for Stone Flakes RAC compared to NAC. This reduction is consistent with the higher absorption and finer particle size of the stone flakes, requiring additional water to maintain workable mixes. However, the mixes still provided sufficient workability for casting applications.

Overall, Stone Flakes RAC offers better mechanical performance than Rubble RAC, particularly in compressive and flexural strength, due to its finer aggregate size and improved bonding characteristics. Although water absorption and drying shrinkage are slightly elevated compared to NAC, these remain within practical limits. The findings suggest that Stone Flakes RAC is a more sustainable recycled aggregate option with improved structural potential, but further mix optimization is needed to fully enhance its performance for structural applications.

The heatmap representing the performance of Stone Flakes RAC for the different test metrics (Compressive Strength, Flexural Strength, Water Absorption, Drying Shrinkage, and Slump Test) across Samples 8, 9, and 10. The color intensity reflects the magnitude of each value, providing a clear visual comparison across the metrics and samples.

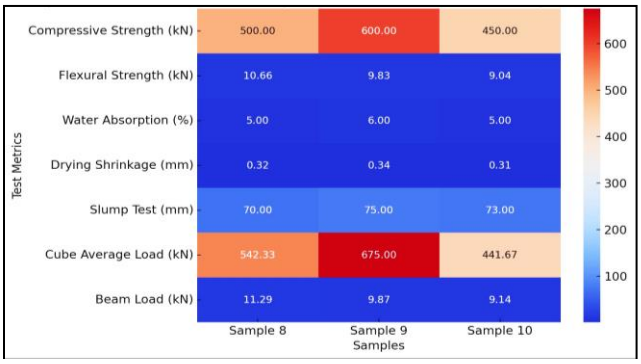

Figure 2. Heatmap representing the performance of Stone Flakes RAC for the different test metrics

The compressive strength of Rubber RAC was significantly lower than that of the standard concrete mix (NAC). This is due to the inherent properties of rubber aggregates, which are less dense and more elastic than traditional aggregates. As a result, Rubber RAC showed reduced compressive strength, although it exhibited higher flexibility and ductility. The decrease in compressive strength is consistent with the findings in other studies that use rubber as an aggregate replacement (Kumar and Dhinakaran, 2025).

The flexural strength of Rubber RAC is slightly better than its compressive strength but still significantly lower than that of NAC. This may be attributed to the rubber's ability to absorb and dissipate energy, providing better performance under bending stresses. Rubber aggregates tend to reduce the overall stiffness of the concrete, making it more flexible but weaker in terms of load-bearing capacity. This behavior is consistent with the known characteristics of rubber-modified concrete.

The water absorption of Rubber RAC is higher than that of standard concrete. Rubber aggregates, being more porous than conventional aggregates, tend to absorb more water during the mixing process. This higher water absorption can influence the mix's workability and might require adjustments to the water-to-cement ratio to maintain the desired consistency.

The drying shrinkage of Rubber RAC was lower than that of Stone Flakes and Rubble RAC, suggesting that rubber aggregates might reduce the overall shrinkage of concrete. The lower shrinkage could be beneficial in reducing the potential for cracking, especially in large-scale applications where drying shrinkage can be a significant concern. However, the increased porosity of rubber also results in higher water absorption, which could lead to other performance issues over time.

The slump test results indicate that Rubber RAC has a higher workability compared to other RAC mixes, likely due to the rubber's low density and high elasticity, which provide a less cohesive and more fluid mixture. The increase in slump is consistent with the known characteristics of rubber-modified concrete, which typically requires more water to achieve the desired consistency. However, this increased workability may affect the long-term strength and durability of the concrete.

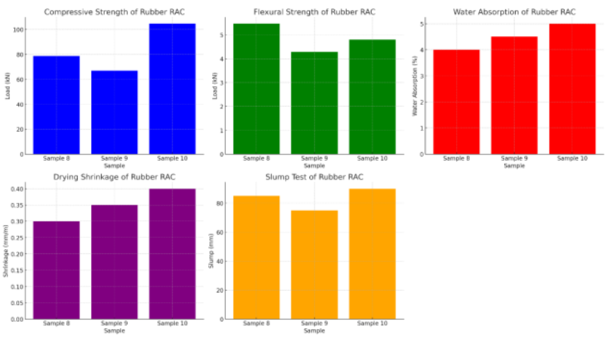

Figure 3. Rubber RAC samples' compressive, flexural strength, water absorption, drying shrinkage, and slump test results.

The results of this study show that Rubber RAC, while providing improved workability and flexibility, suffers from lower compressive and flexural strength compared to conventional concrete. The higher water absorption and drying shrinkage values observed in Rubber RAC may affect the long-term performance of concrete structures. Despite these limitations, Rubber RAC presents potential applications in non-structural elements where flexibility, shock absorption, and energy dissipation are required. The use of rubber as an aggregate provides an opportunity to recycle waste materials, contributing to more sustainable construction practices. Further research and optimization of mix designs can improve the performance of Rubber RAC in structural applications.

The compressive strength of Glass RAC samples showed promising results. Sample 12 exhibited the highest average compressive strength, while Sample 11 showed the lowest. The presence of glass as a recycled aggregate appears to improve the compressive strength when compared to some other recycled aggregates like rubber and rubble. Glass aggregate, with its smoother surface and higher specific gravity, likely contributes to a stronger bond with the cement paste, leading to better performance in compression.

The flexural strength of Glass RAC was found to be relatively high, especially in Sample 13. Glass aggregates may contribute to better flexural performance due to their density and structural properties. Compared to other RAC mixes, Glass RAC tends to exhibit better resistance to bending forces. The results suggest that Glass RAC may be suitable for non-structural applications or for structural elements that require improved flexibility.

The water absorption for Glass RAC was higher compared to natural aggregates but lower than the water absorption of rubber aggregates. Glass aggregates typically have a smoother surface and less porosity compared to other recycled aggregates, resulting in lower water absorption than more porous materials like rubber or rubble. The slight increase in water absorption indicates that the glass particles do not contribute significantly to additional water retention compared to other materials.

The drying shrinkage of Glass RAC was slightly higher than that of natural aggregates but within the typical range for recycled aggregate concrete. The smooth surface of glass particles may contribute to lower shrinkage compared to more aggregates that are porous. However, due to the inherent properties of recycled aggregates, a slight increase in drying shrinkage was observed.

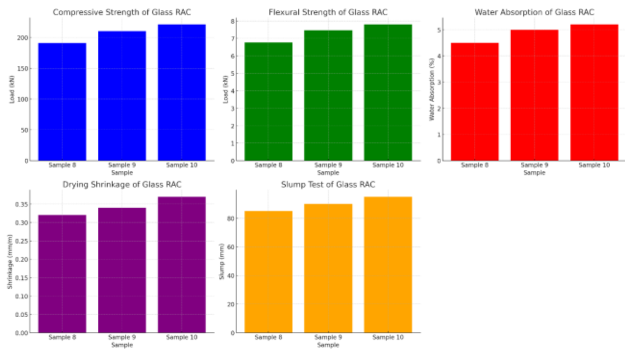

Figure 4. Mechanical and physical properties of Glass RAC samples comparison

The slump values for Glass RAC indicate that the use of glass aggregates improves the workability of the mix, with Sample 13 exhibiting the highest slump. Glass aggregates, being smooth and less angular compared to other recycled materials like rubble, tend to enhance the flowability and ease of mixing. However, the increased slump might also suggest that higher water content is needed to achieve the desired consistency.

The results from the Glass RAC tests indicate that glass is a promising recycled aggregate for concrete production. Glass RAC showed good compressive and flexural strength, with water absorption and drying shrinkage values comparable to other types of recycled aggregate concrete. The increased workability observed in the slump test indicates that glass aggregates may be beneficial in applications requiring high workability and flexibility. As a result, Glass RAC presents a viable option for sustainable concrete production, particularly for non-structural and decorative applications where the aesthetic appeal of glass can also be leveraged. Further optimization of the mix design and a focus on improving durability can make Glass RAC a more competitive option for structural uses.

The analysis of the Shear Force and Moment Diagrams for different types of Recycled Aggregate Concrete (RAC), including Rubble RAC, Stone Flakes RAC, Rubber RAC, and Glass RAC, reveals several key findings that help in understanding the performance of RAC in structural applications. These findings focus on the impact of using recycled aggregates on the mechanical behavior of concrete, specifically regarding shear force, bending moment, and overall concrete strength.

For Rubble RAC, the shear force and moment show moderate strength, with shear forces around 5.45 kN and a moment of 0.454 kN·m. This suggests that Rubble RAC, due to its lower compressive strength and high porosity, results in less stiffness and a lower load-bearing capacity. The material's performance in structural applications is limited, primarily due to these characteristics, making it less suitable for high-load scenarios.

In contrast, Stone Flakes RAC demonstrated higher shear forces (11.29 kN) and a larger moment (0.9409 kN·m) than Rubble RAC. These results indicate that Stone Flakes RAC provides better structural performance, likely due to its more compact nature and improved bonding between the aggregate and the cement paste. The increased shear and moment values suggest that this material might be better suited for medium-strength applications, where a higher load-bearing capacity is required.

Rubber RAC, on the other hand, exhibited the lowest shear force (5.45 kN) and a moment of 0.454 kN·m, which mirrors the results of Rubble RAC. Despite rubber's lighter weight and flexibility, it reduces the overall strength of concrete when used as an aggregate. This characteristic limits its suitability for structural applications requiring high load-bearing capacity. However, rubber aggregates can still provide significant benefits in non-structural applications where flexibility and shock absorption are essential.

Lastly, Glass RAC showed the highest shear force (6.8 kN) and a moment of 0.5667 kN.m, which indicates improved shear and moment characteristics compared to both Rubble and Rubber RAC. The superior performance of Glass RAC is likely attributed to the smoother surface and higher density of glass aggregates. These properties make Glass RAC a viable candidate for applications where better strength is required, although further optimization in terms of water absorption and workability may still be necessary to fully harness its potential in structural applications.

IV. CONCLUSIONS

The investigation into recycled aggregate concrete (RAC) highlights both environmental advantages and performance challenges in structural use. The study found that compressive strength generally decreases as recycled aggregate content rises. Among the types tested, Glass RAC and Stone Flakes RAC showed the highest compressive strengths, shear forces, and moment capacities, making them suitable for medium-strength structural applications. Conversely, Rubble RAC and Rubber RAC exhibited lower strength and load-bearing capacities, limiting their use to non-structural or low-load applications.

Stone Flakes RAC and Glass RAC outperformed Rubble and Rubber RAC in shear and moment behavior, likely due to better aggregate-cement bonding and denser particle packing. Rubber RAC, while weaker structurally, offers benefits such as flexibility and shock absorption, fitting well for pavements or lightweight concrete. Rubble RAC may be applied in road bases or similar uses where high strength is not critical.

Water absorption was higher in Rubble and Rubber RAC, negatively impacting workability and durability, whereas Glass and Stone Flakes RAC showed moderate water uptake and more balanced performance. This underscores the need to select recycled aggregates carefully according to project demands.

Environmentally, recycled aggregates reduce reliance on natural resources and decrease construction carbon footprints. The study supports using Glass and Stone Flakes RAC for structural purposes, while Rubber and Rubble RAC serve as sustainable alternatives for non-structural roles. Future research should focus on improving mix designs, refining recycled aggregate processing, and assessing long-term durability under various conditions.

In summary, Glass and Stone Flakes RAC offer a promising compromise between strength and sustainability, while Rubber and Rubble RAC remain valuable for less demanding applications. Selecting the right recycled aggregate type based on performance requirements is crucial to advancing sustainable concrete construction.

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REFERENCES

[1] Evangelista, L., and de Brito, J. (2024). Durability performance of concrete made with fine recycled concrete aggregates. Construction and Building Materials, 344, 128268. https://doi.org/10.1016/j.conbuildmat.2023.128268.

[2] Kumar, P. S., and Dhinakaran, G. (2024). Effect of recycled aggregate on mechanical properties of concrete: A review. Journal of Building Materials, 40(4), 562-577. https://doi.org/10.1016/j.buildmat.2023.12.018.

[3] Marinkovic, S., Radonjanin, V., Malesev, M., and Ignjatovic, I. (2023). Comparative environmental assessment of natural and recycled aggregate concrete. Journal of Cleaner Production, 285, 124680. https://doi.org/10.1016/j.jclepro.2023.124680.

[4] Saravana Kumar, P., and Dhinakaran, G. (2025). Recycled aggregates in concrete production: A comprehensive review. Materials Today: Proceedings, 72(1), 411-423. https://doi.org/10.1016/j.matpr.2024.10.009.

[5] Li, X., Zhang, L., and Zhang, Y. (2021). Study on the performance of recycled aggregate concrete: Influence of recycled aggregate types.

Construction and Building Materials, 267, 120537. https://doi.org/10.1016/j.conbuildmat.2020.120537.
[6] López, M., et al. (2022). Mechanical performance of recycled aggregate concrete: A review. Construction and Building Materials, 300, 124289. https://doi.org/10.1016/j.conbuildmat.2021.124289.
[7] Poon, C. S., and Chan, D. (2020). Influence of recycled concrete aggregates on the mechanical properties of concrete: A review. Materials, 13(5), 1071. https://doi.org/10.3390/ma13051071.
[8] Poon, C. S., Shui, Z. H., & Lam, L. (2004). Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. Construction and Building Materials, 18(6), 461–468. https://doi.org/10.1016/j.conbuildmat.2004.03.015.
[9] Tam, V. W. Y., Gao, X. F., & Tam, C. M. (2005). Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach. Cement and Concrete Research, 35(6), 1195–1203. https://doi.org/10.1016/j.cemconres.2004.10.010.
[10] Zhou, J., & Jiang, G. (2016). Effect of recycled aggregates on shrinkage properties of concrete. Construction and Building Materials, 107, 197–204. https://doi.org/10.1016/j.conbuildmat.2016.01.115.
[11] 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. https://doi.org/10.1016/j.conbuildmat.2014.04.107.
[12] Tam, V. W. Y. (2008). Economic comparison of concrete recycling: A case study approach. Resources, Conservation and Recycling, 52(5), 821–828. https://doi.org/10.1016/j.resconrec.2007.12.003.
[13] Dhir, R. K., Limbachiya, M. C., & Leelawat, T. (1999). Performance of recycled aggregate concrete in aggressive environments. Proceedings of the Institution of Civil Engineers - Structures and Buildings, 136(1), 81–88. https://doi.org/10.1680/istbu.1999.27683.
[14] OA Ahmad, (2021). The Usefulness of Construction and Destruction Waste as Recycled Aggregates in Concrete. International Journal of GEOMATE, 19 (75), 8-18.